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# ВЕСТНИК
## Национальной инженерной академии Республики Казахстан

# ВЫЧИСЛИТЕЛЬНЫЕ ТЕХНОЛОГИИ
## Федеральный исследовательский центр информационных и вычислительных технологий

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по материалам Международной конференции
«Вычислительные и информационные технологии
в науке, технике и образовании»
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# DEVELOPMENT OF A PARKING SENSOR DESIGN USING AN ULTRASONIC DEVICE FOR A CAR

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**Abstract**

The modern technological process creates all the necessary conditions for motorists to help them solve any tasks facing them. Such new solutions, designed to simplify the task of safe movement, include parkronik. The main part of the parkronics is special sensors installed in the front and rear of the car. The basic principle of this device is to generate signals that reflect various objects and return them to their original state. At the time of Signal Return, you can calculate at what distance the obstacle is located. Parkronik informs the driver that the distance between the car and the obstacle is decreasing.

Parking sensors (also called parking radars) are special equipment that warns the driver of a danger or obstacle on the road, whether it is a large stone, curb, fence or other vehicle. It is also used by students who study the art of safe parking. Parktronic has a different functional orientation. As a rule, the use of parking spaces increases the comfort of using the vehicle, as well as ensures the safety of the car and the safety of its owner. Parking sensors allow you to more accurately control the process of moving the car in close proximity to possible obstacles, for example, when parking in reverse, in other narrow or flooded spaces.

**Keywords:** parking sensor, parkronik, ultrasonic, device, car.

## Introduction

The modern technological process creates all the necessary conditions for motorists to help them solve any tasks facing them. Such new solutions, designed to simplify the task of safe movement, include parkronik. The main part of the parkronics is special sensors installed in the front and rear of the car. The basic principle of this device is to generate signals that reflect various objects and return them to their original state. At the time of Signal Return, you can calculate at what distance the obstacle is located. Parkronik informs the driver that the distance between the car and the obstacle is decreasing.

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Parking sensors allow you to more accurately control the process of moving the car in close proximity to possible obstacles, for example, when parking in reverse, in other narrow or flooded spaces [1].

Considering the huge advantages of parking sensors, I also thought about creating a device with a parking sensor. Considering the possibilities available to me, I decided to design the project in the Arduino electronic constructor.

Ultrasonic sensors are mounted on the bumper of the car, and the directional nature of the emitters allows you to form the necessary sensitivity zone. The initial systems had separate emitting and receiving sensors, which were subsequently used to transmit and receive a single piezoelectric element. The high cost of electronics initially led to mechanical scanning of the rear hemisphere using a single sensor. Today, the sensors are mounted permanently, and the absence of dead zones is achieved by installing several sensors. The simplest systems use two sensors.

The most common systems use 4 sensors located on the rear bumper at a distance of 30-40 cm from each other. This arrangement of sensors avoids the appearance of "dead zones". In more

complex systems, 2 or 4 sensors are installed on the front bumper. Unique systems can use various sensors, as well as sensors located on the side of the car.

Externally, many models of parking sensors are very similar, but they can perform different functions. Choosing this equipment, it is necessary to remember about its main purpose - to provide all conditions for comfortable parking of the car without any obstacles.

The options for installing parking sensors depend on the driving experience of the motorist, as well as on his individual needs in terms of parking convenience.

When parking large cars, the driver often has difficulty tracking the location of objects at different distances. Such objects include, for example, various curbs, columns, large objects that are in the path of the car. In this regard, the development of devices for tracking the distance to the nearest object (the so-called parking sensors) is of interest not only from the point of view of preventing traffic accidents, but also from the point of view of understanding the design of such a device and the implementation of these practices in educational activities.

Mastering the principles of developing practice-oriented devices that combine the basics of design and engineering, measuring physical parameters of the environment, reading and storing data with subsequent processing is relevant for improving learning outcomes and general preparedness of students in the secondary education system [2].

**Materials and Methods**

The purpose of the work is to develop a model, training design of a parking sensor for a car on the Arduino platform, followed by the development of a methodology for conducting training in the secondary education system.

Tasks of the work:

- development of the parktronic configuration, including the definition of functions, the location of elements and assemblies, structural elements;
- assembly of the parking sensors assembly Arduino Uno R3;
- writing a parking sensor data processing algorithm in the Arduino IDE program;
- parktronics launch and operation testing;
- development of a methodology for conducting training sessions on the implementation of this project in the secondary education system [3].

Parktronic (also called parking radar) is a special equipment that warns the driver about a danger or a barrier on the road, whether it is a large stone, curb, fence or other vehicle.

Considering the existing possibilities, it was decided to design the project in the Arduino electronic constructor. Arduino is a small microprocessor board with its own processor and memory, or, in other words, a mini-computer.

There are several dozen contacts on board the board, where various components can be connected: lamps, sensors, electric motors, washers, routers. Arduino allows you to design various automated and robotic systems, smart home systems, 3D printers and much more.

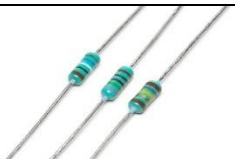
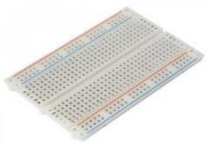
The main part of the parking sensors are special sensors installed on the front and rear of the car. The basic principle of operation of this device is the emission of signals that display various objects and return them to their original state. By the time of the signal return, it is possible to calculate at what distance the resistance is located.

The equipment informs the driver that the distance between the vehicle and the obstacle is decreasing. The parking sensor has a special signal of the piezo-sonic device. When piezo hazard is approaching, voice signals with different frequencies are emitted. Therefore, the closer the danger, the more often the signal is heard. If the signal is heard continuously, it means that the dangerous object is very close to the car, so an emergency stop is necessary [4].

The Arduino Uno board is the center of Arduino - the most popular and affordable device on the market. It is based on the ATmega-Arduino Uno R3 chip-this is ATmega328, but you can still find ATmega168 UNO payment options on the market. The main characteristics and device of the Arduino Uno R3 test board, power requirements, connectivity of external devices, differences from other

boards (Mega, Nano) are given in [2-4]. To create a parking sensors device, a scheme and configuration were developed (table). The device in the assembly is shown in Figure 1.

**Table 1 -** Details needed to create a parking sensor design

| Device Name | Quantity | Image | Price(tenge) |
|---|---|---|---|
| Arduino Uno R3 | 1 |  | 3564 |
| Resistors 200-520 Ом | 6 |  | 990*6=5940 |
| LEDs: Green, Blue, Red, Yellow | 6 |  | 120*6=720 |
| Ultrasonic Distance measurement sensor HC-SR04 | 1 |  | 1545 |
| Breadboard | 1 |  | 684 |
| Piezo | 1 |  | 600 |
| Final price | | | 13143 |

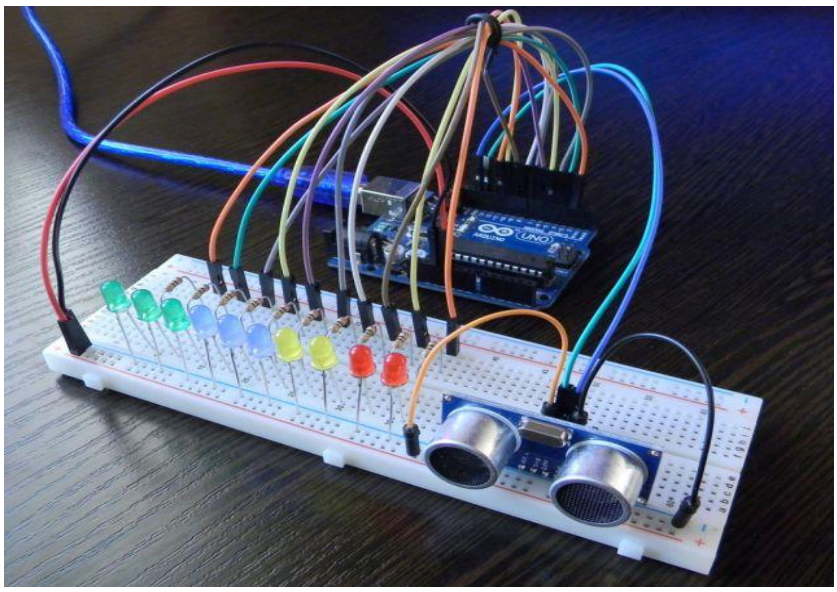


**Figure 1 -** Parktronic elbow without display

For visual control of the distance to the obstacle, we connect the lcd1602 display. Also include in the sketch the condition for adding a notification led to the LCD screen

**Figure 2 -** LCD1602 display

On the front side of the module is an LCD display and a group of contacts.

On the back of the module there are two chips made "drip" (ST7066U and ST7065S) and an electrical connection, it does not make sense to draw a schematic diagram, I will tell you about the resistor R8 (100 ohms), which serves as a limited resistor for LED lighting, so you can connect 5V directly to contact A [5].

A piezo extractor can be called a clip, zoom, piezo buzzer, or speaker. The point is to make one sound.

Usually, kits have two types of clamps-active and passive. They are similar and confuse the beginner.

Above the active beep is a sticker with the mysterious inscription "Remove seal after washing", which is translated by Google translator in a very strange way- "remove seal after washing", which makes the user even more confused. Don't pay attention to the record, it's just a technical point. During the preparation of the parts, it is necessary to wash the flux, but in order not to damage the substance,

the hole is glued on top. But do not rush to remove and throw away the sticker, it will be useful for you.

The active zoom can work independently, just provide energy. Follow the polarity when connecting. There is a plus ( + ) icon on the label, but you should not trust the label, perhaps someone did not close it very carefully. Take a good look at your feet. As a rule, one leg is longer than the other. Long legs are plus, short legs are minus. Connect the long leg to the 5V power supply and the short leg to the ground. You will immediately hear an unpleasant sound. It is for this reason that I advised you not to remove the sticker. If you remove the sticker now, the volume will be much higher.

Passive zoom is similar in appearance, but still slightly different. Compare them with the size and also look at them below. The difference is visible. As a past example with an active speaker, you won't hear anything when connected. It is not enough just to eat, it is necessary to use the software methods included in the Arduino.

Passive buzzer.

They are also found in modular designs, such as KY-006 (passive) or KY-012 (active). The module has three outputs, the average is not used, the S output is connected to the digital output of the board, and the GND output.

**Results and Discussion**

There were two displays with an I2C interface. One is a two-line lcd1602A and the other is a four-line lcd2004a. In the program code, you need to change the display size:

LiquidCrystal_I2C lcd (0x27, 16, 2); / / set the display address and size. This is for LCD1602.

LiquidCrystal_I2C lcd (0x27, 20, 4); // set the display address and size. This is for LCD2004.

The I2C Data Transfer Interface allows you to connect this display to the Arduino via two wires, not counting the power cables. I would also like to pay attention to the address of the display. The address will be 0x27. But I didn't have any characters on the screen on one of the displays. I identified the address using the sketch "I2C address scanner". The address was 0x3f. This is a reference to the sketch [6].

Yes, we identified the following problem: when uploading a sketch to an Arduino, only one First character appeared on the display. It turns out that versions of the Arduino IDE higher than 1.65 have such a breakthrough. Go back to version 1.65 and there will be happiness.

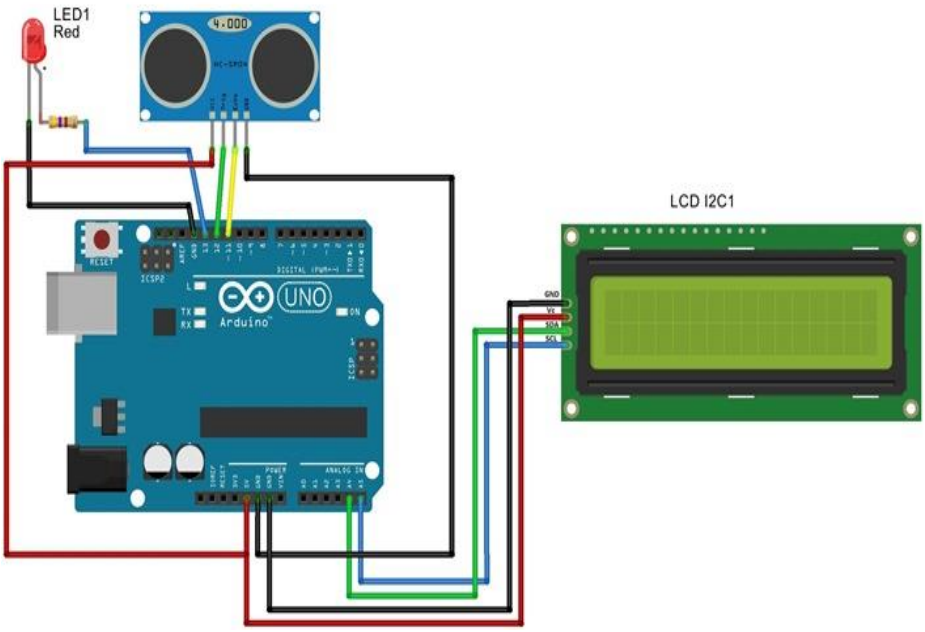



**Figure 3 -** Arduino and display connection scheme

No name Sketch_bb.
The Arduino UNO board has an LED connected to 13 pins. You can use it. The LED is shown separately in the diagram. You can connect it to a free pin and make changes to the code accordingly. Here is the code:

```
// add the necessary libraries
#include <LiquidCrystal_I2C.h>
# < add a wire.h>
LiquidCrystal_I2C lcd (0x27, 16, 2); / / set the display address and size
const Int trigPin = 12; / / Trig pin connects to Arduino pin 12
const int echoPin = 11; / / Echo pin connects to Arduino pin 11
const int ledPin = 13; / / 13 - if you are using a built-in LED on an Arduino
empty installation () {
pinMode (trigPin, OUTPUT); / / set the trigger - output pin
pinMode (echoPin, INPUT); / / set the Echo input PIN
pinMode (ledPin, OUTPUT); / / install LED-output pin
Serial.begin (9600); / / initialize the latter. Porta
Wire.();
lcd.init (); / / LCD initialization
lcd.backlight (); / / enable backlight
lcd.print ("distance:"); //print the text
}
hollow Hook () {
long distance = getDistance (); / / we get the distance from the sensor
Serial.println (distance); / / output to the serial port
lcd.setcursor (10,0); / / set the cursor
lcd.print (distance); / / output to lcd
lcd.print ("cm"); //print text in cm
lcd.print (" " ); / / when the value bit increases, we print spaces to erase unnecessary characters
delay (300); / / set the delay so that the numbers on the screen are not corrupted
if (distance<20) / / set the required distance, for example, less than 20 centimeters
{
digitalWrite (ledPin, 1); / / Turn on the LED
lcd.setCursor (0,1); / / set the cursor at the beginning of the first line
lcd.print ("Attention"); / / Attention
} more

{
digitalWrite (ledPin, 0); / / otherwise disable
lcd.setCursor (0,1); / / set the cursor at the beginning of the second line
lcd.print ("normal"); //print the norm
}
}
// CM determining the distance to an object
long getDistance() {
long distacne_cm = getEchoTiming () * 1.71 * 0.01; //58.4-recalculation coefficient, similar to the division of KE
return distacne_cm;
}
// Determining the delay time
long getEchoTiming() {
digitalWrite(trigPin, LOW);
Delay in microseconds (2);
```

digitalWrite (trigPin, HIGH); / / generating a startup pulse
Delay in microseconds (10);
digitalWrite(trigPin, LOW);
// Determination of the duration of high levels in the echopin pin, mcsec:
long duration = pulseIn (echopin, high);
return duration;
delay(100);
} [7].

Installation of rear view cameras and parktronics.

The popularity of parking systems among motorists is constantly growing. Parking radars and cameras allow you to quickly and trouble-free parking in difficult enough conditions for parking.

The rear view camera is located in a "dead zone" on the Monitor, that is, it reproduces all the details and obstacles that are not visible in the mirror. Auto-cams in expensive configurations of car models install a rear camera. But this option can be installed on any car, it is enough to buy the necessary model of the parking system and install it. The choice of rear view cameras is quite large, so it is not difficult to get such a system [8].

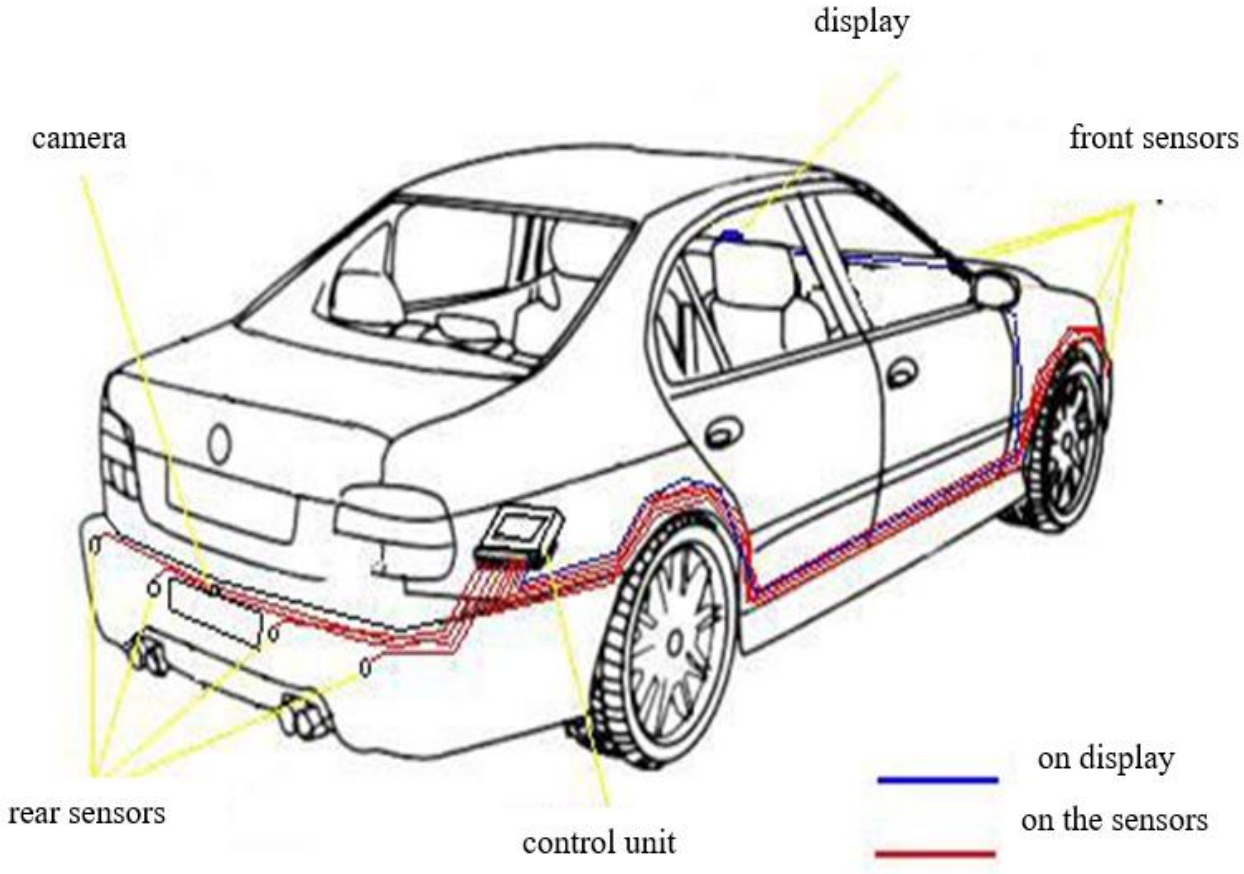



**Figure 4 -** Installing the device on the machine

Parkronik does not have the ability to reproduce the image, and most often a small digital display with a distance indicator is used as a monitor. Such a system is quite simple, and ultrasonic sensors on the rear bumper scan a wide area in the rear of the car. In case of detection of interference at a close distance to the car, the sensor instantly sends a signal to the central unit. The audio signal of the built-in beeper immediately attracts the driver's attention, and then, focusing on the light indicator, you can determine the location of the object that is interfering and the distance to it. Modern parking radars use sensors that can operate in any weather and at different temperatures.

Installing a rear view camera .

This type of work involves disassembling the parts of the cabin, installing a camera and monitor, pulling wires, which are used to connect all the components of this system. Then, of course, you need to put all the resulting parts in their place.

Many people believe that there is nothing complicated in this, but overestimating their own strength can lead to negative consequences. You need to choose the right place where the camera itself will be installed. It can be cut under the trunk or bumper lock, behind the rear windshield and in other places. It is possible to find a camera with a good overview of the rules, but at the same time, the words should be excluded from digging into the details of the body [9].

**Figure 5 -** Place of installation of the device

The monitor is located mainly on the front panel of the cabin, and its attachment is possible in various ways. But you need to connect the wires as carefully as possible, so as not to damage the panel.

The wiring of the wires must also be carried out with knowledge of the case, otherwise they can be "killed" during Operation. Disassembly and assembly of cabin parts has its own secrets, if there is no experience, you can damage the mounting hinges, which will make the product unusable [10].

The necessary skills in installing rear, front and round cameras can only be developed by craftsmen who often work on different car models. Accordingly, the experience gained in practice allows you to accurately choose the optimal location for the camera, conduct wiring with minimal disassembly of interior details and their subsequent installation.

In this case, everything is repeated, only ultrasonic parking sensors are installed instead of the camera. With the help of a special cutter, which is often included in the kit of a parking radar, the sensors are cut into the front or rear bumper of the car, depending on the model of the system.

A special program has been developed for data processing, and the results of the work of praktronics are displayed on a special display. The program implements the function of displaying the distance on the display and the buzzer activation condition. The time between measurements and the distance at which the warning sound is activated can be replaced with a sketch. The parking sensor uses an LED indicator consisting of eight LEDs to determine the distance to the object, give a signal and conditionally warn it. The distance sensor used is the HC-SR04 ultrasonic module. The parking sensor was placed in a special case and represents an almost ready-to-use device. Testing of the device was performed using a car with distance control to the nearest object and showed high accuracy of the device [11].

## Conclusion

Thus, using the Arduino platform allows you to design a simple parking radar. The implementation of the results of the work is carried out within the framework of robotics training courses in the secondary education system. Experience has shown that teaching robotics at school allows students to increase their interest and learning outcomes in information technology, and also develops students' thinking, allowing them to consider the task in a new way and use various devices for measuring and collecting data. Also, it is important to solve the problem of improving the accuracy of parking sensors in conditions of interference (for example, snowfall) and the detection of non-standard objects (chains, ropes, etc.), which is considered as a task for the future.

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# ONTOLOGICAL ENGINEERING FOR STEM EDUCATION IN SCHOOL

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**Abstract**

The article discusses a project-based learning method and its application for STEM-education. It determines advantages and ontological engineering stages for STEM-education. The article considers development of the ontological model "STEM-education in school". It presents an ontology "STEM-Education in School" generated in Protégé 4 editor that contains necessary classes, relations, properties, and persons involved in the school education process. There are requirements to this ontology. A hierarchy of classes and fragments of the generated ontology are presented. Enhancement of school education quality can be achieved through the use of the STEM-approach and semantic description of the knowledge about the subject area with the use of ontological engineering methods. Filling of the ontology with actual data of a school will allow creating a comprehensive database of the school. This approach will help to improve efficiency of lesson plan development with the use of the STEM-approach and the learning content.

Currently, professions appear at the confluence of technologies and natural sciences. Implementation of STEM-education from school time will help schoolchildren to adapt themselves more easily in obtaining higher education and future profession. Promotion of STEM-literacy in students will help them to be in demand and able to meet competition in the labour market.

**Keywords:** STEM, knowledge, school, ontology, ontological engineering, competencies, knowledge base.

## Introduction

The Head of the State Kassym-Zhomart Tokayev emphasizes the need for digitalization of all spheres of life and continuous education of students in the State Program for the Development of Education and Science of the Republic of Kazakhstan for 2020-2025 and in the State Program "Digital Kazakhstan". Digitalization of all spheres of life and economy of Kazakhstan will allow to take leading positions on the global arena and to enhance the quality of life the population and to create favorable conditions for development of entrepreneurship. Digitalization of the education system is not only creation of digital copies of the educational material, digitalization of document flow, and provision of access to high-speed Internet. This is a change of the very approach to teaching schoolchildren, to the content and methods of teaching.

Special attention is currently paid to education in the Republic of Kazakhstan, new approaches are used, and the education system is digitalized. Therefore, it is necessary to develop digital skills in children for further development of their learning skills and personal growth. Schoolchildren need to develop in various key academic fields such as science, mathematics, technologies, and engineering, i.e. in line with STEM, a new education trend [1, 2]. The article discusses a project-based learning method and its application for STEM-education. It determines advantages and ontological engineering stages for STEM-education [3-10].

## Materials and Methods

STEM education is a bridge that connects education and career. Therefore, it requires innovators in the sphere of education in the modern world, which leads to a shift in the established priorities. It is necessary to develop critical thinking skills, and digital skills that are important for innovation and find ways to develop them.

It is reasonable to put forward a research hypothesis that the use of the STEM approach in the process of teaching schoolchildren will increase cognitive interest, activate intellectual processes and form digital skills among schoolchildren.

**The objective of the work** is the application of a STEM approach in the process of teaching schoolchildren, which allows them to form digital skills.

**Tasks:**

1. Search and analysis of literary sources on the thesis topic "Formation of digital skills of schoolchildren in the implementation of Stem projects";

2. Familiarization with the principles of implementation of Stem projects, their advantages and disadvantages;

3. Building an ontological model using the STEM approach in the process of teaching schoolchildren, which allows them to form digital skills.

In solving the problems of scientific research, the method of projects and ontological analysis, an object-based approach to software development, optimization methods, and methods of mathematical and computer modeling are used.

In contrast to conventional teaching, STEM teaching changes the form of the educational process. This form is different from our conventional perception of a school teacher that we are used to. According to the STEM methodology, the focus is on a practical task or problem. Students learn to solve the problem practically right away, by experimenting and finding mistakes, rather than solving it theoretically

STEM education provides a number of advantages, such as comprehensive training, the application of knowledge in life, the development of critical thinking, self-confidence, teamwork, interest in technical disciplines, innovation, interdisciplinary training, and technical and technological development [1, 2].

The advantages of STEM education for the student are shown in Figure 1.

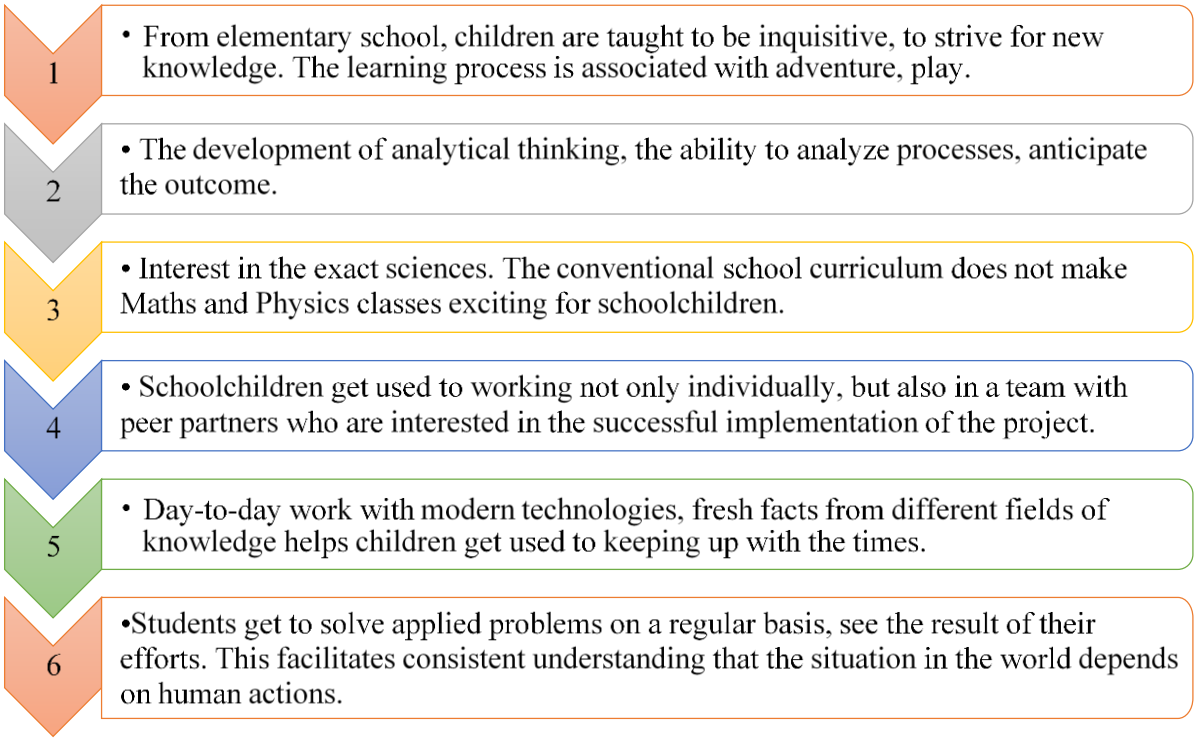


**Figure 1** – Implementation of the STEM approach at school

STEM education implies a different teaching approach that shows the convergence of sciences and disciplines in different spheres of life.

As anything else, the STEM approach to education has its drawbacks. For example, the disadvantages are shown in Figure 2.

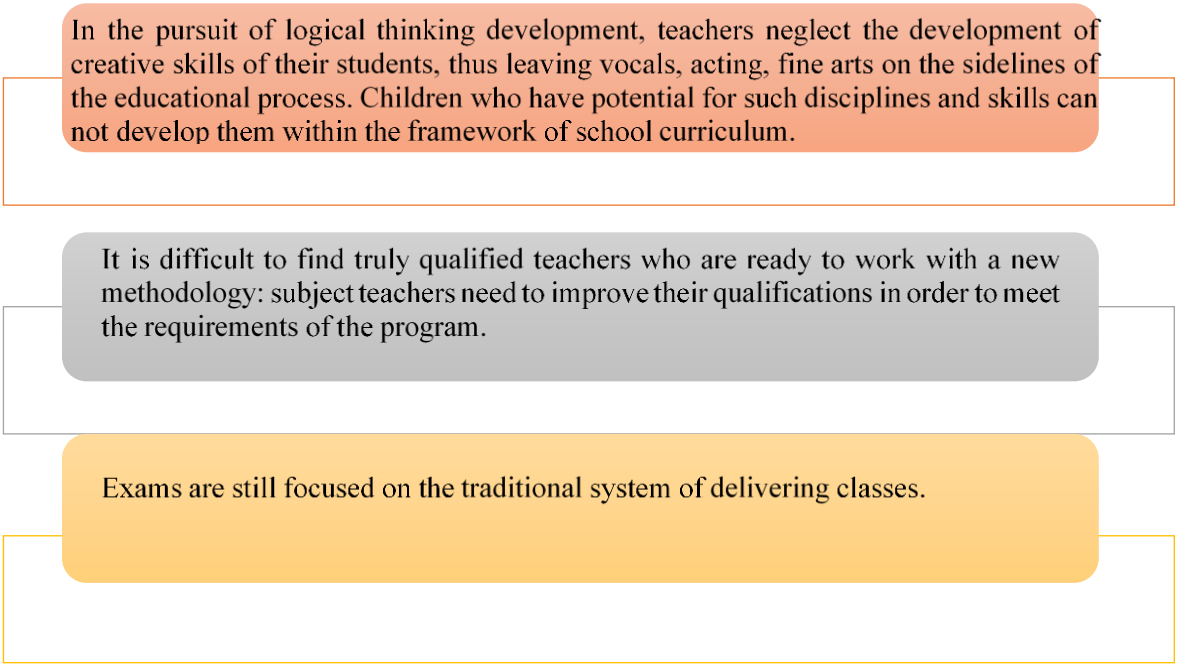


**Figure 2** – Disadvantages of the STEM approach to education

The conditions for the introduction of STEM education are (Fig. 3) [11]:

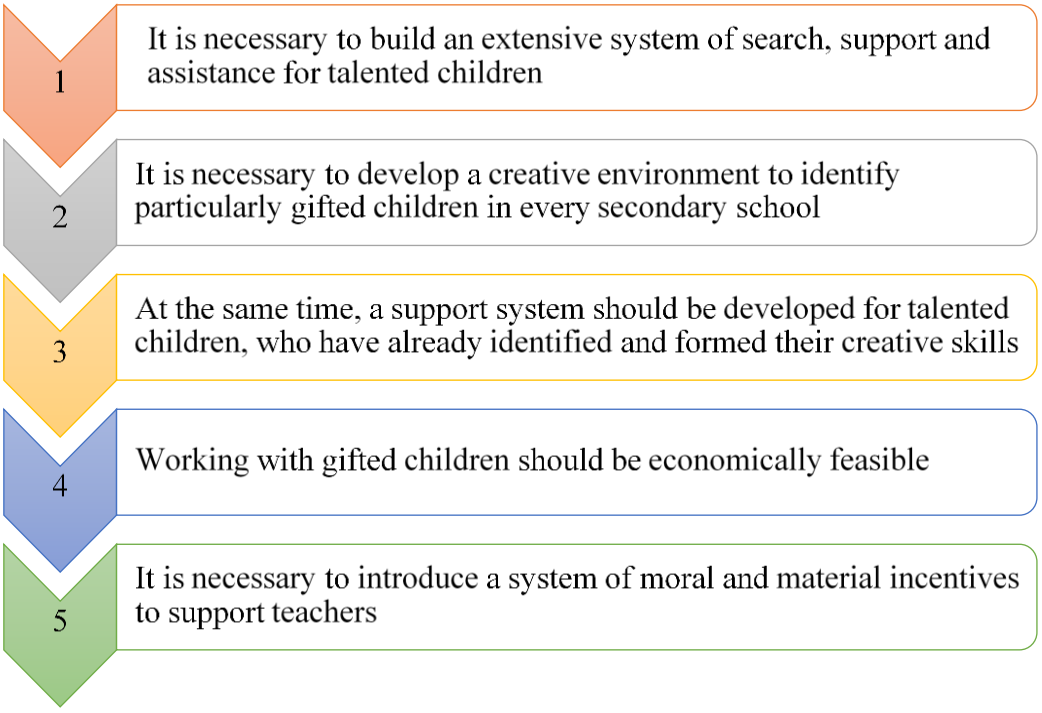


**Figure 3** – STEM technology at school

Ontological knowledge bases have an advantage over traditionally used relational databases. Due to the development of information and communication technologies, it will be necessary to cover the level of semantics, in addition to the level of storage and structures. The use of domain ontology appears relevant and effective for the representation of semantics.

Ontologies contain the following conceptual structures: class hierarchies in object-oriented programming, conceptual maps, semantic networks, etc. [3-9].

The visual approach of ontological engineering is the most popular one. The visual approach combines such basic types of technologies as object-oriented and structural analysis [10].

When building an ontology, it is necessary to determine the basis for describing the main objects, attributes, and classes. For example, "classes" - "relationships" - "functions" - "axioms" - "instances" or a multitude of "objects" - "relationships" - "roles" - "attributes" [3-10].

The main teaching method used to integrate STEM into the educational space is the method of projects or the project method. The STEM approach allows you to combine mathematics and natural sciences, fine arts and technology, computer science, and physics in project work. This, in its turn, allows students to fully explore the world around them. Today, STEM projects allow you to study the topics and directions of a discipline at the applied and fundamental levels [12].

The project method is not new to the teaching process.

This method ensures the interaction between theory and practice of STEM education in the role of an assistant.

This method focuses on the student's cognitive work aimed at achieving goals and solving problems.

Interdisciplinary projects are performed outside of classroom studies under the guidance of specialists in various fields of education.

Depending on the nature of communication, projects are classified as in-class, in-school, regional, and international projects [12].

Integrated lessons are being introduced in the Republic of Kazakhstan, to implement STEM education and meet new trends in education.

The sequence of actions for developing an ontology. First, it is needed to perform an analysis of the subject area, make a synthesis of concepts and relations, then select objects, attributes, relations, and processes.

The stages of ontology development are shown in Figure 4.

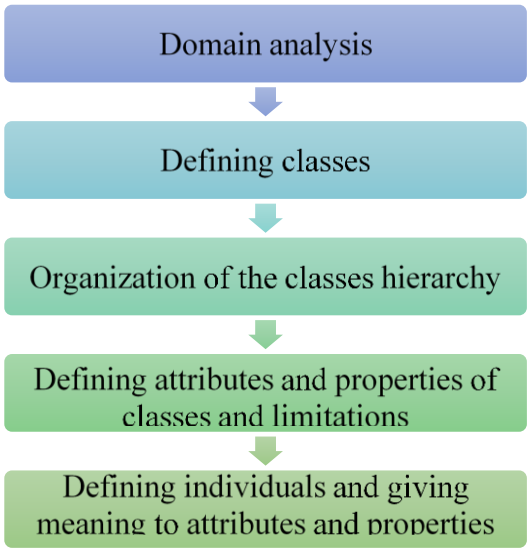


**Figure 4** – Stages of ontology development

Creating and using a knowledge base. Ontologies allow us to build domain models by combining declarative characteristics and definitions. Experts in the field of application set the following basic requirements for the means of creating ontologies (Fig. 5).

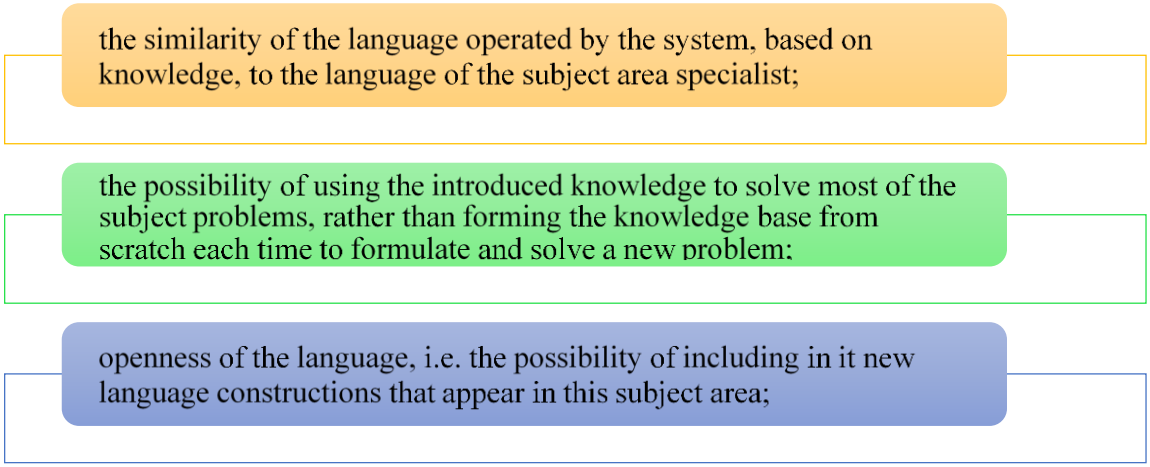


**Figure 5** – The main requirements of experts

Computer Science as a school subject allows students to form digital skills. It is necessary to develop these digital skills and reach new levels. Therefore, it requires the formation of computational and algorithmic thinking in schoolchildren.

One of the steps in this direction is the modernization of the education system, and the introduction of new directions in the field of information technology in school curricula.

In recent years, much attention has been paid to computer-aided learning, robotics, and ontological engineering. It is widely acknowledged that the future of information technology lies behind these trends.

Computer-aided learning is a popular field of knowledge. Computer-aided education begins in high school. Python allows you to study computer-aided learning, bypassing the in-depth Mathematics studying.

Computer-aided learning is one of the most promising areas in the development of information technology. Computer-aided learning methods are used in various fields of human activities. In this regard, it is necessary to study this area starting from the school course on Computer Science. Further, graduates can develop their skills and improve their knowledge at university or in various training courses.

Let's study an example of the implementation of the STEM approach. The interaction of STEM elements for "Computer-aided Learning" is shown in Figure 6.

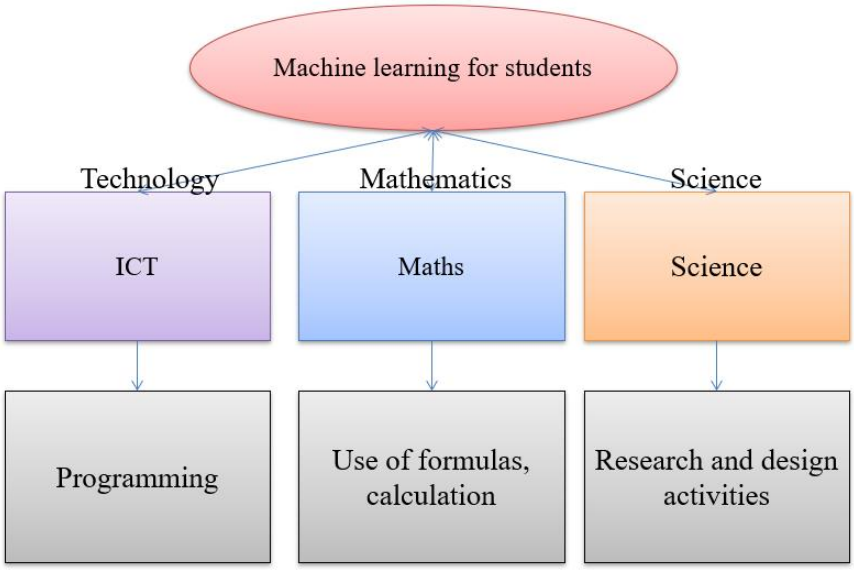


**Figure 6** – Computer-aided learning for schoolchildren

Educational robotics allows you to develop programming and project design skills. It works as an integrator of all STEM elements. Moreover, it is possible to calculate the motion speed of a Lego typewriter and the distance traveled by it in the framework of an optional school course on the Basics of Robotics. This can be done using the terms "arithmetic operations" in Mathematics and "cycle" in Computer Science. This process teaches the student the principle of calculating the total speed of cars, and the distance traveled. Thus, STEM education allows students to develop project thinking by linking their knowledge with environmental processes.

An example of the implementation of the STEM approach, the interaction of STEM elements for "Robotics" is shown in Figure 7.

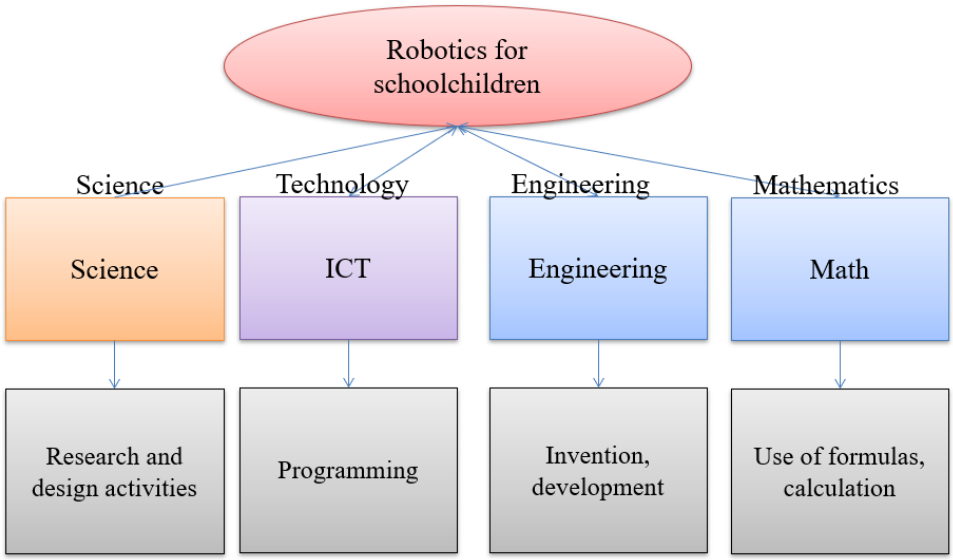


**Figure 7** – Robotics for schoolchildren

Robotics allows students to develop fundamentally new skills: critical thinking, creative problem solving, group work, creativity, adaptation, coding, communication skills, responsibility, systematization, etc.

The STEM approach is actively used in teaching Computer Science. Thus, there are many topics and sections in Computer Science that allow you to interact with STEM elements.

Engineering is a powerful tool that allows you to visualize the knowledge structures of any given subject area [13-15].

Currently, a large number of ontology editors are available. Each editor has its advantages and disadvantages. Figure 8 shows commonly used ontology editors and their descriptions.

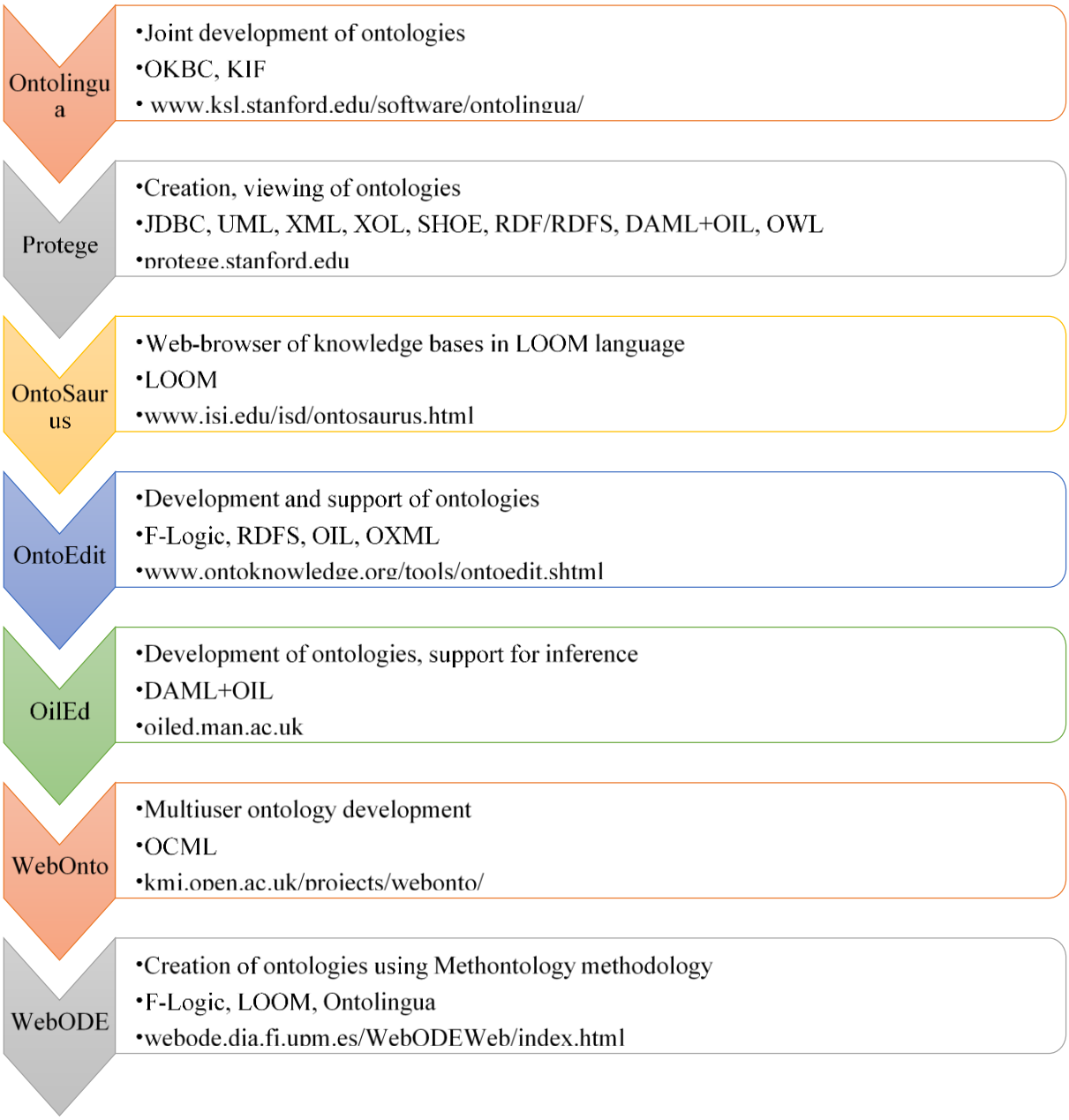


**Figure 8** – Ontology Editors

Various complexes, platforms, and systems also exist for building ontologies and making decisions [15-17]. For the purpose of this thesis, we will be using Protégé 4 since it is the most popular and is freely available.

**Results and Discussion**

The Building of an ontology begins with the creation of an ontological domain model. To do this, you need to define the base classes and the relations between them. It is required since we are developing a school ontology that allows us to show the interaction of STEM elements for Computer Science as a subject [18].

As an example, let's analyse the building of the ontology of the "Robotics" and "Computer-aided Learning" sections. We will be using these ones as they clearly show the interaction between STEM elements.

Robotics is directly related to STEM education. Robotics combines design, technical creativity, and programming. Robotics training begins with forming an understanding of engineering and programming among schoolchildren. Let's apply the ontological approach and STEM approach to the school disciplines mastery, using the example of the "Robotics" discipline. The "STEM Ontological model" fragment is presented in Figure 9.

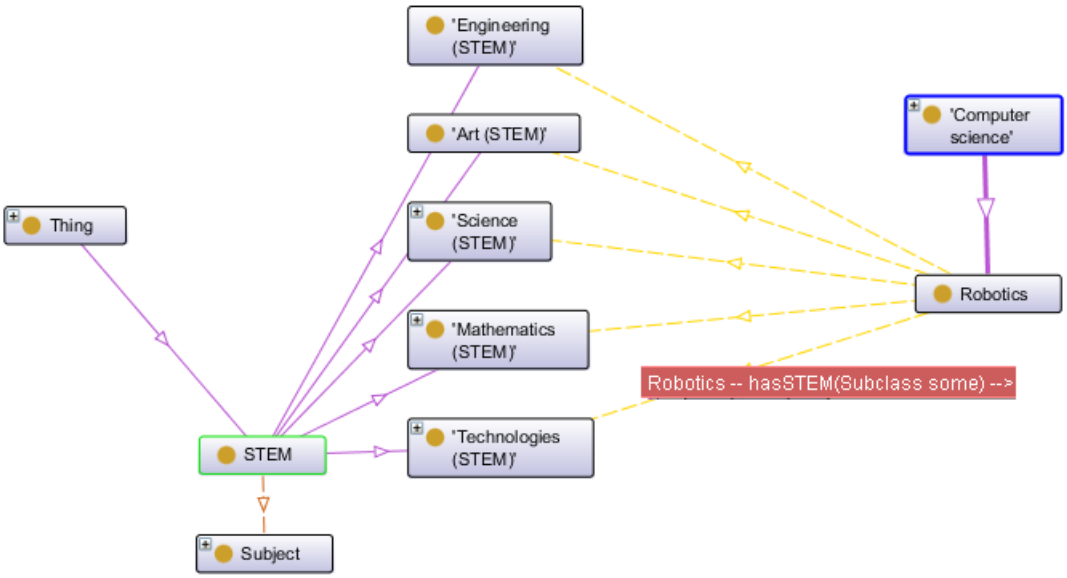


**Figure 9** – The "STEM Ontological Model" Fragment

The processing subsystem of the ontological knowledge base of the university "STEM disciplines" *ontoSchollSTEM.owl*/, is shown in Figure 10.

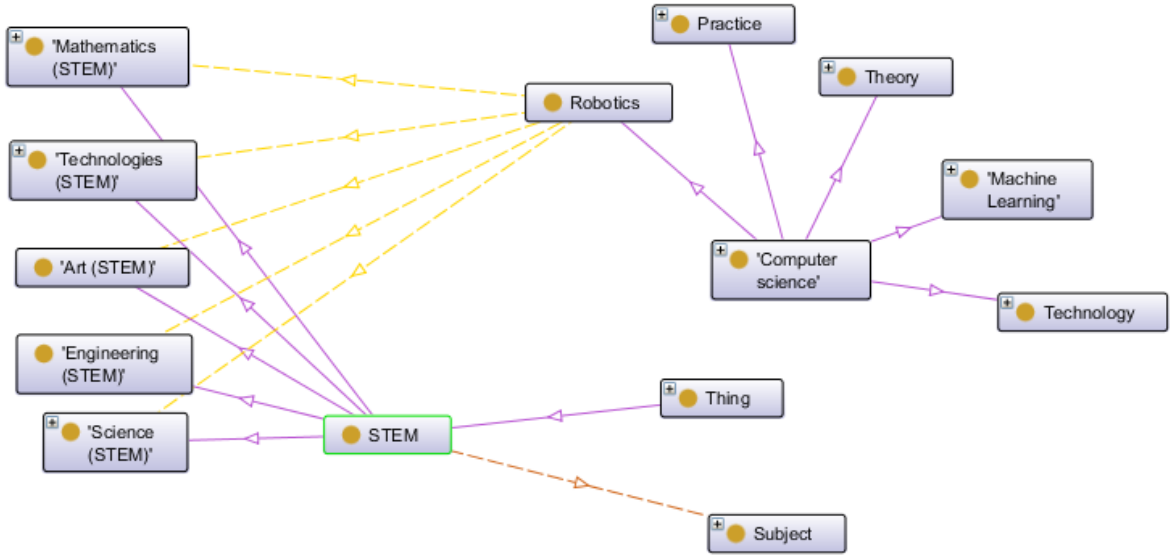


**Figure 10** – A fragment of the classes hierarchy

A lesson plan or a short-term plan for a teacher of a secondary education organization consists of the following basic elements:

- Section;
- Teacher's full name
- Date;

- Grade;
- Lesson topic;
- Teaching objectives in accordance with the curriculum;
- Lesson objectives;
- Lesson phase/ Time;
- Teacher's actions;
- Student's actions;
- Evaluation;
- Resources.

The constructed hierarchy for the (lesson plan) "Plan_uroka" (Fig.11).

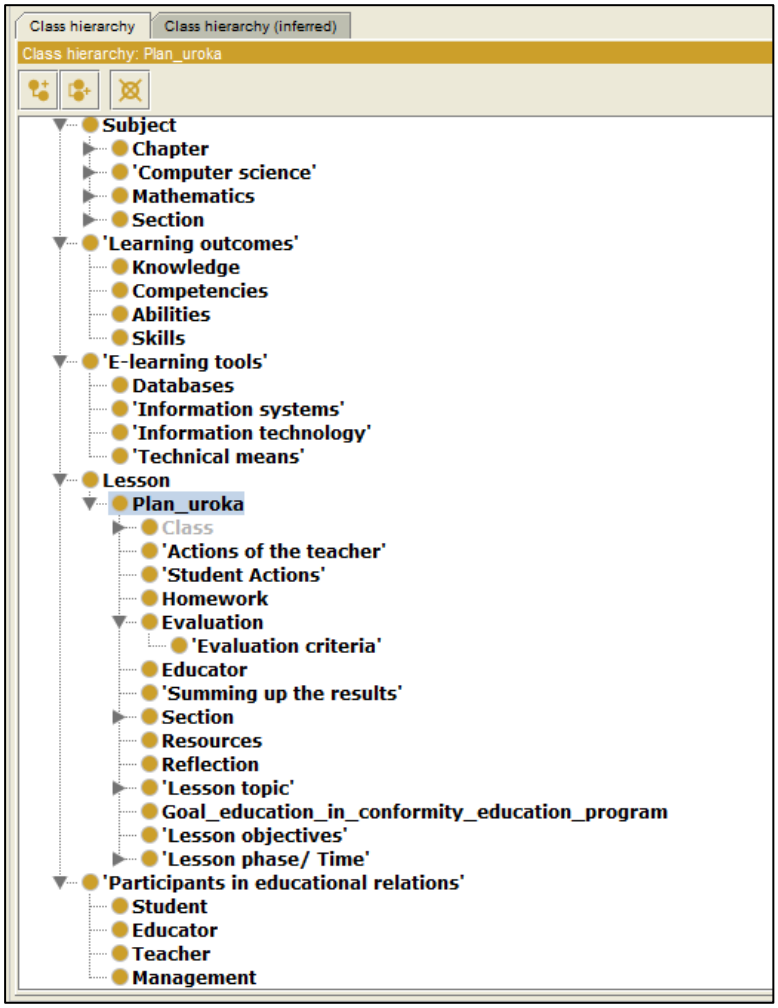


**Figure 11** – "Plan_uroka"

The "Class", and "Teacher" classes have already been created, so we are only going to add them to the Sub Class Of "Plan_uroka" (Fig.12).

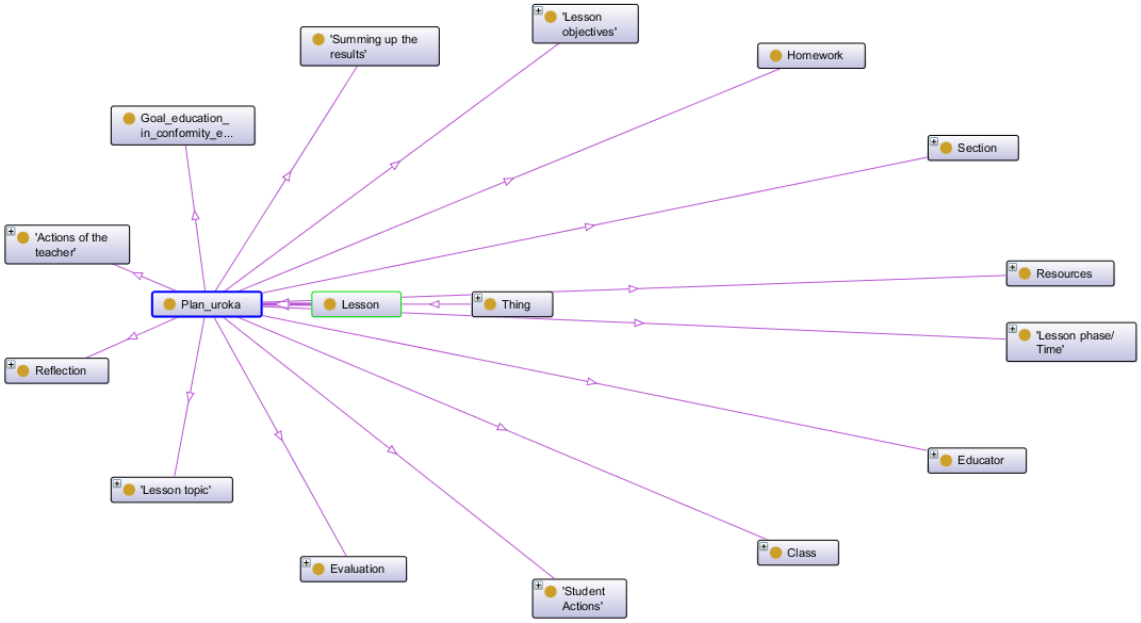


**Figure 12** – A fragment of the "Plan_uroka" ontology

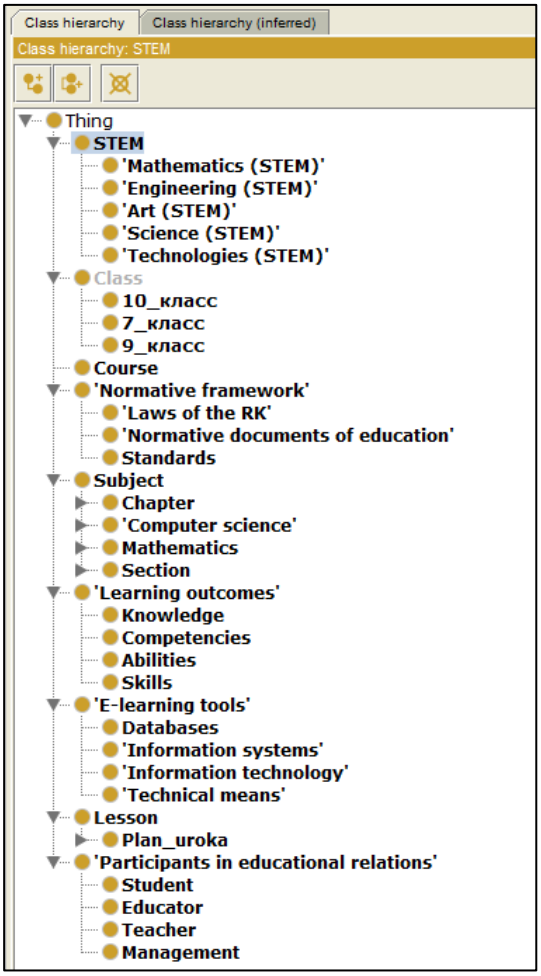


**Figure 13** – A hierarchy of the "STEM education at school" ontology

The «STEM education at school» ontology was built, which includes the structure of the school educational process, STEM elements, and Lesson plan (Fig. 14).

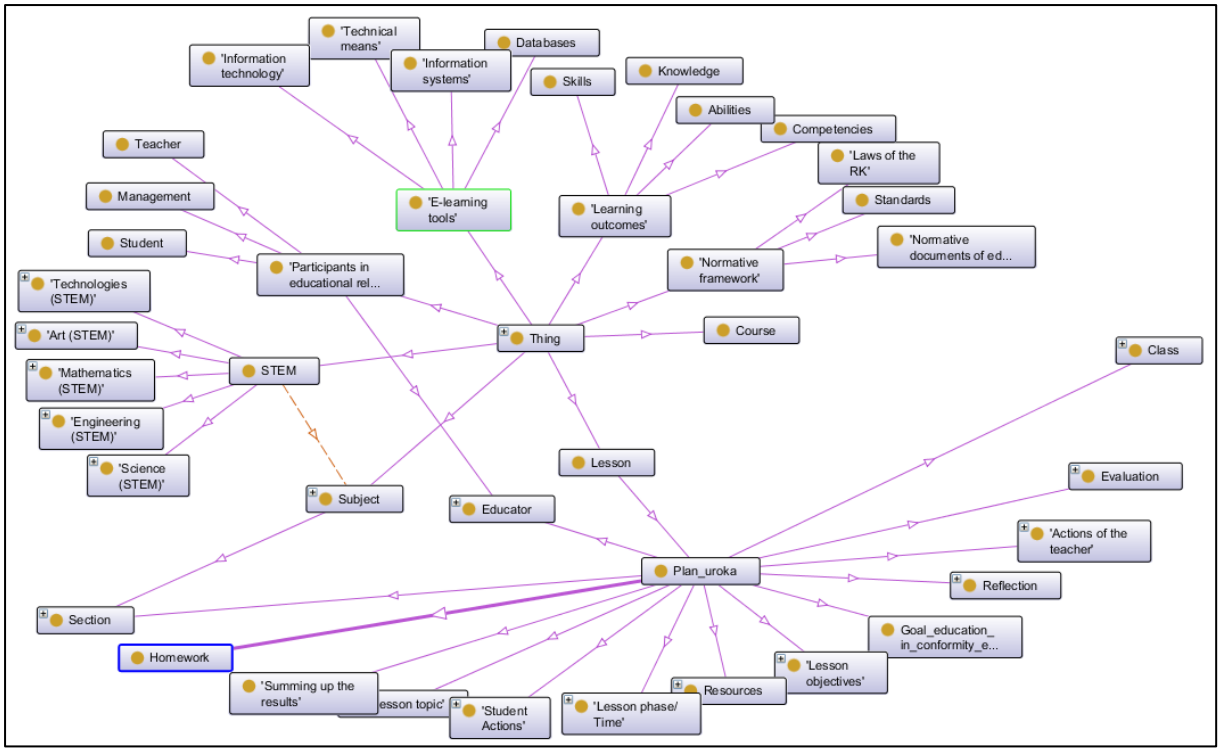


**Figure 14** – "STEM education at school" Ontology

The "STEM Education at school" ontology is a knowledge base for storing knowledge and school data that are interconnected by certain rules and interrelations.

## Conclusion

The "STEM education at school" ontological model has been developed. The ontology "STEM education at school" was built using the Protégé 4 editor. It contains the necessary classes, relations, properties, and individuals of the school educational process. Requests to this ontology have been fulfilled. The hierarchy of classes and fragments of the constructed ontology was presented.

Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using ontological engineering methods.

Replenishing the ontology with real school data will create a complete knowledge base of the school. This approach will improve the efficiency of the development of lesson plans, using the STEM approach and the use of educational content.

Currently, new professions are emerging that are related to technology at the junction with the natural sciences. Improving the quality of school students' education can be achieved through the use of a STEM approach. The introduction of STEM education to the school curriculum will make it easier for students to adapt to further higher education and obtain a future profession. Increasing the student's STEM literacy will ensure demand and competitiveness in the labor market.

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## USING MACHINE LEARNING TO IDENTIFY A FAKE ACCOUNT

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**Abstract**

Nowadays, online social media is dominating the world in several ways. Day by day the number of users using social media is increasing drastically. The general purpose of social media is to keep in touch with friends, sharing news, etc. This provided a new way of a potential attack, such as fake identity, false information, etc. The objective of this project is the automated recognition of fake accounts, using some Classification Algorithms. In order to achieve the set goal, the possible factors of currently known possible fake accounts were studied. The following detection strategy was used to work with them.

The first stage of the project is the collection of information about the account. For this step, Apify platform was used to collect and automate web pages, which can turn any site into an API.

The projects have 2 datasets: the first with 11 feature is used for the recognition of private accounts, which due to their privacy have a limited amount of information to share, the second with 14 features is used with the public accounts, which thanks to their privacy have more information to work with, such as the date of the post published, which gave the

algorithms some information about the index of activity of the account. Every account's feature has been scraped using an Instagram Web Scraper.

Then the two datasets have been subject to a Preprocessing Phase. This phase consists of the standardization and the normalization of the two datasets.

The features, now preprocessed, are taken and given to this Machine Learning Classifier Algorithms:

- Decision tree
- K-Nearest Neighbours (KNN)
- Logistic Regression
- Random Forest
- Support Vector Machine (SVM)

For every algorithm, in addition to the training and the testing phase, has been calculated:

- Confusion Matrix
- Receiver Operating Characteristic / ROC Curve
- Classification Report

**Keywords:** machine learning, Instagram, dataset, prediction, classification.

## Introduction

Online social networks (OSNs) such as Facebook and Instagram are becoming more and more popular and are becoming an important part of the modern world. In addition to being used as a means of communication, OSNs are also used to gain popularity and promote business. At first glance, an account's popularity is measured by some metric, such as the number of followers, or properties of shared content, such as the number of likes, comments, or views. Therefore, users of any social platform may tend to artificially increase their metrics to get more benefits from OSN.

Relevance of the research topic: Fake accounts suppress specific users and perform various malicious activities - sending spam, collecting personal data, etc. b. can be used to break trust in a social network. It is very important to use machine learning when it comes to identifying a fake account on a social network. It develops applications for protection and security of social networks, preventing unauthorized access to personal information, illegal use of user information.

Theoretical and practical significance of the study: Today, with the proliferation of fake accounts, the use of machine learning to identify fake accounts allows you to secure social networks and develop applications for information security.

Widespread use of social media has been a boon and poison to society. The use of social networks for online fraud, the spread of false information is growing rapidly step by step. Fake accounts are the main source of false information on social networks. In particular, fake accounts are used for the following purposes: extortion of money, surveillance, for the sake of insulting a person, etc. Hence, there is a widespread need to discover accounts that can tell for sure whether an account is fake or not. This article uses the classification of machine learning algorithms to detect fake accounts. The process of finding a fake account mainly depends on factors.

## Literature review

Estee Van Der Walt et al. [1] used the SVM Linear, Random Forest and Adaboost algorithms to classify fake and real Twitter accounts and found that Random Forest gave the best result. It also turned out that in social networks you can find such personal data as: location, name, profile picture, number of subscribers, number of friends, account creation date, number of URLs, number of statuses, number of retweets.

Qiang Cao et al. [2] used cluster analysis to detect loosely synchronized malicious account activity at scale, it measures the pairwise similarity of user behavior, and then uses a hierarchical clustering algorithm to group users with similar behavior over a long period of time together.

Indira Sen et al. [3] used Random Forest, Logistic Regression, AdaBoost with random forest as base initiator, multilayer perceptron with feedforward architecture, support vector machine with RBF kernel to identify fake Instagram likes, also found out that a multilayer perceptron with a feed-forward architecture gives the best results. For a multilayer perceptron, a sigmoid activation function is used here.

Cao Xiao et al. [4] used Support Vector Machine, Logistic Regression, and Random Forest to detect clusters of fake accounts in the LinkedIn dataset, and they found that random forest gives the best results. They used three different types of features, i.e., basic distribution features, pattern features, and frequency features.

Yazan Boshmaf et al. [5] developed Integro, a scalable security system that uses a meaningful user ranking scheme. The system starts by predicting victim accounts based on user-level activities. Finally, Integro ranks user accounts based on a modified random walk which starts with a known real account. They also implemented Integro using widely used open-source distributed computing platforms that scale almost linearly.

Manuel Egele et al. [6] introduced CO MPA, a system for detecting compromised social media accounts. CO MPA uses statistical models to characterize the behavior of social media users and uses anomaly detection techniques to detect sudden changes in their behavior. The results also show that their approach can reliably detect compromises involving known social media accounts, and can detect compromises of regular accounts, whose behavior is usually more erratic, by bundling similar malicious messages.

Sai Peddinti et al. [7] implemented a classifier that transforms a four-class classification problem into a binary classification problem for the Twitter dataset. They have used Random Forest as a base classifier for binary classifiers. Here, the choice of classifier and trees count is dependent on cross validation results.

Anna Leontjeva et al. [8] to identify stealthy fraudulent users, in their initial experiments compared several classifiers, including Random Forest, SVM, and logistic regression (using both lasso and ridge regularization). Evaluating their accuracy with a 5-fold cross-validation, we decided to use Random Forest, as it showed the best results (by about 10%).

Ravneet Kaur et al. [9] described the importance and growing trend towards social networks along with the presence of anomalous activity in them. Anomalies were also classified into different categories based on different parameters. Finally, anomaly detection in social networks has been described and the most well-known applicable approaches to anomaly detection in data mining and social networks, respectively, have been described. Each approach determines its importance and appropriate application depending on the type of anomaly being detected.

Surendra Sedhai et al. [10] have proposed a semi-supervised spam detection framework called S3D. It uses four lightweight detectors to detect spam tweets in real time and periodically update models in batches. The results of the experiment demonstrate the effectiveness of the semi-supervised approach in their spam detection system. Through experimentation, they found that strongly tagged groups and tweets made the system effective at capturing new spam patterns.

**Materials and Methods**

A fake account is an account where a person identifies as someone else. You can also describe a fake account as an account that contains false information about its owner. In this research work, Instagram is used as a social network. Because, Instagram has become one of the leading social platforms. Instagram has reached about 1 billion monthly active users and 2 million advertisers per month, and users like 4.2 billion posts per day. Therefore, it is extremely important to maintain a healthy environment in such an important social area.

The first stage of the project is the collection of information about the account. For this step, Apify platform was used to collect and automate web pages, which can turn any site into an API. Apify is a web scraping and automation platform that can turn any website into an API. With Instagram Profile Scraper, it is possible to collect public data about Instagram users. This means that it will give the ability to pull data from public profiles, but not from private ones. It also includes Web Scraper, Google Search Results Scraper, Google Maps Scraper.

The project has 2 dataset: the first with 11 feature is used for the recognition of private accounts, which due to their privacy have a limited amount of information to share, the second with 14 features is used with the public accounts, which thanks to their privacy have more information to work with,

such as the date of the post published, which gave the algorithms some information about the index of activity of the account.

**Table 1** – factors for private accounts

| Profile Pic | Nums / Length Username | Full Name Words | Bio Length | External URL | Is Private | Is Verified | Is Business | #Post | #Followers | #Following |
|---|---|---|---|---|---|---|---|---|---|---|

**Table 2** – factors for public accounts

| Profile Pic | Nums / Length Username | Full Name Words | Bio Length | External URL | Is Verified | Is Business |
|---|---|---|---|---|---|---|
| # Post | # Followers | # Following | Last Post Recent | % Post Single Day | Index of Activity | Average of Likes |

**Features Description**

- **Profile Pic** *boolean value*. 0 if the user does not have the profile pic, 1 otherwise.
- **Nums / Length Username** *double value*. How many special characters of numeric characters the username has on its full length.
- **Full Name Words** *numeric value*. How many words in the full name.
- **Bio Length** *numeric value*. How many characters in the biography of the account.
- **External URL** *boolean value*. 0 if the user does not have an external URL in the biography, 1 otherwise.
- **Is Private** *boolean value*. 0 if the user does not have a private account, 1 otherwise.
- **Is Verified** *boolean value*. 0 if the user does not have the verified badge, 1 otherwise.
- **Is Business** *boolean value*. 0 if the user doesn't have a business account, 1 otherwise.
- **# Post** *numeric value*. The number of the post published by the account.
- **# Followers** *numeric value*. The number of the followers of the account.
- **# Following** *numeric value*. The number of the following of the account.
- **Last Post Recent** *boolean value*. 0 if the user does not have a post published withing 6 months, 1 otherwise.
- **% Post Single Day** *double value*. How many posts has been published in the same day on the total number of the posts.
- **Index of Activity** *double value*. How many posts in average the account publishes every month.
- **Average of Likes** *double value*. Average of the likes of a post of the account.

Every account's feature has been scraped using an Instagram Web Scraper.

Then the two datasets have been subject to a Preprocessing Phase. This phase consists of the standardization and the normalization of the two datasets.

Improvements in model accuracy are often achieved through the first steps of data transformation. Feature scaling is one of the most important data preprocessing steps in machine learning.

There are some feature scaling methods, such as normalization and standardization, that are the most popular and at the same time the most confusing.

Standardization or Z-Score Normalization is the transformation of features by subtracting from mean and dividing by standard deviation. This is often called as Z-score.

```
In [8]: #Стандартизация

In [9]: from sklearn import preprocessing
        scaler = preprocessing.StandardScaler().fit(X_train)
        scaler

Out[9]: StandardScaler(copy=True, with_mean=True, with_std=True)

In [10]: Xtrain_Standard = scaler.transform(X_train)
         Xtest_Standard = scaler.transform(X_test)

         Xtrain_Standard[0]

Out[10]: array([ 0.30116055,  3.46340999, -1.38735742, -0.77273669, -0.53049106,
                -0.49065338, -0.34350781, -0.54202685, -0.23613877, -0.11591222,
                 2.3230234 ])

In [11]: print(clf.fit(Xtrain_Standard, y_train.values.ravel()))

         SVC(C=1.0, break_ties=False, cache_size=200, class_weight=None, coef0=0.0,
             decision_function_shape='ovr', degree=3, gamma='auto', kernel='rbf',
             max_iter=-1, probability=False, random_state=None, shrinking=True,
             tol=0.001, verbose=False)

In [12]: print("TRAIN SET", clf.score(Xtrain_Standard, y_train))
         print("TEST  SET", clf.score(Xtest_Standard, y_test))

         TRAIN SET 0.9051172707889126
         TEST  SET 0.9069264069264069
```

**Figure 1** – Data standardization process code

Standardization can be helpful in cases where the data follows a Gaussian distribution. However, this does not have to be necessarily true. Geometrically speaking, it translates the data to the mean vector of original data to the origin and squishes or expands the points if std is 1 respectively.

Standardization does not get affected by outliers because there is no predefined range of transformed features. The standardization formula is calculated as:

$$Xnew = (X - \mu)/\sigma \quad (1)$$

where:

$Xnew$ – new point;

$X$ – variable;

$\mu$ – the mean of the feature values;

$\sigma$ – the standard deviation of the feature values.

```
In [13]: #Нормалдау

In [14]: normalizer = preprocessing.Normalizer().fit(X_train)
         normalizer

Out[14]: Normalizer(copy=True, norm='l2')

In [15]: Xtrain_Normalized = normalizer.transform(X_train)
         Xtest_Normalized = normalizer.transform(X_test)

         Xtrain_Normalized[0]

Out[15]: array([1.40281976e-04, 7.01409882e-05, 0.00000000e+00, 0.00000000e+00,
                0.00000000e+00, 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
                1.12225581e-03, 1.17836860e-02, 9.99929928e-01])

In [16]: print(clf.fit(Xtrain_Normalized, y_train.values.ravel()))
```

**Figure 2** – Data normalization process code

Normalization or Min-Max Scaling is used to transform features to be on a similar scale. The new point is calculated as:

$$Xnew = (X - Xmin)/(Xmax - Xmin) \quad (2)$$

where:

Xnew – new point;

X – variable;
Xmin – minimum values of the feature;
Xmax – maximum values of the feature.

- When the value of X is the minimum value in the column, the numerator will be 0, and hence X' is 0;
- On the other hand, when the value of X is the maximum value in the column, the numerator is equal to the denominator and thus the value of X' is 1;
- If the value of X is between the minimum and the maximum value, then the value of X' is between 0 and 1.

This scales the range to [0, 1] or sometimes [-1, 1]. Geometrically speaking, transformation squishes the n-dimensional data into an n-dimensional unit hypercube. Normalization is useful when there are no outliers as it cannot cope up with them.

The features, now preprocessed, are taken and given to this Machine Learning Classifier Algorithms:

- Decision tree
- K-Nearest Neighbours (KNN)
- Logistic Regression
- Random Forest
- Support Vector Machine (SVM)

A decision tree is a graphical illustration that uses a branching methodology to illustrate all available call outcomes and supported reliable conditions. The inner node represents an attribute lookup, each branch of the tree represents the result of the lookup, and the end node represents a detailed category label, i.e., a selection created after all attributes have been calculated.

KNN is a supervised machine learning algorithm that can be used to solve both classification and regression problems. The principle of KNN is that the value or class of a data point is determined by the data points around that value.

Logistic Regression algorithm. The assumptions of this model include absence of outliers in the dataset and absence of high correlations between the predictors, which have been taken care of in the preceding steps. In logistic regression, the probabilities predicted using the logit function. The values greater than or equal to the decision boundary belong to one class while the values lower than it belong to the other.

Random Forest is the machine learning algorithmic program that uses a textile approach to make a bunch of call trees with random set. A model is trained a lot of random samples of the dataset to realize sane prediction performance many times. The output of all the choice trees within the tree, combined to create the ultimate prediction. For instance, within the higher than example - if five friends decide that you simply can like building R however solely a pair of friends decide that you simply won't just like the building then the ultimate prediction is that you may like building R as majority continually wins.

SVM algorithm. Machine learning involves predicting and classifying the data tends to use diverse these algorithms in line with the dataset. It will solve linear and non-linear issues and work well for several sensible issues. The thought of SVM is simple: The algorithmic program creates a hyper plane that separates the info into category. In machine learning, the radial basis operate kernel, could be a widespread kernel operate employed in varied kernelized learning algorithms. Especially, it's normally employed in support vector machine classification.

For every algorithm, in addition to the training and the testing phase, has been calculated:

- Confusion Matrix
- Receiver Operating Characteristic / ROC Curve
- Classification Report

A confusion matrix is a table that is used to define the performance of a classification algorithm. A confusion matrix visualizes and summarizes the performance of a classification algorithm. The

confusion matrix, also known as the error matrix, is depicted by a matrix describing the performance of a classification model on a set of test data.

The receiver operating characteristics (ROC) curve is the plot between sensitivity and the FP rate for various threshold values. The area under curve (AUC) is the area under this ROC curve; it is used to measure the quality of a classification model. The larger the area, the better the performance.

The classification report function in sklearn is used to display text reports on the main classification metrics. The report displays accuracy, recall rate, F1 value, and other information for each category. These indicators are calculated by the following formulas:

Accuracy: $\frac{(TP+TN)}{(TP+TN+FP+FN)}$ (3)

Precision: $\frac{TP}{(TP+FP)}$ (4)

Recall: $\frac{TP}{(TP+FN)}$ (5)

F1 score: $2 * (Precision * Recall)/(Precision + Recall)$ (6)

where:

TP is True Positive
TN is True Negative
FP is False Positive
FN is False Negative

**Results and Discussion**

The results of the research work presented in the form of a confusion matrix are as follows:

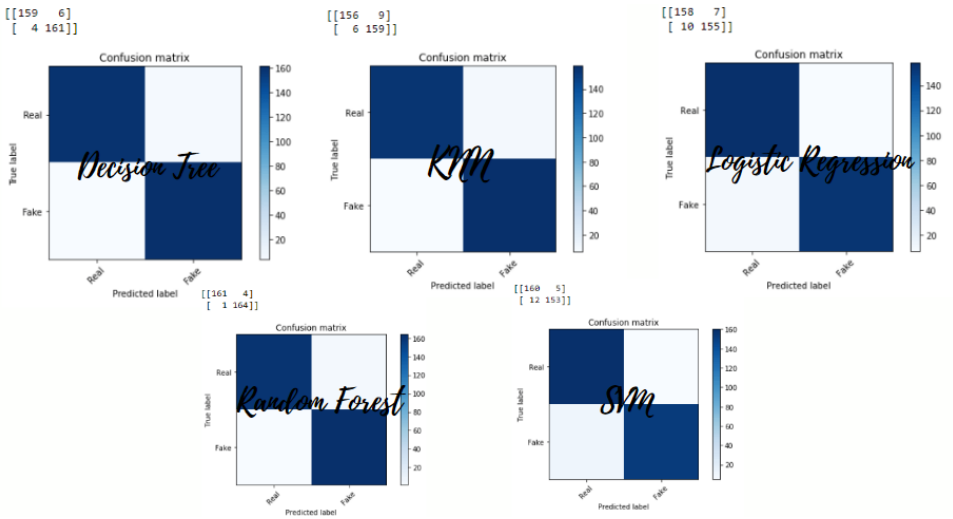


**Figure 3 –** Confusion matrix for each algorithm

The confusion matrix consists of four basic characteristics (numbers) that are used to define the measurement metrics of the classifier. These four numbers are:

1. TP (True Positive): TP represents the number of accounts that were correctly classified as fake accounts.
2. TN (True Negative): TN is the number of correctly classified non-fake accounts.
3. FP (False Positive): FP is the number of accounts misclassified as fake, but they are not actually fake. FP is also known as Type I error.
4. FN (False Negative): FN is the number of accounts that were erroneously classified as not fake but were actually fake. FN is also known as Type II error.

According to the results of the confusion matrix, it can be understood that the values of TP and TN show high rates, while the values of FP and FN are rather low.

The results of the research work, presented as an ROC curve, are as follows:

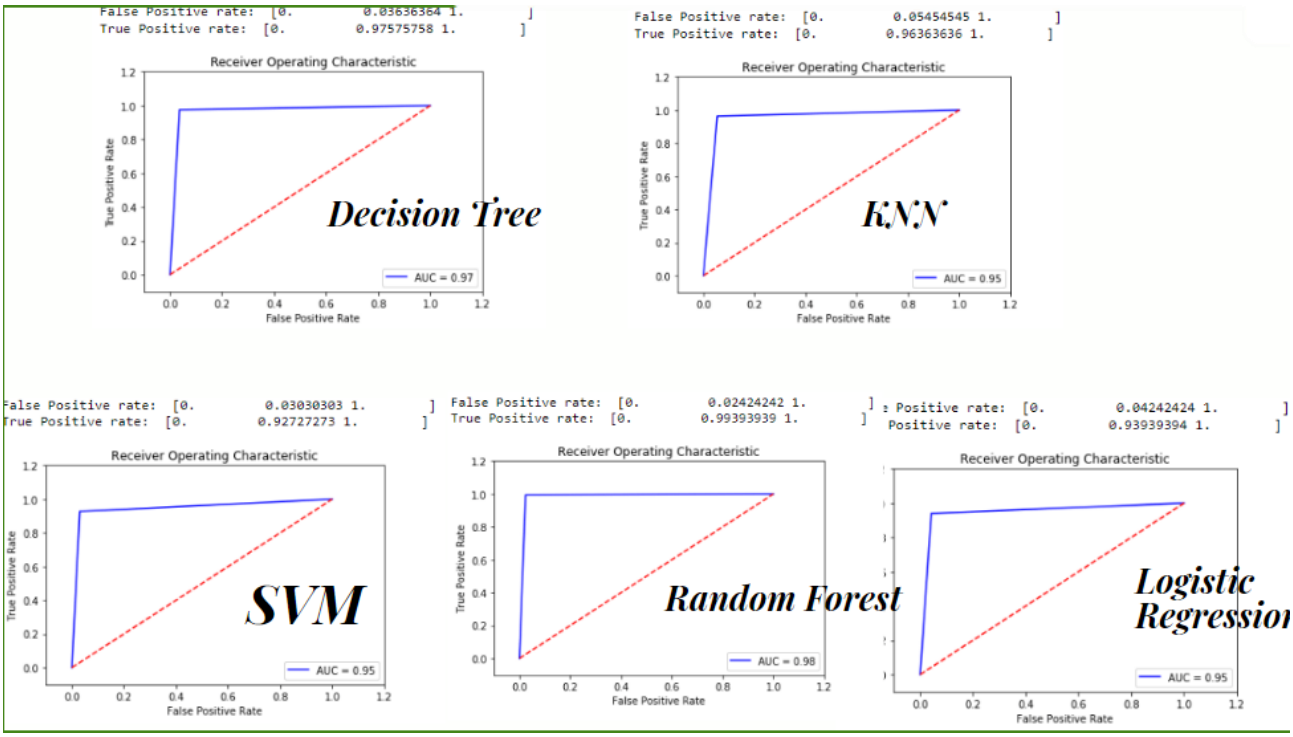


**Figure 4** – ROC curve for each algorithm

An ROC curve plots TPR vs. FPR at different classification thresholds. Lowering the classification threshold classifies more items as positive, thus increasing both False Positives and True Positives. To compute the points in an ROC curve, we could evaluate a logistic regression model many times with different classification thresholds, but this would be inefficient. Fortunately, there's an efficient, sorting-based algorithm that can provide this information for us, called AUC.

AUC ranges in value from 0 to 1. A model whose predictions are 100% wrong has an AUC of 0.0; one whose predictions are 100% correct has an AUC of 1.0. In this research, it can be noted that the AUC value is close in value to 1.0.

The results of the research work, presented in the form of a classification report, are as follows:

**Table 3** – Classification Report for private accounts

| Algorithm | Accuracy | Precision | Recall | F-Score |
|---|---|---|---|---|
| Decision Tree | 96% | 96% | 96% | 96% |
| KNN Classifier | 95% | 96% | 95% | 95% |
| Logistic Regression | 94% | 94% | 94% | 94% |
| Random Forest | 94% | 94% | 94% | 94% |
| SVM Classifier | 94% | 94% | 94% | 94% |

**Table 4** – Classification Report for public accounts

| Algorithm | Accuracy | Precision | Recall | F-Score |
|---|---|---|---|---|
| Decision Tree | 97% | 97% | 97% | 97% |
| KNN Classifier | 95% | 95% | 95% | 95% |
| Logistic Regression | 95% | 95% | 95% | 95% |
| Random Forest | 98% | 99% | 98% | 98% |
| SVM Classifier | 95% | 95% | 95% | 95% |

## Conclusion

The main goal of this research work is the automatic recognition of fake accounts using some classification algorithms. Based on this, a data set was created on the main factors of fake accounts, after which it was pre-processed and went through the stages of training and testing. The results of using machine learning showed that different classification algorithms give different results with fractions of a percentage, but the accuracy is maintained. The development of this project will make it possible to identify fake accounts more accurately, which will help secure the social network.

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# THE ROLE AND INFLUENCE OF ARCHIVAL DATA IN THE LIFE OF THE SCIENTIFIC COMMUNITY. EXPANDING ACCESS TO DIGITAL ARCHIVES


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**Abstract**

The digital turn raises the fundamental question of how knowledge is created, evaluated, taught, transmitted and published. The main purpose of digital research archives is not only to store materials, but also to provide access to what is stored. There was a general understanding that access to the results of the study should be as transparent as possible, taking into account the legal forms of ownership and confidentiality rules. "Open access" to literature means free access to a public network that allows any user to read, download, copy, distribute, search or link to the full texts of these articles, scan them.

This article describes the role of archival systems for the scientific community. Why does archiving play such an important role in the life of the scientific community and directly affects the quality of current research?

New technologies are being used to identify digital archives in order to increase public engagement and participation. Most of the digital records stored in cultural organizations are inaccessible due to confidentiality, copyright, commercial and technical issues. At the heart of this debate are both data openness and privacy issues. How open should digital archives be to the public? Should everything be open and accessible on the Internet, and what is needed to achieve a balance between openness and confidentiality?



**Keywords:** Research method, archival system, metadata, research data, research data archives.

**Introduction**

With the popularization of information technology, people began to produce a huge amount of data. Archival materials contribute to deeper study, as well as inspire and support new and more complex research and open up the potential for new ways of interpretative analysis.

Archiving plays an important role in the life of the scientific community and directly affects the quality of research

● Firstly, complete freedom in choosing the necessary information material contributes to the emergence of scientific interest and research in the most relevant areas and effective methods. The motivation for conducting research is only scientific interest or public demand.

● Secondly, research work on archival systems encourages several groups of scientists to conduct research on similar topics. This creates a wide range of results and views. Researchers have access to the same data, can argue about the results of the study with each other and be based on theoretical conclusions [1].

Digital information is easy to damage or change, to lose, as technologies develop and change at a rapid pace. The solution to this problem not only ensures free access of the scientific community to the results of research, but also increases the reliability of the archive system. This is equally important for scientists, students, the media and scientific organizations.

Over the past three decades, many scientific articles and other materials on digital preservation have appeared. Indeed, the focus was on conservation, and access to digital collections was discussed less and less. The following problematic aspects in archival systems

● Copyright is the reason why some collections are not digitized or made available when digital copies exist. The archive is trying to find a balance between maintaining trust and providing more digitized materials to users. This requires negotiations with copyright holders to obtain permissions and explore different levels of access (for example, by providing online access only to registered users with a username and password).

● Data protection is a serious obstacle to expanding access to digitized materials that contain confidential materials [2].

The barrier to access is confidentiality. The need to manage confidentiality is an urgent problem that needs to be addressed, given that violations can have serious, long-term and harmful consequences for the archive, the researcher believes.

**Materials and Methods**

All studies will include data collection. Most of this data will be collected directly through some form of interaction between the researcher and interested people or organizations using methods such as interviews, focus groups, surveys and participant observation. Such methods involve the collection of primary data, and this is an opportunity for the researcher to develop and demonstrate the greatest skill.

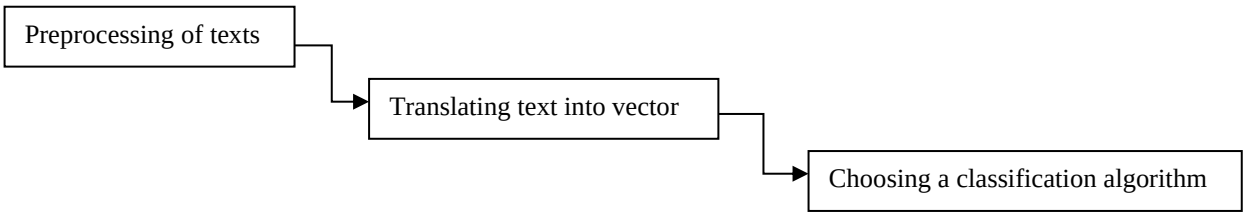
Archived secondary data are documentary records left by people as a by-product of their daily activities. They can be officially archived or simply exist as company records.

Researchers widely use archival materials as a key research method, using a wide range of different documents.

Reliability and validity are important for any research plan, and an important factor when using secondary data is the degree to which they relate to the research question, in other words, how reliably they can answer it.

Documentary data can be used as part of a qualitative or quantitative research plan. Many data, whether from company archives or from published datasets, are statistical and can be used as part of quantitative data. One way to use secondary data in quantitative research is to compare it with data that researchers collect independently, possibly through a survey. For example, you can compare the collected survey data with data from a census or another published survey, which will inevitably have a much larger sample, which will help to summarize and compare the results of the researcher.

Mass digitization has led to the creation of a valuable but underused source of large-scale digital data ready for study by scientists and practitioners in the field of digital humanities. However, the vast majority of digital cultural data stored in archives is inaccessible due to privacy, copyright, or technical issues. First, you need to determine what is confidential. This task can be broad, like a general classification of a text, or very specific, in order to surgically pinpoint parts of texts that may disclose confidential or personal information. Text classification is a classical and studied area of machine learning, where a set of characteristic features extracted from documents is used to predict document classes or categories. This is a typical supervised learning problem where the model was trained by looking through a pre-annotated collection of documents labeled with the correct classes. Learning a model usually means learning the mapping function between input data (objects representing documents) and output data (classes). The function can be a simple linear combination of feature weights or a complex model, for example, a model obtained using deep neural networks, with several nested levels of activation functions and thousands of parameters. One of the most important aspects of this class of algorithms is the definition of a set of functions that adequately reflect the correlation between input and output. When classifying text, functions are usually extracted directly from the text in the form of keywords, that is, individual terms that make up the text.




Artificial intelligence can also be used to search for relevant content. In addition to the search for supporting evidence that is used to prove or refute a case, the discovery of electronic data can also reveal whether evidence has been destroyed or is missing.

Artificial intelligence and machine learning can be used to unlock archives and increase their accessibility, by distinguishing confidential and non-sensitive materials, or by automatically adding tags and other metadata to improve searchability.

An increasing number of institutions are exploring the possibilities of using artificial intelligence and machine learning to make their collections more accessible to discovery and researchers. The automatic creation of metadata is a task that artificial intelligence systems can perform.

Artificial intelligence promises to make digital archives accessible by identifying confidential information, which will allow archival institutions to provide access to confidential information. In the context of digital archives, this technology can lead to training based on existing datasets to automate and simplify complex tasks, such as manually viewing confidential or copyrighted materials, or providing support to users in finding and understanding these archives. However, the opaque mechanisms by which these training algorithms train their models should be the subject of careful study, otherwise the pitfalls in the data from which they are extracted can easily be translated into incorrect decisions and a distorted representation of reality.

This promise to make archives more accessible is not without warnings about potential risks.

- Firstly, there are inherent errors that are hidden behind many algorithms.
- Secondly, trusting artificial intelligence to make decisions in difficult situations can lead to ethical and social problems [3].

Because of the nature of AI, why does a machine make the decisions it makes. The risks of biased, fake or incomplete information are closely related to AI.

The requirement to open data sets and make them searchable contrasts with the need to preserve individual privacy rights and, more generally, for reasons related to national security and international relations.

In the 2020 presentation, Steve Rigden, digital archivist at the National Library of Scotland, spoke about the role of artificial intelligence in identifying confidential materials in the NLS digital collections. He insisted on the role of archivists in analyzing data and making final decisions. Indeed, archivists need to identify datasets; identify the most effective algorithms to apply; test and refine data testing models to give the machine what it needs to learn; and further refinement and retesting [3].

The ability to process and automatically classify big data represents one of the greatest opportunities for using AI for digital archives [3].

The issue of confidential materials is one of the key reasons why so many digital collections cannot be found and are inaccessible. Artificial intelligence and machine learning can be used to view a huge number of digital files and identify problematic materials. In the 2020 presentation, Steve Rigden, digital archivist at the National Library of Scotland, spoke about the role of artificial intelligence in identifying confidential materials in the NLS digital collections. He insisted on the role of archivists in analyzing data and making final decisions. Indeed, archivists need to identify datasets; identify the most effective algorithms to apply; test and refine data testing models to give the machine what it needs to learn; and further refinement and retesting. Rigden argued that archivists do not have to understand the technical aspects of AI, but they should have an interest in participating in the development of such tools as advocates, consultants and testers. In other words, they need to actively participate in this process of “auxiliary verification" of archival documents.

The ability to process and automatically classify big data represents one of the greatest opportunities for using AI for born digital archives. The growing awareness and legal implications resulting from the application of various data protection laws (from the European GDPR to the UK Data Protection Act 2018) conflict with more than 100 different implementations of freedom of information laws and acts around the world, which are instead designed to provide access to government documents. Therefore, unlocking the born digital archives means, first of all, the ability to correctly identify and classify confidential and personal information (PII)[4].

PII refers to any information that can uniquely identify a person, from names, phone numbers and secret data to birth data and medical data. PII includes classified and legal information, as well as data obtained as a result of research experiments. The definition of PII can be elusive and even include information that cannot be directly attributed to an individual, such as search logs and IP addresses, since this can still lead to the identification of people if they are properly mined. For example, Sweeney (2002) demonstrated how it is possible to re-identify people by cross-linking datasets, even if they were previously anonymous, simply by looking at common attributes such as zip codes, date of birth and gender. date of birth and gender [4].

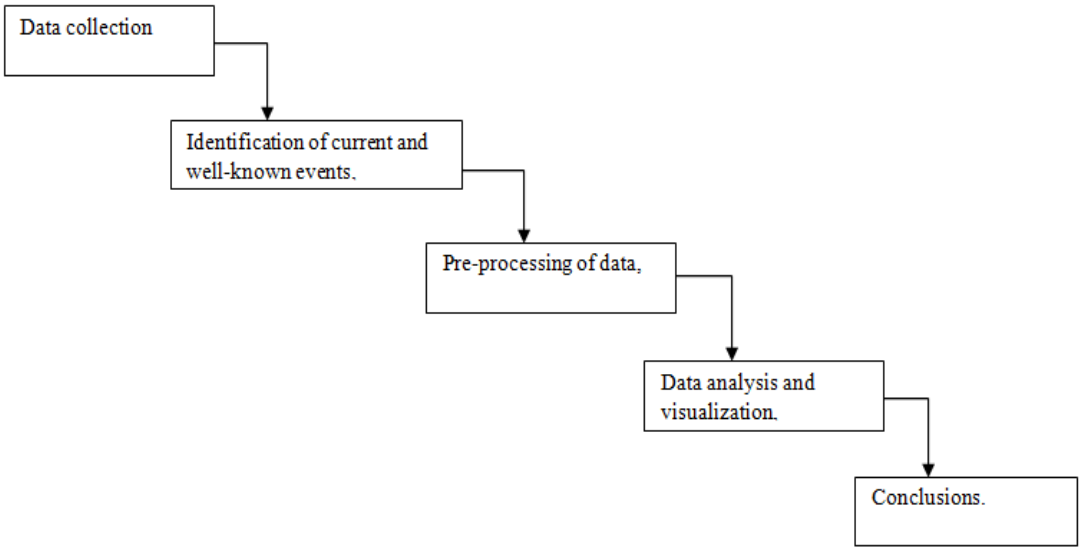
Typical information retrieval systems, such as Internet search engines, are information processors: in an attempt to optimize both accuracy and recall, they follow a policy that if something is available, it can also be found. The right balance between openness and protection can be achieved by revising this approach to data processing and consumption. Protection and search and search and protection are two possible paradigms for solving this problem. However, as Olteanu et al. (2021) please note, we want to keep confidential information not only from the human eye, but also from the search engine. Consequently, a new perspective on the problem can contribute to the creation of new architectures that take into account both relevance and sensitivity [4].

Regardless of the chosen paradigm, we consider two areas of intervention when faced with confidentiality when accessing born digital archives: identification and quantification of confidential information.

Publication of research results in text form is a traditional paradigm of knowledge exchange in scientific communication. Researchers from different communities use different channels to publish. Integration and harmonization of these channels are based on the developed culture of any particular community and community-defined criteria for analyzing the quality of these channels.

Metadata analysis refers to statistical methods used in the synthesis of studies to draw conclusions and provide recommendations based on the results obtained. Data collection must be provided for the analysis. The workflow of this study consists of five stages:

- Data collection,
- Identification of current and well-known events,
- Pre-processing of data,
- Data analysis and visualization,
- Conclusions [5].




Data collection is the process of objectively collecting data from various online sources.

The main purpose of the data preprocessing stage is

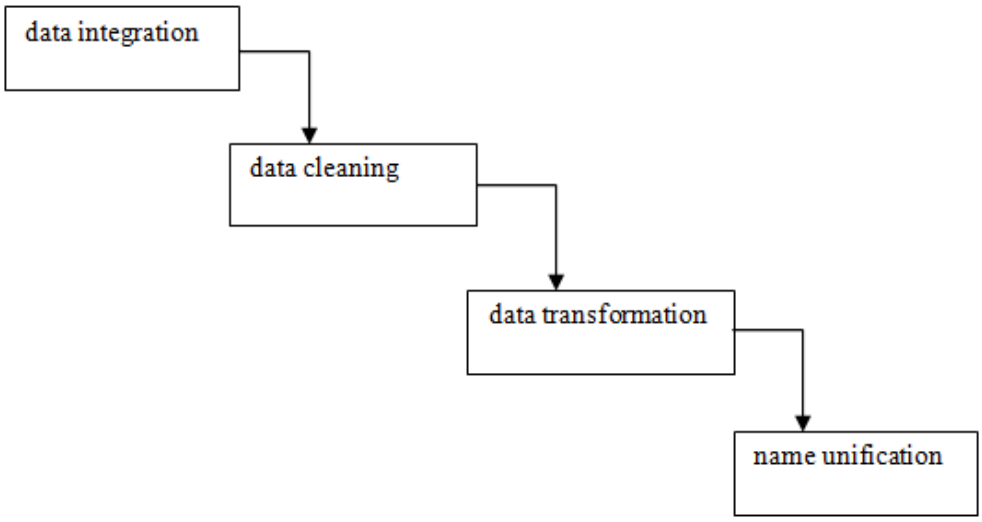
- to fill in the missing data,
- identify incorrect data,
- elimination of irrelevant data
- elimination of inconsistencies[5].

To prepare the raw data for analysis, we performed four preprocessing tasks: data integration, data cleaning, data transformation, and name unification.

- Data integration involves combining data from multiple sources into meaningful and valuable information. In addition, this process also includes the elimination of redundant data that may arise during the integration process. Data cleanup is aimed at deleting incorrect or inaccurate records. For example, some websites provide incorrect information about submitted materials and accepted documents. We have checked this information on the official websites of events or materials published in electronic libraries.
- Data structure transformation involves the conversion of purified data values from unstructured formats to structured ones.
- Combining names involves combining all the individual events of a series with multiple titles under its most recent title. It is important for researchers who want to submit their work to know the recent title, not the name that has been used the longest, as shown in the table [6].

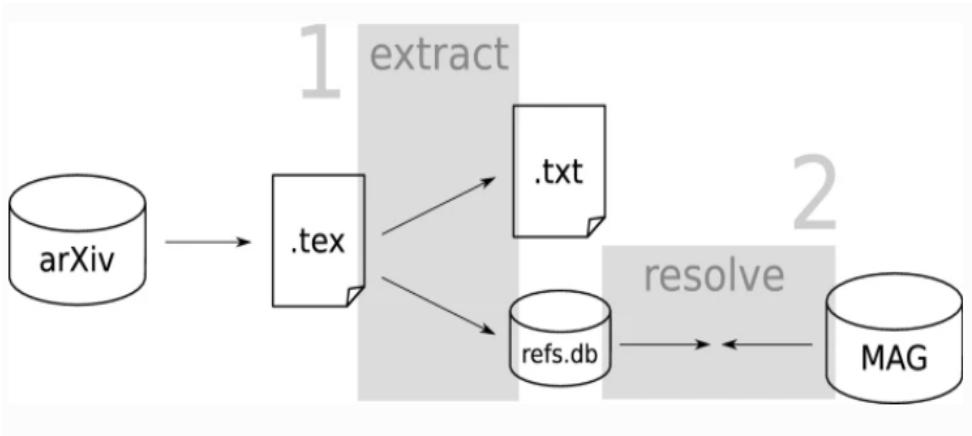
Scientific publications are usually distributed in formats intended for human consumption (for example, PDF), also as source files. Citation-based tasks, such as context-based citation recommendations, on the contrary, require automated processing of the textual content of publications, as well as the relationships between documents through citation in the text. Thus, creating a dataset for such tasks involves two main steps: extracting plain text and resolving links [7].

The variables we seek to investigate fall into two categories: those that assess the quality of research reporting, and those that relate to its reliability [8].




Correlation analysis can be used to assess the reliability and relevance of the materials used in research: a preliminary study of the relationship is carried out by applying correlation analysis to a data set. The approach measures the degree of statistical covariance, i.e. which two observed variables tend to change together. Spearman's correlation coefficient evaluates the degree of linear dependence between two variables, describing both the strength and direction of the statistical relationship. We chose this particular correlation coefficient because its rank approach is less subjective with respect to specific distribution assumptions.

Variable clustering: A statistical approach to identify subsets of highly correlated variables that provide the same information or belong to a common group. This approach is particularly useful for identifying underlying structures and redundancy between variables for size reduction processing. We used a hierarchical agglomerative method to separate the data, iteratively combining less heterogeneous clusters. Later, we conducted a stability assessment to determine which suitable clusters can be combined into one dimension.




Schematic representation of the data set generation process

**Literature review**

In the mid-1990s, the archival community began to develop strategies for preserving digital materials, including archival emails. At that time, the focus was on materials that were in danger of disappearing due to neglect and technological obsolescence. Growing concerns about the digital dark age led in 2002 to the creation of the Digital Preservation Coalition (DPC), created as a partnership between several agencies operating in the UK and Ireland. In the late 2000s, collaboration between

archivists and academics led to the creation of open source digital library tools for curating content, such as BitCurator. However, these examples of cooperation remained exceptional and rarely touched upon issues of access to "dark" archives [9].

There is no point in saving archived records that cannot be used immediately or at a later stage. In a recent article on the National Archives, Sara Martinez-Cardama and Ana Pacios found that "access" and "use" were listed by 14 and 12 institutions as priorities. However, in practice, serious obstacles, including privacy, copyright or technical problems, make it very difficult to access digital cultural data. For example, in the case of email archives, privacy considerations often lead to the closure of entire collections [9].

Developing an appropriate user interface to access the materials is a major challenge for many archival institutions, as they must ensure that users will not be able to modify records or delete them. As with other aspects, managing user access to digital files requires advanced technological skills. Callum McKean (senior curator of the Department of Contemporary Archives and Manuscripts at the British Library) said: "You need not only curators and technologists, and this is also often useful, but I think you need people who can move between these worlds and translate between these worlds to do it effectively." McKean himself took a course in applied data science to learn coding techniques for working with digital collections. This kind of training is still unusual for cultural heritage specialists. According to McKean, developing these skills in staff or hiring for these skills should be a key priority for the sector [9].

In the case of web archives in the UK, the 2013 legal no-seal deposit rules also require users to travel to the site to view materials that were once publicly available on the Internet. Most of the collection can be viewed only in six legally stored libraries located in nine locations: British Library (London, St Pancras and Boston Spa), National Library of Wales (Aberystwyth and Cardiff), National Library of Scotland (Edinburgh and Glasgow), Bodleian Library (Oxford), Cambridge University Library and Trinity College Library, Dublin. In addition, more than 19,000 websites - a small fraction of the 5-10 million different websites that are probably in the UK sphere — have permission from their owners to be viewed from anywhere via the UK Web Archive website [10].

The situation is quite different in the United States, where the Internet Archive regularly collects websites and makes them publicly available on the Internet. The fair use law in the US is much more liberal than the legal rules for depositing without a seal in the UK. Although the British legal framework severely restricts access, it also gives legal depositories clear powers to collect materials that might otherwise disappear. One of the interviewees said: "The fact that we have the legal authority and obligation to collect these things is... this is good, because the British Library and other libraries like it tend to think very long-term, and I think there is a reasonable chance that we will be here in 50 years, in 100 years ". Others are more critical of this situation, which requires users to access UK web archives on-site using a library computer. William Kilbride (executive director of the Coalition for the Preservation of Digital Data) notes: "Very few people even know that it's there, or how they will use it" (Kilbride 2021). It is impossible for Kilbride to save without access, because it is important to properly understand the needs and expectations of the user community [10].

**Conclusion**

Provided with enough sample data from which to learn and train their models, AI, and more specifically machine learning algorithms, offer the opportunity to improve and ease the access to digital archives by learning to perform complex human tasks.

Although the recent advances made by AI in the field of natural language processing, computer vision, machine translation and the like would not have been possible without the use of huge amounts of data on the basis of which these models are trained and studied, there are undeniable risks associated with the provision of data.

Evaluating and applying approaches to research paper-based and citation-based tasks typically requires large, high-quality, citation-annotated, interlinked data sets.

Research on open access aspects should carefully weigh the advantages and disadvantages of different sampling strategies against each other. The approach may be author-oriented, as in this study, or may be journal-based, depending on the relevance of the research questions posed.

This study provides a foundation to discuss and reflect on the current findings. For example, we may reflect on whether we should strive for a stronger relation between rigor and relevance. In case we come to the conclusion that this relation is, in fact, important, then further steps need to be taken to strengthen it.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## BUILDING A MODEL FOR THE DETECTING PNEUMONIA USING DEEP LEARNING


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**Abstract**

The World Health Organization estimates that more than four million deaths occur annually due to pneumonia and other diseases associated with air pollution, and the latest Covid-19 virus has dramatically increased the percentage of pneumonia cases. Also, there is a shortage of radiologists in both developing and developed countries. Currently, the development of artificial intelligence and machine learning technologies, as well as the collection of a large amount of medical images, make it possible to create automated systems for analyzing medical images. The article presents a simple model for detecting pneumonia based on deep learning methods (convolutional neural networks). 5,863 X-ray images from Guangzhou Women's and Children's Medical Center were used for the model. Neural network training took 12 epochs and 26 minutes. The results obtained in the test data are: recall – 96%, precision – 92%, accuracy – 92%, f1 – 94%. This is no less than the indicators in many popular works. The model significantly reduces the burden on radiologists, helps them make decisions and save time, allows them to evaluate the quality of their work and reduce the likelihood of medical errors.



**Keywords:** neural network, pneumonia detection, x-ray deep learning.


### Introduction

Pneumonia is an acute disease of the lower respiratory tract, pulmonary swelling. The World Health Organization (WHO) estimates that more than four million deaths each year are caused by other diseases related to pneumonia and air pollution [1]. To make an accurate diagnosis or to check

the presence of diseases at an early stage, the patient is assigned x-ray image, computer tomography, etc. radiation and functional tests.

One x-ray a year comes from thousands of X-ray scans. There is a shortage of radiologists in low-populated areas (both in developing and developed countries). In 2015, only 11 radiologists served 12 million people in Rwanda, and in Liberia, a country of four million people, there were only two radiologists [2]. Also, pneumonia is a high-risk disease, especially in developing countries, where millions of people are impoverished and unable to access medical facilities. Diagnosis of pneumonia through X-ray images is still a big challenge, because X-ray images have similar area information for different diseases, such as lung cancer. Therefore, the diagnosis of pneumonia through traditional methods takes a lot of time and energy, and it is impossible to determine whether the patient is suffering from pneumonia through a standardized process.

Pneumonia poses a serious threat to elderly people, patients hospitalized in a ventilator and the lives of asthma patients. More than 800,000 children under the age of five a year die from the disease, with about 2,200 dying every day from the disease. There are more than 1400 children with pneumonia per 100,000 children. The statistics, showing the number of deaths in the world as a whole, are given in Figure 1.

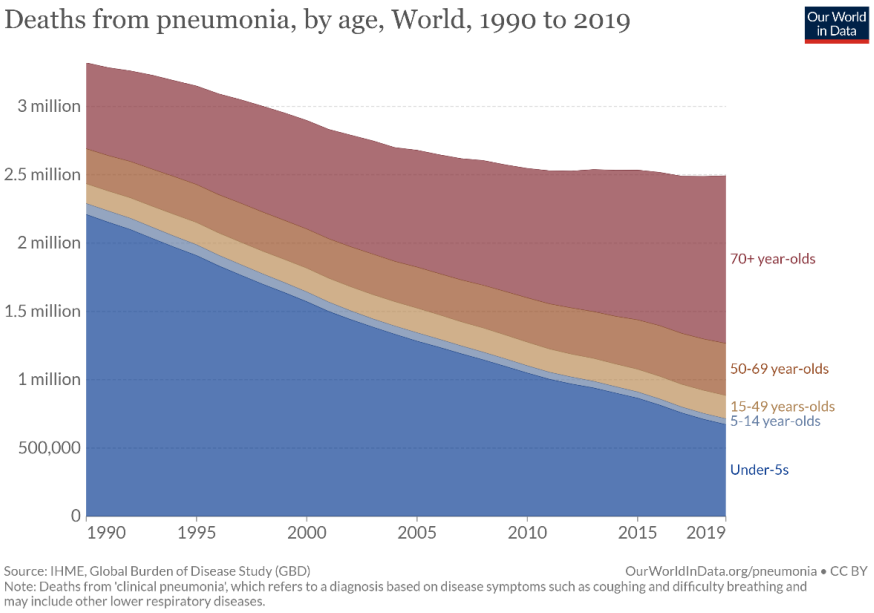



**Figure 1** – The number of deaths due to pneumonia in the world was dynamics and the ratio of age groups from 1990 to 2019.

One of the most important global problems was the sudden outbreak and uncontrolled spread of COVID-19, the main symptom of which is pneumonia. COVID-19 is a rapidly spreading disease of a very constipated nature, caused by the SARS-CoV-2 virus in the coronavirus group. In late January 2020, the World Health Organization (WHO) declared a global health emergency and a pandemic a month and a half later. As of September 25, 2020, 32,110,656 confirmed cases and 980,031 deaths were documented. From a public health point of view, early detection of COVD-19 and isolation of patients due to the lack of appropriate medicines were very important, hospitals had seen an exponential increase in patients due to the limited resources available.

In the future, detection of pneumonia from medical images will help radiologists to make decisions and save time, as well as improve the quality of services.

## 2 Overview of Literature

### 2.1 X-ray images

Currently, the reverse transcription polymerase chain reaction (RT-PCR) is the gold standard used for the diagnosis of COVID-19 infection. However, RT-PCR results may be affected by selection errors and low virus load. As a result, these trials suffer from high rates of false negative outcomes (sensitivity 71%) and may need to be carried out two or more times before the results are finally confirmed. In many articles, the image of the chest is a convenient tool for screening of early COVID-19. The problem is that the sensitivity of CT tomography scanning tests is much higher than RT-PCR tests, which can reach 98%. Unfortunately, CT scanners are inaccessible to many people. However, to get the first results, it is worth noting that the overall process of taking a picture of the chest is much shorter than RT-PCR. Screening takes an average of 15 s (by X-ray) to 21.5 minutes (for CT). Getting a sample for an RT-PCR test is a quick procedure. The difference is not the time of the test/screening, but the time it takes to get the first results.

At the same time, X-rays are cheaper than CT, less harmful and accessible worldwide because there is less radiation dose. Due to the presence of portable devices, X-ray imagery can be carried out in isolated rooms, therefore, the risk of infection is significantly reduced. Chest x-rays also contain extensive information about the patient's health. It creates images of walls, vertebrae, lungs, heart, blood vessels and respiratory tract. It is one of the most valuable tools for diagnosis of diseases, if carefully explained. It can detect and diagnose various diseases such as pneumonia, tuberculosis, interstitial pulmonary disease, pneumothorax and early pulmonary swelling. However, it is difficult to assess the severity of pathology, especially in X-ray images, so only specialists in the field of X-ray scans should explain the chest images.

Figure 2 shows an example of a pneumonic and healthy lung X-ray. The white stains on the pneumonic X-ray (indicated in red) are called infiltrators, which distinguish the pneumonia from a healthy state. However, in order to detect pneumonia, X-ray studies of the chest are susceptible to subjective variability [3, 4].

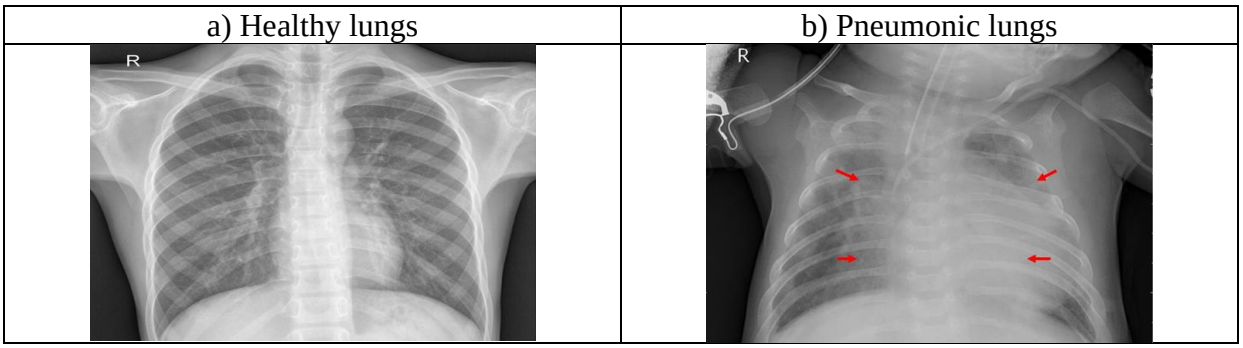



**Figure 2** - Examples of two X-ray images showing a healthy lung (a) and a pneumonic lung (b) (red indicators indicate white infiltrates, which are a special symptom of the pneumonia).

### 2.2 Work in the research area

In recent years, using X-ray images of the chest, several methods have been introduced that describe the short process of detection of pneumonia, especially in-depth training methods. Deep Learning has been successfully used to improve the performance of computer diagnostic technology (CAD), especially in the field of medical imagery [5], image segmentation [6], [7] and image reconstruction [8], [9]. [10] To speed up the diagnosis of the pneumonia, the 121-story CNN model offered a classic deep learning network called DenseNet-121 [11]. In contrast to the practitioners, the team also introduced a weighted binary cross-entropy loss to mitigate the impact of unbalanced classes, the difference between the loss of binary cross-entropy was the different weights of the unbalanced classes according to the number of each class.

Table 1 shows the results and estimates of various methods in the work carried out to identify the pneumonia.

**Table 1** – Analysis of research and results

| Study | Methods used | Database | Results |
|---|---|---|---|
| Comparative performance analysis of machine learning classifiers in detection of childhood pneumonia using chest radiographs [12] | SVM (Support Vector Machine), KNN, NB (Naive Bayes) | PneumoCAD | 77%, 70%, 68% respectively |
| Comparative performance analysis of state-of-the-art classification algorithms applied to lung tissue categorization [13] | Methods of removing labels (7), SVM, RF (Sort Forest) | Clinical data | AUC = 97.8% |
| Detecting Pneumonia in Chest X-Rays with Supervised Learning [14] | k-means clustering | Chest X-ray14 | AUC = 60% |
| Learning to diagnose from scratch by exploiting dependencies among labels [15] | LSTM (Long Short-Term Memory) | Chest X-ray14 | AUC = 76% |
| Labeled Optical Coherence Tomography (OCT) and Chest X-Ray Images for Classification [16] | Transfer learning | Pediatric chest X-rays | 90.7% |
| An Efficient Deep Learning Approach to Pneumonia Classification in Healthcare [17] | CNN (convolutional neural network) | Pediatric chest X-rays | 93.7% |
| Deep Convolutional Neural Networks for Chest Diseases Detection [18] | CNN, CPNN (Competitive probabilistic neural network), BPNN (Back Propagation Neural Network) | Chest X-ray14 | CNN – 92% |

Traditional machine learning algorithms do not reach their limit as the number of data increases, and the performance of neural networks on the contrary increases. It is beneficial to create a system for detecting the pneumonia from X-ray images using this algorithm, because the neural networks, depending on their nature, identify very complex patterns and the level of knowledge required for the successful application of neural networks is much simpler than using traditional methods.

Convolutional neural networks (CNN) are the most modern way to classify images and produce good results in non-linear issues with multidimensional spaces [19]. CNN was used to process signal and biomedical image, to classify multidimensional and thermal images, and to segment the image. CNN has several descriptions that justify their status as an AI and image editing tool. According to Chollet ([19]), these characteristics are simplicity, scalability, and versatileness. Simplicity eliminates the need to create functions by replacing CNN's complex and heavy conveyors with models that are simple and end-to-end learning. CNN scales because they are very convenient for paralleling on GPU or TPU. At the same time, CNN can be taught by repeating large or small sets of data, allowing them to be trained in a voluntary sized data set. Versatility and reusability are seen as opportunities, because unlike many previous approaches to machine learning, CNN can be trained in additional data without restarting from scratch, making them viable for continuous learning. This will allow us to reinvest and reuse past work in complex and powerful models.

## 3 Material and Methods

The development of artificial intelligence and machine learning technologies, as well as the accumulation of large volumes of medical images will create automated analytical systems in the field of medicine. Lately, deep learning algorithms based on CNN (convolutional neural networks) have been a standard choice for classification of medical images, although modern methods constitute a built-in network architecture, such as a system of trial and error. U-Net, SegNet, and CardiacNet are prominent architectures for image medical testing. Evolutionary-based algorithms and reinforcement learning (RL) models have been introduced to find optimal network hyperparameters during training. However, these methods are expensive in terms of calculation and cost a lot of power. Alternatively, this study offers a conceptually simple yet effective network model to solve the problem of detection of pneumonia.

Key steps in the model building process:

1. Data importing;
2. Data preprocessing;

3. Creation of a model architecture;
4. Training;
5. Assessment of quality on validation data;
6. Testing of the model.

### 3.1 Dataset

For the model, a dataset of The Kaggle competition consisting of 5863 X-ray images (jpeg format) of Women's and Children's Medical Center in Guangzhou was used [19] . All chest X-ray images were taken from patients aged one to five years, and the dataset was organized into 3 folders (train, test, val) and classified into every two categories (normal /pneumonia).

All chest x-rays were performed as part of the daily clinical care of patients. For analysis of chest X-ray images, all chest X-rays were initially screened for quality control by eliminating all low quality or unreadable scans. The diagnosis for the images was evaluated by three expert doctors.

The data is becoming unbalanced because there is a large ratio of examples of healthy and pneumonia cases (Figure 3).

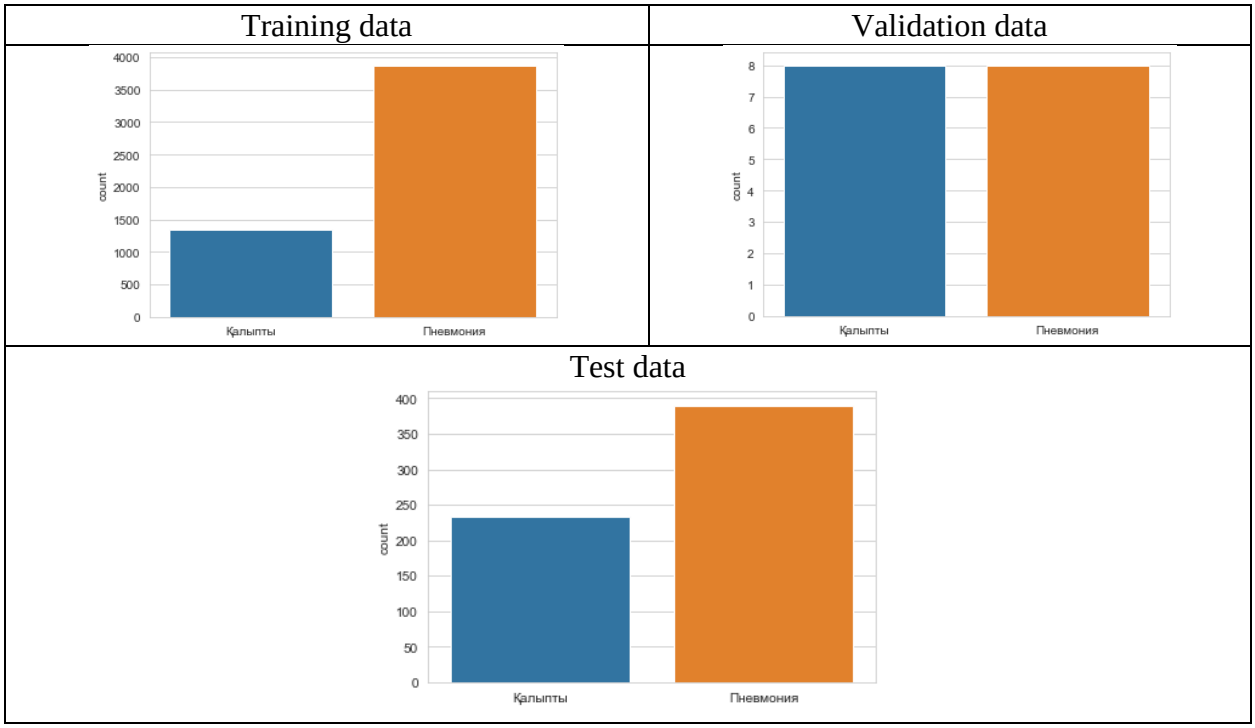



**Figure 3** – Class distributions in different datasets.

The x-ray image examples from the dataset are shown in Figure 4.

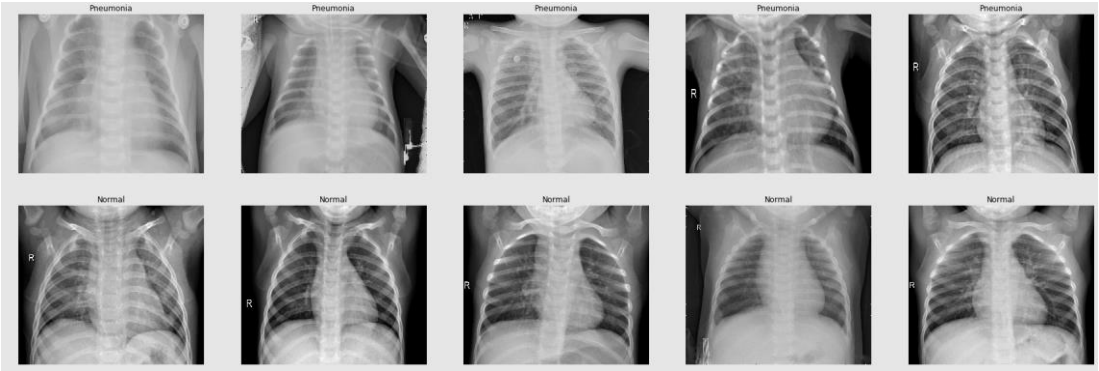



**Figure 4** – Random selected class examples.

### 3.2 Methods

3.2.1 Data preprocessing

The process of creating and customizing a learning pattern for image recognition issues may include the following steps: how to build a template, compress the shape to the desired size, normalize, apply filters, and so on, not all steps are required, but rather some steps may not be used at all, and others may be repeated several times.

**Scaling**

Scaling is to change the vertical and horizontal dimensions of the image. There are two types of scaling:

- Proportional - in this case, the ratio between the height and width of the picture will not change, but the overall size will change.

- In this case, the two dimensions vary differently.

In this work, scaling consisted of changing the vertical and horizontal size of the image to 150x150 pixels.

**Data augmentation**

Overtraining happens when there is little data for training. One way to solve a data shortage is to increase amount of data to a given volume and modifiability. Augmentation is directly related to applying different transformations to source data. This method helps to increase the number of unique inputs that the model no longer see. This, in turn, will help to obtain high accuracy in the testing data.

With Tensorflow.keras, we can generate the changes and new images provided by using the ImageDataGenerator class. To do this, it is enough to give the shapes the transformations that we want to apply as an option.

The options for image augmentation are shown in Table 2.

**Table 2** – Preprocess data options

| Parameter | Value |
|---|---|
| Resize | 150x150 |
| Normalization | (0, 255) → (0, 1) |
| Rotation Range | 0, 30 |
| Zoom Range | 0.2 |
| Width_Shift_Range | 0.1 |
| Height_Shift_Range | 0.1 |
| Horizontal_Flip | False |
| Vertical_Flip | False |

Here is a reason to put false to horizontal and vertical switches (the last two rows in Table 2), the data should be close to real life and not to change the nature of the object being studied, and if we change the shapes completely opposite, it leads to the shift of other organs (particularly heart) in the X-ray image (Figure 5). In addition to studying other diseases, this would give a false result, because the right-sided position of the heart is a disease. This can lead to mistakes, especially in the multiclassification of diseases.

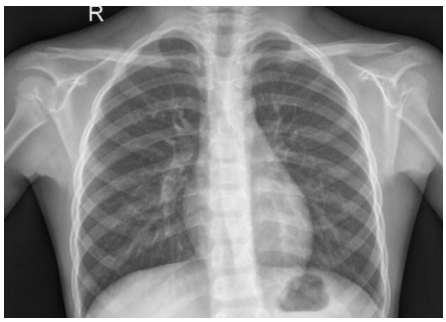
| Original image<br>(heart on the left) | Swapped image<br>(heart on the right) |
|---|---|
|  |  |

**Figure 5** – The result of the opposite replacement of the X-ray image.

3.2.2 Suggested network

The architecture of the neural network model presented in this work (Figure 6):

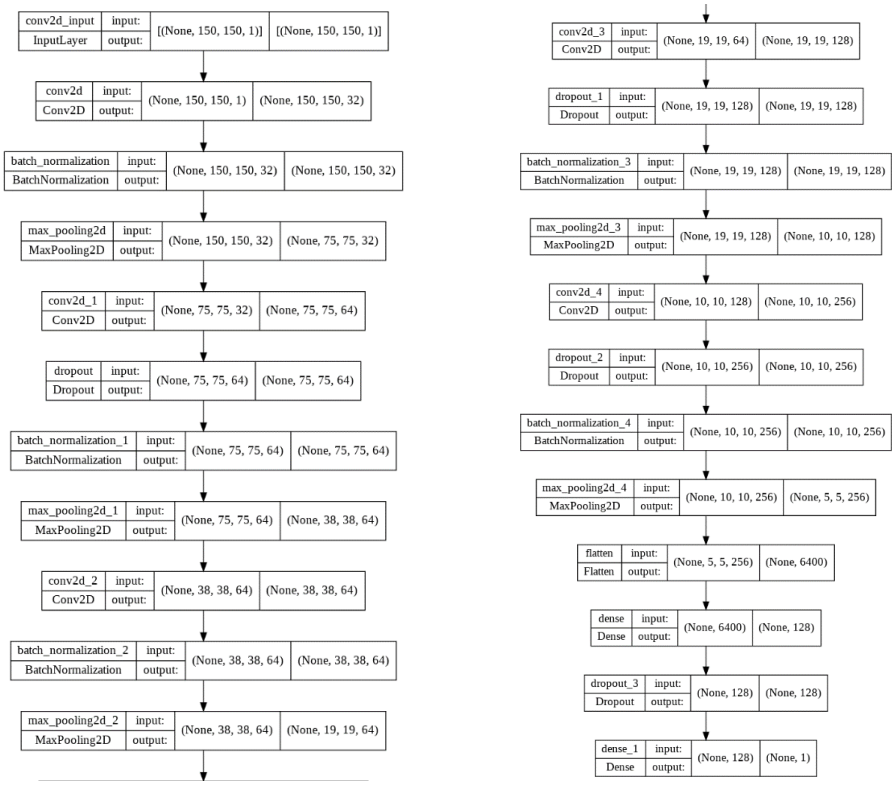



**Figure 6 -** Neural network architecture.

Total options: 1,246,401

Number of training options: 1,245,313

Number of non-training options: 1,088

Keras Sequintial API was used.

The first is the **convolutional (Conv2D) layer**. This is a set of filters that can be studied, with 32 filters for the first conv2D layer, 64 for the next two layers, and 128,256 for the last two layers, each filter converts part of the image (defined by the nucleus size) through a core filter.

CNN separates useful properties from these converted images at all time.

The second most important level on CNN is **the pooling (MaxPool2D) layer**, which simply acts as a zoom filter, which looks at a neighbor's 2 pixels and selects the maximum value, which is used to reduce compute costs and to a certain extent reduce overfitting.

By combining convolutional and pooling layers, CNN can combine local qualities and learn about the more global properties of the image.

**Dropout** is a custom method where the proportion of nodes on the layer is randomly ignored (by zeroing out their weight) for each exercise model, which randomly reduces the network share and forces the network to learn features in a distributed way, which also improves generalization and reduces overtraining.

The **'relu'** is used to add non-linearness to the network.

The **Flatten layer** is used to convert the final property maps to a single 1D vector, which is required to use layers that are fully connected after some convolutional/pooling layers, which combine all the found local features of the previous convolutional layers.

Finally, **two fully connected (Dense) layer** functions were used, which is the classifier of artificial neural networks (ANN,) activation - "sigmoid".

The proposed model uses the keras.callbacks.ReduceLROnPlateau method to reduce the learning rate when encountering a plateau to get a little closer to the global minimum. The options are shown in Table 3.

**Table 3** – The parameters of the ReuceLROnPlaceau method.

| Parameter | Meaning | Value |
|---|---|---|
| monitor | tracked indicator | 'val_accuracy' |
| patience | the number of unimproved epochs, followed by the decline in reading rates | 2 |
| factor | the factor that reduces the pace of study. new_lr = ir * factor. | 0.3 |
| min_lr | lower reading speed limit | 0.000001 |

### 3.2.3 Classification assessment metrics

Four standard assessment metrics were used to evaluate the proposed model in two pneumonia data sets: accuracy, precision, recall, and F1. To determine these metrics, let's first define the terms "true positive," "false right," "true negative," and "false negative." For a binary classification task, say the two classes in the data set are called "positive" and "negative" classes. The terms mentioned above can be defined as follows.

• **True Positive (TP)** represents a model that belongs to a positive class that is properly classified by model.

• **False Positive (FP)** represents an incorrectly classified model as belonging to a positive class.

• **True Negative (TN)** represents a sample that belongs to a negative class that is properly classified by model.

• **False Negative (FN)** represents a model that belongs to a positive class that is incorrectly classified as belonging to a negative class.

We can now determine four assessment metrics as follows:

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN}$$

$$Precision = \frac{TP}{TP + FP}$$

$$Recall\ (Sensitivity) = \frac{TP}{TP + FN}$$

$$F1 = \frac{2}{\frac{1}{Precision} + \frac{1}{Recall}}$$

The accuracy returns the total size of the model's correct forecasting count. However, the model's high accuracy rate does not provide the ability to distinguish different classes equally if the data set is unbalanced. In particular, in the classification of medical images, all classes need a model that can be generalized. In these cases, the Values Precision and Recall provide an insight on the model's performance. Precision shows the accuracy of the model's positive class forecast. By contrast, Recall shows the accuracy of the model's negative class forecast. F1 provides the balance between Precision and Recall, considering both FP and FN.

The important indicator that combines these estimates and returns the overall view is **the confusion matrix** (matrix of errors), which, in the case of binary classification, is as follows:

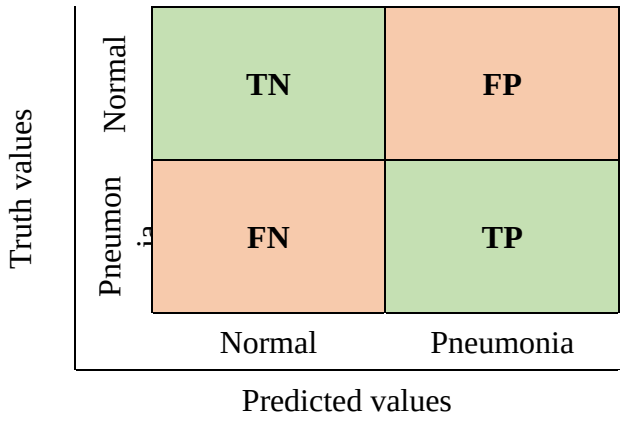



**Figure 7 -** Confusion matrix.

Thus, it is useful to take into account the assessment indicators in the classification of medical images in addition to accuracy for the accurate identification of both healthy and pneumonia cases.

## 4 Training process and results

The training process lasted 12 epochs and took 26 minutes. The accuracy and loss in the training data and validation data during the process varied as follows:

```
Epoch 1/12
163/163 [==============================] - 133s 813ms/step - loss: 0.6684 - accuracy: 0.8372 - val_loss: 23.3720 - val_accurac
y: 0.5000 - lr: 0.0010
Epoch 2/12
163/163 [==============================] - 134s 821ms/step - loss: 0.2757 - accuracy: 0.8967 - val_loss: 27.4178 - val_accurac
y: 0.5000 - lr: 0.0010
Epoch 3/12
163/163 [==============================] - ETA: 0s - loss: 0.2347 - accuracy: 0.9132
Epoch 3: ReduceLROnPlateau reducing learning rate to 0.0003000000142492354.
163/163 [==============================] - 135s 829ms/step - loss: 0.2347 - accuracy: 0.9132 - val_loss: 37.5460 - val_accurac
y: 0.5000 - lr: 0.0010
Epoch 4/12
163/163 [==============================] - 133s 814ms/step - loss: 0.1563 - accuracy: 0.9480 - val_loss: 15.5961 - val_accurac
y: 0.5000 - lr: 3.0000e-04
Epoch 5/12
163/163 [==============================] - ETA: 0s - loss: 0.1348 - accuracy: 0.9530
Epoch 5: ReduceLROnPlateau reducing learning rate to 9.000000427477062e-05.
163/163 [==============================] - 132s 808ms/step - loss: 0.1348 - accuracy: 0.9530 - val_loss: 26.0691 - val_accurac
y: 0.5000 - lr: 3.0000e-04
Epoch 6/12
163/163 [==============================] - 135s 827ms/step - loss: 0.1198 - accuracy: 0.9578 - val_loss: 2.2864 - val_accuracy:
0.5000 - lr: 9.0000e-05
Epoch 7/12
163/163 [==============================] - 133s 816ms/step - loss: 0.1130 - accuracy: 0.9626 - val_loss: 0.3773 - val_accuracy:
0.8125 - lr: 9.0000e-05
Epoch 8/12
163/163 [==============================] - 134s 821ms/step - loss: 0.1137 - accuracy: 0.9653 - val_loss: 3.6626 - val_accuracy:
0.5000 - lr: 9.0000e-05
Epoch 9/12
163/163 [==============================] - ETA: 0s - loss: 0.1171 - accuracy: 0.9618
Epoch 9: ReduceLROnPlateau reducing learning rate to 2.700000040931627e-05.
163/163 [==============================] - 135s 827ms/step - loss: 0.1171 - accuracy: 0.9618 - val_loss: 1.2164 - val_accuracy:
0.6250 - lr: 9.0000e-05
Epoch 10/12
163/163 [==============================] - 135s 827ms/step - loss: 0.1057 - accuracy: 0.9626 - val_loss: 2.0233 - val_accuracy:
0.5625 - lr: 2.7000e-05
```

```
Epoch 11/12
163/163 [==============================] - ETA: 0s - loss: 0.0960 - accuracy: 0.9670
Epoch 11: ReduceLROnPlateau reducing learning rate to 8.100000013655517e-06.
163/163 [==============================] - 134s 823ms/step - loss: 0.0960 - accuracy: 0.9670 - val_loss: 0.7885 - val_accuracy:
0.6250 - lr: 2.7000e-05
Epoch 12/12
163/163 [==============================] - 134s 820ms/step - loss: 0.0941 - accuracy: 0.9701 - val_loss: 2.5837 - val_accuracy:
0.5000 - lr: 8.1000e-06
```

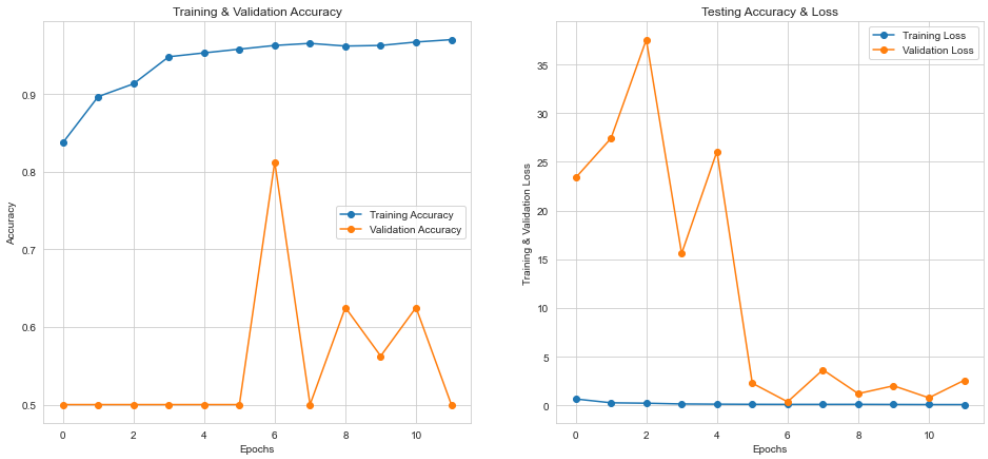



**Figure 8** - Training process.

In the test data**,** the model showed **92.3%** accuracy. Model result report:

| | 0 | 1 | accuracy | macro avg | weighted avg |
|---|---|---|---|---|---|
| **precision** | 0.934579 | 0.917073 | 0.923077 | 0.925826 | 0.923638 |
| **recall** | 0.854701 | 0.964103 | 0.923077 | 0.909402 | 0.923077 |
| **f1-score** | 0.892857 | 0.940000 | 0.923077 | 0.916429 | 0.922321 |
| **support** | 234.000000 | 390.000000 | 0.923077 | 624.000000 | 624.000000 |

In the detection of pneumonia**,** the values of **precision = 91.7%, recall = 96.4%, F1 = 94%** are significantly good indicators. The most important indicator here is recall, because it is more expensive to detect a pneumonia than to give us false results that we have pneumonia having healthy lungs.

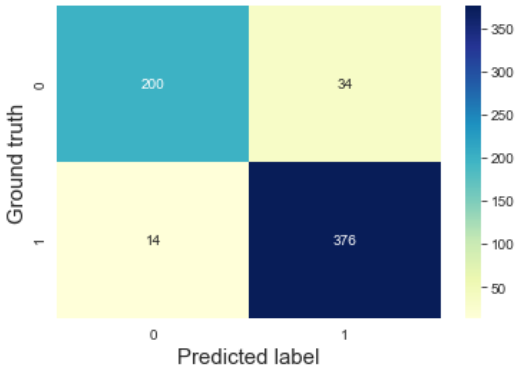



**Figure 9** – Confusion matrix.

Here are the correct, incorrect examples that the model identifies:

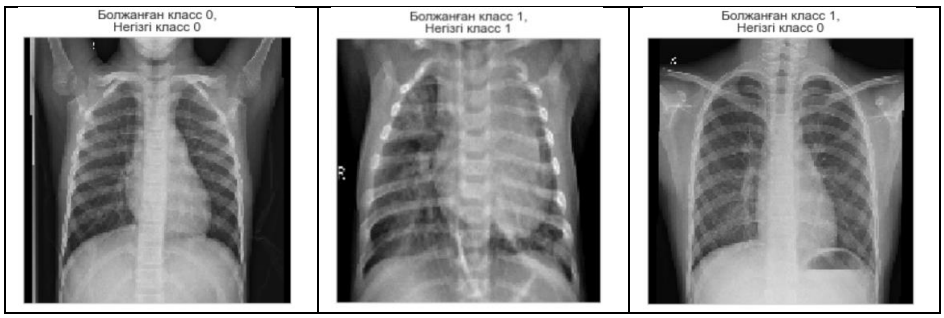



**Figure 10 -** The results of the model classification.

### 4.1 GUI

A simple GUI in Python has been developed using the PyQT5 library to be user friendly. The application and the results are shown in 11-12 figures.

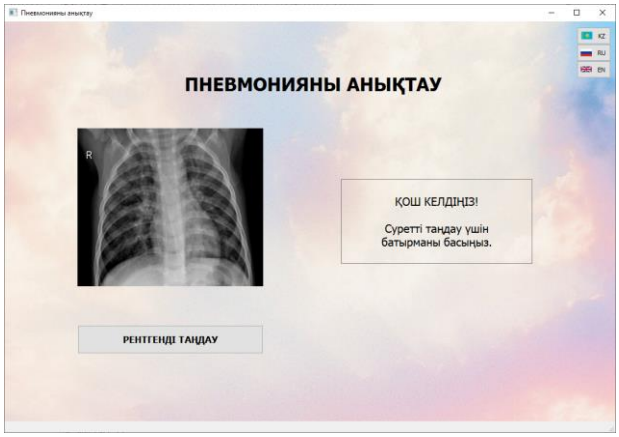



**Figure 11** – The original page of the application.

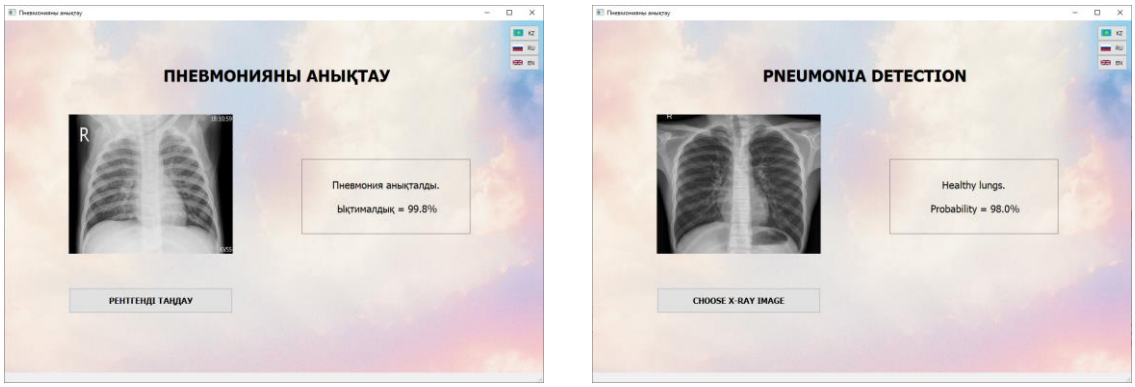



**Figure 12** – The results of classification (interface in Kazakh and English).

### Conclusion

Many authors presented a considerable amount of work, as shown in the analysis table. Most of them are relatively accurate, but the results are evaluated in a small database and cannot be used on a commercial purpose. In this regard, the use of high-quality data, confirmed by several highly specialized independent rheumatologists of large size, can lead to great success, considering the current dynamics.

The advantage of the network offered in this work is:

- time economy;
- relatively high-precision detection of pneumonia (recall - 96%);
- simple model.

In the future, the creation and expansion of the database of the training process, which will be accumulated using trends such as transfer learning in deep learning, is planned. Although the resulting accuracy is relatively high, 99% accuracy itself may not be enough because the area being studied is related to human life.

In the future, the accurate automated analysis of x-rays will improve the efficiency of the radiology workflow, it is important to reduce the costs and response time to improve the quality of medical care. It also has great opportunities to spread the experience to underserved areas.

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## OVERVIEW OF DEEP NEURAL NETWORK TRAINING METHODS

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**Abstract**

Deep neural networks are currently becoming one of the most popular approaches to creating artificial intelligence systems, such as speech recognition, natural language processing, computer vision, etc. The article presents an overview of the history of development and the current state of deep neural network training methods. The model of an artificial neural network, neural network learning algorithms, including the error back propagation algorithm used to train deep neural networks are considered. The development of neural network architectures is described: neocognitron, autoencoders, convolutional neural networks, limited Boltzmann machine, deep trust networks, long-term memory networks, managed recurrent neural networks and residual learning networks. Deep neural networks with a large number of hidden layers are difficult to train due to the vanishing gradient problem. The article discusses methods for solving this problem, which make it possible to successfully train deep neural networks with more than a hundred layers. The review of popular libraries of deep learning of neural networks, which made possible the wide practical application of this technology, is given. Currently, convolutional neural networks are used for computer vision tasks, and recurrent neural networks, primarily long—term memory networks and managed recurrent neural networks, are used for processing sequences, including natural language.

**Keywords:** neural network, machine learning, deep learning.

### Introduction

Deep neural networks are currently becoming one of the most popular machine learning methods. They show better results compared to alternative methods in areas such as speech recognition, natural language processing, computer vision [1], medical informatics [2], etc. One of the reasons for the successful use of deep neural networks is that the network automatically selects important features from the data necessary to solve the problem. In alternative machine learning algorithms, features should be distinguished by people, there is a specialized area of research — feature engineering. However, when processing large amounts of data, the neural network copes with the selection of features much better than a person. The article presents a historical overview of the development of deep neural network architectures and approaches to their training. The task of compiling such a review is significantly complicated by the fact that a lot of variants of deep neural networks have been proposed and the terminology has changed over time [3]. The model of artificial neural networks was proposed in 1943 [4], and the term deep learning became widely used only since 2006 [5, 6]. Prior to that, the terms loading deep networks [7, 8] and learning deep memories [9] were used. The growth in popularity of deep neural networks occurring in the last few years can be explained by three factors. Firstly, there was a significant increase in the performance of computers, including GPU computing accelerators (Graphics Processing Unit), which made it possible to train deep neural networks of the network much faster and with higher accuracy [10]. Previously, the available computing power was not enough to train any complex network suitable for solving

practical problems. Secondly, a large amount of data has been accumulated, which is necessary for training deep neural networks. Thirdly, neural network training methods have been developed that allow for fast and high-quality training of networks consisting of a hundred or more layers [11], which was previously impossible due to the problem of vanishing gradient and retraining. The combination of three factors led to significant progress in the training of deep neural networks and their practical use, which allowed deep neural networks to take a leading position among machine learning methods.

**Artificial neural networks**

The artificial neuron model was proposed by Warren McCulloch and Walter Pitts in 1943 in [4]. The authors used a biological neuron as the basis for their model. The McCulloch—Pitts artificial neuron has N input binary quantities x1, ..., xn, which are interpreted as pulses coming to the input of the neuron (Figure 1). In the neuron, the pulses are added with weights w1, ..., wn.

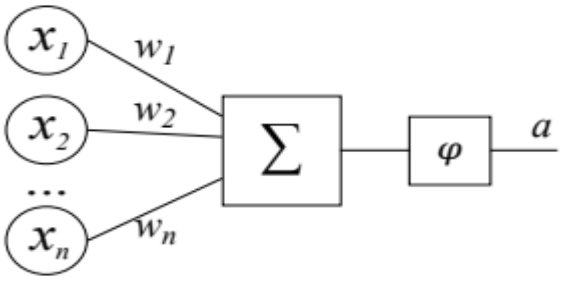


**Figure 1** - McCulloch—Pitts artificial neuron model

The output signal of a neuron is determined by the formula:

$$a = \varphi(\sum_{i=1}^{N} w_i x_i) \quad (1)$$

where the nonlinear function $\varphi$ (activation function) converts the total pulse into the output value of the neuron. The McCulloch—Pitts model used the Heaviside function for this purpose. In the future, it was proposed to use other types of activation functions: logistic sigmoidal $f(x) = \frac{1}{1+e^{(-x)}}$ [12], hyperbolic tangent $tanh(x) = \frac{2}{1+e^{(-2x)}} - 1$ [13] and the radial basis function [14]. Such activation functions provided a smoother change in the output signal of the neuron.

McCulloch and Pitts also proposed a method for combining individual neurons into artificial neural networks. To do this, the output signals of a neuron are transmitted to the input of the next neuron (Figure 2). The neural network consists of several layers, each of which may contain several neurons. The layer that receives signals from the outside world is called the input layer. The layer that outputs signals to the outside world is the output layer. The remaining layers are called hidden.

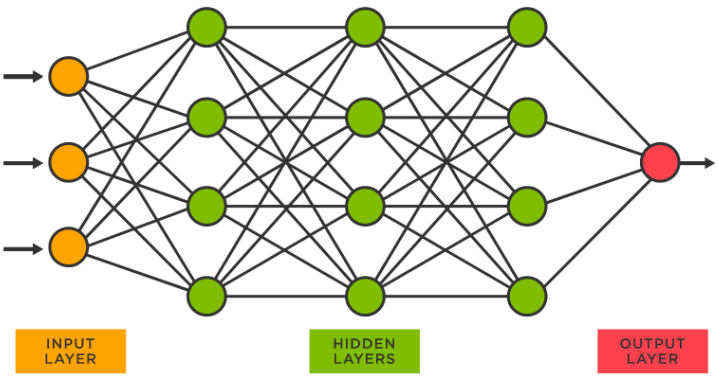


**Figure 2**- Artificial neural network

**Training of neural networks**

Neural network training is the process of determining the weights of connections between neurons in such a way that the network approximates the required function with a given accuracy. There are three approaches to training neural networks [3]: supervised learning, unsupervised learning, and reinforcement learning. When learning with a teacher, the input of the network is supplied with sets of input signals (objects) for which the correct answer is known in advance (training set). The weights change according to certain rules, depending on whether the network produced the correct output signal. In unsupervised learning, objects for which the correct output signal is not known in advance are fed to the network input. Reinforcement learning assumes the presence of an external environment with which the network interacts. Learning takes place on the basis of signals received from this environment.

The idea of training neural networks was first proposed by Donald Hebb in 1949 [14]. According to Habb, the connections of neurons that fire together should be strengthened, and the connections of neurons that fire separately from each other should be weakened. Hubb proposed rules for changing the weight of the input signals of neurons in accordance with whether the network gave the correct answer or not [14] (supervised learning). A.V. Novikov proved the convergence of the proposed neuron learning method based on the Hebb rules [15], provided that the sample of objects is linearly separable. Subsequently, several similar rules were proposed both for learning with a teacher [16–18] and without a teacher [19–23].

Currently, for training neural networks, including deep ones, an error backpropagation algorithm based on the gradient descent method is used. The algorithm was proposed in 1970 in a master's thesis [24, 25] without connection to neural networks. The first application of this algorithm for training neural networks was described in [26], published in 1981. After that, several more works on this subject appeared [27–29]. The backpropagation algorithm uses supervised learning and requires a training set with correct answers known in advance. An error measure is introduced, which determines how much the output values of the network differ from the correct answers. The error measure is then minimized using the gradient descent method by changing the values of the weights in the network. In order to evaluate how much each weight affects the output value, the partial derivatives of the error with respect to the weights are calculated. Then the weights are changed to a small value, taking into account the gradient. This is repeated until the output error is reduced to acceptable values. The initial values of the weights of neurons in the network are set randomly.

There are several options for implementing training of neural networks using the backpropagation algorithm. With full training, the gradient is calculated for all objects in the training set. However, this approach is often not effective when the training set is large and it takes a lot of time to process all its elements. An alternative option is to use the stochastic gradient descent method, in which the weights change when processing one element of the training set (online learning) or several elements (training on batches or mini-samples). In practice, it is the method of stochastic gradient descent or its modification that is most often used to train neural networks [30–32].

**Architecture of deep neural networks**

The neural network shown in Figure 2 is called fully connected. In such a network, each neuron of the next layer is connected to all neurons of the previous layer. However, this is not the only way to connect neurons into a network. This section discusses the development of neural network architectures. In 1980, Kunihiko Fukushima proposed a neural network architecture called neocognitron [33]. The architecture used an analogy with complex and simple cells in the visual cortex of a cat [34]. Simple cells fire in response to simple visual cues such as border orientation. Complex cells are less dependent on the spatial arrangement of signals and are guided by more general features. In the neocognitron, simple cells correspond to convolutional layers, and complex cells correspond to subsampling layers. In convolutional layers, the window of the convolutional unit (convolutional unit) with a given set of weights (convolution kernel) moves over a two-dimensional array of input data, for example, over image pixels (Figure 3).

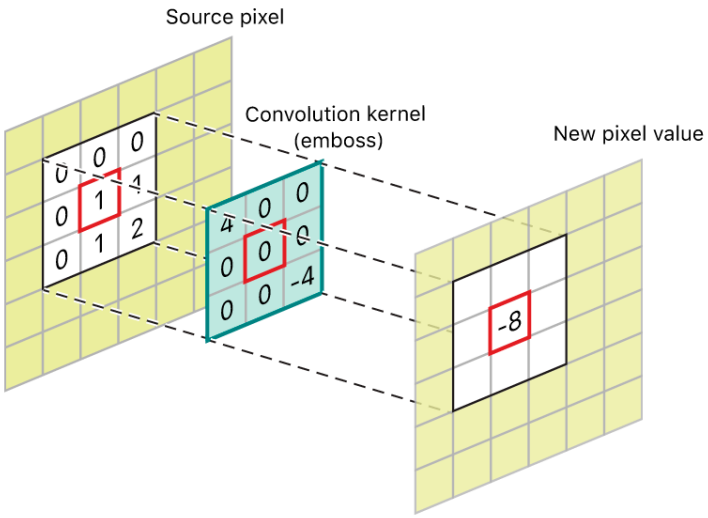


**Figure 3 -** Scheme of the convolutional layer of the neocognitron neural network

The values of the matching elements in the data and the convolution kernel are multiplied, the results are added up and fed into the neuron of the next layer. All convolution nodes use the same convolution kernels, so relatively few parameters are required to describe a convolution network. As a rule, convolutional layers use not one, but several convolution kernels.

The outputs of the convolutional layers in the neocognitron are connected to the inputs of the subsample layers. Moreover, several neurons of the convolutional layer are connected to one neuron in the subsample layer, as a rule, from a square area of 2*2 or more. Neurons in the subsample layer are triggered if at least one of the input signals is active. On this layer, the presence of the signal itself is important, and not its specific coordinates, so the subsample layers are less sensitive to minor shifts and changes in the image scale. The training of convolutional layers in a neocognitron is performed using local learning algorithms without a teacher, or weights are set in advance [35, 36]. Spatial averaging is used for subsampling layers [33, 37]. Thus, despite the fact that the neocognitron is a deep neural network, deep learning is not used in it.

In 1987, Dan Ballard proposed an approach to teaching neural networks without a teacher based on an autoencoder [38]. A simple auto-encoder contains only one hidden layer (Figure 4) with the code h, which serves to represent the input signal x. The auto-encoder contains an encoding function f, which is used to convert the input signal into a code h = f(x) and a decoding function g, which restores the values of the input signals r = g(x) from the code.

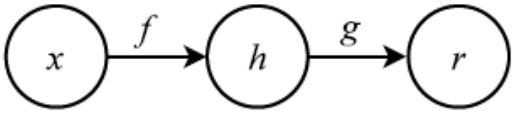


**Figure 4** - Scheme of a simple auto-encoder

Auto encoders are used to reduce the dimensionality of the processed data. Linear methods, such as the principal component method, are used for this. By reducing the dimensionality, the auto-encoder highlights the most significant characteristics of the data.

The recirculation method is used to train auto-encoders [39]. The auto-encoder is trained in such a way that its output has the same signals as the input. After training, the hidden layer of a simple auto-encoder is inserted into a higher-level auto-encoder that contains more hidden layers. In this way, a hierarchy of auto-encoders is built in the form of a stack (Figure 5). At the same time, the dimension of the data decreases at each level of the hierarchy. Such a hierarchy can be used not only for auto-encoders, but also for other methods of teaching without a teacher [40, 41].

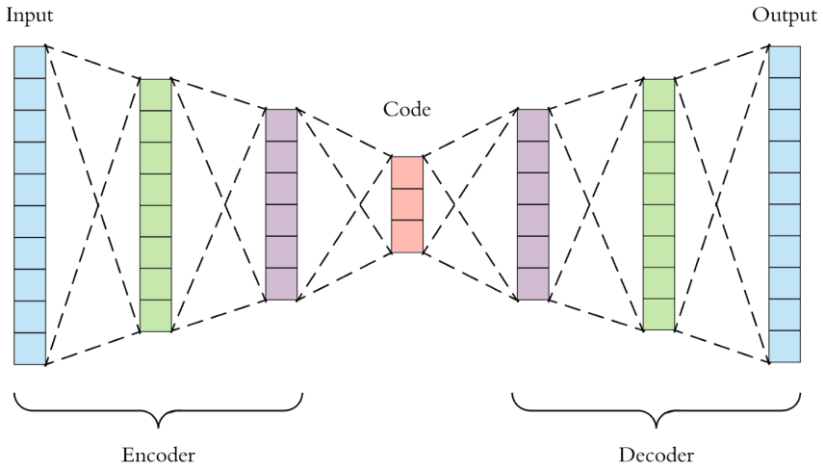


**Figure 5** - Hierarchy of auto-encoders

Yann LeCun (Yann LeCun) in 1989 applied an algorithm for error back propagation to train a network with an architecture very similar to a neocognitron [42]. The network contained convolutional layers with the same weights (convolutional cores) and subsample layers. In the same paper, the MNIST data set was presented, containing handwritten digits, the recognition of which eventually became a very popular test in machine learning. Deep convolutional networks trained by the error back propagation algorithm have shown good results in recognizing handwritten digits [43] and fingerprints [44].

At the end of the 80s of the twentieth century, it became clear that one algorithm for error back propagation is not enough for effective deep learning. Despite some successful examples [43, 44], the use of more than one hidden layer rarely gave advantages in practice [45-47]. The reason for this was formulated in 1991 in [48, 49] — the vanishing gradient problem. When using traditional activation functions (see section 1), signals about back-propagated errors quickly become very small (or vice versa, excessively large). In practical problems, they decrease exponentially with the number of layers in the network. This problem is also known as the long time lag problem [50, 51].

One of the approaches to solving the problem of vanishing gradient is to completely abandon the use of gradient for training. For some tasks, good results can be achieved by assigning weights randomly [52]. The Evolino learning approach [53] uses linear methods to determine the optimal weights for the output layer and evolution to determine the weights of hidden layers. It is also possible to use universal search methods [54, 55].

An alternative approach to solving the vanishing gradient problem is the use of Hessian—free optimization [56-60].

The disappearing gradient problem can be solved by another recurrent neural network architecture — the Long Short–Term Memory network [61-63]. Such networks contain nodes of a special type that allow you to remember values for a long time. The block of the long-term memory network contains a special neuron used as a memory cell (Figure 6). The output of the neuron is connected to its own input with a unit weight. Due to this, the value in the neuron is overwritten at each stage and thus saved. Neuron control is performed using three gates: input, output and oblivion gate. When the input valve is open, the input value is written to the memory cell. If the input valve is closed, the input signals do not affect the contents of the cell in any way. An open output valve allows you to read the value from the cell. When the value is no longer needed, it can be erased using the oblivion valve. The valves are connected to other nodes of the neural network, which in the process of learning determine when it is necessary to open or close a particular valve.

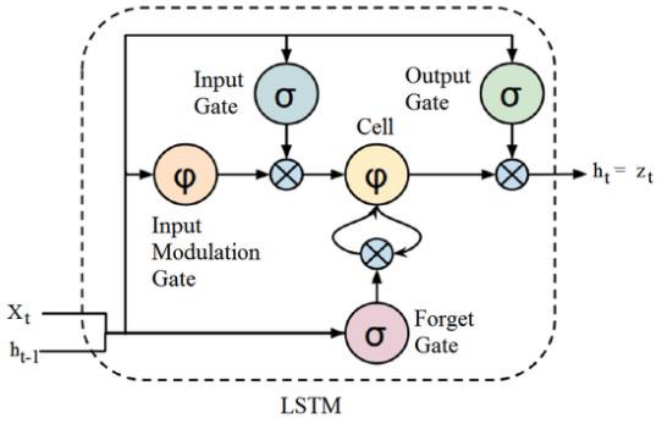


**Figure 6 -** Diagram of the long-term memory network block

Thanks to such cells, long-term memory networks can determine the importance of events that occurred thousands of discrete time steps ago and remember these events. Recurrent networks that were used before could remember an event no longer than ten time steps. The problem of vanishing gradient in long-term memory networks is solved by using the identity function as an activation and feedback with its own input with a weight equal to one (Figure 6). Since the derivative of the identity function is equal to one, the error during transmission through such nodes cannot disappear.

In 1992, the cresceptron neural network architecture appeared [64], which was based on the neocognitron. Unlike the neocognitron, the cresceptron changes its topology during training, by analogy with networks using the method of group accounting of arguments [65]. An important idea proposed in the creseptron is the use of max—pooling layers instead of subsampling layers with averaging. Later and improved versions of the Creseptron also contained blurring layers to reduce dependence on the position of objects [66]. Maximum choice layers are now widely used in convolutional neural networks. However, to train modern convolutional networks, an error back propagation algorithm is used [67], which is more efficient [68].

A significant contribution to the development of convolutional neural networks was made by the proposal to use a semi-linear activation function (rectified linear unit) [69, 70], which is set as follows: ReLU(x) = max(0, x). Such an activation function allows you to get rid of the problem of a vanishing gradient, because with a positive signal value, it does not occur changes, as opposed to sigmoidal activation functions. In addition, the semi-linear activation function reduces the training time of the neural network [71]. Neurons whose output signal is negative do not participate in calculations, and for the rest, only linear calculations are required.

**Software systems for training deep neural networks**

Currently, a large number of software systems have been created for training deep neural networks [72-74]. Among the most popular of them are Caffe, Theano, TensorFlow, Torch and CNTK. Their main characteristics are given in Table.

The Caffe Library [72] is one of the very first popular deep learning systems. It was developed at the Berkeley Computer Vision and Learning Center (Berkeley Vision and Learning Center), the source codes became open in 2014. Caffe includes the largest number of ready-to-use pre-trained models. Theano system [75] was created at the University of Montreal, Canada. Theano is developed in Python, but provides high performance due to the fact that a Python program is automatically converted into a C++ program that is compiled and then executed. TensorFlow [76] was created by Google in 2015 and includes systems for efficient work with tensors and streaming data processing on a graph. The Torch library [77] is developed in Lua and provides a convenient high-level interface for creating machine learning programs, similar to MATLAB. High performance is provided, just like in Theano, due to integration with the C language. The authors of Torch preferred to use Lua instead of Python because of the ease of integration of C and Lua. Microsoft developed the CNTK (Cognitive Toolkit) system [78] and opened its source codes in 2016.

All the listed deep learning systems of neural networks can use both multicore processors and GPU computing accelerators (including the optimized cuDNN library) to accelerate learning. Moreover, a significant advantage is that there is no need to redo the program, parallelization on the CPU and GPU is performed automatically. Caffe and Theano systems additionally support Intel Xeon Phi accelerators, which also help to significantly reduce the training time of deep neural networks [79]. Almost all systems, except Theano, can be used for distributed training of neural networks on computing clusters.

**Table 1** - Comparison of DL software systems

| Characteristics | Caffe | Theano | Tensorflow | Torch | CNTK |
|---|---|---|---|---|---|
| Base language | C++ | Python | C++ | Lua | C++ |
| API | C++<br>Python | Python | C++<br>Python | Python<br>Lua | C++, C#<br>Python |
| Multicore CPU | + | + | + | + | + |
| GPU | + | + | + | + | + |
| Developer | Berkeley Vision and Learning Center | Monreale university | Google | Ronan Collobert, Samy Bengio, Johnny Mariéthoz | Microsoft |
| Open-source code | + | + | + | + | + |
| Pretrained networks | + | - | + | + | + |

**Conclusion**

Since the emergence of neural networks, there have been many changes in their architecture and training methods. Currently, two types of architectures are dominant: convolutional networks, which are successfully used for computer vision tasks, and recurrent networks, which are actively used for natural language processing tasks.

Early convolutional networks were trained by a combination of teaching with and without a teacher using auto-encoders and deep trust networks. Modern methods, such as residual learning, allow you to use only training with a teacher and abandon pre-training, which speeds up and simplifies the learning process. Transfer learning is also an important direction in the development of convolutional neural networks [80]. This approach involves the use of neural networks trained on some data to solve other types of problems. At the same time, fine-tuning of the network and additional training on data from the task we are interested in is applied. As a result, the training time is reduced and the scope of application of pre-trained neural networks is expanded. The joint use of convolutional and recurrent neural networks with reinforcement learning is also promising [81].

For natural language processing tasks, and the more general case of sequence processing, recurrent neural networks are currently used.

Among them, the most effective are long-term memory networks and managed recurrent neural networks, because they allow you to remember interesting events for a long time [82]. An additional advantage of recurrent networks is the possibility of learning without a teacher and without a pre-marked data set.

The widespread practical application of neural networks is possible due to the availability of a large number of ready-made solutions for training deep neural networks [72, 75-78, 83-86], including the possibility of using modern multicore processors, GPU, as well as computing clusters with distributed memory.

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# ONTOLOGICAL ENGINEERING TO DETERMINE REVEAL INTER-SUBJECT RELATIONS BETWEEN MATHEMATICS AND COMPUTER STUDIES

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**Abstract**

The article offers an approach to generation of a conceptual model of the curriculum content for schoolchildren in form of a thesaurus and ontology which will allow using an adaptive collation and ordering of teaching information. The article discusses the possibility and experience of using ontological modeling and engineering for the conceptual description of school teaching. It contains description of the stages of building an ontological model of the subject area using interdisciplinary relation between mathematics and computer studies as an example. The article contains examples of classes and individuals of the school educational process and relations between them. It discusses advantages of ontological modeling of a subject area.

Development of the ontological model and entering data into the school database can help to identify interdisciplinary relationship between mathematics and computer studies. The database can be replenished with necessary data on an ongoing basis to keep the school data up-to-date. The application of ontological engineering methods will help to enhance the quality of school education due to semantic description of the subject area knowledge with the use of interdisciplinary approach in teaching.

**Keywords:** knowledge, school, ontology, ontological engineering, competencies, knowledge base.

## Introduction

The state program for the development of education and science of the Republic of Kazakhstan for 2020-2025 provides for the enhancement of the education system and the development of the interdisciplinary approach.

In recent years, the school educational process has been actively improved according to current requirements. The substance of computer studies in school has changed. It has become necessary to introduce an interdisciplinary approach to education. Therefore, students, from school time, must prepare for life and professional activity in the information environment and opportunities of obtaining higher education with the use of modern information technologies.

Implementation of the interdisciplinary approach helps build a comprehensive understanding of natural phenomena and relationships between them, i.e. the knowledge becomes more substantive and can be used in practice. The ontologies for higher educational institutions are developed in the Republic of Kazakhstan. The school ontologies are relevant but not comprehensively developed [1-9].

## Materials and Methods

The objective of the study is to identify interdisciplinary relations between Mathematics and Computer Science using ontological modeling.

Hypothesis: the use of ontological engineering methods will improve the quality of schoolchildren's education through the semantic description of knowledge about the subject area.

To achieve this objective and verify the proposed hypothesis, the following tasks need to be solved:

- the study of theoretical material, the analysis of literary sources on the topic of interdisciplinary relations in the teaching of the Mathematics and Computer Science school curriculum;
- building the Mathematics and Computer Science ontological model.

For the purposes of this article, ontological modeling and ontological engineering were used to identify Mathematics and Computer Science interdisciplinary relations. Ontological modeling allows carrying out a conceptual description of a specific subject area, which in its turn will increase the efficiency of information retrieval and categorization. The Protégé editor, discretionary logic, and semantic links are used to build the ontological model.

Ontological engineering is part of knowledge engineering. Knowledge engineering is a sub-discipline of engineering, and its main direction is the application of knowledge in information systems to solve complex problems [10].

Ontological engineering is the process of designing and developing ontologies that combines object-oriented and structural analysis, essential core technologies in the design of complex systems. Ontological engineering includes the identification of the main classes of entities, the relationships between these classes, and clusters of features [11, 12]. Ontological engineering is also studied in foreign works [13-16].

The main objectives of ontological engineering are presented in Figure 1.

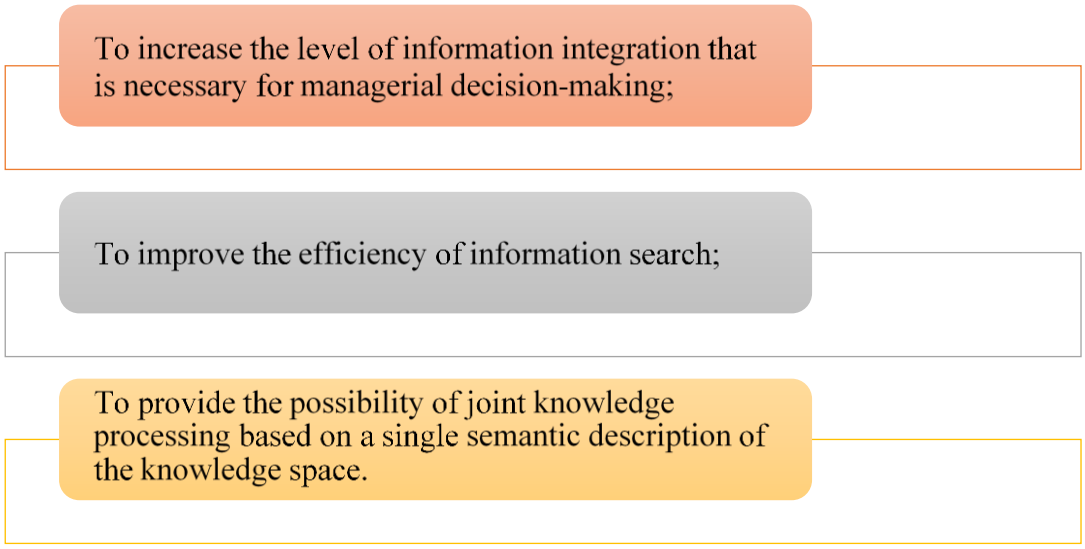


**Figure 1 –** Main objectives of ontological engineering

At the last stages of ontology development instances (entities) of created classes should be added to the knowledge database. This should include specific values of their properties, describing the actual representation of the subject area at issue [6].

Currently, there is a large number of approaches, models, and languages for describing data and knowledge. Ontologies and ontological engineering have recently gained in popularity. Ontology can be interpreted as a scenario or process, as a tool to structure chaos [17]. Ontologies can be interpreted as a dictionary for the representation and exchange of knowledge of a subject area and a multitude of links established between the terms in this dictionary.

Various languages and systems are available and can be used for describing ontologies, but the visual approach seems to be the one of high potential. The visual approach of ontological engineering is the most popular one. The visual approach combines the main technologies of designing large systems – object-oriented and structural analysis. Application of the ontological approach to visualization and knowledge storing with the help of ontologies makes it possible to describe any heterogeneous, however complex subject area.

Multilateral interdisciplinary connections not only help to solve teaching tasks, develop and educate students, but also facilitate laying the foundation for their professional self-determination in

secondary school. For that very reason, interdisciplinary connections are an important condition and a result of an integrated approach to education and upbringing of schoolchildren.

This thesis topic is relevant, since the amount of information to be assimilated during school education has increased, and studying the role of interdisciplinary connections in the activation of cognitive activity of students is of great importance.

Interdisciplinary connections contribute to the better generation of individual concepts in the course of teaching different subjects, groups, and systems, the so-called interdisciplinary concepts, which cannot be rendered to students in the framework of one discipline separately [18].

The implementation of Mathematics and Computer Science interdisciplinary relations (Fig.2) can be achieved through:

- integrated lessons;
- solving mathematical problems in computer science lessons;
- studying mathematics-related topics (algorithms, number systems, etc.)
- preparation of abstracts, presentations on mathematics, and materials for the lesson.

In the 'Methodological recommendations for the preparation and conduct of an integrated lesson' by R.A. Tulpa [19], the following definition is given: "An integrated lesson is a lesson arranged in a special way to combine knowledge from different subjects, aimed at considering and solving any contiguous problem, allowing students to achieve a holistic, synthesized perception of the issue under study, seamlessly combining methods of various sciences, while being practically-oriented."

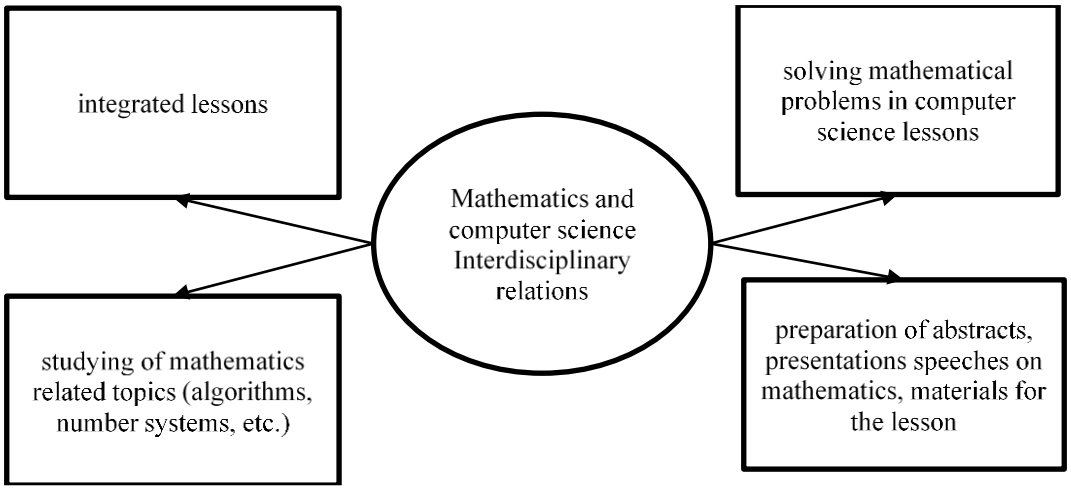


**Figure 2 –** Implementation of interdisciplinary relations between mathematics and computer science

Ontology building, or the so-called visual ontological engineering, is a powerful tool that allows you to visualize the knowledge structures of any subject area [10-12].

Currently, there are a large number of ontology editors. Each editor has its advantages and disadvantages.

There are also complexes, platforms, and systems for building ontologies and decision-making [20-21]. In the study, we will be using Protégé 4, since it is the most popular and is a freely available editor.

Protégé is currently the most popular OWL and RDF editor. The program is distributed under the so-called Mozilla Public License, which allows you to use the editor for free. Protégé is available for free download from the official website along with plugins and ontologies.

Ontological engineering is the process of designing and developing ontologies that combines two main technologies for designing complex systems – object-oriented and structural analysis [4]. Foreign works have a strong focus on ontological engineering [4-7].

The objectives of ontological engineering are to increase the level of information integration necessary for making managerial decisions, to increase the efficiency of information retrieval, and to

provide the possibility of joint processing of knowledge based on a single semantic description of the knowledge space.

The sequence of actions for developing an ontology. First, it is needed to perform an analysis of the subject area, make a synthesis of concepts and relationships, then select objects, attributes, relationships, and processes. This sequence is shown in Figure 3.

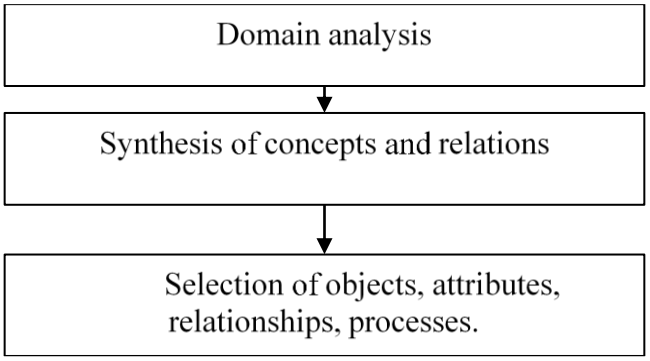


**Figure 3 –** The sequence of actions for ontology development

Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering. The methodology of ontological engineering implies building a three-tier model of the field under study: top-tier ontologies, domain-specific ontology, and applied ontologies [22]. The algorithm of ontological engineering is shown in Figure 4.

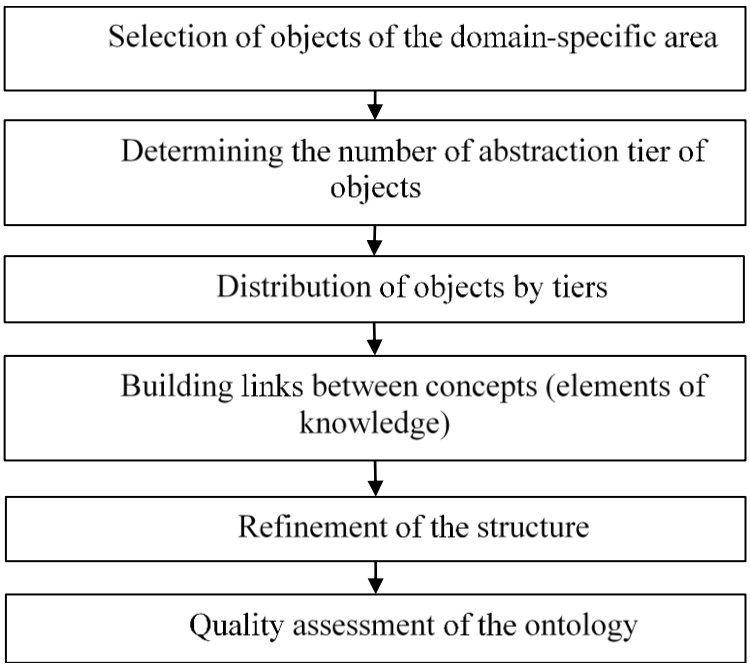


**Figure 4 –**The algorithm of ontological engineering

**Results and Discussion**

Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering.

Let's create classes that describe the subject. Based on the structure of the subject, an ontological model is built in the Protégé editor. Further, it can be exported to XML or another format.

Based on the conducted ontological engineering, an ontology of the curriculum content for schoolchildren was built. This ontology includes the following classes:

– Course;

– Subject;

– Learning achievements (Subclasses: Skills, Abilities, Knowledge, Competencies);

– E-learning tools (Subclasses: Databases, Technical means, Information Technologies, Information Systems);

– Participants in educational relations (Subclasses: Management, Student, Teacher);

– Regulatory framework (Subclasses: Standards, Regulatory documents of education, Laws of the Republic of Kazakhstan).

Combining the ontology built with a specific subject by completing the model with specific data corresponding to the training course will allow you to get a full-fledged knowledge database with which you can perform various actions, forming various representations of educational materials in various formats at the output. This approach will improve the effectiveness of the development of educational courses and the use of educational content.

In the future, this ontology will be supplemented and integrated with existing ontologies, such as university ontology. A hierarchy fragment of ontology classes of the content taught to schoolchildren is shown in Figure 5.

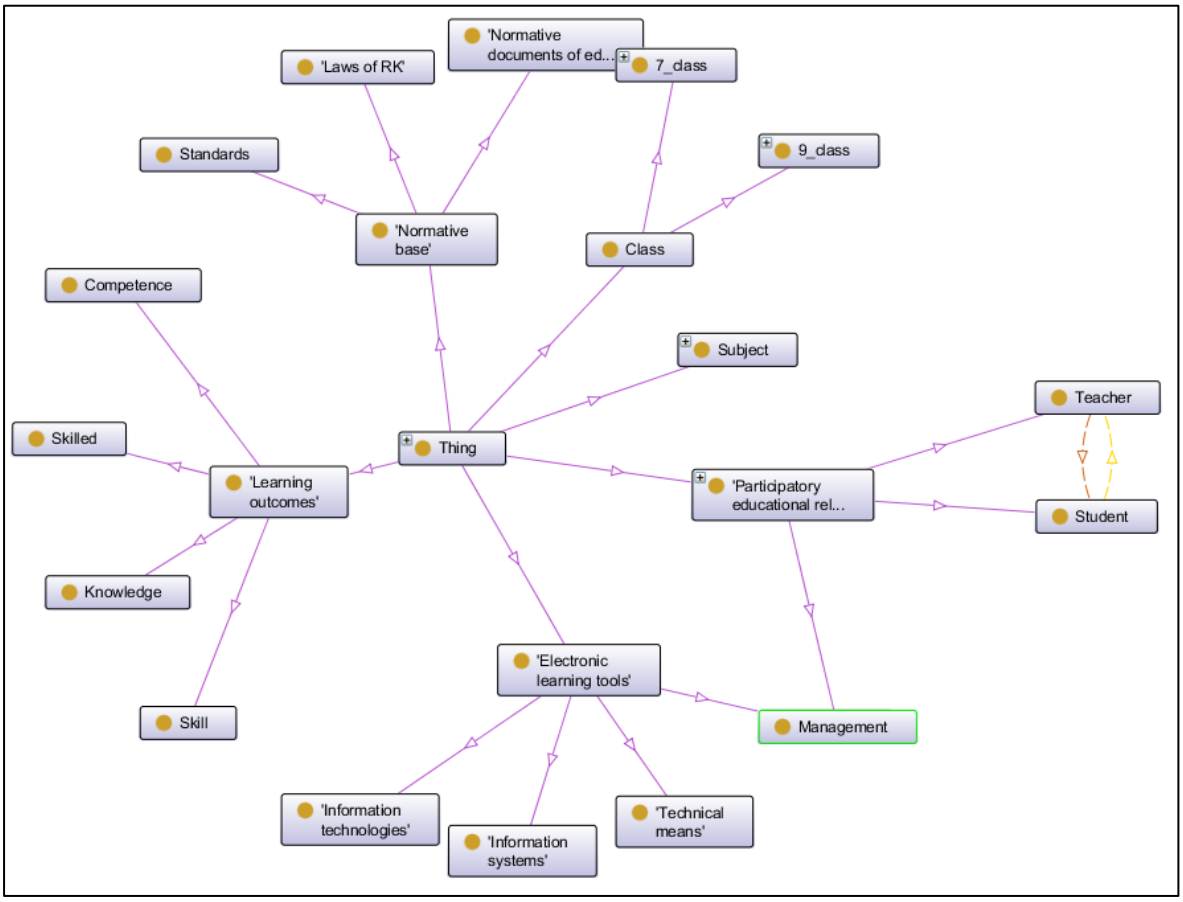


**Figure 5 –** "Ontological model of Mathematics and Computer Science" fragment

Improving the quality of teaching schoolchildren can be achieved through the semantic description of knowledge about the subject area using methods of ontological engineering.

The ontological model of the distributed knowledge database of the university was developed using the Protégé resource.

When using the Protégé resource the administrator is provided with the following features:

- editing hierarchy of classes;
- editing object properties and data type properties;
- creating and editing individuals.

Let's create classes that describe the subject. Based on the structure of the subject, an ontological model was built in the Protégé editor, presented in Figures 6 and 7. Further, it can be exported to XML or another format.

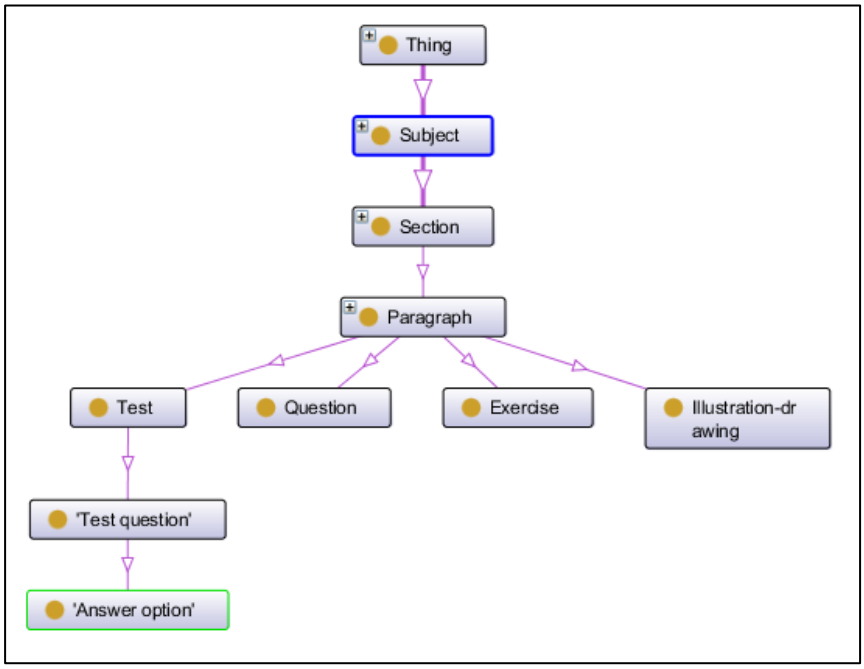


**Figure 6 –** The "Subject" ontological model

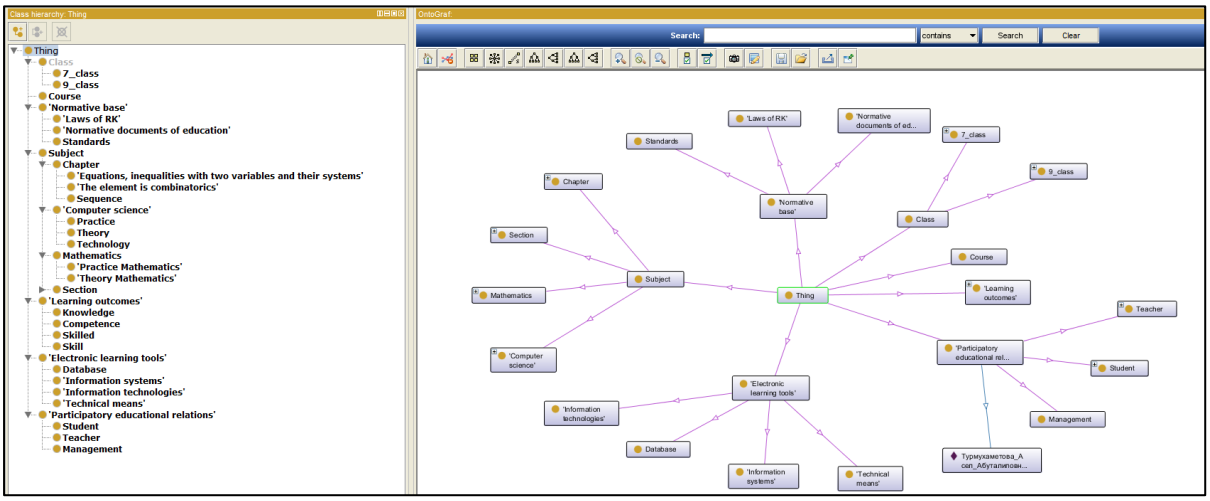


**Figure 7 –** "Mathematics and Computer Science" ontological model

A fragment of the Mathematics and Computer Science ontological model is presented in Figure 8.

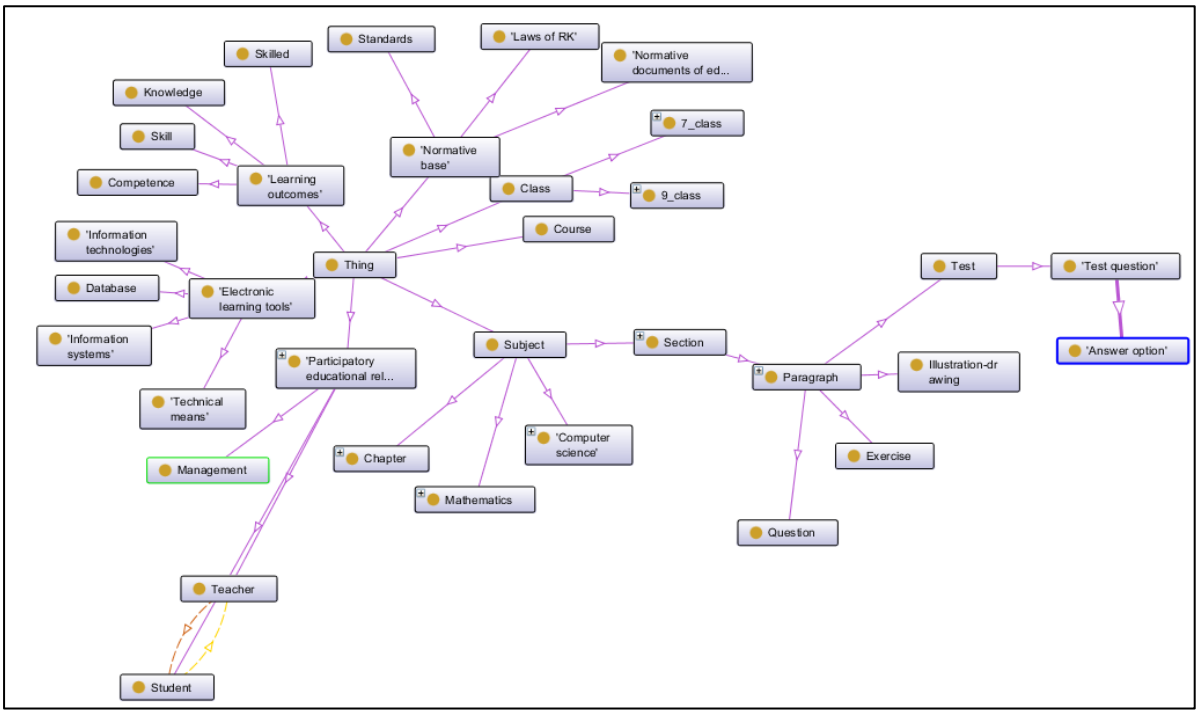


**Figure 8 –** Fragment of the "Mathematics and Computer Science" ontological model

Let's take another electronic textbook on Algebra Grade 9, as an example, to identify interdisciplinary relations between Mathematics and Computer Science.

A fragment of the data entered from the Algebra electronic textbook is shown in Figure 9. Classes, textbook paragraphs, and their relations are shown.

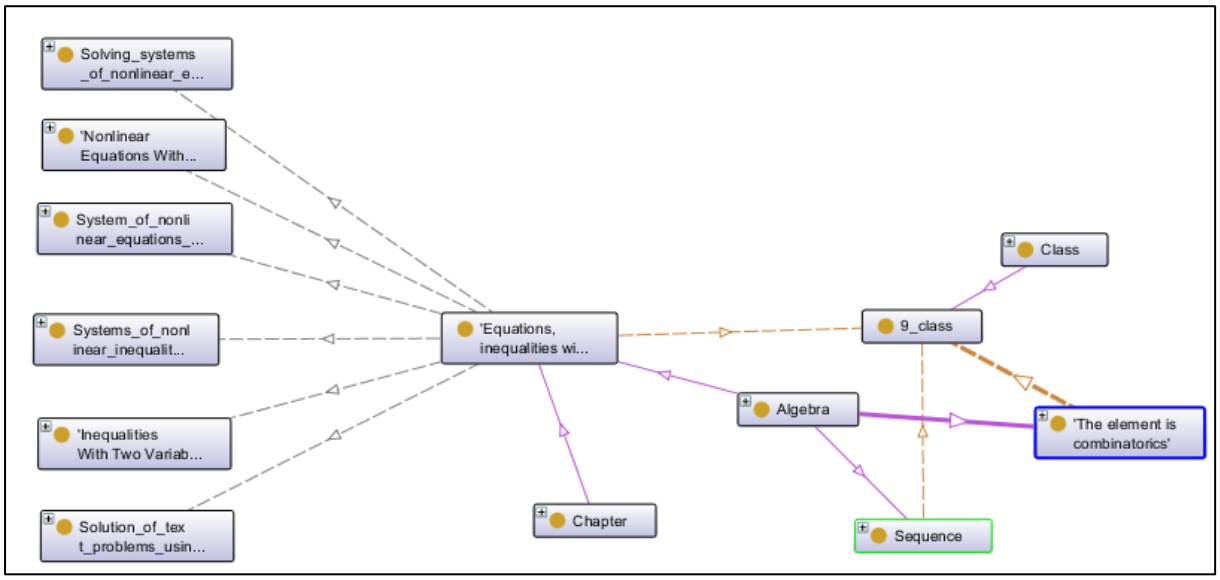


**Figure 9 –** A fragment of the data entered from the Algebra electronic textbook

As an example, let's take another electronic textbook on Computer Science Grade 7 to identify interdisciplinary connections between Mathematics and Computer Science.

A fragment of the ontology Section 1 is shown in Figure 10. Computer Science for the 7th grade, Measurement of information and computer memory storage.

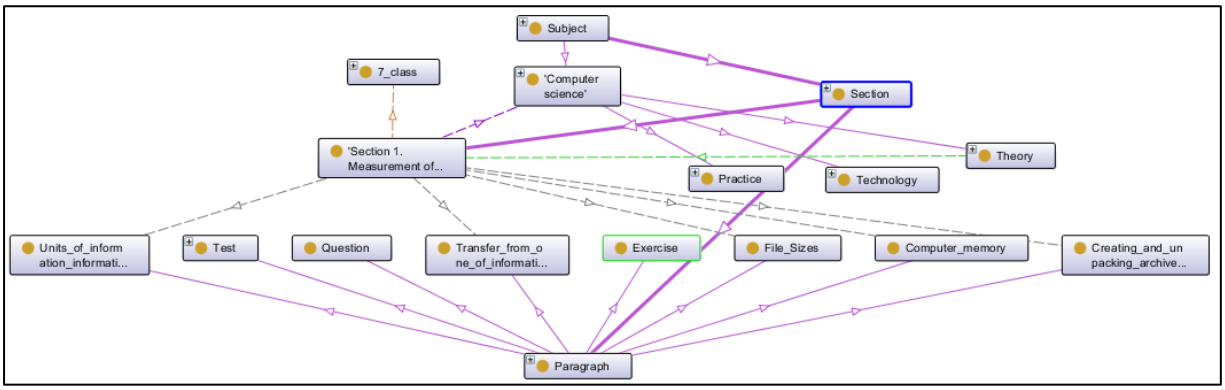


**Figure 10 –** Ontology Fragment Section 1

A fragment of the entered data from the Computer Science electronic textbook is shown in Figure 11. Classes, textbook paragraphs, and their relations are shown.

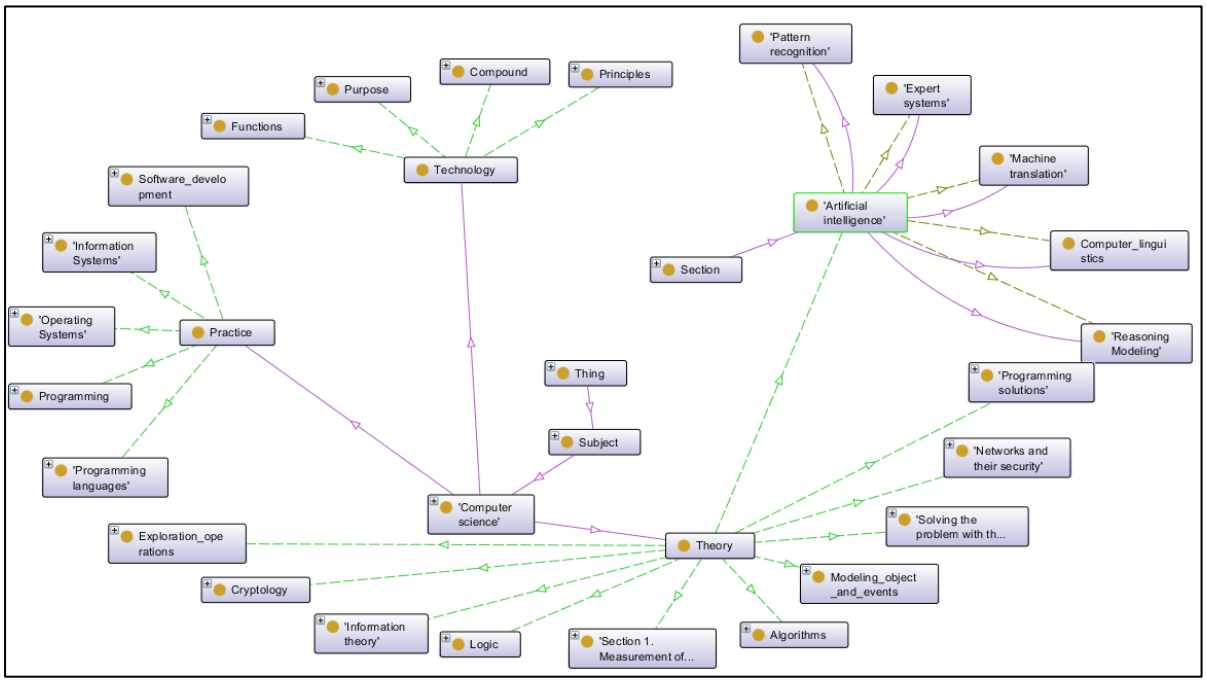


**Figure 11 –** A fragment of the built ontology on the example of relations with the Computer Science subject

A fragment of the built ontology reflecting inter-subject connections is shown in Figure 12.

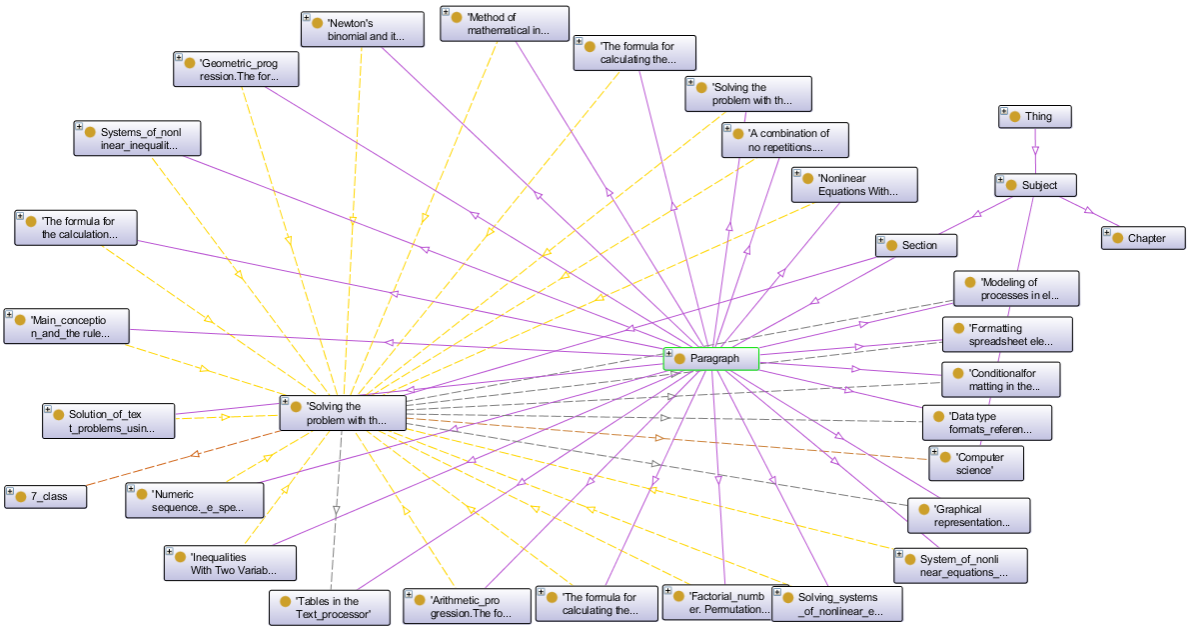


**Figure 12 –** A fragment of the built ontology

Let's create a property of objects reflecting inter-subject relations: hasIntersubjectCommunication (Fig. 14).

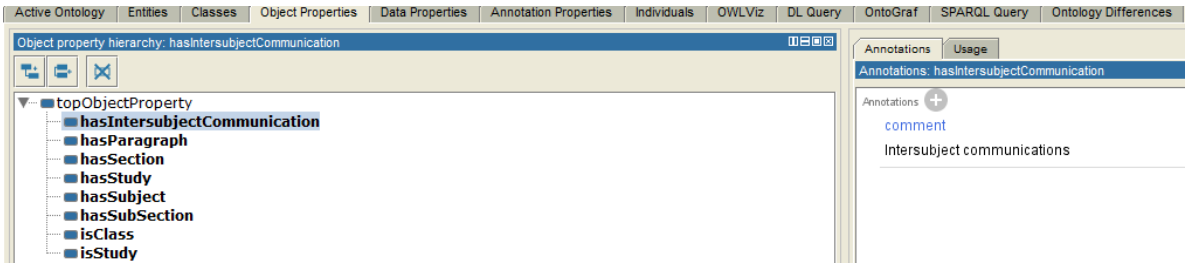


**Figure 13 –** Property of hasIntersubjectCommunication objects

Using the built-in query, we can see the relationship between subject and object, in Figure 15.

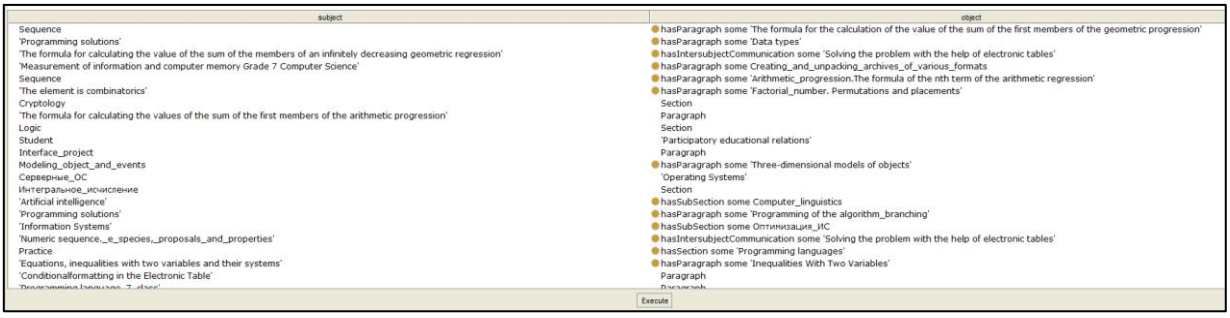


**Figure 14 –** Relations between subject and object

Also, using the tab, let's execute the command Tools-Usage... for the hasIntersubjectCommunication object property, you can see all the Mathematics and Computer Science inter-subject relations in ontology (Fig. 15).

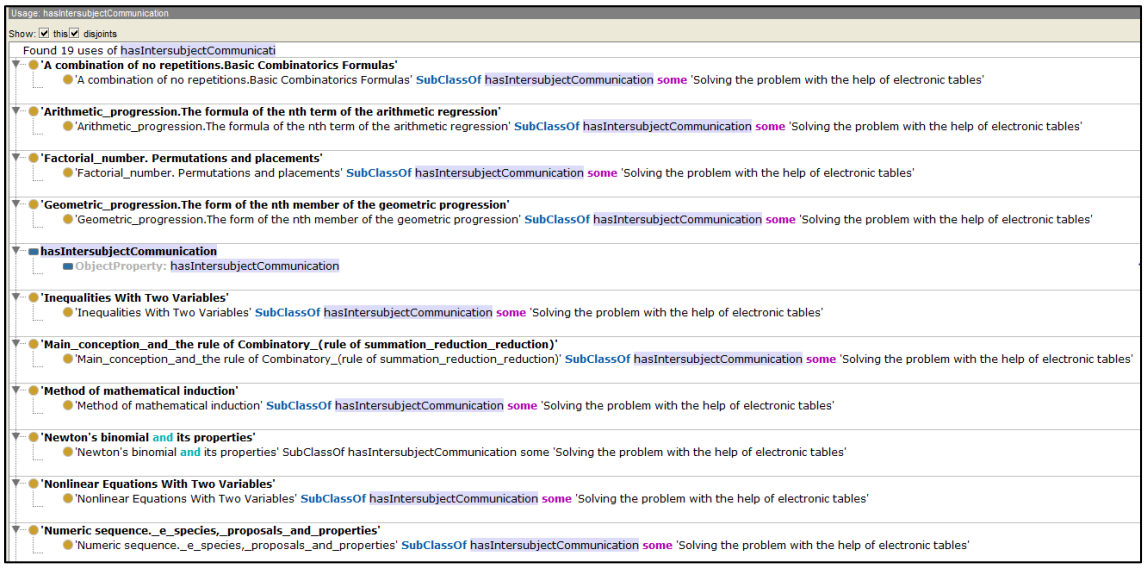


**Figure 15 –** The Tools-Usage command

Let's deduce a small fragment of an ontology with interdisciplinary relations between Mathematics and Computer Science. The arithmetic progression included in Chapter 3 of the Algebra electronic textbook Grade 9 can be solved on the basis of the material provided in the Computer Science textbook for the 7th grade "Solving problems using electronic spreadsheets". (fig. 16).

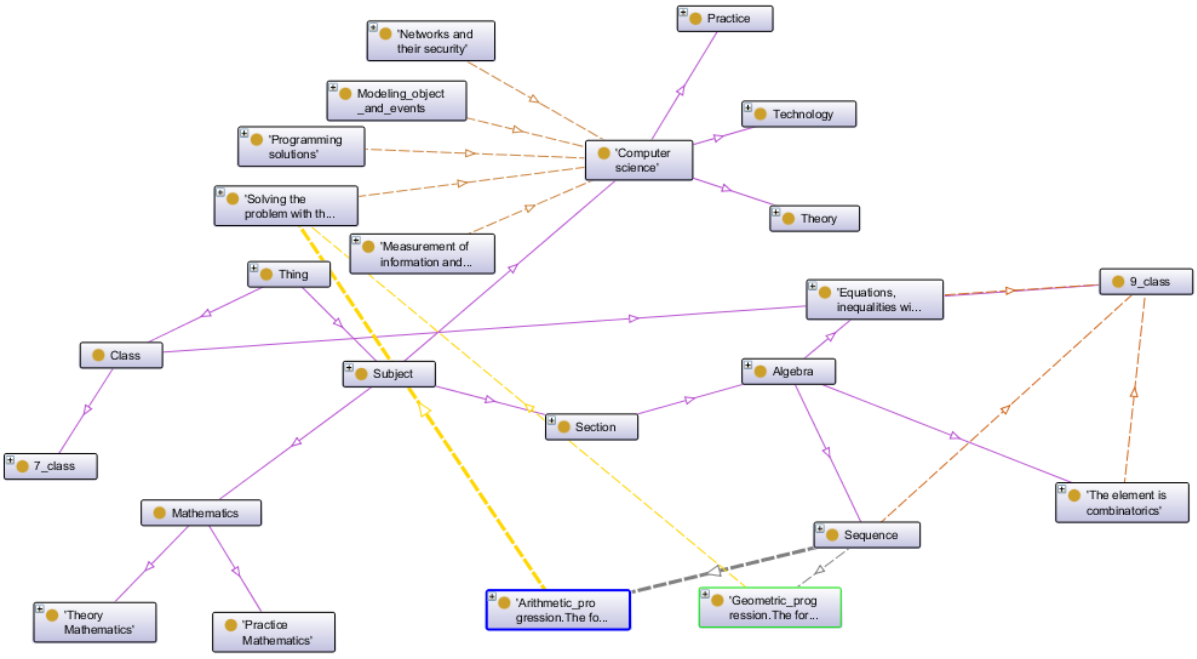


**Figure 16 –** Fragment of the constructed ontology for inter-subject relations between Mathematics and Computer Science

## Conclusion

It is possible to identify interdisciplinary relations between Mathematics and Computer Science with the help of the built ontological model and by replenishing the school's knowledge database. You can continue to make the necessary changes to this knowledge base and thereby update the school's data.

The article provides an ontological description and identification of inter-subject connections for two textbooks Algebra Grade 9 and Computer Science Grade 7 and descriptions of their inter-subject relations. Similarly, if necessary, data from other textbooks can be added to the existing knowledge base structure.

Semantic description of knowledge about the school educational process, using methods of ontological engineering, will improve the quality of teaching schoolchildren.

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# DEVELOPMENT OF A CLASSIFIER USING TEXT CLASSIFICATION METHODS

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**Abstract**

Modern computer systems in most cases operate with large amounts of unstructured or less structured data called big data. Such data processing is usually done by software with good horizontal scalability: these systems are a connected network of computing nodes that can be expanded when the load increases. Communication between nodes is carried out using network protocols and programming interfaces for processing parallel computing, such as MPI (Message Passing Interface).

Convolution method, SVM (Support Vector Machine), k-nearest neighbors method - KNN (K-Nearest Neighbors) and Naive Bayes Classifiers are often used to train neural networks for text classification. NBC) is used.

We used Naive Bayes classifier for text classification, NLP(Natural Language Processing) and packages required for work using NPM(Node Package Manager) in JavaScript programming language. The performance of the model is lower because the data for training is not collected systematically, but already the model is showing good results.

**Keywords:** Machine learning, Bayes Classifier, Neural networks, K-Nearest neighbors, Text classifier

## Introduction

Now the amount of information is growing at a tremendous speed and at the same time there is a problem of increasing the available computing power of a computer, and in this case, automatic classification of data, in particular text data, is becoming increasingly important. Natural language processing is one of the most important technologies of the information age. Understanding languages is also an essential element of artificial intelligence. Natural language processing applications are everywhere because people communicate everything in language: web searches, advertisements, email, customer service, language translation, etc. There is a wide variety of basic machine learning tasks and models for implementing natural language processing applications.

Text classification is one of the main tasks of natural language processing, which consists in determining the category of text, the list of categories may or may not be known. Text classification is often implemented based on the content of texts, analysis of text elements (words, sentences, etc.) and the interaction between them. Classification can be done manually or automatically using machine learning techniques. Modern methods of text classification require huge databases for training, and are able to learn and classify the semantic meanings of texts.

## Materials and Methods

Modern computer systems often work with large amounts of unstructured or less structured data, known as big data. Processing of such data is usually done by software with good horizontal scalability: these systems are a connected network of computing nodes that can be expanded when the load increases. Communication between nodes is carried out using network protocols and programming interfaces for processing parallel computing, such as MPI (Message Passing Interface).

The easiest way to classify text is based on the application of Bayes theorem, which allows to determine the probability of a certain event (A) if another event that is statistically dependent on it (B) has occurred.

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

A Naive Bayesian classifier is used for recognition and classification, corresponding to different variations in image classifiers based on the underlying probability and trueness. Naive Bayes techniques are based on self-defining assumptions.

However, the effectiveness of the neural network model is not limited to the choice of the learning algorithm. Modern research shows that convolutional networks (CNN) are very effective for

text classification. In these networks, each layer uses its own data transformation through convolution.

**Literature review**

In recent years, advances in machine learning have led to significant and widespread improvements in the way we interact with our world. One of the most significant advances in this field is deep learning. Deep learning, based on artificial neural networks that resemble the networks of the human brain, is a set of methods that allow computers to learn from data without human observation and intervention. Moreover, these methods can adapt to changing conditions and ensure continuous improvement of learned abilities. Today, deep learning is pervasive in our daily lives in the form of Google Search, Apple's Siri, Amazon's and Netflix's recommendation systems, to name just a few examples. As we interact with our email systems, online chats, and voice or image recognition systems deployed in companies ranging from healthcare to financial services, we see robust deep learning applications in action [1] .

Human communication is at the heart of development in many of these fields, and the complexity of language makes computational approaches increasingly difficult. However, with the advent of deep learning, the burden shifts from building rule-based approaches to learning directly from data. These deep learning techniques open new horizons in our ability to model human communication and interaction and improve human-computer interaction.

Big data is any source of data that has at least one of four general characteristics:

1. Volume is the amount of data generated and stored. The size of the data determines the value and potential knowledge, and whether it can be considered big data or not.

2. Diversity is the type and nature of data. Big data can be from text, image, audio, video.

3. Velocity – in this context, the speed at which data is generated and processed to meet requirements and tasks. Big data is often available in real time. Compared to small data, big data is created continuously. There are two types of speed associated with big data - generation frequency and processing, recording and publishing frequency.

4. Validity is an extended definition for big data that refers to the quality and meaning of the data. The quality of the data can vary greatly, affecting the final result of the analysis or processing.

Currently, there is no precise definition of big data. Because big data has evolved so quickly and haphazardly that there is no generally accepted formal statement that signifies its meaning. There have been many attempts to define big data, more or less interesting from the point of view of use and citation. However, none of these proposals have prevented authors of works related to big data from extending, updating or even ignoring previous definitions and proposing new ones. Although big data is still a relatively young concept, it certainly deserves an accepted glossary of references that allows for the proper development of the discipline within the scientific community.

But in machine learning, big data is usually associated with data sources used for computer training, analytics, processing, classification, clustering and other operations.

Traditional data use a centralized database architecture in which large and complex tasks are handled by a single computer system. A centralized architecture is expensive and inefficient for processing large amounts of data. Big data is based on a distributed database architecture, where a large block of data is resolved by dividing it into several smaller sizes. Then the solution to the problem is determined by several different computers in a computer network. Computers communicate with each other to find a solution to a problem. A distributed database provides better computation, lower cost, and improved visibility versus a centralized database system. This is because the centralized architecture is based on mainframes, which are as economical as microprocessors in a distributed database system. Also, a distributed database has more computing power compared to the centralized database system used to manage traditional databases.

Big data is a general area of problems and techniques used for application domains that collect and maintain vast amounts of raw data for domain-specific data analysis. The development of the science of big data has been greatly facilitated by modern information technologies, as well as the increase in computing resources and data storage resources. Technology companies such as Google,

Yahoo, Microsoft, and Amazon store data that is measured in exabytes or more. Moreover, social networks such as Facebook, YouTube and Twitter have billions of users constantly generating a very large amount of data. Various organizations have invested in developing products using Big Data analytics to address their monitoring, experimentation, data analysis, modeling, and other knowledge and business needs, making it a central topic in data science research [2].

The accuracy of a machine learning model can increase significantly if it learns from big data. Without enough data, a machine learning algorithm will try to make decisions on small subsets of the data, which can lead to misinterpretation of a trend or lack of a pattern. Data should be checked for credibility and context. The right amount and types of data that can be analyzed to influence outcomes must be determined. Big data includes all data, including structured, unstructured, and semi-structured data from email, social media, text streams, images, and machine sensors.

Machine learning requires the right set of data that can be used in the learning process. Not every institution needs to store big data to use machine learning techniques, but big data can help improve the accuracy of machine learning models. With big data, it is now possible to virtualize the data so that it can be stored in the most efficient and cost-effective way, whether in a data warehouse or in the cloud.

Extracting meaningful patterns from powerful input data for decision-making, forecasting, and other inferences is the foundation of Big Data analysis. In addition to big data analysis, big data analysis poses other unique challenges for machine learning and data analysis, including raw data format change, fast movement of streaming data, robustness of data analysis, highly distributed input sources, noisy and poor data, high dimensionality, scalability of algorithms , unbalanced inputs, unsupervised and unclassified data, limited supervised/observed data, etc. Adequate data storage, data indexing/labeling, and fast information retrieval are other key challenges in big data analysis. Therefore, when working with big data, innovative solutions for data analysis and management are needed [3].

Deep learning saw explosive growth, attention, and availability of tools following its success in computer vision in the early 2010s. Natural language processing soon experienced many of these same benefits from computer vision. Speech recognition, traditionally a field dominated by feature engineering and model tuning techniques, incorporated deep learning into its feature extraction methods resulting in strong gains in quality.

Perhaps one of the largest contributors to the success of deep learning is the active community that has developed around it. The overlap and collaboration between academic institutions and industry in the open source has led to a virtual cornucopia of tools and libraries for deep learning. This overlap and influence of the academic world and the consumer marketplace has also led to a shift in the popularity of programming languages.

Machine learning is quickly becoming commonplace in many of the applications we use daily. It can make us more productive, help us make decisions, provide a personalized experience, and gain insights about the world by leveraging data. The field of AI is broad, encompassing search algorithms, planning and scheduling, computer vision, and many other areas. Machine learning, a subcategory of AI, is composed of three areas: supervised learning, unsupervised learning, and reinforcement learning.

Supervised learning relies on learning from a dataset with labels for each of the examples. For example, if we are trying to learn movie sentiment, the dataset may be a set of movie reviews and the labels are the 0–5 star rating. There are two types of supervised learning: classification and regression.

Unsupervised learning determines categories from data where there are no labels present. These tasks can take the form of clustering, grouping similar items together, or similarity, defining how closely a pair of items is related. For example, imagine that there are several documents and they need to be grouped according to several criteria, for example, documents in biology, geography, history and mathematics. Such tasks are solved in this way.

Semi-Supervised Learning and Active Learning. In many situations when it is not possible to label or annotate the entire dataset due to either cost or lack of expertise or other constraints, learning jointly from the labeled and unlabeled data is called semi-supervised learning. Instead of expert

labeling of data, if the machine provides insight into which data should be labeled, the process is called active learning

Transfer learning. The basic idea behind “transfer learning” is to help the model adapt to situations it has not previously encountered. This form of learning relies on tuning a general model to a new domain. Learning from many tasks to jointly improve the performance across all the tasks is called multitask learning. These techniques are becoming the focus in both deep learning and NLP/speech

Reinforcement learning focuses on maximizing the reward for an action or set of actions taken. Algorithms are trained to encourage certain behaviors and discourage others. Reinforcement learning tends to work well in games like chess or go where the reward can be winning the game. In this case, a series of actions must be taken before the reward can be achieved [4].

Natural language processing (NLP) is an exciting field of computer science that deals with human communication. It includes approaches that help machines understand, interpret and generate human language. They are sometimes called natural language understanding (NLU) and natural language generation (NLG). The richness and complexity of human language cannot be underestimated. At the same time, the need for algorithms capable of understanding language is constantly growing, and natural language processing exists to fill this gap. Traditional NLP techniques are based on linguistics and based on basic semantic and syntactic elements of language such as parts of speech. Modern deep learning approaches can do without intermediate elements and can learn their own hierarchical representations for generalized tasks.

Although there were traces of interesting experiments in the 1940s, an important milestone can be considered the IBM experiment in Georgetown in 1954, during which a machine translation of about 60 sentences from Russian into English was demonstrated. Despite the limited computing resources in the form of software and hardware, some problems of syntactic, semantic and linguistic diversity were identified and an attempt was made to solve them. Just as II experienced a golden age, between 1954–1966 pp. Applied linguistic analysis of 1961. At the Dartmouth Conference in 1956, John McCarthy introduced the term "artificial intelligence". In 1957, Noam Chomsky published his book Syntactic Structures, in which he emphasized the importance of sentence syntax for understanding language. The invention of phrase structure grammar also played an important role at that time. In particular, attempts at the Turing test using software such as LISP, developed by John McCarthy in 1958, and ELIZA (the first chatbot) influenced not only NLP, but the entire field of AI.

In 1964, the US National Research Council (NRC) created a group known as the Automatic Language Processing Advisory Committee (ALPAC) to assess the progress of NLP research. A 1966 ALPAC report highlighted the difficulties involved in machine translation from process to implementation cost, and it influenced funding cuts that nearly halted NLP research. This phase of the 1960s and 1970s was a period of studying world knowledge in which semantics was placed above syntactic structures. Grammars such as case grammar, which explored the relationship between nouns and verbs, played an interesting role in this era. Advanced transition networks were another search algorithm for solving problems such as the best syntax for a phrase. Schenk's conceptual dependence, which expressed language in terms of semantic primitives without syntactic processing, was also a significant development. SHRDLU was a simple system that could understand basic questions and respond in natural language using syntax, semantics and reasoning. LUNAR by Woods et al. was the first of its kind: a question-and-answer system that combined natural language understanding with a logic-based system. Semantic networks, which capture knowledge in the form of a graph, are an increasingly popular topic, highlighted in the work of Silvio Ceccato, Margaret Masterman, Quillian, Bobrov and Collins, Findler, and many others. In the early 1980s, the grammatical stage began, when linguists developed different grammatical structures and began to relate the meaning of phrases to the intentions of users. Many tools and software such as Alvey natural language tools, systran, meteo etc. have become popular for parsing, translation and information retrieval.

The 1990s was the era of statistical language processing, when most NLP-based systems used many new data collection ideas, such as using corpora for linguistic processing or understanding words based on their occurrence and coincidence using probabilistic approaches. The large amount

of data available through the World Wide Web in various languages has created a high demand for research in areas such as information retrieval, machine translation, generalization, topic modeling, and classification. The increase in memory and processing speed in computers has allowed many real-world applications to start using word and speech processing systems. Linguistic resources, including annotated collections such as Penn Treebank, British National Corpus, Prague Dependency Treebank and WordNet, have been useful for academic research and commercial applications. Classical approaches such as n-grams and word set representations with machine learning algorithms such as polynomial logistic regression, support vector machines, Bayesian networks or expectation maximization have been common trained and untrained methods for many NLP tasks. Baker et al. introduced the FrameNet project, which considered "frames" to capture semantics such as entities and relationships, and this led to semantic role labeling, which is an active research topic today [5].

In the early 2000s, the Conference on Natural Language Learning (CoNLL) with common tasks led to interesting NLP research in areas such as fragmentation, named entity recognition, and dependency analysis, to name a few. Lafferty et al. proposed conditional random fields (CRFs), which have become the main part of most modern sequence labeling schemes where there are interdependencies between labels.

Bengio et al. proposed the first neural language model in the early 2000s, which used a mapping of n previous words using a look-up table fed to a feed-forward network as a hidden layer and generating output that was smoothed into a softmax layer for word prediction. Bengio's research was the first use of a "dense vector representation" instead of a "hot vector" or word set model in the history of NLP. Many language models based on recurrent neural networks and long-term short-term memory, proposed later, have become modern. Papineni et al. proposed the Bilingual Evaluation Metric (BLEU), which is still used today as the standard metric for machine translations. Pang et al. presented mood classification, which is now one of the most popular and widely researched NLP tasks. Hovey and others. introduced OntoNotes, a large multilingual corpus with multiple annotations used in various tasks such as dependency analysis and coreference resolution. A remote sensing technique in which existing knowledge is used to create patterns that can be used to extract examples from large corpora was proposed by Mintz et al. and is used in various tasks such as relation extraction, information extraction, and sentiment analysis [6].

Collbert and Weston's research has been instrumental not only in highlighting ideas such as pre-trained word embeddings and convolutional neural networks for text, but also in the collaborative use of a look-up table or embedding matrix for multi-task learning. Multitasking learning allows you to learn several tasks at the same time and has recently become one of the latest major areas of research in NLP. Mykolov et al. improved the effectiveness of word embedding learning proposed by Bengio et al. removing the hidden layer and having an approximate learning objective that gave rise to "word2vec", an efficient large-scale embedding implementation. Word2vec has two implementations: (a) continuous set of words (CBOW), which predicts the central word by neighboring words, and (b) gram skipping, which does the reverse and predicts neighboring words. The efficiency of training on a large array of data allowed these dense representations to capture different semantics and relationships. Embedding words used as representations and pre-training these embeddings on a large corpus is standard practice today for any neural network-based architecture. Recently, many extensions to word embedding have attracted great interest, such as designing embeddings of words from different languages in the same space and thus enabling unsupervised "transfer learning" for different tasks such as machine translation [7].

Sutzkever Ph.D. the thesis, which presented a Hessian-free optimizer for efficient training of recurrent neural networks on long-term dependencies, was an important milestone in the revival of the use of RNNs, especially in NLP. The use of convolutional neural networks for text processing has grown significantly since the achievements of Kalchbrenner et al. and Kim et al. CNNs are currently widely used in many NLP tasks due to their local context dependence through a convolution operation, making them easily parallelizable. Recursive neural networks, which provide a recursive hierarchical structure of sentences and inspired by the linguistic approach, have become another important neural architecture in the world of neural NLP.

Sutzkever et al. proposed sequence-to-sequence learning as a generic neural framework consisting of an encoder neural network that processes the input data as a sequence and a decoder neural network that predicts outputs based on the states of the input sequence and the current states of the output. This framework has found a wide range of applications, such as group parsing, named object recognition, machine translation, question answering, and summarization. Google has begun to replace its monolithic phrase-based machine translation models with neural MP sequence models. Symbol-based rather than word-based representations overcome many challenges, such as lack of vocabulary, and are part of research into deep learning-based systems for various NLP tasks. The attention mechanism of Bahdanau et al. this is another innovation that has been widely popular in various neural architectures for NLP and language. Memory-augmented networks with various variants such as memory networks, neural Turing machines, end-to-end memory networks, dynamic memory networks, differential neural computers, and recurrent object networks have become very popular in the last few years for understanding complex natural language and language modeling tasks. Adversarial learning and the use of adversarial examples have recently become common for distribution understanding, model robustness testing, and transfer learning. Reinforcement learning is another new area of deep learning that has applications in NLP, particularly in areas where there are time dependencies and areas of undifferentiated optimization where gradient methods do not work. Modeling dialog systems, machine translation, text summarization, and visual storytelling, among others, have seen the benefits of reinforcement techniques [8].

Text data analysis in machine learning uses regression, classification and clustering methods.

The main goal of text analysis is to enable users to extract information from textual resources and perform operations such as extraction, classification (machine learning), and summarization. Text analysis consists of several tasks, such as correct document annotation, appropriate document representation, dimensionality reduction to handle algorithmic questions, and an appropriate classifier function to obtain good generalization and avoid overfitting. The extraction, integration and classification of electronic documents from various sources and the discovery of knowledge from these documents are important for research communities.

The pre-processing process is to clean the boundary of each language structure and remove the language-dependent linguistic factors as much as possible.

Document rendering is one of the preprocessing techniques used to reduce the complexity of documents and make them easier to process, the document must be converted from a full-text version to a vector document. Text representation is an important aspect of document classification or clustering, which means mapping a document into a compact form of its content. A text document is usually represented as a vector of scales of terms (lexical features) from a set of terms (dictionary), where each term occurs at least once in a certain minimum number of documents. The main characteristic of the text classification/clustering problem is the extremely high dimensionality of the text data. The number of potential opportunities often exceeds the number of documents. The definition of a document is that it consists of terms that have different patterns of occurrence. Pre-processing includes such stages as: feature extraction (characteristics) and feature selection[9].

Feature extraction is the first stage of preprocessing used to represent text documents in word format. Thus, algorithms for removing stop words, stemming, tokenizing, and others are preprocessing tasks. These algorithms belong to the method of natural language processing (NLP). NLP can be defined as automatic (or semi-automatic) processing of human language. The term NLP is used much more narrowly, often excluding information retrieval and sometimes even excluding machine translation. Nowadays, NLP is actually interdisciplinary: it is closely related to linguistics and machine learning. It also has connections to research in cognitive science, psychology, philosophy, and mathematics (especially logic). In machine learning, NLP is used precisely so that the machine can understand texts written in natural language. There are several NLP algorithms that can be used together, individually or sequentially

- Tokenization is a lexical (semantic) text analysis that finds the minimum unit in the text. The minimum unit is a token. In lexical analysis, a token can be a single word, sentence or paragraph. In this paper, we will use token as a single word.

- Frequency of a term in a document – semantic analysis often uses a word counter algorithm to find the frequency of each word in that text. Why is this technique necessary? To find keywords or unique terms, classify or cluster a large array (corpus) of documents, find corpus similarities, etc. d. Word frequency distribution is a fundamental phenotype of language. Statisticians and linguists have studied word frequency distributions because word usage statistics provide valuable insight into language, its construction, and evolution. These distributions have long been studied outside of statistics and linguistics.
- Stemitization is the transformation of morphological forms of words into their root, by removing the endings of morphological transformations. The root does not have to be an existing word in the dictionary, but all its variants must match this form after the algorithm is finished. There are two points to consider when using a stemmer:
  - The morphological forms of the word are assumed to have the same basic meaning and therefore must be matched with the same root.
  - Words that do not have the same meaning should be kept separate

  These two rules are good enough as long as the roots found are useful for semantic text analysis or language processing. For languages with relatively simple morphology, the influence of morphological transformation is smaller than for languages with more complex morphology.
- Stoplisting – is used to remove stopwords and individual characters that appear in a text document, and it is likely that the frequency of stopwords may be greater than other keywords in that text. This is why this step must be used for a clearer result in machine learning.
- Lemmatization is an algorithm similar to stemmization. The difference is that lemmatization takes into account the morphological analysis of words. This requires having detailed dictionaries that the algorithm can look up to link the form to its lemma (infinitive word) [10].

After obtaining the features, an important step of text preprocessing is the selection of features to construct a vector space, which increases the scalability, efficiency, and accuracy of text classification or clustering. In general, a good feature selection method should take into account the characteristics of the input data and the algorithm. The main idea of feature selection is to select a subset of objects from source documents. Feature selection is performed by saving words with the highest weight according to a given word importance measure. Selected features retain the original content and provide a better understanding of the data and the analysis process. For text classification or clustering, the main problem is the high dimensionality of the space of objects. Almost every text document has a large number of features, most of which are not relevant and useful for the machine learning task, and even some noisy features can drastically reduce the accuracy of the algorithm. Therefore, feature selection is usually used to reduce the dimensionality of the feature space and increase the efficiency and accuracy of machine learning.

In machine learning, a text document may partially match many classification categories or many clustering clusters. The most frequently used feature selection algorithms are:

- Term Frequency - Inverse Document Frequency (TF-IDF) is commonly used to weight each word in a text document according to its uniqueness. Word (token) weight is often used for information retrieval and semantic text analysis. This weight is a statistical measure used to estimate how important a word is to a document in a collection or corpus. In other words, the TF-IDF approach reflects the relevance of words, text documents, and specific categories.
- Word2Vec is a tool (set of algorithms) for computing vector representations of words that implements two main architectures - Continuous Bag of Words (CBOW) and Skipgrams. A text document or a word is passed as input data, and the output data will be represented as vector variables (coordinators in vector space) [11].

Neural networks, which have proven themselves as a powerful algorithm for image classification, have recently become actively used for other machine learning tasks. We used a neural network to classify text data into predefined classes.

## Results and Discussion

We used Naive Bayes classifier for text classification, NLP(Natural Language Processing) and packages required for work using NPM(Node Package Manager) in JavaScript programming language. The performance of the model is lower because the data for training is not collected systematically, but already the model is showing good results.

var natural = require('natural')

classifier = new natural.BayesClassifier(natural.PorterStemmerRu);

As a result, a neural network was created that classifies (classifies) the text into given classes.

## Conclusion

Based on the research, we can say that we have done a great job on the study of machine learning and were able to develop a neural network that classifies incoming data according to the labels of the given classes found in the calculations.

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# INTEGRATED DEVELOPMENT OF AN AUTOMATED TRADING SYSTEM ON THE EXAMPLE OF A DOMESTIC VENDING MACHINE FOR SELLING FLOWERS – A FLOROMAT

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**Abstract**

The vending machine for selling flowers belongs to the automated trade equipment and can be used for the sale of flowers by the self-service method. Such vending machines have received the common name - floromat, sometimes flomat.

Floromats are installed at the airports, train stations, supermarkets, theatres, concert halls, and even maternity hospitals. Their more modern models allow you to sell not only flowers, but also gifts, soft toys and other related products. The advantages of the absence of a seller, a small leasable area and round-the-clock operation of the device make this type of business today one of the fastest paying off.

Currently, only foreign-made vending machines are represented and used in the domestic automated trading market. Moreover, the vast majority of them are used to sell goods such as food. As practice shows, along with them, the number of operating floromats is single copies.

The concept of the integrated development of a separate automated trading unit, which will be considered on the example of the mentioned floromat, includes the following main successive stages: writing a technical task (functions and tasks of the floromat), calculations and selection of electronic and other components available on the market for assembling the device being created, development of an electrical device circuit, writing a control program code loaded into the microcontroller memory for the implementation of an automated sales process, designing and arranging its design using modern computer-aided design (CAD), analysis and simulation of physical processes (CAE), and finally the development of technical documentation for production.

Today, one of the important criteria in terms of various payment methods for goods is a digital payment method, for example, QR code payment via smartphones. The emerging relevance of this payment method has also affected the situation with vending machines, which requires the development of completely new algorithms for the integrated operation of a smartphone and the control center of such a device – the microcontroller.

The given and analyzed practical experience in creating a simple floromat indicates that the availability and presence of all kinds of electronic and ready-made mechanical components on the market, theoretical knowledge in the field of microcontrollers and practical experience with them, as well as certain skills in performing design work, allow us, in general, to create other types of various automated trading devices of our own domestic production.

**Keywords:** Vending machine, Floromat, SolidWorks 2018, Arduino IDE, Mega 2560 PRO MINI, ICT L83, Puloon LCDM-1000

## Introduction

Vending (vend - to trade (through machines)) is the sale of goods and services using automated systems (vending machines). Currently, only foreign vending machines are represented and operate in the Kazakhstani's automated trading market. These devices on the market are mostly aimed at selling of fast food, confectionery, coffee and bottled drinks. However, the recent situation with the COVID-19 pandemic, in which strict restrictive measures were imposed on movement and a global quarantine was introduced, has shown a likely high demand in the future for solutions to the delivery and transfer of medicines, food and many other vital goods for everyday life of a person in a non-contact way. The lack of domestic developments in this direction sets new goals: the creation of our own vending machines to solve the above problems. An example for the development of analogues can be the creation of a vending machine for the automated flower sale - a floromat. Floromats are installed at the airports, train stations, supermarkets, theaters, concert halls, and even maternity hospitals. The advantages of the absence of a seller, a small rented area and round-the-clock operation of the device make this type of business today one of the fastest paying off and very profitable. In this article, a practical example of the floromat development will be considered in detail, starting from the creation of a technical concept of work to the implementation of its prototype.

## Materials and Methods

The basic and main part of the study is aimed at studying the possibility of applying the existing low-cost hardware platforms of the AVR family, originally developed by Atmel, a well-known manufacturer of various microcontrollers and electronic chips, in the development of a vending machine, in our example, a floromat. Certainly, a preliminary review and analysis of existing on the market controllers and mutually agreed devices [2] for assembling vending machines and even ready-made systems [3] was carried out. And so, in order to solve our task such as controlling all the peripheral devices, mechatronics organs and other electronic modules necessary for the developed vending machine (hereinafter referred to as the floromat) for a convenient dialogue between the buyer (client) and the machine, a specific Mega 2560 PRO MINI microcontroller was considered [4]. This model differs from other platforms by the presence of the required number of UART (Universal Asynchronous Receiver-Transmitter) serial ports (4 in total) for connecting peripheral equipment such as a bill acceptor, a money dispenser and a GSM module, data exchange with which it is carried out according to the mentioned protocol. There are also a large number of digital inputs / outputs (54 in total) for transmitting a control signal, sufficiently large supply currents and a wide operating temperature range.

Specifications of Mega2560 PRO MINI:

- Microcontroller: ATmega 2560
- USB-TTL converter: CH340g
- Power Out: 5 Volt – 800mA
- Power IN.: 7 - 9 Volt
- Power IN. VIN/DC Jack: 5 Volt
- Power Consumption 5 Volt, 220mA
- USB: Micro USB
- Clock Frequency: 16MHz
- Operating Supply Voltage: 5 Volt
- Digital I/O: 54
- Analog I/O: 16
- Memory Size: 256kb
- Data RAM Type/Size: 8Kb
- Data ROM Type/Size: 4Kb
- Operating temperature: −40 °C /+85 °C
- Board's Size: 38×54mm

In the development of the terms of reference for the creation of the first prototype of the floromat, such basic factors as: price and availability of individual components (the ability to purchase on the market or place an order); component reliability; availability of the necessary proven libraries for connecting peripheral equipment and modules to the main microcontroller (Mega 2560 PRO MINI) were taken into account.

There are several important requirements for the work of the floromat when writing the terms of reference:

1. The operation of the floromat must be safe for customers and the operator;
2. Floromat must guarantee round-the-clock operation according to the algorithms and rules prescribed in the program code executed by the microcontroller. In the event of an emergency, the floromat must immediately send a message about the causes of the accident to the service operator's mobile phone;
3. After each realized bouquet, the floromat must send information (number of an empty cell) to the serving operator;
4. Floromat must accept all denominations of banknotes approved by the national bank of the country;
5. Floromat should ensure long-term preservation of bouquets, while the temperature regime should be in the range from +5 to +12 °C;
6. Floromat must also accompany all its actions with sound notifications;
7. Floromat should be outwardly pleasant, bright and exciting for customers;

An essential stage in the creation of a vending machine is the design and construction stage of the floromat case. For this purpose, a well-known professional tool for designing and simulating physical processes (CAD/CAM/CAE) - SOLIDWORKS 2018 [5] was used. Figure 1 shows the basic design of a floromat with a single-module cell zone. Structurally, the floromat cabinet is divided into three compartments: the upper compartment 1, where the evaporator of the refrigeration cooling system is installed, and the three-level zone of cells 2 (12 cells in total), the control compartment 3, the compartment for the main refrigeration cooling system (compressor block) 4. The main supporting structure of the floromat made by welding from a profile square pipe with a cross section of 15x15mm., and 1 mm thick sheet metal from which partitions, covers, shelves and a door are made. To reduce heat transfer between the cell area and the other three compartments, they are separated by 10 mm foam sheets, Figure 2.

Almost all models of floromats presented on the market have a small cell window, so there is a high probability of damage to the stems or petals of flowers in the process of loading bouquets by the operator or removing them by customers during purchase. Also, the cells have the same standard sizes for all types of bouquets, which exclude the possibility, for example, to install a bouquet of flowers

with a long stem. In case of breakdown of moving elements (doors, dampers, and servomotors), wire breakage or disconnection of contacts, these structures will not allow you to quickly repair, adjust or even urgently replace of components. To do this you will need to completely remove all the bouquets from the device and move them to another suitable room with a given temperature and humidity. It is also difficult to transport some models of floromats when changing the leased site (object), as they are heavy due to their huge dimensions and the lack of the possibility of their modular disassembly. To eliminate these shortcomings, a proposal was made to create a new convenient multi-module floromat The technical result consists in expanding the functionality of the floromat by the proposed alternative design of the floromat body, which allows for modular assembly and disassembly of the floromat, installation of a more powerful cooling system in it due to the dedicated lower section of the cabinet, which guarantees reliable and uninterrupted operation of the floromat.

The main control unit of the floromat is the control unit in Figure 3, where the following are installed: the microcontroller itself, the electromagnetic relay board, modules, DC-DC step-down converters and power supplies. As a box, an inexpensive PC system unit is used. During maintenance periods (microcontroller firmware, repair or replacement of modules), the control unit, due to the two guides installed at the bottom, is conveniently and easily slides out, without unnecessary need to disconnect the wires.

To fully understand the functionality of the floromat, and how the controls interact with the elements of mechatronics and its other components, the schematic diagram, made in the Fritzing program [6] is shown on Figure 4.

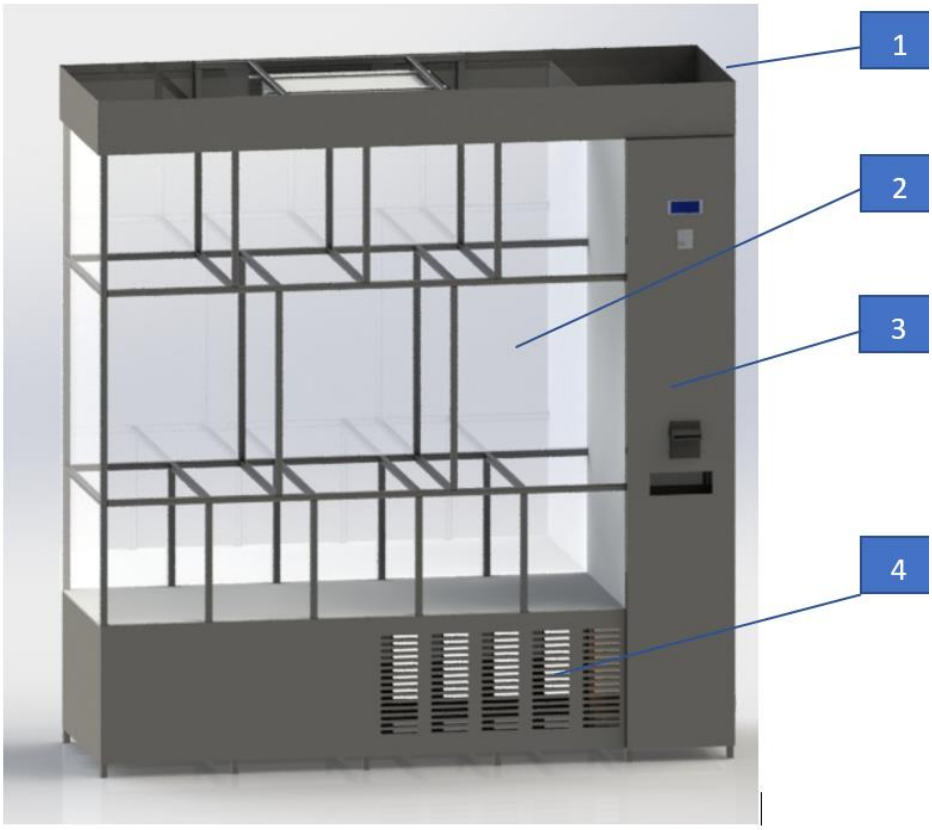



**Figure 1 -** Floromat design

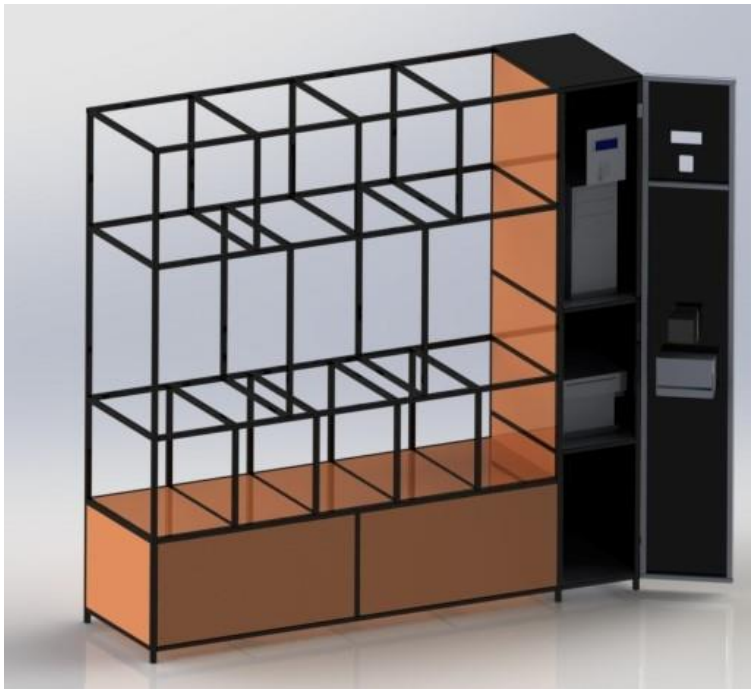


**Figure 2 –** Thermal insulation of the floromat


**Figure 3** – Control block

So, this includes:

1. Microcontroller Mega 2560 PRO MINI;
2. Four-line liquid crystal display (LCD 2004) for displaying information about the selected product (price) and stages of the purchase process;
3. Sound speaker 3W 4 Om;

4. Keyboard (3x4);
5. GSM module;
6. DFPlayer Mini MP3;
7. Electromagnetic relay board (+5V), 16 channels;
8. Servo drive MG90S, 12 pieces;
9. Electric lock (12V), 12 pieces;
10. Bill acceptor ICT L83 (made in Taiwan) [7];
11. Change dispenser (money bill dispenser) Puloon LCDM 1000 (made in South Korea) [8];
12. Max232CSE module, RS232-TTL interface converter;
13. DC-DC step down converter (3.8-30V -> 1.25-35V, 4A);
14. Power supply AC-DC 12V 5A;
15. Power supply AC-DC 24V 5A;

In the normal (standby) mode of the floromat, the DFPlayer module (6) plays background music previously recorded on the Mini SD card through the sound speaker (3). At the same time, the display screen (2) displays a welcome inscription to its customers and a proposal to select a bouquet by cell number. After the client visually selects the bouquet he likes and enters the desired cell number on the numeric keypad (4), the display shows information about the cost of the selected bouquet and the value of the control characters on the keyboard to cancel or confirm the final choice. If the client confirms their choice, then a new message appears about the readiness of the floromat to accept banknotes, while the bill acceptor (10) starts to light up in red. After depositing a sufficient amount of money, the Mega 2560 PRO MINI microcontroller, in accordance with the prescribed algorithm, calculates the amount of change and sends command signals (certain bytes) to the banknote dispenser (11) via the serial port through the Max232CSE module to dispense the required number of banknotes. This dispenser model Puloon LCDM 1000 is designed to load only one denomination of banknotes; in this case 500 tenge banknotes were loaded. At the same time, the settings for the size of selected denomination of the banknote are determined by the position of the jumpers installed on its rear panel according to the technical documentation of the device. Immediately after the payment is made, the Mega 2560 PRO MINI microcontroller once again sends a command (discrete signal) to its desired pin, the output of which is connected to the corresponding pin (channel) on the electromagnetic relay board, after which the electric lock tongue (9) in the cell is automatically pressed. In the meantime, while the electric lock is still on (the tongue is pressed, t=1-2 seconds), the following discrete signal is sent to the servo drive (8) of the same cell, and through the transmitted torque of the servo drive, the door itself opens, the client picks up their bouquet, after an audible notification is displayed that the door will close soon. The floromat thanks the customer for the purchase with audio and text messages. Further, a text message (SMS) about the number of the empty cell is immediately sent to the bouquet loading operator via the GSM module.

In the event of an emergency power outage at the installation site of the floromat, its continuous operation for 1.5 hours is provided by the installed uninterruptible power supply with a capacity of 500 watts (80 Wh). Note that since initially this power is not enough to start and operate the refrigeration unit, the refrigeration unit is non-volatile from the power line of the main control unit.

The refrigeration unit itself is an independent system Figure 5, consisting of an evaporator (1), a compressor unit (2) and a management controller (3) with a temperature sensor (4) installed in one of the floromat cells. The controller uses a sensor to continuously monitor the temperature in the cell area. When the temperature rises above the set point, the built-in relay turns on and the compressor unit starts. The water condensate formed during the operation of the refrigeration unit is drained through the tube from the evaporator to the sump into the compartment of the compressor unit. Also, a timer is set in the control unit, to automatically turn off the compressor unit for periodic defrosting of the snow-covered evaporator.

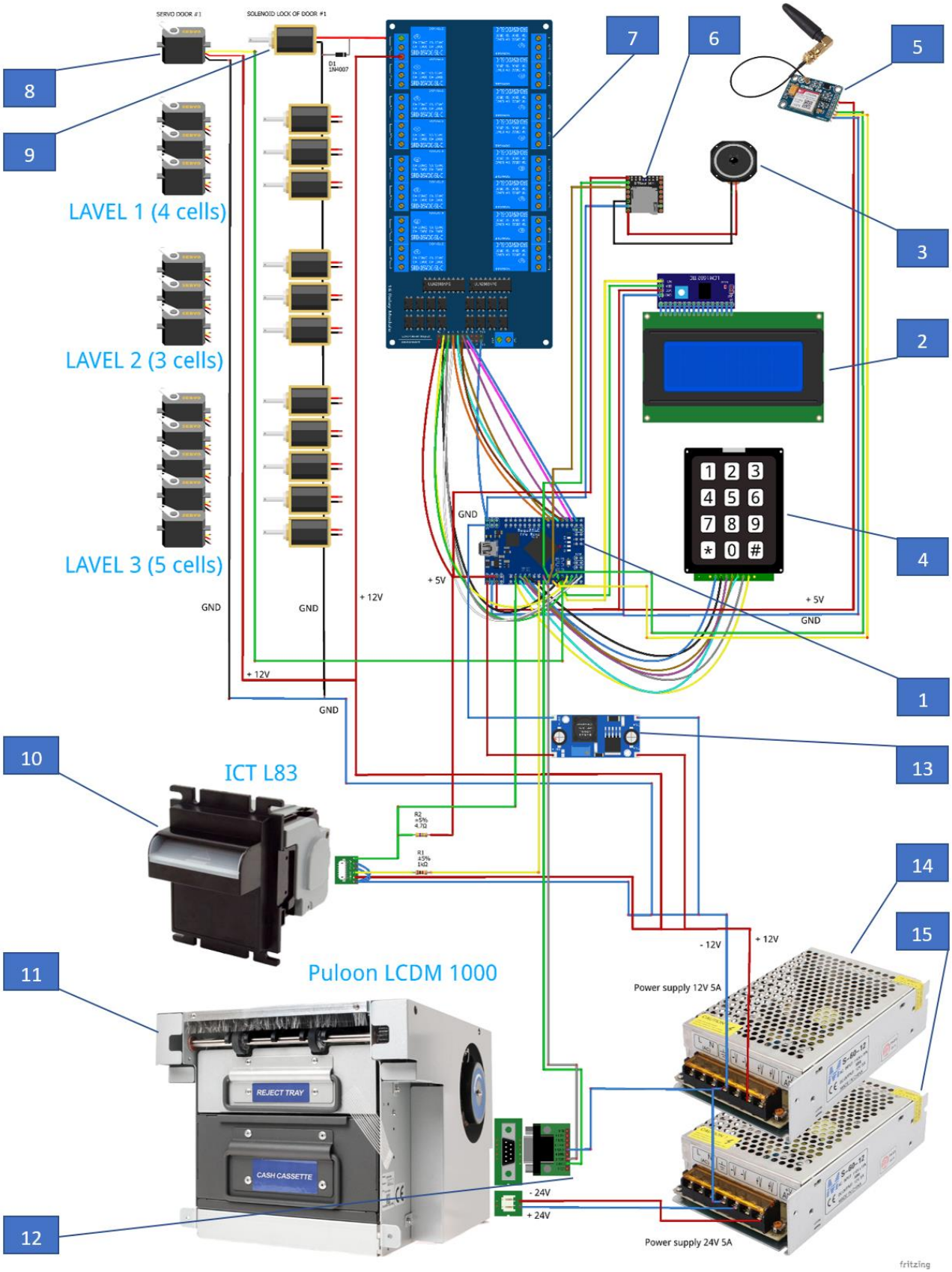



**Figure 4** – Schematic diagram of the floromat

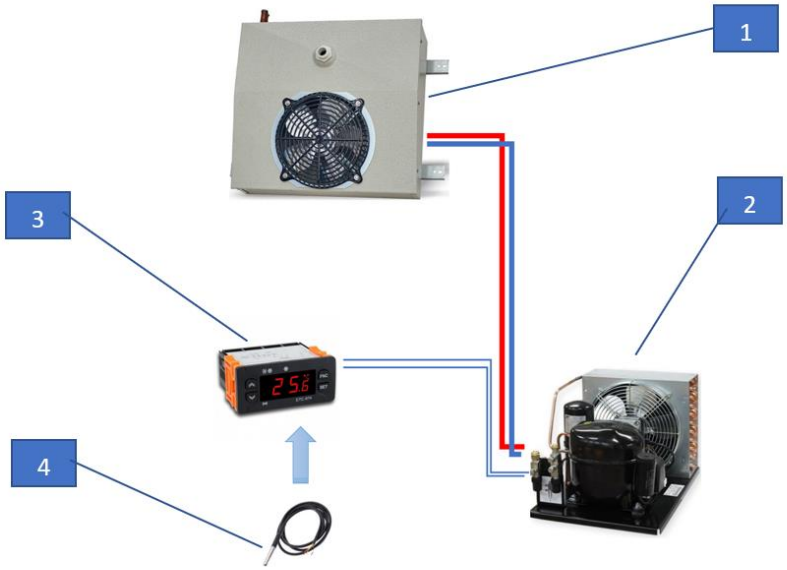



**Figure 5** – Floromat refrigeration system

Figure 6 shows a listing of the initial source code for the executable program. The code is written in C++ in the Arduino IDE 1.8.10 [9], which is compiled and then loaded from there into the memory of the Mega 2560 PRO MINI microcontroller. The code consists of 647 lines, last modified on 09/17/2019.

Program_Mega2560_with_ICTL83_Puloon1000_12_boxes_working_englis | Arduino 1.8.10

Файл Правка Скетч Инструменты Помощь

Program_Mega2560_with_ICTL83_Puloon1000_12_boxes_working_englis §

```
// Mega 2560 pro
// Almaty city, 17.09.2019.
// ©, "Samal Energy" LLP (by Darkhan Dogalakov)
// +7 707 215 2013.


#include <Wire.h>                         // библиотека для управления устройствами по I2C
#include <LiquidCrystal_I2C.h>            // подключаем библиотеку для LCD 1602
#include <Keypad.h>                       // needs to be in the library folder (Arduino/Libraries)
#include <EEPROM.h>                       // подключаем библиотеку EEPROM
#include <SoftwareSerial.h>
#include <DFPlayer_Mini_Mp3.h>

SoftwareSerial Serial_LCDM1000(15, 14);   // RX, TX
SoftwareSerial Mp3_set_serial(17, 16);    // RX, TX


// Настройки основные:
int good = 0;                             // Переменная для выбора товара - программы для выполнения
char keystr_1[5];                         // массив для последовательно набранных символов для выбора товара
char keystr_2[5];                         // массив для последовательно набранных символов для пароля
char keystr_3[5];                         // массив для последовательно набранных символов для выбора товара при добавлении/удалении
String Pass;                              // кодовое слово для режима редактирования наличия в ящиках товара

bool selected_good = false;               // Флаг о проведенном выборе товара
bool purchased_good = false;              // Флаг о проведенной оплате товара
bool mode_loading = false;                // Флаг режима загрузки товара в ящики
bool mode_delete = false;                 // Флаг режима удаления товара в ящиках
char prev_key;
int prev_num;
char key;
// - основные -


// Настройки прайса на цветы для каждого ящика (1-12):
int price[13] = {0, 1000, 4000, 2000, 2000,
                 4000, 4000, 4000,
                 6000, 6000, 6000, 6000, 6000
                };
// - прайс -
```

**Figure 6** – Program source code listing

Figure 7 shows the settings for the coordinated operation of the microcontroller with the ICT L83 bill acceptor via the serial port, according to the instructions described in the device manual:

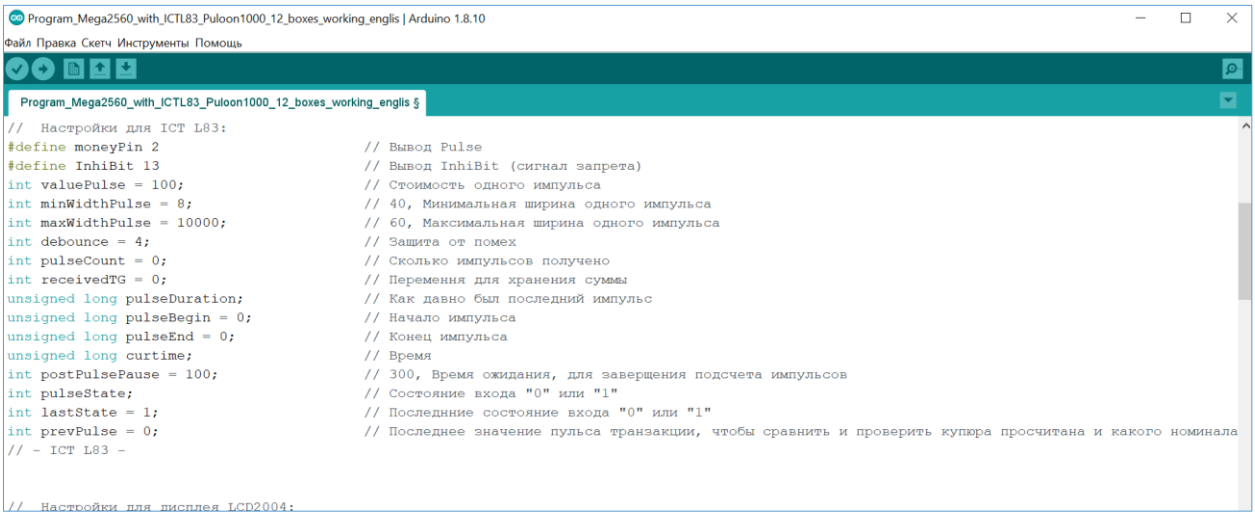



**Figure 7** – Settings for working with the ICT L83 device

Figure 8 shows the settings for the coordinated operation of the microcontroller with the Puloon LCDM 1000 money dispenser also via the serial port, according to the instructions described in the manual of this device:

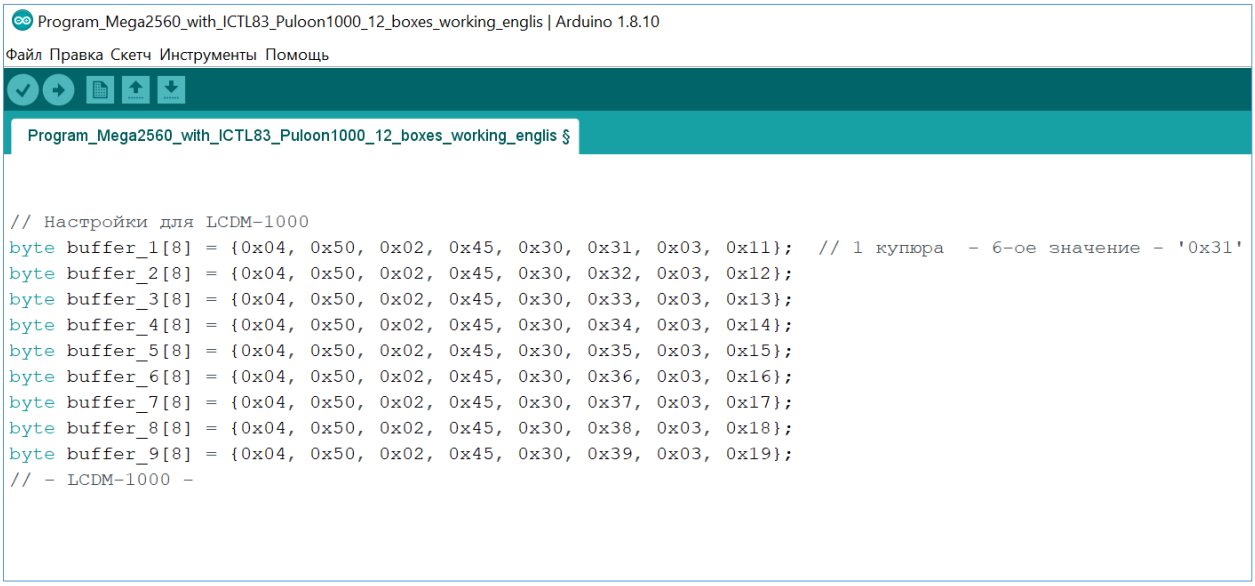
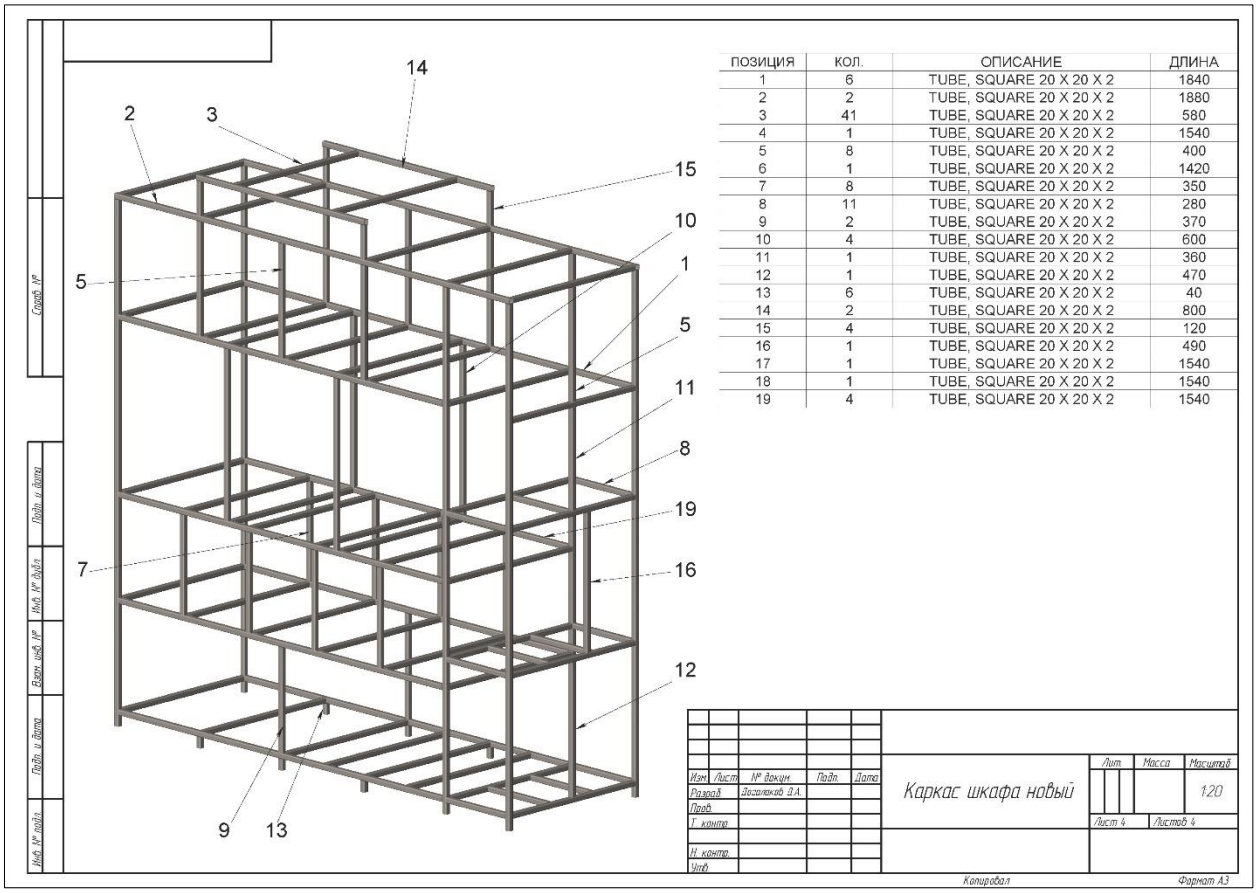



**Figure 8** – Settings for working with the Puloon LCDM 1000 device

The SOLIDWORKS Weldments module included in the main SolidWorks 2018 package has a large set of special tools for convenient and fast creation of welding structures. While preparing design documentation for drawings, an automatically generated list of cutouts of all structural elements can be displayed, Figure 9. These data allow you to calculate the exact required amount of purchased material, and at the same time, pre-calculate the prime cost of the final product. On the drawing Figure 10 with front and right views, you can estimate the dimensions of the cells and the overall dimensions of the floromat.




| ПОЗИЦИЯ | КОЛ. | ОПИСАНИЕ | ДЛИНА |
|---|---|---|---|
| 1 | 6 | TUBE, SQUARE 20 X 20 X 2 | 1840 |
| 2 | 2 | TUBE, SQUARE 20 X 20 X 2 | 1880 |
| 3 | 41 | TUBE, SQUARE 20 X 20 X 2 | 580 |
| 4 | 1 | TUBE, SQUARE 20 X 20 X 2 | 1540 |
| 5 | 8 | TUBE, SQUARE 20 X 20 X 2 | 400 |
| 6 | 1 | TUBE, SQUARE 20 X 20 X 2 | 1420 |
| 7 | 8 | TUBE, SQUARE 20 X 20 X 2 | 350 |
| 8 | 11 | TUBE, SQUARE 20 X 20 X 2 | 280 |
| 9 | 2 | TUBE, SQUARE 20 X 20 X 2 | 370 |
| 10 | 4 | TUBE, SQUARE 20 X 20 X 2 | 600 |
| 11 | 1 | TUBE, SQUARE 20 X 20 X 2 | 360 |
| 12 | 1 | TUBE, SQUARE 20 X 20 X 2 | 470 |
| 13 | 6 | TUBE, SQUARE 20 X 20 X 2 | 40 |
| 14 | 2 | TUBE, SQUARE 20 X 20 X 2 | 800 |
| 15 | 4 | TUBE, SQUARE 20 X 20 X 2 | 120 |
| 16 | 1 | TUBE, SQUARE 20 X 20 X 2 | 490 |
| 17 | 1 | TUBE, SQUARE 20 X 20 X 2 | 1540 |
| 18 | 1 | TUBE, SQUARE 20 X 20 X 2 | 1540 |
| 19 | 4 | TUBE, SQUARE 20 X 20 X 2 | 1540 |

**Figure 9** – Weldment cut list (floromat cabinet)

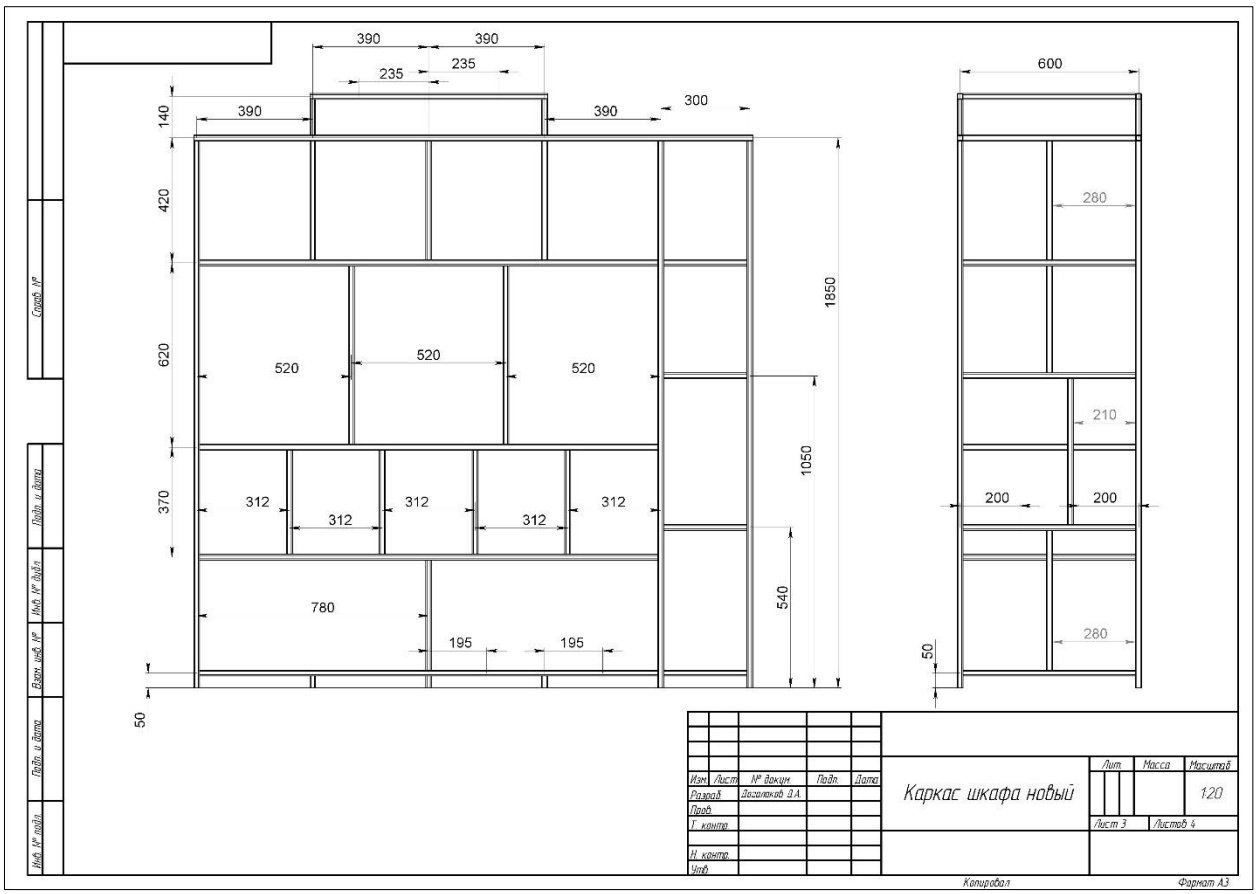



**Figure 10** – Internal and overall dimensions of the floromat cabinet

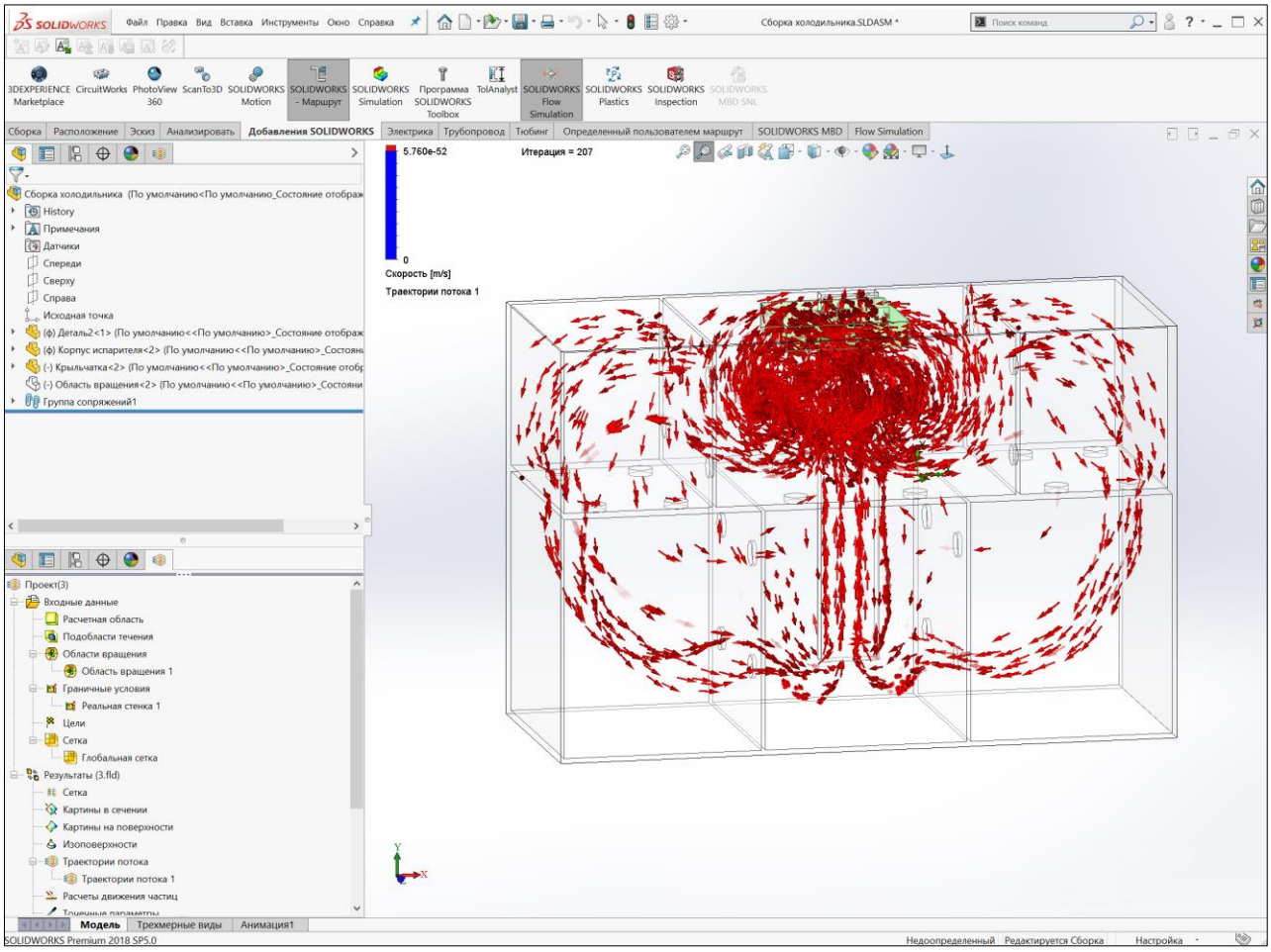



**Figure 11** – Air flow simulation
for cabinet construction with a two-level compartment zone

SOLIDWORKS Flow Simulation [10] is an easy-to-use computational fluid dynamics (CFD) solution built into SOLIDWORKS 3D CAD to simulate fluid and gas flow to calculate product performance and capabilities. In our case, this tool was also used to solve the problem of uniform distribution of the air flow cooled by the refrigeration unit in the cell area, Figure 11**.** As a result of the operation of the cooling system and constant air condensation, water accumulates in the floromat evaporator. To drain it, a tube is used, which is lowered into the sump of the compressor unit. However, in the future, the possibility of re -using this water for watering arranged bouquets in cells is being considered.

In the manufacture of doors, partitions, shelves and outer walls of the floromat, an easily processed transparent material was used - plexiglass, 7 mm thick. The scans (files for loading into the multicam machine) were also made and automatically uploaded in the SOLIDWORKS 2018 program. Energy-saving cold light LED strips were used separately to illuminate the cells at three levels. Figure 12 shows a useful model of a domestic floromat that has passed the first tests.


**Figure 12** – The first instance of the domestic floromat

**Results and discussion**

The conducted research and the results obtained in the course of its work prove that the AVR series microcontrollers can easily cope with the tasks of automating retail outlets by self-service. Using inexpensive and sufficiently reliable AVR microcontrollers and their analogues, when creating such devices, opens up great opportunities for connecting and configuring almost any peripheral device that has at least one of any of the existing matching interfaces. The use of the mentioned CAD/CAE design systems and simulations was a big help during the design and layout stage of such an apparatus, where there are a large number of devices. The next steps for full automation, taking into account today's information know-how in the cashless payment market, namely payment by QR code through mobile applications [11], are: the study and additional development of these technologies for their integration into the control system of the vending machine.

**Conclusion**

The creation of a domestic vending machine with these functions and software will have a significant socio-economic impact on the population and entrepreneurship. It will unite suppliers, logistics companies, lessors of trading floors (shopping and entertainment centers, residential complexes) and the customer directly in the business area. A contactless way to obtain the necessary food, medicine or essential goods in the face of possible lockdowns is one of its solutions. During the implementation of this project, unique experience and practical developments were obtained for the implementation of future domestic vending machines

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# APPROACH TO MUDFLOW HAZARD PREDICTION AS A RESULT OF CHANGES IN SNOW COVER AND ACTIVE SNOWMELT IN MOUNTAINOUS AREAS BASED ON THE APPLICATION OF REMOTE SENSING TECHNOLOGY

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**Abstract**

The ability to find constructive solutions to prevent emergencies in mountainous terrain will contribute greatly to the management of the field of emergency forecasting. One of such solutions is to find solutions using remote sensing and GIS. Nowadays, the study of emergencies, forecasting is very important. The occurrence of each emergency in its own way adversely affects the inhabitants of settlements at risk of emergency [1].

Drone imagery and satellite geodetic work, make it possible to determine the regions of Kazakhstan where emergencies may occur. Of course, it is impossible to fly over the entire territory of the Republic of Kazakhstan by drone, but in this matter, we resort to satellite imagery. The essence of the solution is to find a relevant method and do the necessary analysis.

The method of extracting high-precision DTM (digital terrain models), point clouds, 3D models, orthophotomaps, topographic maps from satellite images with high accuracy can get accurate research results in this direction [2].

Disaster prevention is one of the important applications of remote sensing. Natural disasters, climate change and anthropogenic factors can complicate the work of disaster prevention and mitigation teams. With the help of remote sensing, professionals can better prepare and act faster and more accurately [3]. This can save many lives, reduce property damage and reduce the time and money emergency departments need to do their jobs.

Flood risk modeling shows that cities, city governments, and emergency professionals can take prompt action to reduce flooding [4]. Landslide and avalanche monitoring provides a prediction before landslides occur and gives the public enough time to evacuate.

In carrying out this study, data from open sources were used.

The work identified a specific question of interest about the seasonality of snow cover in the study area and the statistical analysis needed to answer it.

The study area was defined by creating a shapefile to delineate it. A MODIS time series of snow cover products was downloaded from NSIDC, here this would be MOD10A1 or MOD10A2 (depending on the specific question of interest) [5].

**Keywords:** satellite imagery, remote sensing data, precipitation, hydrological model, geographic information systems, drone, emergency

**Introduction**

Occurrence of mudflow hazard and its prediction is now very relevantly studied in many countries, as the question of risk occurrence itself has a topical nature. The risk implies a danger to the residents of the area and the population living in the risk-prone area. The most basic types of risks:

1. The risk coming from the solid medium, i.e., geophysical risk.

2. The risk caused by the occurrence, movement and distribution of surface and underground fresh and salt water is part of the hydrological risk.

3. The risk caused by short-term extreme weather conditions at micro- and mesoscale levels, as well as atmospheric conditions that last from a few minutes to a few days, refers to meteorological risk.

4. The risk caused by atmospheric processes at the meso- and macro-level, from intra-seasonal to multi-year climate variability, refers to climate risk.

5. The risk caused by exposure to live organisms or toxic substances, or the vector-borne diseases they may carry can be classified as biological risk.

6. The risk caused by asteroids, meteoroids and comets is an extra-atmospheric risk.

All emergencies in Kazakhstan are classified according to the following characteristics: the sphere of occurrence, departmental affiliation, the scale of possible consequences.

The territory of Kazakhstan is most prone to droughts, earthquakes, river floods and landslides.

The degree of risk of this or that emergency in Kazakhstan is described in the passports of mudflow, avalanche, landslide sites and objects located in the areas of their impact, as well as in the Rules of state accounting of emergencies of natural and man-made character approved by Order № 175 of the Minister of Internal Affairs of Kazakhstan on March 3, 2015 [11].

According to the Rules, emergencies of natural origin include:

1) geophysical hazards: earthquakes (which occurred in the territory of the Republic of Kazakhstan or bordering (neighboring) states).

2) geological hazards: landslides, rockslides, rockfalls, mudflows, subsidence of loess rocks.

3) meteorological phenomena: strong wind (including squalls and tornadoes), dust (sand) storms, large hail, heavy rain (downpour), heavy snowfall, strong blizzards (snow drifts), heavy ice, strong frost, strong heat, heavy fog, drought, frost, drift, avalanches.

4) hydrological hazards: high water levels (floods) during floods, rain floods, jams and blockages, wind surges; low water levels.

5) natural fires - forest fires, steppe and forest fires, underground fires of combustible minerals.

10) incidents at water bodies.

Man-made emergencies include:

Hydrological phenomena. Floods and floods. Floods are short-term and non-periodic rises in water bodies and rivers caused by melting snow, glaciers, or abundant precipitation. Sometimes the flow of flood water exceeds the flow of flood water; in addition, floods are less regular and difficult to predict. Therefore, they are more likely to result in emergencies.

Floods are situations of flooding of territories adjacent to rivers, lakes, reservoirs, causing material damage, damage to the population, or loss of life. As a rule, the lowered parts of settlements, crops, roads, or industrial and transport facilities are flooded.

Almaty region. In spring period water content of rivers increases in 1,5 - 3 times. The total area of flooding when dams are broken can reach 120 million square meters [12].

The city of Almaty. The highest probability of flooding from May to July.

Mudflows, landslides, avalanches

Mudflow is a violent flow of water and loose debris of destructive force arising in mountain river basins because of heavy precipitation or rapid snowmelt, breakthrough of debris and glacial moraines. In terms of prevalence, recurrence and destructive effect, mudflows are considered among the most dangerous natural phenomena in agglomerations.

High mudflow hazard in Almaty region is created on the Esik, Turgen, Talgar, Kaskelen rivers, the number of people living or working in the impact area is 8,725 people. Under the high mudflow

hazard fall 454 objects. At the same time, 638 objects, as well as 3,706 people of the population fall under the medium risk level [14].

A landslide is a displacement of rocks under the influence of its own weight and additional load due to erosion of the slope, over wetting of rocks, seismic shocks and other processes. Occurrence of a landslide relates to disturbance of stability of a slope by natural processes or people. In terms of frequency and probability of occurrence of these phenomena in the country, Almaty region ranks first, Almaty city ranks second. Almaty city ranks second. According to "Kazselezaschita", 150 objects and 1,311 people are under landslide hazard in the region [16].

Avalanches are the movement of snow and ice down the slopes of mountains, which poses a threat to life and health of the population, causing damage to the economy and the environment. According to "Kazselezaschita" there are 24 objects in the agglomeration that fall within the zone of avalanche impact, with a total area of 76.7 thousand square meters affected. The degree of avalanche danger is low, and 48 avalanche protection facilities have been installed. The number of people living or working in the affected areas reaches 125 people, and all affected areas are resort areas, therefore, the number of victims of emergencies may increase from 160-950 people [11].

In 2015 there was a case of flooding and mudslides, because of which a state of emergency was declared and 900 people were evacuated [11].

Implementation of a new paradigm of the country's development: sustainable development, managed urbanization.

- development and preservation of human capital: quality of life, providing affordable and safe transportation.

- ensuring the safety of the population, infrastructure, and economy from the consequences of emergencies and reducing the risks of natural disasters based on modern methods of monitoring, analysis, and forecasting.

Analysis of the current situation and assessment of potential consequences and development of a specific method, considering international experience.

Studying the structure of the activities of the organization of the monitoring and prediction of emergencies.

Digital solutions as tools for implementation in approaches to solving problems to prevent emergencies in mountainous areas of Kazakhstan.

**Materials and Methods**

The importance of snow cover extent (SCE) has been shown to be closely related to various natural phenomena and human activities; hence, snow cover monitoring is one of the most important issues in the study and understanding of the cryosphere. Because snow cover can change significantly over short periods of time and often extends over vast areas, remote sensing from spacecraft is an effective observation method for continuously tracking it. However, since optical imagery is limited by cloud cover and polar darkness, synthetic aperture radar (SAR) has attracted more attention for its ability to detect day and night under all cloud and weather conditions. In addition to the widely used backscatter method, thanks to advances in space-based SAR sensors and image processing techniques, many new approaches based on interferometric SAR (InSAR) and polarimetric SAR (PolSAR) have been developed to monitor snow cover in both dry and wet snow conditions since the ERS-1 launch in 1991. Critical ancillary data, including DEM, land cover information, and local meteorological data, have also been studied to aid in snow cover analysis. This review provides an overview of existing research and discusses the benefits, limitations, and directions of current developments [1].

**Table 1 –** The types of natural disasters

| № / | Name | Type |
|---|---|---|
| 1 | Floods | Hydrological hazards |
| 2 | Congestion, ice jams, ice jamming | |
| 3 | Waterlogging | |
| 4 | Accidents | Hydrodynamic accidents |
| 5 | Earthquakes | Geophysical hazards |
| 6 | Rural | |
| 7 | Avalanche | |
| 8 | Landslides | Geological hazards |
| 9 | Fires | Natural fires |

Identified a specific question about the seasonality of snow cover in the study area and the statistical analysis necessary to answer this question. Conducted a study on the product for snow cover in the mountainous area. Determined the study area of the mountainous area of Almaty region and created a shapefile to delineate it further. Loaded NSIDC time series of MODIS snow cover products, here it would be MOD10A1 or MOD10A2 (depending on the specific question of interest). Determined the processing sequence, including masking incorrect data flagged with quality bits, to produce an ordered time series of snow cover images. Coding the processing sequence and evaluating the results numerically, graphically, and logically one must answer the question: Does everything work correctly? Do the results make sense? Applying the statistical analysis to necessary region and evaluating the results of the statistical analysis we must answer the question: do the results make sense? To what extent are these results consistent with recent literature? On what points do they differ? Why?

***Kazakhstan Republic statistics on emergencies***

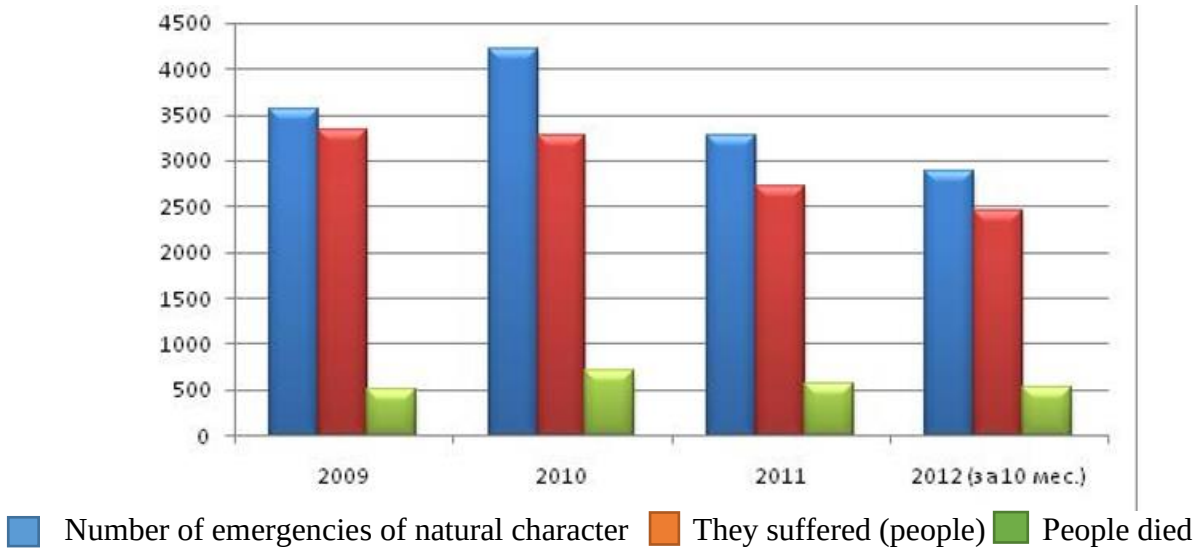



**Figure 1.** – Emergency statistics

The list of equipment and data needed includes:

Satellite imagery, software (U.S. Army Corps of Engineers (USACE CEIWR-HEC-RAS, SaaS - for collection, analysis and distribution of analytical information, reports or raw data), data

collection (current and historical), systematization and storage of incoming information, development and updating, map areas potentially subject to mudflow and landslide hazards, develop flood simulation methods, to assess area exposure to disaster risks, platform - software.

**The number of dangerous natural phenomena in Almaty city and Almaty region in 2010 - 2019**

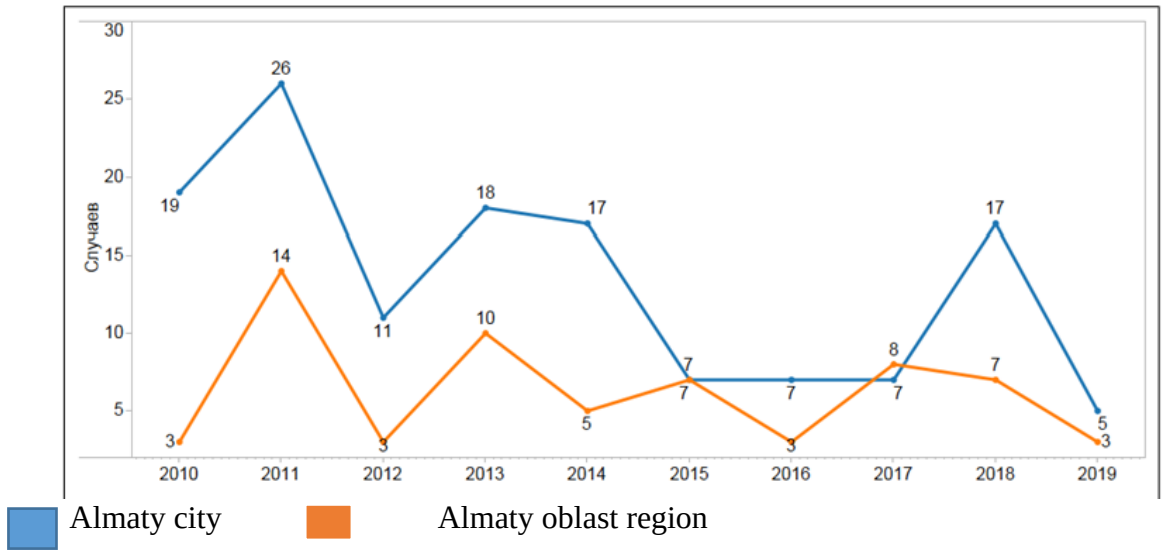



**Figure 2** – Emergency statistics

This dataset contains maps of the location and temporal distribution of surface water from 1984 to 2020 and provides statistics on the extent and change of those water surfaces. For more information see the associated journal article: High-resolution mapping of global surface water and its long-term changes (Nature, 2016) and the online Data Users Guide.

These data were generated using 4,453,989 scenes from Landsat 5, 7, and 8 acquired between 16 March 1984 and 31 December 2020. Each pixel was individually classified into water / non-water using an expert system and the results were collated into a monthly history for the entire time and two epochs (1984-1999, 2000-2020) for change detection.

This mapping layers product consists of 1 image containing 7 bands. It maps different facets of the spatial and temporal distribution of surface water over the last 35 years. Areas where water has never been detected are masked.

The Global Surface Water dataset (Water Occurrence, Water Occurrence Change Intensity and Water Transitions) shows different facets of surface water dynamics. Together the maps show where and when open water was present on the Earth's surface between March 1984 and 31 December 2020. Open water is any stretch of water open to the sky and includes both freshwater and saltwater areas greater than 30m2. The maps display water surfaces that are visible from space, including natural (rivers, lakes, coastal margins, and wetlands) and artificial water bodies (reservoirs formed by dams, flooded areas such as opencast mines and quarries, flood irrigation areas such as paddy fields, and water bodies created by hydro-engineering projects such as waterway and harbor construction).

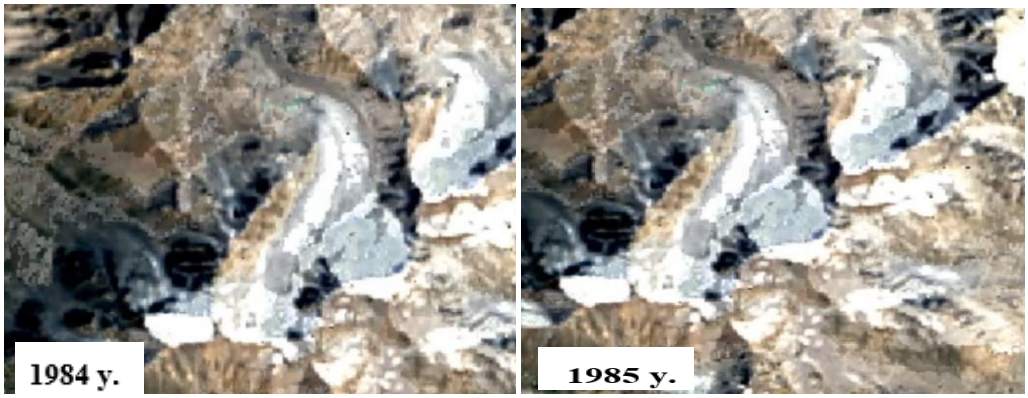
Areas within the region that correspond to one of the water transition classes. The Water Transitions map documents changes in water state between the first year (1984) and the last year of observation (2019). It documents: New permanent water surfaces (i.e. conversion of a no water place into a permanent water place.) Unchanging permanent water surfaces Lost permanent water surfaces (i.e. conversion of a permanent water place into a no water place) New seasonal water surfaces (i.e. conversion of a no water place into a seasonal water place) Unchanging seasonal water surfaces Lost seasonal water surfaces (i.e. conversion of a seasonal water place into a no water place) Conversion of permanent water into seasonal water Conversion of seasonal water into permanent water Ephemeral permanent water (i.e. no water places replaced by permanent water that subsequently

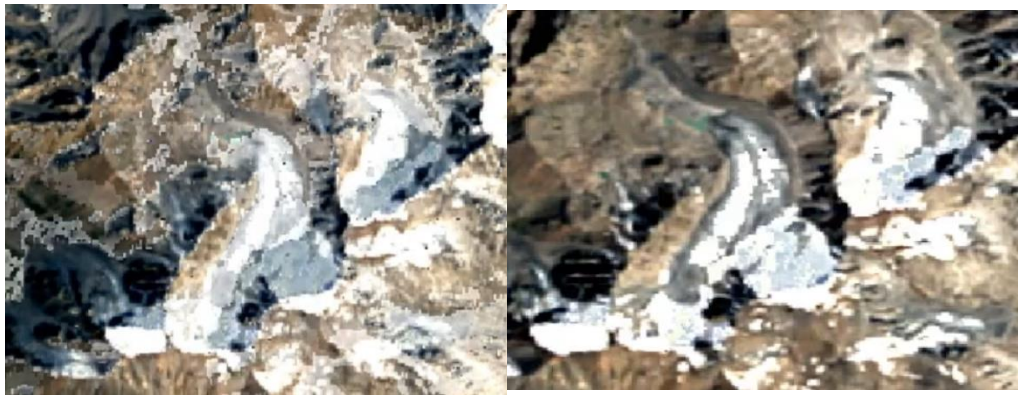
disappeared within the observation period) Ephemeral seasonal water (i.e. no water places replaced by seasonal water that subsequently disappeared within the observation period) Temporal profiles recording the full history of each pixel are provided. These allow us to define monthly the water presence or absence (and also the absence of observation) throughout the archive.

During a survey by specialists of the RK emergency authorities, due to the high temperature, Lake No. 4 has filled up to its maximum mark [16]. Therefore, the specialists of Kazselezaschita conducted work to install here a new branch of siphon, 450 meters long. It can pump out up to 50 liters of water per second, which then enters the Aksai Riverbed [11].

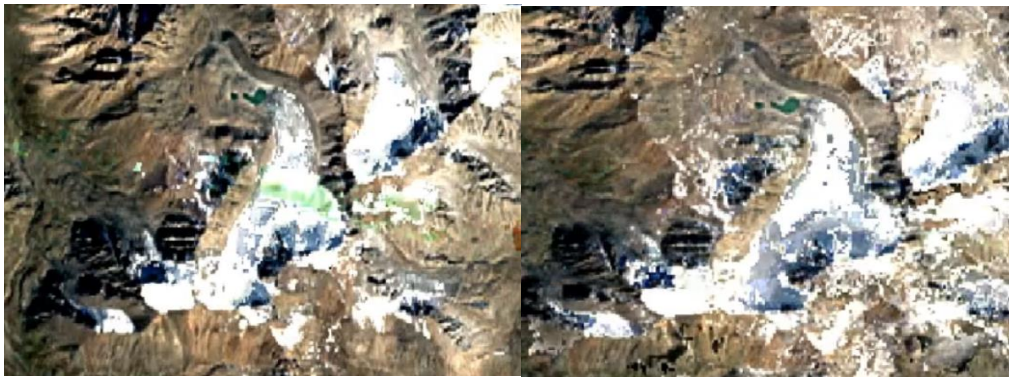
It should be noted that the moraine lake is located 3,500 meters above sea level. In case of a breakthrough, it poses a threat to the settlements of Nauryzbai and Karasai districts.

"We still have a vertical depth pump that runs with a diesel power plant. If the siphon can't handle it, we can pump out with a Deepwater pump, which pumps out 380 liters per second. Source: Kazselezaschita [12].



1988 y. 1991 y.



1999 y.- 2002 y. 2000 y. – 2004 y.

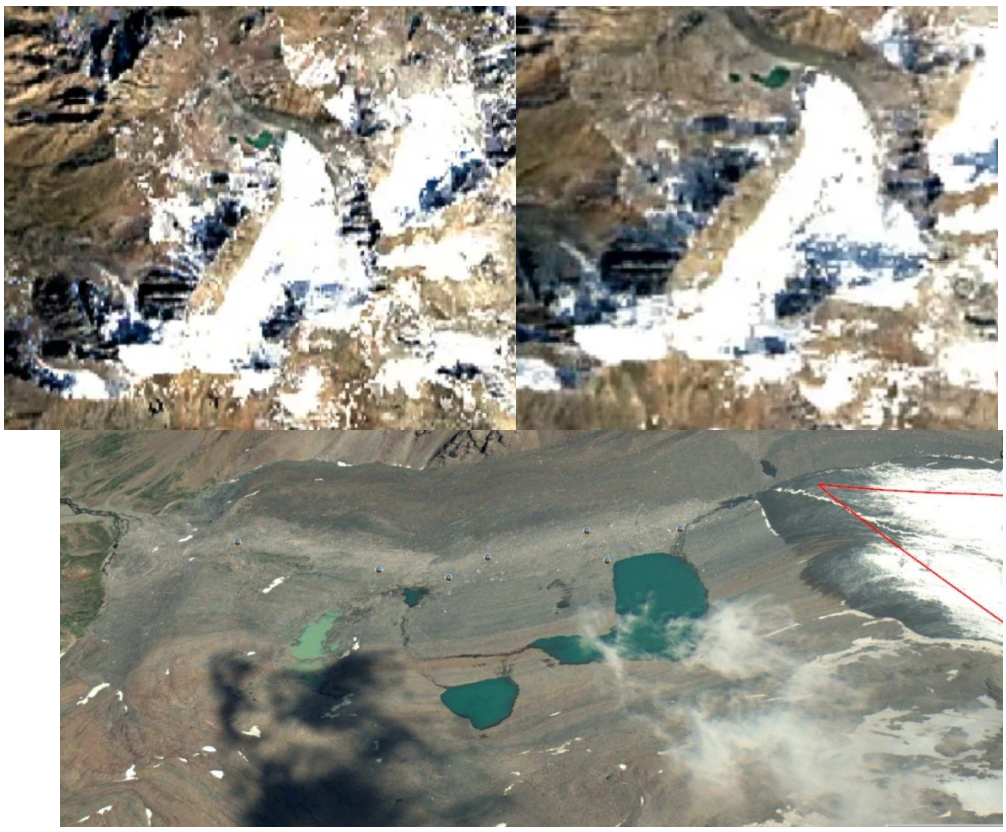


**Figure 4 -** Area of Interesting 1984 y. - 2011 y.

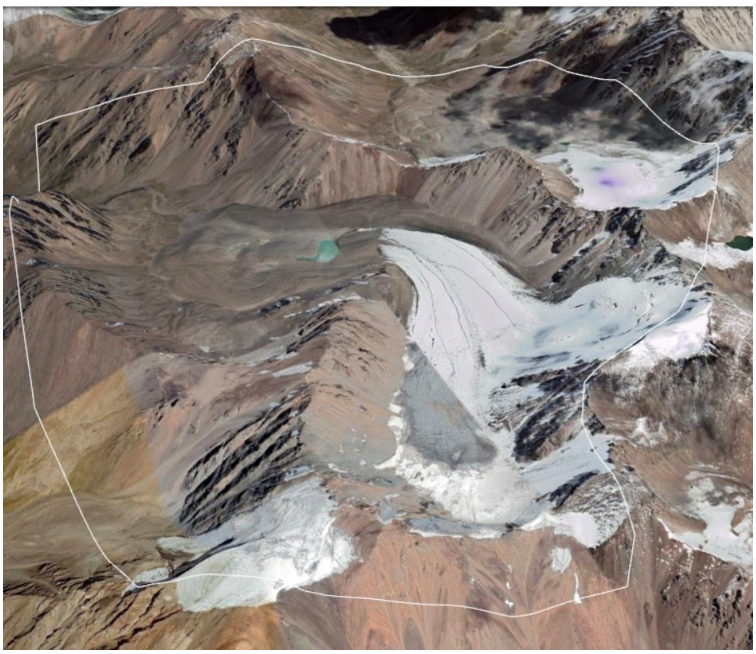


**Figure 5 -** September 2022 y.

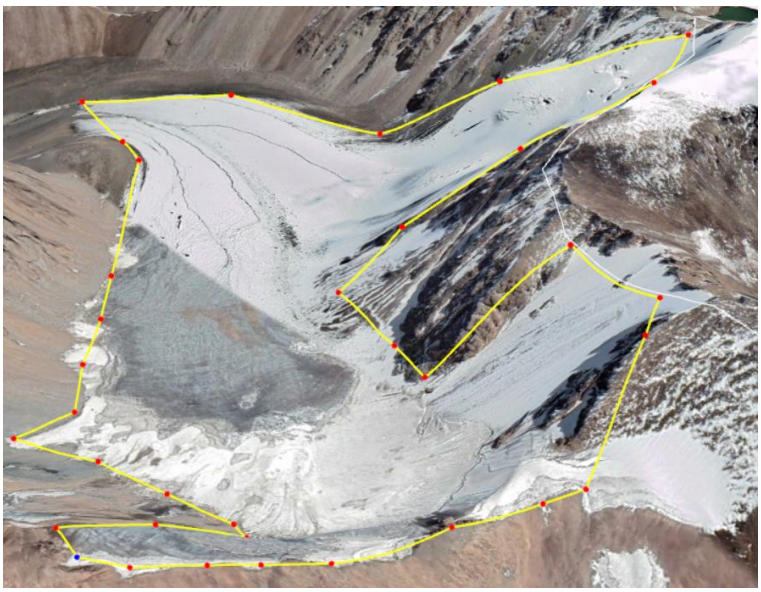


**Figure 4 -** Boundary AOI

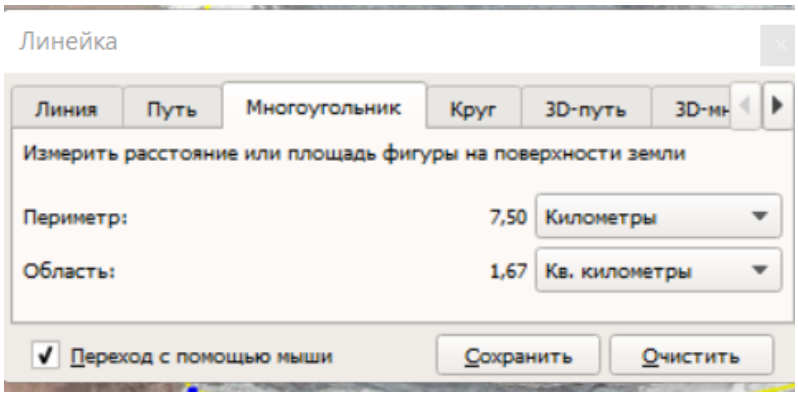



**Figure 5 -** Total area


**Figure 6 -** Source: D. Kovinov

Surface Water occurrence - JRC

Source: Global Surface Water Mapping Layers v1.3 - The European Commission's Joint Research Centre (JRC)

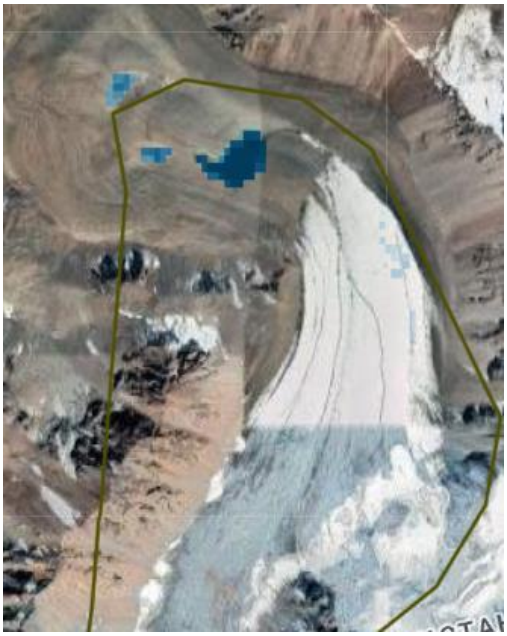


**Figure 7** - Surface Water transitions (JRC)

Source: Joint Research Centre of the EU - Global Surface Water Dataset v1.3

**Aksai river**
Surface Water transitions (JRC) 1984/2020

| Class name | Area(ha) | Area(%) |
|---|---|---|
| Permanent | 3.09 | 1.03 |
| New permanent | 1.12 | 0.37 |
| New seasonal | 0.28 | 0.09 |
| Permanent to seasonal | 0.26 | 0.09 |

**Figure 8** - Surface water transitions

**Figure 9** - 2015 year, Source: Kazselezaschita.

We should add that, if necessary, drilling and blasting operations are used on the evacuation canals. Every summer, because of the abnormal heat, channels have to be blasted and deepened several times. The annual mudflow season in the Almaty mountains will end in early October.

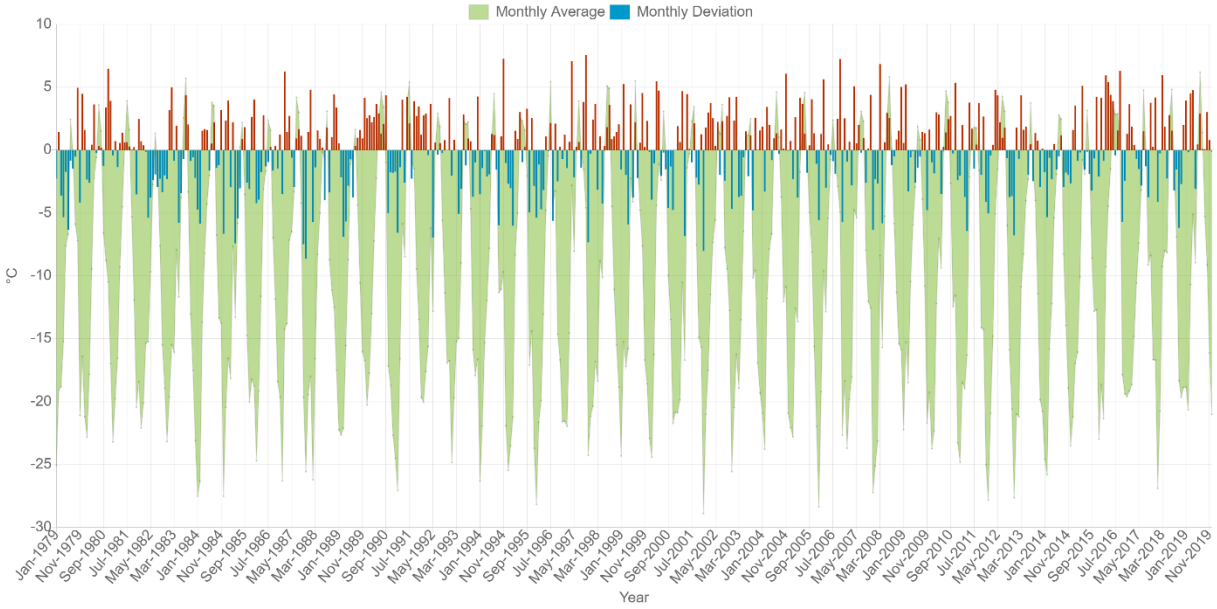



**Figure 10 -** Temperature - Minimum (ECMWF ERA5)-Monthly time series

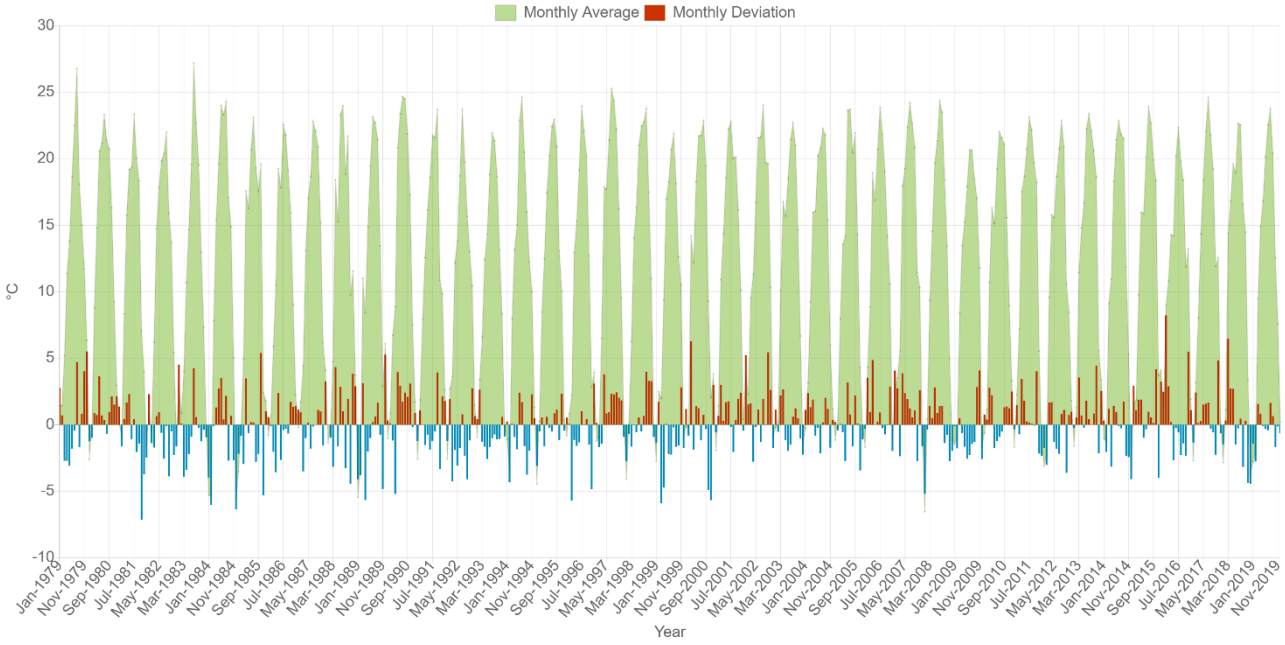



**Figure 11 -** Temperature - Maximum (ECMWF ERA5)-Monthly time series

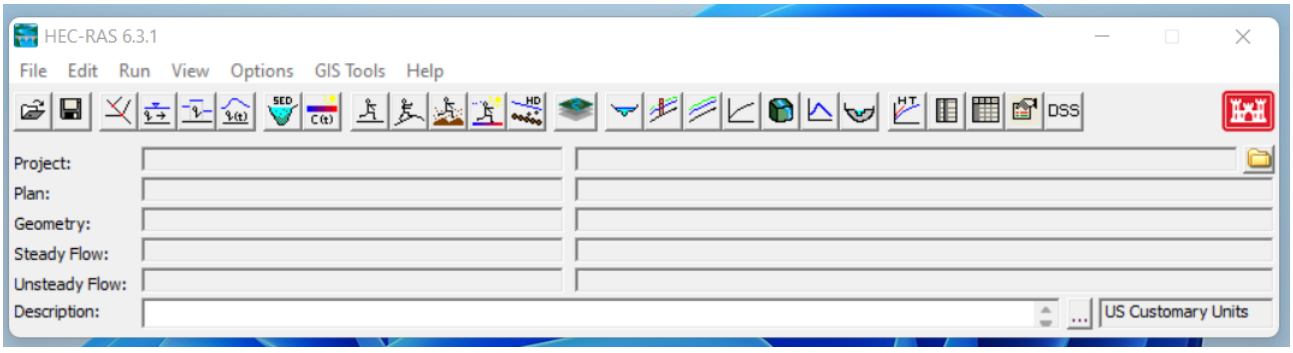



**Figure 12 - HecRas**

A numerical formulation of a one-dimensional physical model of snow cover is presented. This model is used daily by avalanche prevention specialists to predict snow cover subsidence, its stratification, surface energy exchange, and mass balance. Meteorological data obtained from automatic weather stations located near avalanche zones are used as input to the model. This paper formulates one-dimensional equations describing heat transfer, water transport, vapor diffusion, and mechanical deformation of the phase-varying snow cover. New snow, wind drift, and snow entrainment are treated as special mass boundary conditions. Snow is modeled as a three-component (ice, water, air) porous material capable of large irreversible viscous deformations. Phase transitions between the components are modeled. Snow layers are defined not only by height and density, but also by microstructure. That is, by the size, shape, and cohesion of the grains that make up the ice lattice. The basic differential equations are solved using the fully implicit Gauss-Seidel finite element Lagrangian method. An example of calculations of a catastrophic avalanche in the winter of 1999 is presented to document the operation of the model. An overall estimate of the mass balance shows that the model accurately predicts the formation and ablation of seasonal alpine snow cover. An example of catastrophic avalanche calculations in the winter of 1999 is presented to document the model performance. An overall estimate of mass balance shows that the model accurately predicts the formation and ablation of seasonal alpine snow cover. An example of catastrophic avalanche calculations in the winter of 1999 is presented to document the model performance. The overall mass balance estimate shows that the model accurately predicts the formation and ablation of seasonal alpine snow cover.

**Resolution,** 30 meters **Bands**

**Table 2 -** Transition Class Table

| Name | Units | Min | Max | Description |
|---|---|---|---|---|
| occurrence | % | 0 | 100 | The frequency with which water was present. |
| change_abs | % | -100 | 100 | Absolute change in occurrence between two epochs: 1984-1999 vs 2000-2019. |
| change_norm | % | -100 | 100 | Normalized change in occurrence. (epoch1-epoch2)/(epoch1+epoch2) * 100 |
| seasonality | | 0 | 12 | Number of months water is present. |
| recurrence | % | 0 | 100 | The frequency with which water returns from year to year. |
| transition | | | | Categorical classification of change between first and last year. |
| max_extent | | | | Binary image containing 1 anywhere water has ever been detected. |
| Bitmask for max_extent | | | | |

**Table 3 -** Value color description

| Value | Color | Description |
|---|---|---|
| 0 | ffffff | No change |
| 1 | 0000ff | Permanent |
| 2 | 22b14c | New permanent |
| 3 | d1102d | Lost permanent |
| 4 | 99d9ea | Seasonal |
| 5 | b5e61d | New seasonal |
| 6 | e6a1aa | Lost seasonal |
| 7 | ff7f27 | Seasonal to permanent |
| 8 | ffc90e | Permanent to seasonal |
| 9 | 7f7f7f | Ephemeral permanent |
| 10 | c3c3c3 | Ephemeral seasonal |

The frequencies of the different SAR sensors/bands used for snow cover studies are: Alos-2 -1%, COSMO-SkyMed -8%, TerraSAR-X - 7%, ERS - 13%, Envisat -22%, Radarsat-1 -16%, Radarsat -2 -15%, Sentinel-1 -9%, Alos -9%.

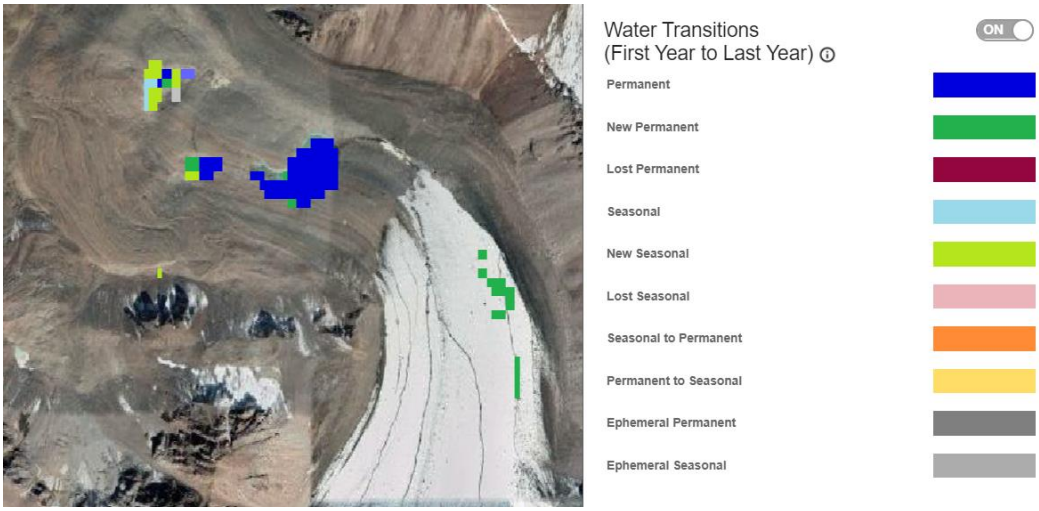



**Figure 13 -** Water Transitions


**Figure 14 -** Global Surface Water

**Equations**

Work was carried out on the study of foreign and our domestic methods of research on the risks of flooding of the territory, taking into account the hydrological computer modeling.

Hydrological processes can be dangerous if natural and anthropogenic changes in water bodies, their condition and regime lead to the risk of various kinds of damages. At present, there are a number of methodological approaches and methods for assessing natural hazards and risks. The main method of risk analysis is the probabilistic method. On its basis, depending on the initial information available, statistical, theoretical and probabilistic or heuristic methods of risk assessment are applied. For medium- and long-term forecasting of manifestations of natural hazards, a probabilistic

deterministic approach based on identifying patterns of their development, in particular their cyclical nature, is widely used.

To calculate the probability of a natural hazard, in this case a flood, it is necessary to use the methods of mathematical statistics. Using a continuous long series of observations of hydrological posts, series of maximum discharges and levels are constructed.

To assess the risk, a damage index is needed. Risk, as a material damage, is defined in the assessment of losses associated with the technosphere and the natural environment. Within the territories where there are objects of the material sphere, direct damage is possible. There is also indirect damage, which is determined by the disruption of economic activity due to the interruption of power supply, transport, water supply, etc. Flood risk can be quantitatively calculated through the amount of damage (in natural or economic terms) of different recurrence or its mathematical expectation [11].

This indicator is calculated according to the formula (1):

$$M(E)= S*p/100 \quad (1)$$

where M (E) - mathematical expectation of damage; S - value of the assessed object; - flood level security, %.

The assessment of integral risk, that is, the total losses in the technosphere, natural and social environment (death and injury of people) is rarely carried out, due to the complexity of assessing the value of human life. Assessment of losses and injuries in the sociosphere is expressed not by damage, but by the indicator of individual risk, which characterizes the probability of human death from a dangerous phenomenon of nature during the year [20].

Features of the analysis and risk assessment of dangerous hydrological phenomena are determined by the spatial scale of the study. The composition of the initial information, methods of its processing, the choice of appropriate indicators and applied mathematical models, the peculiarities of mapping phenomena depend on the spatial level of research [21].

When assessing the risk of dangerous hydrological phenomena at the regional level, the probability of the occurrence of a dangerous process and the degree of vulnerability of the territory are reflected through indirect indicators. When a comprehensive assessment is created a series of thematic maps that reflect the change in the quantitative indicators of natural hazards in space [21].

**Results and Discussion**

- Necessary measures to understand disaster risk:
- Enhance the resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational institutions, hospitals and other health facilities, to ensure that during and after disasters they remain safe, remain effective and continue to operate, providing vital and essential services
- Establish community centers to provide outreach to the public and stockpile materials necessary for rescue and relief operations
- Encourage the collection, analysis, systematization and use of relevant data and practical information and ensure its dissemination, considering the needs of different categories of users, as appropriate
- Recommend baselines for use and refinement and periodically assess disaster risks, vulnerabilities, capacities, exposure, hazard characteristics and their possible subsequent impacts at the appropriate social and spatial scale on ecosystems, considering country-specific circumstances
- Accumulate and periodically update, as appropriate, location-specific disaster risk information, including hazard maps, and make it available to disaster risk managers, the public, and residents in disaster-prone areas in an appropriate format, using geospatial information technology as appropriate

- Systematically assess and record disaster losses and disseminate and publicize them and analyze the economic, social, health, education, environmental and cultural impacts, as appropriate, in the context of information on disaster risk exposure and vulnerabilities on a case-by-case basis
- Provide free and open access to non-confidential information disaggregated by exposure, vulnerability, risk, disasters, and losses, as appropriate
- Facilitate real-time access to reliable data, use space and in situ data, including geographic information system (GIS) data, and use the latest information and communications technology to improve measurement instrumentation and data collection, analysis, and dissemination.
- Raise awareness among government officials at all levels, civil society organizations, residents and volunteers, as well as the private sector, through activities to share experiences, lessons learned and best practices, and training and education on disaster risk reduction, including through existing training and education mechanisms and peer learning practices.
- Encourage and improve dialogue and collaboration between the scientific and technical communities with other relevant stakeholders and policymakers to promote the science-policy interface for more effective decision-making related to disaster risk management
- Ensure the use of traditional and local and indigenous knowledge and methods, as appropriate, to complement scientific knowledge in disaster risk assessment and the development and implementation of sector-specific policies, strategies, plans and programmed, with a cross-sectoral approach that should be modified to suit the terrain and context;

**Conclusion**

Required:

1. High-quality data, analytics, and modeling for a comprehensive risk-based approach;
2. Combination of cost-effective disaster management measures with appropriate tools for implementing sustainable strategies.
3. A policy, legal and regulatory framework which is aligned with international standards to ensure that plans for predicting, and monitoring emergencies are effectively implemented. 4.
4. Capacity building and coordination between various institutions and the population.

**As a result of conducting research on the topic:** Approach to mudflow hazard prediction as a result of changes in snow cover and active snowmelt in mountainous areas based on the application of remote sensing technology.

Collected data on the study area, with further analysis of the collected, cartographic and statistical materials on natural-anthropogenic conditions, monitoring climatic and hydrological historical and current actual remote sensing data.

The analysis of modern domestic and foreign methods of research on the risks of flooding of territories, considering the methods of hydrological computer modeling, was carried out. On the basis of the analysis of modern domestic and foreign methods the methods of research of risks of flooding of territories, taking into account the methods of hydrological computer modeling are defined.

**Acknowledgments**

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# USING THE PHOTOGRAMMETRIC PROCESSING TECHNOLOGY IN THE ISSUES OF 3D MODELS OF URBAN OBJECTS BUILDING

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**Abstract**

Currently, the use of three-dimensional modeling in scientific research allows researchers to solve a number of problems from different fields of science. Such important tasks are, for example, the restoration and reconstruction of historical and cultural heritage, the tasks of architecture and construction, the modeling of geophysical processes, the development of topographic maps and plans, etc. It becomes necessary to use modern methods and technologies for modeling 3D objects in search of a solution to such problems. Using a laser scanner or 3D modeling software is usually expensive and requires a high level of knowledge. However, among 3D modeling technologies, there is an image-based photogrammetric data processing method that offers a cheaper alternative and allows you to get a more accurate 3D model of objects. Thus, this article proposes the results of building 3D models of urban objects using photogrammetric data processing technology. The East Kazakhstan Regional Drama Theater of the Ust-Kamenogorsk city acts as an object for 3D modeling. There is presented a mathematical model of nonlinear distortions described using the Brown model. In addition, the article provides a technique for obtaining the necessary photographs for 3D modeling, as well as an analysis and review of modern technologies for photogrammetric data processing for 3D modeling.

**Keywords:** 3D model, sparse point cloud, dense point cloud, photogrammetry, unmanned aerial vehicles (UAVs).

## Introduction

Behind the rapid development and progress of science, the discovery of new facts, achievements, patterns and significant events, are assumed the development of modern approaches, research methodologies, as well as the emergence of automated technological solutions, programs and applications. Today, modeling has become the most important method of scientific knowledge and research. The modeling method is used in any science, at all stages of scientific knowledge. Technological innovation guarantees our country competitiveness and entry into 30 developed countries. The accelerator for all projects is the implementation of the “Digital Kazakhstan” program. Within the framework of the program, problems of ensuring the safety and accessibility of geological digital information; implementation of technologies for creating smart cities; development of national spatial data infrastructure, etc. were updated.

## Analysis of existing technologies and Related work

In this regard, the solution of these problems is difficult to imagine without the modeling phase, which would contribute to the development of the digital infrastructure of the urban environment, analysis and prediction of its safety from natural and man-made emergencies.

Such a model will objectively and visually reflect the existing urban planning structure, thereby solving the problem of efficient use of space. The initial data for the creation of such terrain models are detailed plans of cities and topographic maps, data obtained using modern GIS technologies [1] and Unmanned Aerial Systems (UASs). Small-sized Unmanned Aerial Systems (UASs) consist of a versatile, simple and cost-effective technology to perform remote sensing-related tasks [2] in different areas [3]. UASs platforms are rapidly becoming a valuable source for data acquisition for inspection, surveillance, mapping and 3D modelling issues [4]. Being UASs low-cost alternatives to the classical

manned aerial photogrammetry, fixed-wing or rotary wing UAVs are capable to perform photogrammetric data acquisition in manual, automatic or semi-automatic flights [4].

Today in the global space you can see a lot of companies involved in the processes of three-dimensional modeling of entire cities, urban areas, electronic mapping using various GIS technologies. Along with this among many companies, it is important to mention some large companies, such as Visicom, NEOLANT and Geoscan, which are engaged in solving 3D-modeling and visualization problems. For example, the Ukrainian company Visicom has been working in the Ukrainian and international markets of geo-information technologies since 1991 and is one of the leading manufacturers of digital maps and geodata.

Since 2000, Visicom has successfully completed more than 900 telecommunications projects, creating high-quality 3D models for more than 850 cities in the world. More recent projects and work of the company are presented in Figure 1.

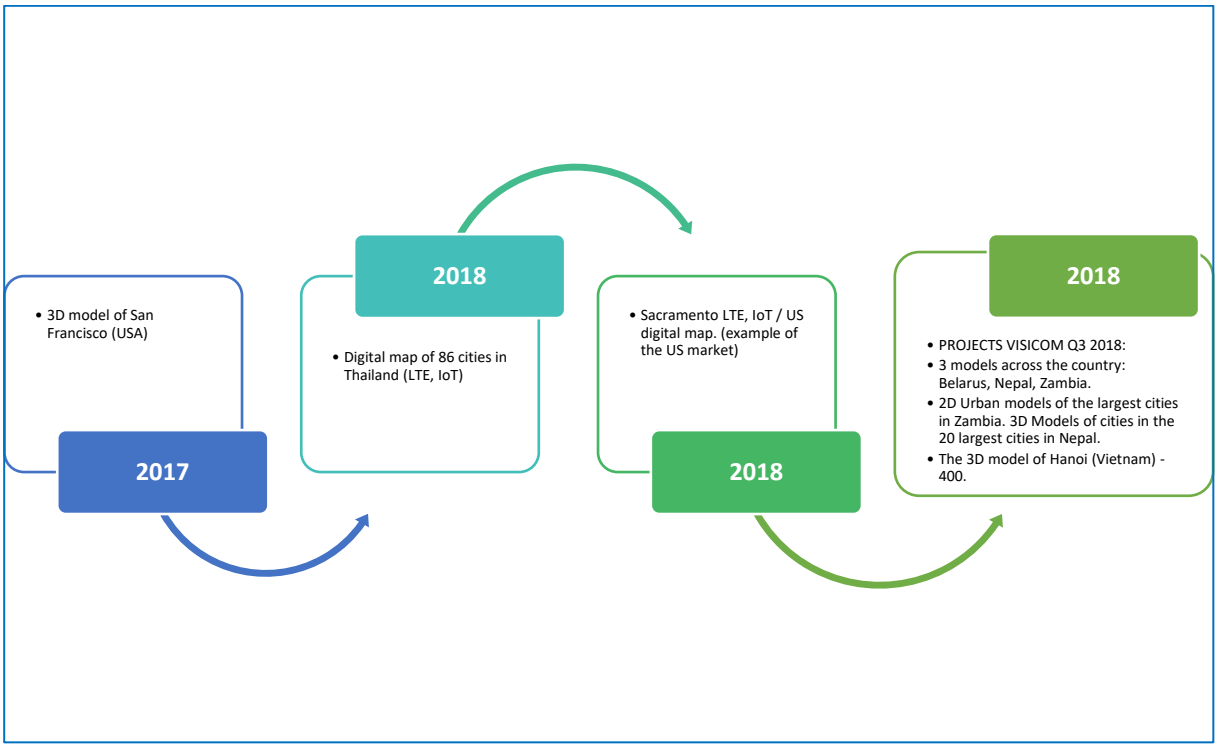



**Figure 1 –** Information about the company (2017, 2018) Visicom on creation 3D models

Also, one of the leaders involved in the development and production of UAVs, as well as the development of software for photogrammetric data processing and three-dimensional visualization, is the Russian group of companies Geoscan. The most significant achievements of the company, implemented within the framework of certain projects, are presented below in Table 1.

**Table 1 –** Examples of projects (software and 3D models, digital maps) of cities (urban areas)

| Date | Company / Technology | 3D-models of the city (urban areas) |
|---|---|---|
| 2015 | NEOLANT / Autodesk Infrastructure Modeler | Interactive 3D map of city Dubna |
| 2013 | Geoscan / Agisoft PhotoScan | 3D-models of city Gatchina |
| 2014 | | 3D-model of city Tomsk |
| 2015 | | 3D-models of city Salekhard |
| 2015 | | 3D-models of sections of the Ring Road of St. Petersburg |

| | | |
|---|---|---|
| 2015 | | 3D models of glaciers in the mountains of Mongolia at an altitude up to 4500 m with the help of the “Geoscan 101” complex |
| 2016 | | 3D-models of city Astana |
| From 2016 to 2017 | | 3D-model of the Tula region using UAV |
| 2017 | | 3D-geoportal "Building a city together" for the administration of city Tomsk |
| 2017 | | 3D-models of city Palmira |
| 2018 | | 3D-models of the cities of Banja Luka and Brcko in Bosnia and Herzegovina |
| 2018 | | 3D-models of the cities Kazan and Naberezhnye Chelny |

Using photogrammetric data processing technology in the form of images or photographs to build highly detailed and realistic 3D models presents promising opportunities for solving 3D modeling problems for a wide range of researchers. For example, in work [5], the research is presented that aims to create and apply a method for providing a virtual reality experience within cultural heritage by developing a workflow for virtual reality applications based on photogrammetric models. The approach proposed by the authors was applied on the iconostasis of the Serbian Orthodox Cathedral of St. Nicholas in Sremski Karlovci (Serbia). This method is implemented in 3 stages, such as creating an accurate 3D reconstruction of the iconostasis using photogrammetry, optimizing a 3D model, and creating a virtual reality using a game engine. In the following work [6], the authors present the research whose goal is to define an accurate imaging technique for creating high-resolution 3D models and 2D orthophotos of objects of particular historical and cultural significance. Image processing also considers photogrammetric image processing technology. The issues of applying the survey methodology and photogrammetric processing are considered in work [7], which are related to the use of archival images for the implementation of operations of virtual reconstruction of lost volumes. The research work [8] proposes a developed methodology for creating virtual 3D models of historical cities. This methodology is based on a combined approach of using 2 methods: laser scanning and photogrammetry. The advantage of the developed methodology is a virtual 3D model that has high geometric accuracy with visual completeness and integration into a web application.

Thus, among the many methods for obtaining 3D models and the use of completely new data processing software, as well as in connection with the progressive development of modern methods and technologies of three-dimensional visualization, the most common method for creating digital topographic maps and plans, in reconstruction and restoration of objects of historical and cultural heritage, as well as in solving problems of architecture, construction, etc., technologies and innovations of 3D modeling of photogrammetric data processing are widely used and improved.

**Approach and implementation**

Photogrammetry (Photogrammetrie is derived from the Greek words phōtos - light, gramma - record and metreō - measurement; literally - measurement of light recording.) is a scientific discipline that studies how to determine the shape, size and spatial position of objects in a given coordinate system according to their photographic and other images [9]. The subjects of studying photogrammetry are the geometric and physical properties of images, methods for their preparation and use to determine the quantitative and qualitative characteristics of the photographed objects, as well as instruments and software products used in the process [5]. Photogrammetry was previously considered as a tedious and not appropriate to use and could only be used by expert users [10]. However, current robust and powerful frameworks with straightforward pipeline turned photogrammetry accessible, even to nonexpert’ users [11].

The main advantages of photogrammetric and stereophotogrammetric methods are:

- high accuracy of the results, as pictures of objects are obtained by precision cameras, and their processing is performed, as a rule, by strict methods;

- high performance achieved due to the fact that they measure not the objects themselves, but their images. This allows the automation of the measurement process and subsequent calculations;

- objectivity and reliability of information, the possibility of repeating measurements, if necessary;

- the possibility of obtaining in a short time information about the state, both of the whole object, and its individual parts;

- safety of work, as the shooting of the object is performed by non-contact (remote) method. This is of particular importance when an object is unavailable or being in its zone is dangerous to human health.

- the possibility to study moving objects and rapidly occurring processes [12].

In the scientific research, the task of which was to obtain a 3D-model of urban objects (buildings, structures) for further use in the calculation and evaluation of seismic resistance, the choice was determined on this method, i.e. in order to implement the solution of this applied problem, photogrammetric processing of digital data was used. As a software solution, the program is based on Agisoft PhotoScan Professional of Geoscan company. The main merits and design decisions of this company have already been listed in Table 1.

At the same time, it is important to note that the group Geoscan for the first time in the world solved a problem in one of the areas of artificial intelligence - automatic creation of a 3D model of an object from a series of multi-angle photos; this software is used in various fields. Currently, this software is delivered to 131 countries of the world [13].

A feature of this software is that image processing for topographic support includes a number of sequentially performed operations, some of which are implemented by modern computer vision methods and are based on the use of a projective geometry apparatus, uniform coordinates and photometric image processing [14]. Data acquisition for this method and the process of photogrammetric data processing is shown in the Figure 2.

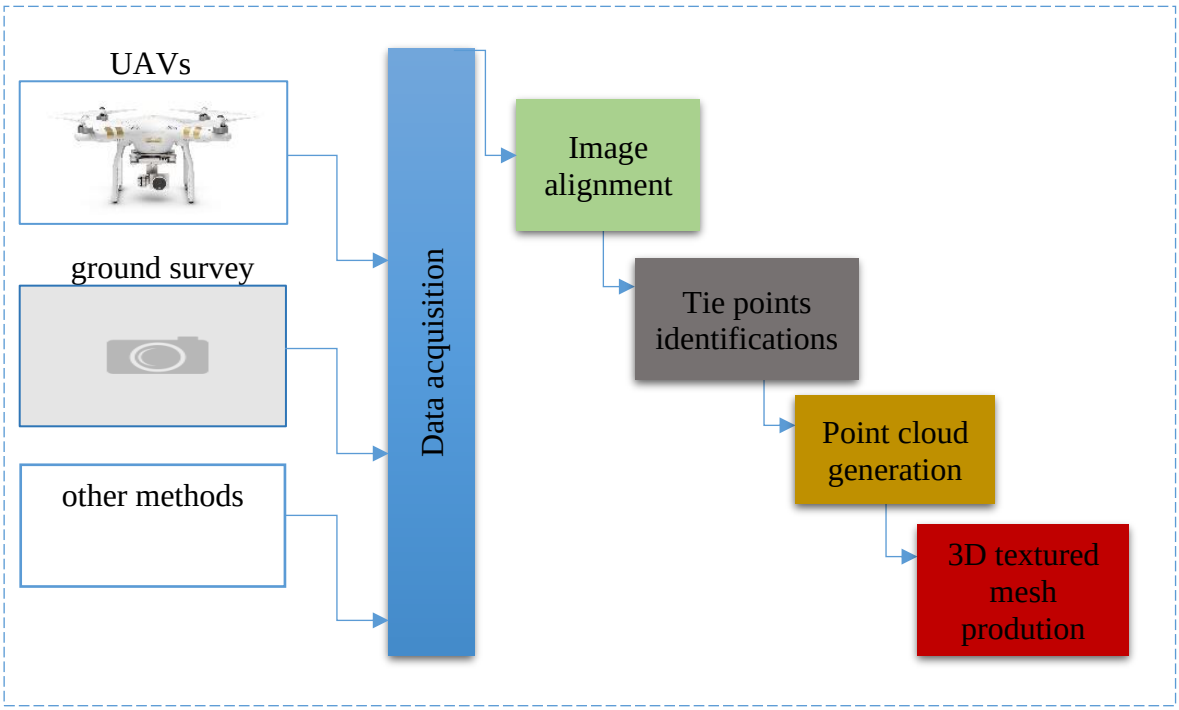



**Figure 2 –** Data acquisition and photogrammetric processing

The principle and algorithm of work of the program Agisoft PhotoScan Professional consists of 4 main stages:

1) Determining the position of the cameras exterior and interior orientation of the cameras. The program automatically determines the position of the camera and its orientation for each frame, then it builds a sparse point cloud (after loading photos into the program). At this stage, the program finds common points of photographs, then after that it determines all the camera parameters, namely the position (up to scale), orientation, internal geometry (focal length, distortion parameters). The program supports several models of lens distortion. Before starting the process of treatment, it is necessary to choose a model that best approximates the actual distortion. All models are valid for a camera with a central projection. The Brown model is used to describe nonlinear distortions.

The following parameters are used in the equations:

(X, Y, Z) - coordinates of a point in the local camera coordinate system, (u, v) - coordinates of a point, projected onto the frame plane (in pixels), f - focal length, $c_x, c_y$- offset of the cardinal point, $K_1, K_2, K_3, K_4$ - coefficients of radial distortion, $P_1, P, P_3, P_4$ - coefficients of tangential distortion, $B_1, B_2$ - coefficients of affinity and non-orthogonality, w - frame width in pixels, h - frame height in pixels [15]. For the frame camera.

$$x = X/Z \quad (1)$$
$$x = Y/Z \quad (2)$$
$$r = \sqrt{x^2 + y^2} \quad (3)$$
$$x' = x(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_1(r^2 + 2x^2) + 2P_2xy)(1 + P_3r^2 + P_4r^4) \quad (4)$$
$$y' = y(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_2(r^2 + 2y^2) + 2P_1xy)(1 + P_3r^2 + P_4r^4) \quad (5)$$

For the “Fisheye” camera.

$$x_0 = X/Z \quad (6)$$
$$y_0 = Y/Z \quad (7)$$
$$r_0 = \sqrt{{x_0}^2 + y_0^2} \quad (8)$$
$$x = x_0 * tan^{-1}r^0/r^0 \quad (9)$$
$$y = y_0 * tan^{-1}r^0/r^0 \quad (10)$$
$$r = \sqrt{x^2 + y^2} \quad (11)$$
$$x' = x(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_1(r^2 + 2x^2) + 2P_2xy)(1 + P_3r^2 + P_4r^4) \quad (12)$$
$$y' = y(1 + K_1r^2 + K_2r^4 + K_3r^6 + K_4r^8) + (P_2(r^2 + 2y^2) + 2P_1xy)(1 + P_3r^2 + P_4r^4) \quad (13)$$
$$u = w * 0.5 + c_x + x'f + x'B_1 + y'B_2 \quad (14)$$
$$v = h * 0.5 + c_y + y'f \quad (15)$$

Spherical camera (equidistant projection).

$$u = w * 0.5 + f * tan^{-1}(X/Z) \quad (16)$$
$$v = h * 0.5 + f * tan^{-1}\left(Y/\sqrt{X^2 + Z^2}\right) \quad (17)$$

where:

$$f = w/(2 * \pi) \quad (18)$$

Spherical camera (cylindrical projection).

$$u = w * 0.5 + f * tan^{-1}(X/Z) \quad (19)$$
$$v = h * 0.5 + f * Y/\sqrt{X^2 + Z^2} \quad (20)$$

where:

$$f = w/(2 * \pi) \quad (21)$$

2) Building a point cloud. At this stage, using the calculated camera positions, the program builds a dense point cloud. A dense point cloud can be edited (cut or deleted).

3) Construction of a polygonal model of an object from a dense point cloud. There are two methods of construction in the program - this is a height map for surfaces in the form of relief, and also arbitrary for any types of surfaces. The model is constructed by triangulation by points. The resulting model can be edited in the program or exported (by the point cloud in the following formats: Wavefront OBJ, Stanford PLY, XYZ text file format, ASPRS LAS, LAZ, ASTM E57, ASCII PTS, Autodesk DXF, U3D, potree, Cesium 3D Tiles, Agisoft OC3 , Topcon CL3, PDF; Wavefront OBJ, 3DS file format, VRML, COLLADA, Alembic, Stanford PLY, STL, Autodesk FBX, Autodesk DXF (as Polyline or 3DFace), U3D, Google Earth KMZ, Adobe PDF).

4) Texture creation. The program has a function of automatic evaluation of photos to improve the quality of textures. If there are images with an estimate of less than 0.5, then it is recommended to exclude them from texture generation, since this will lead to an improvement in the quality of visualization of the final model.

To analyze the capabilities of the program Agisoft PhotoScan Professional, as well as to implement the main task on studying the construction of a 3D model of urban objects based on the photogrammetric data processing method, an object was selected - East Kazakhstan Regional Drama Theater located in Ust-Kamenogorsk Figure 3.


**Figure 3 –** East Kazakhstan Regional Drama Theater

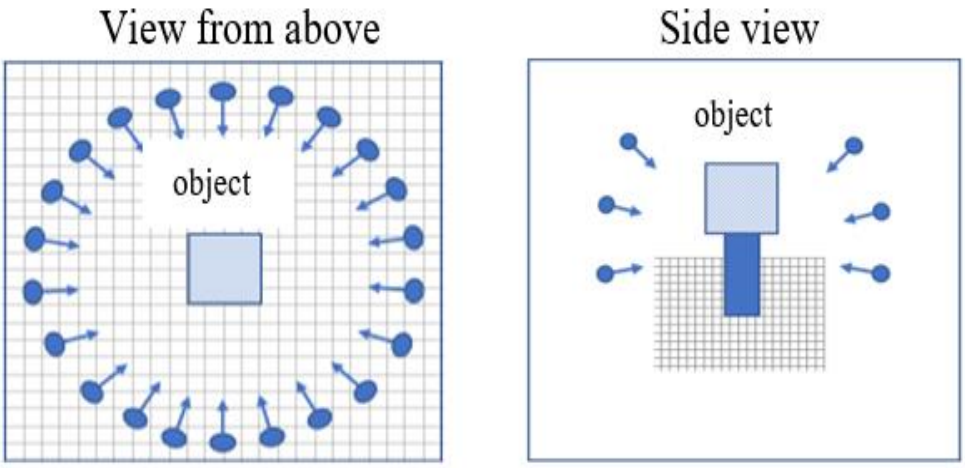
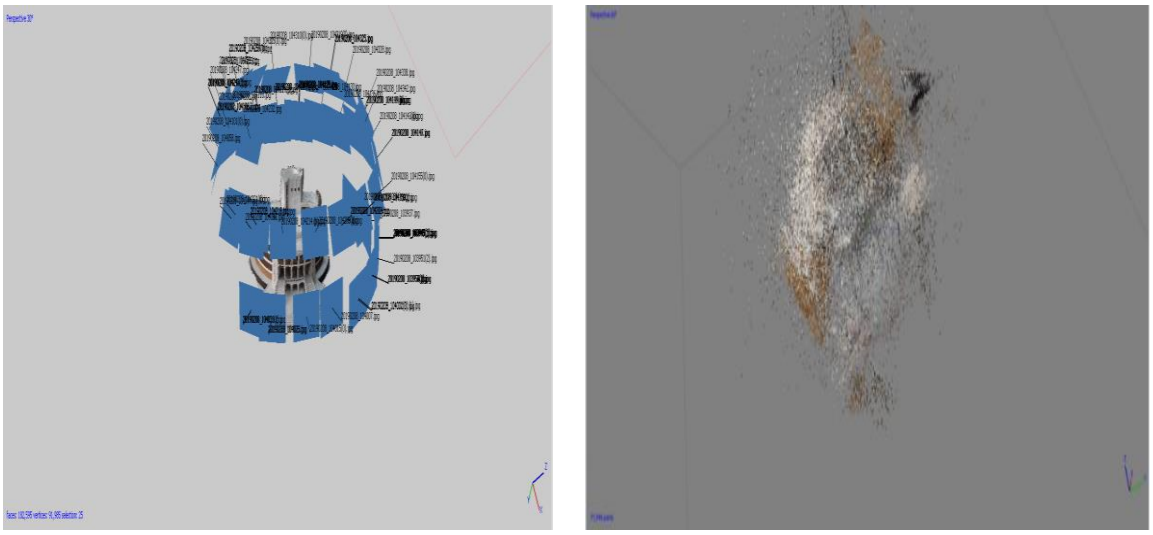



**Figure 4 –** Photographic scheme for object photo modeling

**Results and Discussion**

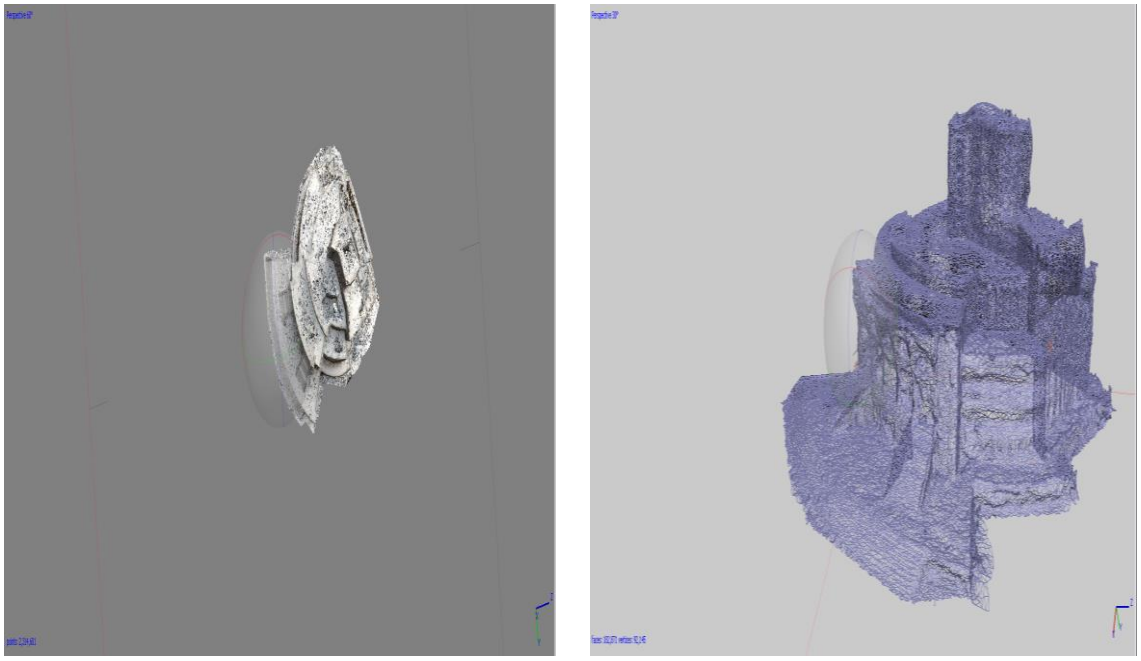
At the first stage of research work after uploading photos to Agisoft PhotoScan Professional, the program automatically determined the position and orientation of the camera for each frame and built a sparse point cloud (Fig. 5).



(a) (b)

**Figure 5 –** (a) Camera alignment result, (b) "Sparse" point cloud

At the second stage, the program has built a dense point cloud, using the calculated camera positions. At the third stage, a polygonal model is constructed using a dense point cloud (Figure 6).



(a) (b)

**Figure 6 –** (a) Obtained dense point cloud, (b) Polygonal model

At the last stage of work, having created a texture, we obtained the final model of Figure 7.

**Figure 7 –** Variations of textured 3D theater model

## Conclusion

At the end of the research work, it can be argued that the construction of a 3D model of a city object (theater) in the Agisoft PhotoScan Professional program showed decent results. This method of photogrammetry, based on the processing of digital photographs, took the least amount of effort to create a 3D model of the object, however, it requires high technical characteristics for image processing for the used computer equipment. When receiving digital photographs, it is necessary to follow a number of conditions, namely: a photographic scheme for photo-modeling of an object as in Figure 4.; take pictures with overlapping frames; playing photos in a spiral; selection of weather conditions (without hitting the frame with elephant highlights); to bind the restored 3D model in a relative coordinate system, it is necessary to memorize or place ground markers within the scene. This method of constructing a 3D model of objects based on digital photos also allows the export of the obtained point cloud to various systems. The digital models produced by this method in Agisoft Photoscan are fully compatible with GIS and CAD.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## ON THE INTERPOLATION PROPERTIES OF DISCRETE NET SPACE

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**Keywords:** Net spaces, discrete Net spaces, Marcinkiewicz type interpolation theorem.

In this paper, we study discrete net spaces $n_{p,q}(M)$, where $M$ is some fixed family of sets from the set of integers $\mathbb{Z}$. Note that in the case when the net $M$ is the set of all finite subsets of integers, the space $n_{p,q}(M)$ coincides with the discrete Lorentz space $l_{p,q}(M)$. For these spaces, the classical interpolation theorems of Marcinkiewicz-Calderon are known. In this paper, we study the interpolation properties of discrete network spaces $n_{p,q}(M)$,in the case when the family of sets $M$ is the set of all finite segments from the class of integers $\mathbb{Z}$, i.e. finite arithmetic progressions with a step equal to 1. These spaces are characterized by such properties that for monotonically nonincreasing sequences the norm in the space $n_{p,q}(M)$ coincides with the norm of the discrete Lorentz space $l_{p,q}(M)$. At the same time, in contrast to the Lorentz spaces, the given spaces $n_{p,q}(M)$ may contain sequences that do not tend to zero. The main result of this work is the proof of the interpolation theorem for these spaces with respect to the real interpolation method. It is shown that the scale of discrete net spaces $n_{p,q}(M)$ is closed with respect to the real interpolation method. As a corollary, an interpolation theorem of Marcinkiewicz type is presented. These assertions make it possible to obtain strong estimates from weak estimates.

Let $S$ be the set of all finite sets of indices from $\mathbb{Z}^n$. For a fixed set $M \subset S$ we define the space $n_{p,q}(M)$ $(0 < p, q \leqslant \infty)$ as the set of sequences $a = \{a_m\}_{m\in\mathbb{Z}^n}$ with quasinorm for $0 < p < \infty$, $0 < q < \infty$

$$\| a \|_{n_{p,q}(M)} = \left(\sum_{k=1}^{\infty} k^{\frac{q}{p}-1}(\bar{a}_k(M))^q\right)^{\frac{1}{q}},$$

and for $q = \infty$, $0 < p \leqslant \infty$

$$\| a \|_{n_{p,\infty}(M)} = \sup_{1 \leqslant k < \infty} k^{\frac{1}{p}} \bar{a}_k(M),$$

where

$$\bar{a}_k(M) = \sup e \in M |e| \geqslant k \frac{1}{|e|} |\sum_{m \in e} a_m|,$$

where $|e|$ is the number of indices in $e$.

These spaces were introduced in [6], and they were called net spaces.

Net spaces have found important applications in various problems of harmonic analysis, operator theory and theory of stochastic processes [1, 2, 3, 9, 10, 7, 11, 8]. In this paper, we study the interpolation properties of these spaces. It should be noted here that net spaces are in a sense close to the discrete Morrey spaces:

$$m_p^\lambda = \left\{ a = \{a_k\}_{k \in \mathbb{Z}} : \quad \sup_{m \in \mathbb{N}} \sup_{k \in \mathbb{Z}} \frac{1}{m^\lambda} \left( \sum_{r=k}^{k+m} |a_r|^p \right)^{\frac{1}{p}} < \infty \right\}.$$

In the case when $a = \{a_k\}_{k \in \mathbb{Z}}$, $a_k \geqslant 0$, for $\lambda = n\left(1 - \frac{1}{p}\right)$

$$\| a \|_{n_{p,\infty}(M)} \asymp \| a \|_{m_1^\lambda}.$$

The question of interpolation of Morrey spaces was considered in the works [12, 5] and it was shown that this scale of spaces is not closed with respect to the real interpolation method.

In this paper we show that if $M$ is the set of all segments from $\mathbb{Z}$ the scale of spaces is closed with respect to the real interpolation method, i.e. the following relation holds

$$\left( n_{p_0,q_0}(M), n_{p_1,q_1}(M) \right)_{\theta,q} = n_{p,q}(M). \tag{1}$$

Let $(A_0, A_1)$ be a compatible pair of Banach spaces [4]. Let

$$K(t, a; A_0, A_1) = K(t, a) = \inf_{a = a_0 + a_1} (\| a_0 \|_{A_0} + t \| a_1 \|_{A_1}), \ a \in A_0 + A_1,$$

be the functional Petre. For $0 < q < \infty$, $0 < \theta < 1$

$$(A_0, A_1)_{\theta,q} = \{ a \in A_0 + A_1 : \| a \|_{(A_0,A_1)_{\theta,q}} = \left( \int_0^\infty (t^{-\theta} K(t, a))^q \frac{dt}{t} \right)^{1/q} < \infty \},$$

and for $q = \infty$

$$(A_0, A_1)_{\theta,q} = \{ a \in A_0 + A_1 : \| a \|_{(A_0,A_1)_{\theta,q}} = \sup_{0 < t < \infty} t^{-\theta} K(t, a) < \infty \}.$$

**Theorem 1.** Let $1 \leqslant p_0 < p_1 < \infty$ and $0 < q_0, q_1, q \leqslant \infty$. Let $M$ be the set of all segments from $\mathbb{Z}$. Then

$$(n_{p_0,q_0}(M), n_{p_1,q_1}(M))_{\theta,q} = n_{p,q}(M),$$

where $\frac{1}{p} = \frac{1-\theta}{p_0} + \frac{\theta}{p_1}$, $\theta \in (0,1)$.

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# METHODOLOGICAL BASES OF TEACHING 3D MODELING IN INSTITUTIONS OF ADDITIONAL EDUCATION

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**Abstract**

In this article, the application of virtual reality media technologies in the educational process is substantiated, the content of the educational and methodological complex is developed. Examples of tasks aimed at involving students in the process of teaching three-dimensional graphics and modeling, the formation of their professional competence, based on the study of the Unity3D, Twinmotion and 3d max virtual reality environment are given. The inclusion of the study of the basics of 3D modeling in the general educational process outside of educational activities opens up wide opportunities for students to create fundamentally new products of labor, mastering new peaks in the study of modern technologies. Students gain practical knowledge in the field of modeling and parametric design, develop their own engineering and technical projects, develop engineering and technical abilities and ensure their competitiveness in professional areas of technical orientation. The development of a program for such a course is an urgent need due to rapidly developing, rapidly changing technologies

**Keywords:** 3D modeling, technology, communication, visualization, information, animation, design.

## Introduction

In the modern world, education is considered as the main factor of stability and development of society. In the new model of progressive development of society, the leading direction will be the

development of the quality of human capital (education, professionalism, morality, culture), as well as the quality of education systems [1].

The use of 3D modeling and animation in education provides teachers with new learning tools. These tools help students easily perceive educational material, increase their motivation, and quickly master a large amount of knowledge. In fact, 3D helps to gain experience in several subjects, which makes it necessary for teachers to use new technologies to introduce modeling into the educational process [2].

Education:

Formation of an idea of the basics of 3D modeling;

* Master the basic tools and operations of working in an online 3D modeling environment;
* Study of the basic principles of building three-dimensional models;
* Create models of objects, parts, and assembly structures.

A necessary condition for the implementation of the course is the use of the methodology of project activities with children. The result of the course is the final draft of the 3D model presented in the final lesson.

**Expected results**

After completing the course "fundamentals of 3D modeling" at Twinmotion, students should master modeling skills in the Twinmotion environment.

**Materials and Methods**

Mastering modern knowledge is a successful work in many types of practical and theoretical activities closely related to the management of spatial images. Ideas created on the basis of 3D models have a different psychological character than those created on the basis of the perception of visual images of certain objects [3].

Modern information technologies allow us to display a variety of visual information in three-dimensional space. The greatest amount of information about the surrounding world is perceived by the visual eye. To achieve maximum accuracy in the perception of information, it is necessary to ensure visual perception as close as possible to reality.

Examples of using 3D technologies in education:

* helps to reveal complex topics and lessons, lectures;
* students create their own VR apps and 3D videos;
* students create 3D projects;
* special technologies (for example, the development of creative abilities).

In fact, 3D helps to gain experience in several subjects, which makes it necessary for teachers to use new technologies that later appear in order to introduce modeling into the learning process.

The chemistry lessons, you can show in more detail the reactivity and properties of chemical elements and their inorganic compounds.

The physics lessons, students clearly see how different forces affect each other or how light rays passing through the lens refract.

The geometry lessons, converting objects from a two-dimensional plane to a three-dimensional plane and working with them makes it easier to interpret complex elements.

The geography lessons, students may feel like they are in the depths of the ocean when the teacher shows them the appropriate images. These are some academic disciplines that require the use of 3D technology.

Visual representation of an object can be obtained by studying the object itself or its physical model, as well as by displaying them with multimedia tools (electronic posters, video clips, animation, etc.), including computer (virtual) 3D images. An important feature of three-dimensional models is the ability to change the properties of both the component elements of the model and the entire model, depending on the needs of the developer. Thanks to this, you can change the location of individual elements in space, change their appearance, use additional objects, and so on.you can create not only static graphics, but also complex spatial animation, as well as show the processes

(including hidden ones) that occur both on the object and inside it. This leads not only to a significant increase in the visibility of the material, but also to a significant saving of time when studying. In addition, modern technologies allow you to get photorealistic graphics based on the model, which are not inferior in quality to photo and video materials.

The main results can be obtained when using 3D modeling:

For teachers:

* saves time devoted to explaining educational material;
* the teacher's work with ICT will be rational;
* increases students ' interest in the subject.

For children:

* ability to perceive information;
* development of spatial imagination;
* increase learning motivation;
* ability to analyze;
* promotes systematization of knowledge.

Both abroad and in our country, experiments prove that students have successfully mastered the fundamental concepts of 3D modeling, which helps to form the student's worldview concepts. The new generation will master technical innovations faster and more easily than the old, for them it will be much easier and more interesting to master the material, especially the perception of such topics as "new technologies" from an early age, because, as everyone knows, the new generation will always follow rapidly changing trends.

Mastering software for 3D modeling contributes to the fact that a person is always in demand in the labor market.

Currently, there are many programs for working with 3D graphics. It is important that the child's motivation is not lost in the early stages of exploring the 3D world after getting acquainted with their inner world.

In the future, learning the basics of 3D modeling can have a negative impact, as it will be necessary to change the established attitudes and habits, which will significantly complicate and slow down the learning process.

Orientation of a person in time and space is a necessary condition for his social life, a form of reflection of the surrounding world, a condition for successful cognition and active transformation of reality.

The analysis of the studied phenomena and objects, which allows us to determine the properties and characteristics of objects that are not observed experimentally based on the use of three-dimensional models, is becoming increasingly important in mastering knowledge. For this reason, in the form of knowledge, there is specific information about individual topics and a description of how to obtain specific data. In mathematics, students get acquainted with algebraic methods of solving problems that differ in the plot, methods of converting geometric objects, as well as mastering their features and properties.

Based on the analysis of the literature, it was concluded that the topic of 3D modeling and prototyping is considered superficially in the school computer science course and little time is devoted to it.

3D modeling is an important, advanced and popular industry in the information technology industry. Without three-dimensional design, it would now be impossible to make any significant production or Fantastic Film. Due to the relevance of this direction, a number of narrow and widely specialized software has been created. Architects often resort to layout construction to more accurately represent the construction of a building.

The selection of the software tool for three-dimensional modeling was carried out according to the following criteria: paid, free service; the presence of a Russian-language interface; the speed of work, the range of tools; the availability of materials and definitions; the ability to create individual shapes and models; learning to print on a 3D printer.

The best programs for 3D modeling and work are:

Twinmotion is a program that provides real-time 3D Architectural Visualization for specialists in the field of architecture and construction.

Twinmotion is based on the Unreal Engine platform, the power of which corresponds to an intuitive interface controlled by icons.

Twinmotion allows you to easily create high-quality images, panoramas, or 360°videos in seconds.

The user is given the opportunity to change scene elements, change the months and weather, set the correct time of day, create a landscape, add animation to characters, animals and plants, and distribute artificial light and ambient sounds to the scene.

Ease of mastering the program

The simple and intuitive interface makes Twinmotion very easy to learn and use, regardless of the size and complexity of your project or skills. Place different light sources, materials, and supports; adjust the season, weather, or even tree growth.

Multidimensional views

The Twinmotion library allows you to animate not only static props such as furniture and stones, but also stage sound effects, moving people and animals, and detailed plants.

Single tool

Create simple images, panoramas, classic and impressive viewing videos, as well as simple interactive presentations to share in seconds. All this with the support of the most popular virtual reality headsets from the Twinmotion scene, Twinmotion can transfer you from BIM to VR in seconds.


**Figure 1** – Animation view of Twinmotion

Currently, a high level of training of technical specialists is required. One of the problems that arise when mastering technical specialties is the need to obtain deeper and more versatile knowledge in a relatively short time. In this regard, there is a need for intensification of education, presentation of educational material in an accessible form, activation of attention to the basic laws, demonstration of the connection of the studied with real tasks.

Modern trends in the development of education they are based on the intensive use of computer technologies, which are designed to improve the efficiency and quality of training. It should be noted that the purpose of education is to teach not only the subject, but also information technology. The use of computer technologies in education develops skills and abilities that are attractive to employers and create conditions for professional growth.

Computer modeling is used in cases when it becomes necessary to replace a full-scale experiment with its model simulation in order to study processes of various nature based on their modeling.

Simulation models are created in such a way as to most fully reflect the logic of real equipment, the logic of real processes, and, unlike a full–scale experiment, allow:

- focus the attention of trainees on the features of the process being studied, excluding insignificant details;

– display physical phenomena that are difficult to reproduce in a real laboratory experiment;

– increase students' motivation to learn by creating models that allow them to consider physical processes "from the inside", to make changes in the course of the process;

–carry out visualizations of fundamentally unobservable phenomena in a laboratory experiment.

Computer modeling is rapidly becoming an effective learning tool. It includes visualization, interactivity, helps students develop abilities in building models and understanding scientific concepts. In addition, the simulation experiment can be made adaptive, that is, configurable depending on the capabilities of the learner, which allows you to implement the principle of individualization.

The demonstration of the studied objects and phenomena can be carried out frontally, ensuring that the experiment is shown to a large audience. The visual model is a set of software tools that allow you to simulate the work of the studied object and its individual components. As such a means for creating visual models, we offer use the Unity graphical tool, designed to create interactive and multimedia applications.

Unity is a professional multiplatform game engine and integrated powerful game editor, created from the very beginning to facilitate the creation of animations. This engine is something like a constructor, as there is an excellent editing environment with a user-friendly interface that allows you to create animations visually. Object properties are set up quickly and simply to assign textures, sound, behavior, scripts, etc. it is enough to perform a few mouse clicks [4].

Unity contains the full set of qualities of a professional application:

– integrated editor. All actions are performed through a simple user interface;

– import of resources. Unity supports all major file formats and almost all graphics creation applications;

– graphics. Unity has a highly optimized graphics pipeline for both DirectX and OpenGL;

– shadows and light. Soft real-time shadows and baked light maps;

– shaders. Unity shader system combines ease of use, flexibility and performance;

– scripts. JavaScript, Boo (Python dialect) and C# based. NET with libraries and great documentation.

– working with the network;

– audio and video. Mixing real-time 3D graphics with streaming audio and video;

– documentation. There are step-by-step lessons, documentation and sample projects;

– one-click placement. Unity supports a wide range of applications.

Unity is a game development environment. There are many platforms for creating games in the world, but this one has always had a lot of fans, especially among novice game designers. This article explains why everyone likes Unity and what features it has.

Visual Editor

Unity is immediately bundled with the development environment. This is both a code editor, and working with graphics, and the logic of the behavior of objects in the game scene, and everything else.

The peculiarity of this editor is that all this can be done and configured right during the launch or testing of the plot. For example, if you didn't like how the car in the game reacts to puddles, then you can correct the desired parameter without leaving the scene and immediately see what has changed.

**Figure 2** – Game view in the program Unity

Three-dimensional and technical modeling. The game engine perfectly copes with tasks like three-dimensional modeling of objects from the real world. After you assemble the model and set the desired properties, you can see how it works in different conditions, including in motion.

Modern graphics

In games, it is important that the picture on the screen looks nice and does not create a feeling of artificiality. Unity has a built—in real-time rendering engine, which means that the image changes immediately as soon as you make a change.

Unity also knows how to work with global light, knows about ray tracing and reflection physics, which allows you to create realistic graphics. To make it all work quickly, the engine supports the API of all popular video card manufacturers and technologies: Vulkan, iOS Metal, DirectX 12, NVIDIA VRWorks and AMD LiquidVR.

Ready-made physics and object interactions

Unity already has ready—made physics and templates for creating your own rules - you can immediately use them in the game. The engine already knows that if you put a box on the slide, it will slide, turn over and stop, and the ball in the same situation should just roll on.

JavaScript and C# scripts

One of Unity's strengths is JS and C# scripts. You don't need to learn the built—in scripting language with its logic and limitations - you just take either of these two programming languages and write what you need.

You can hang anything on the scripts: the appearance of enemies from around the corner, the contents of a treasure chest or the answers of a minor hero. If you know how to program, you can make as complex and interesting a game as you want yourself.

The Unity graphical tool allows you to master the basics of the programming language, and then create visual models of any processes and objects. It is useful to use such models as illustrations during lectures and practical classes to improve the perception of educational material. Such illustrations develop model thinking and focus students' attention on the phenomenon under study, for example, from mechanics, aerodynamics, optics and other fields. When performing laboratory work, students can independently introduce additional objects, impacts and observe how the nature of the process under study changes when its parameters change [5].

Models created with Unity can be played inside the browser thanks to the Unity Web Player Plugin. The size of the plugin is small (about 3 MB), its installation is simple and does not cause difficulties. The plugin works on all modern browsers, including Internet Explorer, Firefox, Safari, Opera. The possibility of placing the model inside the browser and, consequently, on the website allows students to independently study the educational material or repeat it, which also opens up additional opportunities for students studying in absentia or remotely.

Thus, the use of Unity allows you to implement intensive methods and forms of learning, increase the motivation of learning through the use of modern means of processing audiovisual information, increase the level of emotional perception of information, form the ability to implement various forms of independent learning activities [6].

Unity opens up new horizons in learning.

A new generation of educational technologies should allow students to plunge headlong into interactive worlds, explore complex scenarios and concepts in completely new ways.

Interactive and immersive learning

Multiplatform: it is enough to develop an application once and release it on all supported platforms, including the latest VR and AR technologies.

Innovations: allow us to consider complex processes in practice, explore ideas in a new way and achieve better learning outcomes compared to traditional approaches.

The latest technologies: training models accelerate the learning process, make it safer, reduce equipment costs and increase the efficiency of knowledge acquisition.

In the era of computerization, when it is necessary to use information computer technologies in the field of education, there is a problem of finding the necessary educational materials and programs that create these materials. This problem can be solved using the 3D Max program. 3D Max is the market leader in three-dimensional modeling, animation and visualization software. The 3D Max architecture allows animators to take advantage of the use of more than a hundred plug-in applications to quickly and easily add impressive effects. In addition, with 3D Max, they can create their own modular applications to give their creations a unique look [7].

The program 3ds max belongs to a group of programs for three-dimensional computer graphics or 3d graphics (3-Dimensional-3-dimensional) and is designed to synthesize separate images that are reflected in real life or in a fictional world with photographic character and quality , as well as simulate scenes that show the action of objects, called animation.

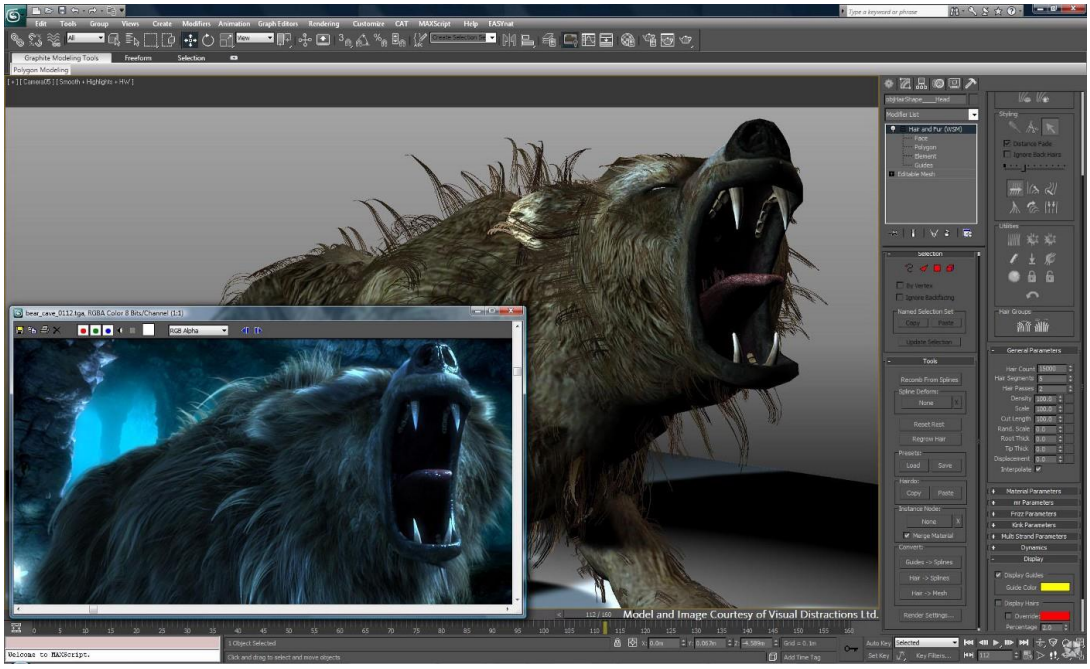


**Figure 3** – Visualization in the program 3ds max

One of the indispensable software tools for creating skeletal animation of characters in the field of animation is the 3ds max program. This program is one of the most popular packages in 3D modeling and animation. With the help of the 3ds max program, it is possible to create a three-dimensional model of any object, analyze the method of object modification, have a deeper understanding of the principles of direct and reverse kinematics and animation, as well as implement a natural symbol with the addition of optical effects in vidiomontages, visualizing the scene [8].

The 3D max program allows you to create and edit three-dimensional objects and animate them using various commands you can change the shape of these objects. In 3D Max, there is only one limit-this is our imagination. There are many possibilities in three-dimensional graphics. This program is used in various fields, especially for designers and webmasters. Webmasters use the program to create images and banners. In the same way, you can create various other objects: projects of large buildings, fountains, etc. After getting acquainted with the 3D Max program and modeling theory, you will learn how to create standard and extended polygons, as well as install various modifiers on them. Applying modifiers to common objects is one of the easiest modeling methods. To model complex objects, you can use the lofting method. The lofting method is performed by two Splins, the first is the contour of the horizontal segment of the object, and the second is the path of the object. Some programmers do not support the lofting method, because when installing the material and structure on an object, they may have a defect. In addition, logical operations can be applied to objects. This type of modeling involves two or more objects. Finally, they merge into one object according to the selected mode, and only intersecting sides remain, or one object is cut off from another object. Today, the most common method of object modeling is implemented by the main methods-network and polygon modeling commands, which are implemented by changing the networks and polygons of the object.

As a result of the analysis of the capabilities, advantages and features of the software tools discussed above, the choice in favor of the Twinmotion program was made. This program is fully suitable for teaching children of primary school age to the basics of 3D modeling. This program allows you to gradually explore the main features. I think that modeling with Twinmotion, creating 3D models will be a fun and exciting game. Thus, 3D modeling plays an important role in the learning process in many subjects, such as biology, mathematics, physics, and chemistry. It is necessary to learn modeling from the level of primary education from an early age children begin to develop spatial imagination. Children are motivated to learn, learn such important skills as analysis. In the future, 3D modeling will help complex disciplines such as architecture and design, mechanical engineering, archaeology and geography, Medical Modeling, Fine Arts, and more.

The use of three-dimensional ("three-dimensional" or 3D) models of real-world objects is an important means of transmitting information, which significantly increases the effectiveness of training, and can also be an excellent illustration during reports, presentations and advertising campaigns. Three-dimensional models are a mandatory element of modern vehicles, architectural structures and interiors. One of the most interesting applications of 3D computer graphics is special effects in modern art and documentaries.

The 3D modeling Basics program at Twinmotion develops children's abilities for creative activity, accumulates and systematizes the acquired knowledge, teaches them to express their ideas, form their own attitude to the problem and ways to solve it. In the process of developing the program, children learn to work in a team and acquire communication skills.

Technical achievements and social changes in the world engineering service imposes new requirements on education. Effective assimilation of educational information requires an understanding of graphic images of technical objects and processes, the ability to navigate in modern technical systems [9].

The inclusion of learning the basics of 3D modeling in the general educational process outside of educational activities opens up wide opportunities for students to create fundamentally new labor products, to master new peaks in the study of modern technologies. Students gain practical knowledge in modeling and parametric design, develop their own engineering and technical projects, develop

engineering and technical abilities and ensure their competitiveness in professional areas of technical orientation [10].

**Conclusion**

* Knowledge of the basic principles of three-dimensional design;
* Mastering the skills of creating 3D models;
* Possess planning skills.

The main computer science course focuses on 3D modeling or working in a specially designed modeling environment. Theoretical problems of modeling are mainly considered in grades 10-11, where among many models, as a rule, there are no more than three types, i.e. modeling as an object is taught only in the computer science course for higher grades.

At all stages of training, priority is given to modeling as a learning tool, taking into account that training itself is an information process. Information modeling as a means of cognition is shown to a lesser extent in existing computer science courses. This is mainly due to the consideration of modeling as a method of scientific research in solving problems in a computer. Modeling is given the least importance as an object of research. Basically, this aspect is reduced to the introduction of the concepts of "model" and "modeling", the consideration of models of different types. The model as a new object is mentioned in a number of textbooks, but mainly at the level of declarative statements. Therefore, I think it is necessary to develop a modeling system not only for school educational programs, but also a methodology for teaching the basics of 3D modeling in institutions of additional education.

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# STABILITY ESTIMATION OF A FINITE - DIFFERENCE PROBLEM SOLUTION FOR A MIXED TYPE EQUATION

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**Abstract**

The problem of determining a function through the integral of a function along the family of curves with a known weight function is considered. Under fairly general assumptions about the family of curves and the weight function, the problem reduces to the inverse problem for a differential equation. The stability and uniqueness of the solution of the discrete analogue of this problem on the space of sufficiently smooth functions is estimated. Due to the absence of a theorem of the existence of a solution, the concept of conditional well-posedness of the problem is used in the work, namely, it is assumed that the solution of a finite-difference problem exists. The results obtained are based on reducing the problem under consideration to a boundary value problem for an equivalent second-order partial differential equation of mixed type. Information about the solution of the set finite-difference problem is given both on the boundary of Γ and in some of its $\varepsilon$ - neighborhood, which is due to the presence of certain kinds of singularities. When proving the stated theorem on estimating the solution, a technique is used, which is based on the use of a special factor.

**Keywords:** inverse problem, boundary value problem, mixed type equation, stability estimation, finite-difference problem.

## Introduction

The problem of restoring the function is closely related to the theory of differential equations and mathematical physics, geometric analysis and has numerous applications in mathematical study of seismic exploration problems, interpretation of geophysical observations data, in solving astrophysics and hydroacoustics inverse problems.

V.G. Romanov obtained uniqueness theorems and estimates of conditional stability of solving integral geometry problems for a fairly general family of curves on the plane [1].

For linear and nonlinear problems of integral geometry in the circle of some regular curves, R.G. Mukhometov showed the uniqueness theorem and stability estimation in the space of plane functions [2]. These results are based on the reduction of integral geometry problem to the boundary value problem of a second-order partial mixed type differential equation.

Study of the uniqueness of the solution of integral geometry problem with its reduction to an equivalent inverse problem for a differential equation was carried out in the paper [3].

## Materials and Methods

Let, $U(x,y) \in C^2(\overline{D})$ and

$$V(\gamma,z) = \int_{K(\gamma,z)} U(x,y)\rho(x,y,z)ds; \quad \gamma \in [0,l], \quad z \in [0,l]. \tag{1}$$

The problem of integral geometry (1) consists of determining a function $U(x,y)$ from given curves $K(\gamma,z)$ and functions $V(\gamma,z)$ in the domain $\overline{D}$ [4].

If a family of curves $K(\gamma,z)$ is satisfied with certain conditions [2], problem (1) is reduced to the following boundary value problem:

$$\frac{\partial}{\partial z}\left(\frac{\partial W}{\partial x}\frac{\cos\theta}{\rho}+\frac{\partial W}{\partial y}\frac{\sin\theta}{\rho}\right)=0, \quad (x,y,z)\in\Omega_1 \tag{2}$$

$$W(\xi(\gamma),\eta(\gamma),z)=V(\gamma,z), \quad V(z,z)=0, \quad \gamma,z\in[0,l] \tag{3}$$

here $\rho(x,y,z)$ - known function, $D$ - a plane bounded by simply connected domain with a smooth boundary $\Gamma$:

$$x=\xi(z),\ y=\eta(z),\ z\in[0,l], \quad \xi(0)=\xi(l),\ \eta(0)=\eta(l),$$

where

z - length of the curve $\Gamma$;

$\Omega_1=\Omega/\{(\xi(\gamma),\eta(\gamma),z): z\in[0,l]\}$, $\Omega=\overline{D}\times[0,l]$;

$K(x,y,z)$ - part of the curve from the family $K(\gamma,z)$ connecting the points $(x,y)\in\overline{D}$ and $(\xi(z),\eta(z))$,

$$W(x,y,z)=\int\limits_{K(x,y,z)} U(x,y)\rho(x,y,z)ds,$$

$\theta(x,y,z)$ - angle of the tangent to the curve $K(x,y,z)$ through the point $(x,y)$ with the $x$ axis, $s$ - length of the curve.

Suppose that the conditions for reducing problem (1) to problem (2), (3) are met for the domain $D$ and the family of curves $K(\gamma,z)$. Assume that any straight line parallel to the axis $Ox$ or $Oy$ intersects the boundary of the domain $D$ at two points.

Let the points $a_i,b_i \quad (i=1,2)$, the grid step $h_j\ (j=1,2,3)$, the number $\varepsilon$, and the sets be $D^\varepsilon, \quad R_h, \quad D_h, \quad D_h^\varepsilon, \quad \Gamma_h^\varepsilon, \quad \Delta_h^\varepsilon, \quad \Omega_h^\varepsilon$ defined as in the paper [7].

Further, we assume that the coefficients and the solution of the problem (2) - (3) satisfy the conditions as follows:

$$W(x,y,z)\in C^3(\Omega^\varepsilon),\ \theta(x,y,z)\in C^2(\Omega^\varepsilon), \quad \Omega^\varepsilon=\overline{D}^\varepsilon\times[0,l], \tag{4}$$

$$\rho(x,y,z)\in C^2(\Omega), \quad \rho(x,y,z)>0, \quad \frac{\partial\theta}{\partial z}>\left|\frac{\partial\rho}{\partial z}\cdot\frac{1}{\rho}\right|. \tag{5}$$

Let's set the following finite-difference problem: find a function $\Phi_{i,j}^k$ that satisfies the equation

$$\left[\Phi_{0\,x}\frac{A}{C}+\Phi_{0\,y}\frac{B}{C}\right]_z=0, \quad (a_1+ih_1,a_2+ih_2,kh_3)\in\Omega_h^\varepsilon, \tag{6}$$

and boundary conditions

$$\Phi_{i,j}^k(z)=F_{i,j}^k(z), \quad (a_1+ih_1,a_2+jh_2)\in\Delta_h^\varepsilon, \quad k=1,...,N_3-1, \tag{7}$$

$$\Phi_{i,j}^{0}(z) = \Phi_{i,j}^{N_3}(z), \quad (a_1 + ih_1, a_2 + jh_2) \in D_h^{\varepsilon}, \tag{8}$$

here

$$\Phi_{i,j}^{k} = \Phi(x_i, y_j, z_k) = \Phi(a_1 + ih_1, a_2 + jh_2, kh_3),$$

$$\Phi_{\underset{x}{0}} = (\Phi_{i+1,j} - \Phi_{i-1,j}) / 2h_1, \quad \Phi_{\underset{y}{0}} = (\Phi_{i,j+1} - \Phi_{i,j-1}) / 2h_2,$$

$$f_z = \frac{f_{i,j}^{k+1} - f_{i,j}^{k}}{h_3}, \quad A = \cos\theta_{i,j}^{k}(z), \quad B = \sin\theta_{i,j}^{k}(z),$$

$$\theta_{i,j}^{k} = \theta(a_1 + ih_1, a_2 + jh_2, kh_3), \quad C = \rho_{i,j}^{k} = \rho(a_1 + ih_1, a_2 + jh_2, kh_3).$$

Note that the derivatives $\theta_z, W_{xz}, W_{yz}, W_{xy}$ have specifics of the type $\left[(x-\xi(z))^2 + (y-\eta(z))^2\right]^{-\frac{1}{2}}$ in the neighborhood of any point of the type $(\xi(z), \eta(z), z)$, so the information about the solution is given both on the boundary $\Gamma$ and in some of its $\varepsilon$ neighborhood [2].

**Results and Discussion**

**Theorem.** *Let the* $(a_1 + ih_1,\ a_2 + jh_2, kh_3) \in \Omega_h^{\varepsilon}$ *function* $\Phi_{i,j}^{k}$ *satisfy relations (6)-(8) for all. Suppose that the solution of problem (6)–(8) exists and in addition*

$$\left|\Phi_{\underset{xz}{0}}\right| \le c_1, \quad \left|\Phi_{\underset{yz}{0}}\right| \le c_1, \tag{9}$$

*where* $c_1$ *- an arbitrary constant, for all* $N_j, \ j = 1,2,3$

$$(AB_z - A_z B) - \left|\frac{C_z}{C}\right| \ge \beta > 0\ . \tag{10}$$

*Then there is a positive constant P such that for all there* $N_j > P, \ j = 1,2,3$ *is an estimate*

$$\sum_{\Omega_h^{\varepsilon}} \left( \Phi_{\underset{x}{0}}^{\ 2} + \Phi_{\underset{y}{0}}^{\ 2} \right) h_1 h_2 h_3 \le c_2 \sum_{\Delta_h^{\varepsilon}} \left( F_{\underset{x}{0}}^{2} h_1 h_3 + F_{\underset{y}{0}}^{2} h_2 h_3 + F_z^2 \left(h_1 + h_2\right) h_3 \right) + c_1 h_3^2\ , \tag{11}$$

*in which* $c_2$ *depends on the functions* $\rho(x, y, z)$ *and the family of curves* $K(\gamma, z)$.

**Proof.** Using the methodology proposed in the works [5] - [7], we multiply both parts (6) by $2C\left(-B\Phi_{\underset{x}{0}} + A\Phi_{\underset{y}{0}}\right)\frac{\partial}{\partial z}$ and write the resulting equality in the form $\mathrm{I}_1 + \mathrm{I}_2 = 0$ where

$$\mathrm{I}_1 = \mathrm{I}_2 = C\left(-B\Phi_{\underset{x}{0}} + A\Phi_{\underset{y}{0}}\right)\left[\Phi_{\underset{x}{0}}\frac{A}{C} + \Phi_{\underset{y}{0}}\frac{B}{c}\right]_z = 0\,.$$

Using the formula

$$(uv)_z = u^k v_z + u_z v^k + h_3 u_z v_z \qquad (12)$$

convert $\mathrm{I}_1$:

$$\mathrm{I}_1 = \left[ C\left( -B\Phi_{\underset{x}{0}} + A\Phi_{\underset{y}{0}} \right)\left( \frac{A}{C}\Phi_{\underset{x}{0}} + \frac{B}{C}\Phi_{\underset{y}{0}} \right) \right]_z -$$
$$-\left[ C\left( -B\Phi_{\underset{x}{0}} + A\Phi_{\underset{y}{0}} \right) \right]_z \left( \frac{A}{C}\Phi_{\underset{x}{0}} + \frac{B}{C}\Phi_{\underset{y}{0}} \right) -$$
$$-h_3 \left[ C\left( -B\Phi_{\underset{x}{0}} + A\Phi_{\underset{y}{0}} \right) \right]_z \left[ \frac{A}{C}\Phi_{\underset{x}{0}} + \frac{B}{C}\Phi_{\underset{y}{0}} \right]_z = 0.$$

Given the formulas

$$\left( \frac{u}{v} \right)_z = \frac{u_z v^k - u^k v_z}{v^k v^{k+1}},$$

(12), equality (6), as well as $D = 2AB = \sin 2\theta, \quad E = A^2 - B^2 = \cos 2\theta,$ and

$$\Phi_{\underset{x}{0}} \Phi_{\underset{xz}{0}} = \frac{1}{2}\left( \Phi^2_{\underset{x}{0}} \right)_z - \frac{h_3}{2}\Phi^2_{\underset{xz}{0}}, \quad \Phi_{\underset{y}{0}} \Phi_{\underset{yz}{0}} = \frac{1}{2}\left( \Phi^2_{\underset{y}{0}} \right)_z - \frac{h_3}{2}\Phi^2_{\underset{yz}{0}}$$

opening the brackets in $\mathrm{I}_1$ and $\mathrm{I}_2$ we get

$$\mathrm{I}_3 + \mathrm{I}_4 + \mathrm{I}_5 + \mathrm{I}_6 + \mathrm{I}_7 + \mathrm{I}_8 = 0, \qquad (13)$$

where

$$\mathrm{I}_3 = \frac{1}{2}\left\{ \Phi^2_{\underset{x}{0}} \left[ (AB_z - A_z B) + D\frac{C_z}{C} \right] - 2\Phi_{\underset{x}{0}} \Phi^{k+1}_{\underset{y}{0}} E\frac{C_z}{C} + \right.$$
$$\left. + \left( \Phi^{k+1}_{\underset{y}{0}} \right)^2 \left[ (AB_z - A_z B) - D\frac{C_z}{C} \right] \right\},$$

$$\mathrm{I}_4 = \frac{1}{2}\left\{ \left( \Phi^{k+1}_{\underset{x}{0}} \right)^2 \left[ (AB_z - A_z B) + D\frac{C_z}{C} \right] - 2\Phi^{k+1}_{\underset{x}{0}} \Phi_{\underset{y}{0}} E\frac{C_z}{C} + \right.$$
$$\left. + \Phi^2_{\underset{y}{0}} \left[ (AB_z - A_z B) - D\frac{C_z}{C} \right] \right\},$$

$$\mathrm{I}_5 = -\frac{h_3^2}{2}\Phi^2_{\underset{xz}{0}} \left[ (AB_z - A_z B) + D\frac{C_z}{C} \right] - \frac{h_3^2}{2}\Phi^2_{\underset{yz}{0}} \left[ (AB_z - A_z B) - D\frac{C_z}{C} \right] +$$
$$+ \Phi^2_{\underset{x}{0}} (A_z B + ABC_z) o(h_3) + \Phi^2_{\underset{y}{0}} (AB_z - ABC_z) o(h_3) +$$
$$+ \Phi_{\underset{x}{0}} \Phi^{k+1}_{\underset{y}{0}} B^2 C_z o(h_3) + \Phi_{\underset{y}{0}} \Phi^{k+1}_{\underset{x}{0}} A^2 C_z o(h_3),$$

$$\mathrm{I}_6 = \underset{x}{\Phi_0}\underset{y}{\Phi_0} BB_z\left(1-\frac{C^k}{C^{k+1}}\right)+\underset{x}{\Phi_0}\underset{y}{\Phi_0} AA_z\left(\frac{C^k}{C^{k+1}}-1\right)-h_3\underset{x}{\Phi_0}\underset{yz}{\Phi_0}\left(AA_z+BB_z\frac{C^k}{C^{k+1}}\right)+$$

$$+h_3\underset{y}{\Phi_0}\underset{xz}{\Phi_0}\left(AA_z\frac{C^k}{C^{k+1}}+BB_z\right),$$

$$\mathrm{I}_7 = \left[\left(-\underset{x}{\Phi_0}B+\underset{y}{\Phi_0}A\right)\left(\underset{x}{\Phi_0}A+\underset{y}{\Phi_0}B\right)\right]_z-\underset{x}{\Phi_0}\underset{yz}{\Phi_0}+\underset{y}{\Phi_0}\underset{xz}{\Phi_0},$$

$$\mathrm{I}_8 = h_3\underset{x}{\Phi_0^2}AB_z\frac{C_z}{C}+h_3^2\underset{x}{\Phi_0}\underset{xz}{\Phi_0}AB_z\frac{C_z}{C}+h_3\underset{x}{\Phi_0}\underset{y}{\Phi_0}AA_z\frac{C_z}{C}+h_3\underset{x}{\Phi_0}\underset{y}{\Phi_0}BB_z\frac{C_z}{C}-$$

$$-h_3^2\underset{x}{\Phi_0}\underset{yz}{\Phi_0}AA_z\frac{C_z}{C}+h_3^2\underset{y}{\Phi_0}\underset{xz}{\Phi_0}BB_z\frac{C_z}{C}-h_3\underset{y}{\Phi_0^2}A_zB\frac{C_z}{C}-h_3^2\underset{y}{\Phi_0}\underset{yz}{\Phi_0}A_zB\frac{C_z}{C}.$$

Next, let us transform these expressions and evaluate them separately.

If the expressions $\mathrm{I}_3$ and $\mathrm{I}_4$ are considered as a quadratic form from $\underset{x}{\Phi_0}$ and $\underset{y}{\Phi_0^{k+1}}$, $\underset{x}{\Phi_0^{k+1}}$ and $\underset{y}{\Phi_0}$, then their positive definiteness follows from condition (10).

Using the inequality

$$ax^2+2bx+cy^2 \geq \frac{2(ac-b^2)}{a+c+\sqrt{(a-c)^2+4b^2}}(x^2+y^2),$$

which holds for a positive definite quadratic form $ax^2+2bxy+cy^2$, we obtain the following estimates

$$\mathrm{I}_3 \geq \frac{1}{2}\left[\left(AB_z-A_zB\right)-\left|\frac{C_z}{C}\right|\right]\left[\left(\underset{x}{\Phi_0^k}\right)^2+\left(\underset{y}{\Phi_0^{k+1}}\right)^2\right], \tag{14}$$

$$\mathrm{I}_4 \geq \frac{1}{2}\left[AB_z-A_zB-\left|\frac{C_z}{C}\right|\right]\left[\left(\underset{x}{\Phi_0^{k+1}}\right)^2+\left(\underset{y}{\Phi_0^k}\right)^2\right]. \tag{15}$$

Given that $\left(1-\frac{C^k}{C^{k+1}}\right)\approx o(h_3)$ and using the inequality $|ab|\leq\left(a^2+b^2\right)/2$ we obtain an estimate for the expression $\mathrm{I}_6$:

$$
\begin{aligned}
\mathrm{I}_6 \le \frac{1}{2}\Bigg\{ & \left[\left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^k}\right)^2\right]\left(AA_z + BB_z\right)o(h_3) + \\
& + \left[\left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^{k+1}}\right)^2\right]\left(AA_z + BB_z\right) + \\
& + \left[\left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^{k+1}}\right)^2 + \left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^k}\right)^2\right] BB_z o(h_3) + \\
& + \left[\left(\underset{y}{\Phi_0^k}\right)^2 + \left(\underset{x}{\Phi_0^{k+1}}\right)^2 + \left(\underset{y}{\Phi_0^k}\right)^2 + \left(\underset{x}{\Phi_0^k}\right)^2\right] AA_z o(h_3)\Bigg\}.
\end{aligned}
\tag{16}
$$

Considering (10) and using conditions (9), we obtain an estimate for the expression $\mathrm{I}_5$:

$$
\begin{aligned}
\mathrm{I}_5 \le & \underset{x}{\Phi_0^2}(A_z B + ABC_z)o(h_3) + \underset{y}{\Phi_0^2}(AB_z - ABC_z)o(h_3) + \\
& + \frac{1}{2}\Bigg\{\left[\left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^{k+1}}\right)^2\right](A_z B + ABC_z)o(h_3) + \\
& + \left[\left(\underset{y}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^{k+1}}\right)^2\right](AB_z + ABC_z) + \\
& + \left[\left(\underset{x}{\Phi_0^k}\right)^2 + \left(\underset{y}{\Phi_0^{k+1}}\right)^2\right] B^2 C_z o(h_3) + \\
& + \left[\left(\underset{y}{\Phi_0^k}\right)^2 + \left(\underset{x}{\Phi_0^{k+1}}\right)^2\right] A^2 C_z o(h_3)\Bigg\} + c_1 h_3^2.
\end{aligned}
\tag{17}
$$

From the formula $\left(uv\right)_{\underset{x}{}}^{0} = u_{\underset{x}{0}} v_i + u_i v_{\underset{x}{0}} + \frac{h_1^2}{2}\left[u_x v_x\right]_{\bar{x}}$ it follows

$$
\underset{y}{\Phi_0}\underset{xz}{\Phi_0} = \left[\underset{y}{\Phi_0}\Phi_z\right]_{\underset{x}{0}} - \underset{xy}{\Phi_{0\,0}}\Phi_z - \frac{h_1^2}{2}\left[\underset{yx}{\Phi_0}\Phi_{zx}\right]_{\bar{x}},
$$

$$
-\underset{x}{\Phi_0}\underset{yz}{\Phi_0} = -\left[\underset{x}{\Phi_0}\Phi_z\right]_{\underset{y}{0}} + \underset{xy}{\Phi_{0\,0}}\Phi_z + \frac{h_2^2}{2}\left[\underset{xy}{\Phi_0}\Phi_{zy}\right]_{\bar{y}}.
$$

Then

$$
\begin{aligned}
\mathrm{I}_7 &= \left[\left(-\underset{x}{\Phi_0}B + \underset{y}{\Phi_0}A\right)\left(\underset{x}{\Phi_0}A + \underset{y}{\Phi_0}B\right)\right]_z - \underset{x}{\Phi_0}\underset{yz}{\Phi_0} + \underset{y}{\Phi_0}\underset{xz}{\Phi_0} = \\
&= \left[\left(-\underset{x}{\Phi_0}B + \underset{y}{\Phi_0}A\right)\left(\underset{x}{\Phi_0}A + \underset{y}{\Phi_0}B\right)\right]_z + \left[\underset{y}{\Phi_0}\Phi_z\right]_{\underset{x}{0}} - \\
&\quad - \left[\underset{x}{\Phi_0}\Phi_z\right]_{\underset{y}{0}} - \frac{h_1^2}{2}\left[\underset{yx}{\Phi_0}\Phi_{zx}\right]_{\bar{x}} + \frac{h_2^2}{2}\left[\underset{xy}{\Phi_0}\Phi_{zy}\right]_{\bar{y}}.
\end{aligned}
\tag{18}
$$

Next, we will estimate $\mathrm{I}_8$:

$$\mathrm{I}_8 \le \frac{h_3}{2}\left\{\left[\left(\Phi_{0\,x}^{k}\right)^2+\left(\Phi_{0\,x}^{k+1}\right)^2\right]AB_z\frac{C_z}{C}+\left[\left(\Phi_{0\,x}^{k}\right)^2+\left(\Phi_{0\,y}^{k+1}\right)^2\right]AA_z\frac{C_z}{C}+\right.$$
$$\left.+\left[\left(\Phi_{0\,y}^{k}\right)^2+\left(\Phi_{0\,x}^{k+1}\right)^2\right]BB_z\frac{C_z}{C}+\left[\left(\Phi_{0\,y}^{k}\right)^2+\left(\Phi_{0\,y}^{k+1}\right)^2\right]A_zB\frac{C_z}{C}\right\}. \tag{19}$$

Assuming that the functions $A,B,C$ are sufficiently smooth bounded functions and considering expressions (14)-(19), from (13) one can obtain

$$\frac{1}{2}\left[AB_z-A_zB-\left|\frac{C_z}{C}\right|\right]\left[\left(\Phi_{0\,x}^{k}\right)^2+\left(\Phi_{0\,x}^{k+1}\right)^2+\left(\Phi_{0\,y}^{k}\right)^2+\left(\Phi_{0\,y}^{k+1}\right)^2\right]\le$$
$$\le\frac{h_3}{2}K\left[\left(\Phi_{0\,x}^{k}\right)^2+\left(\Phi_{0\,x}^{k+1}\right)^2+\left(\Phi_{0\,y}^{k}\right)^2+\left(\Phi_{0\,y}^{k+1}\right)^2\right]+R_{i,j}^{k}+c_1h_3^2, \tag{20}$$

where

$$R_{i,j}^{k}=\left[\Phi_{0\,x}\Phi_z\right]_{0\,y}-\left[\Phi_{0\,y}\Phi_z\right]_{0\,x}-\left[\left(\Phi_{0\,x}A+\Phi_{0\,y}B\right)\left(-\Phi_{0\,x}B+\Phi_{0\,y}A\right)\right]_z+\frac{h_1^2}{2}\left[\Phi_{zx}\Phi_{0\,yx}\right]_{\bar{x}}-\frac{h_2^2}{2}\left[\Phi_{zy}\Phi_{0\,xy}\right]_{\bar{y}}.$$

Let $\left[AB_z-A_zB-\left|\frac{C_z}{C}\right|\right]\ge\beta>0,\quad N_j>9,\quad j=1,2,\quad Kh_3<\frac{\beta}{2}$, i.e. since $h_3=\frac{l}{N_3}$ then $N_3>\frac{2Kl}{\beta}$, where $\beta,\quad K$ are arbitrary constants.

Then from (20) we get

$$\sum_{\Omega_h^{\varepsilon}}\left(\Phi_{0\,x}^2+\Phi_{0\,y}^2\right)h_1h_2h_3\le\frac{2}{\beta}\sum_{\Omega_h^{\varepsilon}}R_{i,j}^{k}+c_1h_3^2. \tag{21}$$

From the last inequality (21), using conditions (7) - (8) and inequality $|ab|\le(a^2+b^2)/2$, we will obtain an estimate (11).

In the estimation, it is assumed that in decreasing of $h_1$ and $h_2$ parameter $\varepsilon$ can also decrease, since $c_1$ does not depend on $\varepsilon$ (the parameter ε was chosen solely to eliminate the features present in original continuous problem). Therefore, the smaller the grid is the narrower the area in which the feature is concentrated.

## Conclusion

In this paper, we obtain stability estimation of a finite-difference problem solution for a mixed-type equation, which is used to justify the convergence of methods for the numerical solution of problems of geotomography, medical tomography, flaw detection and is of great practical importance in solving multidimensional inverse problems of acoustics and seismology.

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# SYSTEM OF LINEAR DIFFERENTIAL EQUATIONS OF SECULAR PERTURBATIONS OF EXOPLANETS WITH VARIABLE MASSES

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**Abstract**

The study of dynamical evolution of exoplanetary systems is actual topic in astrodynamics and in celestial mechanics. For today, more than 3,800 confirmed exoplanetary systems are known [1], and this list is growing rapidly. Researching of dynamics of exoplanets in the non-stationary stage of its formation gives us the opportunity to determine further evolutionary tracks. The influence of the variability of the masses of celestial bodies is explored on the dynamic evolution of planetary systems, considering that the masses of bodies change isotropically with different velocities. The laws of masses are considered be known and given functions of time. The differential equations of motion of $n$ bodies in the relative coordinate system are given in the works [2-3]. The methods of canonical perturbation theory are used, which developed on the basis of aperiodic motion over a quasi-conical cross section [4] in analogues of the second Poincaré system of variables. The obtained canonical equations of perturbed motion [5] are most convenient for describing the dynamic evolution of planetary systems in the case when analogues of eccentricities and analogues of inclinations of the orbital plane are small enough. The Wolfram Mathematica package is used in the expansion of perturbing functions into series. Secular perturbations of Poincare elements are defined as solutions of a system of $4n$ linear differential equations. As an example, we consider the two-planet exosystem *HD 106315* (spectral type *F5 V*) [6] in the non-stationary stage of its evolution. To find secular perturbations, it will be necessary to solve a system of 8 linear non-autonomous differential equations. The obtained equations of secular perturbations are studied by the numerical method.

**Keywords:** dynamical evolution, canonical perturbation theory, variable masses, Poincaré variables, secular perturbations, evolutionary equation.

## Introduction

The research of the dynamic evolution of planetary systems is one of the fundamental tasks of celestial mechanics and astronomy, and has become a more relevant topic after the massive discovery of exoplanetary systems. At the moment, there are more than 5,000 confirmed exoplanets, and more than 3,800 planetary systems. There are also 8,912 unconfirmed candidates [1]. These figures indicate that studying the dynamic evolution of exoplanets and the influence of varying in the masses of the parent star on a non–stationary stage in their development is a problem that requires special research.

To research the formation and orbital motion of exoplanetary systems, it is necessary to study the influence of the varying in the masses of celestial bodies on the dynamic evolution of planetary systems. The research the dynamics of exoplanets on the non-stationary stage of its formation gives us the opportunity to determine further evolutionary tracks. We investigate the influence of the varying in the masses of celestial bodies on the dynamic evolution of exoplanetary systems,

considering that the masses of bodies change isotropically with different velocities. The motions are studied in a relative coordinate system, with the origin in the center of the parent star. The methods of canonical perturbation theory, which developed on the basis of aperiodic motion over a quasi-conical cross section [4] in analogues of the second system of Poincare variables are used here. The system of dimensionless linear differential equations of secular perturbation of exoplanets with variable masses is obtained in analogues of the second Poincare system.

**Materials and Methods**

**1. Brief overview of works by other authors**

Here is a brief overview of the works of other authors who are closely to our topic. The orbital evolution of compact exoplanet systems *61 Vir*, *GJ 3138* and *HD 39194* was studied in [7]. The problem was considered in Jacobi coordinates and equations of motion in average elements were constructed, which are used to study the dynamic evolution of planetary systems with small values of eccentricities, inclinations and ratio of large semi-axes of orbits. Dynamic properties have been studied.

In the paper [8] the dynamic evolution of planetary systems was considered on all stages of their development and the features of the dynamic evolution of planetary systems were described, depending on their type. The stages of the dynamic evolution of planetary systems were considered, taking into account the loss of mass by a star during its stay on the main sequence and during the transition through the stage of a red giant to a white dwarf.

In [9], the authors considered the long-term dynamic evolution of planetary systems. As a result, it was deduced when the central star evolves that aging systems can become unstable, turning into a white dwarf, and lose mass, since the relative strength of interplanetary interactions increases compared to interactions between planets and stars.

In the paper [10] methods for calculating the complex tidal, rotational and dynamic evolution of extrasolar planetary systems were present. One of them involves calculating the evolution of the one-averaged specific angular momentum and the Runge-Lenz and spin vectors, and also directly integrates any other orbits in the system.

In [11], the authors proved that non-gravitational perturbations affect the orbital and rotational dynamics of asteroids in the main belt.

In [12], for a better understanding of the dynamics of some extrasolar planetary systems, the dynamic behavior of a simplified model of the Solar system was studied, changing the mass of the Earth using the mass coefficient.

In [13], the dynamic behavior of a particular case of a classical restricted three-body problem was investigated. In this problem, the infinitely small body under consideration has a variable mass according to Jeans' law.

In the article [14] investigates the dynamic evolution of orbits due to the pressure of solar radiation. In [15], the evolution of planetary systems was studied. The averaged equations of motion are constructed analytically up to the third degree with respect to a small parameter for the case of a four-planetary system. The Sun–Jupiter–Saturn–Uranus–Neptune system was considered here.

In [16], the orbital evolution of the asteroids of the Phaethon cluster was studied, taking into account perturbations from eight major planets, the dwarf planet Pluto, the influence of the Yarkovsky effect, the flattened Sun and relativistic effects.

In our work, in difference from the above-mentioned works, the dynamic evolution of multi-planetary systems is investigated, when the leading factor of evolution is the variability of the masses of these celestial bodies.

**2. Problem statement and differential equations of motion in a relative coordinate system**

In this work, the problem of $n \quad (n \geq 3)$ bodies with variable masses is considered. The laws of mass are known and given functions of time

$$m_0 = m_0(t), \quad m_1 = m_1(t), \quad ....., \qquad m_n = m_n(t)$$

The masses of spherical symmetric bodies change isotropically with different velocities

$$\frac{\dot{m}_0}{m_0} \neq \frac{\dot{m}_i}{m_i}, \quad \frac{\dot{m}_i}{m_i} \neq \frac{\dot{m}_k}{m_k}, \quad i,k = 1,2,..,n, \quad i \neq k,$$

where:

$m_0 = m_0(t)$ - the mass of the parent star;

$m_i = m_i(t)$ - the mass of the planet $P_i$.

Differential equations of motion of $n$ bodies with isotropically varying masses in a relative coordinate system can be written as [2],[4]

$$\ddot{\vec{r}}_i = -f\frac{(m_0 + m_i)}{r_i^3}\vec{r}_i + f\sum_{k=1}^{n}{}' m_k\left(\frac{\vec{r}_k - \vec{r}_i}{\Delta_{ik}^3} - \frac{\vec{r}_k}{r_k^3}\right), \quad (i = 1,2,...,n), \quad (\mathrm{k} = 1,2,...,n) \tag{1}$$

where:

$f$ - gravitational constant;

$\vec{r}_i(x_i, \mathrm{y}_i, \mathrm{z}_i)$ - the radius-vector of the center of spherical bodies;

$\Delta_{ik}$ is mutual distances of the center of spherical bodies

$$\Delta_{ik} = \sqrt{(x_k - x_i)^2 + (y_k - y_i)^2 + (z_k - z_i)^2} = \Delta_{ki}$$

The sign « ' » in summing means that $i \neq k$.

**3. The equation of motion in the osculating elements**

The differential equations of motion of $n$ planets (1) with isotropically varying masses in a relative coordinate system is difficult. Therefore, using perturbation theory, we rewrite these differential equations in the form

$$\ddot{\vec{r}}_i + f\frac{(m_0 + m_i)}{r_i^3}\vec{r}_i - \frac{\ddot{\gamma}_i}{\gamma_i}\vec{r}_i = \vec{F}_i \quad , \qquad \gamma_i = \frac{m_0(t_0) + m_i(t_0)}{m_0(t) + m_i(t)} = \gamma_i(t), \tag{2}$$

where the perturbing forces

$$\vec{F}_i = grad_{\vec{r}_i} W_i, \qquad W_i = W_{ci} + W_{gi} \tag{3}$$

The force functions $W_i$ are decomposed into the main and the additional parts

$$W_{gi} = f\sum_{k=1}^{n}{}' m_k\left(\frac{1}{\Delta_{ik}} - \frac{\vec{r}_i \cdot \vec{r}_k}{r_k^3}\right), \qquad W_{ci} = -\frac{\ddot{\gamma}_i}{2\gamma_i}r_i^2 \tag{4}$$

The resulting form of the equations of relative motion (2) is convenient for using the perturbation theory, developed for such non-stationary systems [4]. The methods of the canonical perturbation theory are used, developed on the basis of aperiodic motion over a quasi-conical cross section . If the perturbing forces (3) equal to zero, then we obtain integrable unperturbed motions that describe the aperiodic motion over the quasi-conical cross section[4],[17]

$$\ddot{\vec{r}}_i + f\frac{(m_0+m_i)}{r_i^3}\vec{r}_i - \frac{\ddot{\gamma}_i}{\gamma_i}\vec{r}_i = 0 \tag{5}$$

The solution of the differential equation (5) is a similar solution to the classical problem of two bodies with constant masses

$$\begin{aligned} x_i &= \gamma_i\rho_i\left[\cos u_i\cdot\cos\Omega_i - \sin u_i\cdot\sin\Omega_i\cdot\cos i_i\right], \\ y_i &= \gamma_i\rho_i\left[\cos u_i\cdot\sin\Omega_i + \sin u_i\cdot\cos\Omega_i\cdot\cos i_i\right], \\ z_i &= \gamma_i\rho_i\sin u_i\cdot\sin i_i, \quad r_i = \gamma_i\rho_i, \quad u_i = \theta_i + \omega_i, \end{aligned} \qquad \rho_i = \frac{a_i\left(1-e_i^2\right)}{1+e_i\cos\theta_i}, \quad p_i = a_i\left(1-e_i^2\right), \tag{6}$$

$$\begin{aligned} \dot{x}_i &= \left(\frac{\dot{\gamma}_i}{\gamma_i}+\frac{\dot{\rho}_i}{\rho_i}\right)x_i + \gamma_i\rho_i\dot{u}_i\left[-\sin u_i\cos\Omega_i - \cos u_i\sin\Omega_i\cos i_i\right], \\ \dot{y}_i &= \left(\frac{\dot{\gamma}_i}{\gamma_i}+\frac{\dot{\rho}_i}{\rho_i}\right)y_i + \gamma_i\rho_i\dot{u}_i\left[-\sin u_i\sin\Omega_i + \cos u_i\cos\Omega_i\cos i_i\right], \\ \dot{z}_i &= \left(\frac{\dot{\gamma}_i}{\gamma_i}+\frac{\dot{\rho}_i}{\rho_i}\right)z_i + \gamma_i\rho_i\dot{u}_i\left[\cos u_i\sin i_i\right], \end{aligned} \qquad \begin{aligned} \dot{\rho}_i &= \frac{1}{\gamma_i^2}\frac{\sqrt{\mu_{i0}}}{\sqrt{p_i}}e_i\sin\theta_i, \\ \dot{u}_i &= \frac{1}{\gamma_i^2}\frac{\sqrt{\mu_{i0}}\sqrt{p_i}}{\rho_i^2}, \end{aligned} \tag{7}$$

where:

$\mu_{i0} = f\left[m_0(t_0)+m_i(t_0)\right]$ - gravitational parameter;

$u_i$ - an analogue of the latitude argument;

$\theta_i$ - an analogue of a true anomaly;

$p_i$ - an analogue of the focal parameter;

$a_i$ - an analogue of a large semi major axis;

$e_i$ - an analogue of eccentricity;

$i_i$ - an analogue of orbit inclination;

$\omega_i$ - an analogue of the pericenter argument;

$\Omega_i$ - an analogue of the ascending node longitude;

$t_0$ - the initial moment of time.

Solution (6)-(7) was used as the initial unperturbed motion.

In the case of quasi-elliptical motion, the dependence of the analogues of the mean anomaly on time

$$M_i = n_i\left[\phi_i(t) - \phi_i(\tau_i)\right]$$

is determined taking into account the laws of mass change. Here $n_i$ - an analogue of the average motion

$$n_i = \frac{\sqrt{\mu_{i0}}}{a_i^{3/2}} = const$$

At the same time, $\phi_i(t)$ – is the antiderivative function from expression

$$\frac{1}{\gamma_i^2(t)} = \left(\frac{m_0(t)+m_i(t)}{m_0(t_0)+m_i(t_0)}\right)^2$$

Accordingly $\tau_i$ is a dynamic element, an analogue of the moment of passage through the pericenter. We emphasize that in unperturbed motion, the average angular velocity is variable and depends on the laws of change of the masses of the corresponding bodies

$$\dot{M}_i = n_i \left( \frac{1}{\gamma_i^2(t)} \right) = n_i \left( \frac{m_0(t) + m_i(t)}{m_0(t_0) + m_i(t_0)} \right)^2$$

In unperturbed motion, formally mathematically, the Kepler equation occurs, which allows us to find coordinates and velocities as functions of time.

The constant integrations of the differential equation of unperturbed motion (5), in the case of quasi-elliptic motion $(e_i < 1)$, can be determined by the following six elements of quasi-elliptic motion

$$a_i,\ e_i,\ i_i,\ \omega_i,\ \Omega_i,\ \phi_i(\tau_i) \tag{8}$$

In [4], using elements (8) as the unperturbed, a corresponding perturbation theory is constructed, which we will use extensively in this paper.

For our purposes, analogues of the second system of canonical Poincare elements are preferred

$$\Lambda_i,\ \lambda_i,\ \xi_i,\ \eta_i,\ p_i,\ q_i,$$

which are introduced according to the formulas

$$\Lambda_i = \sqrt{\mu_{i0}}\sqrt{a_i}, \quad \lambda_i = l_i + \pi_i, \tag{9}$$

$$\xi_i = \sqrt{2\sqrt{\mu_{i0}}\sqrt{a_i}\left(1-\sqrt{1-e_i^2}\right)}Cos\pi_i, \quad \eta_i = -\sqrt{2\sqrt{\mu_{i0}}\sqrt{a_i}\left(1-\sqrt{1-e_i^2}\right)}Sin\pi_i, \tag{10}$$

$$p_i = \sqrt{2\sqrt{\mu_{i0}}\sqrt{a_i}\sqrt{1-e_i^2}\,(1-Cosi_i)}Cos\Omega_i, \quad q_i = -\sqrt{2\sqrt{\mu_{i0}}\sqrt{a_i}\sqrt{1-e_i^2}\,(1-Cosi_i)}Sin\Omega_i \tag{11}$$

where

$$l_i = M_i = n_i\left[\phi_i(t) - \phi_i(\tau_i)\right], \quad \pi_i = \Omega_i + \omega_i$$

Differential equations of motion of spherical bodies in osculating analogues of the second system of Poincare variables (9)-(11) has the canonical form

$$\begin{aligned}
&\dot{\lambda}_i = -\frac{\partial R_i^*}{\partial \Lambda_i} = \frac{\mu_{i0}^2}{\gamma_i^2 \Lambda_i^3} - \frac{\partial W_i}{\partial \Lambda_i}, && \dot{\Lambda}_i = \frac{\partial R_i^*}{\partial \lambda_i} = \frac{\partial W_i}{\partial \lambda_i},\\
&\dot{\eta}_i = -\frac{\partial R_i^*}{\partial \xi_i} = -\frac{\partial W_i}{\partial \xi_i}, && \dot{\xi}_i = \frac{\partial R_i^*}{\partial \eta_i} = \frac{\partial W_i}{\partial \eta_i},\\
&\dot{q}_i = -\frac{\partial R_i^*}{\partial p_i} = -\frac{\partial W_i}{\partial p_i}, && \dot{p}_i = \frac{\partial R_i^*}{\partial q_i} = \frac{\partial W_i}{\partial q_i}.
\end{aligned} \tag{12}$$

where, the Hamilton functions

$$R_i^* = \frac{\mu_{i0}^2}{2\Lambda_i^2} \cdot \frac{1}{\gamma_i^2(t)} + W_i\left(t, \Lambda_i, \xi_i, p_i, \lambda_i, \eta_i, q_i\right)$$

Canonical equations of perturbed motion (12) are convenient for describing the dynamic evolution of planetary systems, when the analogues of eccentricities and the analogues of the inclination of the orbital plane are small enough. This means that bodies move near the equatorial plane along perturbed quasi-conic cross sections with small eccentricity

$$e_i << 1 \quad , \quad i_i << 1 \tag{13}$$

When $W_i = 0$ from equations (12) it can be seen that the average longitude $\lambda_i$ is an increasing function of time and the other canonical variables $\Lambda_i, \eta_i, \xi_i, q_i, p_i$ remain constant.

**4. Decomposition of the perturbing function**

To write explicitly the right-hand sides of the equations of perturbed motion (12), it is necessary to express the perturbing function (3)-(4) through the osculating elements (9)-(11). Expression $W_{ci}$ through the osculating elements is not difficult, its explicit analytical form is known [4]. The main difficulties are represented by the expansion into a series of the force function $W_{gi}$ of the Newtonian interaction of bodies

$$W_{gi} = f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} - \frac{\vec{r}_i \cdot \vec{r}_k}{r_k^3} \right) \tag{14}$$

through the osculating elements (9)-(11).

In the expression of the perturbing function (14), it is advisable to highlight the main and indirect part.

$$W_{gi} = f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} - \frac{\vec{r}_i \cdot \vec{r}_k}{r_k^3} \right) = f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} \right) - f \sum_{k=1}^{n}{}' m_k \left( \frac{x_i x_k + y_i y_k + z_i z_k}{r_k^3} \right) =$$

$$= f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} \right) - f \sum_{k=1}^{n}{}' m_k \left( \frac{r_i \cdot r_k \cdot Cos\psi_{ik}}{r_k^3} \right) = f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} \right) - f \sum_{k=1}^{n}{}' m_k \left( r_i \cdot \left( \frac{1}{r_k^2} \right) \cdot Cos\psi_{ik} \right).$$

We denoted the main and indirect part of the perturbing function (14) as

$$W_{gi,\text{гл}} = f \sum_{k=1}^{n}{}' m_k \left( \frac{1}{\Delta_{ik}} \right), \qquad W_{gi,\text{косв}} = -f \sum_{k=1}^{n}{}' m_k \left( r_i \cdot \left( \frac{1}{r_k^2} \right) Cos\left(\psi_{ik}\right) \right). \tag{15}$$

As in the classical many-body problem [18], the indirect part of the perturbing function (15) does not contribute to the expression of the secular perturbing function. Therefore, to obtain differential equations of secular perturbations in canonical osculating elements (9)-(11), it is sufficient to have an analytical expression of the main part (15) of the perturbing function in terms of canonical elements(9)-(11).

To obtain an analytical expression of the main part of the perturbing function (15), in canonical osculating elements (9)-(11), it is necessary to have decomposition of the expression

$$\left( \frac{1}{\Delta_{ik}} \right) \quad , \qquad i,k = 1,2,..,n, \quad i \neq k \tag{16}$$

These are very cumbersome and time-consuming algebraic computations that are calculated using computer algebra. The Wolfram Mathematica package is used in the decomposition of perturbing functions into series.

**5. Equations of secular perturbations**

The equations of secular perturbations, which determine the behavior of orbital parameters over long time intervals, are obtained from the equations of motion (12), if secular part of perturbing functions is substituted instead of the $W_i$.

$$\dot{\lambda}_i = -\frac{\partial R_i^*}{\partial \Lambda_i} = \frac{\mu_{i0}^2}{\gamma_i^2 \Lambda_i^3} - \frac{\partial W_i^{(\sec)}}{\partial \Lambda_i}, \qquad \dot{\Lambda}_i = 0,$$

$$\dot{\eta}_i = -\frac{\partial R_i^*}{\partial \xi_i} = -\frac{\partial W_i^{(\sec)}}{\partial \xi_i}, \qquad \dot{\xi}_i = \frac{\partial R_i^*}{\partial \eta_i} = \frac{\partial W_i^{(\sec)}}{\partial \eta_i},$$

$$\dot{q}_i = -\frac{\partial R_i^*}{\partial p_i} = -\frac{\partial W_i^{(\sec)}}{\partial p_i}, \qquad \dot{p}_i = \frac{\partial R_i^*}{\partial q_i} = \frac{\partial W_i^{(\sec)}}{\partial q_i}.$$

where

$$W_i^{(\sec)} = W_{gi}^{(\sec)} + W_{ci}^{(\sec)}, \qquad W_{gi}^{(\sec)} = W_{gi,\text{гл}}^{(\sec)}$$

The explicit form of the obtained secular equations of the many body problem with variable masses is as follows

$$\dot{\xi}_i = f\sum_{s=1}^{i-1} m_s \left( \frac{\Pi_{ii}^{is}}{\Lambda_i}\eta_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\eta_s \right) + f\sum_{k=i+1}^{n} m_k \left( \frac{\Pi_{kk}^{ik}}{\Lambda_i}\eta_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\eta_k \right) - \frac{3\ddot{\gamma}_i \Lambda_i^3}{2\gamma_i \mu_{i0}^2}\eta_i,$$

$$\dot{\eta}_i = -f\sum_{s=1}^{i-1} m_s \left( \frac{\Pi_{ii}^{is}}{\Lambda_i}\xi_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\xi_s \right) - f\sum_{k=i+1}^{n} m_k \left( \frac{\Pi_{kk}^{ik}}{\Lambda_i}\xi_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\xi_k \right) + \frac{3\ddot{\gamma}_i \Lambda_i^3}{2\gamma_i \mu_{i0}^2}\xi_i$$

$$\dot{p}_i = -f\sum_{s=1}^{i-1} m_s B_1^{is} \left( \frac{q_i}{4\Lambda_i} - \frac{q_s}{4\sqrt{\Lambda_i\Lambda_s}} \right) - f\sum_{k=i+1}^{n} m_k B_1^{ik} \left( \frac{q_i}{4\Lambda_i} - \frac{q_k}{4\sqrt{\Lambda_i\Lambda_k}} \right) \qquad (17)$$

$$\dot{q}_i = f\sum_{s=1}^{i-1} m_s B_1^{is} \left( \frac{p_i}{4\Lambda_i} - \frac{p_s}{4\sqrt{\Lambda_i\Lambda_s}} \right) + f\sum_{k=i+1}^{n} m_k B_1^{ik} \left( \frac{p_i}{4\Lambda_i} - \frac{p_k}{4\sqrt{\Lambda_i\Lambda_k}} \right)$$

$$\dot{\lambda}_i = \frac{\mu_{i0}^2}{\gamma_i^2 \Lambda_i^3} - \frac{\partial W_i^{(\sec)}}{\partial \Lambda_i}, \qquad \dot{\Lambda}_i = 0$$

here, the index $s$ indicates the inner planet relative to the investigated planet, and the index $k$ indicates the outer one.

Note that when the analogues of eccentricities and the analogues of the inclination of the orbital planes of planets are small enough, the equations of secular perturbations (17) are convenient for describing the dynamic evolution of planetary systems with variable masses.

For $n$ planetary problem of many bodies with variable masses, the system of canonical equations (17) is $4n$ linear non-autonomous equations with complicated coefficients. The explicit form of non-autonomous coefficients in equation (17) is cumbersome, for internal and external perturbing planets they are written separately. From the last equation of (17) follows

$$\Lambda_i = const \qquad \text{or} \qquad a_i = const$$

Note that $\lambda_i$ is calculated after integrating the other equations of the system (17).

Herewith, from the system of differential equations (17) split the system of canonical equations

$$\dot{\xi}_i = f\sum_{s=1}^{i-1} m_s\left(\frac{\Pi_{ii}^{is}}{\Lambda_i}\eta_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\eta_s\right) + f\sum_{k=i+1}^{n} m_k\left(\frac{\Pi_{kk}^{ik}}{\Lambda_i}\eta_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\eta_k\right) - \frac{3\ddot{\gamma}_i\Lambda_i^3}{2\gamma_i\mu_{i0}^2}\eta_i,$$

$$\dot{\eta}_i = -f\sum_{s=1}^{i-1} m_s\left(\frac{\Pi_{ii}^{is}}{\Lambda_i}\xi_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\xi_s\right) - f\sum_{k=i+1}^{n} m_k\left(\frac{\Pi_{kk}^{ik}}{\Lambda_i}\xi_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\xi_k\right) + \frac{3\ddot{\gamma}_i\Lambda_i^3}{2\gamma_i\mu_{i0}^2}\xi_i\ ,$$

$$\dot{p}_i = -f\sum_{s=1}^{i-1} m_s B_1^{is}\left(\frac{q_i}{4\Lambda_i} - \frac{q_s}{4\sqrt{\Lambda_i\Lambda_s}}\right) - f\sum_{k=i+1}^{n} m_k B_1^{ik}\left(\frac{q_i}{4\Lambda_i} - \frac{q_k}{4\sqrt{\Lambda_i\Lambda_k}}\right), \tag{18}$$

$$\dot{q}_i = f\sum_{s=1}^{i-1} m_s B_1^{is}\left(\frac{p_i}{4\Lambda_i} - \frac{p_s}{4\sqrt{\Lambda_i\Lambda_s}}\right) + f\sum_{k=i+1}^{n} m_k B_1^{ik}\left(\frac{p_i}{4\Lambda_i} - \frac{p_k}{4\sqrt{\Lambda_i\Lambda_k}}\right)$$

If, in the decomposition a series of expression (16), we resticte ourselves to the accuracy of the second orders inclusively, relatively small quantities (13), then the system of equations (18) will turn out to be a linear non-autonomous system.

Herewith, approximate formulas for the relationship of various systems of osculating elements, as initial assumptions, have the form

$$\begin{gathered}\xi_i \approx \sqrt{\Lambda_i}e_i\cos\pi_i, \quad \eta_i \approx -\sqrt{\Lambda_i}e_i\sin\pi_i, \quad \Lambda_i e_i^2 \approx \xi_i^2 + \eta_i^2, \quad tg\pi_i = -\eta_i/\xi_i, \\ p_i \approx \sqrt{\Lambda_i}\sin i_i\cos\Omega_i, \quad q_i \approx -\sqrt{\Lambda_i}\sin i_i\sin\Omega_i, \quad \Lambda_i\sin^2 i_i \approx p_i^2 + q_i^2, \quad tg\Omega_i = -q_i/p_i.\end{gathered} \tag{19}$$

The linearity of the system of differential equations (18) in the approximation (19) significantly easies the study of the non-autonomous canonical system of differential equations of secular perturbations (17) in the formulation under consideration.

Then, in turn, the resulting system of canonical equations (18) is divided into two separate subsystems (for details, see [18]). The first subsystem defines the equations of secular perturbations for eccentric elements

$$\begin{aligned}\dot{\xi}_i &= f\sum_{s=1}^{i-1} m_s\left(\frac{\Pi_{ii}^{is}}{\Lambda_i}\eta_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\eta_s\right) + f\sum_{k=i+1}^{n} m_k\left(\frac{\Pi_{kk}^{ik}}{\Lambda_i}\eta_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\eta_k\right) - \frac{3\ddot{\gamma}_i\Lambda_i^3}{2\gamma_i\mu_{i0}^2}\eta_i, \\ \dot{\eta}_i &= -f\sum_{s=1}^{i-1} m_s\left(\frac{\Pi_{ii}^{is}}{\Lambda_i}\xi_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\xi_s\right) - f\sum_{k=i+1}^{n} m_k\left(\frac{\Pi_{kk}^{ik}}{\Lambda_i}\xi_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\xi_k\right) + \frac{3\ddot{\gamma}_i\Lambda_i^3}{2\gamma_i\mu_{i0}^2}\xi_i\end{aligned} \tag{20}$$

The second subsystem defines the equations of secular perturbations for oblique elements.

$$\begin{aligned}\dot{p}_i &= -f\sum_{s=1}^{i-1} m_s B_1^{is}\left(\frac{q_i}{4\Lambda_i} - \frac{q_s}{4\sqrt{\Lambda_i\Lambda_s}}\right) - f\sum_{k=i+1}^{n} m_k B_1^{ik}\left(\frac{q_i}{4\Lambda_i} - \frac{q_k}{4\sqrt{\Lambda_i\Lambda_k}}\right), \\ \dot{q}_i &= f\sum_{s=1}^{i-1} m_s B_1^{is}\left(\frac{p_i}{4\Lambda_i} - \frac{p_s}{4\sqrt{\Lambda_i\Lambda_s}}\right) + f\sum_{k=i+1}^{n} m_k B_1^{ik}\left(\frac{p_i}{4\Lambda_i} - \frac{p_k}{4\sqrt{\Lambda_i\Lambda_k}}\right)\end{aligned} \tag{21}$$

**6. Dimensionless equations of secular perturbations**

In the evolutionary equations (20)–(21) we have transferred to dimensionless variables. The following physical units of measurement are considered for the transition

$$t^* = \tau = \omega_1 t \ , \quad \left(\frac{d}{d\tau}\right) = (\ )' \ , \qquad a_i^* = \frac{a_i}{a_1} \ , \qquad m_i^* = \frac{m_i}{m_{00}} \ , \tag{22}$$

where;

$t^*$ - dimensionless time;

$a_i^*$ - dimensionless distance;

$m_i^*$ - dimensionless mass;

$m_{00} = m_0(t_0) = const$ - the mass of the parent star at the initial moment of time;

$a_1 = a_1(t_0) = const$ - the semi-major axis of the planet $P_1$ at the initial moment of time.

The value $\omega_1$ is defined as follows:

$$\omega_1 = \frac{\sqrt{fm_{00}}}{a_1^{3/2}} = const \tag{23}$$

Accordingly, the period of the planet $P_1$ at the initial time in Earth years is as follows

$$T_1 = \frac{2\pi}{\omega_1} = \frac{2\pi}{\sqrt{fm_{00}}} a_1^{3/2} = const = k_1 \, . \tag{24}$$

Then, using the relations (9)-(11), we can write

$$\xi_i = \xi_i^* \left(fm_{00}a_1\right)^{1/4} \ , \quad \eta_i = \eta_i^* \left(fm_{00}a_1\right)^{1/4} \ , \quad p_i = p_i^* \left(fm_{00}a_1\right)^{1/4} \ , \quad q_i = q_i^* \left(fm_{00}a_1\right)^{1/4} \tag{25}$$

$$\Lambda_i = \sqrt{fm_{00}}\sqrt{a_1}\Lambda_i^* \ , \qquad \frac{3\ddot{\gamma}_i \Lambda_i^3}{2\gamma_i \mu_{i0}^2} = \omega_1 \frac{3\gamma_i''}{2\gamma_i} \frac{\Lambda_i^{*3}}{\mu_{i0}^{*2}} \tag{26}$$

At the same time, dimensionless eccentric and oblique elements have the form

$$\xi_i^* = \sqrt{2\sqrt{\mu_{i0}^*}\sqrt{a_i^*}\left(1-\sqrt{1-e_i^2}\right)}Cos\pi_i, \quad \eta_i^* = -\sqrt{2\sqrt{\mu_{i0}^*}\sqrt{a_i^*}\left(1-\sqrt{1-e_i^2}\right)}Sin\pi_i, \tag{27}$$

$$p_i^* = \sqrt{2\sqrt{\mu_{i0}^*}\sqrt{a_i^*}\sqrt{1-e_i^2}\,(1-Cosi_i)}Cos\Omega_i, \quad q_i^* = -\sqrt{2\sqrt{\mu_{i0}^*}\sqrt{a_i^*}\sqrt{1-e_i^2}\,(1-Cosi_i)}Sin\Omega_i \, , \tag{28}$$

$$\Lambda_i^* = \sqrt{\mu_{i0}^*}\sqrt{a_i^*} \, , \qquad \mu_{i0}^* = 1 + \frac{m_{i0}}{m_{00}} = const \tag{29}$$

Using the introduced notation (22) – (26) and the relations (27) – (29), we transferred to dimensionless variables.

In equations (20)-(21), by dividing the left and right sides by a common multiplier $\omega_1\left(fm_{00}a_1\right)^{1/4} = const$, we obtain the evolutionary equations in dimensionless quantities.

For convenience of writing, omitting the symbol (*), we rewrite equations (20)-(21) in dimensionless variables in the following form

$$\xi_i' = \sum_{s=1}^{i-1} m_s \left( \frac{\Pi_{ii}^{is}}{\Lambda_i}\eta_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i\Lambda_s}}\eta_s \right) + \sum_{k=i+1}^{n} m_k \left( \frac{\Pi_{kk}^{ik}}{\Lambda_i}\eta_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i\Lambda_k}}\eta_k \right) - \frac{3\gamma_i''}{2\gamma_i}\frac{\Lambda_i^3}{\mu_{i0}^2}\eta_i,$$

$$\eta_i' = -\sum_{s=1}^{i-1} m_s \left( \frac{\Pi_{ii}^{is}}{\Lambda_i} \xi_i + \frac{\Pi_{is}^{is}}{\sqrt{\Lambda_i \Lambda_s}} \xi_s \right) - \sum_{k=i+1}^{n} m_k \left( \frac{\Pi_{kk}^{ik}}{\Lambda_i} \xi_i + \frac{\Pi_{ik}^{ik}}{\sqrt{\Lambda_i \Lambda_k}} \xi_k \right) + \frac{3\gamma_i''}{2\gamma_i} \frac{\Lambda_i^3}{\mu_{i0}^2} \xi_i \,, \tag{30}$$

$$p_i' = -\sum_{s=1}^{i-1} m_s B_1^{is} \left( \frac{q_i}{4\Lambda_i} - \frac{q_s}{4\sqrt{\Lambda_i \Lambda_s}} \right) - \sum_{k=i+1}^{n} m_k B_1^{ik} \left( \frac{q_i}{4\Lambda_i} - \frac{q_k}{4\sqrt{\Lambda_i \Lambda_k}} \right),$$

$$q_i' = \sum_{s=1}^{i-1} m_s B_1^{is} \left( \frac{p_i}{4\Lambda_i} - \frac{p_s}{4\sqrt{\Lambda_i \Lambda_s}} \right) + \sum_{k=i+1}^{n} m_k B_1^{ik} \left( \frac{p_i}{4\Lambda_i} - \frac{p_k}{4\sqrt{\Lambda_i \Lambda_k}} \right).$$

At the same time, the expressions $\Pi_{ii}^{is}$, $\Pi_{is}^{is}$, $\Pi_{kk}^{ik}$, $\Pi_{ik}^{ik}$ in equations (30) and the Laplace coefficients retain their form. But, they are already dimensionless quantities.

**Results and Discussion**

As a particular case, the two-planet exosystem *HD 106315* is considered and the evolutionary equations are obtained. Secular perturbations of Poincare elements are described by a system of 8 linear non-autonomous differential equations.

We have explicitly obtained dimensionless evolutionary equations for the particular case when $n = 2$. The planet $P_1$ is affected only by the outer planet $(s = 0, \quad k = 2)$, and for the planet $P_2$ there is only the influence of the inner planet $(s = 1, \quad k = 0)$.

The system of equations of eccentric elements consists of four equations

$$\begin{aligned}
&\xi_1'(\tau) = \left(\beta_2^{1,2} + \beta_3^1\right) \cdot \eta_1(\tau) + \beta_1^{1,2} \cdot \eta_2(\tau), \\
&\eta'_1(\tau) = \left(-\beta_3^1 - \beta_2^{1,2}\right) \cdot \xi_1(\tau) - \beta_1^{1,2} \cdot \xi_2(\tau), \\
&\xi_2'(\tau) = \beta_1^{2,1} \cdot \eta_1(\tau) + \left(\beta_2^{2,1} + \beta_3^2\right) \cdot \eta_2(\tau), \\
&\eta_2'(\tau) = -\beta_1^{2,1} \cdot \xi_1(\tau) + \left(-\beta_3^2 - \beta_2^{2,1}\right) \cdot \xi_2(\tau)
\end{aligned} \tag{31}$$

Similarly, we obtained a system of equations for oblique elements consisting of four equations

$$\begin{aligned}
&p_1'(\tau) = -\beta_5^{1,2} \cdot q_1(\tau) + \beta_4^{1,2} \cdot q_2(\tau), \\
&q_1'(\tau) = \beta_5^{1,2} \cdot p_1(\tau) - \beta_4^{1,2} \cdot p_2(\tau), \\
&p_2'(\tau) = \beta_4^{2,1} \cdot q_1(\tau) - \beta_5^{2,1} \cdot q_2(\tau), \\
&q_2'(\tau) = -\beta_4^{2,1} \cdot p_1(\tau) + \beta_5^{2,1} \cdot p_2(\tau)
\end{aligned} \tag{32}$$

The following notation is introduced in equations (31) and (32)

$$\beta_1^{ik} = \frac{m_k \Pi_{ik}^{ik}}{\sqrt{\Lambda_i \Lambda_k}}, \qquad \beta_2^{ik} = \frac{m_k \Pi_{kk}^{ik}}{\Lambda_i}, \qquad \beta_3^i = -\frac{3\Lambda_i^3}{2\mu_{i0}^2} \frac{\gamma_i''(t)}{\gamma_i},$$

$$\beta_4^{i,k} = \frac{1}{4} \frac{m_k B_1^{i,k}}{\sqrt{\Lambda_i \Lambda_k}}, \qquad \beta_5^{i,k} = \frac{1}{4} \frac{m_k B_1^{i,k}}{\Lambda_i},$$

$$\Pi_{ik}^{ik}=\frac{1}{8}\left(9B_0^{ik}+B_2^{ik}\right)-\frac{9\left(1+\alpha_{ik}^2\right)}{8\alpha_{ik}}C_0^{ik}+\frac{21}{16}C_1^{ik}+\frac{3\left(1+\alpha_{ik}^2\right)}{8\alpha_{ik}}C_2^{ik}+\frac{3}{16}C_3^{ik},$$

$$\Pi_{kk}^{ik}=-\frac{3}{4\alpha_{ik}}B_0^{ik}-\frac{1}{2}B_1^{ik}+\frac{15\alpha_{ik}^2+6}{8\alpha_{ik}^2}C_0^{ik}-\frac{3}{2\alpha_{ik}}C_1^{ik}-\frac{9}{8}C_2^{ik},$$

$$B_0^{ik}=\frac{2a_i\gamma_i}{\pi\left(a_k\gamma_k\right)^2}\int_0^{\pi}\frac{d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{3/2}},\qquad B_1^{ik}=\frac{2a_i\gamma_i}{\pi\left(a_k\gamma_k\right)^2}\int_0^{\pi}\frac{\cos\lambda d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{3/2}},$$

$$B_2^{ik}=\frac{2a_i\gamma_i}{\pi\left(a_k\gamma_k\right)^2}\int_0^{\pi}\frac{\cos2\lambda d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{3/2}},$$

$$C_0^{ik}=\frac{2\left(a_i\gamma_i\right)^2}{\pi\left(a_k\gamma_k\right)^3}\int_0^{\pi}\frac{d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{5/2}},\qquad C_1^{ik}=\frac{2\left(a_i\gamma_i\right)^2}{\pi\left(a_k\gamma_k\right)^3}\int_0^{\pi}\frac{\cos\lambda d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{5/2}},$$

$$C_2^{ik}=\frac{2\left(a_i\gamma_i\right)^2}{\pi\left(a_k\gamma_k\right)^3}\int_0^{\pi}\frac{\cos2\lambda d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{5/2}},\qquad C_3^{ik}=\frac{2\left(a_i\gamma_i\right)^2}{\pi\left(a_k\gamma_k\right)^3}\int_0^{\pi}\frac{\cos3\lambda d\lambda}{\left(1+\alpha_{ik}^2-2\alpha_{ik}\cos\lambda\right)^{5/2}},$$

where the conditions are fulfilled for the outer planet $\left(i<k\right)$

$$\alpha_{ik}=\frac{\gamma_i a_i}{\gamma_k a_k}=\alpha_{ik}\left(t\right)<1.$$

For the inner planet , the notation are as follows

$$\beta_1^{is}=\frac{m_s\Pi_{is}^{is}}{\sqrt{\Lambda_s\Lambda_i}},\qquad \beta_2^{is}=\frac{m_s\Pi_{ii}^{is}}{\Lambda_i},\qquad \beta_3^{i}=-\frac{3\Lambda_i^3}{2\mu_{i0}^2}\frac{\gamma_i^{''}\left(t\right)}{\gamma_i},$$

$$\beta_4^{i,\mathrm{s}}=\frac{1}{4}\frac{m_sB_1^{i,\mathrm{s}}}{\sqrt{\Lambda_s\Lambda_i}},\qquad \beta_5^{i,\mathrm{s}}=\frac{1}{4}\frac{m_sB_1^{i,\mathrm{s}}}{\Lambda_i},$$

$$\Pi_{is}^{is}=\frac{1}{8}\left(9B_0^{is}+B_2^{is}\right)-\frac{9\left(1+\alpha_{is}^2\right)}{8\alpha_{is}}C_0^{is}+\frac{21}{16}C_1^{is}+\frac{3\left(1+\alpha_{is}^2\right)}{8\alpha_{is}}C_2^{is}+\frac{3}{16}C_3^{is},$$

$$\Pi_{ii}^{is}=-\frac{3\alpha_{is}}{4}B_0^{is}-\frac{1}{2}B_1^{is}+\frac{15+6\alpha_{is}^2}{8}C_0^{is}-\frac{3\alpha_{is}}{2}C_1^{is}-\frac{9}{8}C_2^{is},$$

$$B_0^{is}=\frac{2a_s\gamma_s}{\pi\left(a_i\gamma_i\right)^2}\int_0^{\pi}\frac{d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{3/2}},\qquad B_1^{is}=\frac{2a_s\gamma_s}{\pi\left(a_i\gamma_i\right)^2}\int_0^{\pi}\frac{\cos\lambda d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{3/2}},$$

$$B_2^{is}=\frac{2a_s\gamma_s}{\pi\left(a_i\gamma_i\right)^2}\int_0^{\pi}\frac{\cos2\lambda d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{3/2}},$$

$$C_0^{is}=\frac{2\left(a_s\gamma_s\right)^2}{\pi\left(a_i\gamma_i\right)^3}\int_0^{\pi}\frac{d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{5/2}},\qquad C_1^{is}=\frac{2\left(a_s\gamma_s\right)^2}{\pi\left(a_i\gamma_i\right)^3}\int_0^{\pi}\frac{\cos\lambda d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{5/2}},$$

$$C_2^{is}=\frac{2\left(a_s\gamma_s\right)^2}{\pi\left(a_i\gamma_i\right)^3}\int_0^{\pi}\frac{\cos 2\lambda d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{5/2}},\qquad C_3^{is}=\frac{2\left(a_s\gamma_s\right)^2}{\pi\left(a_i\gamma_i\right)^3}\int_0^{\pi}\frac{\cos 3\lambda d\lambda}{\left(1+\alpha_{is}^2-2\alpha_{is}\cos\lambda\right)^{5/2}},$$

where the conditions are fulfilled for the inner planet $\left(s<i\right)$

$$\alpha_{is}=\frac{\gamma_s a_s}{\gamma_i a_i}=\alpha_{is}\left(t\right)<1$$

Further, the differential equations of secular perturbations will be investigated numerically.

## Conclusion

Linear non-autonomous differential equations are obtained, defining secular perturbations of exoplanetary systems with variable masses. These differential equations of secular perturbations can be used for either $n$ planetary problem with variable masses. The obtained differential equations of secular perturbations can be investigated numerically. The obtained differential equations of secular perturbations can be investigated numerically. The differential equations of secular perturbation for the exosystem *HD 106315* (spectral type *F5V*) were written explicitly.


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# COMPANIONS OF FIELDS OF RATIONAL AND REAL ALGEBRAIC NUMBERS

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**Abstract**

Companions of the field of rational numbers and a real-closed algebraic expansion of the field of rational numbers are studied. The description of existentially closed companions of a real-closed algebraic expansion of a field of rational numbers refers to the field of study of classical algebraic structures. The general theory of companions and existentially closed companions, built on the basis of Fraisse's classes in the works of A.T. Nurtazin, is included in the classical field of existentially closed theories in model theory.

**Keywords:** companion, field of rational numbers, real closed field, algebraic field extension, algebraic element, transcendental element.

## Introduction

The theory of existential closure arose in the middle of the twentieth century in the works of one of the recognized classics of model theory Abraham Robinson [1], [2], as well as in the works [3] – [8]. Currently, it is one of the most significant and most developed areas of modern model theory. In previous studies, the most basic form of the concept of companion theory, widely known in the theory of existential closure, is introduced and studied. The criterion of the countable categoricity of this companion theory was found. Some properties of existentially closed and forcing companions have been studied [3] – [9]. Another promising approach to constructing the theory of existentially closed structures based on Fraisse's works [6] is developed in [9] - [16].

Naturally, the development of the general theory of existentially closed companions should be accompanied by the study of classical structures and theories. Historically, one of the classical mathematical objects is the field of rational numbers and the field of all algebraic real numbers. The work studies companion extensions of the named fields. This study is an example of studying a classical object through an approach developed by Nurtazin A.T. and based on Fraisse classes.

## The aim and objectives of the study

The purpose of the work is to describe the companions of the fields of rational and real numbers. For this, for each of the named fields, companions of two types are described, namely, purely transcendental extensions and subsequent algebraic extensions of purely transcendental extensions.

**Literature review and problem statement**

Let: $\mathbf{Q}$ be the field of rational numbers; $\mathbf{R}$ is a real closed algebraic extension of the field $\mathbf{Q}$; $\mathbf{P}[\bar{x}]$, $\mathbf{P}(\bar{x})$ are, respectively, the ring of polynomials and the field of quotients over the field $\mathbf{P}$ of independent variables $\bar{x}=(x_1,...,x_n)$. All used and not given definitions and designations are taken from the monograph [15]. The basic concept of a companion: two models of the same signature are called companions if for any finite submodel of one of them, there is an isomorphic finite submodel in the other. Consider some basic companions of the field $\mathbf{P}$. The class of companions of the field $\mathbf{P}$ is denoted by $C(\mathbf{P})$|.

Obviously, purely algebraic field extensions are not its companions. In turn, the following theorem is devoted to the first basic companions of the field, which are purely transcendental extensions.

**Materials and methods**

The work uses classical algebraic methods for constructing transcendental and algebraic extensions of this field. To describe a simple algebraic extension $\mathbf{P}(\bar{x})[x]/f$ a purely transcendental extension $\mathbf{P}(\bar{x})$ of the field $\mathbf{P}$, as a companion of $f$, the set of zeros of the polynomial n is studied and a method for recognizing the companions of the original field $\mathbf{P}$ is indicated.

**Results and Discussion**

COMPANIONS

Field of quotients

THEOREM 1. Let $\mathbf{P}$ have a field of characteristic 0. Then, the field of quotients $\mathbf{P}(\bar{x})$ is a companion of the field $\mathbf{P}$ i.e. $\mathbf{P}(\bar{x})$|$\equiv C(\mathbf{P})$|.

Proof. Each finite submodel of the ring $\mathbf{P}$ is a submodel of the field $\mathbf{P}(\bar{x})$. Conversely, let there be a finite submodel $F$ of the field $\mathbf{P}(\bar{x})$, we can assume that $F$ is given by a finite system of equalities and inequalities $(\neq)$, the right and left parts of which contain elements $F$ and the operations of addition and multiplication of the field $\mathbf{P}(\bar{x})$. We transform this system of equalities and inequalities into an equivalent system $\mathbf{P}(\bar{x})$ $\&S_i(\bar{x})=0\&\&T_j(\bar{x})\neq 0$, where $S_i(\bar{x})=f_i(\bar{x})\big/g_i(\bar{x})$, $T_j(\bar{x})=u_j(\bar{x})\big/v_j(\bar{x})$ here $f_i(\bar{x}),g_i(\bar{x}),u_j(\bar{x}),v_j(\bar{x})\in\mathbf{P}[\bar{x}],g_i(\bar{x}),v_j(\bar{x})\neq 0$

The latter system is equivalent in $\mathbf{P}[\bar{x}]$ system of equations and one inequality $\&(f_i(\bar{x})=0)\&T(\bar{x})=\prod g_i(\bar{x})u_j(\bar{x})v_j(\bar{x})\neq 0$, where $f_i(\bar{x}),g_i(\bar{x}),u_j(\bar{x}),v_j(\bar{x})\in\mathbf{P}[\bar{x}],g_i(\bar{x}),v_j(\bar{x})\neq 0$.

Let us prove the existence of a set $\bar{a}=(a_1,...,a_n)\in\mathbf{P}$, such that in $\mathbf{P}$ is fulfilled

$\&(f_i(\bar{a})=0)\&T(\bar{a})\neq 0$ ($\mathbf{P}$|$=\&(f_i(\bar{a})=0)\&T(\bar{a})\neq 0$). For any choice of $\bar{a}=(a_1,...,a_n)\in\mathbf{P}$, the equality $\&f_i(\bar{a})=0$ is obvious, since all the coefficients of the variables and the free terms in $\&f_i(\bar{x})$ are equal to zero. By induction on the number of variables $n$, we prove the existence of $\bar{a}=(a_1,...,a_n)\in\mathbf{P}$, which is fulfilled | $\mathbf{P}$ |$=T(\bar{a})\neq 0$. For $n=1$ we choose $a_1\in\mathbf{P}$ which is not a root $T(x_1)$.

Step of induction. Let $\bar{a}_{n-1}=(a_1,...,a_{n-1})\in\mathbf{P}$ be such that the higher coefficient of the polynomial $T(\bar{x})$ considered as a polynomial of $x_1$ over the ring $\mathbf{P}[\bar{x}_{n-1}]$ is not zero. Then, the polynomial $T(\bar{a}_{n-1},x_n)\neq 0$ and hence there is $a_n\in\mathbf{P}$, such that | $\mathbf{P}$ |$=T(\bar{a})\neq 0$ is satisfied. So $\mathbf{P}$|$=\&(f_i(\bar{a})=0)\&T(\bar{a})\neq 0$ is done.

The theorem has been proved.

CONSEQUENCE 1. Let $R_i(\bar{x}), S_j(\bar{x}) \in \mathbf{P}(\bar{x})$, here $\mathbf{P}$ is formally a real field. The system $\&R_i(\bar{x}) = 0 \& \& S_j(\bar{x}) \neq 0$ is equivalent in $\mathbf{P}[\bar{x})$ system of one equation and one inequality $P_1(\bar{x}) = 0 \& P_2(\bar{x}) \neq 0$ where $P_1(\bar{x}), P_2(\bar{x}) \in \mathbf{P}[\bar{x}]$.

Simple algebraic extensions

Let $A_f = \{ (\bar{a}, a) | f(\bar{a}, a) = 0, \ \bar{a}, a \in \mathbf{P}\}$ be an annihilator $f$, where $f(\bar{x}, x) \in \mathbf{P}(\bar{x})[x]$. When considering algebraic extensions of the field $\mathbf{P}(\bar{x})$ by means of an irreducible polynomial $f(\bar{x}, x) \in \mathbf{P}(\bar{x})[x]$, we will assume that $f(\bar{x}, x) \in \mathbf{P}[\bar{x}, x]$ and has content 1, as a polynomial in $x$ over the ring $\mathbf{P}[\bar{x}]$.

Then, the divisibility of any polynomial $g(\bar{x}, x) \in \mathbf{P}(\bar{x})[x]$ by $f(\bar{x}, x)$ is equivalent to the divisibility of a polynomial $g'[\bar{x}, x] \in \mathbf{P}(\bar{x})[x]$ such that $g(\bar{x}, x) = g'(\bar{x}, x)\frac{p(\bar{x})}{q(\bar{x})}$, where $g'[\bar{x}, x]$ is a polynomial with content 1 over the ring $\mathbf{P}[\bar{x}]$, and $q(\bar{x})$ is the least common multiple of the denominators of the coefficients in $g(\bar{x}, x)$.

Next, the field $\mathbf{P}$ is one of the fields $\mathbf{Q}, \mathbf{R}$.

Consider a simple algebraic extension $\mathbf{P}(\bar{x})[x] / f$ of the field that is the companion of the field $\mathbf{P}$.

THEOREM 2. Let $f(\bar{x}, x)$ be an irreducible polynomial over the field $\mathbf{P}(\bar{x})$. Then, the algebraic extension $\mathbf{P}(\bar{x})[x] / f$ of the field $\mathbf{P}(\bar{x})$ is a companion $\mathbf{P}$ if and only if the condition is met: if an arbitrary polynomial $g(\bar{x}, x)$ is not divisible by $f(\bar{x}, x)$, then there is a tuple $(\bar{a}, a) \in \mathbf{P}$ such that $g(\bar{a}, a) \in A_f \setminus A_g$ is satisfied.

Proof. Necessity. Let $\{c_1, ..., c_k\} \in \mathbf{P}$ be all coefficients of polynomials $g(\bar{x}, x)$ and $f(\bar{x}, x)$. By the primitive element theorem, there exists an irreducible polynomial $p(y) \in \mathbf{Q}[y]$ and an element $c^* \in \mathbf{P}$ such that $c_i = q_i(c^*), q_i(y) \in \mathbf{Q}[y]$.

Let us replace each of the elements $c_1, ..., c_k$ by $q_i(c^*)$ in the polynomials $g(\bar{x}, x)$ and $f(\bar{x}, x)$, and obtain $g^*(\bar{x}, x) = g(\bar{x}, x)$ and $f^*(\bar{x}, x) = f(\bar{x}, x)$, $g^*(\bar{x}, x), f^*(\bar{x}, x) \in \mathrm{Q}(\bar{x})[x]$.

We have that $g^*(\bar{x}, x)$ is not divisible by $f^*(\bar{x}, x)$ in $\mathbf{P}(\bar{x})[x]$ ( $\mathbf{P}(\bar{x})[x] \models f^*(\bar{x}, x) \not| \, g^*(\bar{x}, x)$ ) $\Leftrightarrow$ $\mathbf{P}(\bar{x})[x] \models f^*(\bar{x}, x) \not| \, g^*(\bar{x}, x) \Rightarrow$ there is $(\bar{a}, a) \in \mathbf{P}$ such that $g^*(\bar{a}, a) \in A_{f^*} \setminus A_{g^*} \Leftrightarrow$ $g(\bar{a}, a) \in A_f \setminus A_g$ is satisfied. The necessity has been proved.

Sufficiency. By virtue of consequence 1, we can assume that the existential sentence is true in $\mathbf{P}(\bar{x})[x] / f$, after substituting solutions in it is one equality and one inequality $\mathbf{P}(\bar{x})[x] / f \models h_1(\bar{x}, y_f) = 0 \& h_2(\bar{x}, y_f) \neq 0$, where $h_1(\bar{x}, y), h_2(\bar{x}, y) \in \mathbf{P}[\bar{x}, y]$.

Then there is a tuple $(\bar{a}, a) \in \mathbf{P}$ such that $h_1(\bar{a}, a) \in A_f, h_2(\bar{a}, a) \in A_f \setminus A_g$ is satisfied. Thus, $\mathbf{P} \models h_1(\bar{x}, y_f) = 0 \& h_2(\bar{x}, y_f) \neq 0$ is satisfied. Sufficiency, and with it the theorem has been proved.

Let $I(A_f) = \{ g | g \in \mathbf{P}(\bar{x})[x], \ A_f \subseteq A_g \}$, where $f \in \mathbf{P}(\bar{x})[x]$.

PROPOSITION 1. Let $f(\bar{x}, x)$ be an irreducible polynomial over a field $\mathbf{P}(\bar{x})$. Then the following two properties of the polynomial $f(\bar{x}, x)$ are equivalent:

a) If an arbitrary polynomial $g(\bar{x},x)$ is not divisible by $f(\bar{x},x)$ then there is a tuple $(\bar{a},a)\in\mathbf{P}$ that satisfies $g(\bar{a},a)\in A_f\setminus A_g$;

b) The equality $I(A_f)=(f)$ is fulfilled.

Proof. $a)\Rightarrow b)$. Definitely, $I(A_f)\supseteq(f)$. Let $g\in I(A_f)$ and $g\notin(f)$, moreover, n, then by assumption $a)$ there is a set $(\bar{a},a)\in A_f$ such that $g(\bar{a},a)\neq 0$ is a contradiction. So, $I(A_f)\subseteq(f)$.

$b)\Rightarrow a)$. Let $g(\bar{x},x)$ not be divisible by $f(\bar{x},x)$. According to the condition $I(A_f)=(f)$. From here $g(\bar{x},x)\notin I(A_f)$ and hence there is a tuple $(\bar{a},a)\in\mathbf{P}$, which is done $g(\bar{a},a)\in A_f\setminus A_g$. The proposition has been proved.

Here is one necessary property of the companion $\mathbf{P}(\bar{x})[x]/f$ of the field $\mathbf{P}$.

PROPOSITION 2. Let $f(\bar{x},x)$ be an irreducible polynomial over a field $\mathbf{P}(\bar{x})$. Then, if the algebraic extension $\mathbf{P}(\bar{x})[x]/f$ of the field $\mathbf{P}(\bar{x})$ is a companion of $\mathbf{P}$,then each projection of the annihilator $A_f$ is an infinite set.

Proof. Assume the opposite, and let the projection $A_f$ be, for example, finite in the variable $x_1$, i.e. $A_f^1=\{(c_1,...,c_k)\mid\exists\bar{b}_1,...,\bar{b}_k)\mid(c_1,\bar{b}_1),...,(c_k,\bar{b}_k)\in A_f,\bar{b}_i=(b_{1i},...,b_{ni}),b_{ji},c_i\in\mathbf{P}\}$ Then it is fulfilled: $\mathbf{P}[\bar{x})[x]/f\models\exists u_1,...,u_n u(f(u_1,u_2,...,u_n,u)=0\&\&_i u_1\neq c_i)$ but the same sentence is false in $\mathbf{P}$. Contradiction. In the case when $A_f$ is empty, the same proposition is true in $\mathbf{P}(\bar{x})[x]/f$ but false in $\mathbf{P}$. The proposition is proved.

In the case of a simple algebraic extension $\mathbf{P}(x_1)[x]/f$ of the field $\mathbf{P}(x_1)$, Proposition 2 is inverted.

PROPOSITION 3. Let $f(x_1,x)$ be an irreducible polynomial over a field $\mathbf{P}(x_1)$. Then, an algebraic extension $\mathbf{P}(x_1)[x]/f$ from the field $\mathbf{P}(x_1)$ is a companion of $\mathbf{P}$, if and only if each projection of the annihilator $A_f$ onto each of the coordinate axes $Ox_1, Ox$ is an infinite set.

Proof. The necessity was proved in Proposition 2.

Sufficiency. By Proposition 1 and Theorem 2, it suffices to prove the equality $I(A_f)=(f)$. It's obvious that $I(A_f)\supseteq(f)$. Let us prove the inclusion $I(A_f)\subseteq(f)$

Suppose, $I(A_f)\not\subseteq(f)$, and $g(x_1,x)\in I(A_f)\setminus(f)$. Let $d(x_1,x)$ be the greatest common divisor of polynomials $g(x_1,x)$ and $f(x_1,x)$ over a field $\mathbf{P}(x_1)$. Note that due to the fact $f(x_1,x)$ that the irreducible polynomial $d(x_1,x)$ is an element of the field $\mathbf{P}(x_1)$,we denote it by $d(x_1)$. There are polynomials $p(x_1,x),q(x_1,x)\in\mathbf{P}(x_1)[x]$, such that the equality $p(x_1,x)g(x_1,x)+q(x_1,x)f(x_1,x)=d(x_1)$ is satisfied in the ring $\mathbf{P}(x_1)[x]$. Since $A_g\supseteq A_f$, and by condition, the projection of $A_f$ onto the coordinate axis $Ox_1$ is an infinite set, it follows from the last representation of the polynomial $d(x_1)$ in the variable $x_1$ that it has an infinite set of zeros. Contradiction, sufficiency and with it the proposition have been proved.

Let us give a criterion for the mismatch of the ideals $I(A_f)$ and $(f)$.

PROPOSITION 4. Let $f\in\mathbf{P}(\bar{x})[x]$ be an irreducible polynomial over a field $\mathbf{P}(\bar{x})$. The ideals $I(A_f)$ and $(f)$ do not match with $I(A_f)\neq(f)$ if and only if there exists a polynomial $c(\bar{x})\in\mathbf{P}[\bar{x}]$

such that , to the Cartesian power $\mathbf{P}[^{n+1}$ $c(\bar{x}) \in I(A_f)$ is satisfied, i.e. the cylindrical surface $A_c$ in affine space $\mathbf{P}[^{n+1}$ contains $A_f$.

Proof. Necessity. Let be $I(A_f) \neq (f)$. Since $I(A_f) \supseteq (f)$ is always satisfied, then $I(A_f) \not\subseteq (f)$ takes place. Then let be $g(\bar{x}, x) \in I(A_f) \backslash (f)$.

Since $f(\bar{x}, x)$ the field $\mathbf{P}(\bar{x})$, is irreducible, the greatest common divisor $c$ of polynomials $f$ and $g$ can be represented as $u(\bar{x}, x) f(\bar{x}, x) + v(\bar{x}, x) g(\bar{x}, x) = c(\bar{x})$, where $u(\bar{x}, x), v(\bar{x}, x) \in \mathbf{P}[\bar{x}, x], c(\bar{x}) \in \mathbf{P}[\bar{x}]$ . From the last relation we deduce that $c(\bar{x}) \in I(A_f)$. The necessity has been proved.

Sufficiency. Let be $c(\bar{x}) \in I(A_f)$ and $I(A_c) \supseteq I(A_f)$. We have a polynomial $c(\bar{x})$ as a polynomial of zero degree in $x$ is not divisible by a polynomial $f(\bar{x}, x)$ of degree not less than the first in the same variable, therefore $c(\bar{x}) \in I(A_c) \setminus I(A_f)$.

Sufficiency has been proved.

Consider an example of the mismatch of ideals $I(A_f)$ and $(f)$.

EXAMPLE 1. An example of a simple algebraic extension of the non-companion field of rational numbers. Consider in an affine space $\mathbf{Q}^3$ the curve $S$, given by the intersection of the cylinder $x^2 + y^2 - 1 = 0$ and the plane $x + y + z = 0$.

The curve $S$ over the field $\mathbf{Q}$ can be equivalently given as the annihilator of $A_f = \{ (a,b,c) | f(a,b,c) = 0,\ a,b,c \in \mathbf{Q} \}$, of the polynomial $f(x,y,z) = (x^2 + y^2 - 1)^2 + (x + y + z)^2$ over the field $\mathbf{Q}$. Let us write the polynomial $f(x,y,z)$ in powers of the variable $z$: $f(x,y,z) = z^2 + 2(x+y)z + x^4 + y^4 + 2x^2y^2 - x^2 - y^2 + 2xy + 1$. Let us prove that $f(x,y,z)$ is irreducible. Suppose that $f(x,y,z) = (z - p(x,y))(z - q(x,y))$ . Obviously $p(x,y) \neq q(x,y)$, , then for a pair $(a,b) \in \mathbf{Q}$ such that $p(a,b) \neq q(a,b)$ is fulfilled by $f(a,b,p(a,b)) = 0$ and $f(a,b,q(a,b)) = 0$. Since from the equation $x + y + z = 0$, the value of $c = -a - b$ is uniquely determined, then $p(a,b) = q(a,b)$. A contradiction, thus $f(x,y,z)$ is irreducible.

Thus, the cylindrical surface $A_g$ where $g = x^2 + y^2 - 1$ in the affine space $\mathbf{Q}[^3$ contains $A_f$, therefore, $I(A_f) \neq (f)$ and by Proposition 1 and Theorem 2, we obtain a simple extension $\mathbf{Q}(x,y)[z]/f$ of the field $\mathbf{Q}(x,y)$ that is not a companion of the field $\mathbf{Q}$.

An immediate consequence of Proposition 1 and Theorem 2 is the following description, in terms of ideals, of a simple algebraic extension $\mathbf{P}(\bar{x})[x]/f$ of the field $\mathrm{P}(\bar{x})$, that is a companion of the field $\mathbf{P}$.

THEOREM 3. Let $f(\bar{x}, x)$ be an irreducible polynomial over a field $\mathbf{P}(\bar{x})$. An algebraic extension $\mathbf{P}(\bar{x})[x]/f$ of the field $\mathbf{P}(\bar{x})$ is a companion $\mathbf{P}$ if and only if the ideal $I(A_f)$ is the same as the ideal $(f)$.

Algebraic extensions

Let $\mathbf{P}(\bar{x})[y]/f$ and $\mathbf{P}(\bar{x})[y]/f/g$ (here $\mathbf{P}(\bar{x})[y]/f/g = (\mathbf{P}(\bar{x})[y]/f)[z]/g$ be simple algebraic extensions of the fields $\mathbf{P}(\bar{x})$ and $\mathbf{P}(\bar{x})[y]/f$ respectively, and be irreducible polynomials over the fields $\mathbf{P}(\bar{x})$ and $\mathbf{P}(\bar{x})[y]/f$ respectively. Let be $I(A_{fg}) = \{ h | h \in \mathbf{P}(\bar{x})[y,z],\ A_{fg} \subseteq A_h \}$, $A_{fg} = \{ (\bar{a}, b, c) \in \mathbf{P} | (\bar{a}, b) \in A_f, (\bar{a}, b, c) \in A_g \}$

It is obvious that $I(A_{fg})$ is an ideal in the ring $\mathbf{P}(\bar{x})[y,z]$, generated by polynomials $f(\bar{x},y)$ и $g(\bar{x},y,z)$ i.e. $I(A_{fg})=(f,g)$.

Consider now an algebraic extension of a simple algebraic extension of the field $\mathbf{P}(\bar{x})$.

THEOREM 4. The algebraic extension $\mathbf{Q}(\bar{x})[y]/f/g$ of the field $\mathbf{P}(\bar{x})[y]/f$ is a companion $\mathbf{P}$ if and only if, for any polynomial $h(\bar{x},y,z)\in\mathbf{P}(\bar{x})[y,z]$ such that $h(\bar{x},y,z)\notin(f,g)$ there is a tuple $(\bar{a},b,c)\in\mathbf{P}$, such that $(\bar{a},b,c)\in A_{fg}\setminus A_h$.

Proof. Necessity. In the algebraic extension $\mathbf{P}(\bar{x})[y]/f/g$ of the field $\mathbf{P}(\bar{x})$, the system $f(\bar{x},y_f)=0\,\&\,g(\bar{x},y_f,z_g)=0\&h(\bar{x},y_f,z_g)\neq 0$ is satisfied; therefore, there is a tuple $(\bar{a},b,c)\in\mathbf{P}$ $(\bar{a},b,c)\in A_{fg}\setminus A_h$.

Sufficiency. Let $\mathbf{P}(\bar{x})[y]/f/g\models\exists u...\exists v\varphi(\bar{x},y_f,z_g,u,...,v)$ be fulfilled. Since $u,...,v\in\mathbf{P}(\bar{x})[y]/f/g$ we assume that this formula is equivalent in the algebraic extension $\mathbf{P}(\bar{x})[y]/f/g$ of the field $\mathbf{P}(\bar{x})$ to the system $h_1(\bar{x},y_f,z_g)=0\&h_2(\bar{x},y_f,z_g)\neq 0$. Then, there is a tuple $(\bar{a},b,c)\in\mathbf{P}$ such that $(\bar{a},b,c)\in A_{fg}\setminus A_h$. The necessity, and with it the theorem, has been proved.

THEOREM 5. An algebraic extension $\mathbf{Q}(\bar{x})[y]/f/g$ of a field $\mathbf{P}(\bar{x})[y]/f$ is a companion of $\mathbf{P}$ if and only if the ideal $I(A_{fg})$ is the same as the ideal $(f,g)$.

Proof. Necessity. Let be $h(\bar{x},y,z)\notin(f,g)$. Then, in the algebraic extension $\mathbf{P}(\bar{x})[y]/f/g$ of the field $\mathbf{P}(\bar{x})$ the system $f(\bar{x},y_f)=0\,\&\,g(\bar{x},y_f,z_g)=0\&h(\bar{x},y_f,z_g)\neq 0$ is satisfied. Hence, in the companion $\mathbf{P}$ there is a tuple $(\bar{a},b,c)\in\mathbf{P}$, so that $(\bar{a},b,c)\in A_{fg}\setminus A_h$ and $h(\bar{a},b,c)\notin(f,g)$ hence. If $h(\bar{x},y,z)\in(f,g)$, then obviously $h(\bar{x},y,z)\in I(A_{fg})$. The necessity has been proved.

Sufficiency. Let $\mathbf{P}(\bar{x})[y]/f/g\models\exists u...\exists v\varphi(\bar{x},y_f,z_g,u,...,v)$ be fulfilled. Since $u,...,v\in\mathbf{P}(\bar{x})[y]/f/g$ we will assume that this formula is equivalent in the algebraic extension $\mathbf{P}(\bar{x})[y]/f/g$ of the field $\mathbf{P}(\bar{x})$ to the system $h_1(\bar{x},y_f,z_g)=0\&h_2(\bar{x},y_f,z_g)\neq 0$. By definition, it follows from $h_2(\bar{x},y_f,z_g)\neq 0$ that $h_2(\bar{x},y,z)\notin I(A_{fg})$. Then it follows from the equality $I(A_{fg})=(f,g)$, that there is a tuple $(\bar{a},b,c)\in\mathbf{P}$, such that $(\bar{a},b,c)\in A_{fg}\setminus A_h$ and satisfies $\mathbf{P}\models h_1(\bar{a},b,c)=0\&h_2(\bar{a},b,c)\neq 0$. Sufficiency, and with it the theorem has been proved.

Let us formulate a description of the companions of the field $\mathbf{P}$ in the general case.

Let $B=\{\beta_1,\beta_2,....\}$, $X=\{x_1,x_2,....\}$ be countable sets of independent variables, $\bar{\beta}=(\beta_1,...,\beta_m)$, $\bar{x}_n=(x_1,...,x_n)$, $\bar{f}_n=(f_1,...,f_n)$, where $f_i(\bar{\beta},\bar{x}_{i-1}^{\bar{f}_{i-1}},x_i)$ is irreducible in the ring $\mathbf{P}(\bar{\beta})[\bar{x}_{i-1}^{\bar{f}_{i-1}}][x_i]$, where $\bar{x}_i^{\bar{f}_i}=(x_1^{f_1},...,x_i^{f_i})$, $x_i^{f_i}$ is the root of the polynomial $f_i(\bar{\beta},\bar{x}_{i-1}^{\bar{f}_{i-1}},x_i)\in\mathbf{P}(\bar{\beta})[\bar{x}_{i-1}^{\bar{f}_{i-1}}][x_i]$ over the field $f_i(\bar{\beta},\bar{x}_{i-1}^{\bar{f}_{i-1}},x_i)\in\mathbf{P}(\bar{\beta})[\bar{x}_{i-1}^{\bar{f}_{i-1}}]$. The field $\mathbf{P}(\bar{\beta})[\bar{x}_i^{\bar{f}_i}]$ is defined as follows. Let's put $\mathbf{P}(\bar{\beta})[\bar{x}_1^{\bar{f}_1}]=\mathbf{P}(\bar{\beta})[x_1]/f_1(\bar{\beta},x_1)$, $\mathbf{P}(\bar{\beta})[\bar{x}_2^{\bar{f}_2}]=\mathbf{P}[\bar{\beta}][\bar{x}_1^{\bar{f}_1}][x_2]/f_2(\bar{\beta},\bar{x}_1^{\bar{f}_1},x_2)$. We define $\mathbf{P}(\bar{\beta})[\bar{x}_n^{\bar{f}_n}]=\mathbf{P}(\bar{\beta})[\bar{x}_{n-1}^{\bar{f}_{n-1}}][x_n]/f_n(\bar{\beta},\bar{x}_{n-1}^{\bar{f}_{n-1}},x_n)$ by induction. Thus, in the sequence $\mathbf{P}(\bar{\beta})[\bar{x}_1^{\bar{f}_1}],\mathbf{P}(\bar{\beta})[\bar{x}_2^{\bar{f}_2}],...,\mathbf{P}(\bar{\beta})[\bar{x}_n^{\bar{f}_n}]$ - each subsequent field $\mathbf{P}(\bar{\beta})[\bar{x}_{i+1}^{\bar{f}_{i+1}}]$ is a simple algebraic extension

of the previous field by means of an irreducible polynomial $f_{i+1}(\bar{\beta}, \bar{x}_i^{\bar{f}_i}, x_{i+1})$. We define the corresponding ideals $I(A_{\bar{f}_n}) = \{ h \in \mathbf{P}(\bar{\beta})[\bar{x}_n^{\bar{f}_n}] \mid A_{\bar{f}_n} \subseteq A_h \}$, $A_{\bar{f}_n} = \{(\bar{a}, \bar{b}_n) \in \mathbf{P} \mid (\bar{a}, b_{,1}) \in A_{f_1}, ..., (\bar{a}, b_1, ..., b_n) \in A_{f_n}, \bar{b}_n = (b_1, ..., b_n)\}$, where each $f_i \in \mathbf{P}(\bar{\beta})[\bar{x}_{i-1}^{\bar{f}_{i-1}}][x_i]$, $i = 1, ..., n$ is irreducible over the corresponding field $\mathbf{Q}(\bar{\beta})[\bar{x}_{i-1}^{\bar{f}_{i-1}}]$.

Let us give a general description of the companions of the field $\mathbf{P}$.

THEOREM 6. An algebraic extension $\mathbf{P}(\bar{\beta})[\bar{x}_n^{\bar{f}_n}] = \mathbf{P}(\bar{\beta})[\bar{x}_{n-1}^{\bar{f}_{n-1}}][x_n] / f_n(\bar{\beta}, \bar{x}_{n-1}^{\bar{f}_{n-1}}, x_n)$ of a field $\mathbf{P}(\bar{\beta})$ is a companion $\mathbf{P}$ if and only if the ideal $I(A_{\bar{f}_n})$ coincides with the ideal $(f_1, ..., f_n)$.

The proof is a general reproduction of the proof of Theorem 5.

**Discussion of results**

The above results give a fairly complete description of the companions of the fields of rational and real numbers. Construction methods can be used for further studies of field companions and their classes.

**Conclusion**

The general theory of Fraisse's companion classes and their theories, developed by A.T. Nurtazin, constitutes a separate new area in model theory. This approach, applied to specific classical structures and their theories, provides new tools for the study of these objects. The study of the companion class of rational and algebraic real number fields reveals companion fields containing transcendental and possibly algebraic elements with special properties of polynomials defining these elements. The companions of each of the above-named fields are algebraic extensions of the fields of quotients of a certain set of independent variables over the corresponding field, using mutually agreed polynomials.

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# OPTIMAL CHOICE OF IT INFRASTRUCTURE FOR EFFECTIVE INTERNAL COMMUNICATION IN THE COMPANY

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**Abstract**

The study examines aspects of the development of internal digital infrastructure and the problems of its formation in organizations. The necessity of forming a stable and developed technological infrastructure as an important prerequisite for the formation and development of the company's digital infrastructure is substantiated. The most multifunctional computing resources are proposed to improve the process of ensuring the development of digital infrastructure.

**Keywords:** IT, infrastructure, digital, enterprise, database, information system.

## Introduction

Currently, a lot depends on the digital infrastructure: how successful a business is, how much revenue it brings, how efficiently the organization works. Therefore, this system must be reliable, stable and secure. We can say that this is the most important asset of the organization. Personnel management systems, customer service processes, and market analysis tasks are always becoming more complicated and cannot be implemented without the help of information technology. Therefore, the success of a business largely depends on how well the company's IT infrastructure is formed and how well it will work. It is also inevitable that very serious problems will arise in cases when the system does not cope with the tasks assigned to it or cannot ensure data security.

The internal digital infrastructure of the company combines various information resources, without which the organization cannot function normally, and employees cannot perform their work efficiently. Therefore, it is important to provide a reliable means of communication between departments and different modules in the organization. Ensuring the sustainable development of internal digital infrastructures will expand the company's technological capabilities in business, thereby increasing their competitiveness.

The study examines aspects of the development of internal digital infrastructure and the problems of its formation in organizations. The necessity of forming a stable and developed technological infrastructure as an important prerequisite for the formation and development of the company's digital infrastructure is substantiated. The most multifunctional computing resources are proposed to improve the process of ensuring the development of digital infrastructure.

## Materials and Methods

What should be the optimal software for the internal IT infrastructure?

When studying the research material, we consider our own new solution by searching and analyzing the methods that have been used and are being used to date. That is, you can consider existing systems and adapt them to your own. The data obtained and the research are organized through a web service.

IT infrastructure is an information and communication infrastructure: a set of telecommunication and information networks, end devices, information resources that can be used to organize communication and access to any information between users at any time and in any place [1].

In this study, an empirical method of analysis was used, namely comparative analysis. To substantiate the hypothesis put forward, a comparative analysis of various corporate software was carried out. These objects are the software of the corporate portal, which consist of various functions. For example, cloud computing, data storage, security, backup, document management, search engine, corporate communication, cooperative and much more.

*Stage 1.*

6 highly rated on the site were selected for the investigation sourceforge.com software of the corporate portal. A table was built based on the ratings and reviews of independent users of the site. The overall result of the estimates is derived (1 table).

*Stage 2.*

At the second stage of the investigation, a table consisting of technical characteristics was built. Data such as the country of manufacture, the company, the year of foundation, the starting price of the product, the number of integrated products, the languages of the programs were painted (Table 2).

*Stage 3.*

At the third stage of the investigation, functional characteristics were considered. Features such as system requirements, availability of API and mobile application, access to content management, search engine, internal communication, collaboration, document management and file sharing (Table 3).

As a result of the study, 3 tables were built according to the data of 6 corporate programs. Summarizing the analysis of three comparative tables, it was found that all systems are compatible with many popular web ports and portable platforms, there is a data warehouse, mobile applications, and tools for intra-corporate communication, collaboration and working with data. Judging by the functional characteristics, the most suitable cloud platforms are OnBoard Board Management Software and Ntranet. This is due to the fact that these programs have received the highest ratings from users and extensive functionality. However, others are not much inferior.

**Literature review**

The development of a sustainable digital infrastructure is crucial to ensure technological progress that benefits society [1]. Therefore, investments in infrastructure and innovation were necessary for economic growth and global development. This is clearly demonstrated by the United Nations Development Programme (Goal 9: industry, innovation and infrastructure). It focuses on technological progress in the search for sustainable solutions to economic and environmental problems, such as ensuring the growth of new industries with environmentally friendly supply chains and improving energy efficiency [2].

Achieving these goals requires significant efforts on the part of modern organizations working in both the private and public sectors. An efficient technological infrastructure is urgently needed to support optimally functioning organizations [3]. Ensuring the sustainable development of digital infrastructures that take into account environmental problems requires changes in how infrastructures will be developed and used and how the possibility of reuse of digital resources associated with these infrastructures will be ensured [4].

The introduction of service-oriented architecture (SOA) is currently a popular approach that allows companies to gain important benefits such as increased flexibility and efficiency, efficient use of available resources and greater flexibility, and thus has better opportunities to respond to market changes. However, the human and technical resources needed to develop and support these complex

solutions are widespread and do not benefit either companies or the environment. Attention to services makes SOA unique, and it provides transparency in many legacy systems and data sources in a black case. Since services are defined by open standards, SOA provides a common pool of IT resources, regardless of the availability of various IT systems, functionality, language codes and platforms [5, 6].

In many cases, organizations want to keep their inheritance systems because they are still valuable to the business and support certain business functions and processes; the inheritance system is not only a technological artifact-it is part of the organizational culture that is important for both IT professionals and end users. SOA can facilitate the continuous use of legacy systems and can facilitate the efficient use of these systems by adding business intelligence applications to facilitate decision-making supported by digital infrastructure [7].

Digital infrastructure is an important foundation for ensuring the digital transformation of organizations wishing to expand the potential of new digital technologies. Digital infrastructure consists of technical and organizational components, processes and networks. It covers the social environment of users of digital tools, as well as designers and developers of systems connected to the infrastructure. In modern scientific literature, digital infrastructure, in contrast to autonomous information systems, is formulated as the interconnection of various system groups, including software, hardware, standards, the Internet, platforms and people. Digital infrastructure will be indispensable for stable operation in the public and private sectors, and their emergence and growth will be intensified in various industries (pharmaceuticals, healthcare, manufacturing, energy, marine industry and government agencies). Corporate social media platforms, internal educational networks at universities, corporate architecture in the education sector, service-oriented architecture in public administration and e-health services infrastructure are examples of various digital infrastructure options important for growth and development. Three growth mechanisms have been identified as important for stimulating the evolution of digital infrastructure: implementation, scaling and innovation [8].

## Tables

**Table 1 –** Ratings/Reviews [9]

| Enterprise Portal Name | Support | Design | Features | Ease | Overall |
|---|---|---|---|---|---|
| Intrexx | 4.6/5 | 4.3/5 | 4.5/5 | 4.6/5 | 4.7/5 |
| SmartVault | 4.4/5 | 4.4/5 | 4.6/5 | 4.6/5 | 4.7/5 |
| Bitrix24 | 4.7/5 | 4.5/5 | 4.4/5 | 4.3/5 | 4.7/5 |
| OnBoard Board Management Software | 4.9/5 | 4.5/5 | 4.7/5 | 4.8/5 | 4.9/5 |
| Yammer | 4.4/5 | 4.3/5 | 4.3/5 | 4.7/5 | 4.3/5 |
| Ntranet | 5.0/5 | 5.0/5 | 5.0/5 | 4.0/5 | 5.0/5 |

**Table 2 –** Technical specifications

| Enterprise Portal Name | Company | Country | Founded | Pricing | Integrations | lang | website |
|---|---|---|---|---|---|---|---|
| Intrexx | United Planet GmbH | Germany | 1998 | Free Trial available. | 10 API | English, French, German. | www.intrexx.com |
| SmartVault | SmartVault | United States | 2008 | Starting Price: $20.00/month/user | 24 API | English | smartvault.com |
| Bitrix24 | Bitrix24 | United States | 1998 | Starting Price: $24 per month | 96 API | English | www.bitrix24.com |
| OnBoard Board Management Software | OnBoard | United States | 2003 | Free Trial available. | 14 API | English | www.onboardmeetings.com |
| Yammer | Microsoft | United States | 1975 | Starting Price: $3 per user per month | 143 API | English | www.yammer.com |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ntranet | Ncontracts | United States | 2009 | - | 5 API | English | www.ncontracts.com |

**Table 3 –** Functional characteristics

| Enterprise Portal Name | System Requirements | API | mobile app | Collaboration | Chat | Content Management | Document Management | File Sharing | Search |
|---|---|---|---|---|---|---|---|---|---|
| Intrexx | SaaS, Windows, Mac, Linux, iPhone, iPad, Android | + | + | + | + | + | + | + | + |
| SmartVault | SaaS, Windows, Mac, Linux, iPhone, iPad, Android | + | + | - | - | - | + | + | + |
| Bitrix24 | SaaS, Windows, Mac, iPhone, iPad, Android, On-Premise | + | + | + | - | + | + | + | + |
| OnBoard Board Management Software | SaaS, Windows, Mac, iPhone, iPad, Android | | + | + | + | + | + | + | + |
| Yammer | SaaS, Windows, iPhone, iPad, Android | + | + | - | - | - | - | + | + |
| Ntranet | SaaS, Windows, Mac, iPhone, iPad, Android | + | + | + | + | + | + | + | + |

**Results and Discussion**

In the course of this study, comparing ratings and characteristics, six of the best platforms available today for comparative analysis were selected. The list of components and functional requirements for the optimal program of the intra-corporate portal was determined.

Collaboration - allows employees to work in a team, in a remote format and combine the results of work. Chat - helps to conduct business correspondence between departments and modules, coordinate decisions made. The document management system allows you to manage, store and share with the data that is stored in the database. A search engine will help you find the necessary information throughout the company. Advanced software support features allow you to attract users who use various software products.

Summing up, all the above disassembled components will be used in the development of the corporate portal software

**Conclusion**

Enterprise corporate portals provide firms with business transaction processing models that are integrated with their other activities, such as production planning and human resource management. By implementing the company's standard processes and providing it with a single database covering all its activities and all employees, the corporate portal programs ensure the integration of its numerous divided divisions and functional areas. As a result, these systems have led to improved decision-making capabilities, which are manifested in a wide range of indicators, such as downsizing,

acceleration in the process of making business decisions, tracking data leaks, etc. Thus, corporate portals can be used to help firms to increase labor productivity.

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# MATHEMATICAL MODELING OF THE EPIDEMIC PROPAGATION WITH LIMITED TIME SPENT IN COMPARTMENTS TAKING AND VACCINATION

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**Abstract**

The paper proposes discrete and continuous mathematical models of epidemic development. These models suggest a division of the population into nine compartments: susceptible, exposed, vaccinated, contact vaccinated, undetected patients, isolated patients, hospitalized patients, recovered and deceased. At the same time, the time spent in contact and infected compartments is considered limited. A qualitative and quantitative analysis of the proposed models is carried out. The influence of parameters on the studying process is investigated.

**Keywords:** mathematical model, epidemic, vaccination.

## Introduction

The development of the COVID-19 pandemic has largely updated the development of mathematical models of epidemic development. The first application of mathematical methods in the analysis of epidemics is associated with the works of outstanding mathematicians of the second half of the 18th and early 19th centuries D. Bernoulli, I. Lambert, P.S. Laplace. Modern mathematical models of epidemiology go back to the work of R. Ross, published in 1911, on the study of the spread of malaria [1] and, to an even greater extent, to the SIR model proposed in 1927 by W. Kermack and A. McKendrick [2]. This model is based on the division of the entire population into three compartments of susceptible, infected and recovered. The model is a system of non-linear differential equations and describes the change in the number of these population compartments over time.

The main drawback of the SIR model is that it does not take into account the presence of an incubation period, i.e. it assumes that a person who has had contact with a sick person immediately

falls ill. To eliminate it the SEIR model was proposed, in which a compartment of exposed was added, see, for example, [3]. Thus, in the process of infection, a person susceptible to the disease first becomes exposed and only then becomes infected. There are a significant number of SEIR model modifications. Thus, the SEIRD model additionally includes a compartment of deceased [4,5]. In the MSEIR model in addition to the compartments of the SEIR model, people endowed with immunity from birth (maternally derived immunity) are added [6]. In [7], a model which additionally takes into account patients in whom the disease proceeds in an asymptomatic form (asymptomatic) is considered. The SEIRHCD model also has compartments of hospitalized and critical patients [8,9]. Along with continuous models, discrete models, in which time is an integer variable, are also considered, see, for example, [10].

These models do not take into account the limited stay in exposed and infected compartments. In particular, any person who has been in contact with a sick person, after some time, will most likely either get sick or not get sick, which means that they will certainly leave the exposed compartment. Anyone who falls ill after some time will surely either recover or die, i.e. will definitely leave the compartment of infected. This shortcoming is overwhelmed in [8,9,11] for continuous systems and in [11-13] for discrete systems. There are also models that take into account the vaccination of the population [14-22]. In this case, vaccination is considered at certain points in time (impulsive vaccination), as well as vaccination of newborns. Here, vaccinated susceptible people go directly into the compartment of recovered, see [15-18]. In the SIRV model [19], the vaccinated are treated as an independent compartment. The SEIRV model also uses a separate compartment of vaccinated people, some of whom may become infected in the future, and birth and natural mortality are also taken into account [20]. In [21], a model is proposed in which there is an additional compartment of people in quarantine. [22] explores the SUIHTER model, which also includes compartment of asymptomatic and hospitalized patients, and separately considers people received one and two doses of the vaccine.

This paper proposes discrete and continuous models for the development of the epidemic, providing for vaccination and limited time spent in compartments, which are a generalization of the models described in [11] for the case of vaccination. They assume the division of the entire population into nine compartments: susceptible, exposed, vaccinated, contact vaccinated, undetected, isolated and hospitalized patients, as well as recovered and deceased. A qualitative and quantitative analysis of the models is carried out. The influence of various parameters of the system on the process is investigated.

**Description of models**

An isolated population under the conditions of an epidemic is considered. The entire population is divided into the following compartments:

$S$ : susceptible (healthy, but potentially sick);

$V$ : vaccinated (healthy vaccinated);

$E$ : exposed (healthy, in contact with sick);

$C$ : contact vaccinated (vaccinated, who were in contact with patients);

$U$ : undetected (infected with an asymptomatic course of the disease and mildly ill with an undiagnosed disease);

$I$ : isolated (patients in a mild form, undergoing treatment at home);

$H$ : hospitalized (seriously ill, hospitalized);

$R$ : recovered (recovered from illness, who do not have any signs of illness);

$D$ : died.

The sum of $N$ numbers of people in all compartments is considered unchanged, i.e. natural births and deaths are not taken into account in the model.

The change in the number of people in each compartment is carried out due to intercompartment transitions, see Fig. 1.

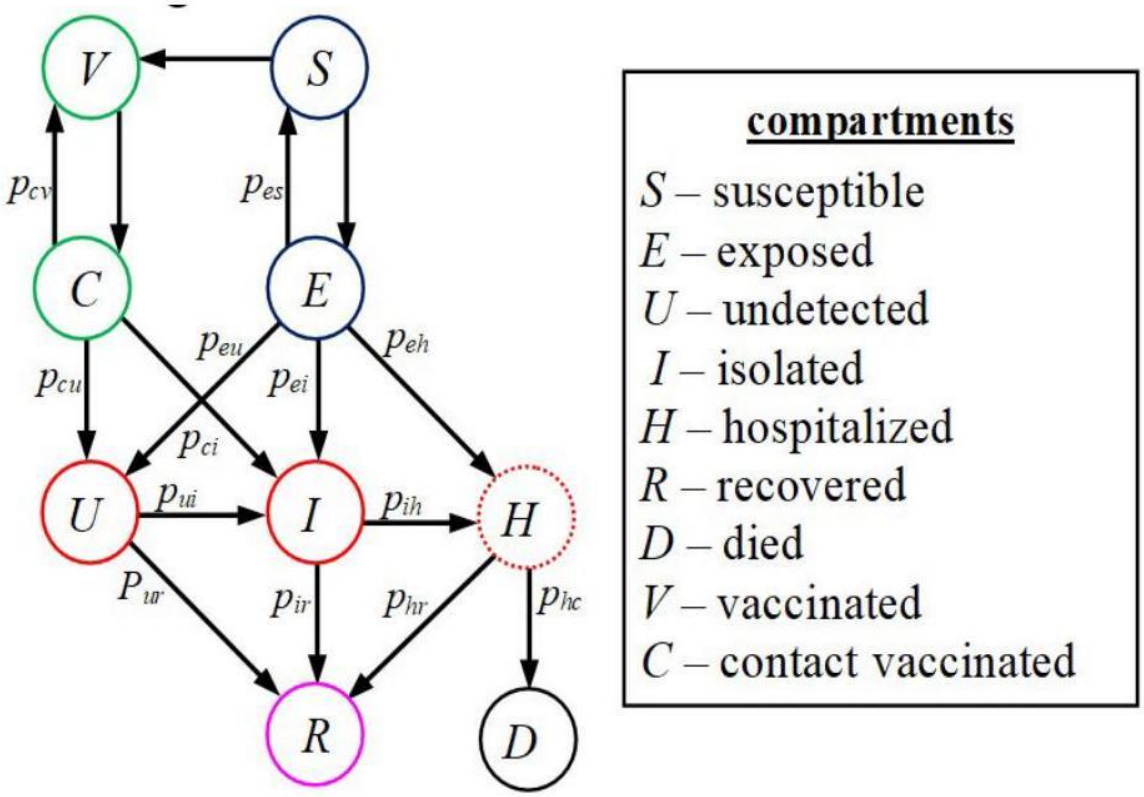


**Figure 1** – Graph of intercompartment transitions.

According to the accepted assumptions, a susceptible person can come into contact with the patient by moving to the exposed compartment, and also be vaccinated. A vaccinated person can also encounter a sick person and move into compartment of contact vaccinated people. The exposed may become ill in any degree of severity or not get ill, returning to the susceptible compartment. A contact vaccinated either does not become ill or becomes undetected or isolated sick. Every patient can recover. An undiagnosed patient may develop symptoms of the disease moving into the isolated compartment in result. An isolated patient may be hospitalized, and a hospitalized patient may die.

The number of days spent in all compartments of contact and patients is considered fixed and is indicated as follows $n_e, n_c, n_u, n_i$ and $n_h$, where the index corresponds to the name of the compartment (the first letter of the compartment name). For vaccinated contacts, the time spent in the compartment is assumed to be the same as for unvaccinated contacts, i.e. $n_c = n_e$. At the end of the time spent in the compartment, each person in it goes into one of the possible compartments in accordance with the above figure. In this case, $p_{\alpha\beta}$ denotes the proportion of people in the compartment indicated as $\alpha$ passing into the compartment $\beta$. In this case, the conditions

$$\sum_{\beta} p_{\alpha}\beta = 1 \forall \alpha,$$

where the sum is taken over all compartments $\beta$, to which you can go from the compartment $\alpha$.

Sources of infection are people in undetected (to a greater extent) and isolated (to a lesser extent) compartments, but not hospitalized. The degree of infectivity is described by the coefficients of contagiousness $k_u$ and $k_i$ undetected and isolated patients, and $k_u > k_i$. Vaccination of the population is characterized by the rate of vaccination $v$.

The mathematical model of the process is a system of equations for the number of people in each compartment that changes over time. In this case, the number of people in each compartment is indicated by the first letter of the compartment name, i.e. $S, V$, etc. These quantities are functions of a continuous argument $t$ or an integer argument $n$, written as an index. Thus, $S_k, V_k$, etc. characterize

the number of susceptible, vaccinated, etc. at the $k$-th time step (on the $k$-th day from the beginning of the study). In the continuous model, the values of $S(t), V(t)$, etc. characterize the number of susceptible, vaccinated, etc. at time $t$ (after $t$ time from the start of the study).

Let us formulate a description of the discrete model. The number of all categories of contacts and patients at a given point in time is the sum of their numbers by the days they were in the compartment, i.e. following equalities are true

$$Z_k = \sum_{j=1}^{n_z} z_k^j, Z = E, C, U, I, H,$$

where $z_k^j$ denotes the number of people in compartment $Z$ at time k on the $j$-th day of being in this compartment. Here, any compartment of exposed and patients is chosen as $Z$, i.e. $Z$ can take the values $E, C, U, I, H$. In this case, each member of $Z$ of the $j$-th day of being in this compartment passes to the category of the $j + 1$ st day of being in the compartment every day, if this was not the last day of being in the compartment, which corresponds to the equalities

$$z_{k+1}^{j+1} = z_k^j, j = 2, \dots, n_z - 1, z = e, c, u, i, h.$$

The susceptible number on the following day is equal to the susceptible number on the previous day minus the number of those vaccinated on that day, minus the susceptible number who contacted infection on that day, plus the number of contacts of the last day of stay in the exposed compartment who did not get infected. At the same time, the vaccinated number is directly proportional to the susceptible number, and the susceptible number contacted with infection is directly proportional to the susceptible number, as well as the number of undetected and isolated patients who are sources of infection. As a result, we obtain the equality

$$S_{k+1} = S_k - vS_k - \frac{k_u U_k + k_i I_k}{N} S_k + p_{es} e_k^{n_e}.$$

The division by the size of the entire population is carried out for reasons of normalization (otherwise, the numbers of two compartments, which are sufficiently large values, are multiplied).

The vaccinated number on the following day is equal to the vaccinated number on the previous day plus the number of new susceptible people who were vaccinated that day minus the number of vaccinated people contacted with infection on that day plus the number of people on the last day of stay in the contact vaccinated compartment who did not get infected. The corresponding quantities are determined in the same way as in the previous formula. As a result, we obtain the equality

$$V_{k+1} = V_k + vS_k - \frac{k_u U_k + k_i I_k}{N} V_k + p_{cv} c_k^{n_c}.$$

The number of all people in compartments of exposed and infected patients on the next day is equal to their number on the previous day plus the number of people who entered this compartment this day, minus the number of people who left the compartment the previous day

$$Z_{k+1} = Z_k + z_{k+1}^1 - z_k^{n_z}, Z = E, C, U, I, H.$$

The recovery number of at the next time point is equal to their number on the previous day plus the number of patients of all compartments who recovered on the previous day.

$$R_{k+1} = R_k + p_{ur} u_k^{n_a} + p_{ir} i_k^{n_i} + p_{hr} h_k^{n_h}.$$

The death number at a subsequent point in time is equal to their number on the previous day plus the number of people that died on this day

$$D_{k+1} = R_k + p_{hd} h_k^{n_h}.$$

The number of new exposed (exposed of the first day of being in the compartment), both unvaccinated and vaccinated, is exactly equal to the number, respectively, susceptible and vaccinated, who had contact with patients on the previous day

$$e_{k+1}^1 = (k_u U_k + k_i I_k)\frac{S_k}{N}, c_{k+1}^1 = (k_u U_k + k_i I_k)\frac{V_k}{N},$$

The number of new undetected is the sum of both exposed compartments of the last day of being in the compartment, who fell ill with an undetected form of the disease

$$u_{k+1}^1 = p_{eu} e_k^{n_e} + p_{cu} c_k^{n_c}.$$

The number of new isolated patients is the sum of the number of both exposed compartments of the last day being in the compartment who fell ill with an isolated form of the disease, and the number of undetected contacts of the last day being in the compartment in whom the disease was detected

$$i_{k+1}^1 = p_{ei} e_k^{n_e} + p_{ci} c_k^{n_c} + p_{ui} u_k^{n_u}.$$

The number of new hospitalized patients is the sum of exposed and isolated patients of the last day of being in the compartment, in which the disease turned into a severe form, as a result of which they were hospitalized

$$h_{k+1}^1 = p_{eh} e_k^{n_e} + p_{ih} i_k^{n_i}.$$

The initial states of the system $S_0, E_0, U_0, V_0, C_0, I_0, H_0, R_0, D_0$ are known, and the distribution of all forms of exposed and patients at the initial moment of time by days of being in compartments is considered uniform, i.e. taken according equalities

$$z_0^j = Z_0/n_z,\ j = 1, \dots, n_z, z = e, c, u, i, h.$$

Relations (1) - (12) constitute a discrete model of the process under study.

Let us proceed to the description of the corresponding continuous model. The change in the number of susceptible people is its decrease due to vaccination and the fact that a certain number of susceptible people contacted with infection, and an increase, since some of the exposed do not get sick. At the same time, the new vaccinated number is directly proportional to the susceptible number and the number of susceptible who became exposed is directly proportional to the susceptible number, as well as the number of undetected and isolated patients. The number of non-diseased exposed is proportional to the exposed number and inversely proportional to the number of days spent in the exposed compartment. As a result, we obtain the equation

$$\frac{dS(t)}{dt} = -vS(t) - \frac{k_u U(t) + k_i I(t)}{N} S(t) + p_{es}\frac{E(t)}{n_e}$$

The change in the vaccinated number is its decrease due to the fact that some part of the vaccinated who contacted with patients, and the increase due to vaccination and the fact that part of the contact vaccinated people does not get sick. The corresponding quantities are determined in the same way as in the previous formula. As a result, we obtain the equality

$$\frac{dV(t)}{dt} = vS(t) - \frac{k_u U(t) + k_i I(t)}{N} V(t) + p_{cv} \frac{C(t)}{n_v}$$

The change in the number of contacts, both unvaccinated and vaccinated, increases due to, respectively, susceptible and vaccinated, who had contact with patients, and decreases due to the limited time spent in these compartments. Thus, we have the equalities

$$\frac{dE(t)}{dt} = \frac{k_u U(t) + k_i I(t)}{N} S(t) - \frac{E(t)}{n_e}$$
$$\frac{dC(t)}{dt} = \frac{k_u U(t) + k_i I(t)}{N} V(t) - \frac{C(t)}{n_c}$$

The number of undetected patients increases due to the disease of both exposed compartments and decreases due to the limited time spent in this compartment:

$$\frac{dU(t)}{dt} = p_{eu} \frac{E(t)}{n_e} + p_{cu} \frac{C(t)}{n_c} - \frac{U(t)}{n_u}$$

The number of isolated patients increases due to the disease of both exposed compartments and the detection of the disease in some of the undetected and decreases due to the limited time spent in this compartment:

$$\frac{dI(t)}{dt} = p_{ei} \frac{E(t)}{n_e} + p_{ci} \frac{C(t)}{n_c} + p_{ui} \frac{U(t)}{n_u} - \frac{I(t)}{n_i}.$$

The number of hospitalized increases due to infection of people in exposed compartment in a severe form and the hospitalization of a part of the isolated ones and decreases due to the limited time spent in this compartment:

$$\frac{dH(t)}{dt} = p_{eh} \frac{E(t)}{n_e} + p_{ih} \frac{I(t)}{n_i} - \frac{H(t)}{n_h}$$

The number of recovered patients is increasing due to the recovery of patients of all categories:

$$\frac{dR(t)}{dt} = p_{ur} \frac{U(t)}{n_u} + p_{ir} \frac{I(t)}{n_i} + p_{hr} \frac{H(t)}{n_h}.$$

The number of deaths increases due to the death of a part of the hospitalized:

$$\frac{dD(t)}{dt} = p_{hd} \frac{H(t)}{n_h}.$$

The initial states of the system $S_0, E_0, U_0, V_0, C_0, I_0, H_0, R_0, D_0$ are known, i.e. the following equalities hold

$$Z(0) = Z_0.$$

where $Z = S, E, U, V, C, I, H, R, D$. The system of differential equations (13) - (21) with initial conditions (22) constitutes a continuous model of the system.

**Analysis of mathematical models**

Let us establish the simplest qualitative properties of the models under consideration. The discrete model is characterized by the following statement.

Theorem 1. For any values of the parameters, the system has a unique equilibrium position, and the limiting values of the numbers of all categories of exposed and infected people are equal to zero, and the functions $R$ and $D$ are increasing.

To prove it, it suffices to pass to the limit in recurrence relations (3) - (7), taking into account that the sequences $\{Z_k\}$ and $\{Z_{k+1}\}$ have the same limit. At the same time, the zero limit values of the numbers of all categories of exposed and patients indicate the end of the epidemic. The monotonicity of the functions $R$ and $D$ (growth in the number of recovered and deceased) is due to the negativity of all expressions on the right side of equalities (6) and (7).

Theorem 2. For any values of the system parameters, problem (13) - (22) has a unique equilibrium position, and the limiting values of the numbers of all categories of contact and patients is equal to zero, and the functions $R$ and $D$ are increasing.

To prove it, it suffices to equate all derivatives to zero in differential equations (13) - (21). The results obtained indicate that the qualitative properties of the continuous and discrete models generally coincide.

The quantitative analysis of both models was carried out at the same parameter values, and the continuous model was implemented using the 4th order Runge - Kutta method. In doing so, the following numbers of days spent in compartments have been taken: $n_e = 14, n_u = 3, n_i = 5, n_h = 7, n_c = n_e = 7$. The coefficients of the equations take the following values: $k_u = 3.180, k_i = 0.171, p_{\text{es}} = 0.679, p_{\text{eu}} = 0.154, p_{\text{ei}} = 0.145, p_{\text{eh}} = 0.022, p_{cv} = 0.9, p_{cu} = 0.05, p_{ci} = 0.05, p_{ui} = 0.03, p_{ur} = 0.97, p_{ih} = 0.021, p_{ir} = 0.979, p_{hr} = 0.982, p_{hd} = 0.018, v = 0.0005$. The calculations were carried out at the initial stage of the epidemic, and $N = 18699640$, which corresponded to the population of Kazakhstan at the time of the start of the COVID19 epidemic. In addition, it was assumed that at the initial moment of time there are 140 contact people, and all the rest are susceptible. Graphs of the obtained solutions are shown in Fig. 2, where the red curves correspond to the discrete model, and the blue curves to the continuous one.

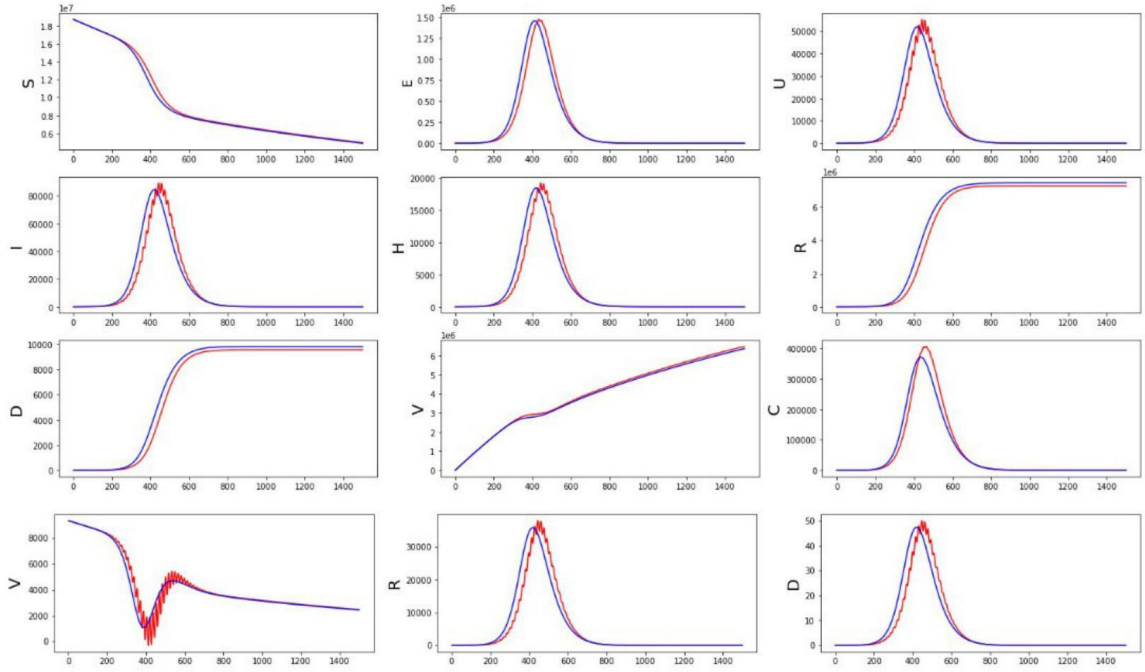


**Figure 2** – System states for discrete (red) and continuous (blue) models.

Based on the results obtained, the following conclusions can be made. The qualitative properties of the solutions of both models are almost the same, and the corresponding functions for the continuous model are smoother. For some time, the number of exposed and patients has been growing. Then the epidemic reaches its peak, after which the incidence decreases. Over time, the system is observed to reach a position of equilibrium, and the number of all compartments of exposed and patients tends to zero, which corresponds to the end of the epidemic. The susceptible number decreases monotonously as more and more people get sick or get vaccinated over time. The number of vaccinated, recovered and dead people is gradually increasing, which is quite natural, since the vaccinated people will no longer become usually susceptible, the recovered acquire immunity.

Table 1 shows the most important quantitative characteristics corresponding to the selected computation variant. According to the results obtained, the general characteristics of the discrete and continuous models are approximately the same. However, for the discrete model, the epidemic proceeds somewhat less intensively than for the continuous model. In particular, the duration of the epidemic is shorter (by about two months), the time of the peak of the epidemic comes later (almost a month), the total number of cases and deaths is slightly less. However, the observed difference is insignificant, as a result of which we can conclude that the considered models are equivalent.

**Table 1** - The most important quantitative characteristics of the system

| | **Discrete model** | **continuous model** |
|---|---|---|
| Epidemic end time | 1101 | 1154 |
| Peak time of the epidemic | 442 | 419 |
| Total number of cases and % of the total population | 7284183 (38.95%) | |
| The total number of recovered and % of the total number of cases | 7274363 (99.87%) | 7456303 (39.93%) |
| The total number of deaths and % of the total number of cases | 9546 (0.13%) | 9822 (0.13%) |
| The maximum number of patients at the same time | 163412 (0.87%) | 154790 (0.83%) |

Let us now estimate the influence of system parameters on the considered process. Each of the tables below shows the values of the most important characteristics of the system for three counting options. The first of them corresponds to the main variant of the computation given above, and the next two correspond to the specified parameter, increased and decreased by some value.

Table 2 evaluates the impact of the coefficient of contagiousness of undiagnosed patients. It turns out to be about the same for both models. In particular, an increase in the contagiousness coefficient leads to a reduction in the duration of the epidemic and the time it takes to reach its peak, as well as an increase in the number of simultaneously ill people, the total number of ill people and deaths. Such changes indicate a greater intensity of the epidemic development, which seems quite logical. At the same time, the percentage of recovered and dead people remains unchanged, since these characteristics are determined by the transition coefficients in the compartments of patients. Comparing the degree of influence of the parameter on the models under consideration, we note, for example, that an increase (respectively, a decrease) in the coefficient by 10% leads to a decrease in the duration of the epidemic by 11.8% for the discrete model and 11.6% for the continuous model (respectively, an increase of 20.5% for the discrete model and 20.4% for the continuous model). At the same time, the total number of cases increases by 21.3% for the discrete model and 21.2% for the continuous model (respectively, it decreases by 32.2% for the discrete model and by 32.4% for the continuous model). Thus, the degree of influence of the parameter on both models is almost the same.

Table 3 shows the results of assessing the impact of the contagiousness coefficient of isolated patients with an increase and decrease in this parameter by 58.8%. With its increase, there is a decrease in the duration of the epidemic and the time it takes to reach its peak, with an increase in the total number of cases of simultaneously infected, the percentage of recovered and dead remains

unchanged. However, with the indicated increase (respectively, decrease) in the contagiousness coefficient of isolated patients, there is a reduction in the duration of the epidemic by 6.8% for the discrete model and by 6.5% for the continuous model (respectively, it increases by 9.1% for the discrete model and by 8.8% for the continuous model). Under the same conditions, there is an increase in the death number by 13.1% for the discrete model and by 13.0% for the continuous model (respectively, a decrease of 16.1% for the discrete model and 16.0% for continuous model). The weaker effect on the process of the contagiousness coefficient of isolated patients compared to the similar coefficient for unidentified patients is explained by the fact that isolated patients are a significantly less important source of infection compared to unidentified ones.

**Table 2 -** Influence of the coefficient of contagiousness of undiagnosed patients

| **Parameter ku** | **Epidemic end time** | | **Peak time of the epidemic** | | **Total number of cases and % of the population** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 3.18 | 1101 | 1154 | 442 | 419 | 7284183 (38.95%) | 7466126 (39.93%) |
| 3.48 | 972 | 1020 | 377 | 344 | 8833599 (47.24%) | 9047409 (48.38%) |
| 2.88 | 1327 | 1389 | 571 | 547 | 4939864 (26.42%) | 5049614 (27%) |

**Table 3 -** Influence of the contagiousness coefficient of isolated patients

| **Parameter ku** | **Epidemic end time** | | **Peak time of the epidemic** | | **Total number of cases and % of the population** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 0.171 | 1101 | 1154 | 442 | 419 | 7284183 (38.95%) | 7466126 (39.93%) |
| 0.271 | 1026 | 1079 | 410 | 376 | 8187581 (43.78%) | 8384067 (44.84%) |
| 0.071 | 1201 | 1255 | 505 | 474 | 6160891 (32.95%) | 6322669 (33.81%) |

Table 4 examines the effect of the recovering proportion of hospitalized patients when it changes by 1.5%. This parameter does not affect the duration of the epidemic, the time of its peak, the total number of cases and the maximum number of cases at a time, since it only applies to those patients who have already been hospitalized. Thus, it can only influence the ratio between the recovered and the dead. In particular, an increase (respectively, a decrease) in this parameter leads to a decrease (respectively, an increase) in the number of deaths by 83.3% for both models. It is clear that a reduction in the death number by a certain amount means an increase in the recovered number by the same amount.

Table 5 examines the impact of the proportion of isolated patients who were hospitalized, with a change of 71.4%. This parameter does not affect the duration of the epidemic and the time of its peak, as well as the total number of cases, however, it affects the further fate of the patient. In particular, an increase (respectively, a decrease) in this parameter indicates a more severe (respectively, milder) course of the epidemic. This is reflected in the fact that the number of deaths

increased by 9.7% for the discrete model and 9.6% for the continuous model (respectively, it decreased by 9.7% for both models).

**Table 4** – Influence of recovering rate of hospitalized patients

| Parameter $p_{hr}$ | The total number of recovered and % of the total number of cases | | The total number of deaths and % of the total number of cases | |
|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous |
| 0.982 | 7274636 (99.87%) | 7456303 (99.87%) | 9546 (0.13%) | 9822 (0.13%) |
| 0.997 | 7282592 (99.98%) | 7464489 (99.98%) | 1591 (0.02%) | 1637 (0.02%) |
| 0.967 | 7266681 (99.76%) | 7448118 (99.76%) | 17501 (0.24%) | 18007 (0.24%) |

**Table 5** - Influence of isolated patients proportion who were hospitalized

| **Parameter $p_{ih}$** | **The total number of recovered and % of the total number of cases** | | **The total number of deaths and % of the total number of cases** | |
|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous |
| 0.021 | 7274636 (99.87%) | 7456303 (99.87%) | 9546 (0.13%) | 9822 (0.13%) |
| 0.036 | 7273712 (99.86%) | 7455356 (99.86%) | 10471 (0.14%) | 10769 (0.14%) |
| 0.006 | 7275561 (99.88%) | 7457251 (99.88%) | 8621 (0.12%) | 8874 (0.12%) |

Table 6 assesses the impact of the proportion of undetected patients who subsequently developed symptoms of the disease and were isolated. A change in this parameter slightly affects the duration of the epidemic, the maximum number of patients at a time, as well as the proportion of recovered and dead. With an increase (respectively, decrease) of this parameter by 66.7%, there is an increase (respectively, a decrease) in the total number of cases by 0.5% for both models. At the same time, the number of deaths increases (respectively, decreases) by 0.8% for both models.

**Table 6** - Impact of the proportion of undetected patients who were isolated

| **Parameter $p_{ui}$** | **Total number of cases and % of the population** | | **The total number of recovered and % of the total number of cases** | | **The total number of deaths and % of the total number of cases** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 0.03 | 7284183 (38.95%) | 7466126 (39.93%) | 7274636 (99.87%) | 7456303 (99.87%) | 9546 (0.13%) | 9822 (0.13%) |
| 0.05 | 7318481 (39.14%) | 7500949 (40.11%) | 7308861 (99.87%) | 7491052 (99.87%) | 9620 (0.13%) | 9897 (0.13%) |
| 0.01 | 7249636 (38.77%) | 7431047 (39.74%) | 7240163 (99.87%) | 7421300 (99.87%) | 9472 (0.13%) | 9746 (0.13%) |

Table 7 examines the effect of the proportion of contact vaccinated pcv who do not become ill. This value does not affect the temporal characteristics of the epidemic, as well as the percentage of recovered and dead, but affects their number. In particular, with an increase (respectively, decrease) in this value by 3.3%, the number of cases decreases by 2.9% for the discrete model and 2.8% for the continuous model (respectively, an increase of 2.8% for the discrete model and 2.7% for the continuous model). This is explained by the fact that with such a change, the number of cases among those who have been vaccinated decreases (respectively, increases). As a result, the number of recovered and dead people also decreases (respectively, increases).

**Table 7** - Impact of the proportion of contact vaccinated who did not infected

| **Parameter $p_{cv}$** | **Total number of cases and % of the population** | | **The total number of recovered and % of the total number of cases** | | **The total number of deaths and % of the total number of cases** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 0.90 | 7284183 (38.95%) | 7466126 (39.93%) | 7274636 (99.87%) | 7456303 (99.87%) | 9546 (0.13%) | 9822 (0.13%) |
| 0.93 | 7071716 (37.82%) | 7260647 (38.83%) | 7062295 (99.87%) | 7250946 (99.87%) | 9421 (0.13%) | 9701 (0.13%) |
| 0.87 | 7486743 (40.04%) | 7661702 (40.97%) | 7477078 (99.87%) | 7651766 (99.87%) | 9665 (0.13%) | 9936 (0.13%) |

Table 8 evaluates the impact of the exposed compartment proportion who did not infected. An increase in this parameter leads to an increase in the duration of the epidemic and the time it takes to reach its peak and a decrease in the number of ill, and therefore recovered and died. This suggests that with less infection, the epidemic becomes less intense, i.e. its terms are stretched, and fewer people get infected overall. In particular, with an increase (respectively, decrease) of this parameter by 1.5%, the duration of the epidemic increases by 12.5% for the discrete model and 13.3% for the continuous model (respectively, a decrease of 9.6% for the discrete model and 9.4% for the continuous model). Under the same conditions, there is a decrease in the number of cases by 19.2%

for the discrete model and 19.3% for the continuous model (respectively, an increase of 15.1% for both models). Roughly the same effect has the proportion of exposed that get infected and isolated.

**Table 8** - Impact of the proportion of exposed who do not get sick

| **Parameter $p_{es}$** | **Epidemic end time** | | **Peak time of the epidemic** | | **Total number of cases and % of the population** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 0.679 | 1101 | 1154 | 442 | 419 | 5887261 (31.48%) | 6024809 (32.22%) |
| 0.689 | 1249 | 1307 | 522 | 497 | 8385774 (44.84%) | 8596170 (45.97%) |
| 0.669 | 996 | 1045 | 393 | 363 | 5887261 (31.48%) | 6024809 (32.22%) |

Table 9 evaluates the impact of the rate of vaccination on the overall process. An increase in this parameter leads to an increase in the duration of the epidemic and the time of its peak and a significant reduction in the total number of cases and those who are simultaneously ill, with a slight decrease in mortality. In particular, with an increase (respectively, a decrease) of this parameter by 80%, it leads to an increase in the duration of the epidemic by 5% for a discrete model and by 4% for a continuous model (respectively, a decrease in the duration of an epidemic by 1.6% for a discrete model and by 0.3% for a continuous model). At the same time, the total number of cases decreases by 36.8% for the discrete model and by 34.9% for the continuous one (respectively, the total number of cases increases by 32.4% for the discrete model and by 30.3% for the continuous model). The number of deaths is reduced by 41.2% for the discrete model and 39.3% for the continuous model (respectively, increases by 40.6% for the discrete model and 37.9% for the continuous model). The results obtained indicate the extreme importance of maintaining a high rate of vaccination of the population.

**Table 9** - Impact of vaccination rate

| **Parameter v** | **Epidemic end time** | | **The total number of deaths and % of the total number of cases** | | **Total number of cases and % of the population** | |
|---|---|---|---|---|---|---|
| | Discrete | continuous | Discrete | continuous | Discrete | continuous |
| 0.0005 | 1101 | 1154 | 7284183 (38.95%) | 7466126 (39.93%) | 9546 (0.13%) | 9822 (0.13%) |
| 0.0009 | 1157 | 1201 | 4601617 (24.61%) | 4857401 (25.98%) | 5610 (0.12%) | 5961 (0.12%) |
| 0.0001 | 1083 | 1151 | 9645972 (51.58%) | 9730947 (52.04%) | 13420 (0.14%) | 13548 (0.14%) |

**Conclusion**

The results obtained indicate a fairly high efficiency of the proposed models and can be used to predict the development of epidemics. In this case, in each specific case, the system is first identified based on the available statistical information, after which the forecasting problem is solved. For models of epidemic development in the absence of vaccination, this procedure is implemented in [5,9,11].

Further refinement of the models can be carried out by considering the possibility of reinfection of those who have been ill due to the mutation of the virus and the gradual decrease of immunity in recovered people, as well as the limited duration of the vaccine. In this case all considered population compartments are preserved, but intercompartment transitions are added,

taking into account the possibility of transition from the compartments of recovered and vaccinated to the susceptible compartment.

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# SOLVING THE PROBLEM OF TIGHTLY COUPLED INTEGRATION OF INERTIAL-SATELLITE NAVIGATION SYSTEMS COMPLETED WITH ODOMETER

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**Abstract**

The paper deals with the solution of navigation problem based on close integration of inertial-satellite navigation systems combined with odometer, in the most general case - without simplifying assumptions about the object model, its trajectory, etc. The effectiveness of the obtained solution for the loss of satellite signals is illustrated by the results of a numerical experiment.

**Keywords:** tight integration, inertial-satellite navigation systems, odometer, nonlinear Kalman filter, continuous-discrete filtering

## Introduction

At present, the leading companies developing and manufacturing integrated navigation systems around the world are actively engaged in the task of close integration of inertial and satellite navigation systems. The task of close integration of inertial (INS) and satellite navigation systems (SNS) arises during the construction of advanced navigation systems, as well as to ensure the functioning of coarse (for example, on MEMS-sensors), redundant INS. A distinctive feature of the task of close integration is the possibility of obtaining integrated solutions when the number of visible navigation satellites is small, when autonomous positioning and velocity satellite navigation solutions are not possible [1,2].

Currently, the development and creation of high-precision positioning systems for moving objects is one of the most important problems in ensuring traffic safety for all types of transport. One of the most promising ways of solving it is close integration of navigation information from SNS with measurements of free inertial navigation system (BINS) of the moving object. At the same time, the development of modern algorithms of integration of inertial-satellite NS implies the use of only linearized equations of BINS (the so-called "error equations") and linearized measurements of SNS, adequate to the real motion only for small time intervals [3], which, in turn, imposes fundamental restrictions on the time of autonomous motion of the object (when the satellite measurement signals disappear).

## Literature review

The beginning of the history of the study of this problem in the literature dates back to the early 1970s [4, 5, 6]. The early sources mainly gave reasons for the importance of solving this problem and described possible schemes for integrating the INS and SNS. The theoretical foundations of the integration task were also developed. Mathematical models of autonomous functioning of inertial navigation systems were described: models of on-board algorithms, error equation models. Satellite navigation models for the U.S. G.P.S. system was developed. A Kalman filter was used as the mathematical basis for solving the problem of INS correction by SNS. Thus, during the 1970s-80s, the basic mathematical models and methods for the problem of tight integration of the INS and SNS were developed.

A new phase of publications came in the 1990s, when the American satellite navigation system GPS/NAVSTAR was fully deployed for operation. Most of the literature at that time is devoted to describing experiments on the close integration of the INS and SNS on real data [7, 8, 9, 10]. In these sources, everything was mostly limited to descriptions of functional integration schemes, the most basic models of INS and SNS functioning. The main emphasis was on the results of processing experimental data with different satellite constellations and inertial systems of different accuracy.

In the 2000s, manuals in which the mathematical models were described quite completely began to appear [11, 12, 13, 14]. The works carried out at the Canadian University of Calgary stand out. Many works have been written under the auspices of this university, containing both a description of experimental material on close integration and mathematical methods and models of this problem [15, 16, 17, 18, 19]. Nevertheless, these models often did not consider many aspects of the specific implementation of algorithms of the close integration problem. There are still virtually no sources that describe a clear algorithmic scheme suitable for creating software and mathematical support. This is largely due to the fact that this software is a trade secret or intellectual property.

In addition to the fuzzy structural description, many sources allow some inaccuracies in the mathematical models, and some essential aspects are not addressed at all. Among these aspects are the question of separating total, dynamic, and kinematic errors in the INS error equation; setting the azimuthal orientation and gyroplatform control for INS platform; and the equivalence of platform and gimbal-less INS. So, in spite of the long history of research of the problem in the Western literature, there is still no clear description of all necessary models in any source.

**Generalized mathematical model of BINS.**

To solve this problem further we use the right-hand coordinate systems (RCS) [2,3]:

- instrumental coordinate system (ICS) $J^{0xyz}$, whose origin is located in the center of mass (CM) of the object, and whose axes are directed along the mutually orthogonal axes of sensitivity of the BINS measuring complex instruments,
- rotating with the Earth Greenwich CS (GrCS) $G^{0\eta\xi\varsigma}$
- inertial CS(InCS) $I^{0\eta_1\xi_1\varsigma_1}$ G with origin at the Earth's center
- accompanying CS (ACS) S OXYZ, whose origin coincides with the object's center of mass, the Y axis coincides with the direction of the local meridian, the Z axis is directed along the plumb line from the Earth's center, and the X axis completes the system to the right

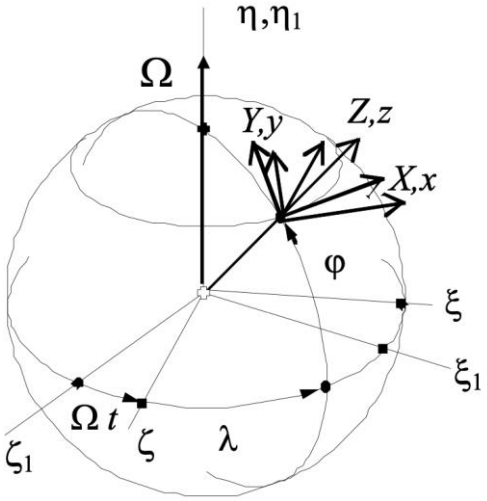


**Figure 1** - Orientation of the SC axes

Consider also that the BINS gauge complex includes three accelerometers and three angular velocity sensors (AVS). The system of equations of navigation parameters of investigated BINS, invariant to the nature of of motion of the object and the type of its physical model, in this case has as follows [3,26]:

$$\begin{vmatrix}\dot{\alpha}\\ \dot{\beta}\\ \dot{\gamma}\end{vmatrix} = \begin{vmatrix}\frac{\sin\gamma}{\cos\beta} & \frac{\cos\gamma}{\cos\beta} & 0\\ \cos\gamma & -\sin\gamma & 0\\ \sin\gamma\tan\beta & \cos\gamma\tan\beta & 1\end{vmatrix}(Z_d - W_d) = \Phi(\beta,\gamma)(Z_d - W_d),$$

$$\begin{vmatrix}\dot{\lambda}\\ \dot{\varphi}\end{vmatrix} = \begin{vmatrix}0 & (\cos\varphi)^{-1}\\ -1 & 0\end{vmatrix}\begin{vmatrix}-V_Y\\ V_X\end{vmatrix}(r+h)^{-1}, \quad (1)$$

$$\begin{vmatrix}\dot{V}_X\\ \dot{V}_Y\\ \dot{V}_Z\end{vmatrix} = C^T(\alpha,\beta,\gamma,\lambda,\varphi)Z_a + \left(\left(2\begin{vmatrix}0\\ \Omega\cos\varphi\\ \Omega\sin\varphi\end{vmatrix} + \begin{vmatrix}-V_Y\\ V_X\\ V_x\tan\varphi\end{vmatrix}\right)\times\begin{bmatrix}V_X\\ V_Y\\ V_Z\end{bmatrix}\right) -$$

$$-\begin{vmatrix}0\\ -\Omega^2(r+h)\cos\varphi\sin\varphi\\ \Omega^2(r+h)\cos^2\varphi + g\end{vmatrix} - C^T(\alpha,\beta,\gamma,\lambda,\varphi)W_a,$$

$$\dot{h} = V_Z,$$

where α, β, γ - Euler-Krylov angles determining the orientation of the InCS tetrahedron relative to the ICS, $Z_d = |Z_x \quad Z_y \quad Z_z|^T$ - the measurement vector of the three orthogonal DUS's, $W_d = |W_x \quad W_y \quad W_z|^T$ the vector of additive noise of the AVS measurements (white Gaussian noise (WGN) with zero mean and intensity matrix $D_d$), λ - longitude, φ - latitude, h - object height, $V_x, V_y, V_z$ - the projections of the linear velocity of the object on the corresponding axes of the accompanying CS, r - Earth radius, Ω - angular velocity of rotation of the Earth, g - gravitational acceleration, $Z_a = |Z_{ax} \quad Z_{ay} \quad Z_{az}|^T$ - output vector signals of the accelerometers, $W_a = |W_{ax} \quad W_{ay} \quad W_{az}|^T$ - vector of accelerometers interference (WGN with zero mathematical expectation and intensity matrix $D_a$), $C(\alpha,\beta,\gamma,\lambda,\varphi) = D(\alpha,\beta,\gamma)D^T(\lambda,\varphi)$ - the matrix of directional cosines, determining the orientation of the ACS with relative to the ICS, $D(\alpha,\beta,\gamma)$ - rotation matrix of the 2nd kind [4], which determines the orientation of the ISC relative to the InCS (given in Appendix 1), $B = D(\lambda+\Omega t = \psi, -\varphi, 0)$ - matrix defining the orientation of the ACS relative to the InCS.

In the Langevin vector form, the original form for posterior estimates, equations (1) are described as:

$$Y = F(Y,t)^{\cdot} + F_1(Y,t)\xi, \quad (2)$$

where $Y = |\alpha \quad \beta \quad \gamma \quad \lambda \quad \varphi \quad V_X \quad V_Y \quad V_Z \quad h|^T, Y(0) = Y_0, \quad \xi = |W_d^T \quad W_a^T|^T,$

Model of BINS complexed with odometer. At the first stage of the solution of the integration problem we consider the complexation of BINS with an odometer, the measurements of which allow to ensure the stability of the algorithm of filtering of the object motion parameters when the SNS signals disappear (i.e. the autonomy of the NS).

In this case, as odometers we will consider two types of meters: a path sensor, the output signal of which is proportional to the length of the path traveled by the moving object, and a differential path sensor (chronometric speedometer), the output signal of which is proportional to the speed of the object (the increment of path length per measurement stroke). Without reducing the generality of the problem under consideration, we consider the output signals of both types of odometers to be continuous, which corresponds to the modern speeds of moving objects and the technological level of performance of modern odometers. Let us first consider the possibility of using as an observer of navigation parameters of the path sensor, the output signal of which is proportional to the length of the path traveled by the object. In this case, the odometer output signal $Z_0$, proportional to the length of the traveled distance, can be represented as follows:

$$Z_0 = S + W_{S0,} \quad (3)$$

where S is the distance traveled by the moving object,

$W_{S0,}$ is a measurement disturbance described in the general case by WGN with zero mathematical expectation and intensity $D_{S0}$.

To be able to use the path observer given in stochastic estimation methods, it is necessary to have a differential equation describing the variable S through other state parameters of the navigation system. This equation, in turn, follows from the physical sense of the path S (integral of the velocity modulus) and has the form:

$$\dot{S} = \sqrt{V_X^2 + V_Y^2 + V_Z^2}$$

and must be included in the system of equations of the state vector of the entire navigation system (1):

$$\begin{vmatrix} \dot{\alpha} \\ \dot{\beta} \\ \dot{\gamma} \end{vmatrix} = \begin{vmatrix} \frac{\sin\gamma}{\cos\beta} & \frac{\cos\gamma}{\cos\beta} & 0 \\ \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma\tan\beta & \cos\gamma\tan\beta & 1 \end{vmatrix} (Z_d - W_d) = \Phi(\beta,\gamma)(Z_d - W_d),$$

$$\begin{vmatrix} \dot{\lambda} \\ \dot{\varphi} \end{vmatrix} = \begin{vmatrix} 0 & (\cos\varphi)^{-1} \\ -1 & 0 \end{vmatrix} \begin{vmatrix} -V_Y \\ V_X \end{vmatrix} (r+h)^{-1}, \tag{4}$$

$$\begin{vmatrix} \dot{V}_X \\ \dot{V}_Y \\ \dot{V}_Z \end{vmatrix} = C^T(\alpha,\beta,\gamma,\lambda,\varphi)Z_a + \left( \left( 2 \begin{vmatrix} 0 \\ \Omega\cos\varphi \\ \Omega\sin\varphi \end{vmatrix} + \begin{vmatrix} -V_Y \\ V_X \\ V_x\tan\varphi \end{vmatrix} \right) \times \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} \right) -$$

$$- \begin{vmatrix} 0 \\ -\Omega^2(r+h)\cos\varphi\sin\varphi \\ \Omega^2(r+h)\cos^2\varphi + g \end{vmatrix} - C^T(\alpha,\beta,\gamma,\lambda,\varphi)W_a,$$

$$\dot{S} = \sqrt{V_X^2 + V_Y^2 + V_Z^2}$$

Such inclusion of the new equation to the system correspondingly changes the vector of navigation parameters and functions of the right side of the canonical equation (2): in this case, in comparison with (2) we have an increase in dimension of the system of equations of the vector of navigation parameters by 1 and the observation in (3) just one navigation parameter S. From theoretical point of view such observation is quite enough to construct posterior probability density function of NS state vector (and consequently, to form optimal posterior estimations), but in practical using of observer (3), due to its low informativity, the stability of estimation process may be problematic. (Increasing the dimensionality of the system as compared to the initial one only increases the estimation error due to additional computational errors).

In this connection, let us further consider the possibility of using as an observer the vector of navigation parameters of a differential odometer (chronometric speedometer), the output signal of which is proportional to the speed modulus of the moving object and can be represented as follows:

$$Z = \Delta S + W_s = k\sqrt{V_X^2 + V_Y^2 + V_Z^2} + W_s = H(Y,t) + W_s, \tag{5}$$

where ΔS is the current increment of the path taken by the object during the measurement cycle,

k is the coefficient of proportionality,

$Ws$ - measurement interference, described in the general case by WGN with zero mathematical expectation and intensity $DS$.

The obtained equations (2,5) in the "object-observer" form easily allow, following [22], to write down the equations of navigation parameter estimation in the form of a generalized Kalman filter for the studied NS:

$$\hat{Y} = F(\hat{Y}, t) + K(\hat{Y}, t)\left[Z - H(\hat{Y}, t)\right], \tag{6}$$

$$K(\hat{Y}, t) = R\frac{\partial H^T(\hat{Y}, t)}{\partial \hat{Y}} D_S^{-1},$$

$$\dot{R}(\hat{Y}, t) = \frac{\partial F(\hat{Y}, t)}{\partial \hat{Y}} R(\hat{Y}, t) + R(\hat{Y}, t)\frac{\partial F^T(\hat{Y}, t)}{\partial \hat{Y}} + F_1(\hat{Y}, t) D_\xi F_1^T(\hat{Y}, t) - K(\hat{Y}, t) D_S K^T(\hat{Y}, t)$$

where $\hat{Y}$ is the vector of the current evaluation of the state vector of the NS Y(t),

$R(\hat{Y}, t)$ - the posterior covariance matrix, $D_\xi = \begin{vmatrix} D_d & 0 \\ 0 & D_a \end{vmatrix}$,

$$\hat{Y_0} = M(Y_0), R_0 = M\left\{(Y_0 - \hat{Y_0})(Y_0 - \hat{Y_0})^T\right\}.$$

Filter (6), easily implemented in the onboard calculator of a moving object, should be used in the absence of satellite measurements, ensuring the continuity and stability of the process of evaluation of navigation parameters in general. In the presence of satellite signals, it is advisable to combine them with odometer signals. Analyzing further the measurements of the SNS, we will consider only the Doppler and code measurements, which provide a complete solution in principle to the problem of building an integrated NS using odometer readings.

**Tight integration of inertial-satellite systems using an odometer.**

In the standard mode the information model of code measurements (pseudodistance measurements) has the form [1,21,25]:

$$Z_R = \sqrt{(\xi_c - \xi)^2 + (\eta_c - \eta)^2 + (\zeta_c - \zeta)^2} + W_{Z_R}, \tag{7}$$

where $\xi_c, \eta_c, \zeta_c$ are the known coordinates of the satellite in the Greenwich SC,

$\xi$ , $\eta$ , $\zeta$ are the current coordinates of the object in the Greenwich SC,

$W_{Z_R}$ - WGN with zero mean and known intensity $D_{Z_R}(t)$, due to algorithmically uncompensated receiver and satellite clock errors, errors arising during signal passage through the troposphere and ionosphere, instrumental errors, etc.

The information signal of Doppler measurements (pseudo-velocity) $Z_V$ in standard mode can be represented as follows [1,21,24]:

$$Z_V = \left[(\xi_c - \xi)(V_{\xi c} - V_\xi) + (\eta_c - \eta)(V_{\eta c} - V_\eta) + (\zeta_c - \zeta)(V_{\zeta c} - V_\zeta)\right] \times \left((\sqrt{(\xi_c - \xi)^2 + (\eta_c - \eta)^2 + (\zeta_c - \zeta)^2})^{-1} + W_{Z_V},\right) \tag{8}$$

where $V_\xi, V_\eta, V_\zeta$ - the projections of the velocity vector of the object on the GrCS axes, $V_{\xi c}, V_{\eta c}, V_{\zeta c}$ - the projections of the satellite velocity vector on the GrCS axes,

$W_V$ - WGN with zero mean and known intensity $D_{Z_V}(t)$, caused by instrumental errors of the transmitter and receiver, random measurement errors, etc.

To be able to use the measurement signals (7,8) as observers of the NS state vector described by system (1), let us express the input variables through the navigation parameters in the ICS. For the object coordinates we have:

$$\xi = (r+h)\cos\varphi\sin\lambda,\ \ \eta = (r+h)\sin\varphi\,, \zeta = (r+h)\cos\varphi\cos\lambda, \tag{9}$$

When determining the velocity projections, consider that the velocity vector in GrCS

$V_G = |V_\xi \quad V_\eta \quad V_\zeta|^T$ is related to the velocity vector $V_S = |V_X \quad V_Y \quad V_Z|^T$ in the ICS with a matrix $B = D(-\varphi, \lambda, 0) = B(\varphi, \lambda)$ of the ICS rotation relative to the GrCS: $V_S = (\varphi, \lambda)V_G$, which allows us to obtain a representation of the $V_G$ vector through the parameters of the object's motion:

$$V_G = B^T(\varphi, \lambda)V_G \tag{10}$$

Based on (9,10), the coded and Doppler signals can be represented as information models of the state vector observers NS (1):

$$Z_R = \sqrt{(\xi_C - (r+h)\cos\varphi\sin\lambda)^2 + (\eta_C - (r+h)\sin\varphi)^2 + (\zeta_C - (r+h)\cos\varphi\cos\lambda)^2} + W_{Z_R}$$

$$= H_R(\varphi, \lambda, h) + W_{Z_R},$$

$$Z_V = \left[(\xi_C - (r+h)\cos\varphi\sin\lambda)(V_{\xi c} - B^T_{(1)}(\varphi,\lambda)V_S) + (\eta_C - (r+h)\sin\varphi)(V_{\eta c} - B^T_{(2)}(\varphi,\lambda)V_S + (\zeta_C - (r+h)\cos\varphi\cos\lambda)(V_{\zeta c} - B^T_{(3)}(\varphi,\lambda)V_S)\right] \times (\sqrt{(\xi_C - (r+h)\cos\varphi\sin\lambda)^2 + (\eta_C - (r+h)\sin\varphi)^2 + (\zeta_C - (r+h)\cos\varphi\cos\lambda)^2})^{-1} + W_{Z_V} = H_V(\varphi, \lambda, h, V_S) + W_{Z_V}$$

where $B^T_{(i)}(\varphi, \lambda)$ – i matrix row $B^T(\varphi, \lambda)$.

Accordingly, the equations of the complex of the satellite observer (odometer+SNS), taking into account the discrete nature of the messages, in vector form take the following form:

$$Z_k^{int} = \begin{vmatrix} Z \\ Z_R \\ Z_V \end{vmatrix} = \begin{vmatrix} H(Y,k) \\ H_R(\varphi,\lambda,h) \\ H_V(\varphi,\lambda,h,V_S) \end{vmatrix} + \begin{vmatrix} W_S \\ W_{Z_R} \\ W_{Z_V} \end{vmatrix} = H^{int}(Y,k) + \zeta_k^{int}, \tag{11}$$

where k - the current clock rate of satellite measurements arrival, $\zeta_k^{int} = |W_S \quad W_{Z_R} \quad W_{Z_V}|^T$ - WGN with zero mean and intensity matrix

$$D_{int} = \begin{vmatrix} D_S & 0 & 0 \\ 0 & D_{Z_R} & 0 \\ 0 & 0 & D_{Z_V} \end{vmatrix}, \quad H^{int}(Y,k) = \begin{vmatrix} H(Y,k) \\ H_R(\varphi,\lambda,h) \\ H_V(\varphi,\lambda,h,V_S) \end{vmatrix}.$$

Such a problem belongs to the continuous-discrete filtering problems and cannot be solved simply with a Kalman filter [22,23].

According to [22], the Gaussian discrete-valued algorithm for the extended observer (11) on k-m measure tact has the form:

$$\hat{Y}(t_k + 0) = \hat{Y}_{K0} + R(t_k + 0)\frac{\partial H^{int^T}(\hat{Y}_{K0}, k)}{\partial \hat{Y}}(H_0^{int}(\hat{Y}_{K0}, k)D_{int}H_0^{int^T}(\hat{Y}_{K0}, k))^{-1} \times$$

$$\times \left[Z_k^{int} - H^{int}(\hat{Y}_{K0}, k)\right] \quad (12)$$

$$R(t_K + 0) = R_{Ko} - R_{Ko} \frac{\partial H^{int}(\hat{Y}_{K0}, k)}{\partial \hat{Y}} \times$$

$$\times \left\{ \frac{\partial H^{int}(\hat{Y}_{K0}, k)}{\partial \hat{Y}} R_{k0} \frac{\partial H^{int^T}(\hat{Y}_{K0}, k)}{\partial \hat{Y}} + H_0^{int}(\hat{Y}_{K0}, k) D_{int} H_0^{int^T}(\hat{Y}_{K0}, k) \right\}^{-1} \frac{\partial H^{int}(\hat{Y}_{K0}, k)}{\partial \hat{Y}} R_{k0}$$

It should be emphasized that between discrete measurements of the SNS (at time intervals $[t_{K-1}, t_K]$, k=1,2,….,) continuous filter (6) is used, due to which its initial conditions $\hat{Y}(t_{K-1})$, R($t_{K-1}$) are the result of discrete estimation $\hat{Y}_{K-1} = \hat{Y}(t_{K-1} + 0)$, $R_{K-1} = R(t_{K-1} + 0)$ parameters of the state of NS Y at the moment $t_{K-1}$:

$\hat{Y}(t_{K-1}) = \hat{Y}_{K-1} = \hat{Y}(t_{K-1} + 0)$, $R(t_{K-1}) = R_{K-1} = R(t_{K-1} + 0)$.

The result of integrating $\hat{Y}(t_K)$ , $R(t_K)$ of the continuous filter equations (6) at the end of the interval $[t_{K-1}, t_K]$ forms the initial conditions $\hat{Y}(t_{K-1} + 0) = \hat{Y}_{K0}$, $R(t_K - 0) = R_{K0} = R_{(t_k)}$ of the discrete estimation procedure (12) at time $t_K$:

$\hat{Y}(t_K - 0) = \hat{Y}_{K0} = \hat{Y}(t_K)$, $R(t_K - 0) = R_{K0} = R_{(t_k)}$.

To illustrate the possibility of effective use of the proposed integration algorithm, numerical simulation of the estimation equations (6), (12) was performed.

**Simulation results**

The simulations were performed on time interval t ∈[0;1000]s with step Δt=0.01s by the Runge-Kutta 4th order. To avoid increasing the dimensionality of the filter equations, an additive Gaussian vector-noise with zero expectation and intensity for: odometers - $(10^{-2}\text{m/s})^2$, code measurements - $(15\text{ m})^2$, Doppler measurements - $(0.5\text{ m/s})^2$was used as the model interference. Satellite signal loss simulations were performed at 400 s for a time interval of 300 s. At the end of the simulation time interval maximum errors of Y-vector components were: by linear velocity projections - 0.25 m/s, by orientation angles - 1.5 angles, by latitude - 10 meters, by longitude - 14 meters, by height - 1 meter, which is comparable with the accuracy of linear motion parameters evaluation by satellite means (angular parameters cannot be estimated by SNS) in absence of satellite measurements.

**Conclusions**

The obtained results and numerical evaluations allow us to conclude both about the theoretical solution of the problem of close integration of the SNS and BINS using other external meters (odometers), and about the possibility of effective practical use of the proposed approach.

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# DEVELOPMENT OF A ROAD SIGN RECOGNITION SYSTEM

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**Abstract**

Recognizing road signs is one of the most important steps to help drivers avoid accidents. In this paper, the convulsive neural network (CNN) was used for an autonomous system for detecting and recognizing traffic and road signs. The proposed system works in real time to recognize the image of road signs. This paper provides model learning using in-depth learning of 43 different road signs using existing data sets and collected local road signs. A system for detecting and recognizing road signs through an 8-layer convulsive neural network is proposed, which acquires different functions by training different types of road signs. Model training has made a great contribution to the achievement of high accuracy of the road sign detection and recognition system, which has allowed our system to solve the problems of limited accuracy and performance under the influence of environmental factors, to be more comprehensive and accurate compared to many modern systems.

**Keywords:** neural network, deep learming, machine learning.

**Introduction**

Road accident – an event caused by the movement of vehicles on the road and its participation, causing harm to human health or causing serious death, as well as causing damage to vehicles, structures, cargo or other material damage [1].

Data on road accident victims in our country exceeds the statistics of such CIS countries as Armenia, Kyrgyzstan, and Tajikistan. This is the result of events that have been implemented for more than 20 years. One of the main elements of the infrastructure is the road. Many factors (such as rain, snow, high temperature, darkness, sun glare, and trucks) cause various damages that have a significant impact on road performance, driver safety, and vehicle cost.

According to official statistics of the National Bureau of statistics of the agency for Strategic Planning and reform of the Republic of Kazakhstan, the number of road accidents in traffic in 2020 is 13,515.

The following tables show statistics on road accidents in Kazakhstan for 2020:


**Figure 1 –** Number of road accidents in 2020 according to official statistics of the National Bureau of Statistics

The largest number of road accidents is observed in Almaty (3245), Almaty region (2150) and Turkestan region(1042).

The number of people killed by the incident is 1,687, and the number of injured is 12,417 [2]. The main causes of road accidents:

- increase speed in restricted areas;
- when crossing a pedestrian crossing;
- non-compliance with the requirements prescribed by road markings [3].

Road signs help prevent road accidents, ensuring the safety of both drivers and pedestrians. In addition, traffic lights guarantee that road users comply with certain laws, which reduces the likelihood of traffic violations. Road signs should be a high priority for drivers or pedestrians. It is more likely that you will not notice road signs for various reasons, such as concentration, fatigue, and sleep. Other reasons that contribute to the absence of road signs include poor vision, exposure to the outside world and environmental conditions, changes in weather conditions, reflection of the sun, etc. The real-time road sign recognition system analyzes images taken by the car's front camera in real time to recognize signs. They help the driver improve their safety by giving them alerts..

**Materials and Methods**

The system for detecting and recognizing road signs consists of a number of components, including:

1. a comprehensive data extraction process that allows you to obtain the necessary information;
2. classification of the received data flow by frame;

3. identification of acquired features;
4. training a neural network, as well as evaluating its effectiveness and accuracy in test data;
5. data set where road signs are stored;
6. identification of objects in the frame;
classification;
7. get results.

Below is an illustration of the architecture of the road sign recognition system based on the CNN model.

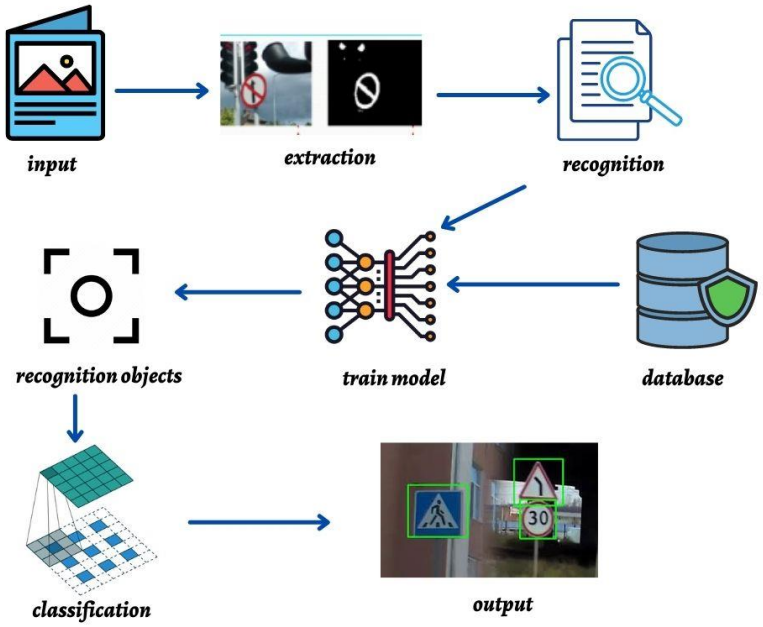


**Figure 2 –** Architecture of the road sign detection and recognition system

The data set used to train the road sign classifier is the road sign recognition test – GTSRB [4]. The GTSRB data set consists of 43 classes of road signs and about 50,000 images. The data set used can be seen in Figure 3.

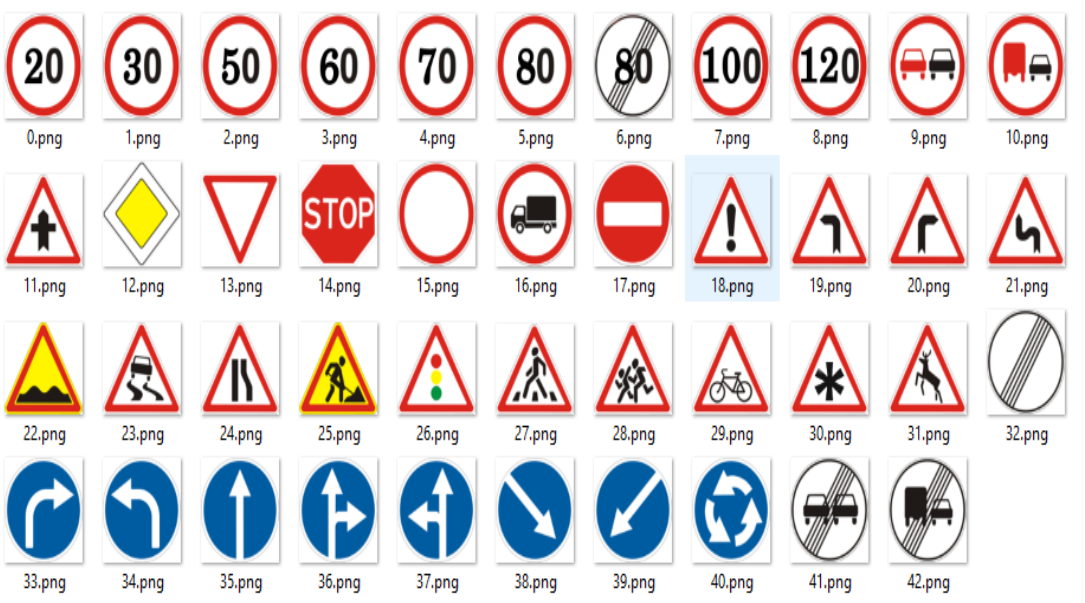


**Figure 3 –** Data set

However, it is necessary to supplement the data in this benchmark. Therefore, by conducting additional experiments with the Tsinghua-Tencent 100k [5] data set, it uses methods with many road scenes with great differences in many aspects, such as light and weather, as well as examples of occlusion.

***Neural network training.*** The main goal of this study is to create a system for identifying and recognizing road signs using deep learning.

First, a model for recognizing road signs was prepared using in-depth training, and the prepared model was tested. The process of deep learning takes a lot of time to train the model, but the classification itself takes a relatively short time.

The purpose of the problem of identifying each character for the image of road signs is to determine whether a particular pixel corresponds to a part of the character. To solve this problem, the proposed solution is based on CNN, which is designed to classify signs with geometric images. The sampling method is used between two fully related levels to reduce over-setup by preventing complex joint adaptations in learning data. The output of each neuron is set to zero with a probability of 0.5. CNN training is accelerated by graphics processing units (GPUs). Further acceleration is achieved by using corrected linear units (ReLU) as an activation function, which is more efficient than Tanh (x) hyperbolic tangent functions and is a Sigma-like function used in traditional neural models both at the training stage and at the evaluation stage. CNN is trained with a batch size of 48 units using the stochastic gradient capture (SGD) method. In the verification kit, it takes less than 20 stages to reach the minimum.

**Literature review**

Road sign detection systems are the most popular systems for detecting small objects (signs). Defining road signs usually involves using colors or geometric features to create candidate areas that may contain road signs in a particular image.

Some approaches directly use RGB color space and color limits to segment the image and define labels. Bouti A.  the researchers examined the road sign recognition system by dividing it into two parts. While the first is to detect signs in real time, the second part is a way to identify signs using data sets. To do this, the researchers used convulsive neural networks [6].

Sun Y. [7] the researchers propose a new structure of deep learning consisting of two components, including the complete convulsive network (FCN), which is controlled by road sign recognition, and the deep convulsive neural network (CNN), which is designed to classify objects. The proposed approach [7] is experimentally compared to R-CNN [8]. E. The researchers [9] use the CNN [10] method to perform road sign recognition, and the results show that this approach is promising. However, the accuracy and speed indicators showed very low accuracy.

Wu Yiqiang et al.researchers [11] implement a real-time road sign recognition algorithm that is resistant to small objects and can identify all categories of road signs. (advanced character selection can be achieved using the latest algorithms, such as spectral clustering [12, 13]). In particular, a two-level definition structure is proposed, consisting of a regional recommendation module (RPM) responsible for identifying objects, and a classification module (CM) responsible for classifying identified objects. Color and shape information was used to determine traffic lights. For example, [14] used RGB or HSV color spaces to recognize traffic lights. In addition to colors, geometric information is widely used. Geometric signs of road signs, the HAF transformation, angle determination, and projections are used to determine the exact location of road signs [15].

**Results and Discussion**

After successful training of the neural network, it is necessary to check its functioning. Below is a snippet of the program code. This is the stage of implementation of the architecture of our model.

```python
#Converting lists into numpy arrays
data = np.array(data)
labels = np.array(labels)

print(data.shape, labels.shape)
#Splitting training and testing dataset
X_train, X_test, y_train, y_test = train_test_split(data, labels, test_size=0.2, random_state=42)

print(X_train.shape, X_test.shape, y_train.shape, y_test.shape)

#Converting the labels into one hot encoding
y_train = to_categorical(y_train, 43)
y_test = to_categorical(y_test, 43)

#Building the model
model = Sequential()
model.add(Conv2D(filters=32, kernel_size=(5,5), activation='relu', input_shape=X_train.shape[1:]))
model.add(Conv2D(filters=32, kernel_size=(5,5), activation='relu'))
model.add(MaxPool2D(pool_size=(2, 2)))
model.add(Dropout(rate=0.25))
model.add(Conv2D(filters=64, kernel_size=(3, 3), activation='relu'))
model.add(Conv2D(filters=64, kernel_size=(3, 3), activation='relu'))
model.add(MaxPool2D(pool_size=(2, 2)))
model.add(Dropout(rate=0.25))
model.add(Flatten())
model.add(Dense(256, activation='relu'))
model.add(Dropout(rate=0.5))
model.add(Dense(43, activation='softmax'))

#Compilation of the model
model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])

epochs = 15
history = model.fit(X_train, y_train, batch_size=32, epochs=epochs, validation_data=(X_test, y_test))
```

**Figure 4 –** Example from the CNN model training phase

Matplotlib is a Python programming language library for visualizing data with two-dimensional (2D) graphics (3D graphics are also supported). Using Matplotlib, we created a graph of model training and matching accuracy and their error.

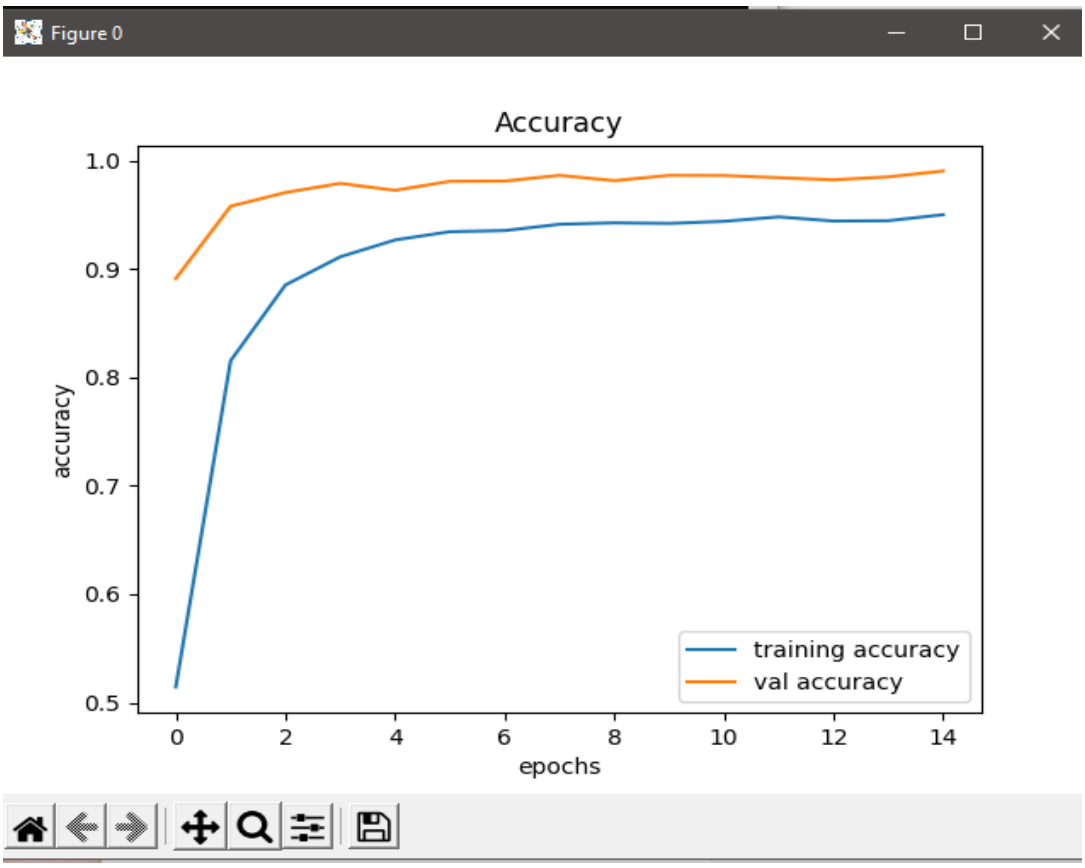


**Figure 5 –** Model training and identification accuracy

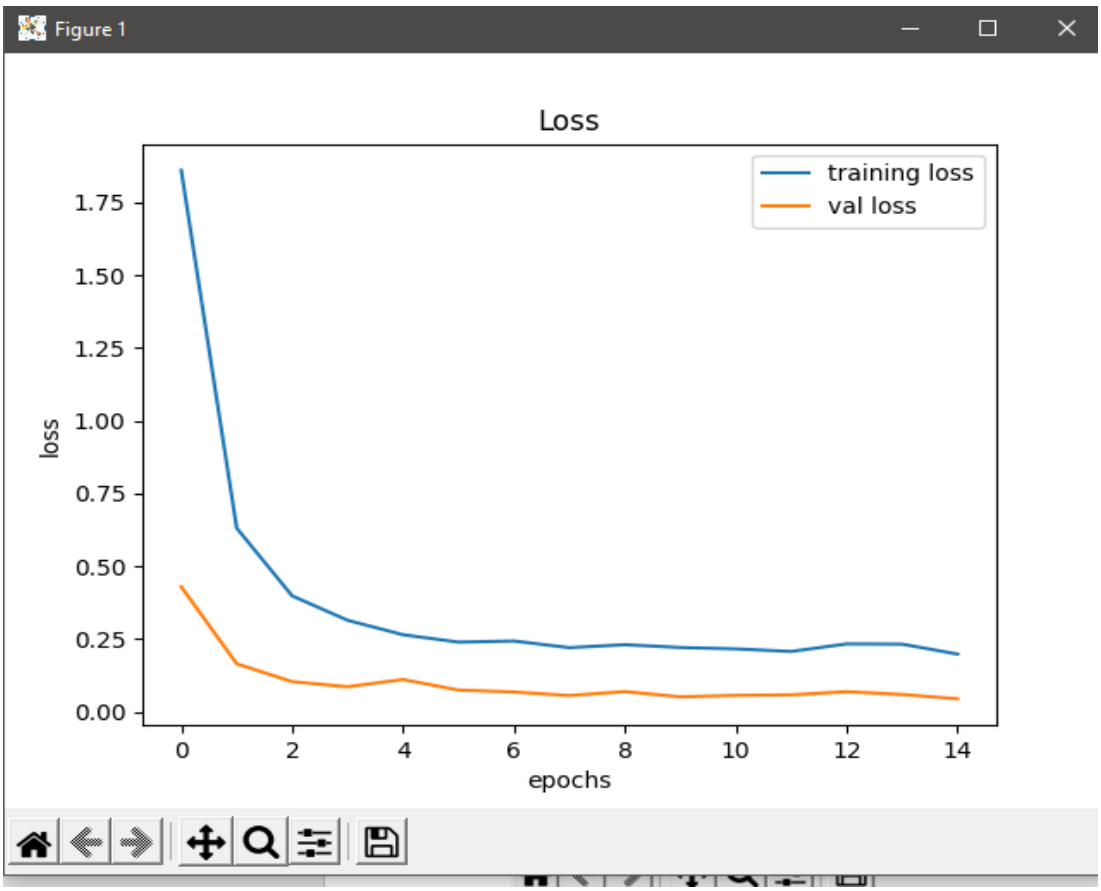


**Figure 6 –** Model training and identification error

As can be seen from the images above, the neural network has been successfully trained and is ready to process new images.

Below is an example of the symptom recognition result of this system.

Based on the results, 95% accuracy of recognizing road signs in real time was achieved using in-depth training in the most well-defined category.

**Conclusion**

In the course of the study, a new way to identify and recognize road signs was proposed. Its purpose, structure, and architecture were described. To increase network performance, focus loss is used to monitor the regional Offer Network. In addition, 3 convolutional and one fully connected layer were used to identify road signs, which is very useful if large road signs are detected. At the recognition stage, dense blocks are used in the classification network to increase accuracy. The proposed approach works very well in identifying and recognizing different categories of road signs.

Based on the results, with the help of in-depth training in the most well-defined category, 95% accuracy of recognizing road signs in real time was achieved. The proposed research work can greatly help in reducing the number of road accidents.


**Figure 7 –** Road signs identified as a result of model training

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# TRANSFORMATION OF THE MARKETING CONCEPT AS A RESULT OF THE DEVELOPMENT OF DIGITAL TECHNOLOGIES

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**Abstract**

Digital marketing is a marketing concept whose goals are achieved through the Internet, computer communication technologies and digital interactive media. Digital marketing uses advanced computer and network technologies to find new markets and new consumers, ensuring maximum economic efficiency. Previously, digital marketing was considered as a form of individual communication with customers in certain areas of activity, but since 2003, the scale of its application has been increasing. Most forms of marketing in traditional areas (for example, direct marketing, targeted advertising) are switching to digital formats. Digital marketing has many unprecedented competitive advantages: it is able to integrate various marketing activities, such as product description, promotion, customer opinion polling, advertising, public relations, customer service, etc. These marketing activities are not limited by time and geography, they are integrated with text, sound, video, web and audiovisual, dynamic or static display and can be quickly and easily updated, and consumers can also re-view requests.

**Keywords:** digital marketing, innovative products, digital economy, digital marketing tools.

## Introduction

As part of the development of modern information technologies, social networks can be called one of the most popular tools for promoting and managing business on the Internet. Social media platforms unite billions of people, and in order to get in direct contact with their customers, brands create business accounts. A business page in a social network is a part of a brand, its representation, it can not only increase customer awareness and loyalty, but also increase financial indicators. The purpose of this article is to analyze the advantages of SMM marketing tools, effective methods and information technologies used for the development of business accounts.

Analysis of the main directions of marketing activities in the context of digital transformation has shown that for successful development in the digital economy, companies need to improve digital methods of collecting, processing, analyzing information; expand interaction with consumers in the digital environment; timely identify destabilizing factors of the competitive environment and respond to emerging threats. The proposed approaches to formalization and algorithmization of decision-making processes about innovative changes in marketing activities, such as generation of new concepts of data use, experimental verification of innovative tools, actualization of value applications, will contribute to the development of innovative strategies for interacting with customers and recognizing threats to destabilize the market situation. Marketing algorithms of digitalization will ensure not only the generalization of best practices and the accumulation of managerial experience in artificial intelligence systems, but also the efficiency of the company's response to emerging opportunities and threats.

At the moment, the audience of social networks is about one billion people and this number is increasing every year. The average user of social networks can view about a hundred pages a day, this level of activity is amazing. What various projects on the Internet have tried to achieve with difficulty, social networks have achieved with amazing speed. Psychologists are already considering dependence on social networks as a real threat to people's health. There was even a certain term "Facebookaddicted" (dependent on Facebook). This is due to the fact that more and more people are

accessing the Internet just for the sake of social networks. They spend several hours a day just to view posts. The audience of social networks is very different from other users on the Internet. For them, the social network has become their "separate" Internet, in which they: watch movies and videos, listen to music, buy goods, communicate, play, work. All offline companies are now striving to capture this audience and attract their attention. They create their own resources, hire specialists to promote them, hold events, share gifts to attract users from social networks. [1]

Thus, we can say that the platform is a tool of a new order, which is many times more effective than other tools, since it includes all the necessary functionality. Many experts give their preference to them and this is not without reason. According to many studies, platforms significantly increase various indicators. They save the advertising budget, increase the profit from sales, increase the conversion of the site, and also contribute to the development of constant contact with the audience.

Internet PR strategy. The strategy is similar to PR in its classical sense. This type is used to increase brand awareness, as well as to attract the target audience. The most effective method is brand promotion in popular Internet resources. Publication of information, news, articles about the company's activities.

Viral marketing. This strategy has been actively gaining popularity recently. The basis of this strategy is the development and publication of viral content (content that is rapidly gaining popularity and is distributed by the users themselves). This method is used in various areas of marketing, be it a blog or a community. The main condition of this method is that viral content should not interact in any way and depend on its creator. The promotion of this content falls entirely on the users who will see it. At the moment, there are a large number of more narrowly focused strategies. Each specialist develops them based on their needs. Using different strategies allows you to get more effective results. At the moment, marketers use not only basic strategies, but also create more narrowly focused strategies for maximum efficiency in online marketing. [2]

**SMM information technology**

Currently, new ways of promoting business on the Internet, attracting customers and stimulating demand for products, goods or services are emerging. One of the innovations of information technologies for promotion can be attributed to SMM — Social Media Marketing. SMM is an effective set of marketing tools that uses social networks or other social platforms to promote brands and solve business problems. As a rule, business accounts are created in certain social networks focused on this in order to post information about the company, its products and products, special offers and new products there. The advantages of SMM account promotion include:

1. A significant reduction in the gap between the company and the client, since social networks allow these two groups to contact directly, through comments and messages.
2. The opportunity to develop at low financial costs, which means that there is no certain risk.
3. The opportunity to reach a huge international audience and enter the foreign market.
4. Reduction of advertising distribution time and processing time of the response to it.

The purpose of the work is to formulate the key directions of digital transformation of marketing activities based on the study of successful projects for the introduction of innovative technologies, to show the possibilities of formalizing the procedures for using innovative tools in marketing. When developing digital transformation strategies, company management faces the problem of determining priorities and directions of development. It includes issues such as the selection of digital technologies and IT solutions in which the company's resources should be invested; assessment of the impact of new technologies on business efficiency and payback periods.

One of the main directions is improving the methods of collecting, processing, and analyzing information. Its implementation is aimed primarily at creating analytics systems, specialized tools for analyzing heterogeneous data. [3]

The organization of interaction with consumers in the digital environment is based on the integration of data processing processes, marketing research with customer relationship management systems (CRM systems). Technologies of artificial intelligence, virtual and augmented reality (AR,

MR and VR), the Internet of Things (IoT) allow creating an ecosystem of marketing interaction around each individual user, combining all available communication channels.

The most important task of marketing is to ensure the competitiveness of the operating enterprise in the digital environment, to help the company adapt to the rapid changes taking place under the influence of new technologies.

Given the speed of digital transformation processes, it is necessary to pay priority attention to the formalization and algorithmization of data processing methods; development, adoption and control of decisions on innovative changes. This will ensure not only the generalization of best practices and the accumulation of managerial experience in artificial intelligence systems, but also the responsiveness to emerging opportunities and threats. [3]

Analyzing successful digital technology application projects, comparing approaches to the formation of digital transformation strategies of high-tech companies, also outlined in the work, we can identify the following key board issues that need to be focused on when developing digital transformation strategies for marketing activities:

• improving digital methods of data collection, processing, analysis;

• organization of interaction with consumers in the digital environment based on identification and reaction to changes in customer behavior;

• monitoring the competitive environment, identifying threats and preventing negative impacts.

The listed directions can be specified in the form of management algorithms used in the development of digital transformation strategies. The main areas of data usage are traditionally:

• analysis of customer behavior in the digital environment in order to improve the efficiency of interaction with users;

• identification of promising areas and points of growth of the company;

• study and formation of the target audience;

• improving customer interaction by individualizing goods and services, personalizing offers, and providing original content.

At the same time, a number of companies are creating and successfully using new concepts of using data for innovative development or creating a new business. The generation of new concepts for the use of data involves the following operations. [4]

1. Determining the direction, purpose, and objectives of data use, for example, penetration into new markets, studying the competitive environment and customer behavior.

2. Definition of data usage formats, for example, unstructured video analytics data on customer behavior in a shopping mall.

3. Development of a plan for achieving goals and solving tasks, for example, based on data collected during the implementation of loyalty programs, a business scenario can be focused on personalizing interaction with customers of a certain target audience with the offer of individual bonuses.

4. Analysis of available data and identification of missing data, sources, methods of their collection and systematization, for example, analysis of social networks that unite a target group of clients to clarify and personalize offers.

5. Development of a new data usage concept, including the technical part, planning changes in business processes, testing and evaluation of a new data usage concept.

**Analysis**

Systematic analysis of competitors' actions, search for technological, product, marketing, organizational innovations should be complemented by operational selection and experimental testing of new ideas in the conditions of their market segment. At the same time, digital technologies allow6 to significantly reduce the time and cost of experimental testing of innovations due to access to a variety of information resources, computer modeling. [5]

The process of experimental verification of innovative tools includes the following steps.

1. The formulation of the problem that the experiment is aimed at solving.

2. Defining the boundaries of the experiment (time, resources that the company is willing to spend on the experiment). Determination of the time and conditions for the completion of the experiment.

3. Formation of a team of participants in the experiment, determination of rights and obligations, conditions of their work, conditions for attracting other employees.

4. Collecting information about the market and key parameters of the experiment.

5. Analysis of the received information and development of several hypotheses that require additional verification.

6. Conducting an experiment (for example, creating simplified prototypes of solutions, testing a simplified business model, obtaining, etc.) and analyzing its results.

7. Making a decision on the success and continuation of the experiment, the possibilities of finalizing and improving the result obtained, using the results obtained to improve the company's work and choosing further directions of experiments.

In the context of digital transformation, it is important to timely identify and implement innovations that ensure the growth of the value of a product or service in the eyes of potential consumers. Digital transformation forces both the company itself and the solutions offered to the market to change very quickly, considered by customers as the value that the company offers to the market, the consumer becomes more demanding of the service component of sales. The algorithm for updating the value application includes the following stages. [5]

1. Study of changes occurring in customer motivation under the influence of digital transformation. Identification of strategically important groups of clients, their goals, tasks, methods of work in the market, the most important needs.

2. Clarification of existing value propositions for each group of clients.

3. Threat recognition for these offers. Identification of new customer requests, as well as values formed as a result of the emergence of new technologies, new offers from competitors, as well as competitive offers from other industries.

4. Analysis of threats, assessment of their impact on existing value propositions.

5. Generation of new proposals taking into account new technologies, customer requests, changes in the business environment. Active discussion of emerging issues with clients and stakeholders.

6. The formation of a new value proposition that expands the already existing value proposition, and devoid of irrelevant, lost value elements.

7. Testing a new value proposition on customer focus groups.

It is possible to propose an algorithm for developing innovative strategies for interacting with customers through network resources in the context of digital transformation, which will include the following stages.

Stage 1 – identification of specific tasks to be solved by the strategy being developed.

Stage 2 – definition of the target audience.

Stage 3 – choosing a model of interaction in social networks that provides a solution to the tasks set.

Stage 4 – formulation of the product concept taking into account the conditions of interaction in the digital environment. The image of the product should be attractive in various situations: when it is discussed in social networks, shown on a smartphone screen, information about the product should be easily accessible and transmitted between customers communicating on social networks using mobile devices.

Stage 5 – determining the criteria for the effectiveness of the strategy and evaluating the expected results of strengthening the competitive positions of the product and the company in the market.

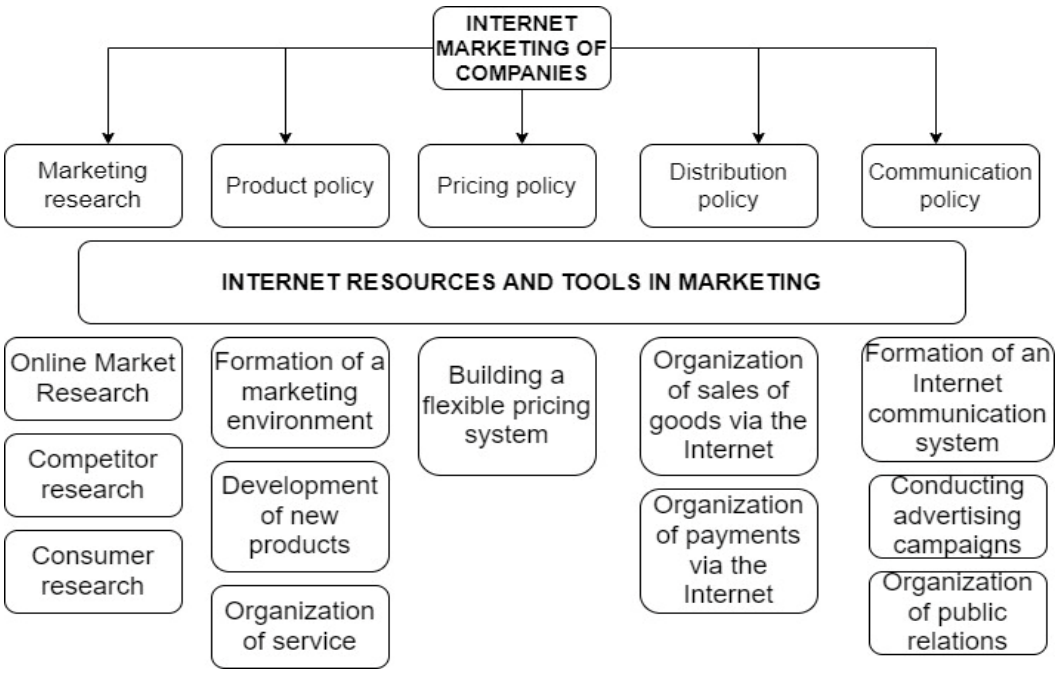


**Figure 1** - The possibilities of using the Internet in the company's marketing mix.

As a result of digital transformation, the development of digital platforms, the company's relationships are changing not only with customers, but also with competitors. There is a transition from the traditional industry linear model to the network model of competition. [6]

Summing up, we can draw the following conclusions regarding online marketing:

1. There are many ways of promotion, and they all perform certain tasks and are effective in special cases, but the most thorough and common are: SMM (social media marketing) and SEO (Search query optimization).

2. Marketing platforms are gaining popularity - a large resource that includes the necessary tools for the effective implementation of a marketing strategy. At the moment there are a huge number of them and they all have different functionality for different purposes.

3. There are a huge number of examples for creating an Internet marketing strategy.

Most of the strategies are narrowly focused and created individually, specifically for companies. Three main and most well-known strategies stand out among them: Internet PR, Viral Marketing, and Integrated Marketing Strategy. These strategies are almost universal and have been used by marketers for a long time. [7]

**Literary review**

Behavioral purposeful is considered a motivational calculate that impacts a particular behavior. In the event that one's purposeful is solid to perform a certain behavior, the person is more likely to perform such behavior. Employees' behavioral purposeful to utilize SMM is a critical figure for comprehending their activities towards utilizing SMM. Behavioral deliberate is separated into two categories, which are favorable deliberate and unfavorable purposeful. Favorable purposeful is related with devotion, eagerness to do something, and exchanging eagerly. On the off chance that SMEs accept that utilizing SMM in their undertakings will advantage them, they will organize to really utilize SMM and attempt to adjust their employees' eagerly to utilize SMM to determine those benefits. Convenience and ease of utilize are seen to be viable indicators of BIS, and, in such situation, the workers will be propelled to mean to utilize SMM in their SMEs. [8]

Social media marketing (SMM) alludes to the showcasing approach that utilizes social media innovation, channels, or program to realize the objectives of showcasing, such as conveying customer data, building quality connections with buyers, and expanding deals, etc. The previously mentioned characteristics empower the social media to have important benefits for undertakings, which can be reflected from the enterprisers' inspirations for embracing social media in their businesses, counting

(1) utilizing social media as an data stage, (2) expanding intelligent with shoppers, (3) building an incredible notoriety and brand picture, (4) finding modern clients, (5) collecting showcase insights or important data, and (6) improving fetched adequacy in showcasing communication. Indeed, in spite of the fact that social media uncover different preferences for endeavors, as depicted over, there are moreover a few drawbacks for endeavors with respect to the use of social media. [9]

The web and social media have changed customer behavior and affected the commerce hones of companies. Social and advanced promoting gives noteworthy openings for organizations: cutting down the costs, expanding brand mindfulness, and boosting deals. Communication with customers can be set up with the utilize of a wide run of computerized channels: websites, promoting on the web, mail informing, social media, portable applications, online distributions focusing on diverse bunches of clients with distinctive inclinations with respect to how they lean toward to get data. Social media instruments permit companies to utilize coordinate and more seriously intelligently shapes of communication and shoppers engagement. Usage of social media showcasing (SMM) allows mechanical companies to realize their showcasing objectives at moderately moo costs – and hence diminish showcasing costs by making SMM a portion of their trade methodology. [10]

Social media are different shapes of online media in which individuals with common interface, objectives, and hones lock in in social intuitive by making individual profiles and sharing data and encounters. These can be full-fledged social media that permit sharing upgrades and photographs, joining occasions, and performing numerous other exercises (e.g. Facebook, VKontakte), photo sharing destinations (e.g. Flickr, Photobucket), destinations for making and sharing recordings (e.g. YouTube, Ustream), online communities, as well as microblogging apparatuses that permit individuals to share brief messages, or “updates”, with others (e.g. Twitter), social labels (e.g. Digg), newsreaders (e.g. Google Peruser), open web gatherings, review/rating locales (e.g. TripAdvisor), blogs/moblogs, labeled destinations, podcasting, wikis, and standalone websites. One of the foremost critical capacities of social media is that they give a web application where clients can effortlessly make and publish different substance within the shape of writings, photographs, recordings, etc. [11]

Social media are progressively getting to be a profitable apparatus for Business-to-Business (B2B) organizations. In any case, social media inquire about in B2B needs a comprehensive diagram from a vital viewpoint, with most investigate to date having been centered on the strategic utilize of social media stages, that's to say, in portraying particular apparatuses to implement a methodology. Within the show efficient writing survey we address this insufficiency. Our discoveries uncover that earlier B2B investigate predominately explored social media as short-term strategies with context-specific confinements. [12]

Effective promotion of an enterprise in social networks begins with a properly developed SMM strategy. The strategy will help to determine the goals of social media presence, ways to achieve them, set priorities, and most importantly, predict the potential effect and not deviate from the planned route. In our opinion, it is appropriate to define the content of the concept of "SMM strategy". In the scientific literature on the subject of the study, one can find various approaches to the definition of the concept of "SMM strategy". So, according to Umanskaya M.V. and S.V. Petrova, SMM strategy is an activity aimed at forming consumer demand in the field of mass communications and on communication platforms. [13]

It should be noted that SMM is not a direct advertisement of goods and services, which often irritates users. In fact, this is an unobtrusive advertisement that awakens the user's desire to purchase a specific product or service based on the analysis of the information provided. It is important to have a trusting atmosphere in the target audience of users, which helps to unite the audience and a positive perception of reviews and opinions of various users when discussing certain goods and services. At the same time, the expressed personal opinion of users is not perceived by other users as explicit advertising. [14]

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The most reason of socio-ethical showcasing ought to be the arrangement of shopper devotion through the creation of affiliations with social programs conducted by undertakings and organizations. In this setting, the assignments of socio-ethical promoting ought to be: the examination of the target audience; development of measures to make a framework of client devotion and reinforce the position of the brand in a specialty showcase; the making strides the quality of products and administrations and their compliance with socio-economic and natural guidelines; the arrangement of a framework of measures that will make strides the quality of life. It was carried out the examination of showcasing devices within the setting of realization of the concept of socio-ethical promoting within the conditions of digitalization. It was considered the conditions of advancement of advanced promoting devices. It was decided that the promoting instruments that are actualized within the advanced economy have certain points of interest within the arrangement of socially characterized attribute. [16]

Companies may improve connections with clients, supply chain, or trade accomplices by capitalizing on the potential benefits of social media and their particular capabilities. One downside with social media promoting is the plausibility that organizations may fall flat to respond suitably to buyer or client reactions. The failure to reply to shopper complaints may lead to antagonistic responses in social media communities. A real life illustration could be a reaction by Verizon to a message that an unsatisfied T-Mobile customer posted on Twitter outlines, the intercession methodologies that firms utilize on social media to progress client connections. In this case, the T-Mobile client did not straightforwardly address Verizon. Be that as it may, by effectively observing client messages that specify competitors, Verizon was able to proactively intercede in an endeavor to persuade the client to switch phone suppliers. [17]

**Conclusion**

1. Digital transformation affects all areas of marketing activities. In order to develop and succeed in the digital economy, companies need to transform the processes of working with data, interacting with consumers, and promptly respond to changes in the competitive environment.

2. The focus of the company's strategy on innovative development becomes the main direction. At the same time, traditional and costly methods of innovation implementation are being replaced by algorithms based on experimental operational and low-budget verification of emerging innovations. The most important condition for conducting experiments is efficiency and the ability to test innovations in real time and in real conditions, providing feedback and readiness for failures.

3. Due to the development of digital technologies, the methods of interaction with consumers are radically changing. The model based on mass production of goods and mass advertising, designed to reach huge audiences, is becoming a thing of the past. It is being replaced by a model based on the individualization of goods for the needs of a particular client, and personalized commercial offers. The Internet, social networks, mobile communications, allowing people to communicate with each other, provide effective feedback to the consumer. The main requirement of customers is easy and fast access to the information they need, ease of use, originality and quality of content. The customer wants to make purchases in one click.

4. Competition becomes non-industry and less hostile. Competitors have to actively cooperate with each other to achieve common success by creating joint or integrated business structures that counter a common threat.

5. One of the most important tasks of competitive analysis is to recognize phenomena, product, technological, organizational innovations that destabilize competitive markets, as well as to develop strategies to counter emerging threats.

6. Existing companies that emerged before digital transformation need to include in their strategic decisions the need for constant changes, with the replacement of outdated business models with modern ones. At the same time, the strategy should take into account that digital transformation

opens up new opportunities, allowing you to expand your business, find new customers and partners in various regions, and gives you a chance to capture new emerging markets emerging as a result of the use of digital technologies.

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# SIMULATION OF FOUR-COMPONENT MIXTURES SEPARATION BY PHASE FIELD AND LB METHODS

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**Abstract**

This article reviews the mathematical and computer modeling of the process of four-component fluid mixture separation by Lattice Boltzmann equations method and phase field method. The process under study is considered in a limited area having the shape of a rectangle. The mathematical model constructed to describe this process is based on solving the continuity equation, Navier-Stokes equations for an incompressible fluid and the Cahn-Hilliard convective equation. The numerical model is built on the basis of D2Q9 scheme of the free energy Lattice Boltzmann equations method. The separation process of four-component mixtures at different points in time was presented in the form of figures depicting the density contours of the mixture components. Four-component mixture separation was considered in two cases: with and without taking into account the influence of the gravity force. The results obtained determine the adequacy of the constructed mathematical and numerical model for the four-component fluid.

**Keywords:** four-component fluid, mixtures separation, Cahn-Hilliard equation, free energy, lattice Boltzmann equations method.

## Introduction

The study of the dynamics of multicomponent fluids is of significant scientific and technological interest. Multicomponent fluids are found in many natural and industrial processes, such as oil and gas production, chemical processing of raw materials, fluid mixture flows in boilers and condensers, etc.

There are various models [1–4] that describe processes in multicomponent fluid mixtures. Considering the thickness of the transition layer between the phases, these models can be divided into two groups: sharp interface models (transition layer between phases has zero thickness) and diffuse interface models (transition layer between the phases has a finite thickness). This article uses the diffuse interface model. Van der Waals [5] was the first to consider the transition layer between phases as a layer of finite thickness. At present, the Cahn-Hilliard approach [6] is widely used to describe diffuse interface models.

This work is a continuation of the work we wrote in [7], which describes the process of separating a three-component fluid mixture. This paper presents a mathematical model of the four-component incompressible fluid flow using the phase field method based on solving the Navier-Stokes equations and the Cahn-Hillard convective equation. The numerical model is based on the D2Q9 scheme of the free energy LB method. The separation process of four-component mixtures at different points in time was presented in the form of figures depicting the density contours of the mixture components. The results obtained determine the correctness of the constructed model for a four-component fluid.

## Problem statement

The process under study is considered in a limited area having the shape of a rectangle with dimensions $[0, L] \times [0, L]$ (Figure1). In this area there are three fluid components with density $\rho_1, \rho_2, \rho_3$ and $\rho_4$, the ratio of which is: $\rho_1 > \rho_2 > \rho_3 > \rho_4$. A fluid with a density $\rho_4$ is indicated in blue, $\rho_3$ – in green, $\rho_2$ – in yellow, and a denser fluid with a density $\rho_1$ – in red.

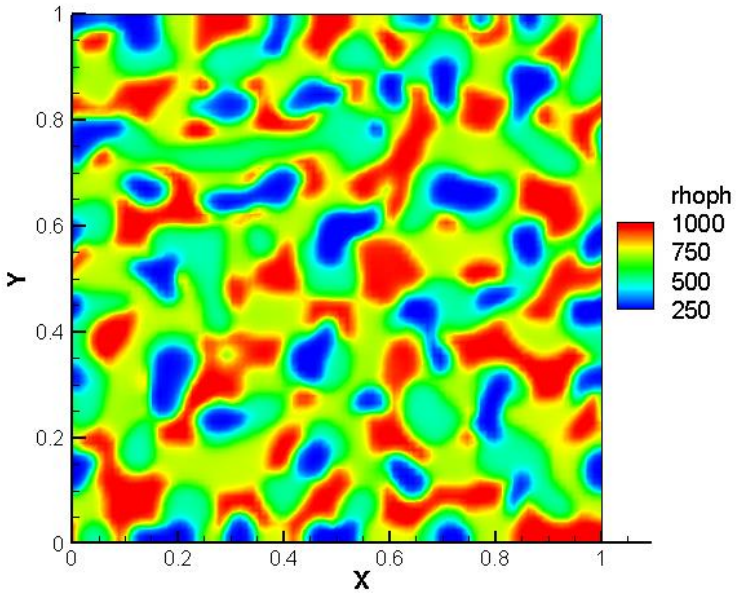



**Figure 1** - Computational domain.

The mathematical model of the process includes the continuity equation, the momentum equation for the mixture and the Cahn-Hilliard convective equation:

$$\begin{gathered} \nabla \cdot \vec{u} = 0, \\ \frac{\partial(\rho\vec{u})}{\partial t} + \nabla(\rho\vec{u}\vec{u}) = -\nabla p + \nabla[\eta(\nabla\vec{u} + \nabla\vec{u}^T)] + F_s + \vec{F}_b, \\ \frac{\partial(c_i)}{\partial t} + \nabla(c_i\vec{u}) = \nabla(M_i\nabla\mu_i), i = 1,2,3,4 \end{gathered} \tag{1}$$

where $\vec{u}$ are the velocity components, $p$ is the pressure, $\rho$ is the density, $\eta$ is the dynamic viscosity, $c_i$ is the phase field for the fluid components: $c_1 + c_2 + c_3 + c_4 = 1$, $\vec{g}$ is the gravitational acceleration, $M_i$ is the mobility coefficient, $\mu_i$ is the chemical potential, $\vec{F} = F_s + \vec{F}_b = \sum_{i=1}^{4} c_i\nabla\mu_i + \rho\vec{g}$ is the total force of surface tension and body force.

For a system of a multicomponent medium, the Landau free energy functional $F$ can be determined based on the concentrations of fluids as follows [8]:

$$F(c, \nabla c) = \int \left[ F_0(c) - \sum_{i,j=1}^{4} \frac{3D}{8}\sigma_{ij}\nabla c_i c_j \right] d\Omega$$

where $F_0(\mathrm{c}) = \sum_{i,j=1}^{4} \frac{3}{D}\sigma_{ij}[g(c_i) - g(c_j) - g(c_i + c_j)]$ is the bulk free energy, $c - (c_1, c_2, c_3, c_4)$ is the phase variable of fluid components, $g(c) = c^2(1-c)^2$, $\sigma_{ij}$ is the surface tension between the fluids, $\sigma_{ii} = 0$, $i, j = \overline{1,4}$, and $D$ is the thickness of the transition layer between fluids.

The variation of the free energy function $F$ with respect to the concentration fractions of fluids yields the chemical potential $\mu_i$ for component $i$ as:

$$\mu_1 = \frac{12}{D}\left[\lambda_1 c_1(1-c_1)(1-2c_1) - 2\lambda_T c_1 c_2(1-c_1-c_2) - 2\lambda_T c_1 c_3(1-c_1-c_3) - 2\lambda_T c_1 c_4(1-c_1-c_4)\right]$$
$$-\frac{3}{4}D\lambda_1\Delta c_1,$$

$$\mu_2 = \frac{12}{D}\left[\lambda_2 c_2(1-c_2)(1-2c_2) - 2\lambda_T c_1 c_2(1-c_1-c_2) - 2\lambda_T c_2 c_3(1-c_2-c_3) - 2\lambda_T c_2 c_4(1-c_2-c_4)\right]$$
$$-\frac{3}{4}D\lambda_2\Delta c_2,$$
$$\mu_3 = \frac{12}{D}\left[\lambda_3 c_3(1-c_3)(1-2c_3) - 2\lambda_T c_1 c_3(1-c_1-c_3) - 2\lambda_T c_2 c_3(1-c_2-c_3) - 2\lambda_T c_3 c_4(1-c_3-c_4)\right]$$
$$-\frac{3}{4}D\lambda_3\Delta c_3,$$
$$\mu_4 = \frac{12}{D}\left[\lambda_4 c_4(1-c_4)(1-2c_4) - 2\lambda_T c_1 c_4(1-c_1-c_4) - 2\lambda_T c_2 c_4(1-c_2-c_4) - 2\lambda_T c_3 c_4(1-c_3-c_4)\right]$$
$$-\frac{3}{4}D\lambda_4\Delta c_4.$$

We substitute the obtained $\mu_i$ into equation (1), as a result of which the system will be complete. The system of equations (1) has the following initial conditions:

$$u = v = 0,$$

$$c_1(\vec{x}, 0) = \bar{c}_1 + \alpha \times rand(\vec{x})$$
$$c_2(\vec{x}, 0) = \bar{c}_2 + \alpha \times rand(\vec{x})$$
$$c_3(\vec{x}, 0) = \bar{c}_3 + \alpha \times rand(\vec{x})$$
$$c_4(\vec{x}, 0) = 1 - c_1(\vec{x}, 0) - c_2(\vec{x}, 0) - c_3(\vec{x}, 0)$$

Boundary conditions:
On the bottom wall at $y = 0$:

$$u = v = 0, \ \frac{\partial c_1}{\partial y} = \frac{\partial c_2}{\partial y} = \frac{\partial c_3}{\partial y} = \frac{\partial c_4}{\partial y} = 0.$$

On the side walls at $x = 0, L$:
The periodic boundary conditions is set for $u, v, c_1, c_2, c_3, c_4$.

On the top wall at $y = L$:

$$u = v = 0, \ \frac{\partial c_1}{\partial y} = \frac{\partial c_2}{\partial y} = \frac{\partial c_3}{\partial y} = \frac{\partial c_4}{\partial y} = 0.$$

**Numerical method**

The numerical solution of this model is based on the D2Q9 scheme of the LB method. Lattice Boltzmann equations are derived by discretizing the continuous Boltzmann equation first in velocity space, then in space variables and time. The method involves solving a system of algebraic equations

with respect to particle distribution functions. The Navier-Stokes equations can be obtained by applying the Chapman-Enskog analysis to this system [9].

The lattice Boltzmann equation in the Batnagar-Gross-Krook (BGK) approximation is written as follows:

$$f_i(\vec{x}+\vec{e_i}\Delta t, t+\Delta t) - f_i(\vec{x},t) = \Delta t\left[-\frac{f_i(\vec{x},t)-f_i^{eq}(\vec{x},t)}{\tau_f}+F_i\right]$$
$$g_i^m(\vec{x}+\vec{e_i}\Delta t, t+\Delta t) - g_i^m(\vec{x},t) = \frac{\Delta t}{\tau_m}\left[g_i^m(\vec{x},t)-g_i^{m,eq}(\vec{x},t)\right]$$

where $m=1,2,3,4$ are the fluid components, $f_i, g_i^m$ are the velocity and phase field distribution functions, $e_i$ is the discrete lattice velocity, $\tau_f = \frac{1}{2}+c_1\left(\tau_1-\frac{1}{2}\right)+c_2\left(\tau_2-\frac{1}{2}\right)+(1-c_1-c_2)\left(\tau_3-\frac{1}{2}\right), \tau_m = 0.8$ is the relaxation time, $F_i$ is the external force component, $\Delta t$ is the lattice time step, $f_i^{eq}, g_i^{m,eq}$ are the equilibrium distribution functions for velocity field and phase field, respectively.

The equilibrium distribution functions are determined as follows [9]:

$$f_i^{eq} = \begin{cases} \rho - \sum_{i\neq 0} f_i^{eq}, i=0 \\ \omega_i\rho\left(1+\sum_{m=1}^{3}\frac{c_m\mu_m}{\rho c_s^2}+\frac{e_{i\alpha}u_\alpha}{c_s^2}+\frac{u_\alpha u_\beta\left(e_{i\alpha}e_{i\beta}-c_s^2\sigma_{\alpha\beta}\right)}{2c_s^2}\right), i\neq 0 \end{cases}$$

$$g_i^{m,eq} = \begin{cases} c_m - \sum_{i\neq 0} g_i^{m,eq}, i=0 \\ \omega_i\left(\frac{\Gamma_m\mu_m}{c_s^2}+\frac{c_m e_{i\alpha}u_\alpha}{c_s^2}+\frac{c_m u_\alpha u_\beta\left(e_{i\alpha}e_{i\beta}-c_s^2\sigma_{\alpha\beta}\right)}{2c_s^2}\right), i\neq 0 \end{cases}$$

where $c_s = c/\sqrt{3}$ is the lattice speed of sound, $c = \Delta x/\Delta t$, $\Delta x = 1$ and $\Delta t = 1$ are the lattice space and time steps.

For the D2Q9 model, discrete speeds are calculated as follows:

$$e_{ix} = (0,1,1,0,-1,-1,-1,0,1)c$$
$$e_{iy} = (0,0,1,1,1,0,-1,-1,-1)c$$

The values of the weight parameters in all directions are defined as:

$$\omega_i = \begin{cases} \frac{4}{9}, i=0, \\ \frac{1}{9}, i=1-4, \\ \frac{1}{36}, i=5-8 \end{cases}$$

In this paper, to approximate the external force $\vec{F} = F_s + \vec{F}_b = \sum_{j=1}^{4} c_j \nabla \mu_j + \rho \vec{g}$ in LBM, we use the scheme proposed by Guo et al. [10]:

$$F_i = \omega_i \left(1 - \frac{\Delta t}{2\tau_f}\right)\left[\frac{\vec{e}_i - \vec{u}}{c_s^2} + \frac{\vec{e}_i(\vec{e}_i \cdot \vec{u})}{c_s^4}\right] \cdot \vec{F}$$

There are two steps for distribution functions like collision and propagation:

$$f_i^{\,*}(\vec{x}, t) = f_i(\vec{x}, t) + \Delta t\left(-\frac{f_i(\vec{x}, t) - f_i^{\,eq}(\vec{x}, t)}{\tau_f} + F_i\right)$$

$$g_i^{\,m,*}(\vec{x}, t) = g_i^{\,m}(\vec{x}, t) + \Delta t\left(-\frac{g_i^{\,m}(\vec{x}, t) - g_i^{\,m,eq}(\vec{x}, t)}{\tau_c}\right)$$

$$f_i(\vec{x} + \vec{e}_i \Delta t, t + \Delta t) = f_i^{\,*}(\vec{x}, t)$$

$$g_i^m(\vec{x} + \vec{e}_i \Delta t, t + \Delta t) = g_i^{m,*}(\vec{x}, t)$$

After the second step, it is necessary to update the macro parameters (density, velocity and phase field) according to the formulas:

$$\rho = \sum_{i=0}^{8} f_i, \rho\vec{u} = \sum_{i=0}^{8} f_i \vec{e_i} + \frac{\Delta t}{2}\vec{F}, c_m = \sum_{i=0}^{8} g_i^m$$

Derivatives of macroscopic variables are calculated using the following isotropic second-order differences [8]:

$$\nabla^2 c_m(\vec{x}, t) = \sum_{i=1}^{8} \frac{2\omega_i[c_m(\vec{x} + \vec{e}_i \Delta t, t) - c_m(\vec{x}, t)]}{c_s^2 \Delta t^2}.$$

For the velocity field, the bounce back scheme is used as the no-slip boundary condition in stationary walls ($\vec{x}_w$) [11]:

$$f_i(\vec{x}_w, t + \Delta t) = f_{-i}(\vec{x}_w, t + \Delta t), \;\; \vec{e}_i \cdot \vec{n} > 0,$$

where the phase is constant and the boundary conditions for the phase field distribution functions are given as follows:

$$g_i^m(\vec{x}_w, t + \Delta t) = g_{-i}^m(\vec{x}_w, t + \Delta t) + 2\omega_i c_w, \quad \vec{e}_i \cdot \vec{n} > 0,$$

where $c_w$ is the near-wall phase.

On all other walls, the Neumann condition is used:

$$g_i^m(\vec{x}_w, t + \Delta t) = g_{-i}^m(\vec{x}_w, t + \Delta t), \;\; \vec{e}_i \cdot \vec{n} > 0.$$

**Simulation results**

We consider the dynamics of a four-component mixture in a rectangular computational domain with dimensions: $N_x \times N_y$, $N_x = 80,\ N_y = 80$. The physical size of the length is $L = 0.01\ m$. The space and time steps are defined as $\Delta x = \frac{L}{N_x} = 0{,}000125, \Delta t = 0.000117188$.

Physical values: the density $\rho_1 = 1000\,\frac{kg}{m^3}, \rho_2 = 750\,\frac{kg}{m^3},\ \rho_3 = 500\,\frac{kg}{m^3}, \rho_4 = 250\,\frac{kg}{m^3}$ and the viscosity $\mu_1 = \mu_2 = \mu_3 = \mu_4 = 0.01\ Pa \cdot s$, the acceleration of gravity $g = 9.8\,\frac{m}{s^2}$. Dimensionless values: the Reynolds number $Re = 234.787$, the capillarity number $Ca = 0.00010435$ and the Atwood number $A = 0.142857$.

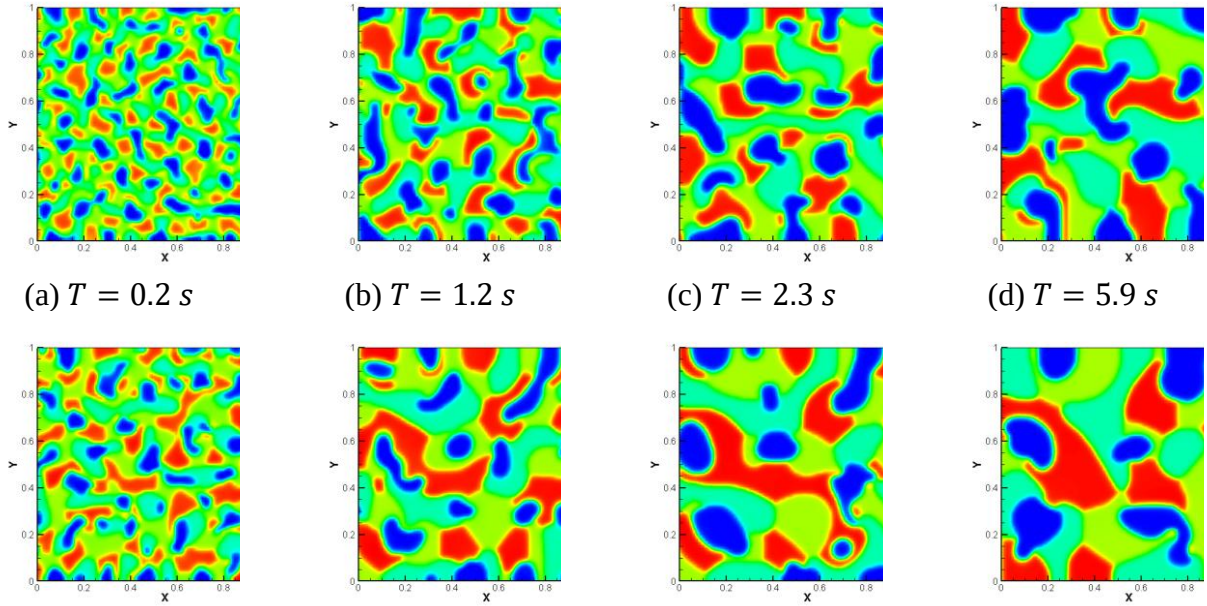
Simulation by the LB method is carried out in lattice units, i.e. the physical parameters of the model are replaced by their lattice counterparts using transformation coefficients $Cu = 1.06667$, $Cg$=9102.22. LB method parameters: the density $\rho_1 = 1.33, \rho_2 = 1,\ \rho_3 = 0.67, \rho_4 = 0.33$, the relaxation times $\tau_1 = \tau_2 = \tau_3 = \tau_4 = 0.8$, the surface tension $\sigma_{ij} = \{0.02, 0.04\},\ i, j = \overline{1,4},\ i \neq j$, the surface thickness $D = 2$, the acceleration of gravity $g = 0.00107666$ and $U_{lbm} = 0.293484$.

The simulation results (density contours of the mixture components) show the mixture separation of immiscible fluids depending on time (Fig. 2, 3). The average values of the components concentrations are taken equal to $(\bar{c}_1, \bar{c}_2, \bar{c}_3, \bar{c}_4) = (0.25,\ 0.25,\ 0.25,\ 0.25)$.

In the first case (Fig. 2), which does not take into account the free fall acceleration, a spinodal separation of the mixture in time is observed, which occurs as a result of the influence of surface tension between the components of the mixture.

In the second case (Fig. 3), which takes into account the free fall acceleration, at an early stage ($T < 1\ s$), the less dense fluid ($\rho_4 = 250\,\frac{kg}{m^3}$) starts to rise, and the denser one ($\rho_1 = 1000\,\frac{kg}{m^3}$) starts its downward movement. As a result, stable four layers of fluid components are formed: a denser fluid at the bottom and a less dense fluid at the top.

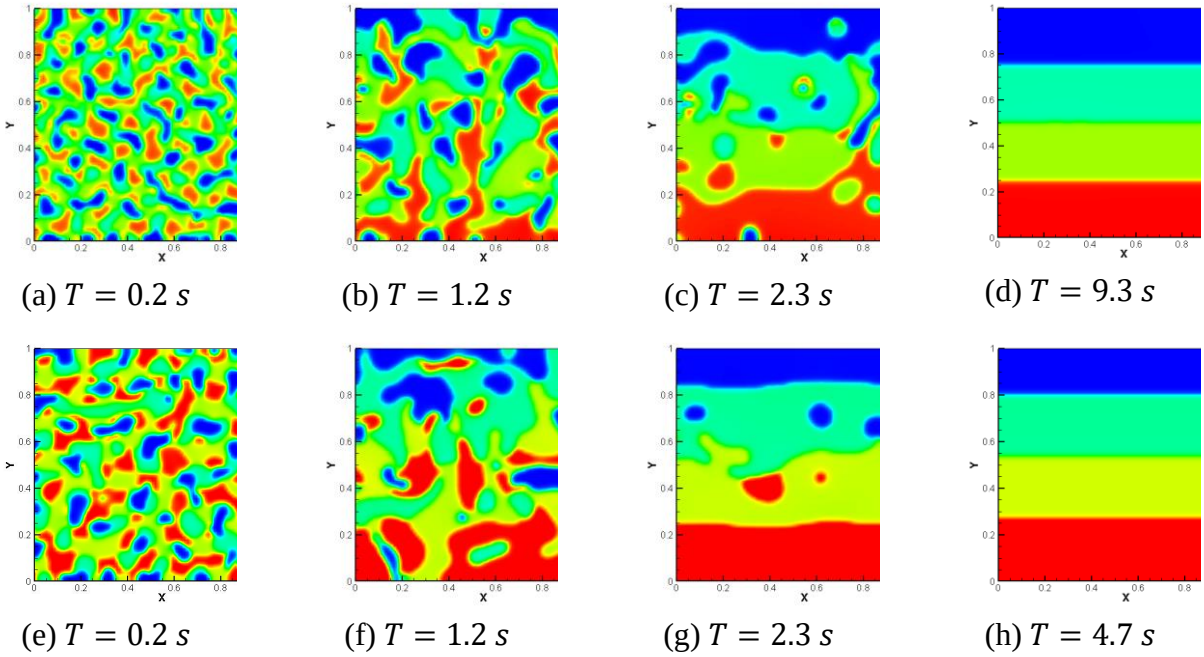
Based on the results obtained, it can be concluded that the higher the value of surface tension, the faster the process of separation of the components occurs, which determines the adequacy of the constructed model of a four-component fluid.



(a) $T = 0.2\ s$ (b) $T = 1.2\ s$ (c) $T = 2.3\ s$ (d) $T = 5.9\ s$

(e) $T = 0.2\ s$ (f) $T = 1.2\ s$ (g) $T = 2.3\ s$ (h) $T = 5.9\ s$

**Figure 2 -** The process of separating the mixture components depending on time at: (a)-(d) - $\sigma = 0.02$, (e)-(h) - $\sigma = 0.04$.



(a) $T = 0.2\ s$ (b) $T = 1.2\ s$ (c) $T = 2.3\ s$ (d) $T = 9.3\ s$

(e) $T = 0.2\ s$ (f) $T = 1.2\ s$ (g) $T = 2.3\ s$ (h) $T = 4.7\ s$

**Figure 3** - Influence of gravity on the process of separation of mixture components depending on time at: (a)-(d) - $\sigma = 0.02$, (e)-(h) - $\sigma = 0.04$.

## Conclusion

The article proposes a mathematical and numerical model for studying the process of separation of a four-component fluid. To implement this model, a two-dimensional numerical algorithm was developed based on the D2Q9 scheme of the lattice Boltzmann equations method in a limited cavity in the shape of a rectangle. Numerical simulation was carried out with and without taking into account gravity. The results of numerical simulation showed that, depending on the surface tension, the spinodal separation of the components occurs in different ways; the greater the value of surface tension, the higher the attraction rate of components particles of the same density. Under the influence of gravity over time, fluids begin to line up in order, from denser to less dense, from bottom to top, respectively. The stability of the process occurs when the denser component is completely lowered. With a larger value of surface tension, taking into account the gravity force, the time for a steady state of the system is half as long. The results of the work prove the applicability of the methods used in the article.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# ИСПОЛЬЗОВАНИЕ АВТОНОМНОЙ НАВИГАЦИОННОЙ СИСТЕМЫ GPS И КОМПЬЮТЕРНОЕ ЗРЕНИЕ ДЛЯ СОВРЕМЕННОГО ДОРОЖНОГО ДВИЖЕНИЯ

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**Аннотация**

В этой статье был проведен обзор глобальной системы позиционирования (GPS) и навигационной системы на основе компьютерного зрения, и был обнаружен большой разрыв между фактическими потребностями в навигации и тем, что существует в настоящее время. Поэтому в предлагаемом исследовании обсуждается новая структура автономной навигационной системы, которая использует GPS, а также компьютерное зрение с учетом тематического исследования современной системы дорожного движения. Предложена аналитическая модель, в которой данные с географической привязкой из GPS интегрируются с сигналами, полученными от визуальных датчиков, как предполагается, для реализации этой концепции.

## Введение

Одним из главных проблем всех больших городов является – пробки и заторы на дорогах. В густонаселенных городах мира люди могут ежегодно терять до 164 часов стоя в пробках. В Казахстане тоже присутствует такая проблема с заторами, особенно в больших городах как Алматы и Нур-Султан. В данный момент в этих двух городах уже который год пытаются решить вопрос с пробками через увеличение полосы проезжей части, увеличением времени светофоров для более предпочтительных улиц. Тем самым еще больше перегружая улицы. В городе Нур-Султан еще в 2014 году начинали вводить «умные светофоры», а в Алматы они начали появляться к 2020 году. Но в обоих городах это не снизило поток машин на главных улицах города.

Таким образом, устойчивость городского транспорта является серьезной проблемой, и ее значение будет только расти. На сегодняшний день наблюдается тенденция интенсивного развития крупных городов Казахстана, что характеризуется ростом площади городов, притоком рабочей силы и приростом городского населения. Развитие городов приводит к увеличению радиуса деловых и культурных поездок жителей крупных городов, расстояний поездок и, каксследствие, времени, затрачиваемого на поездку. В следствии этого, в крупных городах Казахстана имеют место быть проблемы организации дорожного движения. Вышеуказанное определяет актуальность и практическую необходимость настоящего исследования, которое посвящено изучению, исследованию, решению транспортных проблем в городе Алматы, а улучшение управления транспортными потоками позволит применить опыт и в других регионах страны.

Как работают умные светофоры? Принцип работы «умного светофора» достаточно прост. Сюда входит: навигационная служба (GPS, ГЛОНАС), камеры видеонаблюдения, сервера, и датчики. Но на сколько эффективна работа умных светофоров? Можем ли мы улучшить и модернизировать работу навигационных служб для более быстрого получение данных и их обработки? Ответ - да. Далее мы рассмотрим основные проблемы навигационных

систем и их решение. Также будет предложена новая модель ИТС (Интеллектуальной транспортной системы), при которой мы сможем наблюдать улучшенную обработку и передачу данных.

**Насущные проблемы навигационных служб**

По сути, навигационную систему можно рассматривать как сложный вычислительный механизм, облегчающий предоставление навигационных услуг [1]. Типичная навигационная система состоит из географической информации в виде карты, которая предлагает удобный формат чтения географических данных, часто в виде текста. Они также могут использовать различные формы датчиков и другие источники информации, собираемой различными способами. В настоящее время они используются для рекомендации подходящего направления маршрутов для транспортных средств, на которых установлено навигационное устройство. Существуют различные формы навигационной системы, а именно: навигация в глубоком космосе, роботизированное картографирование, инерциальная навигационная система, хирургическая навигационная система (используется в медицинском секторе), спутниковая навигационная система и автомобильная навигационная система [2], [3]. Из всех форм навигационной системы глобальная система позиционирования (GPS) является наиболее распространенным способом среди глобальных пользователей. GPS использует механизм радионавигации, который предоставляет информацию о времени и географическом местоположении приемнику GPS из любой точки земли. Существуют различные причины для более широкого технического внедрения GPS, поскольку он полностью независим от любых данных, передаваемых пользователем, и может работать самостоятельно [4]. У него нет даже зависимости от приема Интернета или каких-либо телефонных услуг, чтобы функционировать, хотя использование этих услуг обеспечивает большую точность навигации. Типичное применение навигационных услуг на основе GPS делает упор на гражданских лицах, учет времени, связь и военные приложения [5]. Однако существуют определенные проблемы, связанные с использованием GPS, т.е.; 1) он не способен отслеживать состояние транспортного средства или объекта, где он находится в качестве приемника, 2) он часто сталкивается с проблемами отключения из-за ослабления сигнала, 3) он часто сталкивается проблемы с отклонениями изменяются в режиме реального времени, и 4) информация, полученная из него, не всегда точна [6]. В связи с этим были проведены различные исследовательские работы по преодолению этих проблем; однако проблема наследия остается более или менее неизменной. Следовательно, GPS часто используется при интеграции инерциальной навигационной системы [7]. Тем не менее, во всем этом по-прежнему есть проблемы. Наряду с этим соображением необходимо также признать, что современная система связи в системе дорожного движения также претерпевает революцию. Концепции автомобильной специальной сети с интеграцией интернета вещей в настоящее время являются будущим современной системы дорожного движения [8]. В этой системе встроенное устройство, называемое бортовыми устройствами, находится в транспортном средстве, которое взаимодействует с точкой доступа, называемой придорожным устройством на дороге, и обеспечивает распределенную автомобильную систему связи. Поскольку бортовые устройства также подключены к информационно-развлекательной системе, которая имеет доступ к навигационной системе на основе GPS, существует большая вероятность того, что может быть разработана автономная и беспроводная навигационная система, которая действительно сможет намного лучше управлять навигацией. Кроме того, уже есть IP-камера наблюдения, которая установлена на дороге. Если эти камеры наблюдения заменяются экономичными визуальными датчиками, чем новая форма навигационной системы, использующей компьютерное зрение. Существует большая вероятность того, что использование компьютерного зрения может предоставить более точную информацию о мобильном объекте, т.е. транспортном средстве, которое может быть интегрировано с данными GPS для обеспечения более точной навигационной системы.

Помимо подхода, основанного на GPS, в современной литературе также используется автономный метод для навигационной системы. В этом подходе было засвидетельствовано использование компьютерного зрения. Работа, проведенная Донгом и др. [19], разработала навигационную систему на основе информации, полученной от датчиков, встроенных в смартфон. Этот метод разрабатывает трехмерную навигационную модель для внутреннего пространства. Установлено, что исследование обеспечивает почти мгновенную локализацию пользователя с меньшей ошибкой. Аппаратные эксперименты с использованием аналогичного подхода навигационной системы с использованием компьютерного зрения засвидетельствованы в работе Лентариса и др. [20]. Авторы использовали полевую программируемую матрицу вентилей (FPGA) с высоко настраиваемым дизайном, где результат показывает значительно меньшее количество ошибок. В работе, проведенной Мансаниллой и др. [21], также использовалось компьютерное зрение для выполнения навигации системы беспилотных транспортных средств. Авторы использовали фильтр Калмана для улучшения оценки позирование с использованием экспериментальной модели робототехники. Существуют различные сопутствующие исследования, в которых компьютерное зрение использовалось для навигационных приложений [22]-[30]. Далее обсуждаются выявленные исследовательские проблемы, которые еще не были решены.

Выявленная исследовательская проблема была изучена после рассмотрения существующих подходов с использованием GPS, а также подхода компьютерного зрения. В этом разделе освещаются открытые исследовательские проблемы, связанные с навигационным фактором: 1) нет исследовательской работы по рассмотрению дефектов механизма устройства, которое выполняет систему INS; 2) нет такой литературы, использующей данные с географической привязкой для другого формата данных, отличных от GPS; 3) существующие методы предлагают ограничения, поскольку объем алгоритмов ограничен только представленным сценарием, а также набором данных.; 4) существующие подходы компьютерного зрения фактически неприменимы в современной транспортной системе; и 5) отсутствует какая-либо стандартная навигационная система, использующая GPS или компьютерное зрение. Поэтому, рассмотрев вышеупомянутые открытые исследовательские вопросы, предлагаемая система формулирует проблему следующим образом: “сложно разработать экономически эффективную и эффективную навигационную систему путем совместного внедрения GPS и компьютерного зрения”. Далее обсуждается предлагаемое решение и принятые им методологии.

Настоящая реализация представляет собой усовершенствованную версию, в которой разработана и разработана новая модель системы для оказания помощи в навигационной системе современного дорожного движения. В предлагаемой системе представлена аналитическая модель, направленная на. После рассмотрения существующих подходов, связанных с навигационной системой, было установлено, что GPS в значительной степени является неотъемлемой частью механизма. В то же время важно знать, что доступность данных GPS не всегда гарантируется. Таким образом, предлагаемая система включает дополнительные данные, которые представляют собой визуальные сигналы, полученные от визуального датчика, размещенного в определенных местах движения. На рисунке 1 показано пересечение 4 полос движения, которое оснащено визуальными датчиками, размещенными на придорожных блоках. Учитывая, что на дороге работает интеллектуальная автомобильная сеть, это будет означать, что бортовые устройства всех транспортных средств подключены к придорожным устройствам, а все 4 придорожных устройства подключены к централизованному транспортному шлюзу в конце.

В исследовании предполагается, что система транспортных шлюзов отвечает за три операции, а именно: 1) прием данных, сгенерированных блоками на обочине дороги, 2) применение алгоритма к данным для определения количества транспортных средств, движущихся по каждой полосе, их соответствующего положения и их направления, и 3) передача результатов в блоки на обочине дороги. Устройства на обочине дороги

дополнительно передают данные своему транспортному средству в пределах диапазона, и им будет предложен новый навигационный сценарий.


**Рисунок 1** - UML-диаграмма построения модели навигационной службы

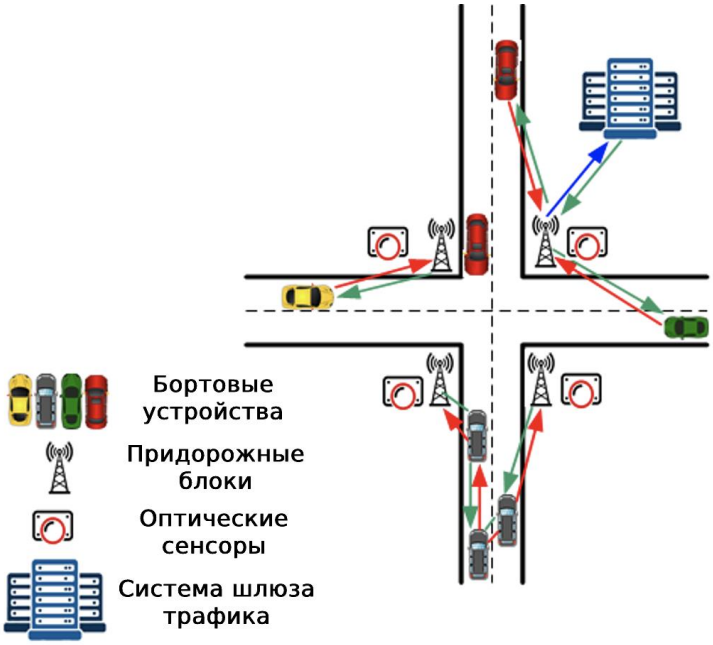


**Рисунок 2** - Наглядная схема предлагаемой модели

Водители могут маневрировать своими транспортными средствами с помощью этой информации. Следовательно, с этой точки зрения необходимо соблюдать две вещи, а именно: 1) точность в позиционирование и 2) более быстрая передача навигационных отфильтрованных данных. Такой подход к навигации никогда не применялся в прошлом, и,

следовательно, он способствует созданию новой экономически эффективной навигационной системы для футуристической транспортной системы. Этот алгоритм также предлагает двойное преимущество, а именно: 1) размер данных еще больше уменьшается, так как характеристики сигнала больше уменьшаются по сравнению с исходным сигналом, 2) он предлагает более точную информацию, которая может сузить поиск для лучшей навигации. Окончательный алгоритм отвечает за дальнейшее отслеживание всех объектов, выполняющих мобильность. Этот алгоритм предлагает следующее преимущество, а именно: 1) он может выполнять отслеживание потоковых данных и, следовательно, результат почти мгновенный, 2) он может отслеживать все объекты, присутствующие на сцене, в статическом или мобильном состоянии, и 3) он может предложить точный подсчет транспортных средств, присутствующих на сцене, чтобы лучше понять процесс принятия решений. Следовательно, в предлагаемом алгоритме нет такого включения какого-либо сложного, трудоемкого и итеративного процесса. Таким образом, представлено экономически эффективное решение для навигационной системы путем объединения GPS и компьютерного зрения.

**Алгоритм для извлечения сигнала с уменьшенной размерностью**

Прежде чем обсуждать этот алгоритм, необходимо указать, что этот алгоритм работает в предположении, что существуют визуальные датчики, которые основаны на различных положениях движения. Сигналы, которые снимаются с визуальных датчиков с определенной интервальной скоростью, передаются в систему шлюза трафика, которая запускает предложенный алгоритм. Это будет означать, что предлагаемый алгоритм реализован поверх данных о трафике, полученных в системе шлюза трафика. Данные о трафике в конечном итоге растут с течением времени и, следовательно, становятся чрезвычайно сложными для обработки. Для принятия эффективного решения для навигационной системы требуется, чтобы данные были четкими и не избыточными, что обеспечит точное и быстрое принятие решения об эффективном исследовании маршрута. В исследовании учитывается, что эти сигналы, генерируемые визуальными датчиками, помечаются информацией на основе GPS как часть гео-привязки. По этой причине сигнал становится довольно тяжелым, и перед обработкой требуется минимизировать размер сигнала. Следовательно, основной целью этого алгоритма является извлечение, обработка и уменьшение полученного сигнала трафика, чтобы сделать его пригодным для дальнейшей обработки. Алгоритм принимает входные данные визуального датчика d от системы шлюза трафика и извлекает информацию, связанную с количеством трафика Tn и положением трафика $T_p$ (строка-1). Эта информация ($T_nT_p$) называется метаданными с географической привязкой. Объект трафика местоположения $T_{loc}$ создается после считывания этих метаданных (строка-3). Аналогичным образом алгоритм извлекает информацию, связанную с потоковыми данными, из шлюза, используя $T_{n1}$ и $T_{p1}$, и создает объект местоположения $T_{loc1}$ (строка-4). Алгоритм выполняет точную настройку определенных свойств, указывая диапазон тестового сигнала test_signal, полученного из $T_{loc}$, с учетом определенного количества сигналов (nsignal) (строка-6). Для квантования сигнала алгоритм учитывает сигнал тестового сигнала (строка-7) и выполняет дальнейший процесс вычисления. Сигнал sig получается после считывания оцифрованного сигнала, извлеченного из $T_{loc}$ (строка-8), а затем он дополнительно подвергается функции изменения размера f(x) для сигнала sig2, полученного с предыдущего шага (строка-9). Помимо этого, функция f(x) также осуществляет управление размером, и поэтому размер получаемого сигнала уменьшается. Наконец, полученный сигнал относительно потоковых данных трафика $T_{loc1}$ перезаписывается поверх уменьшенного сигнала трафика sig (строка-10). Обработка этого алгоритма в конечном итоге приводит к выходному сигналу $O_{sig}$ (Line-10), размер которого значительно уменьшается. Чтобы выделить технологический процесс предлагаемого алгоритма. Шагами алгоритма являются:

Input: d (данные визуального датчика)

Output: $O_{sig}$ (выходной сигнал)

Start

1. For i=1: d
2. $[T_nT_p]$=obtain(i)
3. $T_{loc} \leftarrow [T_nT_p]$
4. $L_{obj} \rightarrow$ read ($T_{loc}$)
5. $L_{obj} \rightarrow$ read ($T_{loc1}$)| $T_{loc} \rightarrow$ f(i)
6. Test signal = $T_{loc}$ (nsignal)
7. For j=1 : $T_{signal}$
8. Sig1 = read($T_{loc}$,j)
9. Sig2 = f(sig1)
10. $O_{sig} \rightarrow$ ($T_{loc1}$, sig2)
11. End
12. End

End

Вклад этого алгоритма заключается в следующем: 1) он помогает в уменьшении размеров, что удобно для передачи по сети, 2) он инициирует надлежащий механизм индексации в отношении количества транспортных средств и их соответствующего местоположения, и 3) он свободен от какой-либо неоднозначной обработки, поскольку вся информация сохраняется в виде матрицы.

**Численный результат исследования**

Численный результат предлагаемого исследования оценивается по двум параметрам производительности, т.е. 1) точности и 2) среднему времени обработки. Результаты, обсуждаемые здесь, получены после тестирования со всеми 5 наборами данных и получения их среднего значения. Кроме того, результаты исследования сравниваются с расширенным фильтром Калмана, который, как сообщается, широко используется в существующей системе навигационной системы.

Из рисунка 4 видно, что предлагаемая система обеспечивает лучшую точность определения местоположения в отличие от существующего фильтра Калмана. Обоснование этого результата заключается в том, что в основном расширенный фильтр Калмана может выполнять оптимальную оценку, если в данных, полученных со сцены, присутствует нелинейность. Таким образом, нет никакой разницы в работе расширенного фильтра Калмана с его устаревшей версией, если существует модель линейного перехода состояния. Предлагаемая система обеспечивает точность 95,21%, в то время как существующая система обеспечивает точность 82,368%. Это не относится к большинству практических приложений для дорожного движения.

Из рисунка 5 видно, что предлагаемая система обеспечивает значительно меньшее время обработки по сравнению с расширенным фильтром Калмана. Невключение какой-либо итеративной операции и правильное индексирование сцены (транспортного средства) приводит к более быстрому подсчету транспортных средств, их отслеживанию и изучению альтернативных маршрутов. Однако расширенный фильтр Калмана обеспечивает высокую итеративность работы, что может привести к затрате времени. Предлагаемая система занимает всего 0,0401 секунды, в то время как существующая система занимает 0,7498 секунды для обработки.

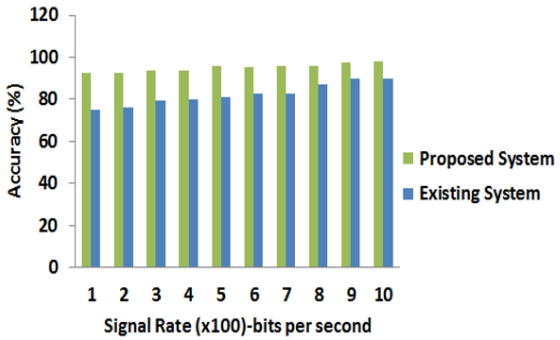


**Рисунок 3** - Сравнительный анализ позиционного рисунка

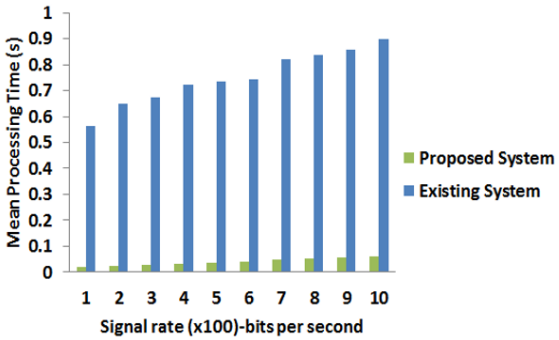


**Рисунок 4** - Сравнительный анализ среднего времени точности обработки

**Заключение**

В этой статье представлен новый подход к современной навигационной системе, в которой используется совместная реализация GPS и компьютерного зрения. Для этой цели разработана аналитическая модель, в которой в качестве входных данных используются сигналы, поступающие от визуальных датчиков. В исследовании учитывалось, что эти сигналы привязаны к географической привязке с использованием данных GPS, которые затем автономно передаются от транспортного средства к системе шлюза трафика, где предполагается развернуть предлагаемый алгоритм. Разрабатываемый алгоритм будет выполнят последовательные этапы работы для обработки сигнала, приводящего к результату мгновенного захвата трафика по сцене. Вклад предлагаемой системы заключается в следующем: 1) предлагаемая система представляет собой вычислительную модель, которая может быть применима для любой формы визуально захваченных сигналов, 2) алгоритм не является итеративным и, следовательно, он быстрее и прогрессивнее в своей работе, что приводит к повышению эффективности затрат, 3) установлено, что модель обеспечивает увеличение точности примерно на 12% по сравнению с часто применяемым фильтром Калмана и 2) модель обеспечивает более быстрое время обработки, где улучшение примерно на 70% лучше, чем существующий подход. Будущая работа будет продолжена в направлении достижения дальнейших подходов, основанных на оптимизации, чтобы предложить больше улучшений с учетом новых задач.

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# ТАСЫМАЛДАУ КОНТЕЙНЕРІНЕН ЖҰМЫС КОНТЕЙНЕРІНЕ МИКРОБҰЙЫМДАРЫН ҚАЙТА ТИЕУ КЕЗІНДЕГІ РОБОТ-МАНИПУЛЯТОРДЫҢ ИННОВАЦИЯЛЫҚ ҰСТАҒЫШЫНЫҢ МОДЕЛІ

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**Аннотация**

*Бұл мақалада* өсімдік микроөсірулерін in vitro тасымалдау контейнерінен топырақпен жұмыс істейтін контейнерге олардың микрокөбейту кезінде топырақта бейімделу сатысында жылжытуға арналған қысқышы бар инновациялық роботтың құрылымдық элементтерінің параметрлерін анықтау моделі ұсынылған.

*Зерттеудің ғылыми-тәжірибелік нәтижесі* өсімдіктердің микро өсінділерін тасымалдау контейнерінен in vitro жағдайында топыраққа бейімделу кезеңінде топырақпен жұмыс істейтін контейнерге ауыстыруға арналған фалангты ұстағышы бар манипуляциялық құрылғының инновациялық роботтық кешенін құру болып табылады. Микроклондық көбею және оның физикалық прототипін сынау 3000 дана сүректі микроөркендерді бейімделген, топырақта тамыры бар өсімдіктер. Алынған зерттеу нәтижелері Қазақстан Республикасындағы ғалымдардың ғылыми-техникалық әлеуетіне және бәсекеге қабілеттілігіне әсер етеді. Қазақстан Республикасында оларды көптеп өндіру үшін өсімдіктерді микроклондық көбейту технологиясын автоматтандыруға байланысты зерттеулер жоқ, оларды қолдану өсімдіктердің көп мөлшерін алуға, отырғызу материалдарының құнын төмендетуге мүмкіндік береді. Сондай-ақ, инновациялық роботтық кешен бойынша зерттеулердің практикалық нәтижелері Қазақстан Республикасының елді мекендерін абаттандыру үшін басқа елдерден ағаш өсімдіктерінің отырғызу материалдарының импортын қысқартуға мүмкіндік береді.

Осыған байланысты ағаш тектес өсімдіктер үшін отандық жоғары сапалы отырғызу материалына деген қажеттілік артады. Қазақстан Республикасының елді мекендерінің аумақтарын көгалдандыру мәселесін шешудің түбегейлі шешімдерінің бірі ағаш тектес өсімдіктерге олардың микроклондық көбеюі арқылы отандық жоғары сапалы отырғызу материалын алу болып табылады.

**Түйінді сөздер:** роботтық кешен, манипулятор, шамадан тыс жүктеме, микроатылым, өсімдіктердің микрокөбейтілуі, ұстау күші.

## 1. Кіріспе

Қазақстан Республикасындағы көгалдандыру мәселесін шешудің түбегейлі шешімдерінің бірі ағаш тұқымдас өсімдіктерді кейіннен масштабтау арқылы микрокөбейту арқылы отандық жоғары сапалы отырғызу материалын алу болып табылады. Өсімдіктерді микрокөбейтуді жүзеге асыратын адамдарды ауыстыру технологиялық тұрғыдан қарапайым да, экономикалық тұрғыдан да мүмкін емес (Sluis C.J., 2008). Осыған байланысты өсімдіктерді микрокөбейтудің технологиялық процесі басты мәселе болып табылады. Сынақ кезінде микропроцессорларды in vitro режимінде құрылғының резервуарынан топырақ жамылғысы бар жұмыс резервуарына ауыстыру үшін инновациялық роботты манипуляциялық құрылғыны құрудың маңызы артып келеді. In vitro процестерінде жағдайлар жасанды және олар in vivo ортаны қалпына келтіру болып табылады [1].

Дүние жүзіндегі табиғи ресурстардың жойылуы мен тозуының негізгі себебі қалалардың өнеркәсіптік дамуы болып табылады. Урбанизация өсімдіктердің түр құрамын, атмосфераны және топырақ жамылғысын басқарады. Биоәртүрліліктің нашарлауы нәтижесінде қоршаған ортаға, соның салдарынан адамға қысым күшейеді. Осы себепті қалалардың экологиялық жағдайын жақсарту үшін мәселелердің шешімін табудың өзектілігі тек артып келеді (Имам А.У.К., 2016). Көгалдандырудағы негізгі құралдардың бірі – ағаштарды отырғызу. Ағаш екпелері қалалардағы экологиялық жағдайды тұрақтандыру тетіктерінің бірі болып табылады. Олар ауадан әртүрлі химиялық токсиндерді сіңіреді, қаланың микроклиматының қалыптасуына қатысады және адамды қолайсыз климаттық әсерлерден қорғауды қамтамасыз етеді (Рей Бенаяс Дж.М., 2012; Джим Си Ю, 2013; Каринанос П., 2017; Дженнингс В., 2019) [2].

Алынған зерттеу нәтижелері отандық ғалымдардың ғылыми-техникалық әлеуетіне және бәсекеге қабілеттілігіне әсер етеді, өйткені әлемде және Қазақстанда өсімдіктерді көп мөлшерде алуға мүмкіндік беретін микроклондық өсімдіктерді көбейту технологиясын жаппай өндіріске автоматтандыруға қатысты зерттеулер жүргізілмеген. Отырғызу материалдарының құнын төмендету. Сондай-ақ, ғылыми-зерттеу жұмыстарының практикалық нәтижелері (инновациялық роботтық кешен) елді көгалдандыру үшін шетелден ағаш өсімдіктерінің отырғызу материалдарын импорттауды азайтады. Осыған байланысты ағаш тектес өсімдіктер үшін отандық жоғары сапалы отырғызу материалына деген қажеттілік артады [3-4].

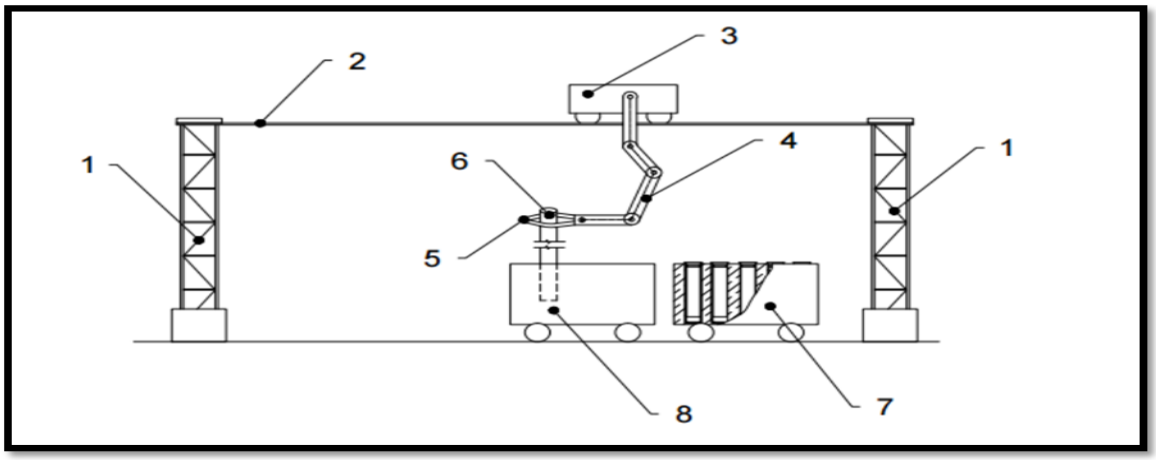
Осыған байланысты өсімдіктерді микрокөбейтудің технологиялық процесі басты мәселе болып табылады. Сынақ кезінде микропроцессорларды in vitro режимінде құрылғының резервуарынан топырақ жамылғысы бар жұмыс резервуарына ауыстыру үшін инновациялық роботты манипуляциялық құрылғыны құрудың маңызы артып келеді. In vitro процестерінде жағдайлар жасанды және олар in vivo ортаны қалпына келтіру болып табылады.

Жасанды жағдайлар зертханада шыны ыдыстардың ішінде бақыланатын жағдайларда қажетті компоненттер мен реагенттерді араластыру арқылы қалыптасады. Көптеген молекулярлық, биохимиялық тәжірибелер сынақ зертханаларында in vitro жағдайында жүргізіледі. In vitro әдістері өндірістің қарапайымдылығына және экономикалық тиімділігіне байланысты микроорганизмдерді пайдалана отырып, ірі фармацевтикалық препараттарды өндіруде фармацевтикалық өндірісте кеңінен қолданылады.

Роботтар қатысатын ауылшаруашылық міндеттері әртүрлі, бірақ оларды топырақ дайындау, тұқым себу, трансплантациялау, егу, дәл ұрықтандыру, кесу, жапырақты алу, обаны анықтау, жинау, кесу, егінді жою және егін жинаудан кейінгі жұмыстарға топтастыруға болады.

Ауылшаруашылық циклінің негізгі кезеңдері топырақ дайындау, отырғызу, өндіру және жинау болып табылады. Олардың әрқайсысында сіз кейбір тапсырмаларды орындауыңыз керек, олардың кейбіреулері робототехникаға ашық.

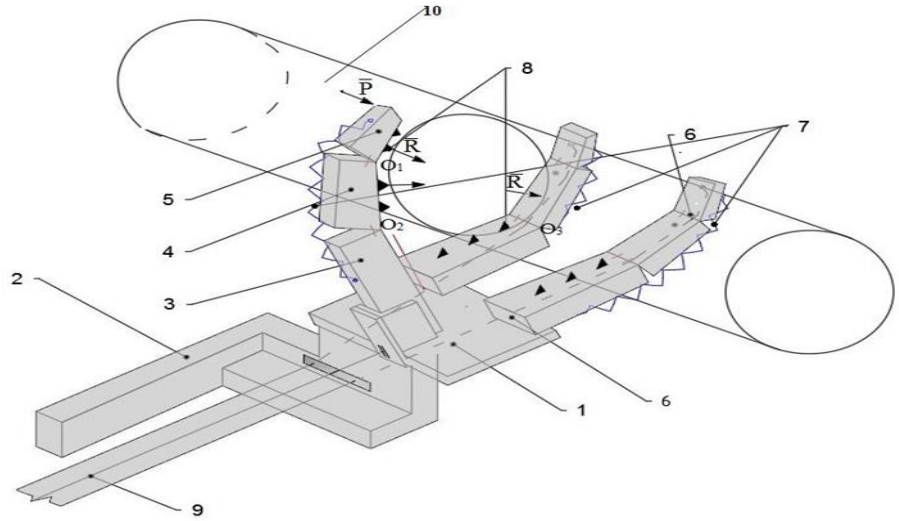
Қашықтан басқарылатын жылжымалы робот (1.1-сурет) инновациялық бейімделгіш ұстағыш жетектері бар тірек тіректерінен 1, көлденең тіреуіштен 2, көліктен 3 (доңғалақты, шынжыр табанды, жүріс және т.б.) тұрады, оған манипулятор 4 PR бекітіледі. адам қолы сияқты бірнеше дәрежелі қозғалыс еркіндігі. Ұстағыш 5 манипулятордың 4 PR шеткі бөлігіне бекітілген. Инновациялық ұстағыш 5 in vitro 6 аралық контейнерден 7 алынып, топыраққа 8 тасымалданады.




**Сурет 1** - Инновациялық манипулятор ұстағышын пайдалана отырып, аралық контейнерден топыраққа in vitro тасымалдау схемасы

Робот: 1 - тірек посты; 2 - көлденең көлденең жолақ; 3 - көлік құралы; 4 - манипулятор; 5 - инновациялық тұтқа; 6 - микротүсіру; 7 - аралық ыдыс; 8 - негізгі контейнер.

Бұрынғылардың [3-22] жұмыстарын талдау негізінде жұмыста робот-манипулятордың үш фалангты адаптивті ұстағыштың – ұстау құрылғысының инновациялық дизайны ұсынылған. Манипулятордың үш фалангты адаптивті ұстағышының инновациялық конструкциясы (2.2-сурет) келесі құрылымдық элементтерден тұрады: фалангтарды бекітуге арналған негіз пластина 1 - манипулятордың шеткі бөлігіне монтаждау рычагымен 2 бекітілген қысқыш рычагтар .




**Сурет 2** - Аралық контейнерден топыраққа in vitro арқылы қайта жүктеуге арналған робот-манипулятордың үш фалангты бейімделгіш тұтқасы.

1-плитка - қысқыш рычагтың негізгі фалангасын бекітуге арналған негіз; 2-манипулятордың бекіту иін; 3-негізгі фаланга; 4-ортаңғы фаланга; 5 бұрышты фаланга; 6-іргелес фалангтарды бір-біріне бекітуге арналған топса; 7 - қатайтатын серіппе; 8- ұстайтын тіс; 9 - икемді тартқыш элемент, 10 - in vitro.

**2. Зерттеудің мақсаты мен міндеттері**

Елді мекендерді көгалдандыру бүгінгі таңда басты мәселелердің бірі болып отыр. Көгалдандырудың ең тиімді жолы – орман екпелерінің экологиялық жағдайын жақсарту. Олар ауадан әртүрлі химиялық токсиндерді сіңіреді, елді мекеннің микроклиматында кездеседі және қолайсыз климаттық жағдайлардан қорғанысты арттырады (Ray Benayas J.M., 2012; Jim S.Y., 2013; Karinanos P., 2017; Jennings V., 2019). [14]

Еліміздегі елді мекендерді көгалдандыру мәселесін шешудің бір жолы – ағаш өсімдіктерін микроклондық жолмен көбейту арқылы жоғары сапалы отандық отырғызу материалын алу (Sluis C.J., 2008). Осыған байланысты бұл мақалада өсімдіктердің микроклондық көбеюінің технологиялық процесінің негізгі кезеңдерін автоматтандыру шешімі ұсынылған.

Бұл ретте биотехнологиялық әдістер қолданылды – өсімдік өсінділерін зарарсыздандыру, бүршіктерді in vitro ыдысына енгізу, өсімдік микроөркендерін көбейту, in vitro өсімдіктердің микро өсінділерін тамырлау болып табылады. Сондай-ақ келесі биотехнологиялық және өсімдік өсіру әдістері: трансплантациялау, тамырлы өсімдік клондарын топырақ субстратында бейімдеу және өсіру.

**3. Қолданылған әдістер**

Өсімдіктің микро өсінділерін түсіру кезінде қажетті қауіпсіздік шегін қамтамасыз ету шарттарынан олардың ұстау күшінің шамасы бойынша шектеулерді және ұстағыштың жанасу нүктелеріндегі серпімді ығысулар шамасының шамалылығын ескеру қажет. Өсімдіктердің микробұйымдары робот ұстағыш құрылымын жобалау 3D CAD моделін қолдану арқылы жүзеге асырылды. 3D басып шығаруды қолдану арқылы фаланкс қысқышының прототипі

жасалды. Тасымалдау цистернасынан шығарылған және жұмыс резервуарына ауыстырылған теннис допының қозғалысы мысалында өсімдік микробұтасының қозғалысын эксперименталды зерттеуі сыналған. Ұстағыштың тағы бір сынағы, мысалы, дөңгелек теннис добын ұстаудың тұрақтылығын тексеруді қамтиды, онда допты ұстағыш алдын ала белгіленген траектория бойынша максималды жылдамдықпен қозғалды, мысалы, мәні 1,0 м/с, теннис добын ұстаудың сенімділігін тексеру.

Өсімдіктердің микро өсінділерін тасымалдау контейнерінен топырақ өңдейтін контейнерге тасымалдауға арналған инновациялық қысқыш прототипі Greenlab Micropropagation компаниясында ағаш өсімдіктеріне арналған сынақтан өтті. Өнеркәсіптік робот-манипулятордың инновациялық тұтқасының құрылымдық элементтерінің параметрлерінің геометриялық, құрылымдық-кинематикалық және динамикалық мәндерін ғылыми негізделген таңдау және негіздеу үшін стохастикалық процестерді ескере отырып, оларды есептеудің математикалық моделі әзірленді. Өнеркәсіптік робот-манипулятордың үш фалангты бейімделгіш тұтқасының құрылымдық элементтерінің параметрлерінің геометриялық, құрылымдық-кинематикалық және динамикалық мәндерін оның денесінің жоғарғы бөлігімен өзара әрекеттесуінің стохастикалық процестерін ескере отырып анықтау дәлдігі, дөңгелек теннис добы, Кальман салмақ коэффициентінің оңтайлы мәнін анықтау негізінде жүзеге асырылды [1][2][3][4].

**4. Нәтижелер**

Тұтқыштың жұмыс элементтерінің санының ұлғаюы жұмыс элементінің жанасу аймағында деформация мен кернеудің болмауы жағдайында үлкен диаметрлі сақинаны ұстау күштерінің рұқсат етілген мәндерінің ауданын кеңейтуді береді. Сондықтан, бұл зерттеуде өсімдік микробұйқасының сақиналы құрылымдық элементін түсіру жағдайлары фалангалы ұстағыштың жұмыс элементінің ішкі бетінің өсімдік микробұйқасының сыртқы бетімен жанасуының төрт, алты және сегіз нүктелерінде қарастырылады. [5-6]-да жұқа қабырғалы сақинаның ұстау күшінің максималды және ең аз рұқсат етілген мәндерін есептеуге арналған келесі формулалар тұтқаның сенімділігін қамтамасыз ету шарттарынан және серпімді ығысу мәндерінің шамалылығынан негізделген. Ұстағыштың жұмыс элементінің сақинамен жанасу нүктелері әрбір фаланганың сыртқы ішкі беттерінің басу күшінің мәні 3-5, олардың әрқайсысына әрбір ұстағыш рычагтың ұстағыш тістері 8 өсімдік микробұйымының жоғарғы бөлігінің сыртқы шектік бетіне бекітілген 10 (Сурет ). 2), [5] формуласымен анықталады:

$$P_{\max} = \frac{\sigma_{доп} l t^2}{0.3967} \quad (1)$$

$$P_{\min} = \frac{G + F_I}{8f} \quad (2)$$

мұндағы $P_{\max}$ – ұстағыштың жұмыс элементінің сақинамен жанасу нүктелерінде шамалы серпімді қозғалыстарды орындау кезінде ұстағыш сақинаның максималды рұқсат етілген ұстау күшінің мәні; $\sigma_{add}$ - сақиналы қимасы бар объектінің рұқсат етілген қалыпты кернеуінің мәні; l және t - сақинаның ені мен қалыңдығы; $P_{\min}$ – өсімдік микрошошағын сенімді ұстау үшін сақинаның сыртқы бетіндегі ең аз рұқсат етілген ұстау күшінің мәні; G – сақина салмағының мәні және FI – сақинаға әсер ететін инерциялық күштің мәні [6].

Тұтқыш рычагтардың фалангтарының айналуын зауыттың микро өсіндісінің денесінің жоғарғы бөлігінің жанында ұстау тұтқаларының фалангтарының тірек тістерін орналастырудың ең тиімді екі нұсқасын қолдану арқылы жүзеге асыру жоспарлануда. [1]:

- ұстағыш рычагтардың фалангаларының ішкі бетінде орналасқан екі тірек тіс (2- сурет) өсімдіктің микробұйра дене бөлігінің сыртқы бетінің бір жағында, бір тірек тістің сыртқы ішкі

бетінде орналасқан. ұстағыш рычагтың фалангасының бөлігі өсімдіктің микроату денелерінің сыртқы бетінің қарама-қарсы жағында орналасқан;

- ұстағыш рычагтың фалангтарының сыртқы ішкі бетінде орналасқан екі тіреуіш тіс (3,б-сурет) өсімдіктің микробұйқасының дене бөлігінің сыртқы бетінің бір жағында және оның сыртқы ішкі беттерінде орналасқан екі ұстағыш тістер орналасқан. ұстағыш рычагтың фалангтары өсімдік микрошош денесінің сыртқы беткі бөлігінің қарама-қарсы жағына жақын орналасқан [2].

**Әдебиеттер тізімі**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# УСРЕДНЕНИЕ АТТРАКТОРОВ СИСТЕМЫ НАВЬЕ-СТОКСА В ПЕРФОРИРОВАННОЙ ОБЛАСТИ[1]

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**Аннотация**

Рассматривается двумерная система уравнений Навье-Стокса с быстро осциллирующими членами в уравнениях и граничных условиях. Исследуя задачу в перфорированной области, мы задаем однородное условие Дирихле на внешней границе и условие Фурье (Робена) на границе полостей. При таких предположениях мы доказываем, что траекторные аттракторы этой системы сходятся в некоторой слабой топологии к траекторным аттракторам усредненной системы уравнений Навье-Стокса с дополнительным потенциалом и нетривиальной правой частью в области без пор. При этом мы выводим предельную (усредненную) систему уравнений и доказываем существование траекторных аттракторов для этой системы.

Key words: аттракторы, усреднение, система уравнений Навье-Стокса, нелинейные уравнения, слабая сходимость, перфорированная область, быстро осциллирующие члены.

## Ведение

В настоящей работе изучается асимптотическое поведение аттракторов начальнокраевой задачи для двумерной системы уравнений Навье-Стокса в перфорированных областях (см. рисунок, о геометрии области см. [1]). Отметим несколько работ по усреднению аттракторов, которые появились в последнее время ( см. [2,3] и [4]).

В настоящей статье доказывается, что траекторный аттрактор $\mathfrak{A}_\varepsilon$ двумерной системы уравнений Навье-Стокса (см. также [5] и [6]) в перфорированной области сходится в слабом смысле при $\varepsilon \to 0$ к траекторному аттрактору $\overline{\mathfrak{A}}$ усредненной системы уравнений в соответствующем функциональном пространстве. Здесь малый параметр $\varepsilon$ также характеризует диаметр полостей и расстояние между ними в перфорированной среде.

## 1 Основной результат

Пусть $\Omega$ - ограниченная область в $\mathbb{R}^2$ с кусочно-гладкой границей $\partial\Omega$. Пусть $G_0$ – область, принадлежащая $Y = \left(-\frac{1}{2}, \frac{1}{2}\right)^2$, такая, что $\bar{G}_0$ является компактом диффеоморфным шару.

Пусть $\delta > 0$ и $M$ - некоторое множество, введем следующее обозначение $\delta M = \{x: \delta^{-1}x \in M\}$. Для $j \in \mathbb{Z}^2$ определим $P_\varepsilon^j = \varepsilon j, Y_\varepsilon^j = P_\varepsilon^j + \varepsilon Y, G_\varepsilon^j = P_\varepsilon^j + \varepsilon G_0$. Далее определим область $\widetilde{\Omega}_\varepsilon = \{x \in \Omega: \rho(x, \partial\Omega) > \sqrt{2}\varepsilon\}$ и множество допустимых индексов $\Upsilon_\varepsilon = \left\{j \in \mathbb{Z}^n: G_\varepsilon^j \cap \widetilde{\widetilde{\Omega}}_\varepsilon \neq \emptyset\right\}$. Заметим, что $|\Upsilon_\varepsilon| \cong d\varepsilon^{-2}$, где $d > 0$ - некоторая постоянная. Рассмотрим следующую область $\Omega_\varepsilon = \Omega \setminus \bar{G}_\varepsilon$, где $G_\varepsilon = \bigcup_{j\in\Upsilon_\varepsilon} G_\varepsilon^j$. Обозначим $Q_\varepsilon = \Omega_\varepsilon \times (0, +\infty), Q = \Omega \times (0, +\infty)$.

[1] Работа Бекмаганбетова К.А. поддержана КН МОН РК (грант AP08855579). Работа Чечкина Г.А. частично поддержана РНФ (проект 20-1120272).

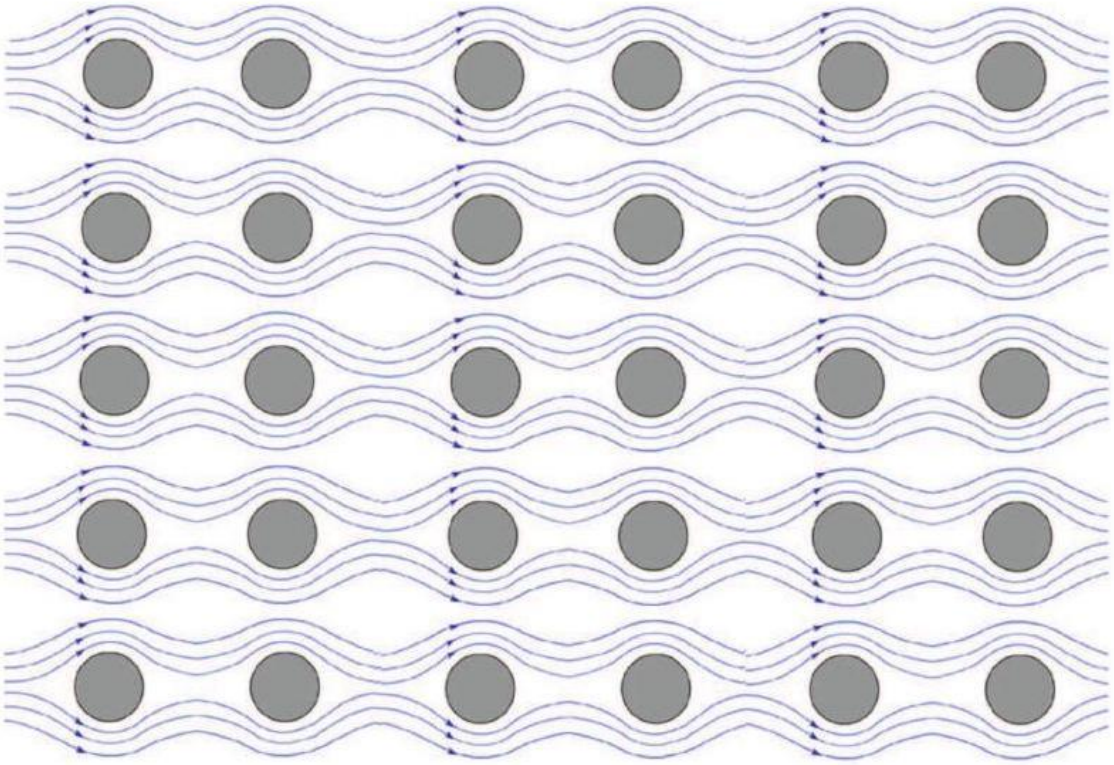

**Рисунок 1** - 2D модель жидкости в среде с мелкими периодическими препятствиями

Введем следующие обозначения для пространств $\mathbf{H}:=[L_2(\Omega)]^2, \mathbf{H}_\varepsilon:=[L_2(\Omega_\varepsilon)]^2$, $\mathbf{V}:=[H_0^1(\Omega)]^2, \mathbf{V}_\varepsilon:=[H^1(\Omega_\varepsilon;\partial\Omega)]^2$ − множество вектор-функций из $[H^1(\Omega_\varepsilon)]^2$ с нулевым следом на $\partial\Omega$. Нормы в этих пространствах определяются, соответственно, следующим образом $\| v \|^2:=\int_\Omega \sum_{i=1}^2 \left|v^i(x)\right|^2 dx, \| v \|_\varepsilon^2:=\int_{\Omega_\varepsilon} \sum_{i=1}^2 \left|v^i(x)\right|^2 dx, \quad \| v \|_1^2:=\int_\Omega \sum_{i=1}^2 \left|\nabla v^i(x)\right|^2 dx, \| v \|_{1\varepsilon}^2:=\int_{\Omega_\varepsilon} \sum_{i=1}^2 \left|\nabla v^i(x)\right|^2 dx$. Изучается асимптотическое поведение траекторных аттракторов следующей начально-краевой задачи для автономной двумерной системы уравнений Навье-Стокса

$$\begin{cases} \dfrac{\partial u_\varepsilon}{\partial t} - \nu\Delta u_\varepsilon + (u_\varepsilon,\nabla)u_\varepsilon = g\left(x,\dfrac{x}{\varepsilon}\right), & x\in\Omega_\varepsilon \\ (\nabla,u_\varepsilon)=0, & x\in\Omega_\varepsilon, \\ \nu\dfrac{\partial u_\varepsilon}{\partial n} + B\left(\dfrac{x}{\varepsilon}\right)u_\varepsilon = 0, & x\in\partial G_\varepsilon, t\in(0,+\infty), \\ u_\varepsilon = 0, & x\in\partial\Omega \\ u_\varepsilon = U(x), & x\in\Omega_\varepsilon, t=0. \end{cases} \tag{1}$$

Здесь $u_\varepsilon = u_\varepsilon(x,t) = (u_\varepsilon^1, u_\varepsilon^2), g = g(x,y) = (g^1,g^2)\in\mathbf{H}, n-$ вектор внешней нормали к границе и $\nu>0, B(s)=\begin{pmatrix} b^1(s) & 0 \\ 0 & b^2(s)\end{pmatrix}$, функции $b^k(s)\in C(\mathbb{R}^2)$ такие, что $b^k(s)-$ 1-периодические по каждой переменной функции на $\mathbb{R}^2$ и удовлетворяют условию $\int_{\partial G_0} b^k(s)d\sigma = 0$, где $\sigma$ - элемент длины кривой $\partial G_0, k=1,2$.

Для вектор-функции $g(x,y)$ будем считать, что функции $g\left(x,\frac{x}{\varepsilon}\right)\in\mathbf{H}$ для любого $\varepsilon>0$ и имеют среднюю $\bar{g}(x)$ в пространстве $\mathbf{H}$ при $\varepsilon\to 0+$, то есть $g\left(x,\frac{x}{\varepsilon}\right)\to\bar{g}(x)$ при $\varepsilon\to 0+$ слабо в $\mathbf{H}$.

Усредненная (предельная) задача имеет следующий вид:

$$\begin{cases} \dfrac{\partial u_0}{\partial t} - \nu \sum\limits_{i,l=1}^{2} \hat{a}_{il} \dfrac{\partial^2 u_0}{\partial x_i \partial x_l} + (u_0, \nabla) u_0 + V u_0 = \bar{g}(x), & x \in \Omega, \\ (\nabla, u_0) = 0, & x \in \Omega, \\ u_0 = 0, & x \in \partial\Omega \\ u_0 = U(x), & x \in \Omega, t = 0, \end{cases} \tag{2}$$

где

$$\hat{a}_{il} = \int_{Y \setminus G_0} \left( \frac{\partial N_l(\xi)}{\partial \xi_i} + \delta_{il} \right) d\xi, \; \bar{g}(x) = \int_{Y \setminus G_0} g(x, \xi) d\xi,$$

$$m_k = - \int_{\partial G_0} b^k(\xi) M^k(\xi) d\sigma, \; V = \begin{pmatrix} m_1 & 0 \\ 0 & m_2 \end{pmatrix},$$

здесь $M^k(\xi)$ и $N_l(\xi) - 1$-периодические функции по $\xi$, удовлетворяющие задачам

$$\Delta M^k = 0 \text{ в } Y \setminus G_0, \; \frac{\partial M^k}{\partial \nu} = -b^k(\xi) \text{ на } \partial G_0,$$

$$\Delta N_l = 0 \text{ в } Y \setminus G_0, \; \frac{\partial N_l}{\partial \nu} = -\nu_l \text{ на } \partial G_0$$

и имеющие нулевые средние по ячейке периодичности. Обозначим $\lambda_0 -$ первое собственное значение оператора $\nu \sum_{i,l=1}^{2} \hat{a}_{il} \frac{\partial^2}{\partial x_i \partial x_l}$ в пространстве $\mathbf{V}$.

Имеет место следующая теорема (см. [7]).

**Теорема 1.1.** Пусть $\lambda_0 > \max\{m_1, m_2\}$, тогда в пространстве $\mathbf{L}_2^b(\mathbb{R}_+; \mathbf{V}) \cap \mathbf{L}_\infty(\mathbb{R}_+; \mathbf{H}) \cap \left\{ v \mid \frac{\partial v}{\partial t} \in \mathbf{L}_2^b(\mathbb{R}_+; \mathbf{H}) \right\}$ справедливо предельное соотношение

$$\mathfrak{A}_\varepsilon \to \overline{\mathfrak{A}} \quad \text{при} \quad \varepsilon \to 0+, \tag{3}$$

где $\mathfrak{A}_\varepsilon, \mathfrak{A}$ - траекторнъе аттракторы задач (1) и (2) соответственно.

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# ДИДАКТИЧЕСКИЕ ВОЗМОЖНОСТИ И ПРЕИМУЩЕСТВА ИСПОЛЬЗОВАНИЯ ПРОГРАММЫ GOOGLE EARTH НА УРОКАХ ГЕОГРАФИИ

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**Аннотация**

В статье рассматриваются дидактические возможности и преимущества использования обучающей платформы Google Earth на уроках географии. В соответствии с типовыми учебными программами по предметной области география, в 7-11 классах общеобразовательных школ Казахстана предусмотрены ряд учебных целей в области информационной грамотности и использования информационных навыков для достижения последующих учебных целей.

География, как школьная дисциплина, придает большое значение образовательным ресурсам и технологиям. Так, геоинформационные системы (ГИС) с ее акцентом на обработку и анализ цифровой информации, могут внести значительный вклад в объединение ряда школьных дисциплин, которые рассматривают пространственные тенденции и элементы географической среды. Несмотря на эти преимущества и дидактические возможности, ГИС по-прежнему недостаточно используется в качестве учебной технологии. Среди множества платформ, можно отметить программу Google Earth, хотя она имеет ограниченные инструменты пространственного анализа по сравнению с настоящей ГИС, но может быть эффективно использована про обучение географии на персональных гаджетах. Она дает возможность изучать пространственную информацию и удобна для учащихся и преподавателей на всех уровнях обучения. Google Earth также может быть использован для решения задач в различных учебных программах, помогая им понимать информацию в пространственном или географическом контексте.

Google Earth дает возможность развить пространственное представление и критические мышление, технологические и мыслительные навыки. При этом важно учесть, чтобы планы уроков должны быть разработаны таким образом, чтобы помочь учащимся учитывать структуру, контекст и качество пространственных данных и образов. Обучающиеся также могут самостоятельно работать и на интерактивной основе, а также сотрудничать с другими учащимися.

Разнообразные интернет- ресурсы могут быть включены в учебный процесс, чтобы дать возможность учащимся получить более глубокие знания в области географии, представляющих для них особый интерес. Во многих ситуациях обучение происходит вне класса; используя технологию, учащиеся могут расширить свои знания и улучшить свои мыслительные и аналитические навыки, а также могут применять внешнее обучение к ситуациям, представленным в классе и вне аудитории.

**Ключевые слова:** программа Google Earth, географическая информационная система, пространственно-ориентированная обучения, пространственный анализ, картографический сервис, цифровые атласы, географическое мышление.

## Введение

Роль компьютера в обучающих технологиях вызвал особый интерес с момента появления персональных компьютеров. Снижение цен на компьютеры и их доступность привели к увеличению их количества в учебных заведениях и на бытовом уровне. Несмотря на то, что многие учебные заведения продвинулись дальше первого уровня внедрения технологий (приобретение и внедрение аппаратного обеспечения и сетевого подключения), технологические учебные программы еще не получили столь широкого распространения. Внедрение географических информационных систем (ГИС) в начальном и среднем образовании за тот же период времени не получило широкого распространения, что подчеркивает отсутствие достаточного обеспечения современными обучающими технологиями учебного процесса. Появление программы Google Earth [1,2] послужило

мощным технологическим инструментом, помогающим устранить эти недостатки в обучении школьной географии.

Цель этой статьи - обсудить целесообразность и возможность использования программы Google Earth как инструмента для обучения географии в 7-8 класса в средних школах Казахстана.

**Материалы и методы**

Как известно, нехватка времени является серьезным препятствием для внедрения ГИС-технологий в учебные программы, обусловленные необходимостью для педагогов изучать программное обеспечение и понимать его основе данные и возможности. Учителям предметникам также необходимо готовить материалы для поддержки таковых уроков, а также предоставлять учащимся достаточно времени для изучения программного обеспечения и включения инструмента в учебный процесс [3]. Внимание преподавателей к инструментам ГИС-технологий было особенно проблематичным из-за количества времени, необходимого для изучения и применения этих инструментов. Время, связанное с изучением приложений ГИС, стало значительным фактором в том, что ГИС и связанные с ними технологии имеют лишь ограниченное применение в 7-11 классах [4,5].

Доступ к соответствующему оборудованию традиционно служил критическим препятствием для внедрения приложений ГИС. Помимо затрат времени, Т.Р. Бейкер [6] привел несколько дополнительных препятствий для внедрения ГИС-технологий на уроках географии, как: недостаточные ресурсы; несовместимые вычислительные и сетевые системы; требования к безопасности, которые требуют использования самой современной операционной системы; разделение предметных дисциплин в соответствии с расписанием школьного дня.

Несмотря на препятствия в пути его внедрения и использования, заметно все большее давление с целью использования ГИС без достаточной поддержки и ресурсов. Пропасть между спросом и способностью внедрять технологии продолжает расширяться в связи с различными стандартами, за которые несут ответственность педагоги, такими как департаменты образования и типовые учебные программы дисциплин.

С появлением компьютеров и развитием цифровых технологий от видеоигр до телевидения, в распоряжении современных учащихся появился другой способ обучения и применения инструментов. Выросшие в информационную эпоху, видео и изображения являются основным средством сбора информации для учащихся. Ориентация на вычислительное оборудование в значительной степени превратилась в основной повседневный инструмент, а не в карьерный путь. Чтобы быть продуктивными в преспективе, учащимся необходимо на раннем этапе приобретать технологические навыки и применять их повседневно и разнообразными способами.

В качестве примера, одним из интересных IT–технологий является программа Google Earth (Планета Земля) [7]. Это компьютерная программа, позволяющая рассмотреть трехмерную модель Земли в мельчайших деталях. При разработке данной программы в ее основу заложили результаты спутниковой съемки, является общедоступной, легко скачивается и устанавливается (рисунок 1).

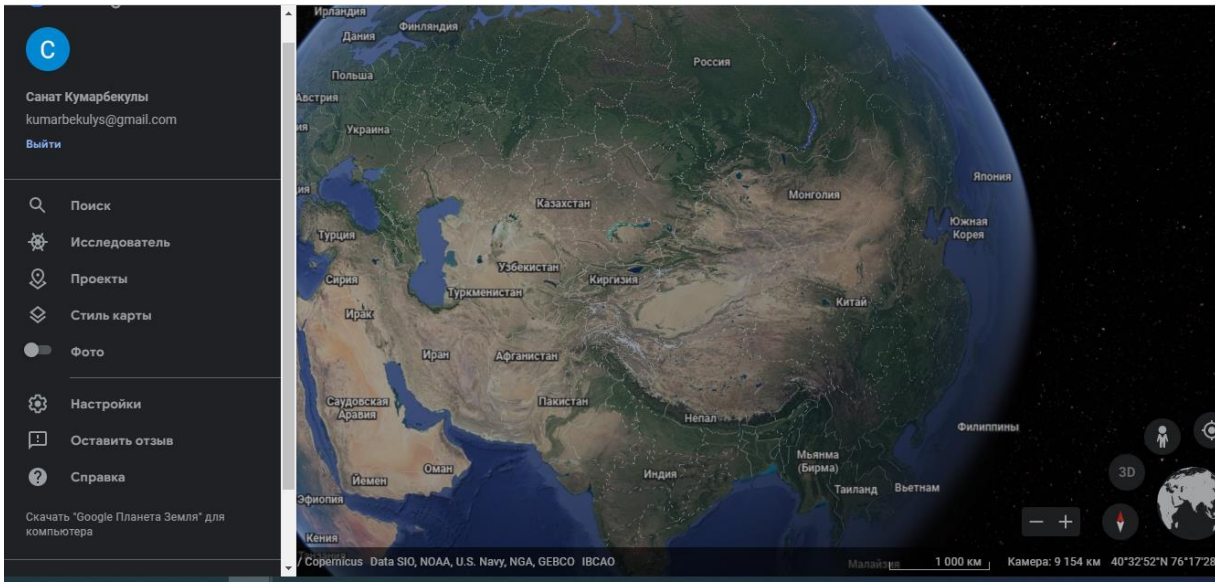


**Рисунок 1** - Google Earth

Использование Google Earth не только поддерживает пространственное мышление, но и помогает развить у учеников критические и аналитические навыки и подготовить учащихся к использованию более продвинутых функций, имеющихся в настоящей ГИС. Это верно, так как, пространственное мышление - это “смесь трех концепций: концепций пространства, инструментов представления и процессов мышления”.

Наряду с вышеизложенным, использование онлайн-ресурсов помогает улучшить понимание учащимися основных концепций и навыков, а также обрести уверенность в географических знаниях и вопросах. Также, запоминаемость информации выше при использовании визуальных образов, нежели чем текста.

Использование Google Earth полностью поддерживает “четыре буквы E” модели жизненного цикла обучения, позволяя учащимся участвовать в уроке, исследовать особенности Земли, объяснять, что они идентифицируют, и оценивать последствия того, что они изучают [8]. Сама Google Earth позволяет учащимся исследовать Землю в динамичной и интерактивной среде, помогая им понять пространственный контекст своего региона и участвовать в пространственно-ориентированном обучении в увлекательной и содержательной форме.

Несмотря на то, что Google Earth является бесплатным инструментом, для него требуется доступ в интернет при достаточно быстром соединении. Этот инструмент не требует больших затрат со стороны пользователя, но недостаточная пропускная способность ограничить возможности Google Earth в классе, отвлекая интересы учащихся, если инструмент не реагирует на запросы пользователя. Использование инструмента имеет три основных существенных требования, сопоставимых с использованием других технологий в классе: возможность (время), мотив (желание) и ресурсы (навыки и возможности). Интерфейс "укажи и щелкни" делает последнюю точку менее навязчивой и трудоемкой, чем другие ГИС-технологии.

Хотя Google Earth и связанные с ней сайты предоставляют широкий спектр доступных данных, учащимся необходимо будет понять, как создать свою собственную учетную запись для поиска данных не включенных в интерфейс Google Earth, а затем, как открыть набор данных после определения желаемого набора данных. В некоторых случаях истинная точность и достоверность данных могут быть недоступны, что может поставить под угрозу образовательную ценность урока.

Google Earth также не является настоящей ГИС (таблица 1). Вводные концепции могут открыть двери для более широкого использования в более сложных инструментах, но Google Earth имеет ограниченные возможности и инструменты для поддержки действительных

операций пространственного анализа. Инструмент не имеет возможности запроса или функциональности для выполнения сложных пространственных операций — даже в версиях, не являющихся бесплатными.

**Таблица 1** - Google Earth как географическая информационная система.

| **Функции ГИС** | **Функциональное описание** | **Возможности Google Earth** | |
|---|---|---|---|
| Запрос | Вопрос, заданный системе поддержки (может быть основан на пространственном местоположении и/или табличном атрибуте). | нет | В настоящее время функция запроса (пространственного или атрибутивного) недоступна. |
| Буфер | Область вокруг объекта на заданном расстоянии должна ограничивать или содержать детали. | нет | Нет инструмента для вычисления буферов. |
| Слои | Использование нескольких слоев пространственных данных, зарегистрированных для всех других используемых слоев данных. | да | Данные, предоставленные Google Earth или в совместимом формате, могут отображаться вместе с другими слоями. |
| Близость | Близость объектов к интересующему объекту или области. | ограниченный | Близость можно определить визуально, но никаких инструментов для расчета близости или расстояний не предусмотрено. |
| Соединение | Взаимосвязанность местоположений (например, характеристики сети). | ограниченный | Подключение можно определить визуально, но для расчета подключения не предусмотрено никаких инструментов. |
| Моделиро-вание | Анализ процессов, результатов, тенденций или прогнозирование возможных результатов решений. | ограниченный | Выполняется визуально, но никаких инструментов для проведения сложных или невизуальных аналитических операций не предусмотрено. |

Несмотря на некоторые недостатки, Google Earth обладает рядом преимуществ, позволяющих использовать ее в средних образовательных учреждениях. Инструмент технологии предлагает огромный потенциал для расширения наших возможностей. Google Earth поддерживает обучение учащихся, поскольку она также может служить развлекательным центром. Включение эмоциональных компонентов или визуальных и эмоциональных образов для общения и мотивации помогает сделать Google Earth мощным инструментом в учебном процессе.

В отличие от многих сервисных приложений, учащимся не обязательно находиться в школе, чтобы использовать приложение. Бесплатная версия Google Earth может быть установлена любым пользователем, что позволяет учащимся использовать приложение вне образовательной среды и не попадать под лицензионные требования, предъявляемые многими коммерческими готовыми ГИС-приложениями.

Сообщество Google Earth и картографический сервис Google Keyhole, служба досок объявлений (BBS; доступен по адресу http://bbs.keyhole.com), содержат множество слоев данных, которые включают дополнительные показания и вспомогательные фотографии и видео [9]. Кроме того, в Google Earth становится доступно все больше сервисов с потоковой передачей мультимедиа (для получения информации, близкой к реальному времени, такой как местоположение спутников и обновления погоды). Keyhole BBS не только предоставляет данные, но и служит форумом для совместной дискуссии для пользователей, чтобы обсудить последствия и эволюцию данных, а также периферийные идеи. Другим дополнительным источником данных и обсуждений является блог Google “Maps Mania” (доступен по адресу http://googlemapsmania.blogspot.com). В блоге представлены различные наборы данных для Google Maps и Google Earth, а также длительные дискуссии об использовании пространственных инструментов Google.

Печатные материалы могут помочь развить пространственное мышление, но их полезность имеет определенные ограничения. Так, географические атласы уже давно предоставляют людям визуальное представление об их мире и охватывают широкий спектр тем. Атласы могут быть бесценными ресурсами для занятий в классе, хотя их ценность для поддержки динамичной, интерактивной учебной программы более ограничена. Б. Райстедт [10] пришел к выводу, что цифровые атласы предоставляют возможности взаимодействия, которых нет в печатных материалах; а Google Earth поддерживает эту идею, расширяя интерактивные компоненты в кажущихся бесконечными измерениях. Google Earth бросает вызов тому, как создаются, распространяются и используются цифровые атласы благодаря своему совместному форуму через Keyhole BBS. Если одна карта неэффективна для иллюстрации процесса, отображение можно сделать более динамичным, предоставляя пользователю информацию, связанную с местом, повышая уровень интерактивности и улучшая опыт пользователя как начинающего исследователя. Например, пользователю не нужно просто видеть Шарынский-каньон из космоса, он может увидеть его с разных ракурсов и оценить его глубину в виртуальном пространстве. То же самое относится и к городским ландшафтам в различных городах по всему миру.

Пользователям не нужно изучать интерфейсы или особые нюансы настольных ГИС-приложений, которые могут потребовать специальных навыков. Интерфейс Google Earth проще из-за ограниченного набора функций. Приложение ориентировано на большее количество операций "наведи и щелкни" без сложных меню и инструментов; версии, не являющиеся бесплатными, предоставляют относительно мощные возможности для разработки и расширения функциональности. Благодаря более простому интерфейсу Google Earth также обладает менее сложной функциональностью и картографическими возможностями, чем настоящие ГИС-приложения, что должно потребовать значительно меньше времени для обучения учителей. Время подготовки учителя также может быть сокращено, поскольку многие наборы данных легко доступны через Keyhole BBS, а также вспомогательные дискуссионные форумы, которые могут помочь учащимся определить контекст для рассмотрения точности и применимости данных. Таким образом, преподаватели могут быть более сосредоточены на уроках, а не на механике самого приложения.

Поскольку географы занимаются пространственной информацией или информацией о местоположении и структуре объектов в пространстве, можно выделить пять основных тем исследований - местоположение, место, отношения с местом, движение и регионы и закладывают основу для надежного геопространственного образования [11]:

(1) задавать географические вопросы;

(2) сбор географической информации;

(3) организация географической информации;

(4) отображение географической информации;

(5) ответы на географические вопросы.

Взаимосвязь этих тем является краеугольным камнем для организации уроков географии с организованной обработкой навыков вокруг пяти основных тем . Геопространственная информация может быть изучена и с помощью различных методов и средств, как показано в таблице 2.

**Таблица 2** - Категории навыков, используемые географами для анализа пространственных связей.

| **Категория** | **Фундаментальный вопрос** | **Примеры** |
|---|---|---|
| Определение местоположения | Где это? | • Относительное расположение (влево, вправо, вверх, вниз, север, юг)<br>• Поиск мест на карте с использованием математических координат<br>• Съемка и навигация. |

| | | |
|---|---|---|
| Описание условий в местоположении | Что здесь? | • Особенности и условия, выявленные на месте |
| Отслеживание связей с другими местами | Как это связано? | • Причины перемещений и структур<br>• Осмотр заграждений, узких мест, каналов<br>• Потоки по соединениям |
| Сравнение местоположений | Чем места похожи или отличаются друг от друга? | • Словесные или графические сравнения двух или более мест<br>• Аналогии, средние значения, соотношения<br>• Тенденции и комплексный анализ |
| Определение зоны влияния вокруг местоположения | Насколько далеко от объекта его влияние является значительным? | • Основные экономические последствия коммерческой деятельности<br>• Роль законов и нормативных актов, влияющих на местоположение<br>• Несимметричные воздействия |
| Разграничение области сходных мест | Какие места поблизости похожи на это? | • Основные региональные границы<br>• Роль границ |
| Описание пространства между местами | Какова природа перехода между местами? | • Уведомление об изменениях во время путешествия<br>• Измерение расстояния, высоты, наклона и действия по интерполяции<br>• Понимание полей в сравнении с отдельными областями |
| Поиск аналога для данного места | Какие отдаленные места похожи на это? | • Рассмотреть городские аналоги<br>• Выявление закономерностей в различных отдаленных районах |
| Определение пространственной модели | Существуют ли уклоны, кластеры, цепочки, пончики, волны и другие характерные модели? | • Проведение различий между «четным» и «случайным»<br>• Выявление предубеждений через разницу в доходах<br>• Учитывайте субъективность анализа пространственной структуры |
| Сравнение пространственных моделей | Похожи ли пространственные модели? | • Закономерности хорошо известных сочетаний признаков (например, засуха и голод)<br>• Выборка и диаграммы рассеяния |
| Определение исключений из правила | Где есть места, в которых чего-то больше или меньше, чем ожидалось? | • Взаимосвязь между природными ресурсами и процветанием и связанные с этим аномалии<br>• Ожидания в сравнении с наблюдаемым уровнем потепления климата, наводнениями, ожидаемой продолжительностью жизни |
| Анализ изменений в структуре с течением времени | Как вещи распространяются? | • Прогнозы погоды<br>• Историческое распространение природных зон и поясов.<br>• Используйте логику для изучения распространения деятельности (например, болезни, экономическое процветание). |
| Разработка пространственных моделей | Связаны ли места одним или несколькими промежуточными процессами? | • Взаимосвязанность мест (например, последствия Эль-Ниньо, миграция беженцев) |

Google Earth может быть использована для дальнейшего улучшения межпредметной унификации благодаря не только существующим стандартом образования в области географии, но и различных межпредметных областях и будут способствовать развитию исследовательских навыков для расширения научных исследований и географического мышления.

Использование Google Earth в учебном процессе будет способствовать выполнению требования стандарта образования и целей обучения типовой учебной программы [12], поскольку:

- используется на уроках, где может быть задан вопрос о том, как люди добывают и используют природные материалы в качестве ресурсов;
- дает возможность учащимся описать особенности Земли;
- делать выводы о том, как поведение человека изменяет поверхность Земли;
- измерять расстояния;
- использовать и другие мыслительные и аналитические способности.

Google Earth часто публикует важные данные на своей главной веб-странице (http://earth.google.com). Учащиеся могут прочитать о текущем событии, просмотреть фотографии и видео в контексте события и написать анализ его последствий, который дает им понимание пространственной информации, в то же время явно развивая навыки критического мышления, анализа и письма.

Способность поддерживать пространственное мышление и помогать учащимся понимать природные и культурные явления, безусловно, является сильной стороной Google Earth. Уроки могут быть разработаны таким образом, чтобы помочь преподавателям рассказать о месте, предоставляя учащимся интерактивный инструмент. Учащиеся также могут изучить некоторые атрибуты, связанные с местом, включая основные взаимосвязи между объектами.

В таблице 3 приведены общие приложения для использования Google Earth. Значение Google Earth для обучения географии более подробно рассматривается в разделе "План урока" (таблицы 3).

**Таблица 3** - Утилита Google Earth для поддержки учащихся на уроках географии

| **Раздел географии** | **Утилита Google Earth для поддержки национального стандарта географии** |
|---|---|
| Мир в пространственном выражении | |
| 1. Как использовать карты и другие географические представления, инструменты и технологии для сбора, обработки и представления информации? | Интерактивный характер Google Планета Земля делает изучение мира более личным (например, поиск места, где вы живете) и увлекательным для изучения мира. Учащиеся могут сравнить картограммы с изображениями Google Earth, чтобы понять, как различаются географические представления. |
| 2. Как использовать ментальные карты для организации информации о людях, местах и окружающей среде? | Рассмотрите восприятие учащимся мира и их относительное место и попросите учащегося уточнить их восприятие по сравнению с реальностью, которую они идентифицируют при использовании Google Earth. |
| 3. Как анализировать пространственную организацию людей, мест и окружающей среды на поверхности Земли? | Измеряйте расстояния и возможности людей взаимодействовать из-за транспортных сетей или географических ограничений на подключение. |
| Места и регионы | |
| 4. Физические и человеческие характеристики мест. | Используйте функцию "Рельеф местности" в Google Планета Земля, чтобы оценить физическую природу местности — например, совершите виртуальный облет Гранд-Каньона или Нью-Йорка. |
| 5. Люди создают регионы, чтобы интерпретировать сложность Земли. | Проанализируйте политические регионы (например, границы штатов) и рассмотрите, как функциональные регионы (например, религиозные культурные регионы) влияют на их постоянство или способствуют их нестабильности. |
| 6. Как культура и опыт влияют на восприятие людьми мест и регионов? | Проанализируйте рост городов в крупных городах и рассмотрите, как такой рост влияет на то, как люди взаимодействуют и воспринимают окружающий мир. |
| Физические системы | |
| 7. Физические процессы, которые формируют структуру земной поверхности. | Посмотрите на гору Тянь-Шань или Мугалжары, чтобы рассмотреть действующие физиологические процессы и влияние вулканических явлений как на местном, так и на глобальном уровнях. Рассмотрите расположение зон разломов и потенциальные социально-экономические последствия потенциальных землетрясений. |
| 8. Характеристики и пространственное распределение экосистем на поверхности Земли. | Рассмотрите расположение речных и лесных систем и последствия их пространственного сокращения. |
| Человеческие системы | |

| | |
|---|---|
| 9. Характеристики, распределение и миграция человеческих популяций на поверхности Земли. | Рассмотрим, какие места являются наиболее наглядными свидетельствами урбанизации и развития. По мере расширения городов учитывайте, как миграция влияет на окружающую среду и физические ресурсы. |
| 10. Характеристики, распределение и сложность культурной мозаики Земли. | Используйте веб-сервисы для просмотра карт культурных регионов и учета этнической напряженности, возникающей в результате конкуренции или конфликта культурных групп. (Такая деятельность также помогает обеспечить использование различных технологий в Google Планета Земля.) |
| 11. Модели и сети экономической взаимозависимости на поверхности Земли. | Рассмотрим, как живут соседи Узбекистан (Что означает отсутствие доступа к земле и что означает зависимость от соседей в плане доступа? Каким образом авиаперелеты уменьшили зависимость от физических соседей в плане экономической жизнеспособности?) |
| 12. Процесс, модели и функции населенных пунктов. | Примените концепцию, например Теорию центрального места, и определите места, где эта концепция очевидна в Google Планета Земля. Подумайте, почему концепция очевидна — или нет — в указанном месте. |
| 13. Как силы сотрудничества и конфликта между людьми влияют на разделение и контроль над поверхностью Земли? | Рассмотрите продолжающийся конфликт на Ближнем Востоке. Учитывайте местоположение Израиля и его стратегическое значение. Используйте карту местности в Google Earth, чтобы понять стратегический характер Голанских высот и то, как развивался конфликт в регионе. |
| Окружающая среда и общество | |
| 14. Как действия человека изменяют физическую среду? | Проанализируйте распределение сельскохозяйственных угодий Северного Казахчстана. Рассмотрите, какое влияние оказывает преобразование степей в сельскохозяйственные угодья, а сельхозугодий - в развитые районы на физическую окружающую среду. |
| 15. Как физические системы влияют на человеческие системы? | Проанализируйте развитие прибрежных районов озера Алаколь и рассмотрите сильных волн как непосредственно, так и с течением времени. |
| 16. Изменения, которые происходят в значении, использовании, распределении и важности ресурсов. | Рассмотрим открытие нефти на западе Казахстана и то, как это повлияло на развитие страны. Найдите примеры поливного земледелия на юге Казахстана и то, как рис повлиял на его развитие. |
| Использование в географии | |
| 17. Как применять географию для интерпретации прошлого? | Определите местоположени Караганды, Жезказгана, Каратау, Актау. Рассмотрите физическое окружение этих городов. Как природные ресурсы одновременно влияли и ограничивали их развитие. |
| 18. Применять географию для интерпретации настоящего и планирования будущего. | Найдите свой дом или район в Google Earth. Почему ты там живешь? Как мог выглядеть этот район пятьдесят лет назад? Подумайте, как изменился район за эти пятьдесят лет и какие удобства находятся поблизости. Как может измениться этот район в течение следующих пятидесяти лет и что необходимо для поддержки такого развития или омоложения? |

Будучи цифровым ресурсом, Google Earth также поддерживает технологические стандарты, поскольку предоставляет инструменты повышения производительности для совместной работы и общения, а также поиска, оценки и сбора информации из различных источников. Google Earth предоставляет технологические ресурсы для решения проблем и принятия обоснованных решений — важные возможности ученики должны быть продуктивными членами общества. (Иллюстрации этих ресурсов и приложений приведены в таблицах 1, 2 и 3 и изложены в прилагаемом плане урока.)

Расширенные версии Google Earth предоставляют возможность создавать пространственные данные и загружать их на форумы, рассмотренные выше. В то время как профессиональная версия может оказаться непомерно дорогостоящей для многих школ, последствия разработки локальных наборов данных для улучшения обучения за счет понимания собственной среды учащегося огромны. Следует также отметить, что формат данных Google Earth представляет собой настраиваемый текстовый формат на основе расширяемого языка разметки (XML), который пользователи могут создавать и редактировать

с помощью простого текстового редактора, такого как блокнот Windows. Спецификации языка разметки замочной скважины на основе XML (KML) являются общедоступными, если учащиеся захотят разработать свои собственные наборы данных и изучить конкретную технологию.

Ориентированный на реализацию цели обучения в восьмом классе, был разработан специальный образовательный инструмент. Оно включало в себя объединение нескольких типов данных в один файл KML Восьмой класс был выбран для реализации навыков мышления таксономии познания Блума и поддержки создания целей обучения на соответствующем возрастном уровне, чтобы продемонстрировать применимость различных стандартов и полезность Google Earth. Данные в файле KML предназначены для иллюстрации как широты, так и глубины использования Google Earth как потенциального образовательного инструмента.

План урока предусматривал собой использование данных из KML и базовых данных изображений, доступных непосредственно через Google Earth. План урока разработан, чтобы помочь учащимся в нескольких образовательных направлениях, в частности:

- знание (запоминание, распознавание, припоминание);
- понимание (организация, описание, интерпретация);
- применение (применение информации, решение проблем, поиск новых способов использования информации);
- анализ (поиск глубинных структур, разделение целого на компоненты, выявление мотивов и скрытых смыслов);
- обобщение (компиляция, объединение);
- оценка (принятие ценностных решений и суждений).

Тповые учебные программы 7 и 8 класса достаточно интегрированы и с другми областями знаний, в особенности с историей. Учебная задача, стоящая перед учащимися в плане урока, состоит в том, чтобы заставить их мыслить контекстуально, связывая географическое пространство и ландшафты в историческом аспекте. Например, история формирования рельефа юго-востока Казахстана. Вопросы и ответы на которые содержатся в плане урока, помогают учащимся выявлять закономерности, причинно-следственные связи, учитывать сложные взаимосвязи, развивать навыки, основанные на технологиях, приобретать важные навыки в поддержку различных стандартов математики, естественных наук и обществознания, а также эффективно (но неявно) понимать пять тем географии.

Конкретные цели урока включают в себя ряд учебных действий учащихся:

- ознакомиться с Google Earth как с технологическим инструментом, исследуя Землю через интерфейс Google Earth, включая и выключая слои данных;
- ознакомиться с интерпретацией данных аэрофотосъемки, полученных с помощью дистанционного зондирования, ответив на вопросы, включенные в план урока, включая рассмотрение особых тенденций и закономерностей;
- определить географически значимые объекты и рассмотреть их важность, а также влияние развития на них как на уникальные ресурсы;
- подумайте, как изменилась земля с течением времени и как внешние угрозы и силы способствовали таким изменениям.

**Результаты и обсуждение**

Использование Google Earth в учебном процессе обеспечивает более активный подход к обучению, поскольку этот инструмент помогает облегчить процесс обучения. Он поддерживает понимание многих географических процессов и явлений, помогет ученикам рассматривать историю в контексте географии (например, почему была построена плотина вдоль Аральского моря), так, обмеление Аральского моря способствовало появлению на поверхности большого количество островов. Многие из них обладают весьма внушительными размерами (например, остров Барсакельмес является природным заповедником, а остров Кокарал – сухопутным перешейком между двумя большими частями моря), как это помогло

сформировать культуру (например, выявление изменений в населении с течением времени и как улучшения в транспорте повлияли на влияние на городское развитие), а также экологические последствия неэффективно управляемого роста (например, последствия вмешательства сельского хозяйства и развития в уникальный ландшафт Аральского моря). Учащимся предлагается рассмотреть стратегическое расположение таких достопримечательностей, как порт Муйнак, и почему в определенных районах с течением времени происходит изменение численности населения.

**Заключение**

Как и при любом внедрении образовательной технологии, наблюдается нехватки времени и соответствующих инструментов для достижения намеченных учебных целей. Не исключением является и Google Earth, хотя его интуитивно понятный интерфейс и простые инструменты помогают устранить имеющиеся проблемы. Способность учащихся применять дедуктивную логику для получения выводов способствует развитию аналитических навыков, требуют письменных объяснений наблюдений, использование различных инструментов помогает развивать географическую грамотность.

Google Earth расширяет возможности учащихся, предоставляя им средства для выполнения сложных географических и межпредметных задач и предоставляя им значительную свободу действий при разработке проектов. Учащиеся осведомлены о пространственных и временных тенденциях и последствиях. Хотя Google Earth не обладает таким множеством инструментов и возможностей, как настоящая ГИС, но он позволяет учащимся изучать географические пространственные закономерности и мыслить пространственно. Это также подготавливает почву для участия обучающихся в ГИС, поскольку они начинают задавать более сложные и подробные вопросы после того, как достигнут предела полезности использования Google Earth.

Вышеизложенно предназначено для того, чтобы выявить целесообразность и згачимость оспользования Google Earth в качестве образовательного инструмента. В нстоящее время существует потребность в том, чтобы дидактики и педагоги вступали в конструктивный диалог относительно плюсов и минусов использования этой программы и технологии. Дальнейшее значение для будущих исследований должно включать разработку научно-обоснованных критериев измерения для критической оценки эффективности обучения учащихся на уроках географиис использованием Google Earth.

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# ОБУЧЕНИЕ ГЕОГРАФИИ В ИНТЕРАКТИВНОЙ ОБРАЗОВАТЕЛЬНОЙ СРЕДЕ: ВОЗМОЖНОСТИ И ДИДАКТИКА

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**Аннотация**

В статье рассматривается возможности интерактивного образования, которое представляет собой сложную содержательную и дидактическую систему, включающую интерактивные стратегии, интерактивные технологии и интерактивные методы. Целью интерактивного обучения является развитие у учащихся навыков межличностного общения. Интерактивное обучение осуществляется посредством взаимодействия и диалога между участниками процесса и между учащимися.

Философский фундамент интерактивных стратегий опирается на социокультурные теории обучения, в которых конструктивизм, исследовательский подход и когнитивная рефлексия взаимосвязаны и играют приоритетную роль. При этом, новая парадигма, философской основой которой являются конструктивизм и гуманитарное образование, определяет изменение образовательной среды, включая аргументацию образовательных целей и задач – методику обучения (от монолога к диалогу), изменение образовательных технологий (от стимульной реакции к взаимодействию), изменение педагогического диалога и взаимодействие между учителем и учеником.

Интерактивный метод означает метод обучения, преподавания и изучения, который включает в себя методы взаимодействия коммуникаторов, между ними и с учителем. Суть интерактивных методов обучения основана на получении нового познавательного опыта в процессе активного и хорошо организованного продуктивного взаимодействия между собой, с учителями, с компьютерами, с природой и с различными источниками информации по географическим проблемам современности.

В нашем понимании интерактивные методы рассматриваются как процедуры, систематические способы, содержащие последовательность общих действий для достижения определенной цели в определенной научной области, в данном случае в географии.

**Ключевые слова**: обучение, образовательная среда, интерактивные методы обучения, географическое образование, географическая грамотность, взаимодействие, коммуникация.

**Введение**

Межпредметный потенциал школьного курса географии и особенность учебной программы, дают большую возможность для осуществления связей с предметами из цикла социальных и естественных наук. Все это может служить основанием для разработки и апробации интерактивной образовательной среды, основанной на конструктивно-когнитивной, которая является фактором формирования географической культуры и грамотности учащихся.

Конструктивно-когнитивная психология интерактивного образования может быть успешно интерпретирована до уровня конкретной вариативной образовательной технологии при сочетании с интерактивными методами и приемами, которые могут быть применены в обучении географии путем решения основополагающих задач[1], как:

- концептуализация представлений о природе и классификации интерактивных методов в контексте целенаправленного формирования географической грамотности для построения модели интерактивного обучения, в соответствии со спецификой географического образовательного контента;

- определение и уточнение понятийного аппарата для создания концептуальной основы с акцентом на когнитивные, ценностные, нормативные и деятельностные аспекты географической грамотности во всех компонентах образовательного процесса;

- разработка интерактивных дидактических технологий в сочетании с интерактивными техническими средствами обучения и методами, с акцентом на сотрудничество и совместное использование в познавательной деятельности;

- формирование стимулированного контекста содержания образования, соответствующего определенным целям в национальных образовательных ценностях, важно отметить, что в последние годы весьма актуальной является проблема экологизации географического образования. Внедрение экологических критериев во все формы человеческой деятельности в качестве нового подхода к решению экологических проблем потребует адекватной географической культуры.

Принятие геоэкологических и этических норм, ценностей и установок целесообразно из-за изменений в способе взаимодействия развивающейся личности с окружающей средой и необходимости повышения экологической ответственности учащихся, как один из важных компонентов устойчивого развития.

Идея об устойчивом развитии нашла одобрение и своих последователей в 179 странах мира, представители которых достигли консенсуса относительно человеческого развития, которое должно отвечать потребностям современного поколения, не идя на компромисс со способностью будущих поколений удовлетворять свои потребности, необходимость повышения восприимчивость людей и степень их участия в поиске решений проблем, связанных с окружающей средой, при этом, образование в области устойчивого развития является чрезвычайно важной неотъемлемой частью системы мер по выживанию современного общества и окружающей среды в целом.

Все вышеизложенное ставит вопрос об эффективном географическом образовании, определяя ее цели, структуру, форму и методы, инструменты исследований.

**Материалы и методы**

Планирование, организация и реализация современного образования в интерактивной образовательной среде является необходимым условием, обеспечивающий эффективность и результативность педагогического процесса. Раскрытие характера интерактивной образовательной среды предполагает прояснение ключевых понятий, как взаимодействие, интерактивность, интерактивное обучение.

Активность и интерактивность вводят диалог и взаимодействие между субъектами, которые так необходимы и полезны для целей эффективного образования и обучения. Учитель и ученик в интерактивной среде преобразуют свои функции и место в образовательном процессе по направлениям и степени взаимодействия, гарантируя реальное качественное

улучшение результатов обучения. Взаимодействие означает вид деятельности или более конкретно - “взаимодействие и взаимовлияние между людьми в процессе их общения”.

Понятие интерактивности рассматривается как совокупность двух слов – ”интер“ (вместе, между) и ”активность" (действие, инициатива), и связано с взаимодействием между учеником и учителем, а также между самими учениками [2]. Взаимодействие в учебном процессе предполагает взаимную деятельность двух или более лиц, оказывающих на них особое воздействие и включающая общение и сотрудничество в процессе выполнения одной общей задачи с взаимным результатом от нее.

Каждый участник образовательного процесса вносит свой вклад в развитие образовательной среды. Взаимодействие помогает прояснению взглядов, терпимости в общении. Это предполагает умение слушать, понимать, обсуждать различные точки зрения, мнение или позицию, отличную от вашей собственной.

Конструктивно-когнитивная психология для интерактивного образования может быть успешно интерпретирована до уровня образовательной технологии с сочетанием интерактивных методов, которые могут быть применены в географическом и геоэкологическом образовании.

Интерактивный образовательный процесс предоставляет собой большое разнообразие методов и средств обучения, которые превращают учащихся из пассивных наблюдателей и потребителей в активных партнеров и создателей собственных знаний.

Разъяснение природы и разнообразия интерактивных стратегий, методов и приемов, а также создание сбалансированной теоретико-эмпирической модели интерактивного образования в области географии и экологии активизируют познавательную деятельность для формирования географической грамотности с ее ключевыми характеристиками и компетенциями.

Педагогический метод как способ достижения цели в образовательном процессе находит свое наиболее яркое воплощение в характере взаимодействия преподавателя и учащихся. Наиболее популярная классификация методов, используемых в обучении географии (объяснительно-иллюстративный, репродуктивный, исследовательский), предопределяет характер деятельности учителя (информатор, организатор, лидер). Эти методы широко используются при обучении географии. Так, например, репродуктивный метод используется при изучении серии объектов одного типа, а исследовательский при изучении природы и экономики родного края.

Термин “метод” происходит от греческого слова “metodos” – способ изучения, познания, теории [3]. Способы, с помощью которых может быть достигнута определенная цель, которые используются для исследований или применяются в определенном виде деятельности, определяются как методы.

Методы обучения формируют процессуальную сторону технологии обучения. Через них может быть реализована связь между содержанием образования, процессом его усвоения учащимися и организацией, и управлением этим процессом. Метод представляет собой конкретный вид совместной деятельности преподавателей со студентами.

Интерактивные методы требуют партнерских взаимоотношений и диалогового типа общения между всеми участниками педагогического процесса. Использование интерактивных форм, методов и средств дает возможность преодолеть коммуникационные барьеры, стимулирует мышление, генерацию и обмен идеями. Каждый участник образовательного процесса вносит свой вклад в развитие образовательной среды.

При осуществлении учебной деятельности посредством интерактивных методов обучения идет процесс совместной познавательной деятельности, в которых участники взаимодействуют друг с другом, обмениваются информацией, моделируют ситуации, оценивают действия и поведение, попадают в реальную атмосферу сотрудничества для совместного решения реальных проблем на краеведческой основе в различных видах образовательной деятельности.

Интерактивные методы представляют собой средства для взаимного участия в одном отдельном действии, то есть навыки и логические, технические, лингвистические средства обучения, например: постановка вопросов, рационализация и формулирование ответов, использование рабочих листов, удержание внимания, применение того, что было изучено, запоминание и другие. Интерактивные технологии (система методов) и интерактивные приемы (система навыков и средств) доступны и необходимы на каждом этапе образовательного процесса.

При интерактивном образовании одновременно создаются условия (что?) для повышения внутренней активности учителя, а также ученика в их взаимодействии и возможности (что?) для их внешнего выражения с помощью гибких и динамичных методов (как?) в процессе обучения (где?) с умелым и компетентным применением современных динамично развивающихся средств обучения учителем (кто?) в подходящей образовательной среде (где?), в форме урока и вне урока. Интерактивные технологии представляют собой своеобразный тип личностно ориентированных технологий, которые умело сочетают в себе деятельность, направленную на “то, что изучается” (содержание учебного материала) и “как быть изученным”. Технология, алгоритм (как быть изученным) имеет приоритет в качестве личностно-ориентированного подхода перед теоретической подготовкой к географической грамотности (что изучается).

Что касается важности интерактивных методов для создания новой образовательной среды, мы отмечаем следующее (рисунок 1):


**Рисунок 1** - Значение интерактивных методов

Применение интерактивных методов в обучении географии дает возможность для расширения знаний учащихся, включая теоретические, эмпирические и методологические знания о мире в целом, отдельных материках и государствах.

Анализ литературных источников показывает, что до сих пор нет четкой и устоявшейся классификации интерактивных методов обучения с выделением их критериев. Рассмотрим интерактивные методы обучения разделив их на три группы: ситуационные, дискуссионные, экспериментальные или эмпирические.

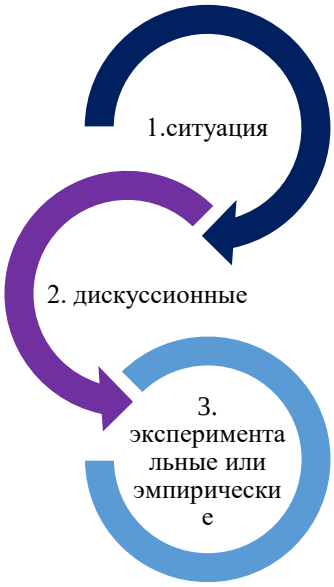


**Рисунок 2**- Группы интерактивных методов

Ситуационные методы предполагают максимальное приближение образовательного процесса к реальной жизни. Особое значение имеет выбор ситуации из реальности, характерной для конкретного вида человеческой деятельности. Различные аспекты анализа этой ситуации побуждают учащихся искать альтернативные решения. Таким образом, стимулируется их мышление, а их знания и навыки обновляются. При стимулировании идет перенос знаний в новую ситуацию и в условиях поиска оптимального решения поставленной цели. Значимым для ситуации методов является то, что их применение связано не столько с приобретением новых знаний, сколько с закреплением и творческим применением уже изученного учебного материала.

Ситуационные модели представляют собой введение в ситуацию и анализ ситуации. Ряд авторов выделяют три его варианта:

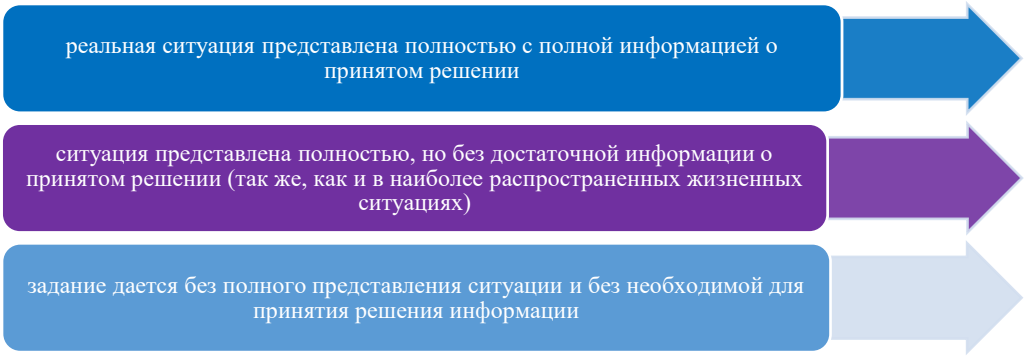


**Рисунок 3**- Варианты ситуации

К ситуации относится метод конкретной ситуации (кейс-стади), кейс, моделирование, игра, ролевая игра, инсценировка.

В использовании ситуационных методов выделяются ряд этапов как: определение цели, которая должна быть достигнута учащимися; представление содержания ситуации; указание действий, которые должны быть выполнены учащимися; формирование групп, выбор ответственного, уточнение правила работы; групповое обсуждение ситуации, высказывание различных мнений, выбор доказательств для защиты; межгрупповое обсуждение и анализ мнений каждой из групп; выводы и оценка результатов.

Имитационные методы представляют один из видов игры. Особого внимания заслуживают ролевые (симуляционные) игры. Они построены на основе реальных ситуаций, то есть имитируют реальность.

Костова З. [4] определяет моделирование и игры как ситуационные методы. В них чаще всего используется метод моделирования. Он представляет собой использование метода аналогии, при котором сложная исходная система заменяется упрощенной моделью. Наиболее распространенная классификация симуляций - по уровню абстракции. К моделированию относятся тематические исследования, ролевые игры, моделирование игр, машинное моделирование.

Метод кейса представляет собой моделирование и решения проблемных ситуаций. Его можно по-разному использовать в образовательном процессе. Эффективность использования кейсов определяется его соотношением с содержанием обучения, возрастными особенностями учащихся, умением автора кейса представить ситуацию с введением, изложением и постановкой задачи, быть ясным, лаконичным и не направлять на конкретное решение.

Кейсы структурированы следующим образом: цель – описание конкретного кейса, предоставление полной информации – практические задачи. Кейсы описывают реальные ситуации из практики, они основаны на опыте и являются результатом применения подхода к совместному обучению. Это реализуется на этапе составления кейсов и для оценки результатов индивидуальной и/или групповой работы, если это необходимо.

Например, используя кейсы при обучении географии, учащийся ищут дополнительную информацию, которая поможет им решить ту или иную проблему. Учащиеся выявляют причинно-следственные связи между объектами, процессами и явлениями, т.е. случай является фактором для изучения закономерностей в географической науке.

Ключевым моментом в применении кейсов в курсе является обсуждение (рисунок 5).

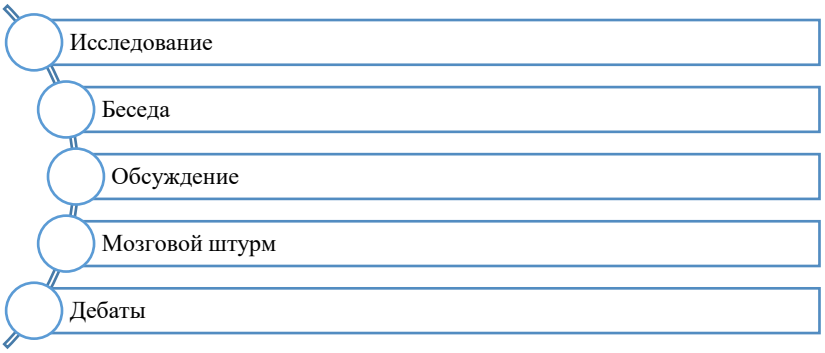


**Рисунок 4** - Методы обсуждения

Метод, при котором в последние годы занимает новые позиции в процессе обучения - дискуссия. Это своеобразный тип обмена идеями и мнениями по конкретной, четко определенной теме. Не обязательно обсуждение заканчивать принятием решения. Дискуссии требуют тщательной подготовки по теме, навыков аргументации, анализа, сравнения, обобщения, передачи знаний. Обычно они стимулируют творческое мышление, объективность, смелость высказываться и отстаивать свои позиции. Дискуссия обогащает и расширяет знания учеников. Это развивает навыки исследования и сбора информации, сокращения знаний в соответствии с конкретностью темы, представления проблемы в различных аспектах. Мы не можем пренебрегать тем фактом, что это способствует развитию речевой культуры учащихся, их умению быстро, четко, правильно и логично выстраивать свои ответы. Они развивают коммуникативные способности и межличностные отношения.

На рисунке 5 схематично представлены идеи и требования к обсуждению.

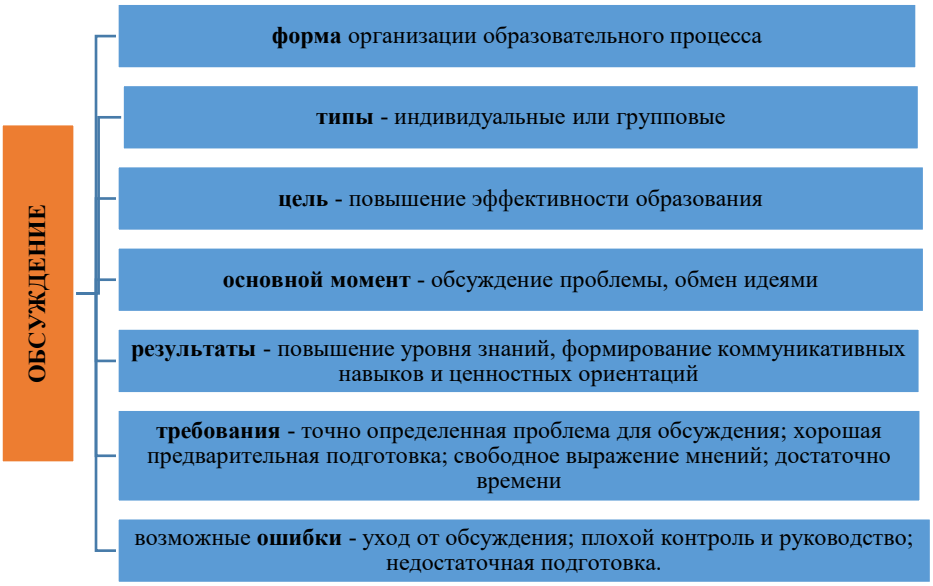


**Рисунок 5** - Методы обсуждения

Метод мозгового штурма используется для стимулирования творческой активности студентов по определенной теме или вопросу[5]. Работа проводится с группой учащегося и включает в себя: генерацию идей, анализ проблемной ситуации, оценку идей и генерацию противоположных идей. Приветствуются шутки, замечания и неформальность. Учащиеся свободно выражают идеи или мнения, которые в данный момент не обсуждаются и не оцениваются. Мозговой штурм продолжается до тех пор, пока у группы не кончатся идеи или она не завершит задание за отведенное время. Из всех идей выбираются наиболее подходящие, которые наиболее правильно соответствуют поставленной задаче (рисунок 6).

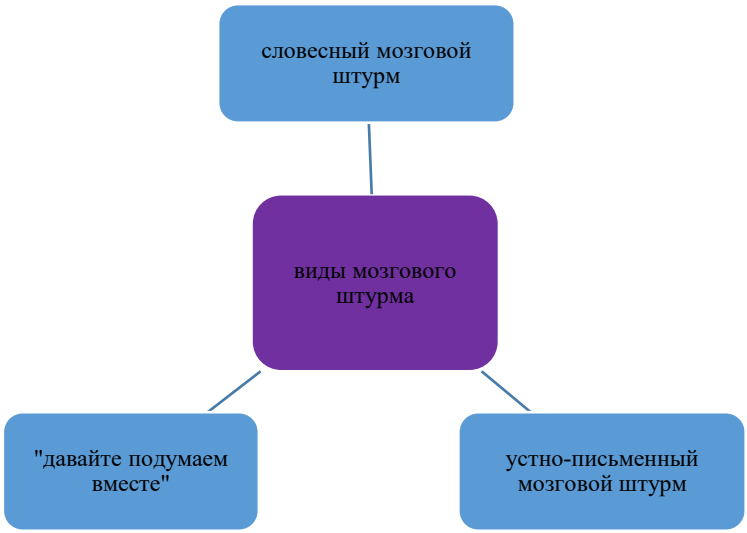


**Рисунок 6** - Виды мозгового штурма как процедуры

Использование интерактивных методов (мозговой штурм, кейс стади, ролевые игры, инцидент и кейс) является фактором формирования и развития эмпирических знаний обучающихся [6]. Навыки обучающихся извлекать географическую информацию, интерпретировать ее, представлять и генерировать информацию (в соответствии с учебной программой) достигаются за счет использования интерактивных методов для решения конкретной проблемы. Экспериментальные (эмпирические) методы представлены на рисунке 7.

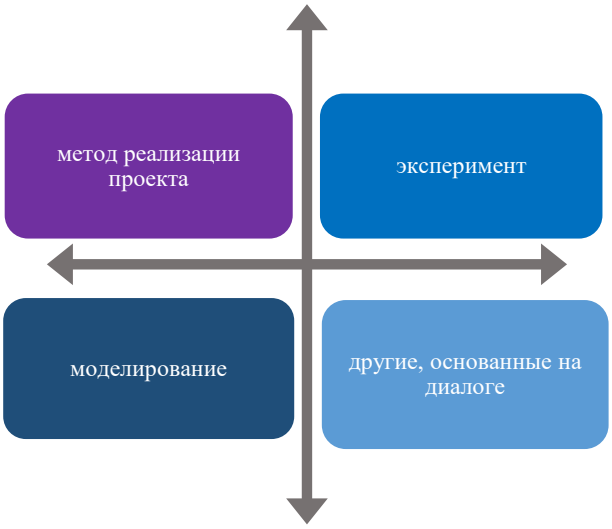


**Рисунок 7**- Экспериментальные (эмпирические) методы

Основная идея метода разработки проектов, это обучение через действие. Основой конкретного проекта всегда является “живое занятие с пережитой реальностью, посредством которого общими усилиями достигается одно или несколько решений конкретной проблемы, которые в конечном итоге сливаются в один продукт, в конкретный результат” [7].

Этот метод обычно комбинируют с другими методами. В проектах над одной реальной задачей преподаватели и учащиеся работают одинаково. Характер проектов определяется спецификой содержания образования, возрастными особенностями учащихся, а также его охватом и тематикой. Проектный метод проходит ряд последующих этапов (рисунок 8).

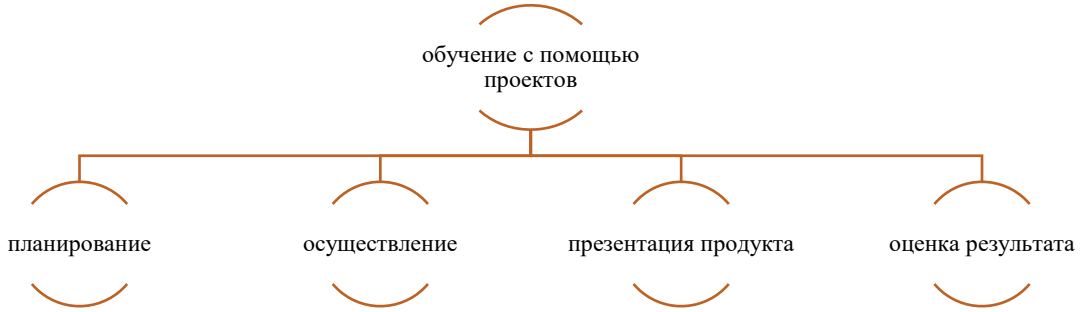


**Рисунок 8** - Этапы проектного метода

При планировании проекта формируется рабочая группа, определяется сфера участия и тема, распределяются задачи. Педагоги и учащиеся работают в соответствии с рабочим планом: сбор информации, проведение интервью, создание продукта, подготовка презентаций и другие. Результат работы оформляется в виде презентация продукта – презентация, плакаты и другие. На завершающем этапе осуществляется оценка полученных результатов.

Продуктами проектов с использованием потенциала информационных технологий могут быть: визуальная презентация урока – представление некоторых тем из образовательного контента в деятельности класса; система онлайн-обучения – подготовка материалов, предназначенных для интернета.

Информационно-коммуникационные технологии предоставляют разнообразие методов и средств, которые показывают возможности содействия образовательному процессу, поскольку учитываются индивидуальные потребности учащихся и в них формируются важные цифровые компетенции, необходимые для достижения географии, “основанной на знаниях”.

Проведенный анализ отдельных методов обучения с точки зрения их преимуществ, ограничений, возможностей использования интерактивных методов и вопросов о рефлексии дал нам возможность выбрать наиболее подходящие из них для целей географического образования.

Интерактивная форма обучения, которая стимулирует не только общение, взаимодействие и сотрудничество, но и развитие таких личностных качеств, как ответственность и терпимость - экспертное обучение [8]. Оно помогает выработать независимую стратегию обучения и навыки передачи концепций другим, для социализации и интеграции в сообщество.

Экспертное обучение может быть успешно реализовано в географическом образовании при помощи правильно расположенной последовательности ее этапов/шагов (рисунок 9).

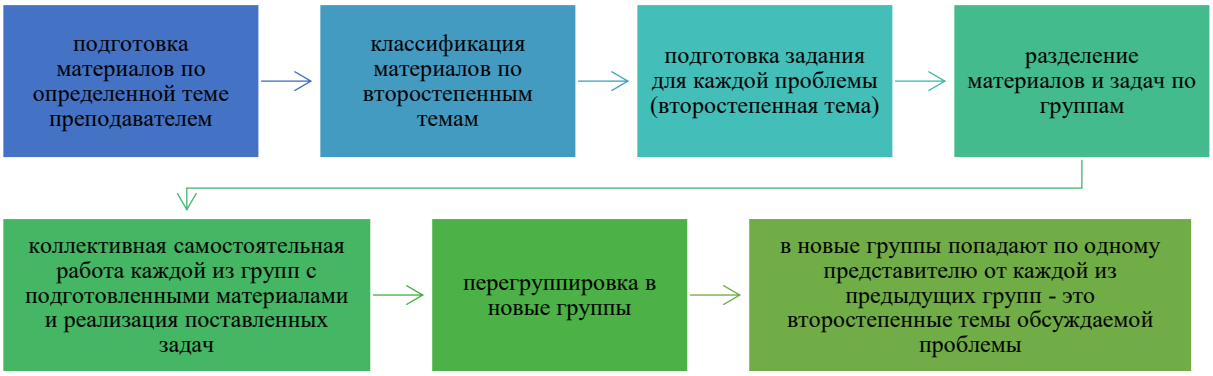


**Рисунок 9** - Последовательные шаги в обучении экспертов

Интерактивные методы могут быть также классифицированы в соответствии с основной функцией (рисунок 10).


**Рисунок 10** - Классификация интерактивных методов в соответствии с основной функцией

Основными условиями использования интерактивных методов обучения являются: ориентация на командную работу, реализация проектов, подготовка плакатов, построение концептуальных карт, рефлексивная оценка результатов, решение задач междисциплинарного характера, повышение самостоятельности учащихся в познавательной деятельности [9].

Формирование географической культуры учащихся является результатом применения современных образовательных стратегий, основным компонентом которых являются интерактивные методы обучения. Они являются одним из возможных путей повышения качества географического образования и достижения его цели, поскольку их применение приводит к формированию: нового типа взаимодействия, основанного на взаимодействии;

новых компетенций и личностных навыков – способности к самостоятельному изучению, принятию новых методов обучения (в том числе интерактивные), критическое мышление; креативность; обучение на протяжении всей жизни; способность к рефлексии; новые навыки - для работы с постоянно меняющейся информацией, для отстаивания собственного мнения, для командной работы и другие.

Географическое образование с использованием интерактивных форм и методов оказывается успешным в развитии географической грамотности во всех ее компонентах (рисунок 11).

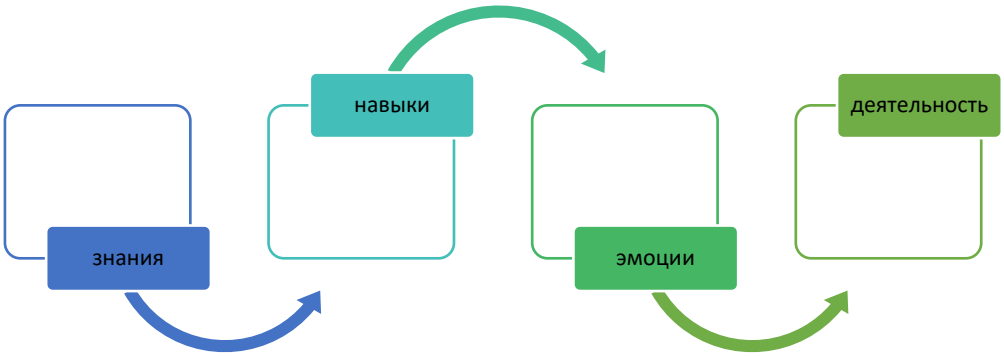


**Рисунок 11** - Компоненты географической грамотности

Причины использования интерактивных методов в образовании по географии основаны на следующих моментах:

- требования общества к географическим знаниям, определенные национальной образовательной политикой в казахстанских средних школах для перехода к новому типу образования.

- возможность с их помощью достичь географической культуры, компетенций и навыков.

- возрастные и личностные особенности учащихся – интерактивные методы могут быть использованы в младших классах средней и старшей школы.

Применение информационных технологий и интерактивных методов обучения способствует активизации и повышению качества навыков; стимулирует критическое и самокритичное мышление; формированию положительной мотивации и познавательных интересов; позитивного отношения к учебе и школьному предмету.

1. Проблема формирования навыков не нова, но она представлена по-новому с точки зрения информационных технологий.

2. Это новшество с точки зрения индивидуальной познавательной деятельности учащихся – искать информацию, интерпретировать ее и представлять.

3. В настоящем диагностическом исследовании представлены методические решения по использованию интерактивных методов – тематические исследования, разработка и защита проектов. При реализации этих методов применяется специфическое для них следствие деятельности.

4. Реализация интерактивных методов обучения наиболее успешна при групповой форме организации работы. Это способствует формированию некоторых важных учебно-познавательных навыков, стимулирует конкуренцию между учащимися и группами и помогает развитию организационных и исполнительских навыков.

5. Творческая индивидуальная работа способствует раскрытию сил и возможностей молодых людей, повышает их уверенность в себе и делает их желанными партнерами для учителей.

Вышеизложенное побуждает педагогов стремиться к изменению практики преподавания для улучшения географического образования и экологической грамотности, и ответственности в надежде, что использование интерактивных методов обучения, которые раскрывают социальные аспекты научных достижений и включают действия по улучшению качества окружающей среды на местном уровне, может изменить их глобальное мышление.

Методическая литература показывает разнообразие концепций навыков и их классификации. Мы принимаем и используем для нужд этого исследования определение навыков составления географических характеристик для наиболее специфических интеллектуальных навыков в учебной работе по географии. Процесс формирования навыков включает в себя три важных процесса (рисунок 12).


**Рисунок 12** - Процесс формирования навыков

Критерии и показатели в этом исследовании относятся к принятым трем группам навыков для получения, интерпретации и представления информации в процессе изучения географии и экономики в Казахстане в 9-м классе. Мы показываем их существенные характеристики с соответствующими показателями. В процессе изучения раздела “Природные регионы Казахстана”, в качестве конкретных критериев и показателей определены те, которые приведены в следующей таблице.

**Таблица 1** - Критерии и показатели для формирования навыков составления географической характеристики природного региона

| **Критерий** | **Показатели** | **Уровень образования** |
|---|---|---|
| 1. Умение собирать информацию | 1. Подбор фотографий и картинок, с помощью которых достигается наилучшая наглядность. | может выбрать<br>частично<br>не может выбрать |
| | 2. Выбор оптимальных графиков для представления конкретной задачи. | может выбрать<br>частично<br>не может выбрать |
| | 3. Избирательность при сборе информации из Интернета. | низкий<br>удовлетворительный<br>средний<br>высокий |
| 2. Умение интерпретировать информацию | 1. Характеристика природного региона с помощью алгоритма. | очень низкий<br>низкий<br>средний<br>высокий<br>очень высокий |
| | 2. Экономическая оценка условий и ресурсов в природном регионе. | очень низкий<br>низкий<br>средний<br>высокий<br>очень высокий |

| | | |
|---|---|---|
| 3. Умение преподносить информацию | 1. Эстетичный внешний вид | удовлетворительно<br>хорошо<br>очень хорошо |
| | 2. Использование оптимального объема текста | использует оптимальную громкость<br>не использует оптимальную громкость |
| | 3. Личная приверженность проблеме | представление<br>частично<br>отсутствия |
| Источник: авторская адаптация критериев и показателей | | |

В разделе “Экономическая и социальная география Казахстана” тема “Численность населения» и «Миграция населения” предполагает определение других критериев и показателей. Разница заключается в показателях, касающихся второй группы навыков – для интерпретации информации.

**Таблица 2**- Критерии и показатели для формирования навыков в теме “Численность населения» и «Миграция населения”

| Критерий | Показатели | Уровень образования |
|---|---|---|
| 1. Умение собирать информацию | 1. Подбор фотографий и картинок, благодаря которым достигается наилучшая наглядность. | может выбрать<br>частично<br>не может выбрать |
| | 2. Выбор оптимальных графиков для представления конкретной задачи. | может выбрать<br>частично<br>не может выбрать |
| | 3. Избирательность при сборе информации из Интернета. | низкий<br>удовлетворительный<br>средний<br>высокий |
| 2. Умение интерпретировать информацию | 1. Характеристика движения населения. | очень низкий<br>низкий<br>средний<br>высокий<br>очень высокий |
| | 2. Оценка демографического потенциала как фактора экономического | очень низкий<br>низкий<br>средний<br>высокий<br>очень высокий |
| 3. Умение преподносить информацию | 1. Эстетичный внешний вид | удовлетворительно<br>хорошо<br>очень хорошо |
| | 2. Использование оптимального объема текста | использует оптимальную громкость<br>не использует оптимальную громкость |
| | 3. Личная приверженность проблеме | представление<br>частично<br>отсутствия |
| Источник: авторская адаптация критериев и показателей | | |

Интерактивные методы и формы обучения, которые мы предпочли, выбранные критерии и показатели для регистрации результатов их использования мы комбинируем с соответствующими инструментами для проведения эмпирических исследований. Для

регистрации результатов используется подходящая шкала уровней и соответствующая количественная оценка (рисунок 13).

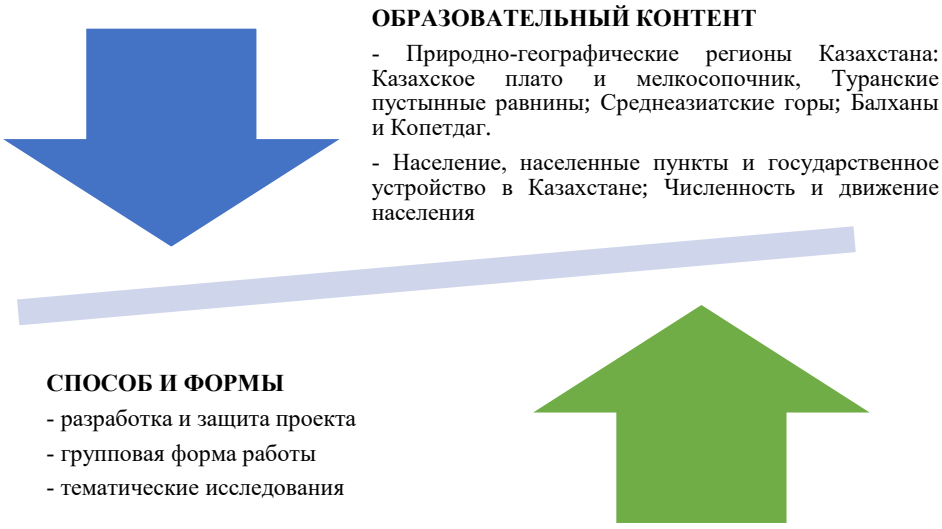


**Рисунок 13** - Методы и формы для определения содержания образования

Навыки составления плакатов, презентаций PowerPoint и интеллектуальных карт можно оценить по 5 показателям [10] (рисунок 14)


**Рисунок 14** - Показатели для оценки

С применением выбранных интерактивных методов формирование вышеизложенных навыков могут быть реализовано также во время уроков для получения новых знаний. Важную роль в этом играют мультимедийные презентации, с помощью которых уже изученный материал может быть синтезирован, визуализирован, быстрее усвоен, продуман и применен.

**Результаты и обсуждение**

Экспериментальная работа, проведенная с целью формирования навыков использования интерактивных методов в обучении географии, дает нам основание сделать некоторые выводы:

1. Использование интерактивных методов в процессе обучения не является новинкой, но становится все более актуальным, и они оказываются применимыми в образовании по географии и экологии. Причина этого заключается в том, что их применение повышает интерес и познавательную активность, а также помогает процессу формирования навыков.

2. Внедрение инновационных образовательных технологий и методов в образовательный процесс, таких как создание и защита проектов и тематических исследований, позволяет рационализировать планирование, проектирование, реализацию, оценку педагогической деятельности, стимулирует творческое мышление и независимость.

3. Реализация настоящего исследования сталкивается с некоторыми проблемами, в основном технического характера – доступ к технике и отсутствие лаборатории по географии. Другой проблемой является относительно небольшое количество классов в учебных программах, предусмотренных для изучения географии в средних школах.

4. Применение интерактивности дает больше возможностей для формирования сложных географических навыков составления географических характеристик. Это подтверждается статистической обработкой и анализом результатов эмпирического исследования. Процесс формирования этого навыка можно контролировать, поскольку применяется следствие действий, которые включены в этот навык: навык сбора, интерпретации и представления информации.

5. Создание и защита проекта – мультимедийная презентация повышает интерес и мотивацию учащихся, потому что они более уверены и полны энтузиазма, когда они являются партнерами или участвуют в презентации проекта;

6. Применение проектного метода требует следующих конкретных образовательных технологий: планирование проекта; реализация; презентация продукта; оценка и анализ результатов.

7. Использование подобных методов в обучении географии и экологии стимулирует творческое и аналитическое мышление, способствует формированию и совершенствованию навыков. В отличие от большинства интерактивных методов, повышающих познавательную активность учащихся, мультимедийные презентации не занимают много времени для представления в классе. Наоборот, систематизированная информация усваивается быстрее и появляется некоторое свободное время для решения дополнительных задач.

Все эти факты побуждают нас сосредоточиться на изменении практики преподавания для улучшения географического образования, экологической грамотности и ответственности в надежде, что использование интерактивных методов обучения может изменить глобальное мышление учащихся.

Характер интерактивных методов обучения основан на приобретении нового познавательного опыта в процессе взаимодействия между учащимися, с учителем, с компьютером, с природой и с различными источниками информации, касающимися географических проблем современности.

После проделанной экспериментальной работы, представленных результатов и выводов можно сделать некоторые рекомендации.

1. Из-за повышенного интереса учащихся и результатов проектной работы определенно можно сделать вывод, что они, как и интерактивные методы, имеют место в образовании по географии. Реальные возможности для их реализации дают практически все темы основного курса “География Казахстана”. Имея в виду уже сделанный вывод об организации работы над проектом и большой доле самостоятельной деятельности студентов, преподавателю желательно очень четко давать задания для самостоятельной работы и осуществлять постоянный контроль.

2. Поскольку подготовка проекта связана с получением дополнительной информации, хорошим знанием возможностей различного программного обеспечения и интернета, рекомендуется интеграция или консультация с преподавателями информатики и математики.

3. Целесообразно также использовать интерактивные методы и формы организации обучения, но это требует большой работы с обеих сторон. Несмотря на зарегистрированные высокие результаты, не следует переусердствовать с их применением.

**Заключение**

Интерактивные методы обучения как способы совместной познавательной деятельности учащихся, в которых они взаимодействуют друг с другом, обмениваются информацией, моделируют ситуации, оценивают собственные действия и поведение, попадают в реальную атмосферу сотрудничества для совместного решения реальных проблем на местном уровне в различных видах образовательной деятельности, обеспечивают качественное изучение содержания географического образования.

Природа интерактивных методов обучения основана на приобретении учащимися нового познавательного опыта в процессе активного и хорошо организованного продуктивного взаимодействия между ними, с учителем, с компьютером, с окружающей средой и с различными источниками информации о геоэкологических проблемах современности.

Интерактивное образование реализует на практике философию конструктивизма и когнитивной психологии, поскольку оно структурирует образовательный процесс вокруг потребностей учащихся и социальной природы знаний, поскольку оно создает условия для социал-демократического общения и творческого взаимодействия и в то же время формирует знания, развивает навыки и компетенции.

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# РАВНОМЕРНЫЕ ОЦЕНКИ РЕШЕНИЙ ОДНОГО КЛАССА НЕЛИНЕЙНЫХ УРАВНЕНИЙ В КОНЕЧНОМЕРНОМ ПРОСТРАНСТВЕ

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**Аннотация**

В этой статье мы получаем две теоремы об априорных оценках решений нелинейных уравнений в конечномерном пространстве. Эти теоремы доказаны при выполнении некоторых условий, которые заимствованы из условий которым удовлетворяют конечномерные аппроксимации одного класса нелинейных начально-краевых задач.

## Введение

Задача описания динамики несжимаемой жидкости, в силу своей теоретической и прикладной важности, привлекает внимание многих исследователей. В середине 2000-го года математическим институтом Клея (Clay Mathematics Institute) эта задача была сформулирована как Шестая проблема тысячелетия (The Millennium Prize Problems) о существовании и гладкости решений уравнений Навье-Стокса для несжимаемой вязкой жидкости [1].

Решению этой проблемы и до объявления ее проблемой тысячелетия было посвящено бесчисленное множество работ. Так как их необозримо много, мы их список просто не приводим. Далеко не полный список работ приведен в моей статье [2].

Этой проблемой занимались многие первоклассные математики, которым удавалось решить другие важные математические проблемы, в том числе в задачах газо-гидро-динамики. Существенные результаты получены в работах таких крупнейших математиков XX века, как А.Н. Колмогоров, J. Leray, E. Hopf, J.-L. Lions. Полное решение проблемы для двумерного случая дано О.А. Ладыженской [3]. В [4] приведен достаточно полный анализ современного состояния проблемы и обзор имеющейся литературы, предложены методы решения

Работа выполнена при поддержке гранта AP 08857604 Министерства образования и науки Республики Казахстан. задачи. В частности, основная проблема глобальной однозначной разрешимости трехмерной задачи Навье-Стокса сведена к вопросу о нахождении сильной априорной оценки для всех возможных решений.

Работы [5-12] посвящены к исследованию разрешимости в целом уравнений типа Навье-Стокса, непрерывная зависимость решения параболического уравнения, а также гладкости решения.

Эта работа возникла в результате многочисленных попыток авторов решить проблему существования сильного решения уравнения Навье-Стокса.

В этой работе мы получаем две теоремы об априорных оценках решений нелинейных уравнений в конечномерном гильбертовом пространстве. Работа состоит из четырех пунктов. В первом пункте приводятся используемые обозначения и формулировка основных результатов. Во втором пункте приведены основные леммы. Третий пункт посвящен доказательству теоремы 1. В четвертом пункте доказывается теорема 2. Условия теорем такова, что можно использовать при изучении некоторого класса начально-краевых задач для получения сильных априорных оценок при наличии слабых априорных оценок. В этом и состоит смысл этих теорем.

## 1. О постановке задачи и формулировка основного результата

В этой работе мы занимаемся выводом равномерных оценок решений нелинейных уравнений вида

$$u + L(u) = g \in H, \quad (1)$$

где $H$ - конечномерное гильбертово пространство, $L(\cdot)$ - нелинейное непрерывное преобразование, $g$ - элемент пространства $H$, решение $u$ задачи (1) ищется в $H$.

Мы нацелены на такие конечномерные уравнения вида (1), которые есть конечномерные аппроксимации бесконечномерных задач вида (1) в бесконечномерном гильбертовом пространстве. При этом окажутся весьма важными получение независимых от номера аппроксимации оценок, позволяющих переходить к пределу и получить в пределе априорную оценку для решения бесконечномерной задачи. Бесконечномерные задачи вида (1), на которые мы нацелены, являются, как правило, задачами математической физики, записанными в ограниченной форме.

В этом разделе $f(u)$ будет означать операцию вида

$$f(u) = u + L(u). \quad (2)$$

Если $\xi$ - параметр из $[0, +\infty)$ и вектор $u(\xi)$ есть вектор- функция, непрерывно дифференцируемая по параметру $\xi$, то будем предполагать, что также непрерывно дифференцируема и вектор- функция $L(u(\xi))$, а также возникающие в дальнейшем из $L(u)$ и $f(u)$ выражения.

Введем обозначение $L_u$ :

$$(L(u(\xi)))_\xi = L_{u(\xi)} u_\xi(\xi). \quad (3)$$

Очевидно, что $L_u$ (при каждом $u \in H$ ) будет линейным оператором

$$L_u v = (L(u(\xi)))_\xi\big|_{u_\xi = v}. \quad (4)$$

Имеем

$$(f(u(\xi)))_\xi = u_\xi + L_u u_\xi = (E + L_u) u_\xi.$$

Здесь и всюду в дальнейшем $E$ - единичное преобразование.

Обозначим

$$D_u^* = E + L_u^*, \quad (5)$$

$$D_u^* f(u) = (E + L_u^*) f(u). \quad (6)$$

Приведем используемые условия У1-У4.

**Условие У1.** Для преобразования $L(\cdot)$ и операторов $L_u, L_u^*, D_u$ и $D_u^*$ выполнены условия

$$\| L(u) - L(v) \| + \|L_u^* - L_v^*\|_{H \to H} \le \psi(\| u \|) \| u - v \|, \quad (7)$$

$$\|D_v u\| + \|D_u^*\| \le \psi(\| v \|) \| u \|, \quad (8)$$

где $\psi(\cdot)$ - непрерывная на $[0, \infty)$ функция.

**Условие У2.** Существуют линейные обратимые операторы $T$ и $G$ такие, что

$$\| G \| \le 1, \ \| T \| \le 1, \|G^{-1}\| + \|T^{-1}\| < \infty \quad (9)$$

и для любого $u \in H$ выполнены соотношения

$$\langle L(u), Tu \rangle \ge 0, \langle Tu, u \rangle \ge \| Gu \|^2 \ge \| Tu \|^2. \quad (10)$$

**Условие У3.** Если $u \in H$ - собственный вектор оператора $G^* G$, то выполнено неравенство

$$\| u \|^2 \le (\| f(u) \|^2 + 2)^m, m \ge 1. \quad (11)$$

**Условие У4.** Если $D_u^* f(u) = \lambda u, \lambda > 0$, то

$$\gamma(u) : \equiv \langle D_u^* f, u \rangle \| u \|^{-2} \ge (\| f(u) \|^2 + 2)^{-m} \| u \|^{-2}. \quad (12)$$

Справедлива

**Теорема 1.** Если выполнены условия У1 и У2, то для любого $g \in H$ задача

$$f(u) = g$$

имеет решение $u \in H$ такое, что выполнена оценка

$$\| Gu \| \le \| g \|. \quad (13)$$

**Замечание 1.** Мы в приложениях увидим, что теорема 1 позволяет получить существование слабого решения некоторого класса задач математической физики, записанной в ограниченной записи (интегральной форме), для которых задача

$$u + L(u) = g$$

является конечномерной аппроксимацией.

Имеет место

**Теорема 2.** Если выполнены условия У1, У2, У3 и У4, то задача

$$u + L(u) = g$$

для любого $g \in H$ имеет решение удовлетворяющее оценке

$$\| u \|^2 \leq C_0 \exp\left\{-\exp\{\| g \|^2\}\right\}, \tag{14}$$

где $C_0$ - постоянное число не зависящее от $g \in H$ (зависящее от $m$-из условия Y4).

Замечание 2. Эта теорема позволяет получить существования сильного решения некоторых задач математической физики (записанной в ограниченной форме). Условия У3 и У4 можно заметно ослабить, но остальных условии У1 и У2 не достаточны для получения оценки (14) из теоремы. Из хода доказательства теоремы 2 можно заметить, что оценку (14) можно существенно улучшить. Такую возможность оставляем читателям.

**2. Доказательство теоремы 1**

Уравнение $u + L(u) = g$ скалярно умножим на $Tu$. Тогда, используя условия У2 получаем

$$\langle Tu, g\rangle = \langle u, Tu\rangle + \langle L(u), Tu\rangle \geq \langle u, Tu\rangle \geq \| Gu \|^2.$$

Отсюда и из условия У2 вытекает оценка

$$\| Gu \|^2 \leq \langle Tu, g\rangle \leq \| Tu \| \| g \| \leq \| Gu \| \| g \|.$$

Из этой оценки получаем априорную оценку

$$\| Gu \| \leq \| g \|. \tag{15}$$

Обозначим

$$M = \{u: \langle Tu, u\rangle \leq 8\langle Tg, g\rangle\}. \tag{16}$$

Напомним, что $\langle Tu, u\rangle$ - положительный (строго!). Поэтому $\langle Tu, u\rangle$ и $\langle Tg, g\rangle$ можно принимать за квадраты норм.

Пусть уравнение $u + L(u) = g$ не имеет решения. Определим преобразование $F(u)$

$$F(u) = -\frac{u + L(u) - g}{\sqrt{\langle T(u + L(u) - g), u + L(u) - g\rangle}}\sqrt{8\langle Tg, g\rangle}. \tag{17}$$

Так как уравнение $u + L(u) = g$ не имеет решения это преобразование непрерывно. Но

$$\langle TF(u), F(u)\rangle \leq 8\langle Tg, g\rangle.$$

Поэтому непрерывное преобразование переводит множество $M$ в себя. Но тогда (так как $H$-конечномерно) согласно теореме Браудера преобразование $F$ имеет неподвижную точку, т.е.

$$F(u_0) = u_0. \tag{18}$$

Подействуем на (18) оператором $T$, а затем полученное равенство скалярно умножим на вектор $u_0 + L(u_0) = g$. Тогда используя (17) имеем

$$-\frac{\langle T(u_0 + L(u_0) - g), u_0 + L(u_0) - g\rangle}{\sqrt{\langle T(u_0 + L(u_0) - g), u_0 + L(u_0) - g\rangle}}\sqrt{8\langle Tg, g\rangle} = \langle Tu_0, u_0 + L(u_0) - g\rangle$$

или

$$-\sqrt{8}\sqrt{\langle Tg, g\rangle}\sqrt{\langle T(u_0 + L(u_0) - g), u_0 + L(u_0) - g\rangle} = \langle u_0, T(u_0 + L(u_0) - g)\rangle. \tag{19}$$

Умножим скалярно равенство (18) на вектор $T(u_0 + L(u_0) - g)$. Тогда используя (17) вместо (19) получаем

$$-\sqrt{8}\sqrt{\langle Tg, g\rangle}\sqrt{\langle T(u_0 + L(u_0) - g), u_0 + L(u_0) - g\rangle} = \langle Tu_0, u_0 + L(u_0) - g\rangle. \tag{20}$$

Сложим равенства (19) и (20), тогда получаем

$$-\sqrt{8}\sqrt{\langle Tg, g\rangle}\sqrt{\langle T(u_0 + L(u_0) - g), u_0 + L(u_0) - g\rangle} = \frac{1}{2}(\langle u_0, T(u_0 + L(u_0) - g)\rangle - \langle T(u_0 + L(u_0) - g), u_0\rangle). \tag{21}$$

Теперь, так как $\langle Tx, x\rangle \geq \| Gx \|^2 > 0$, то можно $\frac{1}{2}(\langle y, Tx\rangle + \langle Ty, x\rangle)$ принять за скалярное произведение. Тогда $\langle Tx, x\rangle$ и $\langle y, Tx\rangle + \langle Ty, y\rangle -$ будут квадратами норм. Тогда, так правая часть (21) должен быть отрицательным, получим

$$-\sqrt{8}\sqrt{\langle Tg, g\rangle} \geq -\langle Tu_0, u_0\rangle$$

или

$$\sqrt{8}\sqrt{\langle Tg, g\rangle} \leq -\langle Tu_0, u_0\rangle.$$

Это неравенство противоречить принадлежности $u_0$ множеству $M$ из (16). Поэтому уравнение $u + L(u) = g$ имеет решение $u$, для которого в силу (15) выполнено оценка (13). Теорема 1 доказана.

**Замечание 3.** Отметим, что теорему 1 можно доказать при более общих предположениях, чем условия У1 и У2. Сказанное следует из доказательства теоремы. Приведенная нами оформления теоремы 1 для нас удобны.

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# О СИСТЕМЕ КОРНЕВЫХ ВЕКТОРОВ ВОЗМУЩЕННОГО РЕГУЛЯРНОГО ДИФФЕРЕНЦИАЛЬНОГО ОПЕРАТОРА ВТОРОГО ПОРЯДКА НЕ ОБЛАДАЮЩЕГО СВОЙСТВОМ БАЗИСНОСТИ

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**Аннотация:** В статье рассматривается спектральная задача для оператора кратного дифференцирования при интегральном возмущении краевых условий одного типа, являющихся регулярными, но не усиленно регулярными. Ядром интегрального возмущения является функция $p(x) \in L_2(0,1)$. Особенностью рассматриваемой задачи является отсутствие свойства базисности у системы собственных функций невозмущенной задачи. Построен характеристический определитель спектральной задачи. Доказано, что множество функций $p(x)$, для которых система собственных функций возмущенной задачи (1),(4) не образует безусловного базиса в $L_2(0,1)$, является плотным в $L_2(0,1)$. Показано, что сопряженный оператор имеет аналогичную структуру.

**Ключевые слова:** Дифференциальный оператор второго порядка, интегральное возмущение краевых условий, базисность, корневые векторы, система собственных функций, собственное значение, характеристический определитель, нагруженный дифференциальный оператор, сопряженный оператор.

## 1. Введение и постановка задачи.

Хорошо известно, что оператор, заданный формально самосопряженным дифференциальным выражением, с произвольными самосопряженными краевыми условиями, обладает дискретным спектром, и система его собственных функций образует ортонормированный базис пространства $L_2$. Вопрос о сохранении свойств базисности при некотором (слабом в определенном смысле) возмущении исходного оператора исследовался во многих работах. Для случая самосопряженного исходного оператора аналогичный вопрос исследовался в [1-3], а для несамосопряженного – в работах [4-6]. В настоящей статье рассматривается спектральная задача, близкая к исследованиям [7-11]:

$$l(u) \equiv -u''(x) = \lambda u(x), \quad 0 < x < 1 \tag{1}$$

$$U_1(u) \equiv u'(0) + u'(1) - \alpha u(1) = 0, \quad \alpha > 0, \tag{2}$$

$$U_2(u) \equiv u(0) = 0, \tag{3}$$

где $\alpha > 0$ - произвольное положительное число.

Общеизвестным фактом является, что система корневых функций обыкновенного дифференциального оператора с произвольными усиленно регулярными краевыми условиями образует базис Рисса в пространстве $L_2(0,1)$. В случае, когда краевые условия являются регулярными, но не усиленно регулярными, свойство базисности систем корневых функций, в отличие от свойства полноты, не определяется даже конкретным видом краевых условий. Впервые этот эффект был замечен В.А. Ильиным [5], и соответствующий пример был построен для дифференциального оператора второго порядка общего вида. Как показано, в этом случае на наличие свойства базисности помимо краевых условий влияют также значения коэффициентов дифференциального оператора. Причем это свойство может меняться при сколь угодно малом изменении значений коэффициентов в метрике тех классов, в которых заданы эти коэффициенты.

Пусть $L_1$–оператор в $L_2(0,1)$, заданный выражением (1) и "возмущенными" краевыми условиями:

$$U_1(u) \equiv u'(0) + u'(1) - \alpha u(1) = 0, \quad \alpha > 0, \tag{4}$$

$$U_2(u) \equiv u(0) = \int_0^1 \overline{p(x)} u(x) dx, \quad p(x) \in L_2(0,1)$$

Через $L_0$ обозначим невозмущенный оператор (случай $p(x) = 0$), то есть соответствующий к задаче (1)-(3).

В работе [12] исследованы вопросы устойчивости базисности корневых векторов спектральной задачи, когда $\alpha = 0$.

В наших предыдущих работах [13-15] рассмотрены различные варианты интегрального возмущения краевых условий. В этих работах, в предположении, что невозмущенный оператор $L_0$ обладает системой собственных и присоединенных функций (СиПФ), образующей базис Рисса в $L_2(0,1)$, мы построили характеристический определитель спектральной задачи для оператора $L_1$. На основании полученной формулы делаются выводы об устойчивости либо неустойчивости свойств базисности Рисса СиПФ задачи при интегральном возмущении краевого условия.

Принципиальным отличием настоящей работы является то, что у невозмущенной задачи (1)-(3) система собственных функций полна, но не образует базиса в $L_2(0,1)$ [16].

Поэтому используемый нами метод из предыдущих работ в данном случае не может быть применим. В нашей работе [11] было исследовано «возмущение» оператора $L_0$, когда возмущалось первое краевое условие $U_1(u)$.

**2. Построение вспомогательного базиса.**

Краевые условия в невозмущенной задаче (1)-(3) являются регулярными, но неусиленно регулярными [17]. Система корневых функций оператора $L_0$ является полной системой, но не образуетдаже обычного базиса в $L_2(0,1)$ [16].

Однако, как показано в [18] на основе этих собственных функций может быть построен базис, позволяющий применить метод разделения переменных для решения начально-краевой задачи с краевым условием (2).

Представляя общее решение уравнения (1) по формуле

$u(x,\lambda) = C_1 \cos(\sqrt{\lambda}x) + C_2 \sin(\sqrt{\lambda}x)$,

и удовлетворяя его краевым условиям (4), получаем линейную систему относительно коэффициентов $C_k$:

$$\begin{cases} C_1\left(-\left(\sqrt{\lambda}\sin(\sqrt{\lambda}) + \alpha\cos(\sqrt{\lambda})\right)\right) + C_2\left(\sqrt{\lambda}\left(1+\cos(\sqrt{\lambda})\right) - \alpha\sin(\sqrt{\lambda})\right) = 0, \\ C_1\left(1 - \int_0^1 \overline{p(x)}\cos(\sqrt{\lambda}x)\,dx\right) - C_2\int_0^1 \overline{p(x)}\sin(\sqrt{\lambda}x)\,dx = 0. \end{cases} \tag{5}$$

Поэтому характеристический определитель задачи (1), (4) имеет вид

$$\Delta_1(\lambda) = \left(\sqrt{\lambda}\sin(\sqrt{\lambda}) + \alpha\cos(\sqrt{\lambda})\right)\cdot\int_0^1 \overline{p(x)}\sin(\sqrt{\lambda}x)\,dx -$$
$$-\left(\sqrt{\lambda}\left(1+\cos(\sqrt{\lambda})\right) - \alpha\sin(\sqrt{\lambda})\right)\left(1 - \int_0^1 \overline{p(x)}\cos(\sqrt{\lambda}x)\,dx\right) \tag{6}$$

При $p(x) = 0$, отсюда получается характеристический определитель невозмущённой задачи (1) – (3), его обозначим через

$$\Delta_0(\lambda) = \alpha\sin(\sqrt{\lambda}) - \sqrt{\lambda}\left(1+\cos(\sqrt{\lambda})\right).$$

Решая уравнение

$$\Delta_0(\lambda) \equiv 2\cos\left(\frac{\sqrt{\lambda}}{2}\right)\left[\alpha\sin\left(\frac{\sqrt{\lambda}}{2}\right) - \sqrt{\lambda}\cos\left(\frac{\sqrt{\lambda}}{2}\right)\right] = 0,$$

имеем две серии собственных значений невозмущённой задачи (1) – (3):

$\lambda_k^{(1)} = (\pi + 2\pi k)^2, \quad k = 0,1,2,\ldots,$

$\lambda_k^{(2)} = (2\beta_k)^2, \quad k = 0,1,2,\ldots.$

Здесь $\beta_k$ - корни уравнения

$$\cot\beta = \frac{\alpha}{2\beta}, \quad \beta > 0. \tag{7}$$

Они являются положительными и удовлетворяют неравенствам

$$\frac{\pi}{2} + \pi k < \beta_k < \pi + \pi k, \quad k = 0,1,2,\ldots.$$

Для разности $\delta_k = \beta_k - \left(\frac{\pi}{2} + \pi k\right)$ при достаточно больших $k$ выполняется асимптотика

$$\delta_k = O\left(\frac{1}{k}\right). \tag{8}$$

Собственные функций невозмущённой задачи (1) – (3) имеют вид

$u_k^{(1)}(x) = \sin(\pi + 2\pi k)x, \quad k = 0,1,2,\ldots,$

$u_k^{(2)} = \sin(2\beta_k x), \quad k = 0,1,2,\ldots.$

Собственные функции сопряженной к невозмущённой задачи (1) – (3) (то есть при $p(x) = 0$):

$$l*(u) \equiv -v''(x) = \overline{\lambda} v(x), \quad v'(1) + \alpha v(0) = 0, \quad v(0) + v(1) = 0, \tag{9}$$

имеют вид

$v_k^{(1)}(x) = C_k^{(1)}\left(cos(\pi + 2\pi k)\, x - \frac{\alpha}{\pi+2\pi k} sin(\pi + 2\pi k)\, x\right), \quad k = 0,1,2,\ldots,$

$v_k^{(2)}(x) = C_k^{(2)}\left(cos(2\beta_k x) - \frac{\alpha}{2\beta_k} sin(2\beta_k x)\right), \quad k = 0,1,2,\ldots.$

Выберем $C_k^{(1)}, \quad C_k^{(2)}$ из соотношений биортогональности

$\left(u_k^{(1)}, v_k^{(1)}\right) = 1, \quad \left(u_k^{(2)}, v_k^{(2)}\right) = 1.$

Отсюда легко видеть, что

$$C_k^{(1)} = -\frac{2(\pi+2\pi k)}{\alpha}, \quad C_k^{(2)} = -\frac{4}{\alpha}\beta_k + O\left(\frac{1}{k}\right) = -\frac{4}{\alpha}\left(\frac{\pi}{2} + \pi k\right) + O\left(\frac{1}{k}\right). \tag{10}$$

Поэтому

$$\lim_{k\to\infty}\left\|u_k^{(1)}\right\| \left\|u_k^{(1)}\right\| = \lim_{k\to\infty}\left|C_k^{(1)}\right|\frac{1}{2}\sqrt{1 + \left(\frac{\alpha}{\pi+2\pi k}\right)^2} = \lim_{k\to\infty}\frac{\pi+2\pi k}{|\alpha|} = \infty. \tag{11}$$

То есть, не выполняется условие равномерной минимальности

$$\lim_{k\to\infty}\|u_k\| \, \|v_k\| < \infty,$$

которое является необходимым условием безусловной базисности системы.

Следовательно, в силу (11), система собственных функций $\left\{u_k^{(1)}(x), u_k^{(2)}(x)\right\}$ не образует безусловного базиса в $L_2(0,1)$. Воспользуемся идеей работы [18], в которой предложен метод построения базиса из системы собственных функций задачи, подобной исследуемой нами.

Рассмотрим вспомогательную систему

$$u_{2k}(x) = u_k^{(1)}(x), \quad k = 0,1,2,\ldots,$$

$$u_{2k-1} = \left(u_k^{(2)}(x) - u_k^{(1)}(x)\right)\cdot(2\delta_k)^{-1}, \quad k = 1,2,\ldots.$$

Биортогональной системой к ней является система

$$v_{2k}(x) = v_k^{(2)}(x) + v_k^{(1)}(x), \quad k = 0,1,2,\ldots,$$

$$v_{2k-1} = 2\delta_k v_k^{(2)}(x), \quad k = 1,2,\ldots.$$

построенная из собственных функций задачи (9).

Покажем, что система $\{u_k(x)\}$, а следовательно и система $\{v_k(x)\}$ образуют базис Рисса в $L_2(0,1)$. Хорошо известно, система, квадратично близкая к базису Рисса, также является базисом Рисса. В качестве известной системы выберем следующую

$$\varphi_{2k}(x) = \sin(\pi + 2\pi k), \quad \varphi_{2k-1}(x) = x\cos(\pi + 2\pi k)x, \quad k = 0,1,2,\ldots$$

Эти функции являются собственными $(\varphi_{2k})$ и присоединенными $(\varphi_{2k-1})$ функциями задачи типа Самарского-Ионкина

$$-\varphi''(x)=\lambda\varphi(x),\quad 0<x<1,$$
$$\varphi(0)=0,\quad \varphi'(0)+\varphi'(1)=0.$$

Как показано в [16], система собственных и присоединенных функций этой задачи образует базис Рисса в $L_2(0,1)$. Покажем, что системы функций $\{u_k(x)\}$ и $\{\varphi_k(x)\}$ квадратично близкие. Действительно, имеем

$$\sum_{k=1}^{\infty}\|\varphi_k-u_k\|^2=\sum_{k=1}^{\infty}\|\varphi_{2k-1}-u_{2k-1}\|^2.$$

Непосредственным вычислением получаем

$$u_{2k-1}(x)=\frac{\sin(\delta_k x)}{\delta_k}\cos(\pi+2\pi k+\delta_k)x.$$

Поэтому

$$\|\varphi_{2k-1}-u_{2k-1}\|\le\left\|x\cos(\pi+2\pi k)x-\frac{\sin(\delta_k x)}{\delta_k}\cos(\pi+2\pi k+\delta_k)x\right\|\le$$
$$\le\left\|x\cos(\pi+2\pi k)x-\frac{\sin(\delta_k x)}{\delta_k}\cos(\pi+2\pi k)x\right\|+\left\|\frac{\sin(\delta_k x)}{\delta_k}\cos(\pi+2\pi k)x-\frac{\sin(\delta_k x)}{\delta_k}\cos(\pi+2\pi k+\delta_k)x\right\|\le$$
$$\le\left\|x-\frac{\sin(\delta_k x)}{\delta_k}\right\|+\|\cos(\pi+2\pi k)x-\cos(\pi+2\pi k+\delta_k)x\|\le O(\delta_k).$$

Принимая во внимание асимптотику (8), отсюда получаем, что

$$\sum_{k=1}^{\infty}\|\varphi_k-u_k\|^2=C\sum_{k=1}^{\infty}\frac{1}{k^2}<\infty.$$

То есть, системы функций $\{u_k(x)\}$ и $\{\varphi_k(x)\}$ – квадратично близкие. Таким образом доказана.

**Лемма.** Вспомогательная система $\{u_k(x)\}$, а следовательно и система $\{v_k(x)\}$ образуют базис Рисса в $L_2(0,1)$.

## 3. Характеристический определитель спектральной задачи (1),(4)

Функцию $p(x)\in L_2(0,1)$ представим в виде ряда Фурье по вспомогательной системе $\{v_k(x)\}$:

$$p(x)=\sum_{k=0}^{\infty}\alpha_k v_k(x). \tag{12}$$

Вычислим интегралы входящие в (6):

$$\int_0^1\overline{p(x)}\sin(\sqrt{\lambda}x)dx=\sqrt{\lambda}\left(1+\cos(\sqrt{\lambda}\right)-\alpha\sin\sqrt{\lambda}\cdot$$
$$\cdot\left[\sum_{k=1}^{\infty}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right]$$
$$\int_0^1\overline{p(x)}\cdot\cos(\sqrt{\lambda}x)dx=\alpha\cdot\left(1-\cos(\sqrt{\lambda}\right)-\sqrt{\lambda}\sin\sqrt{\lambda}\cdot$$
$$\cdot\left[\sum_{k=1}^{\infty}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right].$$

Используя полученное, определитель (6) приводится к виду:

$$\Delta_1(\lambda)=\left(\sqrt{\lambda}\sin\left(\sqrt{\lambda}\right)+\alpha\cdot\cos\sqrt{\lambda}\right)\cdot\left(\sqrt{\lambda}\left(1+\cos\sqrt{\lambda}\right)-\alpha\sin\sqrt{\lambda}\right)\cdot$$

$$\cdot\left[\sum_{k=1}^{\infty}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right]-$$
$$-\left(\sqrt{\lambda}\left(1+\cos\left(\sqrt{\lambda}\right)\right)-\alpha\cdot\sin\sqrt{\lambda}\right)\cdot\left(1-\left(\alpha\left(1-\cos\sqrt{\lambda}\right)\right)-\sqrt{\lambda}\sin\sqrt{\lambda}\right)\cdot$$
$$\cdot\left[\sum_{k=0}^{\infty}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right].$$

Несложными упрощениями получаем, что характеристический определитель $\Delta_1(\lambda)$ спектральной задачи (1), (4) представляется в виде

$$\Delta_1(\lambda)=\Delta_0(\lambda)\cdot\left[1+\alpha\cdot\left(\sum_{k=0}^{\infty}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right)\right], \quad (13)$$

где $\Delta_0(\lambda)=\alpha\sin\sqrt{\lambda}-\sqrt{\lambda}\left(1+\cos\sqrt{\lambda}\right).$

Выражение в квадратных скобках обозначим через $A(\lambda).$

Сформулируем полученный результат в виде теоремы.

**Теорема 1.** Характеристический определитель спектральной задачи (1),(4) с возмущенными краевыми условиями представим в виде (13), где $\Delta_0(\lambda)$ -характеристический определитель невозмущенной задачи, а $\alpha_k$ - коэффициенты Фурье разложения (12) функции $p(x)$ по биортогональной системе $\{v_k(x)\}$, составленной из собственных функций сопряженной задачи (9).

Функция $A(\lambda)$ при $\lambda=(\pi+2\pi k)^2$ и $\lambda=(2\beta_k)^2$ имеет полюса первого порядка, а функция $\Delta_0(\lambda)$ имеет нули первого порядка в тех же точках. Поэтому функция $\Delta_1(\lambda)=\Delta_0(\lambda)\cdot A(\lambda)$ - является целой аналитической функцией переменной $\lambda$.

Случай простой формы характеристического определителя (13) получаем в случае, когда $p(x)$ представляется в виде конечной суммы в (12). То есть, когда существует такой номер $N$, что $\alpha_k=0$ для всех $k>N$.В этом случае функция $A(\lambda)$ принимает вид

$$A(\lambda)=\left[1+\alpha\cdot\left(\sum_{k=0}^{N}\alpha_k\cdot\left(\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}+\frac{C_k^{(1)}}{\lambda-(\pi+2\pi k)^2}\right)+\sum_{k=1}^{\infty}\alpha_k\cdot 2\delta_k\cdot\frac{C_k^{(2)}}{\lambda-(2\beta_k)^2}\right)\right], \quad (14)$$

Из формулы (14) заметим, что $\Delta_1\left(\lambda_k^{(1)}\right)=\Delta_1\left(\lambda_k^{(2)}\right)=0$, для всех $k>N$. Следовательно, все собственные значения $\lambda_k^{(1)},\lambda_k^{(2)},k>N$ невозмущённой задачи (1)-(3), (то есть задачи при $p(x)=0$) являются собственными значениями возмущённой задачи (1),(4). Кратность собственных значений $\lambda_k^{(1)},\lambda_k^{(2)},k>N$ сохраняется. Из условия биортогональности системы собственных функций $\{u_k(x)\}$ и $\{v_j(x)\}$ следует

$$\int_0^1\overline{p(x)}u_k(x)dx=0,\quad k>N.$$

Таким образом, собственные функции $\left\{u_k^{(1)},u_k^{(2)}\right\},\ k>N$ невозмущённой задачи (1)-(3) (то есть задачи при $p(x)=0$), удовлетворяют краевым условиям возмущённой задачи (1),(4). Итак, система собственных функций возмущённой задачи (1),(4) и система собственных функций невозмущённой при ( $p(x)=0$ ) задачи (1)-(3) совпадают, которое не образующих базис, за исключением конечного числа первых членов.

Отсюда следует, что система собственных функций возмущённой задачи (1),(4) также не является базисом в $L_2(0,1)$ в этом частном случае. Так как множество функций $p(x)$,

представляемых в виде конечной суммы (12) плотно в $L_2(0,1)$, то получаем следующий результат.

**Теорема 2.** *Множество функций $p(x)$, для которых система собственных функций задачи (1),(4) не образует безусловного базиса в $L_2(0,1)$, является плотным в $L_2(0,1)$.*

Одной из особенности рассматриваемой возмущённой спектральной задачи то, что сопряжённой к (1), (4), является спектральная задача для нагруженного дифференциального уравнения

$$L_1^* v \equiv -v''' - p(x)v'(0) = \bar{\lambda} v(x), \quad 0 < x < 1 \tag{15}$$

с краевыми условиями (9) при $\alpha > 0$.

Считая $v'(0)$-некоторой независимой константой, убедимся, что общее решение уравнения (15) представимо в виде

$$v(x) = C_1 \cos\left(\sqrt{\bar{\lambda}}x\right) + C_2 \sin\left(\sqrt{\bar{\lambda}}x\right) + v'(0)\int_0^x p(\xi)\sin\left(\sqrt{\bar{\lambda}}(x-\xi)\right)d\xi \tag{16}$$

Отсюда, полагая сначала $x = 0$, а затем удовлетворяя (16) краевым условиям (9), получаем систему из трех уравнений, которая в векторно-матричной форме представима в виде:

$$\begin{bmatrix} 0 & 1 & -1 \\ \alpha - \sqrt{\bar{\lambda}}\sin\sqrt{\bar{\lambda}} & \sqrt{\bar{\lambda}}\cos\sqrt{\bar{\lambda}} & \sqrt{\bar{\lambda}}\int_0^1 P(\xi)\cos\left(\sqrt{\bar{\lambda}}(1-\xi)\right)d\xi \\ 1+\cos\sqrt{\bar{\lambda}} & \sin\sqrt{\bar{\lambda}} & \int_0^1 P(\xi)\sin\left(\sqrt{\bar{\lambda}}(1-\xi)\right)d\xi \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ v'(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}. \tag{17}$$

После стандартного вычисления получаем, что характеристический определитель $\Delta_1(\bar{\lambda})$ спектральной задачи для нагруженного дифференциального уравнения (15) с краевыми условиями (9) представляется в виде (6), которое редуцируется к виду (13), то отсюда следует

Следствие 1. Характеристический определитель нагруженной спектральной задачи (15), с краевыми условиями (9) представим в виде (13), где $\Delta_0(\bar{\lambda})$-характеристический определитель невозмущенной задачи, а $a_k$–коэффициенты Фурье разложения (12) функции $p(x)$ по биортогональной системе $\{v_k(x)\}$, составленной из собственных функций сопряженной невозмущенной задачи (9).

Отметим, что сопряженной оператор $L_1^*$ имеет аналогичную структуру в этом частном случае, то есть система собственных функций сопряженной задачи (15) с краевыми условиями (9) также не является базисом в $L_2(0,1)$.

Из этого частного случая несложно обосновать следующее

Следствие 2. Множество функций $p(x)$, для которых система собственных функций задачи (15), (9) для нагруженного дифференциального уравнения в пространстве $L_2(0,1)$ не образует безусловного базиса, является плотным в $L_2(0,1)$.

Итак, приходим к выводу, что сопряженные операторы одновременно не обладает свойством базисности.

Базисные свойства корневых вектор – функций нагруженных дифференциальных операторов исследовались в работах И.С.Ломова [19], [20], где на случай нагруженных дифференциальных операторов распространён метод спектральных разложений В.А.Ильина [21]. Идеи В.А.Ильина на случай несамосопряженного возмущения самосопряженной периодической задачи развивались в работе А.С.Макина [1] и антипериодической задачи в

наших исследованиях [22], которое оператор изменялся за счет интегрального возмущения одного из краевых условий.

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**СОДЕРЖАНИЕ**