

4th Workshop for Young Scientists in Computer Science & Software Engineering

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Abstract

This is an introductory text to a collection of selected papers from the 4th Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW 2021), which was held in Kryvyi Rih, Ukraine, on the December 18, 2021. It consists of short summaries of selected papers and some observations about the event and its future.

Keywords

computer science, software engineering, young scientists

1. CS&SE@SW 2021: At a glance

Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW) is a peer-reviewed workshop focusing on research advances, applications of information technologies.



CS&SE@SW topics of interest since 2018 [1, 2, 3, 4] are:

- Computer Science (CS):
 - Theoretical computer science
 - * Data structures and algorithms [5]
 - Computer systems
 - * Computer performance analysis [6]

CS&SE@SW 2021: 4th Workshop for Young Scientists in Computer Science & Software Engineering, December 18, 2021, Kryvyi Rih, Ukraine

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 CEUR Workshop Proceedings (CEUR-WS.org)

- * Databases [7]
- Computer applications
 - * Computer graphics and visualization [8]
 - * Human-computer interaction [8, 7, 9, 10]
 - * Scientific computing [11, 5, 12]
 - * Artificial intelligence [8, 13, 7, 12, 10, 14]
- Software Engineering (SE):
 - Software requirements [15]
 - Software design [7, 16, 17, 18, 19]
 - Software construction [20, 11, 7, 16, 17, 19]
 - Software configuration management [11]
 - Software development process [7, 17, 19]
 - Software engineering professional practice [21, 22]
 - Software engineering economics
 - Computing foundations [5]
 - Mathematical foundations [12]
 - Engineering foundations [12]

This volume represents the proceedings of the 4th Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW 2021), held in Kryvyi Rih, Ukraine, on December 18, 2020. It comprises 2 keynote and 15 contributed papers that were carefully peer-reviewed and selected from 22 submissions. Each submission was reviewed by at least 3, and on the average 3.14, program committee members. The accepted papers present the state-of-the-art overview of successful cases and provides guidelines for future research.

2. CS&SE@SW 2021 Program Committee

Dr. **Stuart Charters**, Senior Lecturer in Applied Computing, Lincoln University, Canterbury, New Zealand.

Stuart Charters, received a Bachelor of Science with Honours (Computer Science) and a Doctor of Philosophy from Durham University. Since 2006, he has worked at Lincoln University, New Zealand where he is currently Programme Director for the Master of Applied Computing. His research interests include evidence-based software engineering, visualization and the application of technology in agroecological contexts.

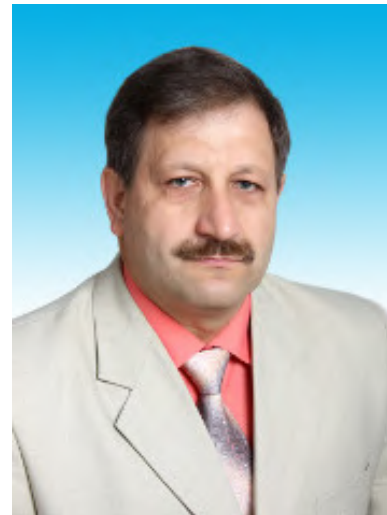
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Dr. **Pavlo Hryhoruk**, Professor of Department of Automated Systems and Modeling in Economics of Khmelnytskyi National University, Khmelnytskyi, Ukraine.

Prof. Pavlo Hryhoruk received a Doctor of Economic Sciences degree from the Khmelnytskyi National University in 2013. Since 1997, he has been working in economic and mathematical modeling at the Khmelnytskyi National University, where he is currently Head of the Department of Automated Systems and Modeling in Economics. He is Editor-in-Chief of “Herald of Khmelnytskyi National University. Economic Sciences”, Deputy Editor-in-Chief of the scientific journal “Modeling the Development of the Economic Systems”. He has published more than 100 scientific manuscripts in domestic and international journals and book series, two monographs, twelve chapters in collective monographs. Fields of studies are related to decision-making, multidimensional modeling of socio-economic systems, comprehensive assessment of economic phenomena latent characteristics, financial security, sustainable development, information technologies in education.

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Dr. **Oleksii Ignatenko**, deputy director of research, Institute of Software Systems NAS Ukraine, Kyiv, Ukraine.

Oleksii Ignatenko, born in 1979, received a Candidate of Physical and Mathematical Sciences from V. M. Glushkov Institute of Cybernetics NAS Ukraine, in 2007 and a Doctor of Physical and Mathematical Sciences from Institute of Software Systems NAS Ukraine in 2019. Since 2002, he has been working in the field of game theory and its applications in computer science, agent-based modeling, reinforcement learning. He is an associate professor at the Institute of Applied System Analysis of Igor Sikorsky Kyiv Polytechnic Institute (from 2006), Kyiv-Mohyla Academy (from 2019) and Kyiv Academic University (from 2019). He is a Vice Editor of Problem of Programming Journal.

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Dr. **Arnold Kiv**, Ben-Gurion University of the Negev, Israel.

Arnold Kiv received the D. Sc. (Dr. Hab.) degree in solid state physics from Tartu Institute of Physics, Tartu, Estonia, in 1978. From 1964 to 1982, he was a Senior Researcher and a Head of the Laboratory of Radiation Effects, Institute



of Nuclear Physics, Academy of Sciences, Tashkent, Uzbekistan. From 1983 to 1998, he was a Head of the Department of Theoretical Physics, South-Ukrainian National Pedagogical University, Odessa, Ukraine. In 1997, he was an Invited Professor, Western Ontario University, Canada. From 1999 to the present, he is a Professor-Researcher in the Department of Materials Engineering, Ben-Gurion University of the Negev, Israel. In 1996 and 2011 he was co-Director of NATO Advanced research Workshops and an Editor of two NATO Series books. He has about 200 publications, three monographs and three Invention Certificates in the field of radiation effects in solid state electronics. His research interests include mechanisms of formation of radiation defects in solids, interaction of fast particles with materials, radiation methods in microelectronics, including computer simulation, analytical calculations and experimental studies.

Dr. Oleksandr Kolgatin, Professor of Informatics, Department of Information Systems, Simon Kuznets Kharkiv National University of Economics, Kharkiv, Ukraine.

Oleksandr Kolgatin, born in 1966, received a Candidate of Technical Sciences degree (Dr. phil.) from the Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, in 1995, the field of scientific interests was computational modeling of the heat and mass transfer processes. Since 1990, he worked in the field of teaching informatics and using information technologies in education and received a Doctor of Pedagogical Sciences degree (Dr. habil.) from the Institute of Information technologies and Learning Tools of the National Academy of Pedagogical Sciences of Ukraine, in 2011. His research interests include computational modeling, pedagogical diagnostics, information systems and technologies in education.

He has published a number of papers in international journals and volumes in book series, is a member of editorial boards of Journal of Information Technologies in Education and associate editor of Information Technologies and Learning Tools.

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Andrey Kupin was born in Slovianoserbsk, Luhansk region, Ukraine, in 1972. He received the engineering degree in robotic systems and complexes from East-Ukrainian State University, in 1994 and the Ph.D. degree in automation from Kryvyi Rih Technical University, in 2001. From 2006 to 2007, he worked as an Associated Professor of the Department of Informatics, Automation and Control Systems. In 2010 he



became a doctor of science in automation, professor (2013). Dean of the Faculty of Information Technology (2011–2015). From 2007 he is the Head of the Department of Computer Systems and Networks. He is the author more than 190 articles and 8 patents. Professor Kupin as a scientific adviser has prepared 4 PhD and 1 DrSc. His research interests include artificial intelligence, information and integrated automation of technological processes.

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Viacheslav Osadchyi, born in 1975, received a Candidate of Pedagogical Sciences (PhD in Education) from the Vinnytsia State Pedagogical University named after Mykhailo Kotsiubynsky, Ukraine, in 2006, and a Doctor of Pedagogical Sciences from the Vinnytsia State Pedagogical University



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Marco Roveri received a Ph.D. degree in Computer Science from the University of Milano, Italy in 2002. He is an Associate Professor in the Information Engineering and Computer Science Department of the University of Trento, Italy. He was Senior Researcher in the Embedded Systems Unit of Fondazione Bruno Kessler in Trento, and before a researcher in the Automated Reasoning Division of the Istituto Trentino di Cultura also in Trento. His research interests include automated formal verification of hardware and software systems, formal requirements validation of embedded systems, model based predictive maintenance, and automated model based planning, and application of such techniques in industrial settings.

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Serhiy Semerikov is professor of Department of Computer Science and Applied Mathematics at Kryvyi Rih State Pedagogical University. He got both PhD and DSc in education (informatics) from the National Pedagogical Dragomanov University in 2001 and 2009, respectively. The main directions of Dr. Semerikov's research is methods of learning and educational technology.

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Dr. **Andrii Striuk**, Ph.D., Head of Simulation and Software Engineering department of Kryvyi Rih National University, Kryvyi Rih, Ukraine.

Andrii Striuk, born in 1979. In 2000 he graduated from the Kryvyi Rih Technical University with a degree in Automated Systems Software. In 2001, he received a master's degree in computer science. Has been working at the Department of Modeling and Software of Kryvyi Rih National University since 2000. Combines educational activities with practical, developing and implementing educational software products. In 2011 he defended his Ph.D. thesis. From 2014 to 2017 he is studying at the doctoral program in Institute of Information Technologies and Learning Tools of the NAES of Ukraine (Kyiv, Ukraine). In 2017, he was awarded the Prize of the President of Ukraine for young scientists. Heads the Simulation and Software Engineering department of Kryvyi Rih National University since 2018. Field of scientific interest: professional training



of software engineers, mobile learning technologies, the use of augmented reality technologies in education.

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Nataliia Veretennikova, born in 1990, received PhD degree from Vernadsky National Library of Ukraine in 2017. She is a winner of the President's Award for Young Scientists in 2019 and a winner of the Regional Prize for Young Scientists and Researchers for Scientific Achievements that Contribute to Social and Economic Transformation in the Region and Affirm the High Authority of Lviv Region Scholars in Ukraine and in the World. Her scientific research relates to the field of electronic science, linguistic support, and social communications. She is an author of a lot of papers in domestic and international journals as well as volumes. She is a member of editorial boards and joins in Programme and Organizing committees of international conferences or workshops.



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3. CS&SE@SW 2021 keynotes

This year a 3 keynote speakers were selected by CS&SE@SW 2021 program committee (figure 1):

- (1) Andrii I. Kostromytskyi “How to become a professional DevOps” (abstract only, [21], figure 2);
- (2) Bohdan V. Hrebenuk “Effective participation in programming contests” (abstract only, [22], figure 3);
- (3) Andrii M. Striuk “Software requirements engineering training: problematic questions” (full paper, [15], figure 4).

4. CS&SE@SW 2021 papers overview

4.1. Software engineering

The article “Software requirements engineering training: problematic questions” [15] by Andrii M. Striuk (figure 4), Serhiy O. Semerikov, Hanna M. Shalatska and Vladyslav P. Holiver

KEYNOTE SPEAKERS



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DEVELOPMENT LAB HEAD, PHD



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KRYVYI RIH NATIONAL UNIVERSITY,
DEPARTMENT OF SIMULATION AND
SOFTWARE



BOHDAN HREBENIUK
ZARAFFASOFT, TEAM LEAD / FULL
STACK ENGINEER


Figure 1: CS&SE@SW 2021 keynote speakers.

discusses the key problems of training Requirement Engineering and the following ways to overcome the contradiction between the crucial role of Requirement Engineering in industrial software development and insufficient motivation to master it in the process of Software Engineering specialists professional training were identified based on a systematic research analysis on the formation of the ability of future Software Engineering specialists to identify, classify and formulate software requirements: a) use of activity and constructivist approaches, game teaching methods in the process of modeling requirements; b) active involvement of stakeholders in identifying, formulating and verifying requirements at the beginning of the project and evaluating its results at the end; c) application of mobile technologies for training of geographically distributed work with requirements; d) implementation of interdisciplinary cross-cutting projects on Software Engineering; e) involvement of students in real projects; f) stimulating the creation of interdisciplinary and age-old student project teams.

This article highlights further research by the authors, begun in [23, 24, 25, 26, 27, 28, 29].

Personal finances are the own capital of an individual or family, which he manages independently. Personal finance management includes the ability to manage them, which requires separate training. The purpose of the article “Development of a simulator to determine personal financial strategies using machine learning” [20] by Dmytro S. Antoniuk, Tetiana A. Vakaliuk, Vladyslav V. Didkivskyi and Oleksandr Yu. Vizghalov (figure 5) is to develop the mechanics of a personal finance simulator and build a system for determining personal financial strategies

The path to Junior Position at EPAM




UNIVERSITY PROGRAM
epam

INTRODUCTION TO EPAM UNIVERSITY PROGRAM

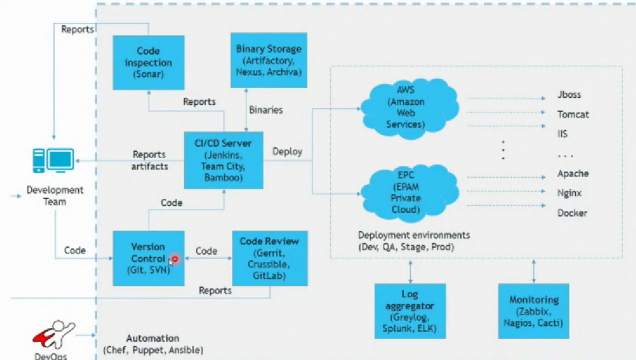
NEED EXPERIENCE TO GET JOB

NEED JOB TO GET EXPERIENCE

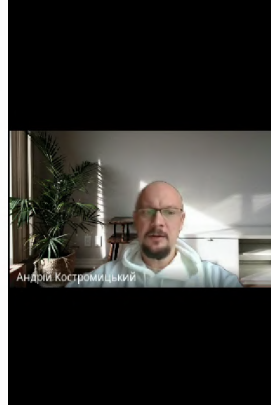


Андрій Костроміцький

DevOps responsibility



Available AWS Certifications https://aws.amazon.com/certification/?nc1=h_ls



Андрій Костроміцький

Professional


Two years of comprehensive experience designing, operating, and troubleshooting solutions using the AWS Cloud

Associate

One year of experience solving problems and implementing solutions using the AWS Cloud

Foundational

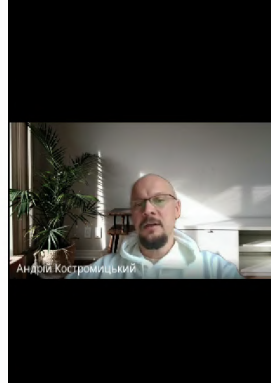
Six months of fundamental AWS Cloud and industry knowledge



Specialty

Technical AWS Cloud experience in the Specialty domain as specified in the exam guide

ASA #3 in 15 Top-Paying IT Certifications for 2021



Андрій Костроміцький

Figure 2: Andrii I. Kostromytskyi “How to become a professional DevOps” [21].

using machine learning. The development of a personal finance management simulator will allow in the future using it to teach the elements of managing such finances, even at school age. The developed software package consists of two parts: a personal finance management simulator and a system for determining financial strategies, which uses reinforced learning opportunities. The direction of future research is the integration of the recommendation system into the web application of the simulator. In addition, to improve the system and give flexibility in recommendations that could be adjusted to the current financial condition of the participant, it is necessary to pay attention to the use of “policy-based” methods of training with reinforcement, which are widely used in autopilot training systems for cars. Just as an autopilot cannot

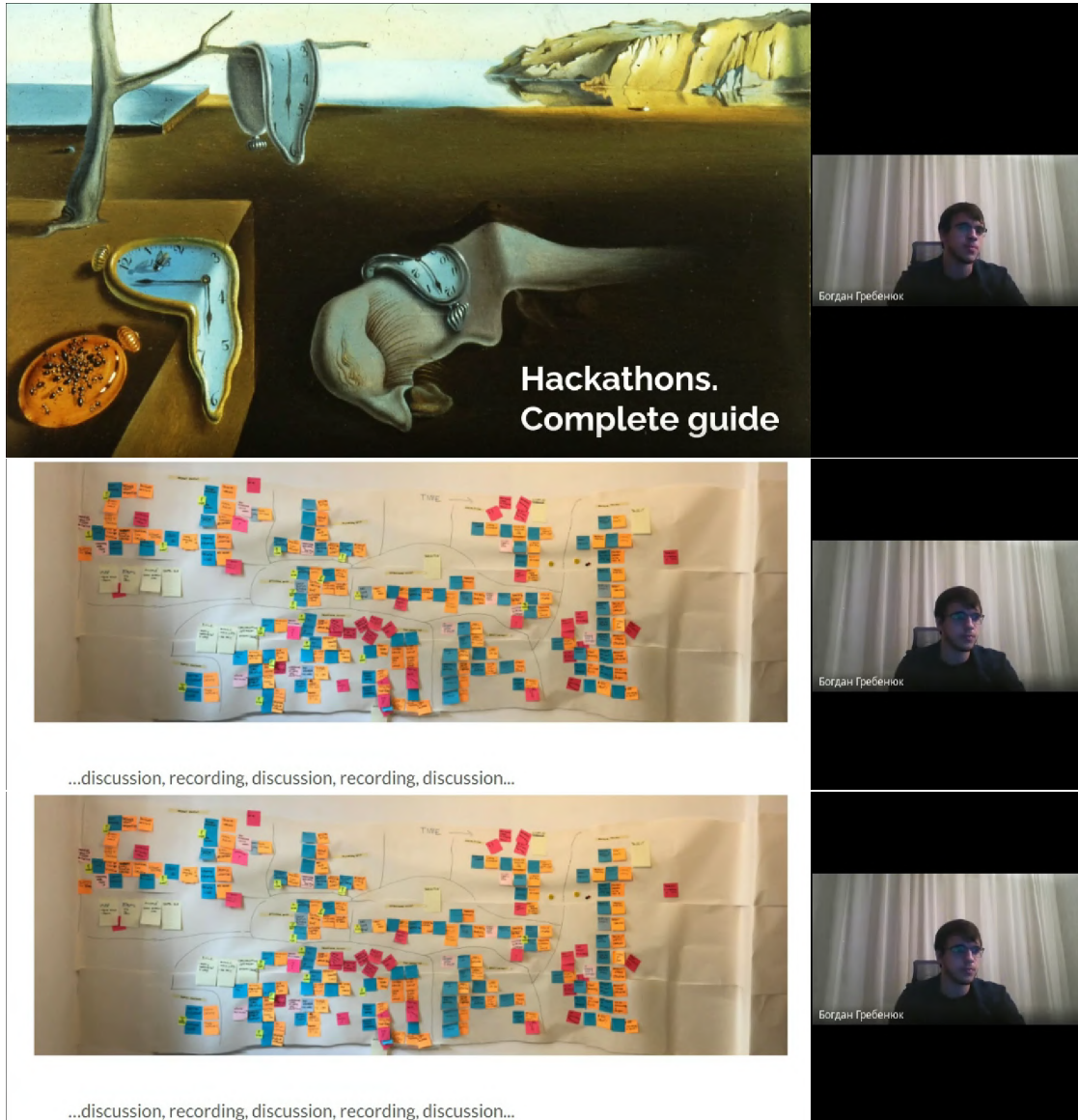


Figure 3: Bohdan V. Hrebenuik “Effective participation in programming contests” [22].

predict what may happen on the road in a second, can a person predict neither unexpected expenses nor profits (which is rare, but can happen).

This article highlights further research by the authors, begun in [30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49].

The article “Development of a machine vision program to determine the completeness of wrapping plants in the soil” [11] by Oleksandr V. Kanivets (figure 6), Irina M. Kanivets, Tetyana M. Gorda and Oleksii A. Burlaka analyzes the process of natural restoration of the main component of the soil – humus, as a result of which the dependence of the thickness of the humus layer on

Що таке інженерія вимог?

Інженерія вимог (requirements engineering) – це процес виявлення, формалізації та документування вимог, що відбувається під час комунікації із замовником та іншими зацікавленими особами, які зазвичай не володіють методами інженерії програмного забезпечення.

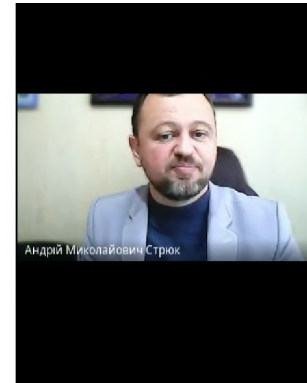
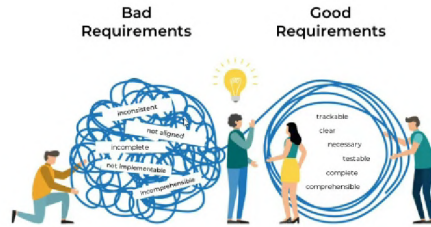


Figure 4: Presentation of paper [15].

the number of plants embedded in the soil was revealed. The technological process of surface tillage requires constant monitoring of the completeness of plant burying. The article analyzes the literature, which showed that machine vision systems are widely used in agriculture, for example, when detecting weeds for spot treatment with herbicides, analyzing citrus forms and diseases, automated counting of roundworms of cut trees, etc. A machine vision system is proposed as a control tool for detecting weeds on the soil surface. The authors proposed their own approach to control the completeness of burying pruned weeds in the soil using machine vision systems. The work of our own program for detecting weeds on the soil surface is described in detail and step by step. The program's operability was checked on some plant models and its effectiveness of reliable operation was confirmed. Experimental studies were conducted in the laboratory. Based on the results of research in the computer program developed by the authors, the following results were obtained: photos of the soil surface were analyzed; contours of plant models were identified; plant areas and their percentage in relation to the image area were determined, and a message was received on the screen about the presence of weeds on the surface in accordance with agrotechnical standards.

This article highlights further research by the authors, begun in [50, 51].

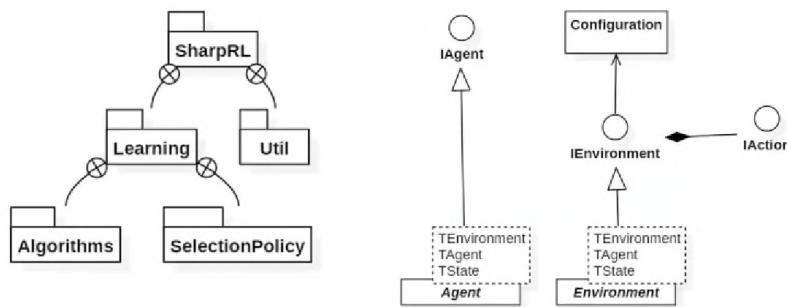
The article "Development of CRM system with a mobile application for a school" [16] by Nataliia I. Cheboksarova (figure 7), Tetiana A. Vakaliuk and Iurii M. Iefremov substantiates the need to develop a CRM system with a mobile application for a school. The existence of their educational environment, which will provide interaction between pupil and teacher in a school, is a topical issue today. Relationship management can be implemented in the form of a CRM system. For a deeper understanding of the research problem, certain analogs are considered, their advantages and disadvantages are given. The work aims to design and develop a CRM system with a mobile, cross-platform, application for a school. As a result, the architecture of the software package was built, the choice of tools was substantiated, the use and structure of the system were determined, the object-oriented structure of the system was designed, the data storage structure was developed, the system operation algorithms were designed and implemented, the system installation and administration procedure the procedure for working with the software package.

Development of a simulator to determine effective personal financial strategies using machine learning

Dmytro S. Antoniuk, Tetiana A. Vakaliuk,
Vladyslav V. Didkivskiy, Oleksandr Vizghalov

Zhytomyr 2021

The structure of the adapted collection "SharpRL" and class diagram of the adapted assembly "SharpRL"



Simulation page

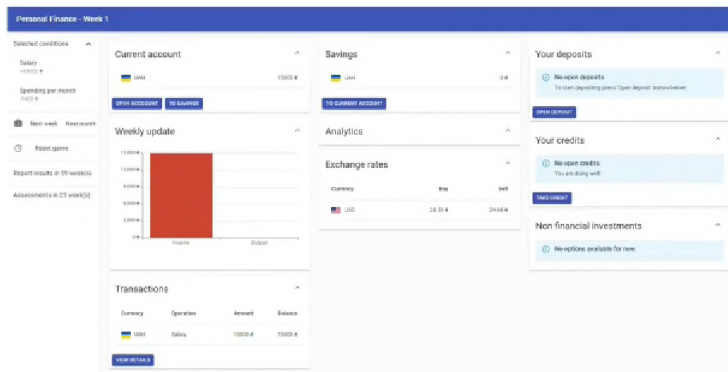


Figure 5: Presentation of paper [20].

The rapid growth of modern information technologies influences all aspects of human life. Companies all over the world are adopting new approaches to solve business problems, such

Poltava State Agrarian University
Poltava Polytechnic College

DEVELOPMENT OF A MACHINE VISION PROGRAM TO DETERMINE THE COMPLETENESS OF WRAPPING PLANTS IN THE SOIL

Oleksandr V. Kanivets
Irina M. Kanivets
Tetyana M. Gorda
Oleksii A. Burlaka

Poltava – 2021

CONDUCTING AN EXPERIMENT ON A SOIL CHANNEL

7



1 – a personal computer; 2 – a webcam;
3 – a soil channel; 4 – plant models

Figure 6: Presentation of paper [11].

as diverse automation, by using information technologies. Automation substitutes routine human work and noticeably increases efficiency. The article “An approach for processing and document flow automation for Microsoft Word and LibreOffice Writer file formats” [17] by Pavlo V. Zahorodko (figure 8) and Pavlo V. Merzlykin examines different approaches to document automation. Basic concepts of document processing using XML and existing solutions have been reviewed and a library based on LibreOffice UNO API has been designed and implemented.

Development of CRM system with a mobile application for a school

Nataliia Cheboksarova, Tetiana A. Vakaliuk
and Iurii Iefremov

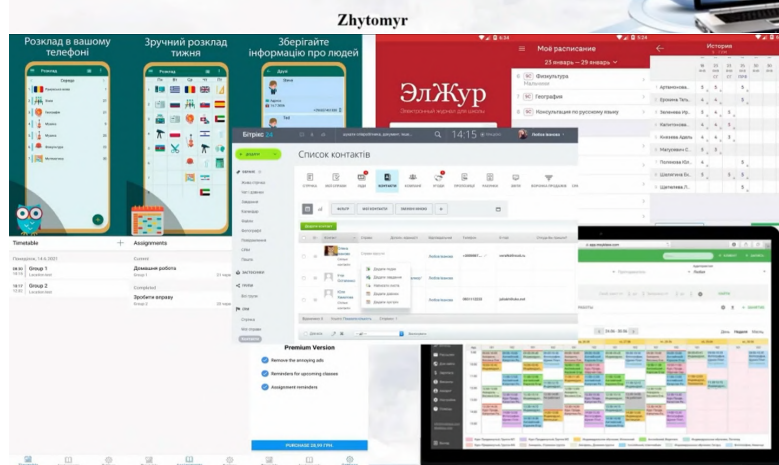


Diagram showing the architecture for Flutter & Firebase

BLOC pattern

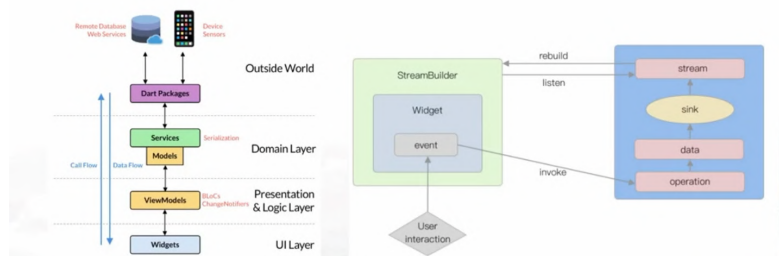


Figure 7: Presentation of paper [16].

The library contains different helpers, wrappers, and processing tools to create an additional layer of abstraction. Moreover, the library is aimed at simplifying processing, working, and converting documents, which might considerably optimize a process of creating document reports generators.

This article highlights further research by the authors, begun in [52, 53, 54, 55, 56, 57, 58].

The role of progressive web applications in students' educational activities is researched in the article "Design a progressive web application to support student learning" [18] by Svitlana

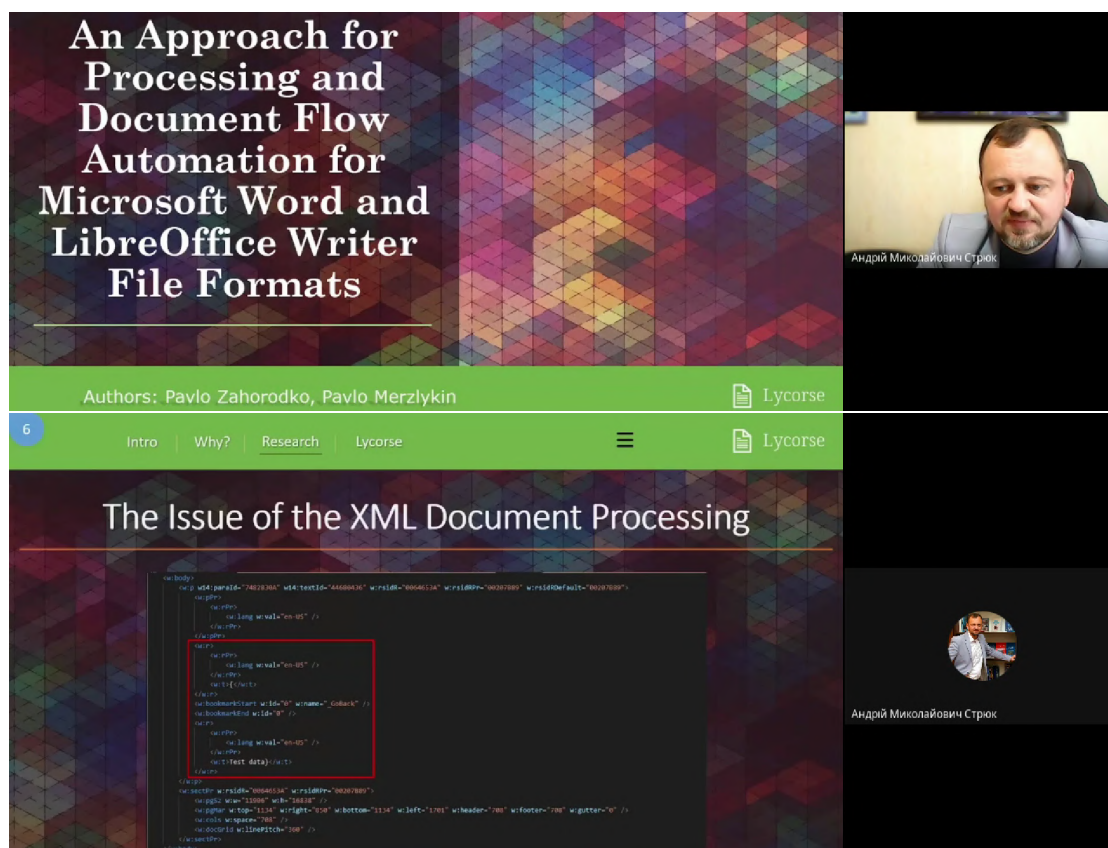


Figure 8: Presentation of paper [17].

O. Leshchuk, Yurii S. Ramskyi (figure 9), Anastasia V. Kotyk and Serhiy V. Kutsiy. Authors compare them with applied and hybrid programs; determine the features of PWA technology as well as analyze the architecture of progressive web applications. The study aim is to develop and implement the progressive web application that is an information portal of the Faculty of Physics and Mathematics Ternopil Volodymyr Hnatiuk national pedagogical university using PWA technology. To achieve this goal, the following required resources for the' training organization of student's activities have been selected. They are the schedule of the educational process, lessons schedule, schedule of modular and final controls, information on practice, schedule of final exams, regulatory and methodological software. On the first stages of work a website template was created in addition to information gathering. The next stages of practical implementation were aimed at the development of logic and implementation of PWA technology, namely defining the interface, adding a worker, creating auxiliary functions. The final stage of the study is the project deployment. The results obtained by the authors can be used in the process of higher specialists training in educational institutions. The web application itself is practical for organizing students' educational activities.

This article highlights further research by the authors, begun in [59, 60].

E-petition is a relatively new tool for expressing community demands and influencing on the

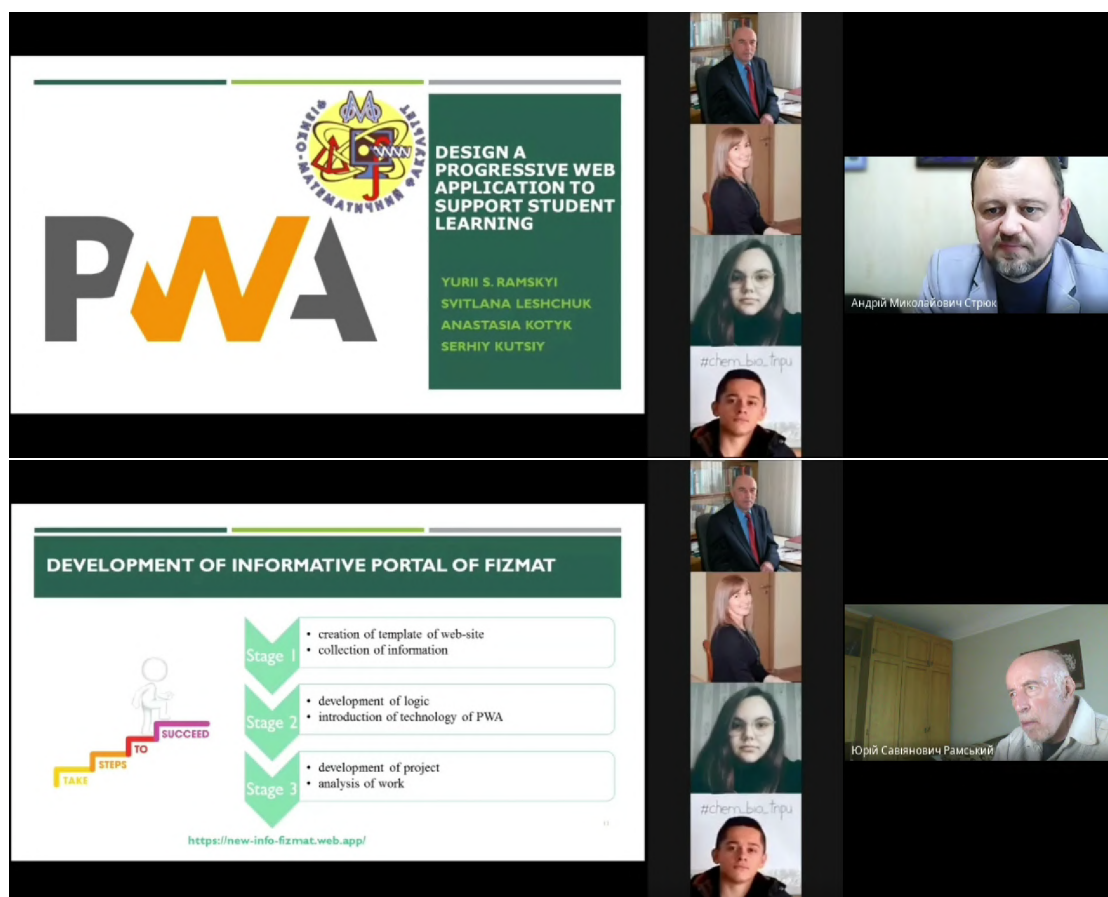


Figure 9: Presentation of paper [18].

legislative process. An issue of voting falsifications detection is rarely considered in e-petition analysis reports. Within research “Designing a software for digital forensic investigations of e-petitions voting falsifications” [19] by Ivan I. Kovalenko (figure 10) and Pavlo V. Merzlykin, an illegal petition falsification service has been examined and some methods of voting fabrication detection have been suggested and implemented in mobile app. To illustrate the discussed techniques, some suspicious activities regarding two popular petitions to the president of Ukraine were detected.

4.2. Theoretical computer science

Mathematical models building is widely used in different branches of human activity to describe statistical data obtained during observation of various phenomena. The main tool for this problem solution is approximation theory, especially ordinary least squares method. Basic goal during approximation is minimizing deviation between observed and estimated data. Analysis showed that providing given accuracy is possible based on usage of segmented regression models. Such models contain one or more switching points for segments connection. The

Designing a Software for Digital Forensic Investigations of E-Petitions Voting Falsifications

Ivan Kovalenko
Kryvyi Rih State Pedagogical University

ГО «Електронна демократія»

Аналітика першої електронної петиції

чи можна за графіком виявити накрутки?



Активіть з побудованим графіком та сторінка з петицією.

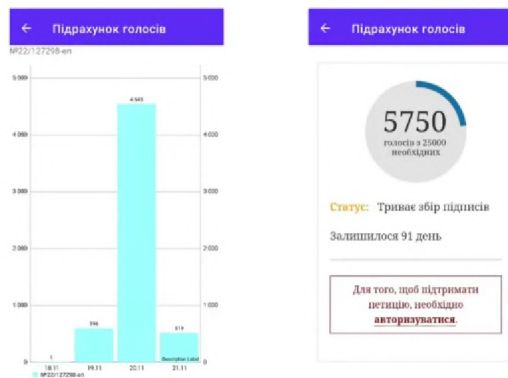


Figure 10: Presentation of paper [19].

article “New approach to switching points optimization for segmented regression during mathematical model building” [5] by Valeriyi M. Kuzmin, Maksym Yu. Zaliskyi (figure 11), Roman S. Odarchenko and Yuliia V. Petrova deals with a problem of calculation of optimal values of switching point abscissa for segmented regression. Analytical expression for segmented

regression was obtained using the Heaviside function. Switching point's determination is based on the usage of multidimensional optimization paraboloid. Paper presents the methodology for optimal segmented regression building. Simulation results and example of data processing proved increasing the accuracy of approximation in case of using the proposed methodology.

4th Workshop for Young Scientists in Computer Science Software Engineering

New Approach to Switching Points Optimization for Segmented Regression during Mathematical Model Building

Valeriy Kuzmin, National Aviation University, Kyiv, Ukraine
 Maksym Zalishkyi, National Aviation University, Kyiv, Ukraine
 Roman Odarchenko, National Aviation University, Kyiv, Ukraine
 Yuliia Petrova, National Aviation University, Kyiv, Ukraine

Kryvyi Rih, Ukraine, December 18, 2021

INTRODUCTION AND MOTIVATION

Fig. 1. Block diagram of maintenance system.

INTRODUCTION AND MOTIVATION

The one of the main motives to build mathematical models is:

- a greater understanding of researched phenomena,
- to analyze the object mathematically,
- to provide experimentation with model using simulation methods.

Application during radio equipment operation:

- detection of deterioration,
- predictive maintenance,
- RUL estimation,
- to prevent the failure.

Fig. 2. Technical condition deterioration (changepoint study).

METHODOLOGY

Step-by-step procedure

b) Segmented parabolic regression

$$f_2(X) = a_{0,2} + a_{1,2}X + a_{2,2}X^2 + \sum_{i=1}^r a_{i,2,2}(X - x_{sw,i})^2 h(X - x_{sw,i}) \quad (4)$$

In the case of two segments usage, functional dependence (4) contains one switching point and four unknown coefficients

$$f_2(X) = a_{0,2} + a_{1,2}X + a_{2,2}X^2 + a_{i,2,2}(X - x_{sw,i})^2 h(X - x_{sw,i})$$

$$\begin{pmatrix} a_{0,2} \\ a_{1,2} \\ a_{2,2} \\ a_{i,2,2} \end{pmatrix} = \begin{pmatrix} a & \sum_{i=1}^n x_i & \sum_{i=1}^n x_i^2 & \sum_{i=1}^n (x_i - x_{sw,i})^2 \\ \sum_{i=1}^n x_i & \sum_{i=1}^n x_i^2 & \sum_{i=1}^n x_i^3 & \sum_{i=1}^n x_i(x_i - x_{sw,i})^2 \\ \sum_{i=1}^n x_i^2 & \sum_{i=1}^n x_i^3 & \sum_{i=1}^n x_i^4 & \sum_{i=1}^n x_i^2(x_i - x_{sw,i})^2 \\ \sum_{i=1}^n (x_i - x_{sw,i})^2 & \sum_{i=1}^n x_i(x_i - x_{sw,i})^2 & \sum_{i=1}^n x_i^2(x_i - x_{sw,i})^2 & \sum_{i=1}^n (x_i - x_{sw,i})^3 \end{pmatrix} \begin{pmatrix} \sum_{i=1}^n y_i \\ \sum_{i=1}^n y_i x_i \\ \sum_{i=1}^n y_i x_i^2 \\ \sum_{i=1}^n y_i (x_i - x_{sw,i})^3 \end{pmatrix}$$

c) Segmented linear-parabolic regression

$$f_3(X) = a_{0,3} + a_{1,3}X + a_{2,3}X^2 p(X) + \sum_{i=1}^r a_{i,3,3}(X - x_{sw,i})^{p(i)+1} h(X - x_{sw,i}) \quad (5)$$

SIMULATION RESULTS AND NUMERICAL EXAMPLE

	$x_{sw1}=40$	$x_{sw1}=45$	$x_{sw1}=50$	$x_{sw1}=55$	$x_{sw1}=60$
$x_{sw1}=10$	72.179	63.561	57.41	56.026	59.484
$x_{sw1}=15$	62.257	53.526	48.362	49.261	55.562
$x_{sw1}=20$	56.561	49.227	46.246	49.677	57.516
$x_{sw1}=25$	58.777	53.585	52.425	56.532	63.941
$x_{sw1}=30$	66.45	62.128	61.318	64.713	70.661

For paraboloid types (7) and (8) following equations were obtained. These paraboloids are shown in Fig. 5 and Fig. 6, respectively.

$$z(x_{sw1}, x_{sw2}) = 364.893 - 6.635x_{sw1} - 10.012x_{sw2} + 0.111x_{sw1}^2 + 0.090x_{sw2}^2 + 0.047x_{sw1}x_{sw2}$$

$$z(x_{sw1}, x_{sw2}) = 317.416 - 4.261x_{sw1} - 9.062x_{sw2} + 0.111x_{sw1}^2 + 0.090x_{sw2}^2$$

Fig. 5. Obtained paraboloid (7).

Fig. 6. Obtained paraboloid (8).

Figure 11: Presentation of paper [5].

4.3. Computer systems

The article “Available parking places recognition system” [7] by Vitalii L. Levkivskiy (figure 12), Dmytro K. Marchuk, Nadiia M. Lobanchykova, Ihor A. Pilkevych and Dmytro I. Salamatov describes algorithms and methods of working of the available parking places recognition system by analyzing the flow of video data, coming from the city cameras. Search an available parking place is usually a significant problem in modern cities, which requires finding new information technologies, approaches to solve it. Therefore, the purpose of this work is to analyze existing solutions and finding new information technologies for the task of optimizing the parking process. In addition, the software implementation of the proposed algorithms and methods has been implemented. The system was developed with Python and PHP programming languages. With Python an algorithm for recognizing free spaces for car parking and a chatbot for Telegram were implemented. PHP was used for the developing of the content management system with MVC (Model-View-Controller) architectural pattern. MySQL was chosen as the database management system. Communication between the chatbot and the script for recognition is carried out using memory-resident NoSQL DBMS Redis. The implemented system allows drivers to search available parking places in the selected parking lot with a minimum of time, providing information via a Telegram chatbot. The system can be deployed on Apache2 webserver and Linux OS.



This article highlights further research by the authors, begun in [61, 62, 63, 64, 65].

Causes and solutions of the problem of free space lack on the system partition during exploitation of Windows (Vista/7/8/8.1/10) operating system are analyzed in the article “Research methods and tools for cleaning the system partition of Windows operating systems” [6] by Andrii P. Stupin (figure 13), Vitalii V. Bulatetskyi, Lesia V. Bulatetska, Tetiana O. Hryshanovych and Yuliia S. Pavlenko. Main objects of the file structure, system paths to them, their purpose and role in system partition space usage have been prospected. Some operating system settings that allow to manage relatively large system files and folders and adjust the amount of free space have also been explored. In the course of the research, a set of third-party software was used as an auxiliary tool to compare the cleaning efficiency of individual objects of the system partition and to form own cleaning methods. Commands sets for correct cleaning of such objects are offered. They can be used for writing batch files and scripts, which allows automating the system partition optimizing process in the future.

This article highlights further research by the authors, begun in [66].

4.4. Computer applications

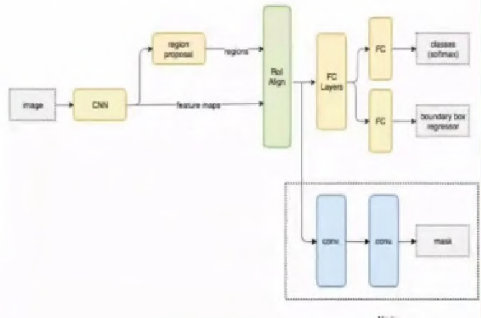
The usage of serious games with AI and immersive technologies in education is considered in the article “Game based learning with artificial intelligence and immersive technologies: an overview” [8] by Yulia Yu. Dyulicheva and Anastasia O. Glazieva (figure 14). Authors discussed the development of serious educational games with adaptability and personalization based on recognition of the images, human emotions, speech, and intelligent agents usage for the simulation of “being there” effect of a human opponent, and control of the complexity of game levels and game contents. Authors investigated some tools for teachers and students to allow the creation of the educational games based on AI and immersive technologies without

Available parking places recognition system

Vitalii Levkivskiy
Nadiia Lobanchykova
Dmytro Marchuk
Ihor Pilkevych
Dmytro Salamatov

Concept of Mask R-CNN



Mask of R-CNN represents a two-stage structure: at the first stage, an image is scanned, and regions are generated, which can contain an object. At the second stage, suggestions are classified, and bounding boxes and masks are created.

Figure 12: Presentation of paper [7].

programming skills existence: Aurora Neverwinter Nights toolset, eCraft2Learn tool with visual programming on Snap!, Scratch with AI abilities, Metaverse Studio for AR applications development with computer vision models using Google AI, CoSpaces Edu and EV Toolbox constructors for immersive apps.

This article highlights further research by the authors, begun in [67, 68].

Due to the similarity of the computational and probabilistic nature of quantum computing and machine learning, the idea arose to optimize the learning process using quantum methods. There are both fundamentally new algorithms, such as HHL, and quantum-improved ones: QPCA, QSVM. In the article “Classification problem solving using quantum machine learning mechanisms” [13], Alina O. Savchuk (figure 15) and Nonna N. Shapovalova are look at the QSVM algorithm step by step, starting from the basics described in section 2 and gradually delving into the composition of the algorithm. Thus, after the basics, authors considered the quantum phase estimation, which is part of the HHL algorithm, and then the QSVM algorithm, the component of which is the HHL. Authors also considered the QPCA algorithm, which



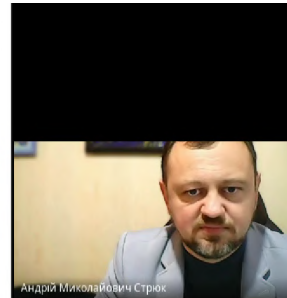
Research methods and tools for cleaning the system partition of Windows operating systems



Andrii P. Stupin, Vitalii V. Bulatetskyi, Lesia V. Bulatetska, Tetiana O. Hryshanovych and Yuliia S. Pavlenko



Lesya Ukrainka Volyn National University, Lutsk, Ukraine



Андрій Миколайович Струк



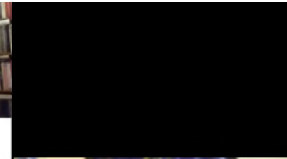
4

Installer

`%windir%\Installer` { `.msi, .msp` (files)
`.tmp-` (directories)

`get-wmiobject Win32_Product | Sort-Object -Property Name`
`| Format-Table IdentifyingNumber, Name, LocalPackage -AutoSize.`

`%windir%\Installer$PatchCache$` { The base versions of the directories



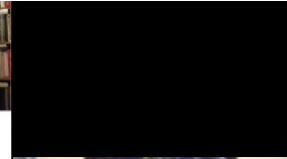
Андрій Миколайович Струк

15

Comparison of software for the system partition cleaning

Comparison of system partition cleaning and optimization software ((«-» – no such function, «satisfactorily» – insignificant cleaning, «good» – significant cleaning, «excellent» – almost complete cleaning.)


Object	Patch Cleaner	Driver Explorer	Store	DISM++	Wise Cleaner	Disk
Updates and fixes	-	-	-	good	-	excellent
Installer	good	-	-	satisfactorily	-	satisfactorily
WinSxS	-	-	-	excellent	-	satisfactorily
Devices Drivers	-	-	excellent	good	-	-
Temporary Files	-	-	-	excellent	-	good



Андрій Миколайович Струк

Figure 13: Presentation of paper [6].

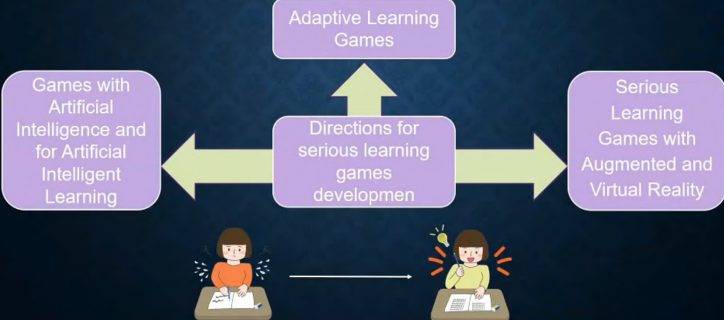
can be applied before the QSVM algorithm to reduce the dimension of the data sample. In this way, authors explore the fundamental difference between classical algorithms and their quantum counterparts. Authors also implement the QSVM method in practice and compare the obtained practical results with theory. As a result, they obtained high quality of accuracy (100 %)



GAME BASED LEARNING WITH ARTIFICIAL INTELLIGENCE AND IMMERSIVE TECHNOLOGIES: AN OVERVIEW

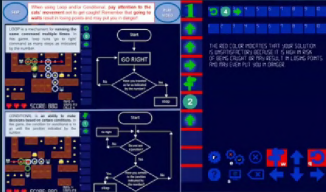
YULIA YU. DYULICHEVA, ANASTASIA O. GLAZIEVA

SERIOUS GAMES FOR EDUCATION AND USAGE OF MACHINE LEARNING

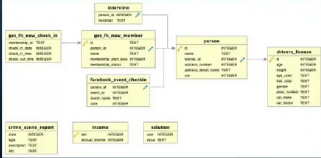


The diagram illustrates the development of serious learning games. At the center is a box labeled "Directions for serious learning games development". Three arrows point towards this central box from three surrounding boxes: "Adaptive Learning Games" (top), "Games with Artificial Intelligence and for Artificial Intelligent Learning" (left), and "Serious Learning Games with Augmented and Virtual Reality" (right). Below the central box, there are two cartoon illustrations of a person sitting at a desk, representing a learner or developer.

ADAPTIVE LEARNING GAMES




AutoThinking



SQL Murder Mystery

SERIOUS LEARNING GAMES WITH AUGMENTED AND VIRTUAL REALITY

Screenshot of the gaming environment showing the patient character and the virtual assistant with different postures to be performed.



Screenshot of the setup environment showing one patient trying to replicate the virtual assistant posture.




Figure 14: Presentation of paper [8].

compared to the classical SVM (83 %) on a data sample of dimension 72. However, authors found out that the learning time on a quantum device is far from ideal (it can reach 5 min for a sample of this size). The study aims to theoretically argue or disprove the hypothesis about the efficiency of quantum computing for machine learning algorithms. The object of research is the programming of quantum computers. The research subject is the study of quantum computing mechanisms for the implementation of machine learning problems. The research result is a software module that allows evaluating the efficiency of the classification task on a quantum computer. It also can be used to compare the results obtained from classical and quantum devices. Research methods: theoretical analysis of the foundations of quantum computing: principles of superposition and entanglement, linear algebra, probability theory over complex numbers; building a model of one qubit and multi-qubit system; research of quantum machine learning algorithms' work principles and their complexity; empirical comparison of quantum machine learning methods with their classical counterparts.

This article highlights further research by the authors, begun in [69, 70].

A system and method of automatic collection of objects in a room focused on the minimum energy consumption is proposed in the article "System and method of automatic collection of objects in the room" [9] by Mariia Yu. Tiahunova (figure 16), Halyna H. Kyrychek, Tetiana O. Bohatyrova and Daryna D. Moshynets. This result is achieved by the implementation of an improved method of automatic collection of items in the room and mathematical method for calculating the desired motion trajectory; development and implementation of algorithms that implement the proposed method; software and hardware implementation of the system for automatic collection of items with minimal energy consumption, including the small number of system components and an improved movement trajectory. The system's main component is the Arduino Uno, which acts as a controller. The developed software makes it possible to evaluate the implemented method's effectiveness in a real-life system. An application example of the proposed method is given.

This article highlights further research by the authors, begun in [71].

The article "Methodology for control of helicopters aircraft engines technical state in flight modes using neural networks" [12] by Serhii I. Vladov (figure 17), Yuri M. Shmelov and Ruslan P. Yakovliev is devoted to the development of a methodology for control of helicopters aircraft engines technical state using recurrent neural networks, which, unlike other types of neural networks, have a more optimal method for training a neural network, and also after training allows you to get a lower percentage of errors in comparison with a convolutional neural network and multilayer perceptron. A mathematical description of the methodology for control of helicopters aircraft engines technical state in flight mode with the use of neural networks, which is based on the numerical solution of a discrete optimal control problem, has been implemented. The quality of the trained neural network is assessed, including the calculation of the testing error, which is no more than 1.2 % of the deviation from the a priori correct result on the vectors of the test set of sets. With an allowable value of 2 %, this allows to speak about the efficiency of the method.

The perspectives of application of machine learning, especially, decision trees, random forest and deep learning for educational data mining problem solving, and learning analytics tools development are considered in the article "Learning analytics of MOOCs based on natural language processing" [10] by Yulia Yu. Dyulichева and Elizaveta A. Bilashova (figure 18) .



Розв'язування задач класифікації за допомогою механізмів квантового машинного навчання

Савчук Аліна Олегівна

18 грудня 2021

Порівняння результатів виконання на симуляторі на пристрої belem

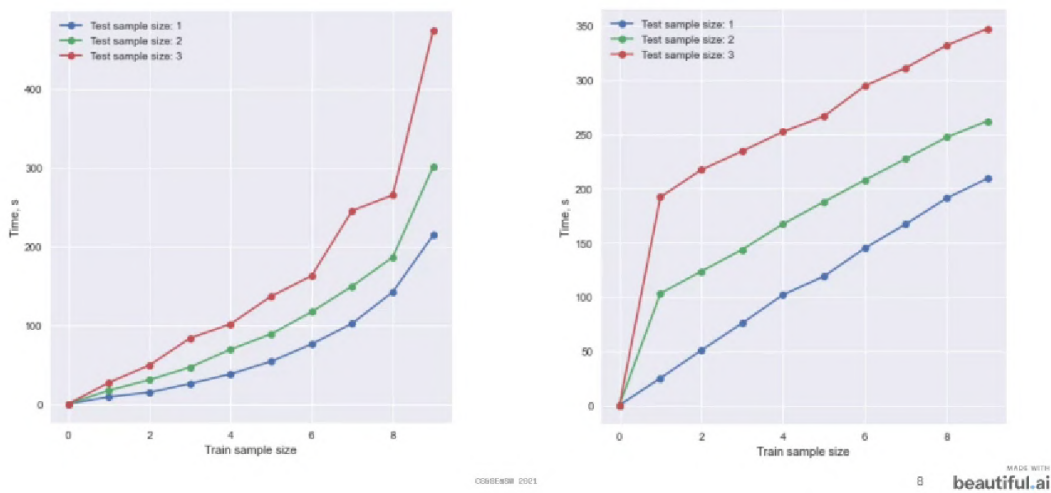
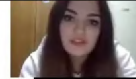


Figure 15: Presentation of paper [13].

The abilities of sentiment analysis with BERT deep model, clustering based on kMeans with the different approaches to the text vectorization are investigated for the development of learning analytics tools on the example of the learning analytics of some programming MOOCs from Udemy. Authors analyze 300 titles of MOOCs and proposed their clustering for better understanding the directions of learning and skills, and 1150 sentences that contain the word “teacher” or its synonyms and 2365 sentences about the course for sentiments detection of students and top of words that describe opinions with positive and negative polarities and the issues during learning.

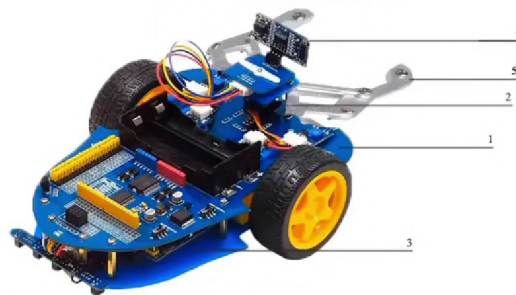
Facial recognition technology is named one of the main trends of recent years. It’s wide range of applications, such as access control, biometrics, video surveillance and many other interactive human-machine systems. Facial landmarks can be described as key characteristics of the human face. Commonly found landmarks are, for example, eyes, nose or mouth corners. Analyzing these key points is useful for a variety of computer vision use cases, including biometrics,



System and method of automatic collection of objects in the room

MARIIA TIAHUNOVA, HALYNA KYRYCHEK, TETIANA
BOHATYROVA AND DARYNA MOSHYNETS
NATIONAL UNIVERSITY "ZAPORIZHZHIA POLYTECHNIC",
ZHUKOVSKY STR., 64, ZAPORIZHZHIA, 69063, UKRAINE

System structure



- 1 - Alfabot double-deck robotic platform
- 2 - MG995R servo motor is used for automatic remote control of the claws
- 3 - Arduino Uno board
- 4 - HC-SR04 ultrasonic sensor
- 5 - Claws

Connections to the Arduino board

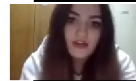
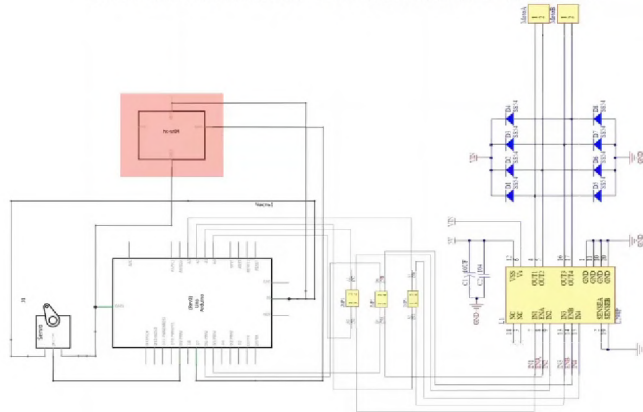


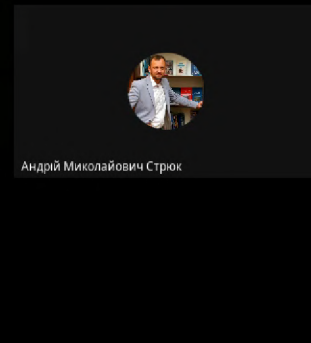
Figure 16: Presentation of paper [9].

**KHARKIV NATIONAL UNIVERSITY OF INTERNAL AFFAIRS
KREMENCHUK FLIGHT COLLEGE**

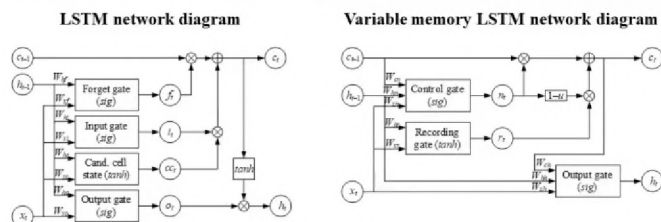


Methodology for Control of Helicopters Aircraft Engines Technical State in Flight Modes Using Neural Networks

by Serhii Vladov, Yurii Shmelov and Ruslan Yakovliev



LSTM STRUCTURE RECURRENT NEURAL NETWORK MODIFICATION



The modified LSTM network contains three nodes – control node (*Control gate*), a recording node (*Recording gate*) and an output node (*Output gate*). To calculate the memory tensor, two of them are used – control and recording nodes:

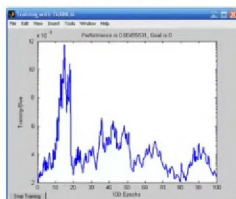
$$c_t = n_t \circ c_{t-1} + (1 - n_t) \circ r_t$$

The main difference between the proposed network architecture is the use of network memory in the output node:

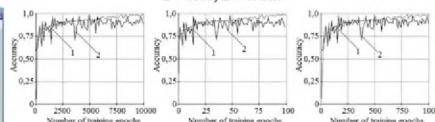
$$h_t = \sigma(W_{ch} \cdot c_t + W_{hh} \cdot h_{t-1} + W_{xh} \cdot x_t + b_h)$$

FORMATION OF TRAINING AND TEST SUBSETS

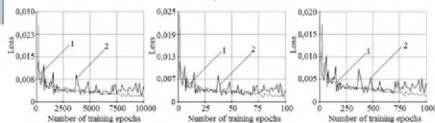
Neural network training results graph



Model training results in terms of the Accuracy indicator:
1 – test; 2 – train



Model training results in terms of the Loss indicator:
1 – test; 2 – train



Average values of neural network testing indicators

Accuracy	F-measure	Precision	Recall	Average time, s	Average Accuracy	Dispersion Accuracy
0.98867	0.97234	0.94617	1.0	1204.12	0.99011	0.0000085



Figure 17: Presentation of paper [12].

Learning Analytics of MOOCs based on Natural Language Processing

Yulia Yu. Dyulicheva, Elizaveta A. Bilashova

Educational Data Mining is considered as a methodology for mining regularities from big educational data that are gathered in educational environments. Learning Analytics is aimed at tools development for analyzing and optimization learning. The following purposes are stated in the paper

- studying the effectiveness of the machine learning algorithms application for solving learning analytics problems;
- the development of the learning analytics tool for extracting the regularities from some programming language MOOCs using python libraries.

Figure 18: Presentation of paper [10].

face tracking, or emotion detection. Different methods produce different facial landmarks. Some methods use only basic facial landmarks, while others bring out more detail. Elena Yu. Tarasova (figure 19) and Iryna S. Mintii use 68 facial markup, which is a common format for many datasets. Cloud computing creates all the necessary conditions for the successful implementation of even the most complex tasks. Authors created a web application using the Django framework, Python language, OpenCV and Dlib libraries to recognize faces in the image. The purpose of the article “Web application for facial wrinkle recognition” [14] is to create a software system for face recognition in the photo and identify wrinkles on the face. The algorithm for determining the presence and location of various types of wrinkles and determining their geometric determination on the face is programmed.

This article highlights further research by the authors, begun in [72, 73, 74, 75, 76, 77, 78].

5. CS&SE@SW 2021: Conclusion and outlook

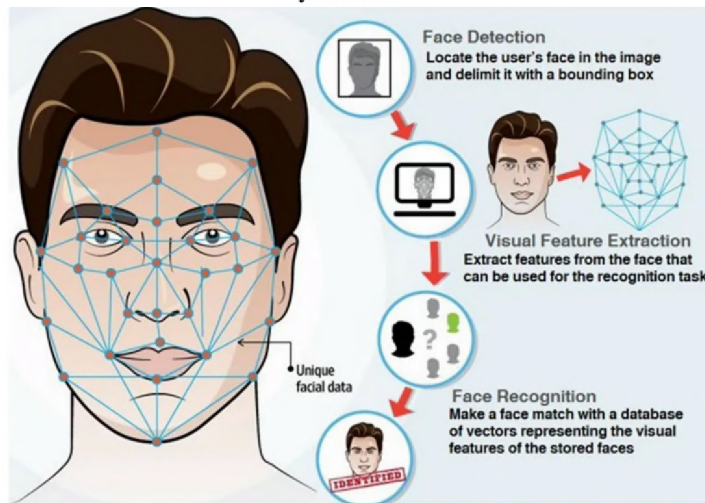
The vision of the CS&SE@SW 2021 is provides an expert environment for young researchers, who are at the beginning of their career, to present and discuss the most recent of ideas and early results of research projects. Young researchers, who will join us to take part in discussions and/or present their papers, will be offered an opportunity to exchange and discuss their research ideas with their peers, supervisors, and senior scientists working in the fields that are within the scope of CS&SE@SW.

The fourth installment of CS&SE@SW was organized by Kryvyi Rih National University, Ukraine (with support of the rector Mykola I. Stupnik) in collaboration with Kryvyi Rih State Pedagogical University, Ukraine (with support of the rector Yaroslav V. Shramko), Institute of Information Technologies and Learning Tools of the NAES of Ukraine (with support of the director Valeriy Yu. Bykov), University of Educational Management (with support of the

Web application for facial wrinkle recognition



Olena Tarasova (speaker)
Iryna Mintii



3

OpenCV Overview: > 500 functions
opencv.willowgarage.com

Robot support

- General Image Processing Functions
- Image Pyramids
- Geometric descriptors
- Segmentation
- Camera calibration, Stereo, 3D
- Features
- Utilities and Data Structures
- Tracking
- Machine Learning:
 - Detection
 - Recognition
- Fitting
- Matrix Math

5

Figure 19: Presentation of paper [14].

vice-rector for research and digitalization Oleg M. Spirin) and Ben-Gurion University of the Negev, Israel (with support of the rector Chaim J. Hames).

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We hope you enjoy this workshop and meet again in more friendly, hilarious, and happiness of further CS&SE@SW 2022 at Kryvyi Rih, Ukraine on December 16, 2022.

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How to become a professional DevOps

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Abstract

An important part of the EPAM university program is the training of DevOps specialists. This is primarily due to the high demand for these specialists both inside and outside EPAM. DevOps specialists act as integrators of two closely interrelated areas of companies' activities: development and operation. Developer roles are primarily application development/modification; try new technologies. Operations roles: build, deploy, and release; performance and availability; create or improve services.

From planning through delivery, the goal of DevOps is to improve collaboration across the value stream by developing and automating a continuous delivery pipeline. In going so, DevOps: increases the frequency and quality of deployments; improves innovation and risk-taking by making it safer to experiment; realizes faster time to market; improves solution quality and shortens the lead time for fixes; reduces the severity and frequency of release failures; improves the Mean Time to Recovery (MTTR).

Common DevOps responsibilities: application and infrastructure planning, testing and development; maintaining CI/CD pipelines; automation implementation; on-call, incident response and incident management; monitoring.

Common DevOps roles: integration engineer; cloud specialist; automation Engineer; release Engineer; security Engineer.

Main areas of knowledge for DevOps and examples: programming languages (Bash, Python, Groovy, PowerShell, Ruby, Go); Operation Systems (Linux, Windows); Version Control System (Git); Cloud computing (AWS, Google, Azure); Containerization (Docker, Kubernetes); Infrastructure as code (Ansible, Chef, Puppet, SaltStack); CI/CD (Jenkins, Bamboo, TeamCity); Test Automation (Selenium, Apache JMeter).

A detailed analysis of the requirements for DevOps specialists allowed us to develop a DevOps External program. Training in this program allows you to quickly prepare specialists of the Junior level.

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 CEUR Workshop Proceedings (CEUR-WS.org)

Effective participation in programming contests

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Abstract

Hackathons are one of the most popular ways to organize competitions between programmers. Usually, during a hackathon, teams are offered a task, for the solution of which a certain time is allocated, for example, a day. As a solution, the team must develop an application. The jury evaluates its functionality, originality, creativity of the approach to the solution.

Hackaton is an ideal place to test your programming strength; solid platform for launching and testing startups; effective way to get job offer; also good place to have fun.

The experience of multiple participation in various competitions allowed us to summarize the main conditions for successful participation.

The first such condition is the correct formation of the team. The team should have specialists in various fields who are ready to take on different roles, for example, front-end or back-end. At the same time, the amount of work between different developer roles is not uniform. For example, working on a frontend application requires more time and effort throughout the entire task process. Therefore, it would be advisable to strengthen the team with an additional front-end developer or full-stack developer who can change his role in the course of solving the problem. It is desirable that one of the frontend developers is a good designer. It is also advisable to include in the team a specialist in the application area for which the application is being developed.

The second condition is a thorough preliminary technical preparation: creating generic solutions; creating repositories; server rental; preparing presentation.

The third condition: rational distribution of time. It is advisable to make the generation and selection of ideas as the first stage of development. Brainstorming is a good way to do this. You can allocate 1-2 hours for it. Then stop at the best idea and focus on its implementation.

An important intermediate stage should be the selection and systematization of all the functionality of the future program.

In the process of developing a program, it is important to run side quests from time to time. For example, it might be a short questionnaire describing a project and asking you to rate it. The questionnaire form can be sent to friends, acquaintances, and get feedback from them. The presentation of these statistics will help not only improve the program, but also get additional points from the jury.

It should also be remembered that participation in hackathons is associated with strong emotional stress. An important condition is constant communication between team members, voicing problems that have arisen, etc. You should also remember to rest, especially before the final stage - the presentation of the solution.

Much depends on the quality of the presentation, its completeness, brevity and, of course, positive tone.

And remember that the end of the event does not mean the end of the work. It is imperative to analyze the work done, to note the positive and negative points in order to take into account the experience gained in further work and new competitions.

CS&SE@SW 2021: 4th Workshop for Young Scientists in Computer Science & Software Engineering, December 18, 2021, Kryvyi Rih, Ukraine


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 CEUR Workshop Proceedings (CEUR-WS.org)

Software requirements engineering training: problematic questions

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Abstract

The key problems of training Requirement Engineering and the following ways to overcome the contradiction between the crucial role of Requirement Engineering in industrial software development and insufficient motivation to master it in the process of Software Engineering specialists professional training were identified based on a systematic research analysis on the formation of the ability of future software engineers to identify, classify and formulate software requirements: use of activity and constructivist approaches, game teaching methods in the process of modeling requirements; active involvement of stakeholders in identifying, formulating and verifying requirements at the beginning of the project and evaluating its results at the end; application of mobile technologies for training of geographically distributed work with requirements; implementation of interdisciplinary cross-cutting Software Engineering projects; involvement of students in real projects; stimulating the creation of interdisciplinary and age-old student project teams.

Keywords

software requirements, software engineering training, software engineer competencies

1. Introduction

The first course in Software Engineering was developed under the guidance of Friedrich Ludwig Bauer [1, 2], it contained only a brief overview of the process of determining the requirements for the software product such as functions, user needs and operating environment requirements.

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Just as 50 years ago, defining software system requirements is the first step in development which largely ensures its success.

Recommendations for the development of curricula for Software Engineering bachelors define the competence to find compromises, the essence of which is to reconcile conflicting project goals, find acceptable trade-offs for cost, time, knowledge, existing systems and organizations: “Students should engage in exercises that expose them to conflicting and changing requirements. ... Curriculum units should address these issues, with the aim of ensuring high-quality functional and nonfunctional requirements and a feasible software design.” [3, p. 21].

Requirements engineering is the process of identifying, formalizing and documenting requirements, that occurs during communication with a customer and other stakeholders who are not typically proficient in software engineering techniques. The identification of requirements demand from the Software Engineering specialist to apply the following general professional competencies [4]:

- ability to think abstractly, analyze and synthesize;
- ability to apply knowledge in practical situations;
- ability to communicate orally and in writing;
- ability to search, process and analyze information from various sources;
- ability to work in a team;
- ability to act socially responsible and conscious.

The formation and development of these competencies takes place in teaching of disciplines that do not belong to the professionally oriented, which reduces the attention of students to their study. At the same time, software requirements engineering is perceived as an unimportant course, which is not directly related to the activities that novice students associate with Software Engineering, especially with the creation of software code.

The solution to this problem is possible by developing a practice-oriented methodology for training engineering requirements based on an activity approach aimed at overcoming *the contradiction between the decisive role of requirements engineering in the practice of large software projects industrial development and insufficient motivation to acquire essential knowledge in the process of software engineers professional training.*

2. Results

The guidelines for the development of undergraduate programs in Software Engineering (“Software Engineering 2014” [3]) state that the requirements reflect the real needs of users, customers and other stakeholders associated with the system being developed. Defining requirements includes identifying and analyzing the needs of stakeholders and creating an appropriate description of the desired behavior and qualities of the system, as well as relevant limitations and assumptions.

“Computing Curricula 2020” [5, p. 120] identifies the following competencies for defining software requirements:

1. Identify and document software requirements by applying a known requirements elicitation technique in work sessions with stakeholders, using facilitative skills, as a contributing member of a requirements team.
2. Analyze software requirements for consistency, completeness, and feasibility, and recommend improved requirements documentation, as a contributing member of a requirements team.
3. Specify software requirements using standard specification formats and languages that have been selected for the project and be able to describe the requirements in an understandable way to non-experts such as end-users, other stakeholders, or administrative managers, as a contributing member of a requirements team.
4. Verify and validate the requirements using standard techniques, including inspection, modeling, prototyping, and test case development, as a contributing member of a requirements team.
5. Follow process and product management procedures that have been identified for the project, as a contributing member of the requirements engineering team.

Sedelmaier and Landes [6] indicate that requirements engineering is a major component of Software Engineering, but it is difficult to train. In training, Software Engineering is usually limited to small “toy” projects that only partially reflect real tasks. There are several reasons for this.

1. At the initial stage of training in Software Engineering specialists, there is a *bias towards programming training*, rather than the identification, classification and formulation of software requirements. Typically, programming tasks are small and well-defined: students develop simple software components, often in small groups or individually, with assignments focused on a specific task that demonstrates, for example, the use of loops, arrays, or algorithms related to their processing. That is, software development tasks mainly focus on the technical aspects of programming and specific programming languages in an area that is familiar to students.
2. As a result, the teacher provides clearly defined and understandable requirements in this area without the use of unfamiliar terminology or unusual concepts, which gives students a misconception that they do not need to worry about the requirements because they *incorrectly summarize their initial programming experience in software development projects*: there is no such thing as vague requirements for stakeholders who use unfamiliar terminology because students have never encountered them. This information is often not readily available, and should be obtained from a number of relevant stakeholders, who are often difficult to identify and who do not cooperate. Students underestimate the importance of requirements engineering because its methods do not help to better solve programming problems. In addition, programming tasks are usually separate and unrelated to other tasks. Even if there is more than one possible way to solve the problem, the chosen approach will not have consequences for the following tasks: students do not need to compare the advantages and disadvantages of alternative solutions, as they will not suffer from the consequences of error, which means it doesn't matter if the requirements are wrong or not.

3. Often students cannot even imagine the problems in Software Engineering that arise due to errors in defining requirements, and do not trust teachers-practitioners, believing that they are exaggerating them. Methods for determining requirements seem boring and useless to them, because *students mostly don't know why they need them*.
4. In the later stages of Software Engineering training, even when the programming bias is shifted to Software Engineering, in particular requirements engineering, the situation remains problematic: due to time constraints *the complexity of real problems can hardly be reproduced in university education*, so students do not perceive interdependence between requirements, mistakenly believing that complexity scales linearly, while increasing the number of requirements exponentially increases the interdependence between them.

Given the limited training time for Software Engineering specialists, it is difficult to create conditions for students that reflect the real problems of requirements engineering: due to the lack of real customers, students cannot imagine the complexity and relationship between requirements within a large Software Engineering project.

Ouhbi et al. [7] formulate recommendations for teachers on the formation of the ability to identify, classify and formulate software requirements:

1. Learn to identify the scope of the problem, avoid general and vague specifications. To do this, teachers should take into account the individual characteristics of students, which can be determined, in particular, by questionnaires. This gives teachers the opportunity to form teams that demonstrate the best results. Acuña et al. [8] have shown a significant positive correlation between personality extraversion factor and software product quality, including requirement satisfaction.
2. Teach to choose and use appropriate requirements engineering tools: students must know the capabilities of modern tools and be able to choose the best tool for the project according to its needs – isolation of requirements, analysis of requirements, specification of requirements, verification and confirmation of requirements, requirements management.
3. Facilitate requirements analysis and modeling activities in addition to requirements management and implement the concept of prototyping in learning: through prototyping, a working model of a software product can be created before the final product is implemented, and prototypes presented to stakeholders are very effective for clarifying the requirements.
4. Involve students in real projects to give them the opportunity to acquire sufficient knowledge and skills. It is also advisable to invite practitioners to present real projects and gained experience.
5. Develop the abilities, skills, and strategies needed to align engineering requirements with modern conditions of geographically distributed (global) software development [9].
6. Teach students an approach to solve problems, methods and tools of development. Students do not understand the importance of activities to determine the requirements and their impact on the success or failure of projects in the lecture-laboratory form of requirements engineering training. Teachers are encouraged to use alternative forms of learning, such as games.
7. Use mobile devices as learning tools in a mobile learning environment: students can share a virtual board, e-textbooks and exchange data through a network environment

to actively participate in course discussions. These devices help to intensify student's educational and cognitive activities [10].

Mich [11] points out the contradiction between the importance of requirements isolation activities for industrial projects and the lack of student motivation to learn requirements isolation due to their lack or little experience in the field and the corresponding disregard for business requirements, focusing on modeling requirements with a bias in detail instead of a preliminary global review of the project, analysis of requirements for the implementation of "toy" projects instead of industrial, non-involvement of stakeholders at the stages of problem statement and evaluation of student performance, etc.

To overcome the isolated contradictions, Mich [11] suggests using CASE tools to support modeling using UML and provides recommendations for reducing the risks of requirements modeling in a hurry due to the desire of students to start modeling requirements, even if business analysis and requirements detection is just beginning. The researcher developed a template for a student project aimed at:

- demonstration the role of computer systems in solving business problems or developing business strategies;
- integration of organizational issues into problem analysis to answer questions such as "Who should collaborate to collect the data needed to develop the system?";
- understanding the role of requirements analysis in the system development process, including contractual implications;
- detection and management of conflicting requirements;
- use of UML from the very first step of requirements modeling, also for business processes and subjects;
- documenting requirements as project specifications and their confirmation.

Mich [11] points out that thanks to the developed template, projects become more and more connected with real organizations or companies. Initially, companies participated little in the projects, through the initial representation of the company by its representative and the final presentation of the results by students. Later, more and more interviews were conducted with stakeholders representing real organizations.

Goswami and Walia [12] emphasize that requirements development is one of the earliest and most important phases of a software development lifecycle. This is a critical phase when program requirements are collected from a variety of stakeholders (both technical and non-technical) and described in natural language in an official document known as the software requirements specification. Due to the ambiguity, inaccuracy and uncertainty of the natural language, errors are often made during the development of the specification. Therefore, the focus should be on identifying and correcting inconsistencies in the early stages of the software development lifecycle to avoid unnecessary effort and cost of software processing in the later stages. To do this, researchers suggest using software assessment (inspection, survey) methods when qualified professionals review documentation, code, and other project artifacts to identify and report problems. Such inspection is a systematic method of detailed study of software artifacts. The study confirmed the benefits of verifying artifacts developed at different stages of software development (e.g. requirements, design, code, interfaces). The main stages of inspection are:

a) selection of qualified inspectors; b) individual examination to identify problems; c) team meeting to systematize problems and d) further actions to eliminate them.

Ozkaya et al. [13] offer two half-semester mini-courses for students majoring in architecture and construction.

The purpose of the first mini-course “Software Requirement Modeling” is to review the methods of modeling software requirements and to demonstrate with the help of modeling requirements strategies for solving problems in software development. Requirements modeling helps engineers (not only software engineers) to better understand the task, reveals the essence of the relationships that characterize it. Researchers emphasize that this is a significantly different approach than considering the functionality of the final product. For specific engineering tasks, such as building a geometric representation of information models, designing communication programs for mobile devices or building data models for different stages in design, the engineer must not only identify the requirements for the software being developed, but also understand the requirements of the engineering industry for which it is being developed. In other words, customer expectations and needs must be systematically modeled for better design of software solutions.

The content of the first mini-course is purposefully focused on the development of software for automated architectural and engineering design. It offers a study of several methods for identifying requirements and ways to obtain basic information that will help in software development. The application of the discussed methods of determining the requirements for the software project should take place with the participation of stakeholders: some real stakeholders, usually with customers. Upon completion of the first mini-course, students acquire the ability to develop a prototype of the designed system and specification of software requirements.

The program results of the proposed course are:

- ability to correctly use basic terminology for identifying and specifying software requirements;
- ability to choose different data collection methods to identify software requirements;
- ability to distinguish types of requirements and classify relevant information;
- ability to document requirements in various forms;
- ability to use information about software requirements to improve design;
- ability to evaluate different methods of identifying requirements and develop strategies for selecting the most appropriate [13, p. 5].

The purpose of the second mini-course “Software Requirement Application” is to teach the application of certain requirements to solve practical problems. Researchers point out that it is not enough to just define software requirements, typically in design, requirements relate to the context in which the problem is solved. The designer produces various drawings, notes and diagrams as part of the solution aimed to meet these requirements. The step of transforming requirements into a project is crucial, and mistakes made in processing of requirements during the design become a source of many software projects failure.

The program results of the second mini-course are:

- ability to build charts, in particular UML, to represent requirements;

- ability to use needs management in the software development life cycle;
- ability to choose software development method suitable for managing specified requirements;
- ability to apply methods of validation, verification and tracking of requirements;
- ability to develop strategies for transferring information about needs to high-level design [13, pp. 6-7].

The program results of the “Software Modeling” course, developed by Sedelmaier and Landes [6], are:

- deepening the understanding of the term “requirements” and their role in software development;
- ability to use specification of functional and non-functional requirements methods and determination of their priorities;
- understanding the role of communication with other parties involved in the development of requirements;
- understanding the role of business processes as a source of requirements;
- ability to jointly apply appropriate methods and designations to determine the requirements for software product example;
- ability to use methods to assess the complexity and cost of software systems.

The objectives of the “Software Modeling” course are:

- 1) forming student understanding of the role and importance of requirements for their future careers – students must know the problems of requirements development, recognize their importance and difficulties in their formation; students must be able to extract requirements from future users, model business processes and create documents with requirements;
- 2) improvement of specific communication skills demanded for requirements development – students must be able to meet with customers for identify requirements that they did not invent themselves, but formulated in collaboration with a real customer, learn to ask customers about information that can be the basis for requirements, document requirements, assign roles, etc.;
- 3) strengthening self-reflection, self-organization and responsibility of students as a basis for development of appropriate competence.

The learning environment for such course is proposed by Sedelmaier and Landes [6] on the basis of a constructivist approach, in which teachers act as trainers, creating conditions for students to gain individual learning experience. Without determining the special ability to identify, classify and formulate software requirements, the researchers highlight following 4 groups of competencies necessary for the formation of such ability [6]:

- 1) problem awareness: knowledge of the subject area, ability to abstract;
- 2) context sensitivity: ability to moderate and present, meet with customers, integrate into a team, empathy, endurance;
- 3) personal competencies: methods of work, self-organization, role distribution, time management, personal involvement, purposefulness, ability to self-reflection;

4) creativity, variety of techniques.

The main components of the approach proposed in [6] are the broad, active student participation in learning and a realistic, integrated environment, which includes writing a document with requirements for a complex project and extracting requirements from real clients, as they play a dual role in addition to the source of requirements, they also act as external communication experts.

3. Conclusions

1. An overview of the sources on the research problem show the commonality of problems in teaching requirement engineering of future Software Engineering specialists:
 - student lack of understanding of the importance of requirement engineering due to insufficient experience in working with real customers;
 - insufficient attention to the process of identifying interrelated requirements in communication with stakeholders who do not interact with each other;
 - bias in learning languages and means of modeling requirements, in which their detailing precedes detection;
 - high clarity of requirements for training projects with Software Engineering in comparison with real ones;
 - nonlinear dependence of the software project complexity on the growth of the number of requirements.
2. The ways to overcome these problems in teaching requirement engineering for training Software Engineering specialists:
 - use of activity and constructivist approaches, game teaching methods in the process of modeling requirements;
 - active involvement of stakeholders in identifying, formulating and verifying requirements at the beginning of the project and evaluating its results at the end;
 - application of mobile technologies for training of geographically distributed work with requirements;
 - implementation of interdisciplinary cross-cutting Software Engineering projects;
 - involvement of students in real projects;
 - stimulating the creation of interdisciplinary and age-old student project teams.

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Development of a simulator to determine personal financial strategies using machine learning

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Abstract

Personal finances are the own capital of an individual or family, which he manages independently. Personal finance management includes the ability to manage them, which requires separate training. The purpose of this work is to develop the mechanics of a personal finance simulator and build a system for determining personal financial strategies using machine learning. The development of a personal finance management simulator will allow in the future using it to teach the elements of managing such finances, even at school age. The developed software package consists of two parts: a personal finance management simulator and a system for determining financial strategies, which uses reinforced learning opportunities. The direction of future research is the integration of the recommendation system into the web application of the simulator. In addition, to improve the system and give flexibility in recommendations that could be adjusted to the current financial condition of the participant, it is necessary to pay attention to the use of “policy-based” methods of training with reinforcement, which are widely used in autopilot training systems for cars. Just as an autopilot cannot predict what may happen on the road in a second, can a person predict neither unexpected expenses nor profits (which is rare, but can happen).

Keywords

personal finance, simulator, business simulator, machine learning, development

1. Introduction

More and more questions and problems related to finances are becoming relevant for everyone. Therefore, it is very important not only to be aware of the latest economic and market developments but also to be competent in the ability to manage personal finances.

Personal finances are the own capital of an individual or family, which he manages independently. Personal finance management includes the ability to manage them, which requires separate training [1].

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Personal finance management and planning has a wide range of approaches discussed in scientific and applied sources worldwide. Traditionally the problem is studied within the prism of efficient and safe personal fund liquidity management. Kaplan and Violante [2] discuss so-called “hand-to-mouth” consumption as the challenge to solve with improving personal finance competence while designing fiscal stimulus payments. The evidence of the importance of conscious management of personal finance was the found and highlighted with extensive data analysis in the study of Olafsson and Pagel [3].

Behavioral finance approaches are getting popular in analyzing and consulting personal financial habits and management. The comprehensive study on the publications in the field of behavioral economics and behavioral finance highlights high interest and publication activity in the field, while concluding that despite behavioral finance has the higher publication activity and a broader network of authors, it concentrates on the definition of theoretical problems and pays less attention to finding solutions [4].

Application of the ICT to study, visualize and develop personal finance management is a reasonable and inevitable movement revealing itself in the modern digitalized and computerized world. The use of business simulations in higher education establishments highlights the effectiveness and efficiency of this active learning method to support traditional educational methods [5]. More sophisticated approaches of the use of artificial intelligence to employ behavioral finance apparatus in investment banking, back-end, and client-facing operations are being studied now. Königstorfer and Thalmann [6] conducted a structured literature review of the examples of the productive application of AI and behavioral finance to bank operations as well as the challenges to it.

The problem of development immersive, realistic, and ML-enabled educational simulation in the area of private finance competency development is not sufficiently developed and described. This work aims to contribute to this field of theoretical study and practical application.

The purpose of this work is to develop the mechanics of a personal finance simulator and build a system for determining effective personal financial strategies using machine learning. The methods of web programming, object-oriented programming, machine learning, analysis of scientific and scientific-practical publications, experimental analysis were used in the work.

The development of a personal finance management simulator will allow in the future to use it to teach the elements of such financial management, even at school age [1].

2. Results

Proper management of personal finances requires separate training. Therefore, in this work, it is necessary to develop a simulator that will allow users to develop skills in personal finance management.

Also in this work, it is necessary to develop a system for determining effective strategies for the development of the developed simulator. Performing this task and integrating such a system into a simulator would make it possible to give tips to users who could form in users an idea of how to better manage their finances.

To achieve this goal, the following tasks have been identified that relate to the functionality of the simulator:

1. *Develop a home page.* The page should contain the title and description of the simulation. To start the simulation, the user must enter the following data:

- country;
- currency, which will be considered the main currency of the user and cannot be changed during the simulation;
- approximate salary and average monthly expenses.

The user must be able to enable or disable the “assessment mode”. The user must be able to start the simulation.

2. *Develop a simulation page.* This page should contain the following information/features:

- data on salary and average monthly expenses indicated by the user on the home page;
- the possibility of moving to the next week of the simulation;
- the possibility of moving to the next month of the simulation;
- the ability to stop the simulation and return to the home page;
- information on user rewards by categories of savings and deposits (this information should be displayed for 24 weeks of the simulation and only if the user has enabled the “evaluation mode” on the home page);
- information on funds on current accounts;
- the ability to open a new account;
- the ability to transfer funds from a current account to savings;
- the ability to exchange currencies (this option must be available if the user has added at least one additional currency);
- information on savings;
- the ability to transfer funds from savings to the current account;
- information on current exchange rates;
- the opportunity to open a deposit in one of the available currencies;
- information on open deposits;
- opportunity to replenish an open deposit;
- opportunity to take a loan;
- information on open loans;
- opportunity to invest in non-financial investments;
- information on their contributions to non-financial investments;
- information on the latest changes in the accounts for the last week;
- information on the dynamics of changes in funds on the accounts during the entire time of the simulation;
- information about the last executed transactions on all accounts.

3. *Develop a system of random events,* which is that at the beginning of each week the user may have an “unexpected event”: illness, birth, etc. Each event should occur no more than once in 10 weeks, which will not distract the user too often from other features of the simulator.

4. *Develop a page with the results of the simulation*, which should be available when you reach the 60th week of the simulation. The participant should be able to get acquainted with the averages in his country, as well as view the averages of participants from other countries. The participant must also be able to leave feedback or suggestions in a special field. The information must be sent to the e-mail address of the site administrator.

2.1. Substantiation of technologies and means of software implementation

To implement the server part of the software package to create and conduct simulations to determine the effectiveness of personal financial strategies using machine learning capabilities, the object-oriented programming language C#, and modern technology for creating cloud applications ASP.NET Core 2.2.

Among the advantages of ASP.NET Core 2.2 [7]:

- high productivity and optimization;
- the ability to develop and run in Windows, macOS, and Linux;
- tools that simplify the process of modern web development;
- the only solution for creating a user web interface and Web API;
- arranged system of implementation of dependencies, which allows the components of the developed system to be weakly connected, to adhere to the principles of inversion of dependencies and a single duty.

During project development, the project was upgraded from ASP.NET Core 2.2 to a new version of ASP.NET Core 3.1. ASP.NET Core 3.1 includes many enhancements that reduce memory usage and improve bandwidth.

Framework SQLite technology was chosen to access the data, which allows you to work with the database using objects without having to write a large amount of code to access the data. SQLite is a lightweight relational database management system [8].

SQLite technology was chosen because of the following features: easy to use; does not require installation, as well as administration; the database is stored together with the application; speed of operations.

To implement the client part, the JavaScript programming language was chosen, which is the undisputed and unalterable leader in the development of client interfaces for web applications [9].

To create a user interface, the React library was used to create one-page sites. The purpose of React is to provide high speed, simplicity, and scalability [10].

React is often used with Redux, an open JavaScript library designed to manage the state of the program. Redux helps developers optimize program code. The main concept of Redux [11]:

1. *The only source of data.* Redux stores the state of the entire application in the object tree in one repository. One state tree makes it easy to debug or test a program; it also allows you to maintain the state of the application during development, to speed up the development cycle.

2. *The state is read-only.* The only way to change the state is to single out an action, an object that describes what happened. This ensures that neither views nor function callbacks will ever change status. Instead, they only express their intention to do so. All changes are centralized and occur one after another in a clear sequence. Because actions are simple objects, they can be registered, serialized, saved, and later played back for debugging or testing.
3. *The state changes with the help of pure functions.* Reducers are just functions that take the previous state and action and return to the next state. In the development process, reducers can be divided into smaller reducers that control certain parts of the state tree. Because reducers are just functions, they allow you to control the order in which they are sent, transfer additional data, or even create duplicate reducers for common tasks such as paging.

The open-source library Formik was chosen to build custom forms. Formik has the following advantages: saves and tracks changes in field values; organizes the check and processes the entered values; saves information about visited fields. Formik allows you to focus more on business logic and spend less time building forms.

To simplify the development of the user interface and design, a set of Material UI tools was used, which contains CSS and HTML templates for forms, buttons, and other interface components, as well as additional JavaScript extensions.

The developed simulator is a web solution that is deployed on the Internet. The Microsoft Azure cloud platform was used to deploy the site. Microsoft Azure is designed to develop cloud computing applications and is designed to simplify the process of creating online applications [12].

2.2. Identify options for using the simulator

The developed personal finance management simulator assumes the existence of the following roles: “Guest”; “Participant”.

To understand what opportunities are provided for users of the system, a description of the options for using the site. The user with the role “Guest” has the opportunity to enter information about himself and start the simulation. The “Guest” who started the simulation changes his role to “Participant”.

We will describe all the functionality of the simulator for comprehensive training of the user in personal finance. On this page, the user with the role of “Participant” has many opportunities to learn how to manage personal finances. The following is a list of information that a user with the role “Participant” can see, as well as opportunities that the participant can perform on the simulation page:

- Can see his salary and average monthly expenses, which the participant indicated on the home page.
- Can move to the next week of the simulation.
- Can move to the next month of the simulation.
- Can stop the simulation and return to the home page.

- Can see information about their rewards by categories of savings and deposits (this information is available from the 24th week of the simulation and only if the user has enabled the “evaluation mode” on the home page).
- Can see information about funds in current accounts.
- Can see information about savings.
- Can open an account in any currency of the world.
- Can transfer funds from a current account to savings.
- Can buy the currency of any country in the world (this option is available if the user has opened a current account in at least one other currency).
- Can transfer funds from savings to a current account.
- Can get acquainted with current exchange rates.
- Has the opportunity to open a deposit in one of the available currencies.
- Can see information about open deposits.
- Has the opportunity to replenish an open deposit.
- Has the opportunity to take a loan.
- Can see information about open loans.
- Has the opportunity to invest in non-financial investments.
- Can see information about their contributions to non-financial investments.
- Can see information about the latest changes in accounts for the last week.
- Can see information about the dynamics of changes in funds in the accounts throughout the simulation.
- Can see information about recent transactions on all accounts.

2.3. Software architecture

To develop a personal finance management simulator, a cloud architecture was chosen that allows access to the developed system using a centralized resource – the Internet.

The designed website provides a minimum number of pages, but those that contain a lot of complex functionality. The pages of a website provide constant dynamic changes that depend on the user’s actions. That is why a one-page architecture (SPA) was chosen for this application.

A one-page application (SPA) is a website that interacts with the user, dynamically rewriting the components of the current page with new data, which in most cases is provided by a web server, instead of the default browser loading entire new pages, as in multi-page applications (MPA). The SPA approach on the Internet is similar to the single-document interface (SDI) presentation technique popular in personal computer programs [13].

Among the main advantages of using SPA architecture: faster user interaction with the site; reduction of traffic; much greater opportunities to develop complex in terms of design functional components.

SPA moves logic from the server to the client, and the role of the webserver is transformed into a pure API that only provides data, often in JSON format. This architectural style is called Thin Server Architecture. In such a web application architecture, complexity is transferred from the server to the client, with the argument that this ultimately reduces the overall complexity of the system, making it flexible.

In figure 1 shows a diagram of a personal finance management simulator, which consists of the following components:

1. A client (web browser). Responsible for building views and displaying them to the client. Because the SPA architecture of the web application has been chosen, the client makes the first request to the server, which loads the initial page structure. The following requests are made to the webserver API, which returns the JSON data used by the client to modify individual view components.
2. FinanceSimulator ASP.NET WebApp – a web server that acts as an API, ie is responsible for storing and providing data to the client. The application consists of the following collections:
 - 2.1. FinanceSimulator.Web contains APIs that the client accesses to retrieve data or perform certain operations.
 - 2.2. FinanceSimulator.Core manages and stores data by accessing the SQLite data-base that is deployed with the web application. Contains the main classes of the simulator related to its business logic

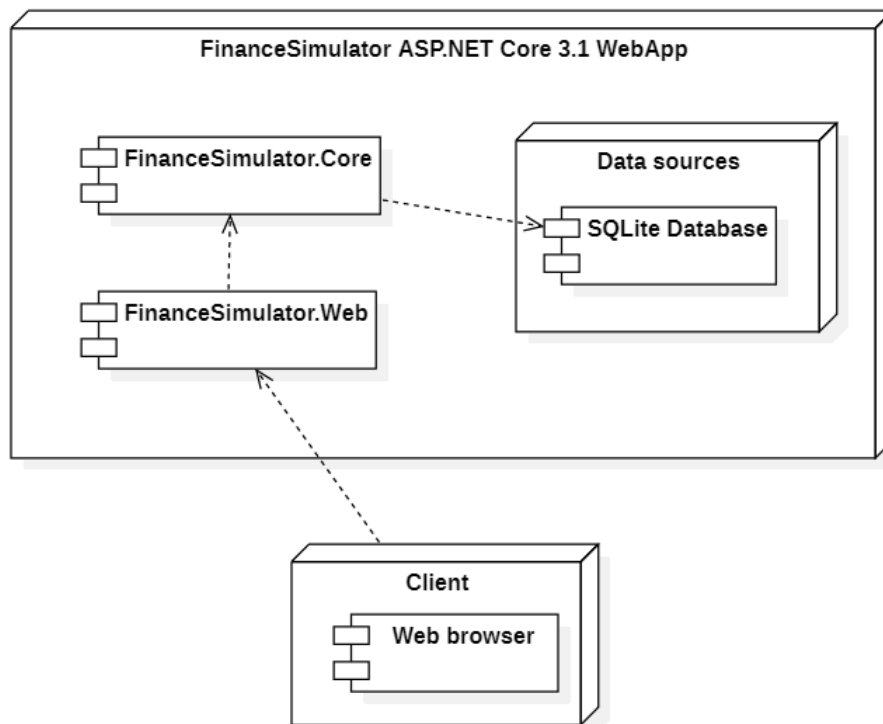


Figure 1: Diagram of simulator components.

One of the most popular modern libraries for creating one-page sites is React, which was chosen to implement a personal finance management simulator.

During the development of the project, it was also decided to use the architectural approach Flux. The main feature of Flux architecture is the one-way direction of data transfer between components. The architecture imposes restrictions on the data flow, in particular, eliminates the possibility of updating the state of the components them-selves. This approach makes the data flow predictable and makes it easier to track the causes of possible errors in the software [14].

The Flux architecture provides the following components [15]:

1. Actions – assistants that simplify the transfer of data from the manager.
2. Dispatcher – takes action and sends the load to registered handlers.
3. Stores – containers for program status and business logic in handlers registered in the manager.
4. Views – React components that collect the state of storage and pass it to child components through properties.

Nowadays, one of the most popular implementations of Flux architecture is the Redux library, which was used in the development of the simulator.

The .NET platform was chosen to create a program that could determine effective action strategies in a simulator using machine learning. As described in the previous section, this system will be created using the open-source library SharpRL, as Microsoft and its ML.NET platform do not yet have a ready-made solution to solve problems with reinforcement.

The program is a console application that is in the same solution as the simulator, but despite this, this system is a separate program that runs separately.

In figure 2 the structure of the decision tree with the developed program of finding financial strategies is presented.

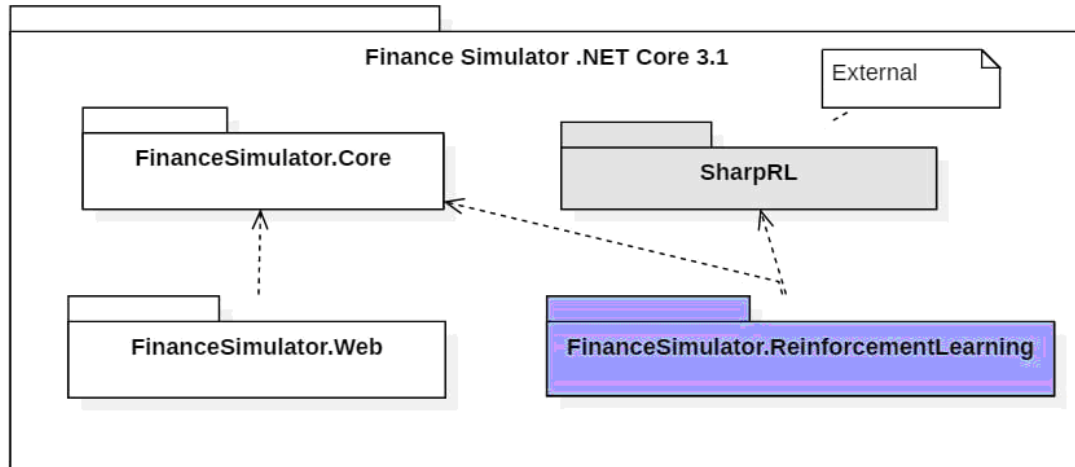


Figure 2: The structure of the solution in the form of assemblies.

As can be seen from the diagram in figure 2 the developed machine learning program uses a joint with the simulator assembly FinanceSimulator.Core, which is required to avoid duplication of code.

The SharpRL library contains basic classes and interfaces for programming reinforced model learning. The machine learning algorithm used in this library is Q-learning, which was described in the previous section (figure 3).

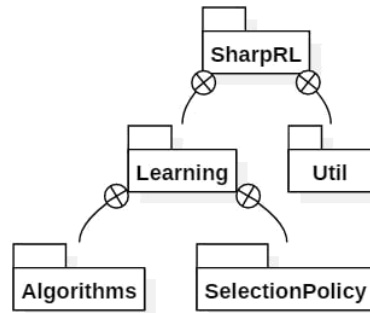


Figure 3: The structure of the adapted collection SharpRL.

To narrow the general space of possible actions in the simulator that can be done by the agent of the machine learning system, it was decided to allocate one type of action for each tool, for example, savings, deposits. For each type of instrument, it was necessary to create a list of possible changes in the balance in percent (if the action falls from 0% of changes in the balance, then nothing changes after its execution). Each week, the agent must perform one action for each tool. To implement this idea, it was necessary to partially change the source code of the library "SharpRL", which is why this external assembly was connected to the solution together with the source code.

Figure 4 shows a class diagram of the adapted SharpRL assembly, which describes the following classes and interfaces:

1. *Agent* – a class of system agents that implements the interface agent, which describes the entity that makes decisions in the environment. As a result of decision-making, they affect him and the environment. Thus the environment of the system is investigated.
2. *Environment* – a system environment-class that implements the environment interface. The environment can contain many agents who explore it by making decisions about the implementation of specific actions by the environment.
3. *Configuration* – a class that contains learning parameters that must be configured externally.

The learning process is carried out specified in the parameters of the number of simulations. Next, to obtain the final results of the training, there is an assessment in compliance with the policy of choice of actions of the agent.

2.4. Adjust simulator settings

The developed personal finance management simulator is a web application that has been deployed on the Internet [16].

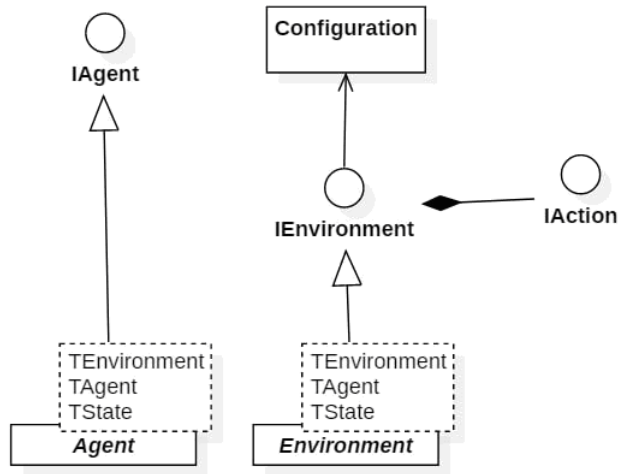


Figure 4: Class diagram of the adapted assembly SharpRL.

A Microsoft Imagine subscription was used to deploy the website, a program of Microsoft Corporation that offers students and graduate students free access to software design and development tools.

In figure 5 presents the site control panel, which provides various management and monitoring capabilities. As you can see from the figure, the site works stably without critical errors.

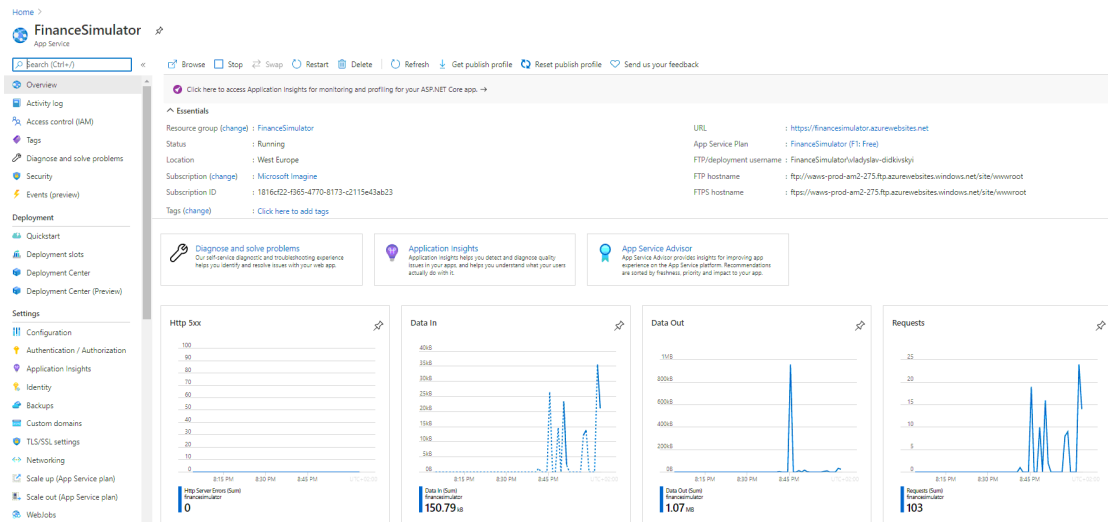


Figure 5: Microsoft Azure site control panel.

A deployment diagram was developed to represent the hardware components of the website and how the different parts of the system work with each other (figure 6).

The diagram shows the following components:

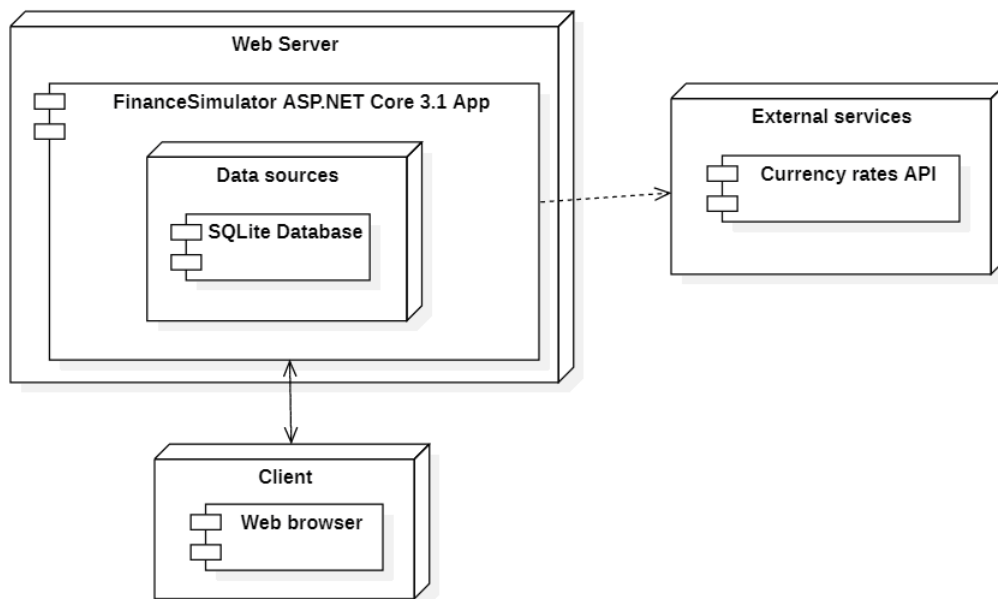


Figure 6: Deployment diagram of the developed simulator.

1. A *client*, which is a web browser, makes HTTP requests to a web server.
2. A *web server* that receives HTTP requests from the client and returns the re-requested data in response. The SQLite database is deployed with the web application.
3. *External service* to obtain information on current exchange rates.

A configuration mechanism has been developed for easy control of the simulator functionality. You can change the settings on the server without any interference with the source code. The settings consist of the following files:

- `appsettings.json` – contains settings for connection to the database, as well as a key to the API of the external system, which provides information about currency exchange rates;
- `Countries.json` – contains a set of settings about the countries that the user can select in the simulator;
- `Currencies.json` – contains a set of settings about currencies that the user can select in the simulator;
- `Deposits.json` – contains a set of settings about deposits that the user can open in the simulator;
- `NonFinancialInvestments.json` – contains a set of settings for non-financial investments that the user can buy in the simulator;
- `UserEvents.json` – contains a set of settings about random events that may happen to the user in the simulator;
- `UserQuiz` – contains a set of test settings that the user must take within the time specified in the settings.

2.5. The structure of the simulator interface

Consider the part of the functionality that directly relates to the mechanics of the simulator. The first page that the user will see when opening the simulator site is a welcome page. This is the only page that a guest can see before starting the simulation. This page contains a set of fields that must be filled in by the user to start the simulation. The home page contains the following fields to fill in (figure 7):

1. *Country* – required only for grouping user data by country in the final graphs. The country is determined automatically depending on the location of the user, but he can change it.
2. *Currency* – the main currency of the user, in which he or she receives a salary and incurs daily expenses.
3. *Monthly salary and expenses*. The user can choose from several options or enter their data.
4. *Evaluation enables the option*. This option will allow the user to check the list of completed and uncompleted assessment tasks by different categories. This information is available after reaching 24 weeks of simulation. After 24 weeks, the user can still complete all tasks.

Welcome to Personal Finance

To start simulation select your country, default currency and your month salary/spending.

Country
UA - Ukraine

Currency
UAH - Ukrainian Hryvnia

Salary/spending
10000/7000

Enable assessment

*Enabling assessments will allow you to check the list of completed and uncompleted estimation tasks by different categories after 6 months of simulation. After that you'll still be able to complete assessments.

START GAME

Figure 7: Home page of the simulator.

After the guest fills in all the data and clicks on the “Start game” button, he or she will change his or her role to “Participant” and will be redirected to the simulation page (figure 8).

The simulation page is divided into 3 main parts:

1. Site header contains only the site title and the number of the current simulation week.

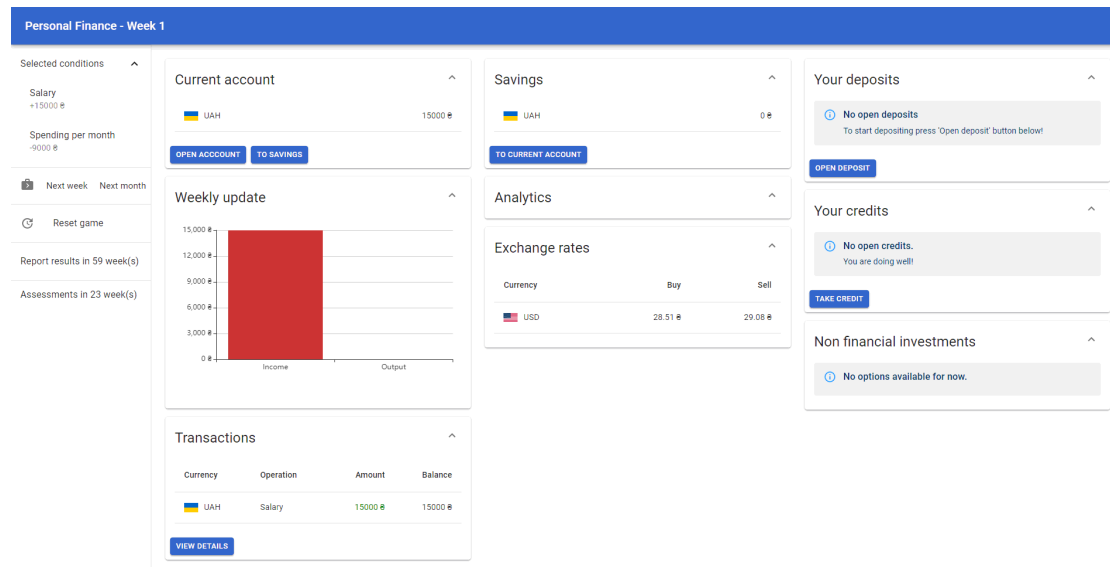


Figure 8: Simulation page.

2. The control panel, which is located on the left side of the window.
3. The main part with cards of separate functionalities of the simulator.

Consider in more detail the control panel of the simulator.

The simulator control panel contains:

1. User-entered data on monthly salaries and expenses.
2. “Next week” button moves to the next week of the simulation. After this transition, the amount of $\frac{1}{4}$ monthly expenses is automatically deducted from the user’s current balance. After the transition to the next month, the current balance of the user is automatically accrued salary.
3. “Next month” button moves to the next month. That is, this option does the same thing that will happen if you click 4 times on “Next week”.
4. The “Reset game” button, which completes the simulation, changes the user’s role from “Participant” to “Guest” and translates to the home page. To avoid the risk of losing the entire result of the simulation due to carelessness, the user must confirm the completion in an additional window that will appear after clicking on the “Reset game” (figure 9).
5. At 60 weeks, you will have the opportunity to review your simulation results (this option will be described in more detail below). Until the 60th week, information will be displayed on how many weeks are left before the opportunity opens.
6. At 24 weeks, you will be able to view the evaluation results if the "Enable assessment" option has been enabled on the home page. Here the user will be able to check the list of completed and uncompleted assessment tasks for different categories (figure 10). Until the 24th week, information will be displayed on how many weeks are left before the opportunity opens.

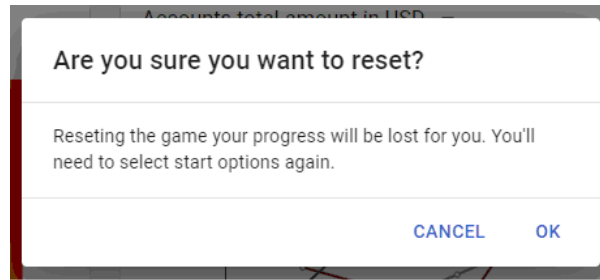


Figure 9: Example of confirmation of completion of the simulation.

Assessment	Deposits (70%)
<p>Savings (40%)</p> <ul style="list-style-type: none"> ✓ Answer quiz question ✓ Total savings amount reaches 20% of monthly spending ✓ Total savings amount reaches monthly spending ✓ Total savings amount doubling monthly spending ✗ Total savings amount reaches up to 6 months spending ✗ Total savings amount stays in range between 4 and 8 months spendings during one year 	<ul style="list-style-type: none"> ✓ Deposit is opened ✗ Deposit is opened with capitalization ✗ Flexible deposit is opened ✓ Long running deposit is opened (6+ months) ✓ At least 5% of income in average is invested to deposit during 3 months ✓ Having deposits at least in two different currencies

Figure 10: Example of the evaluation result.

3. Conclusions

The developed software package consists of two parts: a personal finance management simulator and a system for determining financial strategies, which uses reinforced learning opportunities.

The direction of future research is the integration of the recommendation system into the web application of the simulator. Also, to improve the system and give flexibility in recommendations that could be adjusted to the current financial condition of the participant, it is necessary to pay attention to the use of “policy-based” methods of training with reinforcement, which are widely used in autopilot training systems for cars. Just as an autopilot cannot predict what may happen on the road in a second, neither can a person predict unexpected expenses or profits (which is rare, but can happen). The built recommendation system based on the “value based” method assumes that the participant of simulation will follow absolutely all steps of the offered way. If any accidental event occurs that affects the financial situation or the participant simply decides at some point not to perform the actions specified by the system, in this case, the

recommendations will not lead to the intended result. That is why in the future it is advisable to research the possibility of applying “policy-based” methods to improve the finding of optimal strategies for personal finance management.

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Development of a machine vision program to determine the completeness of wrapping plants in the soil

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Abstract

The article analyzes the process of natural restoration of the main component of the soil – humus, as a result of which the dependence of the thickness of the humus layer on the number of plants embedded in the soil was revealed. The technological process of surface tillage requires constant monitoring of the completeness of plant burying. The article analyzes the literature, which showed that machine vision systems are widely used in agriculture, for example, when detecting weeds for spot treatment with herbicides, analyzing citrus forms and diseases, automated counting of roundworms of cut trees, etc. A machine vision system is proposed as a control tool for detecting weeds on the soil surface. The authors proposed their own approach to control the completeness of burying pruned weeds in the soil using machine vision systems. The work of our own program for detecting weeds on the soil surface is described in detail and step by step. The program's operability was checked on some plant models and its effectiveness of reliable operation was confirmed. Experimental studies were conducted in the laboratory. Based on the results of research in the computer program developed by the authors, the following results were obtained: photos of the soil surface were analyzed; contours of plant models were identified; plant areas and their percentage in relation to the image area were determined, and a message was received on the screen about the presence of weeds on the surface in accordance with agrotechnical standards.

Keywords

machine vision, soil, Phyton, OpenCV, agriculture, agrotechnical requirements

1. Introduction

Mechanical tillage combined with fertilization is one of the most difficult conditions for obtaining high and stable yields. Proper mechanical tillage is important in the system of measures to increase soil fertility in all natural and climatic zones of Ukraine [1].

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The main task of basic and surface tillage is to create favorable conditions for sowing seeds to the optimal depth, growth and development of cultivated plants, preservation and restoration of humus, protection of soil from water and air erosion, destruction of weeds, pathogens and pests of cultivated plants.

Modern agriculture can be divided into two large groups – intensive and organic. The main object of agriculture is soil.

Soil is an organic structure. It consists of: live biomass, organic remains of plants, animals, microorganisms, products of their metabolism and humus.

Dokuchaev [2] noted that if a layer of soil is isolated from virgin soil, then you can see plant roots, grass, beetle burrows, worms, larvae, as well as a small part of the ground. Insects and microorganisms recycle the soil and contribute to the creation of a loose structure. A similar position is defended by Darwin [3]. He notes that the worms began to properly cultivate the soil long before the start of arable units.

Yu. A. Slashchalin [4] examined clean ground that was not poisoned by herbicides and pesticides. Research data showed that about 400 kg of bacteria, worms and other microorganisms live on 0.01 hectares of soil. These living organisms process more than 500 kg of humus per year.

Humus is an important component of the soil. It is formed during the decomposition of various organic materials by microorganisms, such as roots, stems, leaves of plants, dead invertebrates, etc. The humus content in the soil is an indicator of the level of fertility. Almost all soil properties are directly dependent on the content of organic matter, 90% of which is accounted for by humus. Humus contains more than 95% of all soil nitrogen reserves, 60% phosphorus, up to 80% sulfur, and a significant part of trace elements. The nutrients in humus are not available to plants. Only after its decomposition by microorganisms do nutrients become available to plants [5]. Green plants have the largest biomass and their annual growth exceeds the biomass of invertebrates and microorganisms by several tens or hundreds of times, and vertebrates – by several thousand times. So, young grasses contain a lot of nitrogen, but less enrich the soil with humus. Organic substances of young grasses decompose quickly. Mature plants with a stiff stem contain organic substances that decompose over a long period of time. Therefore, above ground and root litter of higher plants provide the main material from which the organic matter of the soil is formed. It is these components that are used to restore humus.

In intensive agriculture, control over the quality of tillage is carried out on the basis of agrotechnical requirements and the establishment of quality indicators.

The quality of plowing is evaluated by the timing, depth and uniformity of its implementation, the completeness of the soil overturning, the degree of loosening and clumping, the absence of flaws, the completeness of sod embedding, crop residues, weeds, fertilizers, and the plowing of the field edges.

The timeliness of plowing is assessed by comparing the actual time with the established agricultural rules for each specific district. The depth of plowing is measured with a furrow meter or ruler with divisions. Measurements are made in at least 25 places of the bend. A deviation from the specified depth on the plowed field of no more than 5% is allowed when determining the depth on the plowed field. A correction is made for looseness, for which the measured average depth is reduced by 1/4.

The quality of turning the slice is determined by a special protractor. For embedding sod, crop

residues, weeds and manure in the soil, the soil overturning must be at least 135°. Embedding of crop residues, weeds and the absence of flaws is determined visually along the diagonal of the field.

Agrotechnical measures include tillage (stubble husking, winter plowing, pre-sowing cultivation, steam treatment, row-to-row cultivation), periodic mowing of weeds on roadsides, canals, meadows, pastures and mulching of the soil.

Many years of agricultural experience show that winter plowing provides higher yields compared to spring plowing. According to research institutions, the spring grain harvest after winter plowing is 25-35% higher than in spring plowing.

The advantage of winter cultivation over spring plowing is that during autumn plowing, more moisture and nutrients accumulate in the soil, weeds, pathogens and pests of agricultural crops are destroyed, and the effect of organic and mineral fertilizers applied increases. With the introduction of winter plowing, the stress in the spring period is reduced, which makes it possible to use the machine and tractor fleet completely for spring sowing [6].

When growing cultivated plants, the humus content in the soil is constantly decreasing due to its mineralization. Deep plowing reduces the activity of worms and microorganisms, destroys the structure of the soil, reduces its fertility. During deep plowing, the soil is actively saturated with oxygen. This process activates soil bacteria to break down humus into mineral elements. A thick layer of humus on plowed virgin ground ensures high yields. After a few years, the humus layer decreases. As a result, yields decrease, plant immunity weakens, pests and diseases spread, which leads to the use of fertilizers, herbicides and pesticides [7].

According to [8], with intensive application technologies, 97-99% of insecticides and fungicides and 80-95% of herbicides enter the soil, reservoirs, and air. The negative effect of mineral fertilizers is that when they are systematically applied to the soil, harmful sedentary substances accumulate – heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, vanadium, zinc, etc.). With each ton of phosphorus applied to the fields, up to 160 kg of fluoride enters the soil, the high concentration of which changes the direction of biological processes in the soil.

Plant residues play an important role in differentiating soil indicators by profile: the content of organic matter, the accumulation of which in the soil is the plants themselves with root and crop residues. Under normal conditions, the soil receives 1.5-2 times more organic matter than with organic fertilizers [9].

Among the agrotechnical measures that significantly affect microbiological activity in the soil, mechanical tillage and mulching are among the leading places. When they act on the soil, its agrophysical properties change, which affect the water-air and thermal regimes of the soil. The influence of mechanical processing on the development of soil microflora is manifested through changes in the physical regime of the soil, movement and redistribution of organic substances within the treated layer, improvement of plant growth and development conditions [8].

Thus, there is a need for high-quality tracking of the number of embedded plants in the soil during mechanical processing and its complete closure during mulching. If agrotechnical requirements do not meet, it is necessary to make adjustments to the corresponding technological process.

Currently, machine vision systems are widely used not only in the gaming industry, but also in agriculture, namely: for predicting yield, recognizing fruit ripeness, tracking the placement

of weeds in the field for applying herbicides, determining the type of plants by the Shape of leaves and stems, etc. Cubero et al. [10] use computer vision to study the color spectrum of citrus fruits to detect defects and diseases. They note that the color of the peel of oranges can indicate a number of dangerous diseases. Machine vision technologies make it possible not only to sort fruits according to commercial strategies, but also to remove unwanted fruits from the conveyor. Similar studies are carried out by Su et al. [11] during the detection of potato defects by machine vision.

Choi et al. [12] developed a machine vision system for quantifying citrus fruits that have fallen to the ground. As a result, the system received an algorithm for improving the image for different lighting conditions and estimating the number of drops on the fruit and the mass of citrus fruits.

Kefei et al. [13] proposed a quadcopter-based machine vision system for agricultural environmental monitoring. The advanced quadcopter recognizes images to monitor the environment of agricultural land. It collects high-definition images in real time. So it's easy to analyze the state of growth of agricultural crops and regularly monitor the temperature, humidity and other parameters of the atmospheric environment. In turn, Zhang et al. [14] monitors in real time the optimal time for collecting fresh tea leaves. They proposed a method that provides the basic conditions for the future operation and management of tea plantations using information technology, automation and intelligent systems.

The task of recognizing roundwood patterns is very important in the woodworking industry. Chiryshv and Atamanova [15] are solving this problem. They show an overview of existing roundwood recognition solutions, their advantages and disadvantages, and describe the features of their own pattern recognition algorithm. Li et al. [16], Seng et al. [17], Ahmed et al. [18] also showed their own research on the use of machine vision systems for recognizing apples, grapes, and determining the position of weeds in the field.

A review of literature sources has shown that machine vision systems are widely used in various areas of agriculture, and therefore it can also be applied to determining the completeness of plant embedding. The purpose of this publication is to study a method for detecting plants on the soil surface during plowing by means of machine vision to control agrotechnical requirements and warn the operator of a machine-tractor unit in real time about their violation. These studies can also be used to track the quality of mulching in organic farming.

2. Study results

Agrotechnical requirements for the completeness of embedding plants in the soil were described by Chernilevskyy et al. [19]. Their essence boils down to the following: the agronomist goes around the plowed field diagonally, finds not embedded plants, puts a meter frame 1 on the plowed field (figure 1) and calculates the area of 2 plants lying on the soil surface per 1 hectare.

This method has a number of disadvantages: labor intensity, durability, and inaccuracy. It provides for conducting a study of the quality of embedding plants in the soil by the eye method of a limited part of the bend along the diagonal of the field. At the same time, the completeness of embedding plants in the soil is checked after processing the entire field or part of it, and adjustments to the technological process are made later.



Figure 1: Frame for calculating the area of not embedded plants.

Since the quality of plants embedding in the soil affects the process of humus formation, all weeds must be pruned and buried. So, the classical method of determining the completeness of embedding plants in the soil needs to be improved using modern digital technologies.

The essence of the proposed method for determining the completeness of plant embedding is explained in figure 2: the digital camera 1 is mounted on the tillage machine 3 using auxiliary equipment 2, and its screen is directed to the freshly treated area 4. Digital image clarity is provided by the digital camera stabilization device 5. The camera generates images or frames from the video stream at a given frequency, which are transmitted to a computer or mobile device 6. A computer or mobile device is equipped with software developed on the basis of a machine vision system of our own production [20], which recognizes and highlights the contours of all plants and determines their total area. The total area of images or frames of the video stream is also calculated and the percentage of the resulting areas is determined. The following information is displayed on the computer or mobile device screen: an image with marked plant contours, the total area of the image, the total area of plants, and the percentage of the area of not embedded plants.

Author's computer program "Slidopyt" [20] refers to image processing programs using

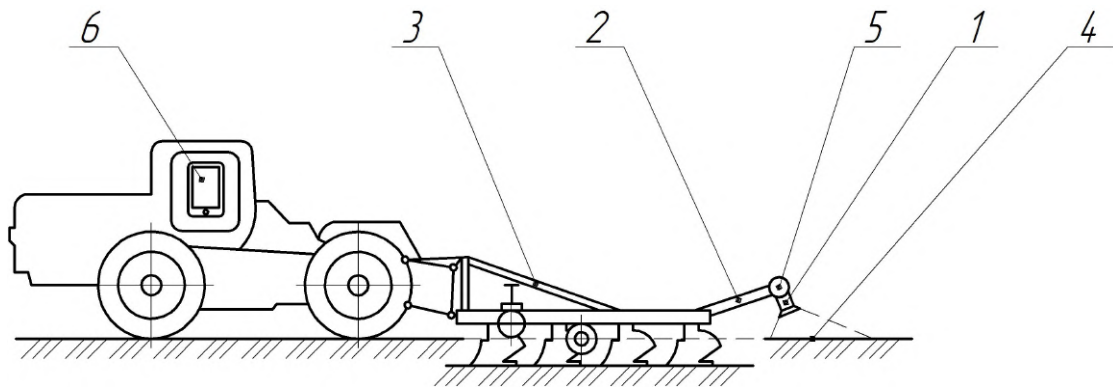


Figure 2: Scheme of the unit for studying the completeness of embedding plants in the soil by means of machine vision.

machine vision tools. The program works according to the following algorithm:

- opens the studied image;
- defines the area of the entire image;
- using a filter and mask, it outlines the entire spectrum of green shades of the plant mass, which is shown in the figure;
- enter the found contours in rectangles of the specified thickness and color of lines;
- defines the total area of all rectangles;
- determines the percentage of the total area of rectangles to the total area of the image;
- displays an image with rectangles on plants, the total area of the image itself, the area under plants, and the percentage of not embedded plant mass in the soil.

The development of a machine vision system should begin with the installation of the Python programming language on a personal computer [21]. As a program code editor, you should use the free version of PyCharm [22].

This program provides for working with images and data arrays, so you need to connect OpenCV [23] and NumPy [24] libraries:

```
import cv2
import numpy as np
```

The OpenCV library contains algorithms for working with images, digital cameras, optical defects, detecting duplicates, analyzing object movement, determining the shape of an object and tracking an object, 3D reconstruction, object segmentation, gesture recognition, etc. In other words, it is a set of data types, functions, and classes for image processing by computer vision algorithms. This is a library with free source code. It is widely used in scientific and commercial projects. NumPy is an open source library for the Python programming language that supports multidimensional arrays.

According to the scheme (figure 2) camera 1 takes photos of the plowed soil 4 and transmits the image to the appropriate folder on the PC. Before performing any manipulations with the image, it must first be read from the file. OpenCV uses the `imread` function for this purpose:

```
while True:  
img = cv2.imread('Ground.jpg')
```

The test file for speech recognition is called "Ground.jpg". Using the OpenCV library, the program read the test image and wrote it under the new name "img".

Recognition of green grass on the surface of black plowed soil is rational to filter by color. Color is the property of bodies to reflect or emit visible radiation of a certain spectral composition and intensity.

There are different color models: linear, such as RGB, and nonlinear – HSV. Using the HSV model is much more convenient, because the coordinates of this color model are chosen taking into account human perception.

HSV (Hue, Saturation, Value) is a color model in which the color coordinates are (figure 3):

- Hue – color tone, (for example, red, green, or medium blue). It varies from 0 to 360°.
- Saturation varies from 0 to 100 or from 0 to 1. The higher this parameter is, the “cleaner” the color, which is why this parameter is sometimes called color purity. And the closer this parameter is to zero, the closer the color is to neutral gray.
- Value (color value) or Brightness. Set in the range from 0 to 100 or from 0 to 1.

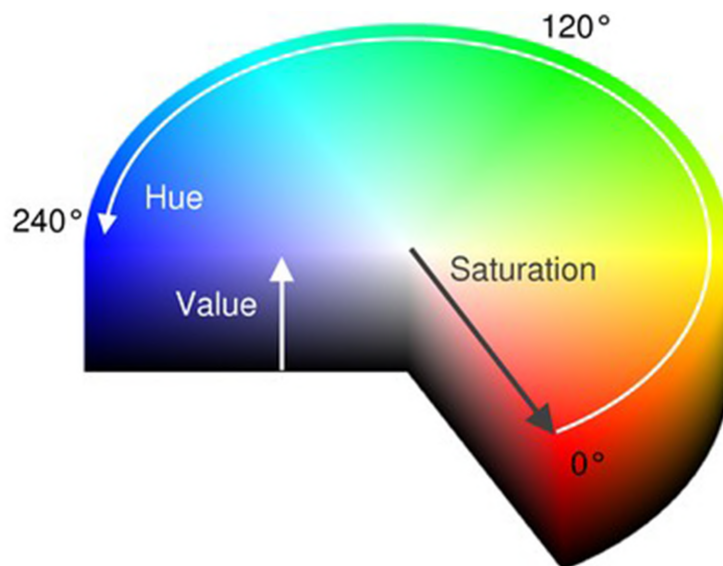


Figure 3: HSV color model structure.

Using the `cv2.cvtColor` function we transform the color model:

```
hsv = cv2.cvtColor(img, cv2.COLOR_BGR2HSV)
```

Thus, the color model changed from BGR to HSV. We overwrite the data under the new name "hsv". Filtering the green hue is performed by the `cv2.inRange` function and written to the "mask_green" variable:

```
mask_green = cv2.inRange(hsv, (33, 102, 46), (102, 255,255))
```

In the function itself, we specify the target image "hsv", as well as the lower and upper limits of the filter. We find the range of the green hue using trackbars:

```
cv.createTrackbar (low_H_name, window_detection_name, low_H,  
max_value_H, on_low_H_thresh_trackbar)  
cv.createTrackbar (high_H_name, window_detection_name, high_H,  
max_value_H, on_high_H_thresh_trackbar)  
cv.createTrackbar (low_S_name, window_detection_name, low_S,  
max_value, on_low_S_thresh_trackbar)  
cv.createTrackbar (high_S_name, window_detection_name, high_S,  
max_value, on_high_S_thresh_trackbar)  
cv.createTrackbar (low_V_name, window_detection_name, low_V,  
max_value, on_low_V_thresh_trackbar)  
cv.createTrackbar (high_V_name, window_detection_name, high_V,  
max_value, on_high_V_thresh_trackbar)
```

With the function `cv2.findContours` we find all the contours of green color and write them in the variable `contours`:

```
contours, hierarchy = cv2.findContours(mask_green, cv2.RETR_TREE,  
cv2.CHAIN_APPROX_SIMPLE)
```

It is advisable to choose the `mask_green` mask as the target image for searching for contours. The grouping mode is `cv2.RETR_TREE`, which groups contours into a multilevel hierarchy. The packaging method used `cv2.CHAIN_APPROX_SIMPLE`, which glues all horizontal, vertical, and diagonal contours together.

The found green contours, i.e. plant contours, may not be closed. They do not consist of a single connected line, but of many broken lines. This makes it difficult to calculate the area of contours. To refute the shape of contours, you need to fit them into simple geometric shapes, such as rectangles.

The next loop iterates through all the plant contours found in the loop and places them in rectangles:

```
for cnt in contours:  
rect = cv2.minAreaRect(cnt)  
box = cv2.boxPoints(rect)  
box = np.int0(box)  
area = int((rect[1][0]+1) * (rect[1][1]+1))  
if area > 10:  
cv2.drawContours(img, [box], -1, (0, 0, 255), 2)
```

The `cv2.minAreaRect` function writes each contour in a rectangle of minimum area and writes it to the "rect" variable. The next function `cv2.boxPoints` determines the coordinates of the

four vertices of the rectangle and writes it to the "box" variable. The `np.int0 (box)` function rounds the coordinates of the rectangle of the "box" variable. The area is calculated using the `int((rect[1][0]+1) * (rect[1][1]+1))` function. 1 pixel thick contour to determine the area runs inside the rectangle. Thus, the actual area is smaller. To eliminate this effect, add 1 pixel to the coordinates of the rectangle vertices. Now the rectangle will run along the outside of the contour. We write the data to the "area" variable. The `cv2.drawContours` function draws the outlines of the rectangles of the "box" variables in the "img" image. The line thickness is 2 pixels, the color is red. Only contours with an area of more than 10 pixels are displayed.

Defining the total area of all contours:

```
square = int(area) + int(square)
```

The "area" and "square" variables are expressed as integers. The initial value of the "square" variable is assigned to 0.

The total area of the frame for calculating the percentage of plants to soil is determined in the same way using the method described above.

First you need to select a white mask:

```
mask_white = cv2.inRange(hsv, (0, 0, 0), (255, 255, 255))
```

Write the data to the "mask_white" variable.

Find the outline of the entire frame of the "mask_white":

```
contour_w, hierarchy_w = cv2.findContours(mask_white, cv2.RETR_TREE, cv2.CHAIN_APPROX_SIMPLE)
```

Data on the contour of the frame is written to the "contour_w" variable.

Enter the rectangle in the "contour_w" mask and determine its area:

```
for cnt_w in contour_w:
    rect_w = cv2.minAreaRect(cnt_w)
    box_w = cv2.boxPoints(rect_w)
    box_w = np.int0(box_w)
    area_w = int((rect_w[1][0]+1) * (rect_w[1][1]+1))
    if area_w > 10:
        square_w = int(area_w) + int(square_w)
```

We calculate the percentage of plant area to the total area of the image, i.e. the percentage of not embedded grass:

```
percent = int(square) * 100 / int(square_w)
```

We write the data to the "percent" variable.

A certain percentage is compared with agrotechnical requirements [19]:

```

if percent < 95:
print("Agrotechnical requirements - Norm")
else: print("WARNING!!! It is necessary to adjust the unit!!!")

```

If the variable "percentage" is more than 5%, then the screen displays the inscription: "Agrotechnical requirements - Norm", if less - "WARNING!!! It is necessary to adjust the unit!!!".

We display all the defined data on the screen:

```

print("The area under the grass : ", square)
print("Total area for analysis : ", square_w)
print("The percentage of not embedded grass : ", percent, "%")

```

We show an image of the test soil with marked plant contours:

```

cv2.imshow('Najdenie rastenia', img)

```

To test the developed program in the laboratory, we make plant models from green paper. The leaves and stems of plants have different shapes, so we use rectangle, square, triangle, and circle as model shapes. Plant 1 Models and Ruler 2 for displaying the scale are shown in figure 4.

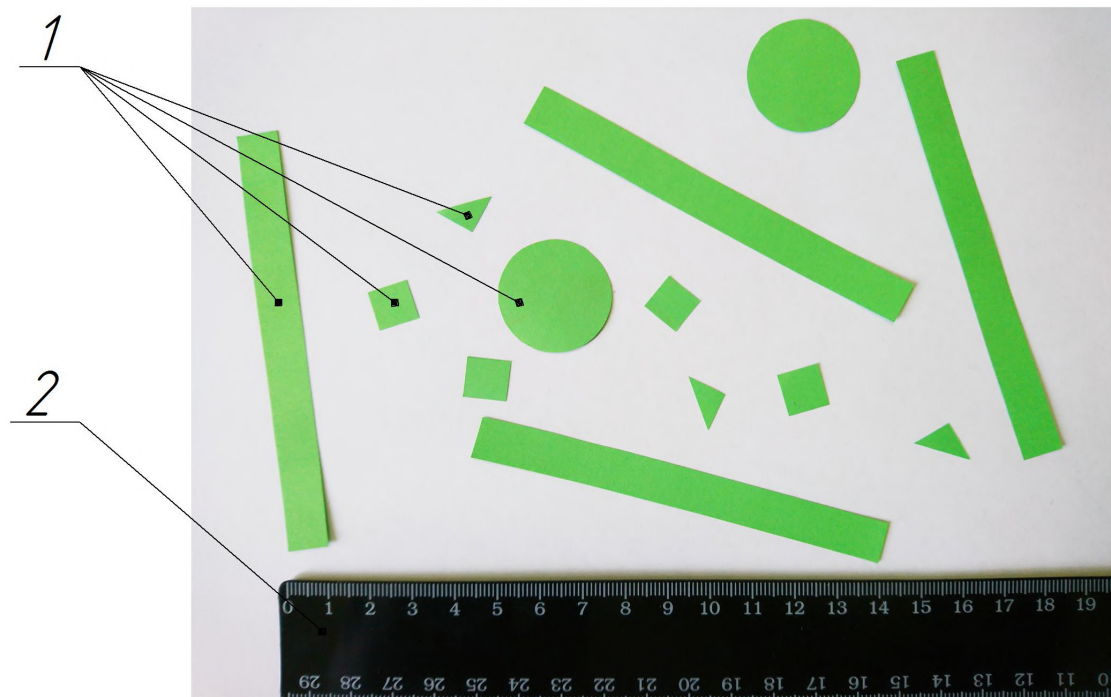


Figure 4: Plant models and a ruler to demonstrate the scale.

The size and shape of the plant models are as follows:

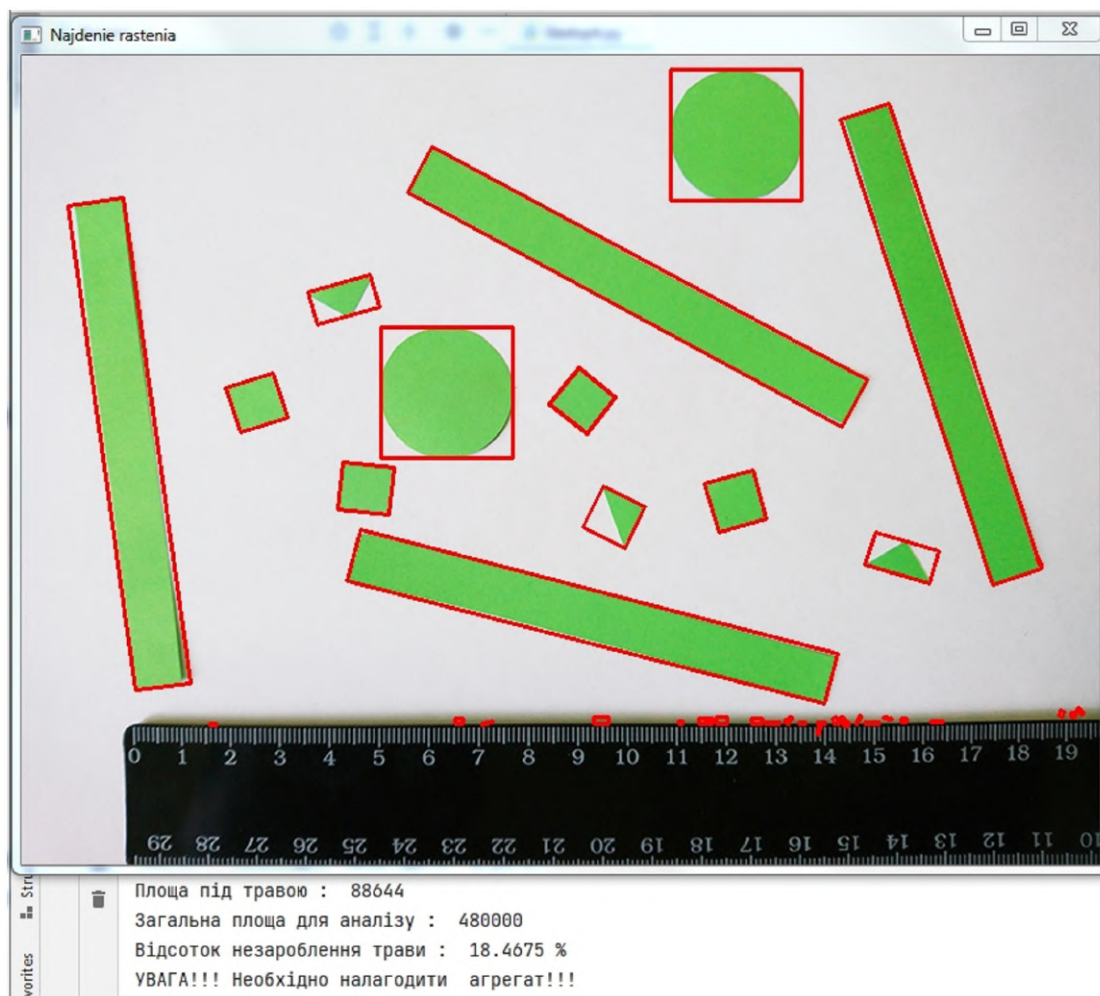


Figure 5: The processing of the test image with a computer program.

- rectangle 10×96 mm;
- 10×10 mm square;
- a right triangle with a leg length of 10 mm;
- a circle with a diameter of 25 mm.

We check the correct operation of the program using the following method:

- upload the image to figure 4 go to the program and determine the percentage of not embedded grass;
- print out the image of figure 4 on paper and we make measurements and calculate the percentage of not embedded grass manually;
- we compare two indicators. The margin of error should not exceed 3%.

The processing of the test image by a computer program is shown in figure 5.

The image with plant models has a size of 800×600 pixels. So, the program correctly calculated the total area of the image – 480,000 square pixels. She selected areas of the green spectrum, outlined them, and calculated an area of 88,644 pixels. Each contour was enclosed in a red rectangle of the smallest shape. The percentage of not embedded grass was 18.4675%.

Let's manually determine the areas of the test image. The measurement result is shown in figure 6.

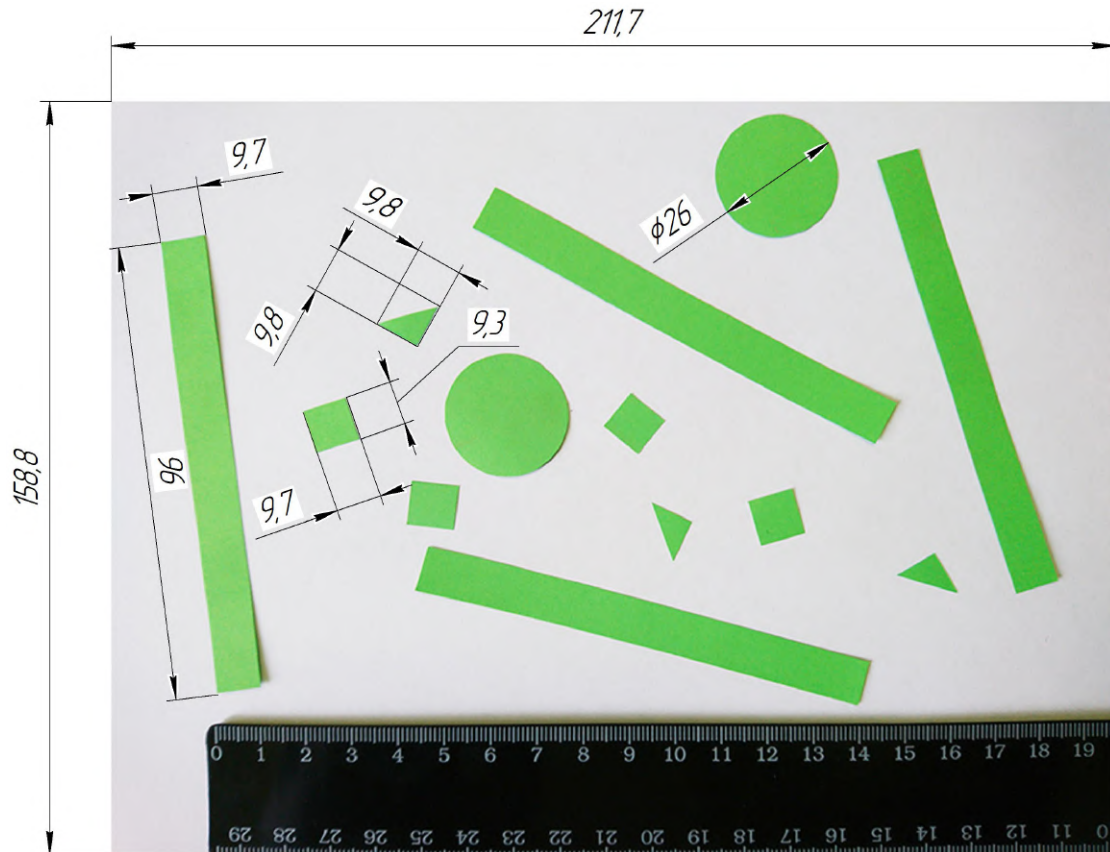


Figure 6: Result of manual measurement of the test image.

The results of measurements and calculation of the area of each figure are listed in table 1.

Table 1 shows that the total area of plant models is $5,291.52 \text{ mm}^2$, and the total area of the image is $33,617.96 \text{ mm}^2$. The percentage of not embedded grass when manually calculating the area of plant models was 15.74% of the total area of the image. Thus, the deviation from the values of the computer program is 2.73%, which does not exceed the error limit. This makes it possible to state that the program correctly determines the area of plant models and can be used in further laboratory studies.

Laboratory tests were performed on a ring-type soil channel. In figure 7 shows the process of conducting the experiment.

Table 1

Measurement results and calculation of the area of each shape.

Item name	Side dimensions, <i>mm</i>	Area, <i>mm</i> ²	Number of objects	Total area, <i>mm</i> ²
Rectangle	9.7×96	931.2	4	3,724.8
Triangle	9.8×9.8	48.02	3	144.06
Square	9.7×9.3	90.21	4	360.84
Circle	26	530.91	2	1,061.82
Total				5,291.52
Test image	211.7×158.8	33,617.96	1	33,617.96

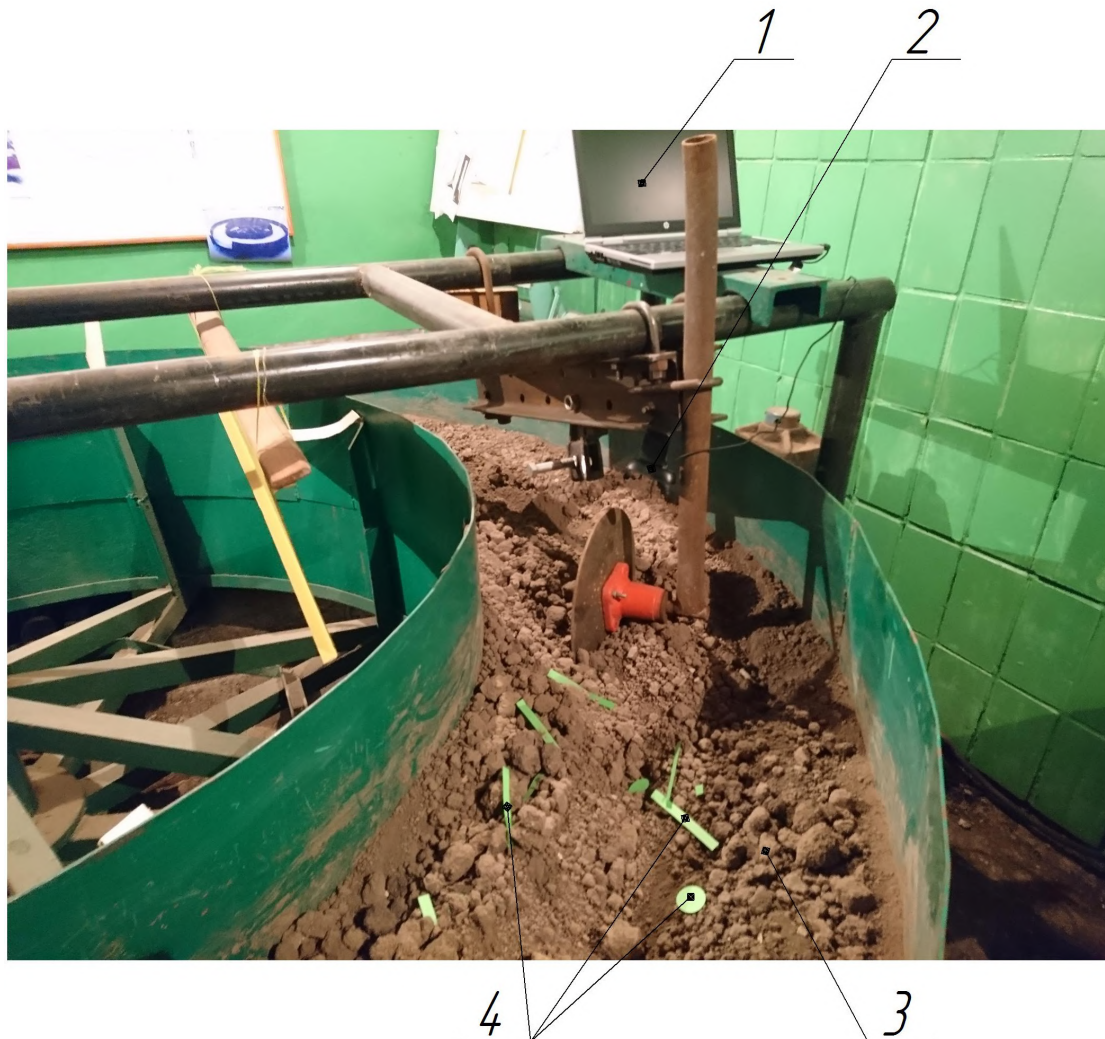


Figure 7: Conducting an experiment on a soil channel.

The laboratory installation consists of a personal computer (PC) 1 with a computer program installed, a webcam 2, a soil channel 3, and plant models 4. The PC is fixed on the fixed frame of the ground channel. The webcam is mounted on a fixed stable working body and is configured to photograph the soil surface of the channel with plant models. Before starting the experiment, plant models are decomposed on the soil surface. The channel rotates. The stationary working body loosens the ground and presses the plant models. Meanwhile, the webcam takes photos of the soil surface. Photos are saved on your PC in the appropriate folder. A machine vision computer program analyzes each image and shows the recognition results. The process of analyzing the soil surface of the channel with plant models is shown in figure 8.

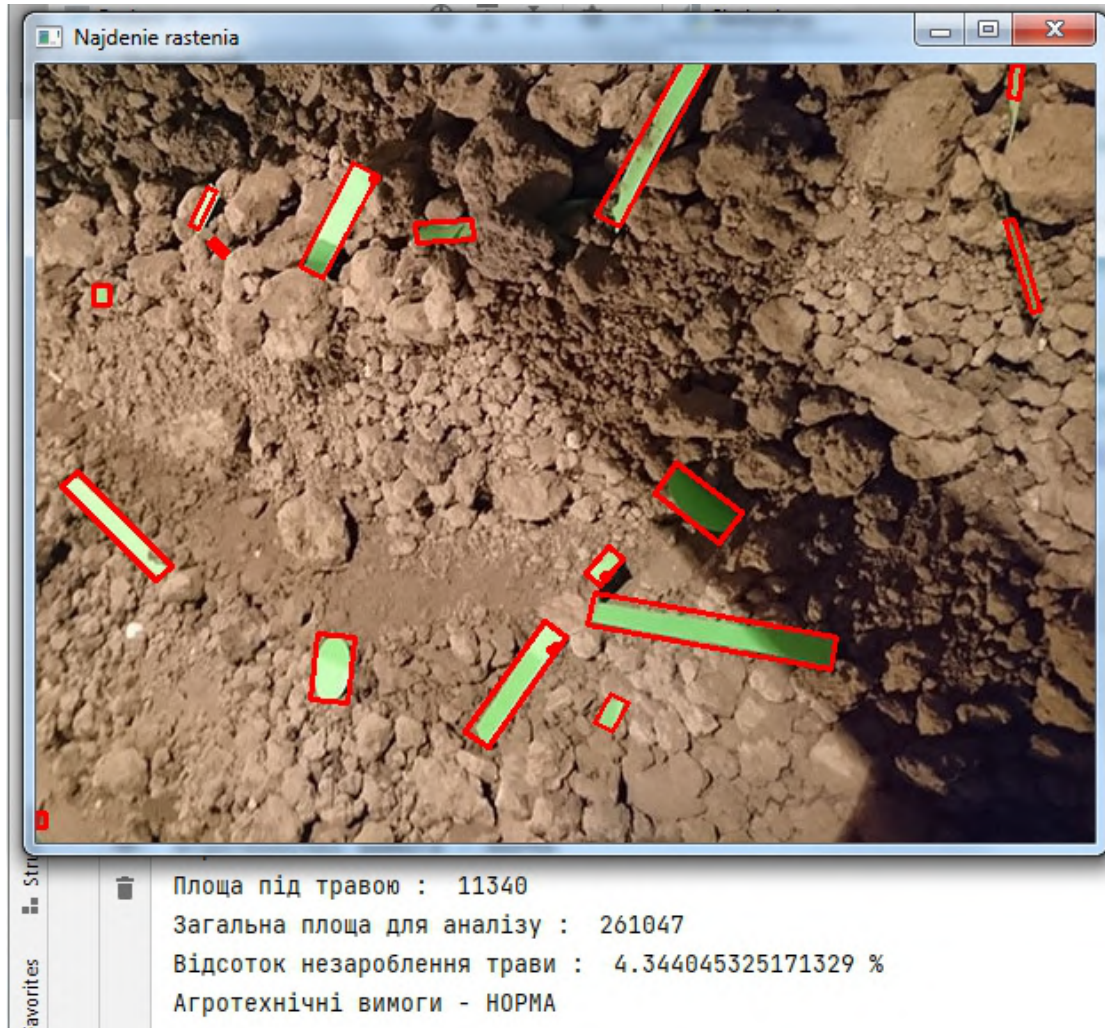


Figure 8: The process of analyzing the soil surface of a channel with plant models.

As a result of image analysis, the program recognized all plant models on the soil surface, selected them with contours, and entered each contour in the corresponding red rectangle. The total area of the image was 261,047 square pixels, the area of plant models was 11,340

square pixels, and the ratio of plant area to the total area of the photo is 4.34%, which meets agrotechnical requirements.

3. Conclusions and perspectives of further research

Soil is an important component of agriculture. Its fertility depends on many factors, including the thickness of the humus layer. The main building material of humus is decomposed and recycled plant remains (weeds). During soil exploitation, the use of herbicides and pesticides, the amount of humus is constantly decreasing.

One of the ways to naturally restore soil fertility is to control the process of maximum embedding of weeds during plowing so that not a single plant remains on the surface.

Modern agrotechnical requirements control the number of plants on the soil surface after plowing in an “eye-measuring” way by bypassing the diagonal of the field, which is not accurate.

The use of our proposed machine vision program during the operation of the arable unit tracks the presence of all plants on the soil surface. Laboratory experiments performed on plant models showed high measurement accuracy. The discrepancy between manual and automated determination of plant areas on the soil surface was only 2.73%, which indicates the effectiveness of the developed program. The program developed by us can also be used in the opposite direction, in particular, during the mulching process, namely: to track the closure of the soil with plant residues.

Further research focuses on the influence of light on the quality of object recognition, as well as improving the accuracy of object recognition by constructing better contours.

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Development of CRM system with a mobile application for a school

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Abstract

The article substantiates the need to develop a CRM system with a mobile application for a school. The existence of their educational environment, which will provide interaction between pupil and teacher in a school, is a topical issue today. Relationship management can be implemented in the form of a CRM system. For a deeper understanding of the research problem, certain analogs are considered, their advantages and disadvantages are given. The work aims to design and develop a CRM system with a mobile, cross-platform, application for a school. As a result, the architecture of the software package was built, the choice of tools was substantiated, the use and structure of the system were determined, the object-oriented structure of the system was designed, the data storage structure was developed, the system operation algorithms were designed and implemented, the system installation and administration procedure the procedure for working with the software package.

Keywords

CRM system, mobile application, school, learning environment, development

1. Introduction

One of the main issues in the management of educational institutions, including schools, is to increase the level of educational and methodological work of a particular institution. A digital educational platform would allow the effective use of available educational institution resources, and students and teachers would be allowed to use modern technologies in practice.

The main advantages of such technologies are: performing various types of educational work, control, and evaluation of knowledge online; open learning environment for subjects of the educational process, etc. All this leads to the fact that the use of various digital technologies provides an opportunity to: keep electronic journals; use online services for the learning process; conduct correspondence, testing, and assessment of knowledge online; communication, etc.

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Given the pace of modern life, many people seek to save their time by using mobile applications. But at the beginning of their design, there is a choice: to choose a ready cross-platform framework or to develop separate applications for each end platform. Both solutions have their disadvantages and advantages. For example, cross-platform solutions significantly speed up the development process, because they meet the principle: deliver - as much as necessary and write once. And native applications have much faster performance than universal ones. However, they require separate construction of interfaces and writing application functionality for each of the platforms.

The existence of their educational environment, which will provide interaction between student and teacher in a school, is a topical issue today. Relationship management can be implemented in the form of a CRM system.

CRM (Customer Relationship Management) is literally means “customer relationship management and refers to all strategies, methods, tools, and technologies used by business to develop, retain and attract customers” [1].

2. Theoretical background

In recent years, many studies by various scholars have focused on the design and use of the digital learning environment [2, 3, 4, 5, 6]. In particular, Uchitel et al. [7] considered the implementation of future agricultural engineers’ training technology in the informational and educational environment. Munk et al. [8] researched cloud-based educational platforms, Vlasenko et al. [9] raised the issue of management of online platform development and support process.

Sultanova et al. [10] investigated the potential of Google Classroom web service for lecturers of higher educational establishments under pandemic conditions, Shyshkina [11] proposed service models of the cloud-based learning environment of the educational institution, Popel and Shyshkina [12] researched the areas of educational studies of the cloud-based learning systems.

Soroko et al. [13] considered educational electronic platforms for STEAM-oriented learning environment at general education school, Osadcha et al. [14] conducted the review of the adaptive learning systems for the formation of individual educational trajectory.

Some scholars have attempted to analyze the possibilities of integrating business simulations software into the learning environment of technical university [15]. In addition, Vakaliuk et al. [16, 17] considered it appropriate to research the state of ICT implementation in institutions of general secondary education.

3. Related work

For a deeper understanding of the research problem, consider certain analogs, in particular, the application “School – Learning Assistant”, the interface of which is presented in figure 1. In this figure, it is possible to view the list of classes for a specific day, the schedule of the week, and the list of added information about other students and teachers.



Figure 1: School application interface – Learning Assistant.

Analyzing the application revealed significant shortcomings, in particular: the lack of ability to specify the exact time of class and make the so-called “windows” (because it is not always necessary for all classes to take place one after another), lack of functionality designed only for teachers, and no the possibility of interaction between teacher and student, in addition, the student must enter all the information about the lesson, schedule, classmates themselves.

Among the advantages are the convenience of viewing the schedule for the week, the ability to save homework, save information about classmates. You can also note the intuitive interface, so understanding the work of the application was quite easy.

Next, we will consider the application ElZhur.Uchitel. The purpose of this appendix is a journal for the teacher, which shows a list of subjects and the journal of student assessments (figure 2).

A significant disadvantage is that the journal is designed only for the teacher and its data are not displayed to students. In general, there is no functionality for students, so, as in the previous application, there is no interaction between users.

Among the advantages can highlight the convenient division of the list of the magazine into academic quarters, as well as the calculation of the average score. It was also appropriate to use one color scheme and conciseness of the whole design.

Next, consider the application Weeklie. After analyzing the application, significant shortcomings were identified, including the lack of educational material on using the application with such functionality, the lack of functionality designed only for the teacher, and the lack of interaction between teacher and student, in addition, the student must enter all information about classes, schedules. Functionality is not enough for easy use.

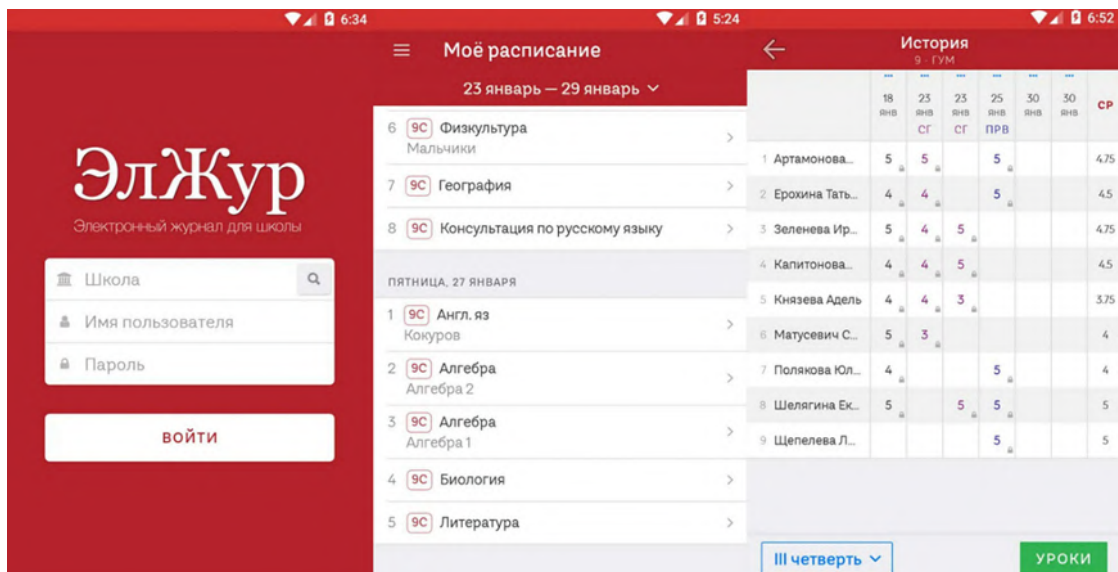


Figure 2: The interface of the application ElZhur.Uchitel.

Among the advantages is the ability to specify the exact time of the lesson, the ability to save homework, user notification system (figure 3).

Moyklass.com is a CRM system for educational institutions, including schools, that allows you to perform the following functions: individual and group classes, view lesson schedules, keep a log of visits, homework, and grades, students' birthdays, students' accounts, downloads documents, financial accounting, reports on various forms of work, mobile version, etc (figure 4).

bitrix24.ua is the CRM system for educational institutions. This is a system for automating the work of various educational institutions. CRM is a convenient set of tools for all actors in the educational process: students, teachers, school leaders, etc. This system provides the following features: viewing class schedules, video communication, automatic creation of student rankings based on analysis of attendance and performance, maintaining digital documentation of the school, integration with special systems for online testing of students (figure 5).

After getting acquainted with the analogs and their analysis, we can conclude that each software application is significantly different from its competitors.

The biggest disadvantage of all the above applications is the lack of interaction between students and teachers. All data is stored locally by the user and does not affect the system as a whole. Benefits include easy to use schedules, track homework, alert system, and statistics collection.

The work aims to design and develop a CRM system with a mobile, cross-platform, application for a school.

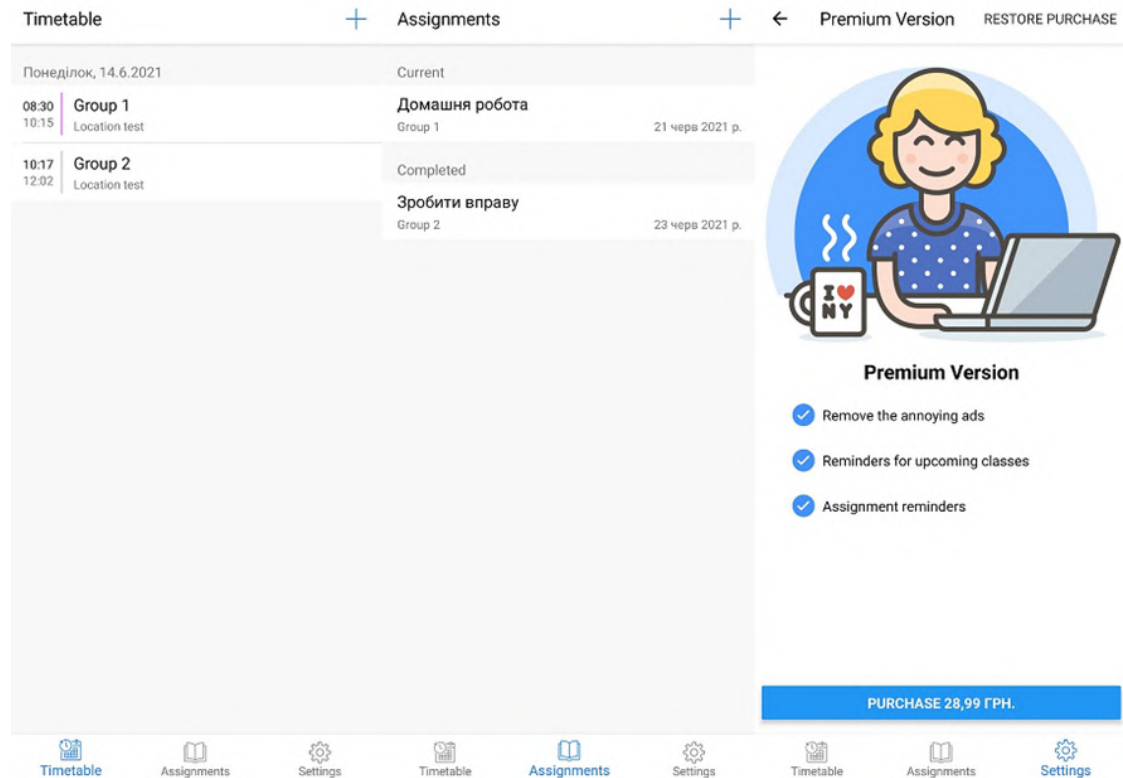


Figure 3: Weeklie application interface.

4. Results

4.1. Construction of software architecture

The application architecture can be considered the foundation that holds everything together and supports the codebase as it grows. If you have a good foundation, it becomes easier to make changes and add new things. The architecture uses design templates to solve problems effectively. Therefore, it is necessary to choose the design templates that best suit the problem to be solved.

Client-server architecture is the dominant technology in the creation of distributed network applications. It provides data exchange and interaction between developed software products. Client-server architecture can be defined as the concept of an information network in which the bulk of its resources are concentrated in servers serving their clients. The model of client-server interaction is determined primarily by the division of responsibilities between the client and the server.

Clients and servers of this architecture operate in parallel and are independent of each other. More than typical is the situation when one server simultaneously processes requests from different clients; on the other hand, the client can access one server or another. Clients need to know about available servers but may have no idea about the existence of other clients.

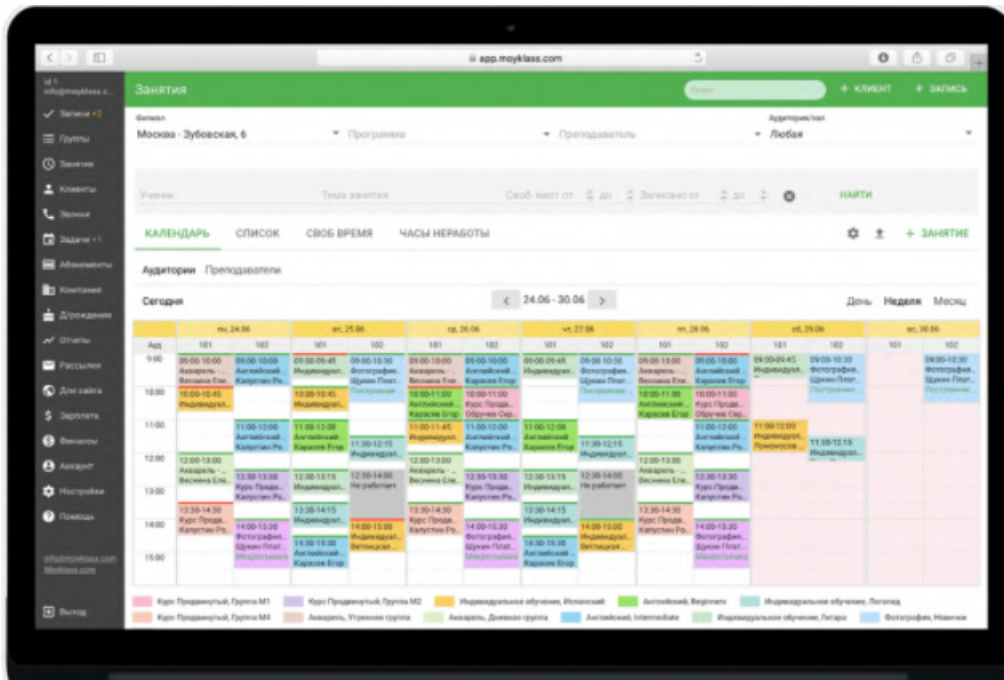


Figure 4: Moypass application interface.

The advantages of this architecture include the reduction of the load on the client, which, in turn, leads to a reduction in the cost of the system and reduce the requirements for hardware and software of clients. Logically, we can distinguish three levels of operations: the level of data representation, which, in essence, is a user interface and is responsible for presenting data to the user and the input of control commands from him; application level, which implements the basic logic of the application and at which the necessary information processing; level of data management, which provides data storage and access to them.

If it is not possible to identify a good architecture, the developer does not have clear agreements on how to structure the application. The lack of composite components leads to the appearance of code that has many dependencies. This type of code is difficult to understand. Adding new features becomes problematic, and it's not even clear where the new code should go.

Some other potential problems are also common:

- The application has many variables, which complicates the knowledge of which widgets are rebuilt and when.
- It is unclear when certain variables may or may not be null because they are passed through multiple widgets.

All of these issues can significantly slow development and nullify the performance benefits that are common to Flutter.

In figure 6 shows a diagram of the architecture. Dotted horizontal lines define clear layers of

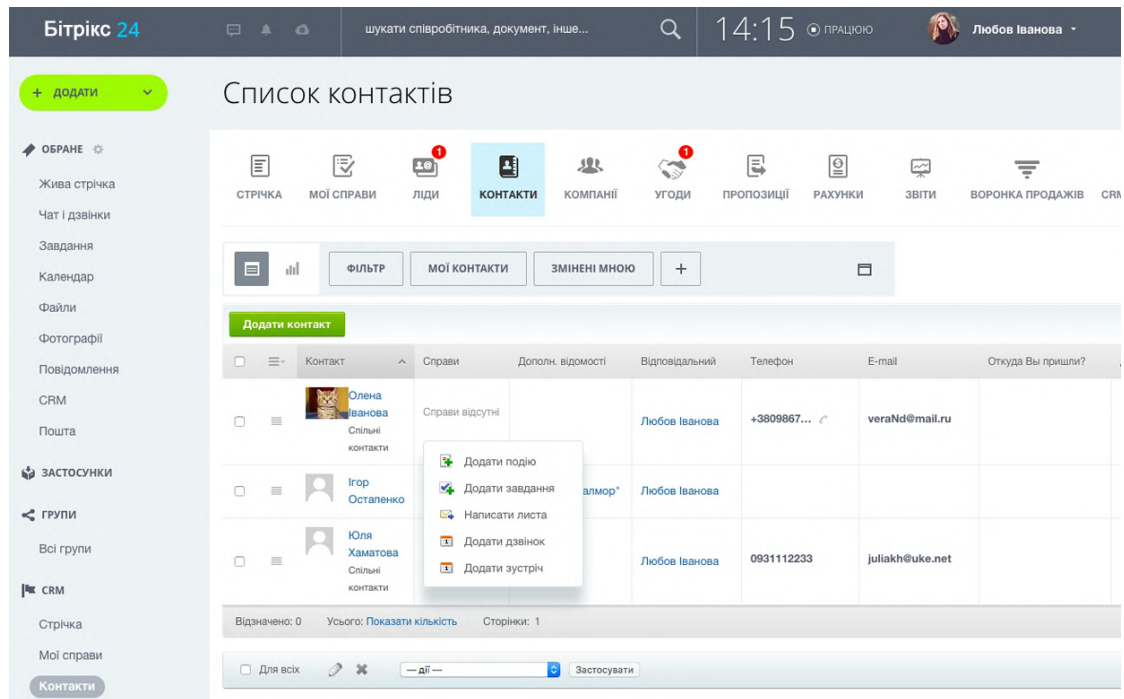


Figure 5: bitrix24.ua application interface.

the application. This comes down to the single responsibility principle: each component in the application must do only one.

The following patterns can be used to separate business logic: MVC (Model View Controller); MVVM (Model View ViewModel); BLoC (Business Logic Component); MVP (Model View Presenter) [18].

This system is event-oriented, so the MVC pattern is not entirely appropriate. Because the View component will create events to which the Controller component must respond. And this, in turn, violates the concept of the pattern, because the View component should not affect the Controller. In addition, there are more appropriate patterns for such tasks.

MVVM consists of three components: models, presentation models, and presentations. This pattern is quite common in the design of mobile applications, which is quite justified because it is quite easy to use. MVVM is convenient to use instead of the classic MVC and the like in cases where the platform where the development is, there is a “data binding”. The MVVM architecture has a clear division of responsibilities. Functional connections between the user interface and the ViewModel are implemented through bindings, which are essentially rules such as “if the A button was pressed, the `onButtonAClick()` method of the ViewModel must be called”. Bandages can be written in code or defined declaratively [18].

BLoC (figure 7) is a pattern quite similar to popular solutions for mobile devices, such as MVP or MVVM.

It separates the level of presentation from the rules of business logic. This is a direct application of the declarative approach that Flutter emphasizes, ie $UI = f(state)$. BLoC is where events

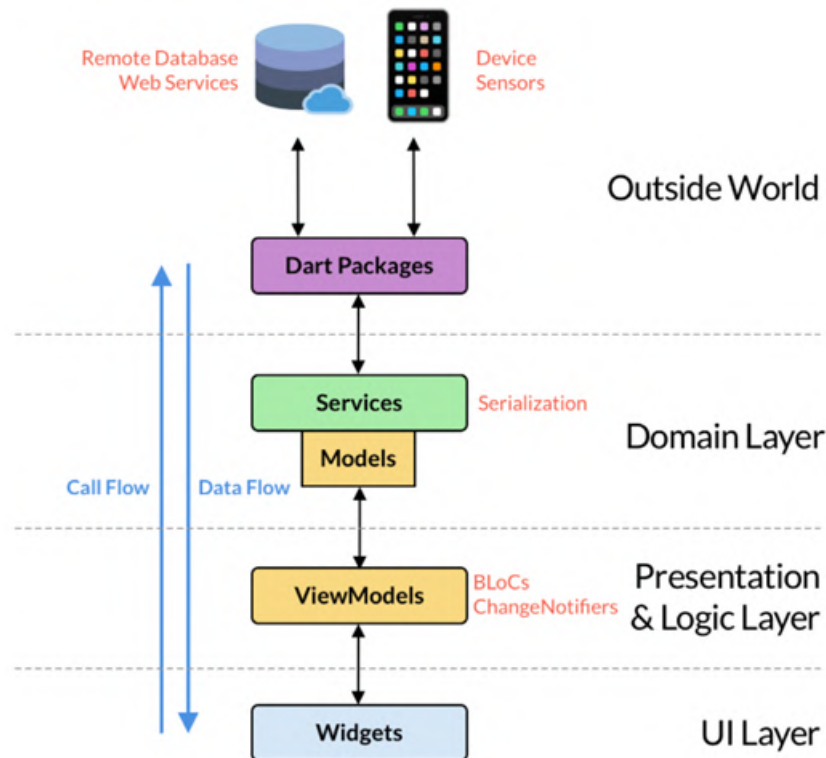


Figure 6: Diagram showing the architecture for Flutter & Firebase.

from the user interface go. Within this level, as a result of applying business rules to a given event, BLoC responds to a certain state, which then returns to the user interface. When the presentation level receives a new state, it restores its appearance following what the current state requires [18, 19].

MVP is a design template derived from MVC that separates the visual display and behavior of event processing into different classes, namely: View and Presenter. It is most often used for logically simple representations, but because most complex representations are logically complex, its use will also not be appropriate. In the case of simple representations, it can still be used, but mixing different patterns complicates the development and subsequent perception of the application code.

Therefore, to implement reactivity and meet the requirements of the mobile application, it will be advisable to use MVVM and BLoC patterns. The main advantage of BLoC over MVVM is that business logic can be completely separated from view, which is generally the best way to do something. As modern software development requires more and more changes to the user interface (as these are different screen sizes, densities, platforms, etc.), detaching the interface side from the models is a fantastic feature for reusing code.

Thus, the most flexible mobile application architecture was analyzed and selected.

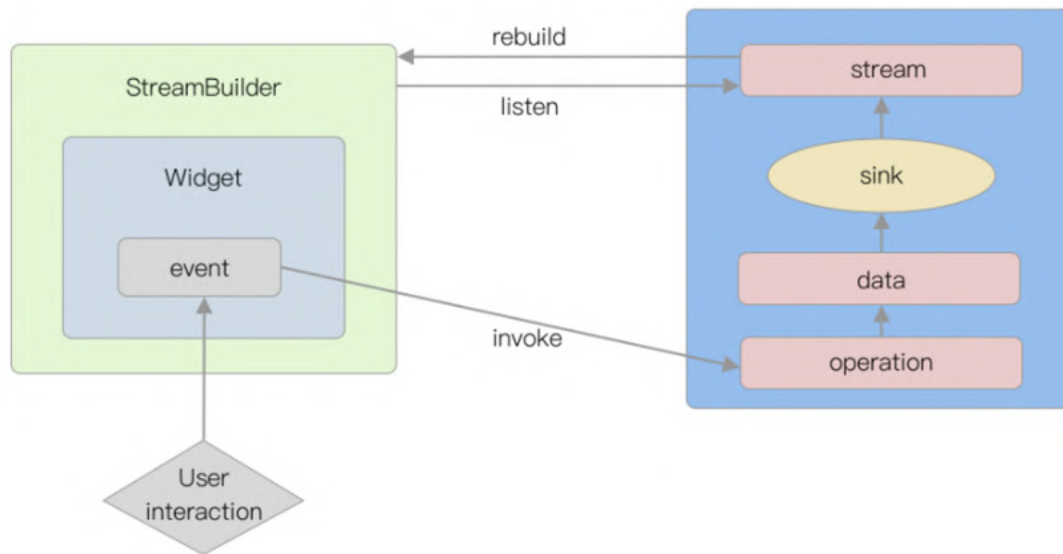


Figure 7: BLoC pattern.

4.2. The rationale for the choice of tools

In the world of cross-platforms, all frameworks are approximately the same in structure. At the heart of everything - the target platform (iOS, Android), for which development is underway, and a layer of abstraction, which promises to do quickly, cheaply, and beautifully, and between them the bridge that connects the two entities.

This architecture has typical problems. They are partly because the layer of abstraction, relatively speaking, tries to sit on two chairs. Hence the difficulties: on each platform, the application is displayed and behaves differently. Sometimes this is not a problem, but there are times when the unique design and behavior on both platforms is an added business value [20].

In terms of requirements, one of the highest priorities is speed. Also, taking into account the experience of knowing these languages, the impression of developing mobile applications on these frameworks [21], and the availability of prototypes, Flutter was chosen.

Dart is an object-oriented and customer-optimized language for fast applications on any platform. The strengths of this language are:

- Improving the ease of development. JavaScript has a wide entry threshold. Dart should not complicate anything, but on the contrary, if possible to make the threshold easier (due to a clearer and more concise syntax), as well as to preserve the incorruptible and well-established essence of JavaScript.
- Increase productivity. Speed is one of the main problems of all modern technologies.
- Friendly to code editors and additional developer tools.
- Security.

The Firebase platform was chosen to work with the database. The main reason for choosing Firebase is the availability of the Firebase Realtime authentication service and database on

the platform in the cloud. The authentication service allows the user to link their accounts to the application, and accordingly – link any of their data. This service supports all standard authentication features. Each authorized user is provided with a unique Firebase user ID, which is used when integrating other Firebase services [22].

Work with the Firebase Realtime database is carried out in real-time without the need to make GET requests to the server. The data is stored in JSON format and synchronized with each connected client [22].

Finally, it is worth mentioning Firebase Storage. Firebase Storage is a service that supports downloading files from both the project and the project. It was decided to use this service in the application for reliability, convenience, and security. All uploaded photos will be stored in Firebase Storage.

4.3. Designing an object-oriented structure of the system

Patterns need to be carefully selected and adjusted to the system. This is necessary for the implementation of effective solutions and their justified use. Next, will consider the patterns used in the design of the mobile application.

This mobile application is event-oriented. The components of the application interface that interact with the user are built on the BLoC pattern.

Events and actions are the input to the BLoC architecture. They are usually created in response to user interaction with the interface, such as button presses or life cycle events such as page loading. States are the results of the BLoC architecture. Moreover, they are part of the overall state of your application. Interface components can receive status notifications and redraw parts based on the current status.

BLoC (a component of business logic) converts a stream of input events into a stream of output states. BLoC is like a “brain” that receives information, processes it, and responds.

Stream is a sequence of asynchronous data. The user interface and BLoC listen to this stream and respond to any changes.

This application uses 13 BloCs:

1. AuthenticationBloc – the main block responsible for the definition of user authentication. Checks whether the user is logged in to his account, and if this is his first time, then send to the page to fill out the profile.
2. ChatBloc – using Stream, gets a list of chats of the current user.
3. GradebookBloc – using Stream, gets a log of grades depending on load options, such as student ID, group.
4. GroupBloc – to add a new group, also responsible for field validation.
5. GroupListBloc – using Stream, gets a list of groups depending on the load options.
6. LessonBloc – to add a new lesson with the choice of teacher, group, location, as well as fields such as homework, lesson topic, or regular class, or not blocked.
7. LessonListBloc – using Stream, gets a list of lessons depending on the load options.
8. LocationBloc – to add a new location, also responsible for field validation.
9. LoginBloc – is responsible for the user’s login. Responds to field changes using events (EmailChanged, PasswordChanged, LoginWithCredentialsPressed). Performs field validation.

10. MessagingBloc – is responsible for streaming messages, sending them. SendMessageEvent, MessageStreamEvent events.
11. ProfileBloc – is responsible for saving user profile information. Responds to field changes and validates them. Events NameChanged, BirthDateChanged, PhotoChanged, Submitted.
12. SignUpBloc – is responsible for user registration in the application, as well as field validation.
13. StudentListBloc – get a list of students of a certain group, or students who are not yet assigned to a group.

For all this to work, BLoC must be available. There are several ways to make it available. For example, through the global Singleton. This method is not recommended because Dart does not have a class destructor, so it will not be possible to free resources properly. Therefore, a separate instance of BLoC is created in the application. Initialization takes place inside the StatefulWidget.

The Repository architectural pattern was also used in this mobile application. Dart serves as an abstraction between the client code and the data provider, so as a developer working on features, you don't need to know where the data comes from. It can come from an API provider or a local database. So it's a good practice to use the Repository template.

The combined BLoC and Repository patterns work well together (figure 8).

The project uses 7 classes Repository (ChatRepository, GradebookRepository, GroupRepository, LessonRepository, LocationRepository, MessagingRepository, UserRepository).

4.4. Development of data storage structure

The data storage structure plays an important role in project development. Namely, Cloud Firestore was chosen for storage. It is a flexible, scalable NoSQL cloud database for storing and synchronizing data for the client and server-side development. Cloud Firestore also offers seamless integration with other Firebase and Google Cloud products, including cloud features. And Storage for Firebase is a powerful, simple, and cost-effective object storage service. Firebase cloud storage SDKs add security to Google for uploading and downloading files for Firebase applications, regardless of network quality.

The following tables are required to implement the project database: messages, chats, users, gradebooks, gradebookRecords, groups, lessons, locations, cities.

Using Firebase, you can create subcollections. For example, the gradebooks collection, which is responsible for grades and attendance, contains a subset of records for each student.

4.5. Design and implementation of algorithms for system operation

The first algorithm encountered by the user in the application is to determine whether the user is logged in. Then the role of the user is determined, whether it is a teacher, a student, or a manager. Depending on the role, the corresponding tab opens. In figure 10 shows the tab algorithm for the teacher.

If the role was defined as a student, then the first tab is displayed – GroupInfoPage. In figure 11 shows a diagram of student. For the student, the second tab is ClassmatesPage, where the student can view his profile information and a list of classmates. The second tab for the

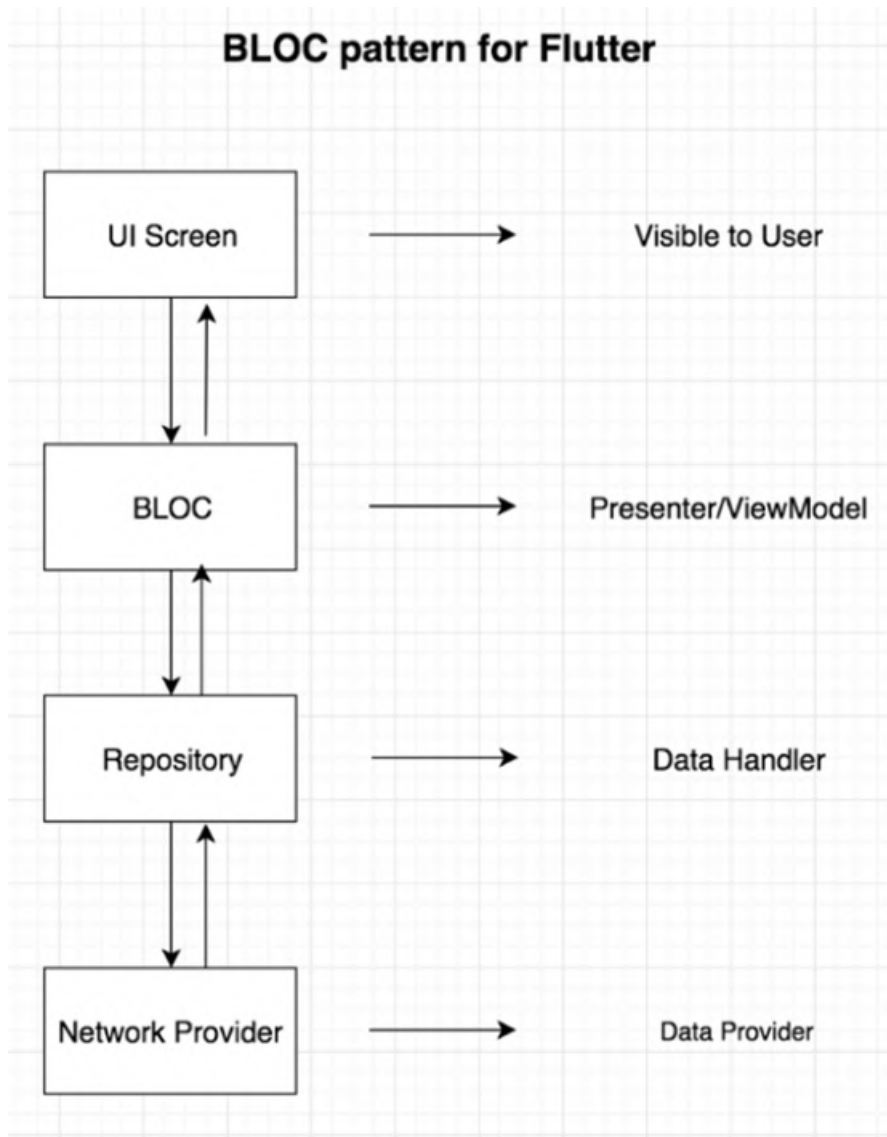


Figure 8: Using BLoC and Repository.

teacher is GroupListPage with a list of groups and the ability to add new groups, locations, and lessons (figure 12).

4.6. The procedure for installing and administering the system

The Flutter architecture differs from other software frameworks (React, Apache Cordova) in that it does not use HTML, CSS, and Javascript to build the interface, respectively, and the built-in WebView engine. It uses its engine for rendering. Flutter uses only one Dart programming language. Flutter is an innovative technology for developing cross-platform mobile applications

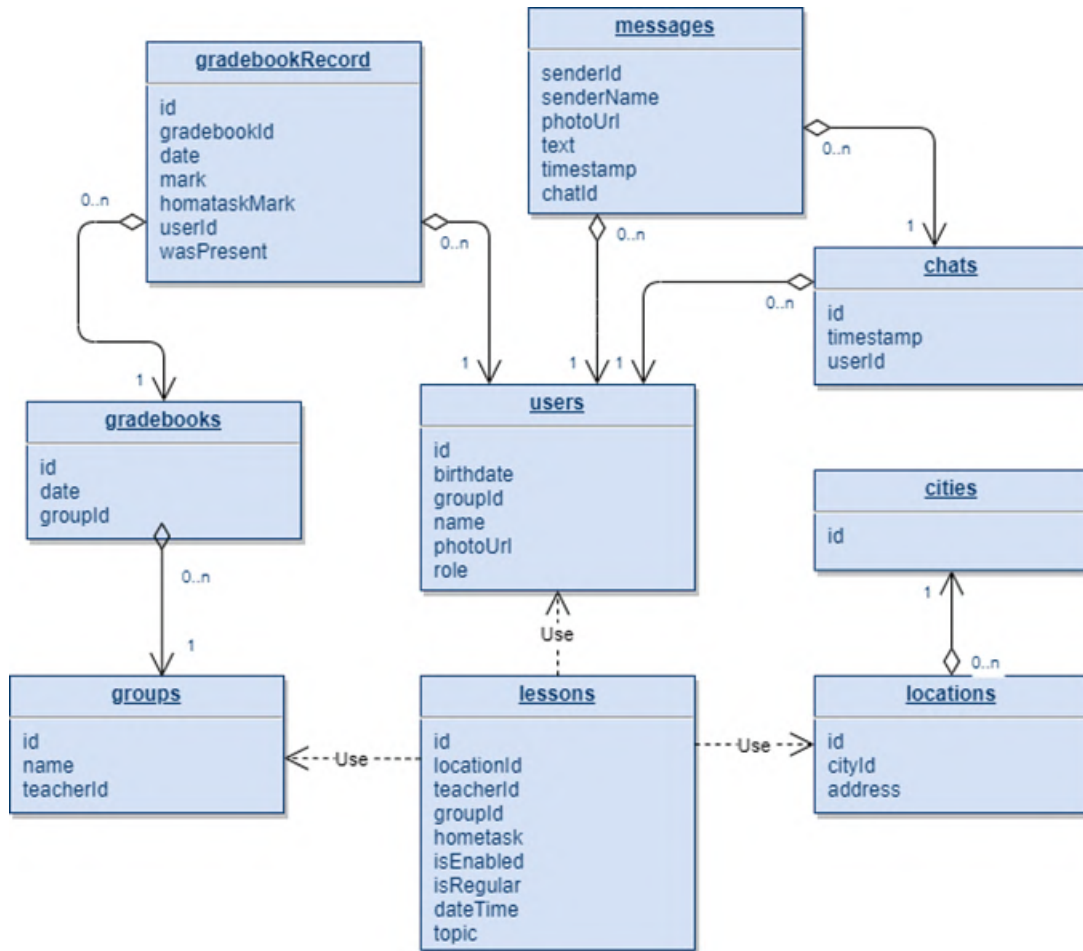


Figure 9: Scheme of the database.

for Android and iOS. Its advantage is the deployment of both Android and iOS at the same time using a single code base. Development is faster without losing productivity.

The chart is built using the online resource app.creately. In the diagram we see that it is divided into two component components, namely:

- Smartphone;
- Firebase Server is a serverless structure that allows you to automatically run server code in response to events caused by Firebase functions and HTTPS requests.

To exchange data between the client (we are considering the application on the smartphone) and the server (webserver) is mainly used HTTP protocol or its extension HTTPS for secure data transfer.

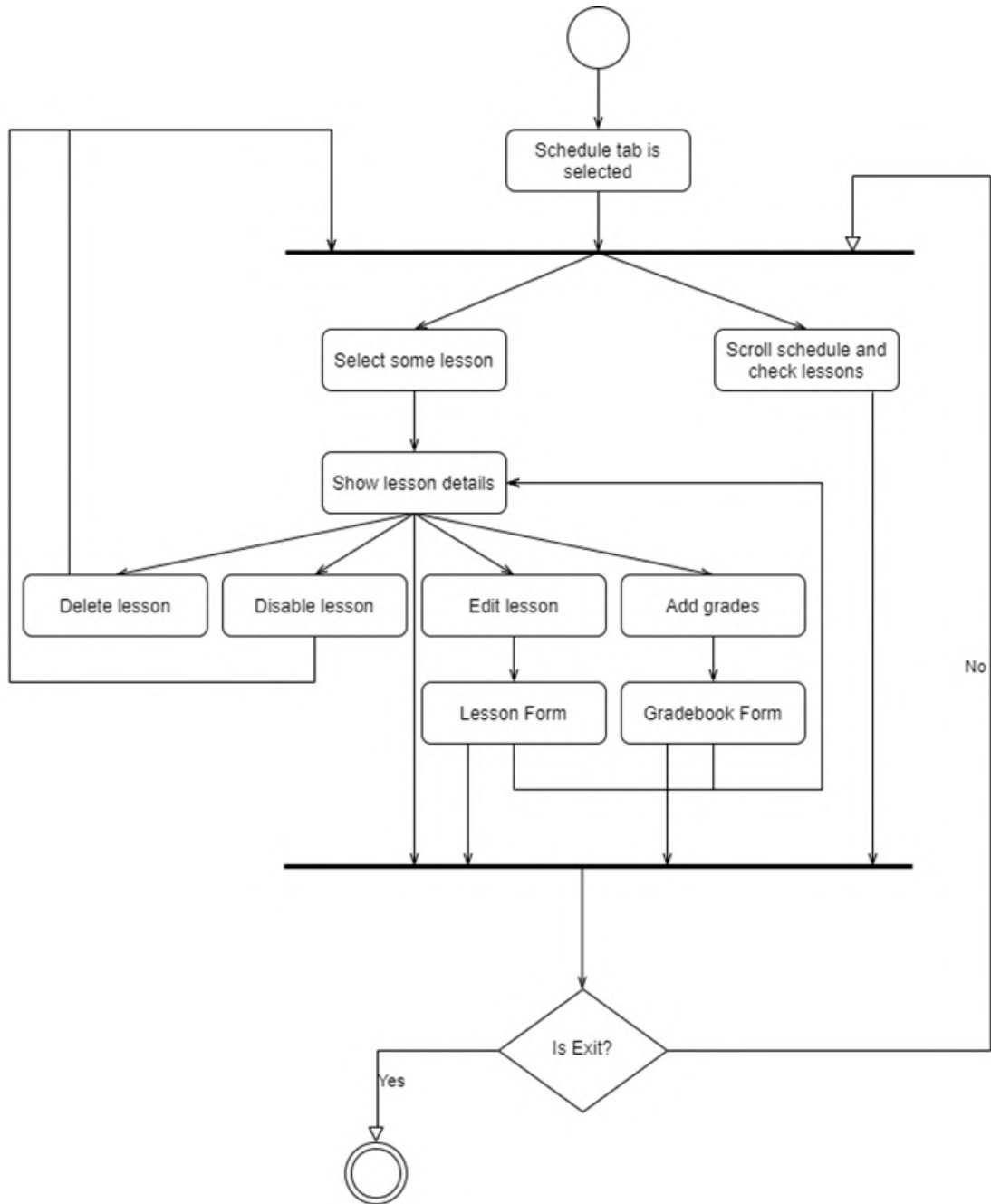


Figure 10: Diagram of teacher activity for the Schedule tab.

4.7. Interface and procedure for working with the software package

On the desktop, the first thing the user sees is the application icon. It should be notable, interesting and include universal symbols that will be equally perceived by people with different

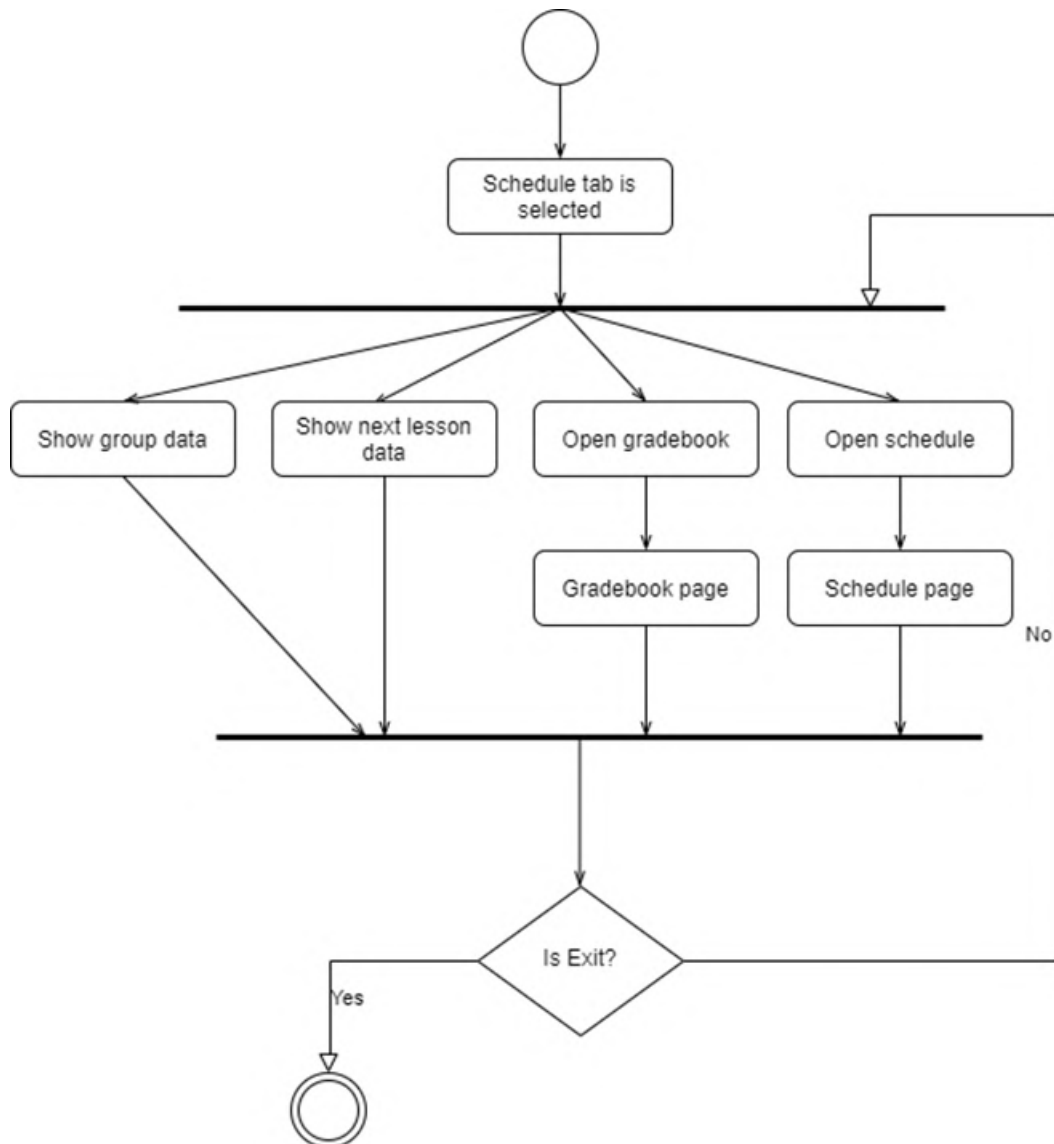


Figure 11: Student activity chart for the Schedule tab.

religious views. The style and logo were taken from the school Uprise Center, for which this product is developed.

The next thing that catches the user's eye is the download screen. It should also be stylistic and should be concise. It does not make sense to add a lot of text to it, because the application loads quickly and the user will not be able to read that information. Therefore, the design and text should be minimal.

The unauthorized user is the first to see the authorization page. If the user is new, he can click on the text in the form and go to the registration page. When the fields are filled, the button becomes active and changes color.

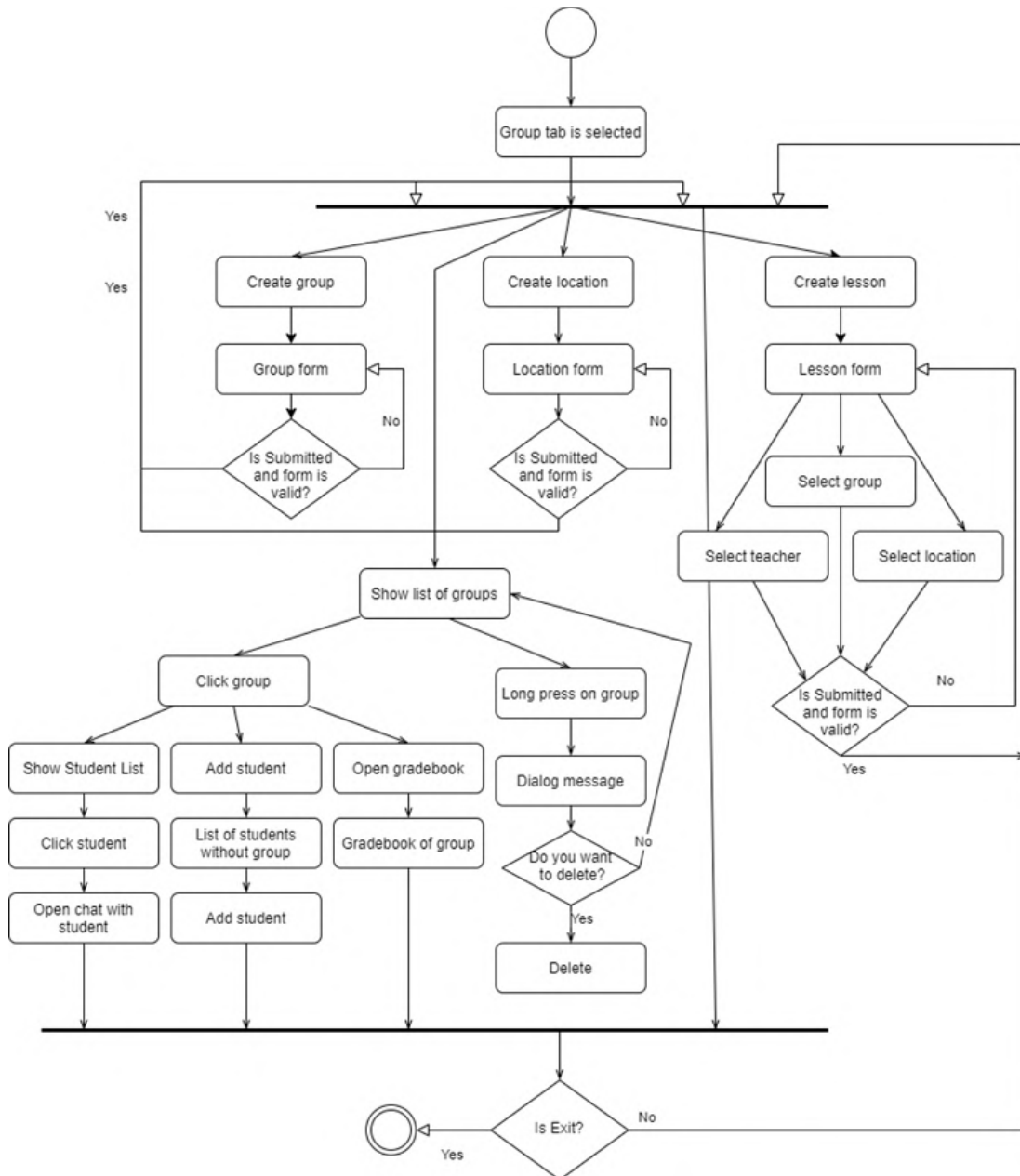


Figure 12: Diagram of teacher activity for the second tab.

To begin with, consider the type of application for the teacher. On the first page, we are greeted by the teacher’s schedule (figure 14, A). Figure 15 shows the lessons in the schedule. Lessons differ in color because they have differences.

Blue classes are regular (held every week, `isRegular = true`), and active (`isEnabled = true`). This activity is displayed in the calendar each week on the appropriate day from the beginning

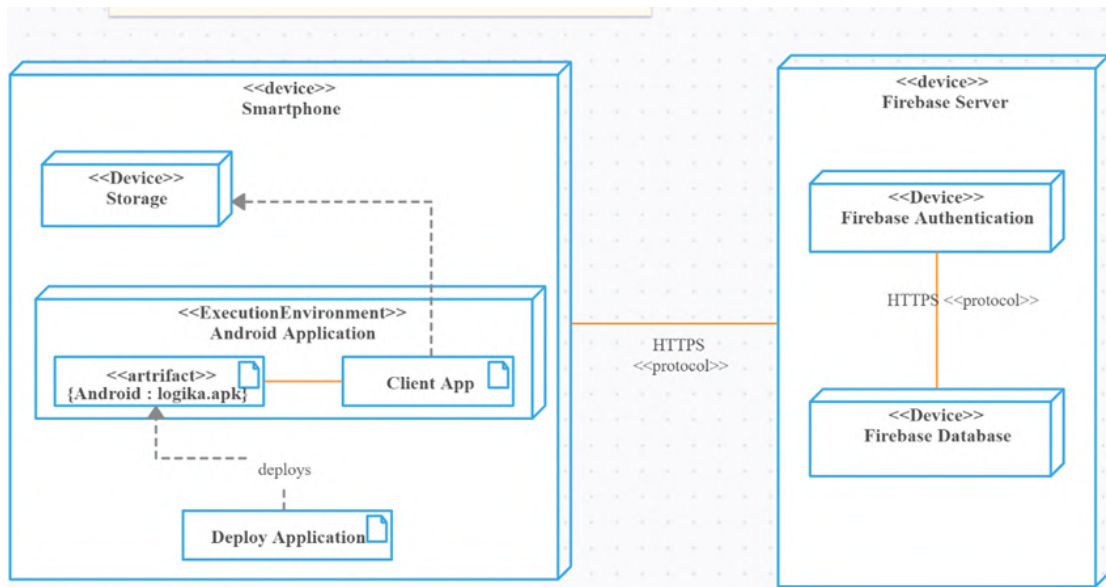


Figure 13: Deployment diagram.

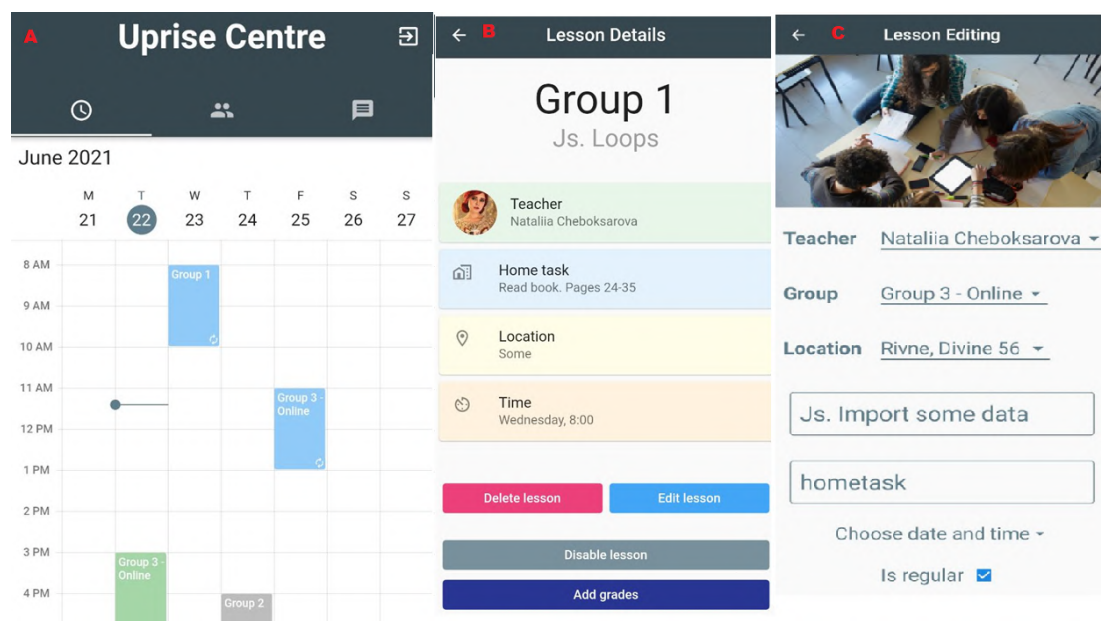


Figure 14: Teacher's schedule page.

of this lesson.

Green means that the lesson is single (ie will take place once, isRegular = false), active (isEnabled = true). This lesson is displayed in the calendar only once at a specified time.

Gray is a blocked activity (isEnabled = false). Whether it's a regular class or not, we can block

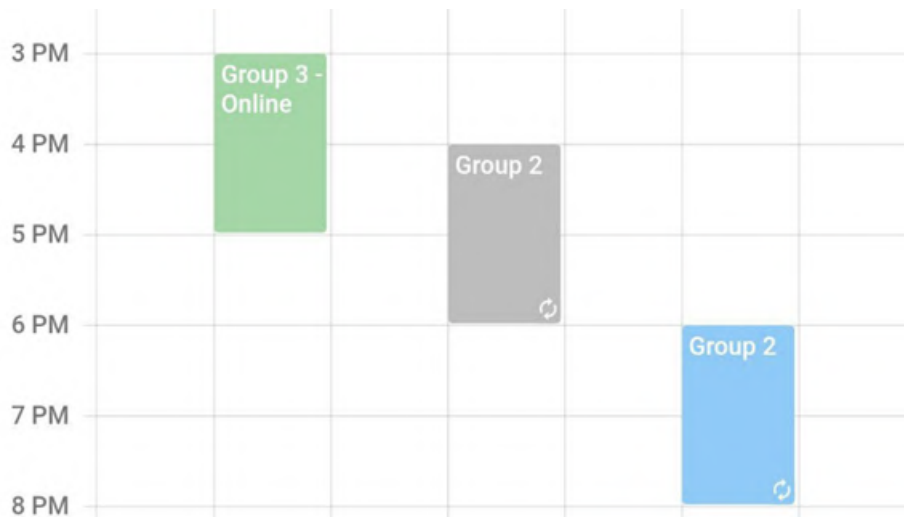


Figure 15: Display lessons in the schedule.

classes. That is, it will no longer appear in the student, but it can be activated at any time. This convenience helps to avoid deleting the lesson.

When you click on the lesson, detailed information about the lesson opens, and buttons for actions on the lesson are displayed (figure 14, B). For example, we can delete a lesson or edit it. Also, block the lesson and add grades to it.

The form for editing a lesson is the same as when creating a lesson. The difference is that it is already filled with data that is about this lesson. So that the user does not have to rewrite everything again, and he just changed the field he needs. The lesson editing page is shown in figure 14, C.

To create an entry in the journal, you must click on the “Add grades” button when editing the lesson. Then a form will open with a list of all students, where in front of each will be a tick that can be clicked and turned into a cross, which means whether the student was present. Also, next to each name you can put grades for the lesson and homework. Grades are given in a five-point system. By default, the student was present at the lesson, and the grades will be recorded as 0. The peculiarity of a school is that the grade for the lesson and homework is mandatory. Therefore, 0 is considered a full grade for poor performance in class. The completed and blank journal entry form is shown in figure 16. The second tab of the teacher is the tab of groups, as well as adding new locations, groups, and lessons.

When you click on the buttons Create group, Create lesson, Create location, the corresponding form of creation opens. Validation is calculated for each field. And if the form is not valid, the button is not active.

For such fields as City, Group, Location, Teacher the drop-down list from the received data is provided.

The last tab is chats, it is common to all users. It shows a list of chats. You can see the name and photo of the user you were talking to, as well as the last chat message and how long ago this message was sent.

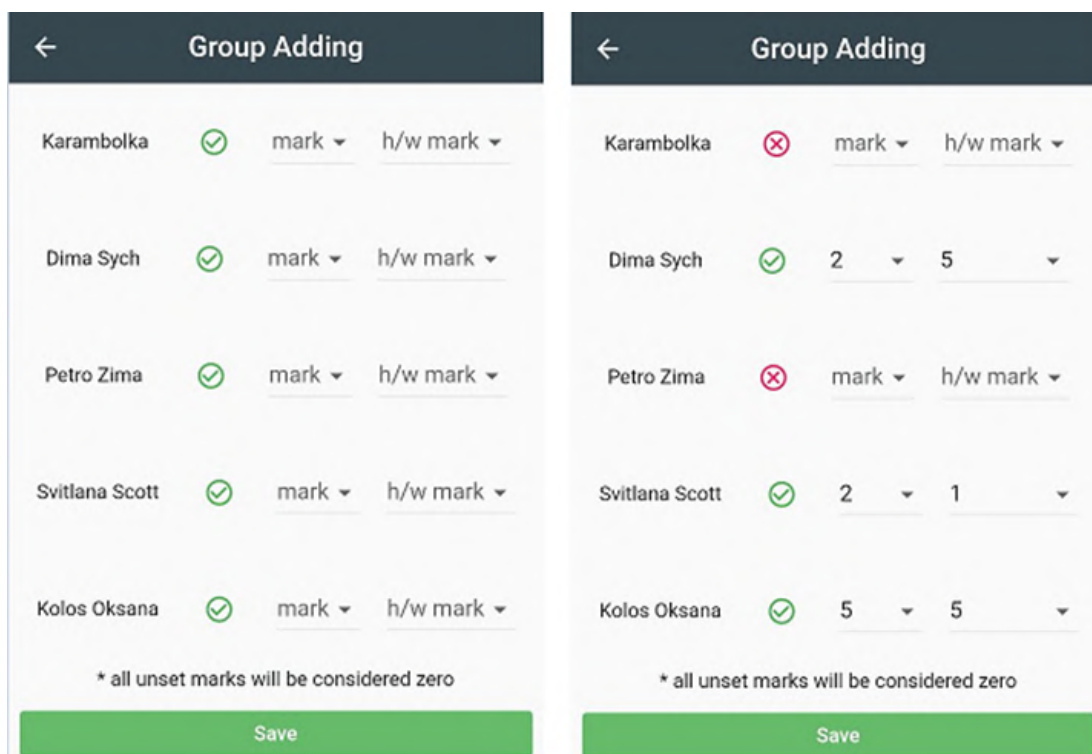


Figure 16: Empty and filled form of assessments and attendance at the lesson.

When you click on the chat it opens and all messages are displayed, showing who sent them and when. Also below is a text entry field, as well as a button to add a photo. When opened, the chat is initially scrolled down and shows the last message. You can send both short and long messages, photos, emoticons.

When you long-click on a group in the group list, or a chat in the chat list, or a student in the corresponding list, a dialog box will pop up, asking if you want to delete the item. When you select “no”, the action is canceled. If you agree, the item will be deleted and the list will be updated, so the deleted item will no longer be displayed.

For the student, the appearance of the first two tabs will be different. For example, the first tab will show the name of the group and detailed information about the next lesson (figure 17). The next lesson is based on single and regular lessons but ignores the lessons that are blocked. There are also buttons to show grades and schedules, which work in the same way as the teacher. The difference is that only this student’s grades and schedule will be shown.

On the second tab, the student is waiting for his profile information, which he filled out after registration, as well as a list of all the children in the group to which he is attached. Clicking on any student will open a chat with him. You can also open chats, as in the teacher, going to the last tab (figure 17).

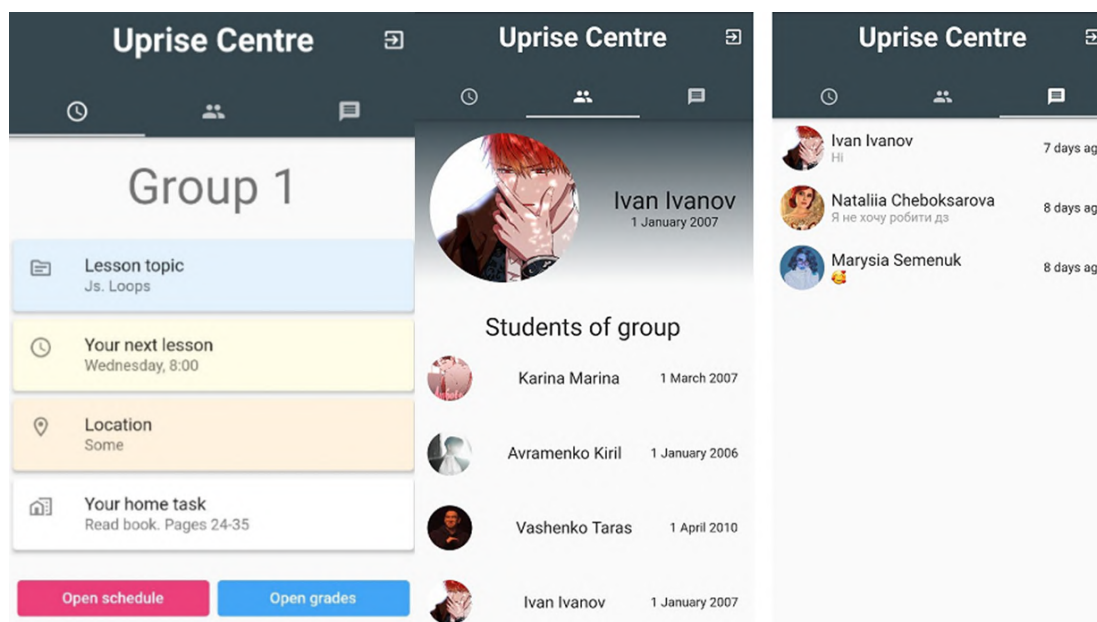


Figure 17: All tab of the student.

5. Conclusions

In this work, a software product was developed – a CRM system with a mobile application for a school. In the course of the work, the processes of modeling, building architecture, and implementation of web application functionality were described. This CRM system is implemented in the educational process of a school and undergoes initial testing. Further development and support of the developed software product are planned. Thanks to a properly designed architecture, these processes will take place without undue delay in adapting the structure of the application.

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An approach for processing and document flow automation for Microsoft Word and LibreOffice Writer file formats

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Abstract

The rapid growth of modern information technologies influences all aspects of human life. Companies all over the world are adopting new approaches to solve business problems, such as diverse automation, by using information technologies. Automation substitutes routine human work and noticeably increases efficiency. This research examines different approaches to document automation. Basic concepts of document processing using XML and existing solutions have been reviewed and a library based on LibreOffice UNO API has been designed and implemented. The library contains different helpers, wrappers, and processing tools to create an additional layer of abstraction. Moreover, the library is aimed at simplifying processing, working, and converting documents, which might considerably optimize a process of creating document reports generators.

Keywords

document processing, automation, library, OpenDocument, Office Open XML

1. Introduction

A significant amount of organizations, companies, and educational institutions deal frequently with different document-related processes. Eventually, the growth of a company causes a demand on optimizing processes. Documentation generators are one of the earliest and substantial stages of business processes automation [1].

According to McKinsey Global Institute [2], which is a part of the worldwide management-consulting firm McKinsey&Company, from 9 to 26 percent of working hours could be saved by automation. Additionally, with a midpoint of 15 percent, about 30 percent of working places could be displaced by 2030, which is equivalent to 400 million full-time working days. In addition, the research admits that about 50 percent of working time, which is spent on different types of work, might be optimized with automation.

Hospitals, as well as other organizations, work with an immense amount of documents. According to Steve Wilson's paper on Electronic Health Reporter website [3], every day doctors have to deal with a large amount of different documents, starting from physician agreements

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and credential documents to time sheets and other organizational forms. Undoubtedly, it is hard to handle or search through such a number of paper documents in comparison with digital ones. Another, surely important, reason to use automation is working with patients. Digital forms help to avoid human interaction, which has become crucial due to the COVID-19 pandemic. In addition, digital forms might help simplify the whole process of requesting prescriptions.

Whilst the described problem seems completely explored, it is not exactly so. Many existing implementations are proprietary, that is to say you could not obtain their source code easily. This leads to the fact that it is hardly possible to launch software locally for your company or set it up preferably, for instance, choose a web-server or database. Moreover, the assortment of the supported documents is usually meager and often includes only Microsoft Office formats. Another hot topic is privacy. If processed documents contain users' sensitive or corporate data, you could not trust proprietary cloud services you are not able to control. Moreover, it could be simply considered illegal in some countries to transfer personal data to 3rd parties servers. Consequently, it is critical for document automation systems to allow users to have control over their data. The aforesaid leads us to the reasons why we decided to develop our own document management system as an attempt to solve the mentioned problems.

2. Overview

A review of scientific literature [4, 5, 6, 7] on the topic of document flow automation showed that the topic is relevant. But due to the lack of access to the source code, we will examine only those implementations that are open or provide, at least partially, free trial access to the service.

Let's take a look at the proprietary document processing systems.

Hypatos [8, 9] is a workflow automation system which uses artificial intelligence, namely Cognitive Process Automation (CPA) technology. It is a fairly high-quality and professional tool. It supports AWS and cloud storage. Both API and free version are available.

DocuPhase [10] is a system for automating business processes. It supports web forms that allow one to generate ready-made PDFs. It also features a document management system with user-friendly interface for processing and managing files shared among different departments.

Docupilot [11] is an automation and documentation generation system. It supports working with cloud services such as Zapier, DropBox, Docusign. It has a good templating engine with conditional statements, tables and loops support. It could handle docx, pptx, pdf or a custom, created with a WYSIWYG editor, template. It also supports email messages sending. There is documentation and examples of using the internal API.

Contactbook [12] is a platform for organizing, storing and processing documents. The service supports docx and pdf files. An integration with 3000+ programs has been implemented. A public API as available as well.

Now let's take a look at the open-source applications.

One of these is Docassemble [13], an open-source system for working with web forms and documents. The system is implemented with Python, YAML and Markdown. It is focused on "Interview" questions. That is to say, one web form is divided into several questions and at the end you can get a result. It supports YAML code in configuration files. With Markdown, one could dynamically create PDF, RTF, and DOCX files.

M2Doc [14] is an open-source plug-in for automating MS Word files processing. There are add-ons for MS Word and Eclipse IDE. The generator takes input data from a generator configuration `.genconf`. One is able to work with the original Java API.

Summarizing this section, the reviewed systems are competitive and powerful tools. But, they have the following disadvantages:

1. Static patterns. Most tools use only one proposed pattern for fields filling. It means that only system prefix and suffix ought be used in templates. For instance, with the prefix `{` and the suffix `}`, field definition would look like `{{field}}`.
2. Solely Microsoft Word formats support. Most mentioned systems don't support LibreOffice file format or other similar formats. However Microsoft products usage is not always possible or acceptable by some companies.
3. No internal converters. Sometimes it is needed to convert a document into different format than docx or pdf.

Thus, it was decided to design our own system for documents processing that would satisfy our needs.

3. Approaches in document processing

Document management system needs a core document processing tool. There are a few different approaches in Microsoft Office and LibreOffice documents processing. We will overview the most popular: XML processing and frameworks.

Microsoft Office and LibreOffice documents are basically archives with all content inside. Most of the files inside are XML files. They represent document's structures, styles, metadata, settings, and other configurations.

Microsoft Office documents (doc and docx) have their own XML-based file format developed by Microsoft, which is called Office Open XML (OOXML). Its structure is shown on the figure 1.

The actual content of the document is stored in the word folder in the document `.xml` file.

LibreOffice documents also have their own XML-based format called Open Document Format (ODF) also known as OpenDocument [15]. ODF is developed by The Document Foundation. The structure of the document is shown on the figure 2.

In this case, the actual content of the document is stored in the `content.xml` file. Depicted structures may vary depending on the complexity of a document. In comparison to docx document, which has three folders files hierarchy, an odt document has a similar structure but contains additional folders such as configurations.

In the case of document generating on the basis of a template with custom keywords, the keywords might be split by office software into different tags. Therefore, this approach needs additional validation and handling of the keywords parts to merge them together.

To inquire the issue let us look at a simple document that contains the following text:

```
1
${Keyword}${Keyword2} and ${Keyword3}
${Keyword4} some text.
```

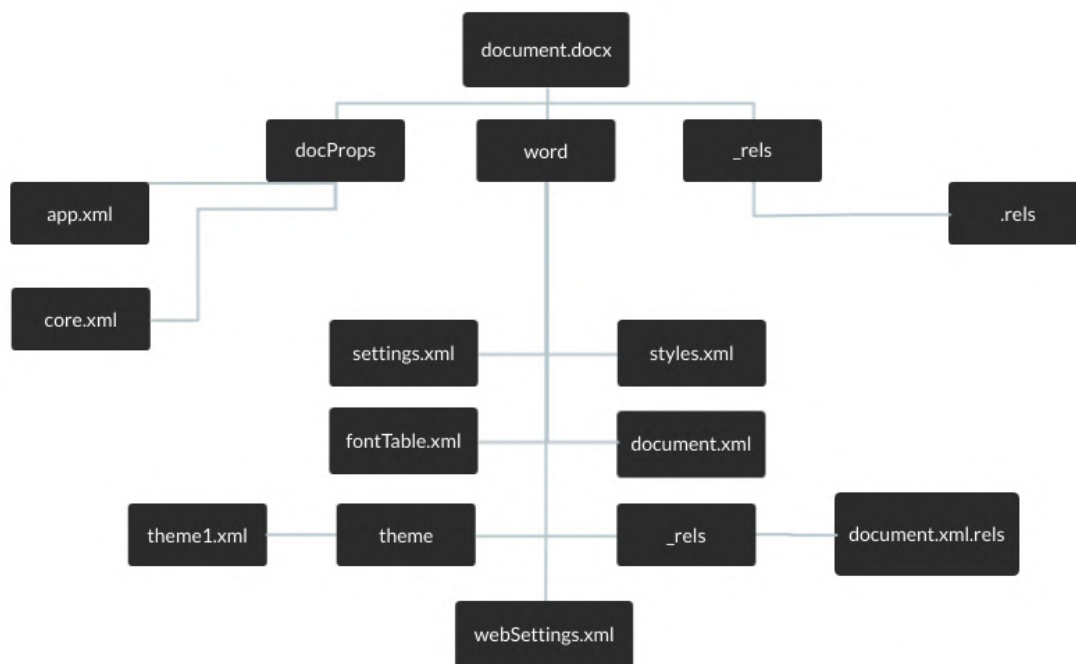


Figure 1: Docx file structure.

$\{$ and $\}$ statements indicate the beginning and the ending of a keyword. All the paragraphs have the same style family, namely Calibri 11 pt. However, things appear to be more surprising in the content file. Figure 3 shows the XML representation of the first keyword.

Microsoft Word splits text into different $w:r$ elements called *runs*. Inside each run, we can see a $w:r$ tag that represents a text element. So one keyword in this example has 3 different runs with different parts of the keyword. The second keyword is shown on figure 4.

In this case, we have four different runs. The number of runs depends on the length of the keyword and different special symbols. The same issue may be found in LibreOffice documents.

For the LibreOffice document, we will use the same font family and font size. Right after document creation, we get the solid not split paragraphs. The XML representation of the text is shown on the figure 5.

A problem may appear after editing the document with LibreOffice editor. Let's change the `KeyWord2` keyword to `KeyWord_New`. The result of this replacement is depicted on the figure 6.

As a result of a slight document editing, the XML changed significantly. New elements were added and the keyword split into 2 parts, even though the keyword still has the same style. At first glance, it may seem that the problem is in using the underscore character. However, to dispel this assumption, we will return the original value to the keyword. The result is shown on the figure 7.

Even after original value recovery, we still have the XML code which is different from the initial one. Moreover, two extra `text:span` elements appeared. In the case of the LibreOffice

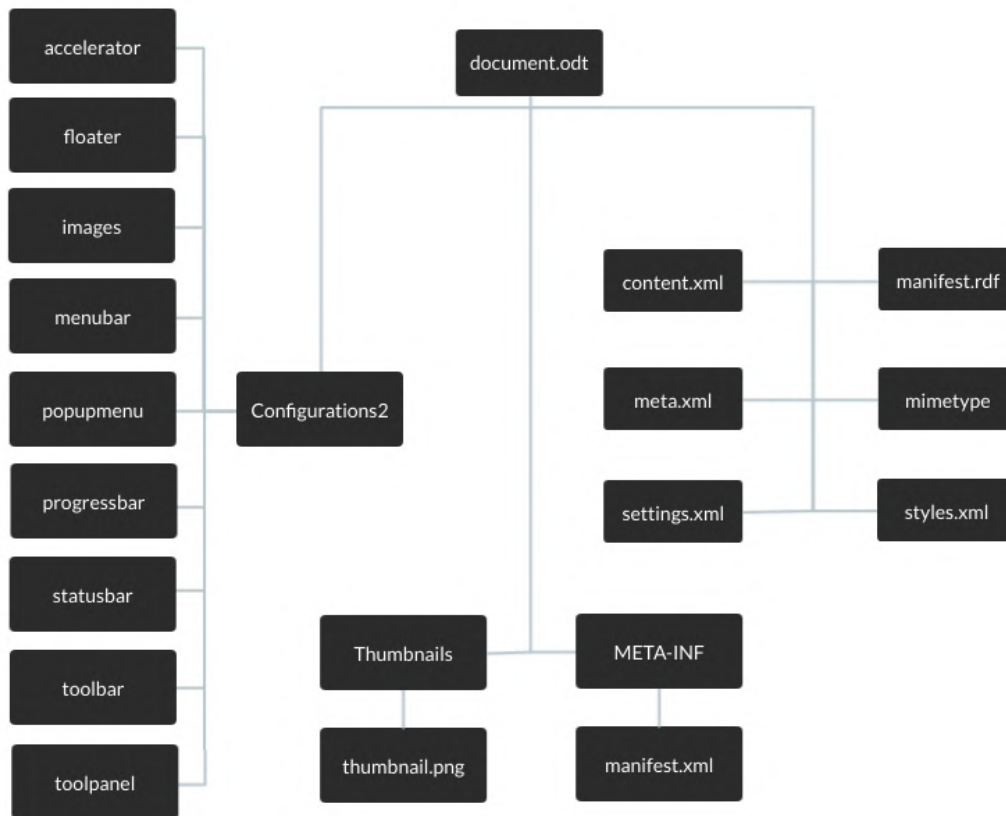


Figure 2: ODT file structure.

documents, `text` : span elements may be added as a consequence of updating or text changing within the document.

Another approach is using LibreOffice UNO API. LibreOffice provides Universal Network Objects, which allows using this API in different programming languages, such as C++, Java, Python, Perl, C#, JavaScript, and many others. This API supports working with different formats, originally LibreOffice applications, but partly including support of Microsoft Office applications. As a matter of fact, LibreOffice UNO API is almost completely compatible with OpenOffice.

LibreOffice has a Frame-Controller-Model paradigm (FCM) that is similar to the Model-View-Controller paradigm (MVC) [16]. The model contains the document data and methods to change them. The controller views the status of the documents and manipulates screen presentations. The frame contains the controller and knows which windows are being used. This approach allows interacting easily with the application's GUI and its functionality.

LibreOffice UNO API is extremely functional and useful in document manipulation. However, API documentation is bulky and might be time-consuming to read [17]. Due to this fact, we decided to develop a library as a layer over the LibreOffice UNO API.

```

23 <w:r>
24   <w:rPr>
25     <w:lang w:val="en-US" />
26   </w:rPr>
27   <w:t>${</w:t>
28 </w:r>
29 <w:proofErr w:type="spellStart" />
30 <w:r>
31   <w:rPr>
32     <w:lang w:val="en-US" />
33   </w:rPr>
34   <w:t>Keyword</w:t>
35 </w:r>
36 <w:proofErr w:type="spellEnd" />
37 <w:proofErr w:type="gramStart" />
38 <w:r>
39   <w:rPr>
40     <w:lang w:val="en-US" />
41   </w:rPr>
42   <w:t>}</w:t>
43 </w:r>

```

Figure 3: XML representation of the first keyword.

Returning to the split issue in XML documents, LibreOffice UNO API allows one to use GUI and work with text in a simpler manner. It handles text as though it had been edited by user. In addition, in comparison with the XML approach, this API provides access to styles and other functionality, like pictures, converters and other GUI functions.

We have chosen the Java programming language to work with the LibreOffice UNO API. Our library provides an abstraction to process documents easier in comparison with UNO API, and it does not require knowledge of the LibreOffice UNO API. As a part of this library, we have implemented classes for XML manipulations. In more detail, this library will be discussed in the next section.

4. Documents processing Java library implementation

The easier document processing approach is XML processing. It allows developers to implement a simple keywords replacement. On the other hand, LibreOffice UNO API provides a rich set of functionality for document manipulation. Nevertheless, it does not nullify the usefulness of the XML approach. A combination of two different approaches allows choosing developers which one is the most appropriate for their application. Usually, one ought to use two different libraries or frameworks to implement it, but our library provides a simple interfaces to interact with both solutions simultaneously.

Our library's purpose is to simplify access to the documents and their handling by providing

```

44     <w:r>
45         <w:rPr>
46             <w:lang w:val="en-US" />
47         </w:rPr>
48         <w:t>${</w:t>
49     </w:r>
50     <w:proofErr w:type="gramEnd" />
51     <w:r>
52         <w:rPr>
53             <w:lang w:val="en-US" />
54         </w:rPr>
55         <w:t>{Keyword</w:t>
56     </w:r>
57     <w:r>
58         <w:rPr>
59             <w:lang w:val="en-US" />
60         </w:rPr>
61         <w:t>2</w:t>
62     </w:r>
63     <w:r>
64         <w:rPr>
65             <w:lang w:val="en-US" />
66         </w:rPr>
67         <w:t>}</w:t>
68     </w:r>
69     <w:r>

```

Figure 4: The XML representation of the second keyword.

```

41     <text:p text:style-name="P2">1</text:p>
42     <text:p text:style-name="P3">
43         <text:span text:style-name="T1">${Keyword}${Keyword2} and ${Keyword3}</text:span>
44     </text:p>
45     <text:p text:style-name="P1">
46         <text:span text:style-name="T2">${Keyword4} some text.</text:span>
47     </text:p>
48     <text:p text:style-name="P1">
49         <text:span text:style-name="T2" />
50     </text:p>

```

Figure 5: The XML representation of the text in the LibreOffice document.

an additional abstraction. The library has been implemented using the Java programming language. The source code may be found at [18].

The XML approach is quite simple to use. The main class is `OdtDocumentPatternsAdjust`. It has two constructors. The first one is empty, and the second one with a `Pattern` parameter. The `Pattern` class is a `JavaBean` class with two fields, the start of the pattern and the end of the pattern.

The `OdtDocumentPatternsAdjust` class implements the `DocumentPatternsAdjust` interface which has two methods for adjusting the XML content. The methods are the following:

```
String adjustPatterns(File archive)
```

```

35 <text:p text:style-name="P1">1</text:p>
36 <text:p text:style-name="P2">
37     ${Keyword}${Keyword_
38     <text:span text:style-name="T1">New</text:span>
39     and ${Keyword3}
40 </text:p>
41 <text:p text:style-name="P2">${Keyword4} some text.</text:p>
42 <text:p text:style-name="P2" />

```

Figure 6: The XML document after editing.

```

38 <text:p text:style-name="P1">1</text:p>
39 <text:p text:style-name="P2">
40     ${Keyword}${Keyword
41     <text:span text:style-name="T2">2</text:span>
42     <text:span text:style-name="T1"></text:span>
43     and ${Keyword3}
44 </text:p>
45 <text:p text:style-name="P2">${Keyword4} some text.</text:p>
46 <text:p text:style-name="P2" />

```

Figure 7: The document XML after return the original value.

String adjustPatterns(File archive, Pattern pattern)

The actual processor of the XML content is the `OdtXmlPatternAdjustProcessor` class. It contains different methods for content processing, most of which are private. One of the public method is `processXml`. The algorithm of XML content processing is the following:

1. Get the position of the start and the end of the pattern.
2. Set offset to the position of the start of the pattern.
3. Get text before the next tag. It is needed to get the part of the pattern before there will be the next tag like `w:r` or `text:span`.
4. Move offset by adding the length of the found part of the pattern.
5. Look for the next possible part of the pattern meanwhile skipping tags without actual text inside.
6. When the next part of the pattern is found, get the text. At this step, the text will be extracted and inserted into the beginning of the pattern in the XML content.
7. Check whether the offset is less than the position of the end of the pattern; if it is, then repeat every action starting with step 5, otherwise the next step.
8. If the next part of the pattern could be found, repeat every action starting with step 1, and add the earlier found pattern into the `ArrayList`, otherwise return the list of the pattern.

The LibreOffice UNO API part is larger and offers richer functionality. There are a few essential classes. First of all, consider the `DocumentManagerProvider` class. This class is a Factory and provides the implementation of corresponding `DocumentManager` depending

on file extension. This class contains one static method called `createDocumentManager` and has the following signature:

```
DocumentManager createDocumentManager(File file)
```

`DocumentManager` is an interface that provides an ability to open a passed document. It has the following method:

```
Document openDocument(File file);
```

The `openDocument` method returns a `Document` instance, which is also an interface. This approach allows avoiding specific implementations for a developer. The `Document` class contains the following set of methods:

```
void saveDocument(File file);  
void saveDocument(String filepath);  
void saveDocument();  
void saveDocumentAs(File file, DocumentConvertTypes convertTo);  
void saveDocumentAs(String filepath, DocumentConvertTypes convertTo);  
void saveDocumentAs(DocumentConvertTypes convertTo);  
void replace(String search, String replace);  
void close();
```

These methods allow converting documents to any supported format and replacing a particular value in a document. The LibreOffice UNO API supports a considerable amount of formats to convert. All of them are described in Apache OpenOffice Wiki [19]. Partly, those types had been moved to our library and stored in an enum called `DocumentConvertTypes`. We decided to use enums to simplify the usage of constants that can be used as properties. In comparison with final static variables, enums make it easier to specify what should be passed there.

To provide more functionality, a lower abstraction layer is available. The `LibreOfficeUnoManager` contains most of the implemented methods in the `Document` class. This class provides basic methods to interact with documents without direct work with UNO API. As return values, it uses API's objects, so it may be considered an additional functionality layer.

There are small utility classes which might help in working with documents. Nevertheless, developers will rarely use them because most of the `LibreOfficeUnoManager` methods already have been optimized with the use of those utility classes. Let us look into two useful classes. The `OdtDocumentProperties` provides a wrapper for the `PropertyValue` class to simplify working with document properties. The `OdtFilePathHandler` helps to convert the initial `File` class into an understandable LibreOffice UNO API string. The reason for `OdtFilePathHandler` class existence is that LibreOffice UNO API works with Uniform Resource Identifier (URI). This means that the file path should be started with the `file:///` prefix and all backslash characters should be replaced with the slash character.

The next example demonstrates a basic usage of our library to replace keywords in the document and convert it into an appropriate format:

```
File file = ResourceManager.getResourceFile("Document.odt");
DocumentManager documentManager =
    DocumentManagerProvider.createDocumentManager(file);
Document document = documentManager.openDocument(file);
document.replace("{Search}", "Value");
document.saveDocumentAs(new File(
    "C:/Users/hp/IdeaProjects/XmlDocumentProcessing/File.docx"),
    DocumentConvertTypes.MS_WORD_2007_XML);
```

In order to work with text, we implemented a few specific classes. The `LibreOfficeUnoManager` class supports working with text using the `findAllAsText` method. The method's signature is the following:

```
public List<Text> findAllAsText(String search);
```

This method returns a list of `Text` classes. The `Text` class supports text editing, creating cursor, getting all paragraphs, setting font weight, and paragraph adjustment. The list of the methods is shown on the Figure 8.

An example of getting a text and performing some basic operations is shown below.

```
Text allDocumentText = libreOfficeUnoManager.findAllAsText("and").get(0);
allDocumentText.createCursor().gotoStartOfTheSentence(true);
allDocumentText.setCenteredAdjustment();
```

The `Cursor` class is basically usual graphic cursor. In order to move through the text, LibreOffice UNO API implements cursor as a main mechanism for this purpose. But, considering the fact of complexity of some original UNO API methods, we have implemented a simplified wrapper class. The list of its methods is shown on the figure 9.

The names of most methods, such as `gotoNextSentence`, are intuitively recognizable. Every type of `goto` moving has two different implementations. One does not have parameters and another one has a `Boolean` parameter. The `Boolean` parameter is used for telling the LibreOffice UNO API, whether should we stop and select current word or go to next one. Methods without parameters basically just use methods with parameters by passing `false` to them.

Also, to implement a more convenient way of `Cursor` class methods usage, `goto` methods take advantage of `Builder` design pattern. The example of such use is shown below.

```
allDocumentText.createCursor()
    .gotoStartOfTheSentence()
    .gotoNextSentence()
    .gotoNextWord()
    .gotoPreviousWord();
```

It is impossible to predict different components usage due to LibreOffice UNO API complexity and massiveness. So, to simplify it for developers, all the classes contain corresponding methods

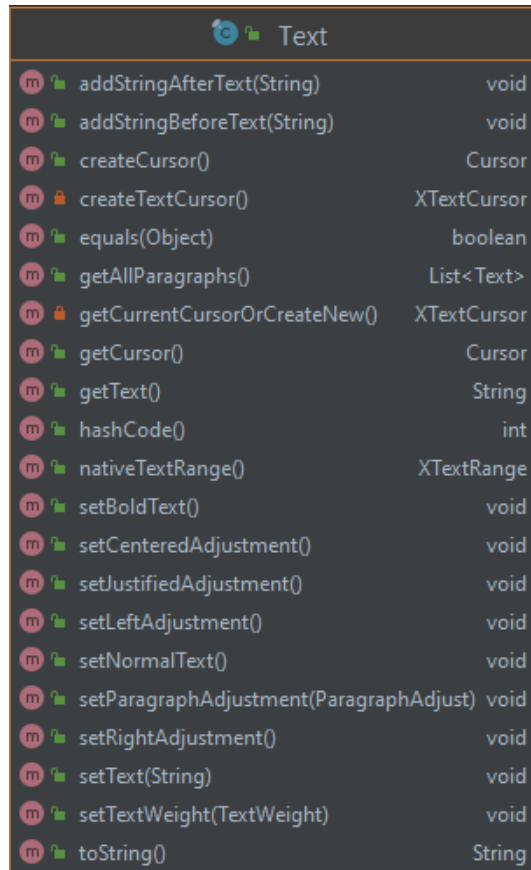


Figure 8: The list of Text class methods.

which return the original LibreOffice UNO API objects. For instance, the Cursor class has `getTextCursor`, which returns a `XTextCursor` object.

In order to demonstrate the developed library usage, we implemented a cloud-based system which aims to automate document flow.

The application is divided onto frontend and backend parts. The development stack is shown below:

- Server development stack: Spring (Spring boot, Spring Security, Spring WebFlux, Spring JPA), jjwt (Java JWT: JSON Web Token for Java and Android), Connector/J (Mysql Java Connector).
- Client development stack: Vue.js 3 (Vue Cli, Vue Router, Vuex, Vue i18n, Vue Class Component, Vue FontAwesome, SFC, Element Plus), Typescript, Javascript, Babel, Webpack.

The backend has microservice architecture. In order to minimize the application load, we have implemented 3 different microservices:

1. Microservice for login and token generation.

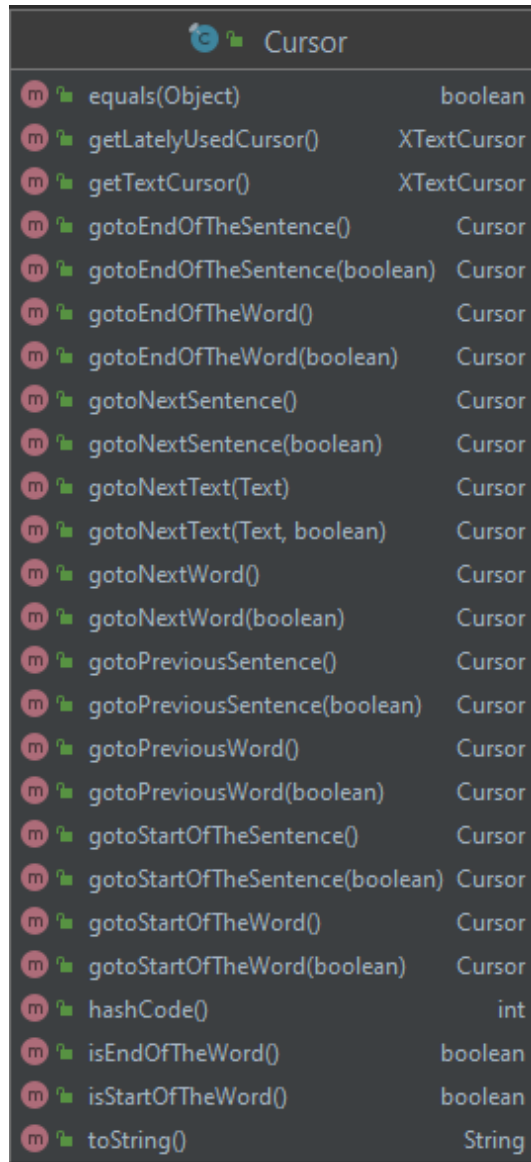


Figure 9: The list of Cursor class methods.

2. Microservice for document processing (storage and document management).
3. Microservice for generating documents according to the data.

As a matter of application security and microservice communication, we have used the JWT token as the most eligible.

For signing up and signing in into the application, the login page may be used (figure 10).

After this procedure, the user goes to the main page for handling documents, which is called Document Management (figure 11).

Create an account'."/>

Welcome to our system!

Username

Password

Sign in

Still have not registered in our system? [Create an account](#)

Figure 10: The login page.

This page contains all the document information. To create a document, one should push a side bar button which leads to a document adding page (figure 12). The index of the documents is shown as a list, and each item has two different buttons:

1. Generate Form. This button is responsible for form generating. These forms may be used as data origins for producing documents from templates.
2. Delete. Remove the entry.

Furthermore, our system supports custom template patterns, which means that documents may contain any kind of keyword distinguishers.

The forms are common way of document generating from an uploaded template. All created forms are displayed and might be changed in the Form page (figure 13).

The actual form page, which may be accessed by using the View Form button, contains all of the extracted from the template document keywords. The example of a form is shown on the figure 14.

Considering the fact that key words are not always named human-friendly, it is also possible to change their display name using the Edit button on the table. After submitting a form, the user automatically receives the document.

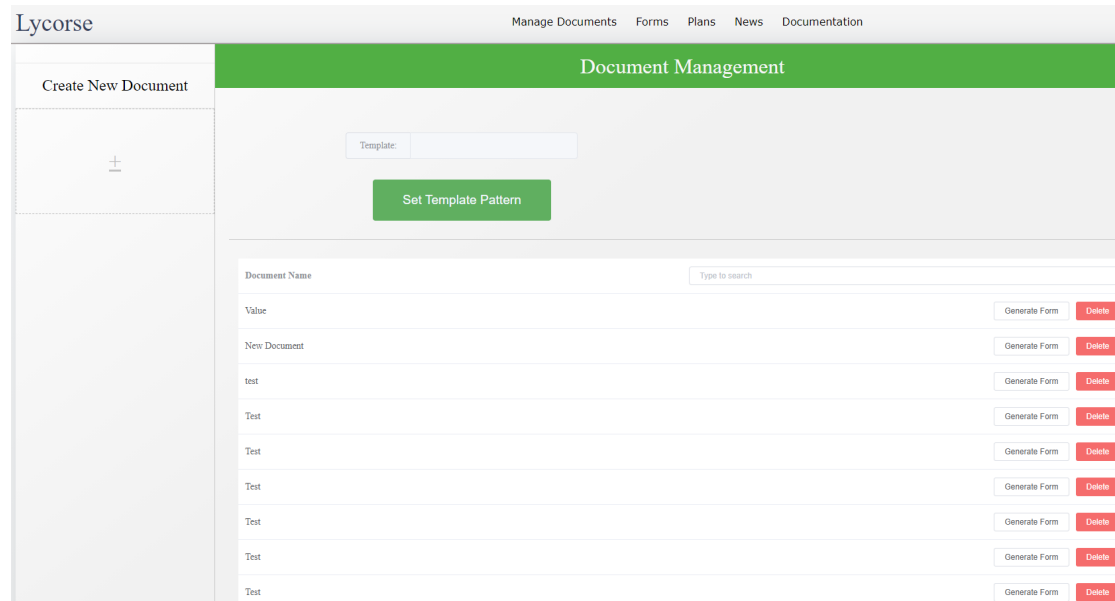


Figure 11: The Document Management page.

At the moment, the following features have been implemented:

1. The XML adjuster.
2. Document handling without working with UNO API directly.
3. Simplified classes for working with UNO API and its components.
4. Utilities for working with URI.
5. Converters.
6. Constants classes implemented as an enum class.
7. A cloud-based system for documents automation.
8. Interfaces and classes which help to add custom implementations of most mechanisms of the library.

We are planning to implement a cloud-based interface for working with documents without coding. In addition, we have intention to provide the richest functionality for working with LibreOffice UNO API.

5. Conclusion

Document processing may be complicated and confusing. The XML processing is more complicated and limited. The reason is that handling raw XML is difficult, especially when a document is massive.

LibreOffice UNO API is one of the richest open-source APIs for processing documents. It provides the necessary functionality to edit and process documents. In comparison with XML

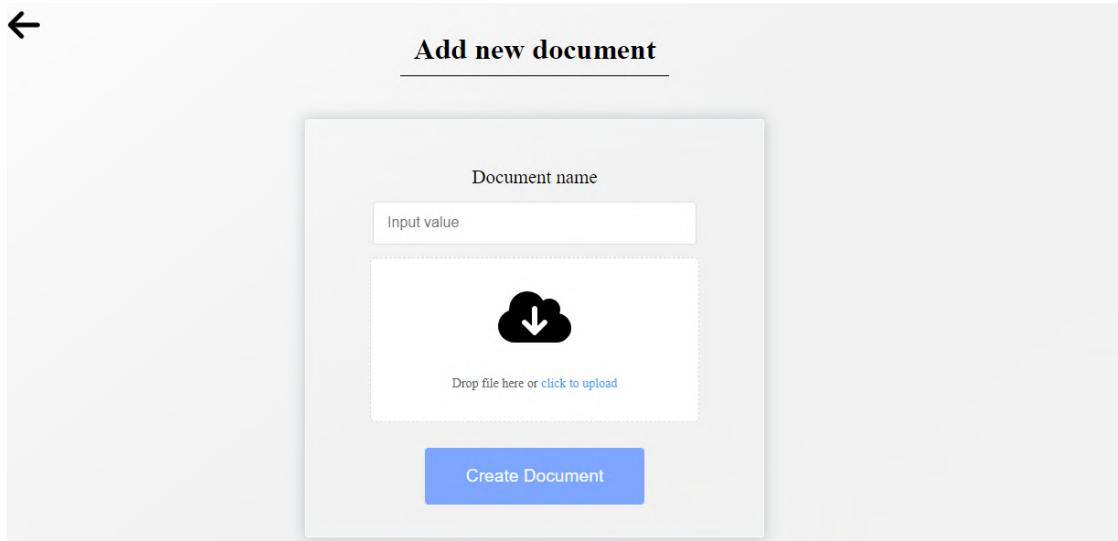


Figure 12: The document adding page.

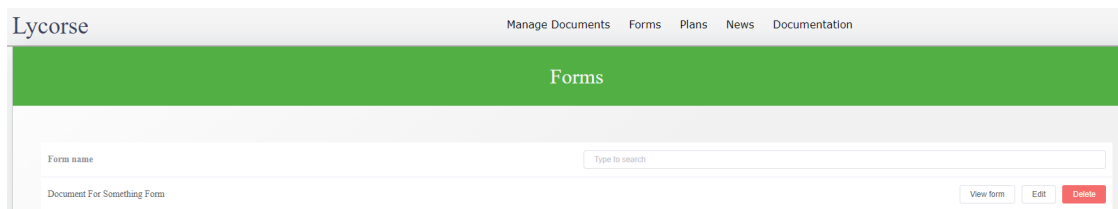


Figure 13: The Form page.

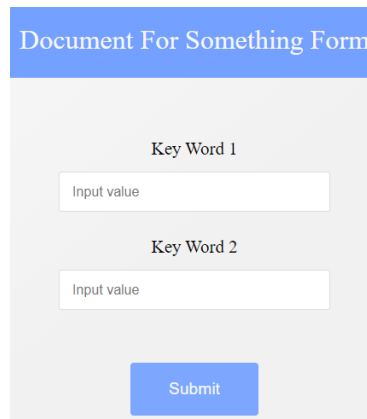


Figure 14: The generated form page.

processing, this approach is more advantageous. Moreover, the LibreOffice UNO API solves the keyword splitting issue, or to be more precise, allows avoiding it.

The developed library allows one to handle both of the described processing approaches. It is easier to combine them regardless of whether you only need to process patterns or additionally edit the inner structure of the document. Looking at the future, we are planning to complete the development of this library. Converters of the library are useful tools because there are not many solutions that could manage all the major formats, such as doc, docx, odt, html, and others. As an application of this library, we are currently working on creating a cloud-based document management system that will be able to help in storing, handling, and processing documents. It is going to be discussed in the further reports.

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Design a progressive web application to support student learning

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Abstract

The role of progressive web applications in students' educational activities is researched in the work. Authors compare them with applied and hybrid programs; determine the features of PWA technology as well as analyze the architecture of progressive web applications. The study aim is to develop and implement the progressive web application that is an information portal of the Faculty of Physics and Mathematics Ternopil Volodymyr Hnatiuk National Pedagogical University using PWA technology. To achieve this goal, the following required resources for the training organization of student's activities have been selected. They are the schedule of the educational process, lessons schedule, schedule of modular and final controls, information on practice, schedule of final exams, regulatory and methodological software. On the first stages of work a website template was created in addition to information gathering. The next stages of practical implementation were aimed at the development of logic and implementation of PWA technology, namely defining the interface, adding a worker, creating auxiliary functions. The final stage of the study is the project deployment. The results obtained by the author can be used in the process of higher specialists training in educational institutions. The web application itself is practical for organizing students' educational activities.

Keywords

progressive web application, web-programming, future computer science teacher, information portal, organization of educational activities

1. Introduction

Technological innovations always affect how goods and services are developed. In recent years, there has been an increase in Internet services [1]. This is due to the introduction of new and improvement of existing technologies. Things that were previously impossible now exist. The application of technology can be traced in all areas such as business, education, science, health, agriculture. Today, business perceives the Internet as a business platform and requires constant scaling.

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Therefore, there is a need for fast and reliable applications, including for mobile phones. The rapidly growing market of mobile devices has set a need for applications being available at anytime, anywhere, and on any device. Although this evolution provides users an unprecedented freedom, developers are facing the challenges caused by mobile device fragmentation [2].

Current application development solutions are insufficiently optimized for the high diversity of mobile platforms and hardware characteristics.

After solving these problems, it remains relevant a need for fast and reliable web applications. One such web technology is the Progressive Web App (PWA). It transforms the site into an application. If you delve into its architecture, the developer is offered technologies (Service Worker, Push Notifications, WebApp manifest, HTTPS, App shell) and outlines goals (Reliable, Fast, Engaging). Since PWA has no limitations like traditional applications, they can be as advanced as possible and can run on all possible operating systems.

We can teach this to students today. Designing a mobile-oriented environment for professional and practical training requires determining the stable (fundamental) and mobile (technological) components of its content and determining the appropriate model for specialist training. In work [3] it has been established that the fundamental core of software engineers' training should ensure that students achieve such leading learning outcomes: to know and put into practice the fundamental concepts, paradigms and basic principles of the functioning of language, instrumental and computational tools for software engineering; know and apply the appropriate mathematical concepts, domain methods, system and object-oriented analysis and mathematical modeling for software development; put into practice the software tools for domain analysis, design, testing, visualization, measurement and documentation of software.

Thus, there is a need for fast and reliable web applications. One such web technology is the Progressive Web App (PWA). It transforms the site into an application. If you delve into its architecture, the developer is offered technologies (Service Worker, Push Notifications, Web App manifest, HTTPS, App shell) and outlines goals (Reliable, Fast, Engaging). Since PWA has no limitations like traditional applications, they can be as advanced as possible and can run on all possible operating systems. Therefore, consider this area of research relevant.

2. The research apparatus

This work is a research project on a progressive web application. The main goal was to evaluate and implement advanced technologies for creating a web application. The project is implemented by studying the theoretical foundations and developing a prototype PWA web application. The React and React Material web components were used to create the user interface. Web App Manifest, Service Worker, App Shell, and Web Push Notification have been implemented to keep the application running offline, increasing its download speed on slow networks.

The **purpose** of this work is to introduce a progressive web application in the activities of students of the Physics and Mathematics Faculty of Ternopil Volodymyr Hnatiuk National Pedagogical University [4]. The study took place over several stages.

1. Development of a site template.
2. Collection of necessary information about the work of the faculty.
3. Development of the logic of the application.

4. Development of the PWA application (mobile and desktop versions).
5. Project deployment

The *object of research* is the technology of creating advanced web applications.

The *subject of research* is a progressive web application as a means of implementing educational interaction.

To achieve this goal, we used a set of *research methods* such as analysis of scientific and technical literature, generalization, modeling of information processes, observation, analysis of experience in the use of PWA technology, software development and testing.

The approbation of the research was carried out within the activity of the STEM-center of the Physics and Mathematics Faculty of Ternopil Volodymyr Hnatiuk National Pedagogical University, in particular in the educational process.

3. Research results

The role of progressive web applications in students' educational activity is considered in the work. A significant role is devoted to the comparison of this technology with applied and hybrid programs. The features of PWA technology are also studied, the architecture of advanced web applications is analyzed.

3.1. Analysis of the basic concepts of the study

To understand what Progressive Web Apps (PWA) is, it is enough to imagine that a site interacts with the user as an application. The user can install it on any gadget, receive messages and work with it. And the work can continue even offline. This application model offers combine the features of modern browsers and the benefits of mobile applications. Progressive Web App is a hybrid of a site and an application.

Progressive web applications give the user access to information in one click. The involvement of the resource increases, because the client can quickly visit the resource at any convenient time. At the same time, PWAs are able to run on almost all hardware platforms, which reduces the cost of development: you do not need to create a separate product for each operating system, just develop one universal PWA-application. Progressive mobile applications demonstrate good behavioral factors. This is because users actively navigate the pages and receive lower bounce rates. This has a positive effect on the ranking of the site in search. PWA only works with the HTTPS protocol, which also improves the security of the site.

In terms of User Experience (UX), PWA also has advantages. With the progressive web application, the user can enjoy not only browsing, searching and downloading resources, but also the time saved and nerves saved. Such solutions are especially interesting in terms of Ukrainian realities, where 3G / 4G coverage is not so ideal. However, Progressive Web Apps cannot completely replace mobile applications, because the native mobile application still has more features. However, in many cases, the PWA site is becoming a cheaper alternative to mobile applications. The advantages of PWA include:

- PWAs are small in size due to the fact that they effectively use the capabilities of the browser;

Table 1

Comparison of progressive and mobile applications.

Features	PWA	Mobile Application
Instant installation	+	-
Higher development speed	+	-
The device takes up less memory	+	-
Low development cost	+	-
Cheaper to develop and maintain	+	-
Interaction with a microphone and a smartphone camera	+	-
Use of functions of access to proximity sensors, bluetooth, etc.	-	+
No need for stores to distribute them	+	-

Table 2

Comparison of progressive applications and sites.

Features	PWA	Site
Higher download speed	+	-
Work offline	+	-
Faster and easier access	+	-
Push notifications	+	-
More user-friendly interface	+	-
Support for many browsers	+	-

- faster in development;
- in progressive applications it is easier to edit content (you do not need to edit content separately in the application and separately on the site);
- it is easier to use a PWA site, which increases the SEO indicators of the site.

Some features of progressive and mobile applications are shown in the tables 1, 2.

PWA's popularity is growing very fast in the field of e-commerce, business, Internet portals, and other industries due to these characteristics [5].

Creating advanced web applications that meet all the requirements based on performance, availability, adherence to best practices and SEO is quite a challenge. To do this, all PWA components, such as Service Worker, Web App Manifest, Application Shell model, and Web Push notifications, must be implemented with great care and testing.

3.2. Set of selected technologies

- **React.** It was used in this project to display the results of the components, as well as through the convenience of creating new projects using the utility react-create-app, which provides all the necessary tools to the developer right of the box. Any data is passed to the components using props, in the component they are already processed in order to render the result. Another important advantage is the ability to use states. That is, it is data that can change asynchronously depending on the user's actions. For example, a user

entering data into a form text box can update the data in the components via `setState()`, or data coming from API can update the input field value asynchronously, so there is no need to reload the browser page to see new data, and the user always will see the latest version of the site.

- **React-Router.** In the developed program, as well as in any typical website, routing is used. There is no special choice here, because react-router is probably the only popular solution available. The router allows you to easily and flexibly control the display of the application depending on the route in the browser, redirect the user to other routes and block unwanted transitions.
- **Webpack.** It was decided to use Webpack to build the applications. This is the most powerful and popular solution at the moment. From scratch, setting up an assembly can take a decent amount of time, so it was decided to use `npx create-react-app`, which allows you to deploy a ready-to-develop application environment. When a webpack processes an application, it internally creates a dependency graph that display each module that the project needs and generates one or more package.
The entry point indicates which web package of the module should be used to build an internal dependency graph. Webpack will find out which other modules and libraries this entry point depends on (directly and indirectly).
The output property tells the webpack where to place the created sets and how to name these files. By default, the path will be in `./dist/main.js` for the main source file and the `./dist` folder for any other created file.
By default, the web package only understands JavaScript and JSON files. Downloaders allow the webpack to process other types of files and convert them into active modules that can be used by the application and added to the dependency graph.
Although loaders are used to convert certain types of modules, plug-ins can be used to perform a wider range of tasks, such as package optimization, asset management, and the introduction of environment variables.
To use the plugin, you need to call the `require()` command with the name of the plugin and add it to the plugin array. Most plugins can be customized with options. Because the plugin can be used multiple times in the configuration for different purposes, you need to instantiate it by calling it with the `new` operator.
You also need to set the development mode parameter, one of: `development`, `production`, or `none`. This way, the webpack will enable built-in web package optimizations that are appropriate for each environment. The default value is `production`. Webpack runs on Node.js version 8.x or newer.
- **Git.** It was used as the version control system. The git process is shown in the figure 1. Before you start, you need to initialize git by calling the `git init` command. This command will create a `.git` directory where it was called. The `git add` command is used to add new files. The next step is to call the `git commit` command, which creates a committee in the current branch with the entered message, as well as files that are in the stack.
- **PhpStorm development environment** PhpStorm is an intelligent editor for PHP, HTML and JavaScript with the ability to analyze code on the fly, prevent errors in raw code and automated refactoring tools for PHP and JavaScript. The autocompleate code in PhpStorm supports the PHP 5.3 / 5.4 / 5.5 / 5.6 / 7.0 / 7.1 specification (modern and traditional

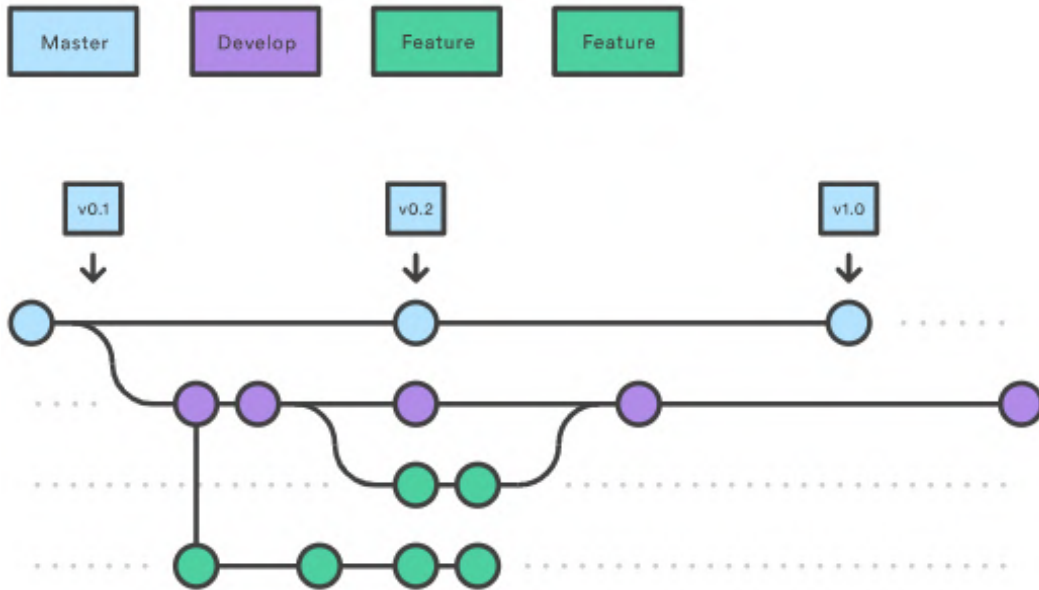


Figure 1: Scheme of work Git.

designs), including generators, coroutines, namespaces, locks, types, and short array syntax. There is a full-fledged SQL-editor with the ability to edit the results of queries [6]. PhpStorm is based on the IntelliJ IDEA platform, written in Java. Users can extend the functionality of the development environment by installing plug-ins designed for the IntelliJ platform or by writing their own plug-ins. All WebStorm functionality is included in PhpStorm.

PhpStorm is ideal for working with Symfony, Drupal, WordPress, Zend Framework, Laravel, Magento, Joomla, CakePHP, Yii and other frameworks.

PhpStorm deeply analyzes the structure of the code, supporting all the features of the PHP language in both new and legacy projects. The editor supports code auto-completion and refactoring, prevents errors on the fly.

PhpStorm has the ability to work with the most modern technologies: HTML5, CSS, Sass, Less, Stylus, CoffeeScript, TypeScript, Emmet and JavaScript. Refactoring, debugging and unit testing will be available. Thanks to the Live Edit function, all changes can be viewed immediately in the browser.

It is convenient to perform monotonous tasks directly in PhpStorm. IDE is integrated with version control systems, supports remote deployment, databases and SQL, command line tools, Docker, Composer, REST client and many other tools.

PhpStorm includes all WebStorm functionality, as well as full support for PHP, databases and SQL.

PhpStorm takes care of the quality of the code with the help of hundreds of inspections, which check the code on the fly and analyze the whole project. PHPDoc support, a formatting tool, quick fixes, and other features help developers write neat code that is easy to maintain.

PhpStorm securely converts code by reliably refactoring renaming, moving and deleting, extracting methods, entering changes, moving items up or down, changing signatures, and more. Refactoring that takes into account the specifics of a particular language will help to apply changes throughout the project in a couple of clicks. In this case, any transformation can be canceled.

3.3. Creating an information portal FIZMAT

PWA development is based on a stack of selected technologies for this project. It should be added that you can create a PWA without additional frameworks or libraries. To begin with, HTML and Javascript are enough.

The first stage was the deployment of the project infrastructure, and the git version control system was initialized. All packages used in the web program are at the root of the project in the package.json file (figure 2).

```
{
  "name": "pwa-experiment",
  "version": "0.1.0",
  "private": true,
  "dependencies": {
    "@fortawesome/fontawesome-svg-core": "^1.2.32",
    "@fortawesome/free-brands-svg-icons": "^5.15.1",
    "@fortawesome/free-regular-svg-icons": "^5.15.1",
    "@fortawesome/free-solid-svg-icons": "^5.15.1",
    "@fortawesome/react-fontawesome": "^0.1.11",
    "bootstrap": "^4.5.3",
    "html-webpack-plugin": "latest",
    "http-server": "^0.12.3",
    "jquery": "^3.5.1",
    "popper.js": "^1.16.1",
    "react": "^15.5.4",
    "react-dom": "^15.5.4",
    "react-router": "3.0.5"
  },
}
```

Figure 2: Packages used in development.

To initialize the git version control system, the git init command is called, which creates a new repository in the current folder. The .git folder contains all the information needed for the project in version control, and all the information about the commit, the address of the remote repository, and so on. They are all present in .git folder. It also contains a journal that preserves the history of the committees.

Creating React Components. Components are independent and reusable bits of code. They perform the same goals as JavaScript functions, but work in isolation and return HTML through a rendering function. There are two types of components, class components and function compo-

nents, this project uses class components. When you create a React component, the component name must begin with a capital letter. The component must include the `React.Component` extends statement, which creates a descendant from `React.Component` and gives the component access to the `React.Component` functions. The component also requires the initialization of the `render()` method in the class, this method returns HTML (figure 3).

```
import React from 'react';
import Header from "./Header";
import {Link} from "react-router";
import {FontAwesomeIcon} from "@fortawesome/react-fontawesome";
import {faDownload} from "@fortawesome/free-solid-svg-icons";

export default class StudyProcess extends React.Component {
  constructor(props) {
    super(props);
    this.state = {
      loading: true,
    };
    this.offlineSrc = process.env.PUBLIC_URL + '/documents/study-process.html';
    this.onlineSrc = 'http://docs.google.com/document/preview?hgd=1&id=1Y8zu0-Uc

    this.files2download = [
      {filename: 'study-process.pdf', src: process.env.PUBLIC_URL + '/document
      {filename: 'study-process.rtf', src: process.env.PUBLIC_URL + '/document
      {filename: 'study-process.docx', src: process.env.PUBLIC_URL + '/documer
    ];
  }
}
```

Figure 3: Class schedule component of training.

The submitted component is passed to another component of the library `react-router` `<Route/>`.

Website resources are stylized in the `App.css` file. Also connected are fontawesome icons by a separate npm package. Components are rendered to reflect the resources of the Faculty of Physics and Mathematics, such as a component that displays a graph of modular and final controls (figure 4).

The next step is to test the progressive web application offline (figure 5).

3.4. Practical implementation of the model

Stage 1. Creating a site template.

The first step is to create an `index.html` file. Which will be the main template of the site, which connects all the other necessary resources, such as: styles, scripts, manifest file, the necessary images to install the website on the user's device. Also in this file the entry point for the created

Графік модульного та підсумкового контролів

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Графік модульного та підсумкового контролів

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Figure 4: Component of the schedule of modular and final controls.

progressive web application is defined, as an element in which the virtual DOM created by React components will be rendered there will be a div element with the root identifier. The index.html template checks for the presence of a web worker in the browser, if the browser supports PWA technology, the worker is registered in the browser by specifying the path to the file in which it is defined.

Stage 2. Collection of information.

The web application is designed for students of the Faculty of Physics and Mathematics, so the information provided in it will be useful, especially for physicists. The application provides all the necessary information:

- schedule of the educational process;
- schedule of classes for full-time and part-time education;
- schedule of modular and final controls;
- information about the practice;
- schedule of final certification;
- normative and methodological support;
- schedule of individual classes;
- schedule of liquidation of academic debt;

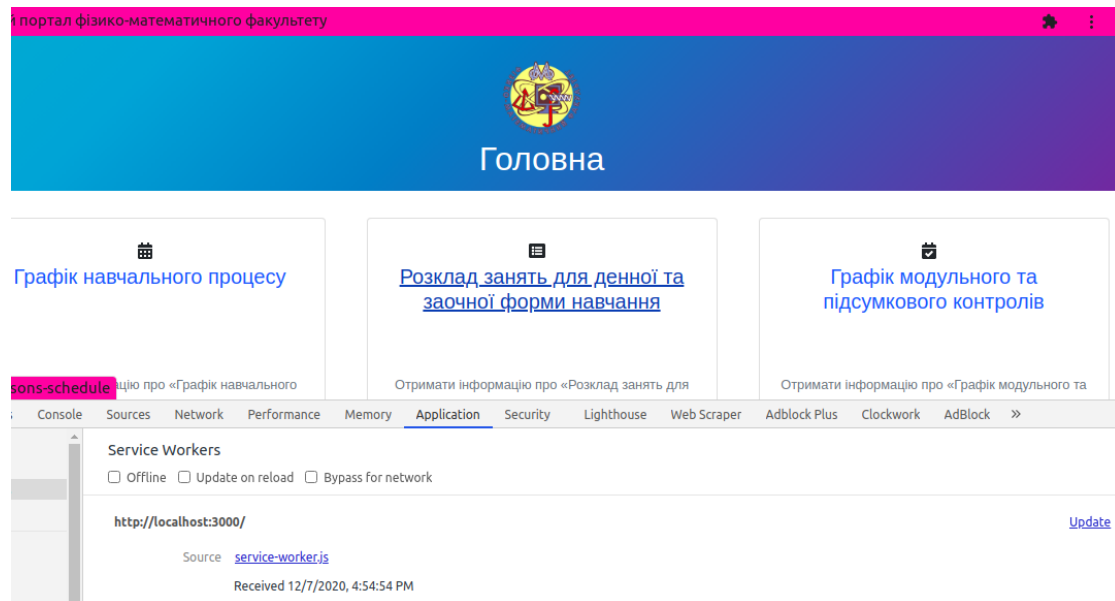


Figure 5: The homepage of the web application is offline.

- disciplines of choice.

Stage 3. Development of logic.

The use of selected technologies allows the developer to build the architecture of the application following the already defined rules of writing code and the correct structuring of the file hierarchy in the project. All pages on the site are available at a specific link. Since the routing is on the client side, a react-router library was used, which intercepts all transitions on the site, calling the desired component for each of the links. React supports the component approach in programming, so all pages on the site are components that are passed to the appropriate `<Route />` as component properties. A component is a class that is inherited from `React.Component`, which initializes all the properties and states required to run the component. In the constructor of a class the transferred properties as props, and also public properties of a class which are necessary for correct display of contents rise to the parent class. In the render class method, all file paths are defined, depending on the state of the user's network, and a template is returned with the data ready to be displayed in the user's browser.

Stage 4. Introduction of PWA technology.

The first step in implementing PWA technology was to add the `manifest.json` file. The web application manifest is a JSON file that defines the PWA interface. It determines how you download and display progressive web applications, as well as your own application from the application store. The manifests of this web application include: the name of the program, description, style, theme, icons, the initial path when opening it on the device, and a list of necessary resources. Unlike regular bookmark-only web applications, PWAs can use regular web APIs and be installed on the device home screen.

The successor korok needs to create a worker file, and also to connect yo-go on a site in a

root template. The file, according to the recommendations of google developers, creators of this technology, is called service-worker.js. It is placed in the public folder on the same level with the manifest file. This file specifies the path from where to start caching files, in this case the root of the site was selected so that all files are stored in the browser cache and the cache version is specified to identify its different versions. The handler added handlers for events that come from the browser, these are: install, activate, fetch.

The install event is a standard event in which the worker is prepared for work. For example, creating a cache using the built-in API saves the necessary resources that are needed to run offline.

Activate event – the handler of this event clears outdated cache and other things related to the previous version of the service employee, ie the file service-worker.js.

Fetch event – is triggered when a user, in this case a browser, or a device, sends a request to obtain a specific resource. The handler works to retrieve the resources stored in the cache and send the requested data to the client using the respondWith event method.

Each resource in the cache is stored with the name of the generated hash, so the resources cannot be duplicated in memory. To work with hashed files, auxiliary functions were created: removeHash, hasHash, hasSameHash.

Stage 5. Project deployment.

As a hosting for the project, the Firebase platform was used. Hosting Firebase provides fast and secure hosting for hosted web applications, static and dynamic content and microservices. You must first install the developer tools to call the Firebase features from the console. Tools are installed using the npm install firebase-tools-g command. The next step is to log in to the Firebase platform, such authentication is performed using the firebase login command, where you need to enter your email address and password from the account. After successful user authentication, you need to initialize the project by calling the firebase init command. During the initialization process, you will be prompted to configure the project upload process to the host. You must specify a folder that contains the static resources used by the web application. After the initialization of the process of uploading files to the host, Firebase will create files: .firebaserc, firebase.json. These files are automatically generated when you need to make a commit and upload the last commit to the host, so that locally the developer and the host had consistent data of the web application.

The developed web application is available at: <https://new-info-fizmat.web.app/>

3.5. Experimental study

Usually, the experiment is carried out as part of scientific research and serves to test the hypothesis, to establish causal links between phenomena. In a passive experiment, information about the object under study is accumulated by passive observation, ie information is obtained in the normal functioning of the object. The results of the experimental study we obtained by analyzing the questionnaire.

The aim of the questionnaire was determination of efficiency of the use of informative portal physical Faculty of Mathematics using PWA technology. Among the questions: research of requirements in such web applications, comfort of establishment and use, selection of content, design. Informative materials for organization of educational activity of students can be found

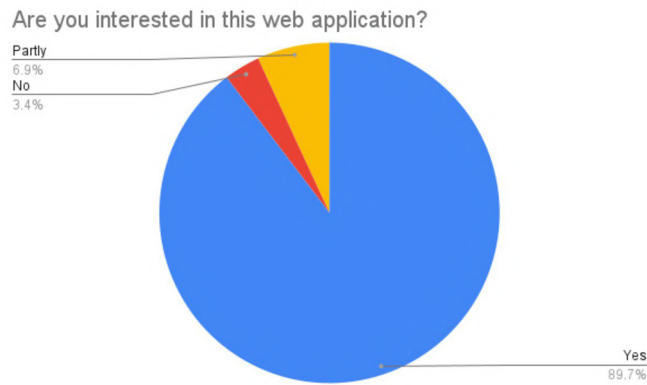


Figure 6: The level of interest of respondents.

and on the web-site of university. But exactly optimization of access to them induced this research. In his experimental part we compare traditional access to these resources with the use of worked out to web-addition of PWA. We present the processing of the results of twenty-seven respondents (figure 6).

The content of the information portal received the highest marks (23% – “4” out of “5”, 74% – “5”). We received more than 95% of positive feedback on the block of questions regarding the design of the interface and design. It should be added that the design is subject to change and does not require significant changes to the code, its structure, or logic.

An important result is that most respondents were able to install a website on their device (figure 7):

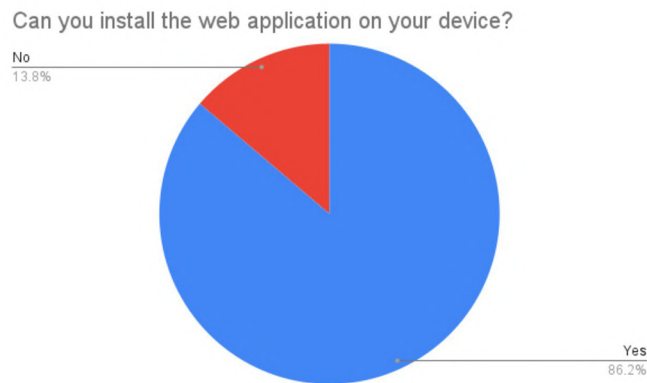


Figure 7: Evaluate the installation of a web application on the device.

The question regarding the recommendation of the web relationship received a 100% positive answer. This indicates that students need a quick and easy application that does not need to be downloaded and installed on a device that will have all the information they need. As a result,

we received mostly positive results from respondents. This allows us to talk about a sufficient level of demand for websites of this type and its quality development (figure 8).

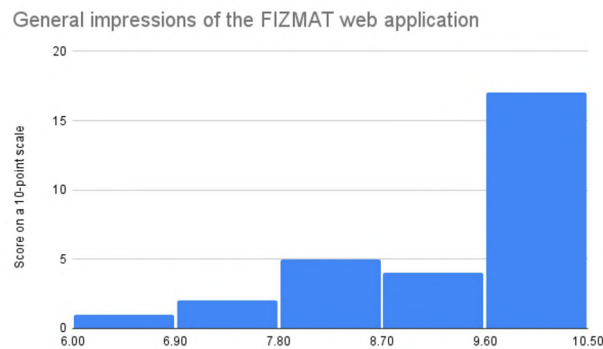


Figure 8: Assessment of the overall impression of use.

4. Conclusions

This work was performed as a research project on a progressive web application. The main goal was to evaluate and implement advanced technologies in the application. This study was conducted by studying the relevant theory and developing a prototype PWA web application. The React and React Material web components were used for the user interface, while Web App Manifest, Service Worker, App Shell and Web Push Notification were implemented to make the program work offline, load quickly even on unstable networks and send the appropriate push notifications as a native application. The study demonstrates how PWA combines the best practices of websites and applications. In addition, it also demonstrates some of the challenges that PWA faces in today's information technology environment, and that PWA is still in its infancy. Meanwhile, Google is actively developing this technology and working hard to provide and support tutorials. Thus, with growing browser and platform support, PWA may be the future of mobile Internet.

Collection of technical information for development of PWA of applications can be used for organization of similar projects and studies of students of technological profiles. A research and practice result is development of progressive web application as to the means of realization of educational co-operation.

After conducting a theoretical study, implementing the developed web application (filling it with information materials), and evaluating the effectiveness of its application, we can conclude that the purpose of the work – the introduction of a progressive web application in the activities of students of the Faculty of Physics and Mathematics of Ternopil Volodymyr Hnatiuk National Pedagogical University achieved.

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Designing a software for digital forensic investigations of e-petitions voting falsifications

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Abstract

E-petition is a relatively new tool for expressing community demands and influencing on the legislative process. An issue of voting falsifications detection is rarely considered in e-petition analysis reports. Within this research, an illegal petition falsification service has been examined and some methods of voting fabrication detection have been suggested and implemented in mobile app. To illustrate the discussed techniques, some suspicious activities regarding two popular petitions to the president of Ukraine were detected.

Keywords

e-petition, falsification, voting, president, Android

1. Introduction

In 2015, the changes to the Law of Ukraine “On Citizens’ Appeals” [1] were introduced, according to which the Internet-based petitions acquired the legal status as a tool for influence on the legislative process. Thus, an e-petition allows, with insignificant limitations, to make an online appeal to Ukrainian authorities, e.g. president, parliament, local governments etc. It should be noted that e-petition has no absolute power, it only obliges the authority to examine the issue and deliver the official verdict. Petitions therefore announce the wishes and demands of the citizens. On the other hand, this relatively new tool may be illegally mishandled in behalf of influential individuals or groups.

Since there are no tools for public control of voting process, we are working on creating a software for detecting possible falsifications. In this report we analyze e-petitions to President of Ukraine, but our approach may be generalized for other e-petition services and even for social media voting.

2. Overview

First, e-petitions may be abused by corrupted representatives of authorities to force their self-seeking decisions under the guise of society will. Indeed, they may have access to some personal


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data of citizens, so it is possible to produce fake votes for profitable petitions. The access to e-petition Internet platform makes it possible to reduce the number of votes if it is beneficial to certain individuals. For example, such activities may have been carried out by related to Kryvyi Rih city council persons when e-petition service accidentally turned off just before the resonant petition gained few last votes [2].

There are other issues related to e-petitions cheating. For example, there even exist illegal services to trade votes for petitions to the President of Ukraine, e.g. [3]. We have contacted (figure 1) the representatives of the service via chat and they confirmed that it is possible to buy some voices for a petition to the president of Ukraine. The also assured us that they pay to real people for signing petitions and it is possible to buy a test package of 50 votes for \$25. We have also found out that their Telegram account is @redzona and the Skype account is god19952.

We have checked the domain and discovered that it belongs to Danesco Trading Limited [4] which is a registered at Cyprus domain name provider [5]. At the same time, the specified at the website social network user profile leads to the page of Nikita Kuznetsov [6] who is registered as a resident of Moscow. This example represents another threat to e-democracy. While corrupted local authorities technically might be brought to justice, it is not easy to resist external voting intrusions.

3. The analysis of existing solutions

An example of an organization that analyzes the gain of online petitions votes is the “League of Interns” NGO [7], which has been examining electronic petitions to the Verkhovna Rada of Ukraine with the support of the USAID RADA Program [8] carried out by the Eastern Europe Foundation since March 2017. During this time, e-petitions have monitored and a number of information and training materials were prepared. For three years in a row, e-petitions concerning the activities of the Verkhovna Rada of Ukraine, the President of Ukraine, and the Cabinet of Ministers of Ukraine have been in the lead.

An analysis the “League of Interns” community activities lets us spot a serious approach to data collection and a significant amount of data processed. The organization’s task is to analyze the operation of the mechanism of online voting, its efficiency and popularity. They do not detect possible cheating on the site.

Another statistics on e-petitions that could be found is one provided by the “Communication for Change” center [9]. This statistics show that Ukrainians are quite active in exercising their right to influence the government and consistently submit petitions to address pressing issues in the country. The statistics covers the hot topics of submitted petitions, the rate of president’s replies and so on. However, it does not consider any kind of vote gain cheating.

As for foreign e-petition researches, there is an analysis of five years operation of White House e-petitions platform, which is called “We the People” [10]. But it generally discusses the impact and most common subjects of e-petitions. Quite interesting, however, that Russo-Ukrainian War takes the second place in the top list of foreign policy petitions right after Middle East issues.

Another report by Janne Berg [11] addresses the problem of anonymous e-petitions in Finland and why people decide to conceal their names while signing e-petitions. It mention the fake

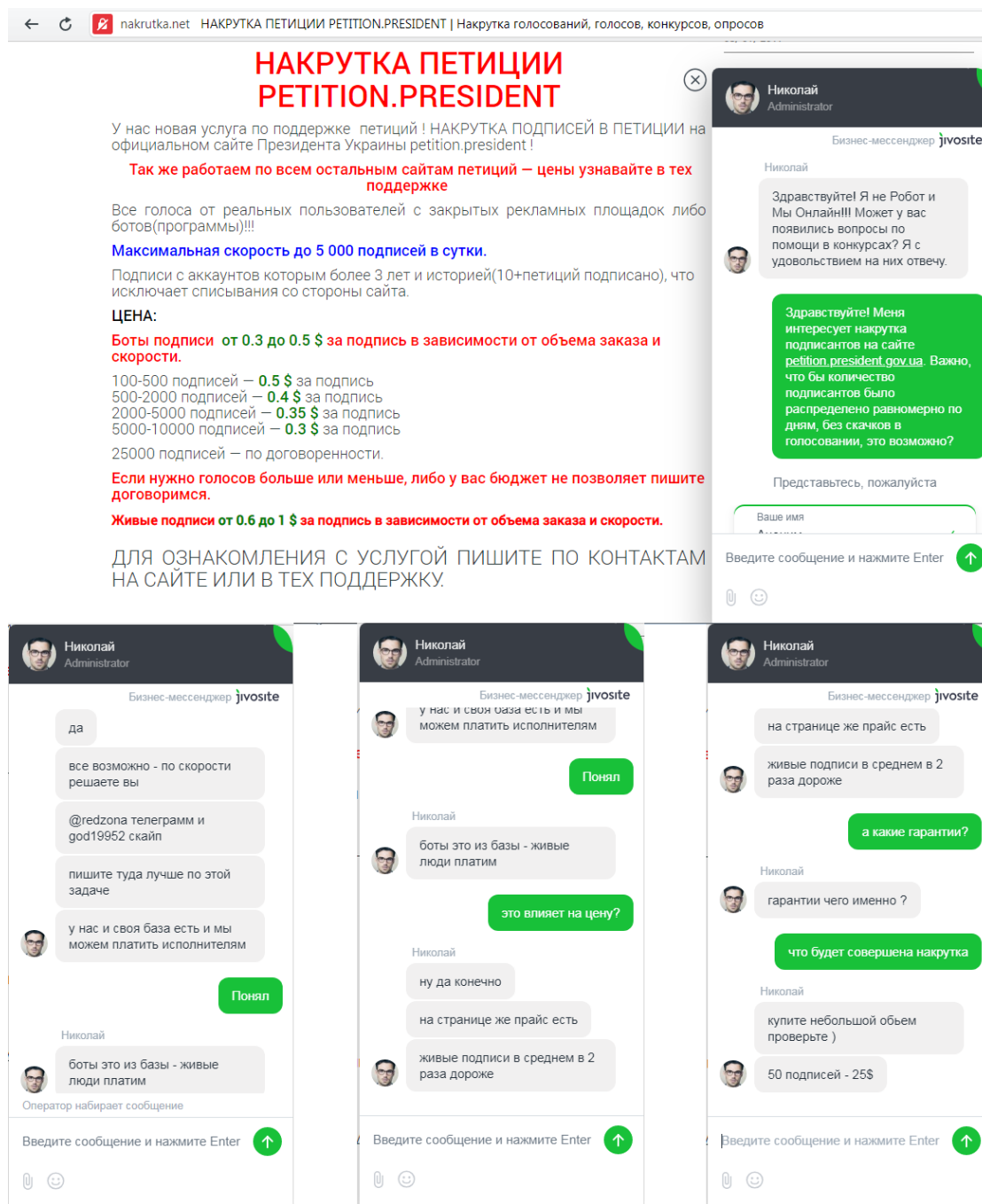


Figure 1: Communication with nakrutka.net staff.

signatures problem, but it is basically out of the research scope.

Taking into account the aforesaid, it could be seen that e-petitions indeed play a significant role in public life, but there are no monitoring tools available in Ukraine. The NGOs who

analyze e-petitions do not even take into account possibilities of falsifications. So there is a need for a tool to detect suspicious activity on particular petitions to attract public attention to possible falsifications.

4. Implementation

We decided to implement our service as a mobile application since it would allow users to monitor e-petitions they are interested in, and such decentralized approach makes our system less vulnerable. It is shown on the figure 2. The application consists of active windows and a service for obtaining up-to-date information about voting on the e-petitions website and comparing groups of signatories from different petitions. For further analysis of the obtained data, the table with comparison results is also exported. The program has several active windows (Activities), which may be switched by user.

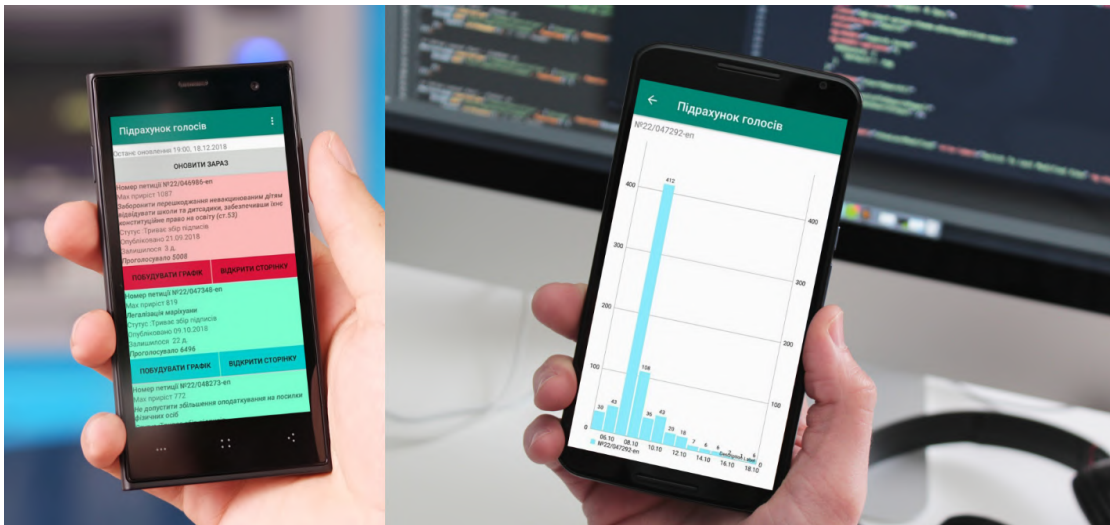


Figure 2: The e-petition falsification tracking mobile application.

After launching the client, one would see a window with a button to manually update the list of petitions. Main menu is at the top right corner. It includes a button “About the program”, “Comparison” and buttons to open a list of petitions “Under consideration” or “With answer”. The first upgrade process takes about 30 minutes. The service runs in the background, which does not require to keep the application window open during the entire update time.

Once one has obtained the list of petitions, it is possible to view the voting plot or visit the petition webpage. The list is arranged according to the number of votes per day. Petitions with more than 1,000 votes per day are highlighted with red and are at the top of the list. The petitions, with more than 100 votes a day are also highlighted, but they are not so interesting, because such vote bursts are common, especially for important petitions. An example is shown on the figure 3.

After clicking the “Plot” button, the user will see the Activity with a chart of daily votes.

Підрахунок голосів		Підрахунок голосів	
Останє оновлення 19:00, 18.12.2018		Останє оновлення 19:00, 18.12.2018	
ОНОВИТИ ЗАРАЗ		ОНОВИТИ ЗАРАЗ	
<p>Номер петиції №22/047818-еп Мах приріст 5542 Не допустити обкладання посилок фізичних осіб вартістю понад 22 євро додатковими податками Стутус :Триває збір підписів Опубліковано 31.10.2018 Залишилося 44 д. Проголосувало 19664</p>		<p>Номер петиції №22/046986-еп Мах приріст 1087 Заборонити перешкоджання невакцинованим дітям відвідувати школи та дитсадики, забезпечивши їхнє конституційне право на освіту (ст.53) Стутус :Триває збір підписів Опубліковано 21.09.2018 Залишилося 3 д. Проголосувало 5008</p>	
ПОБУДУВАТИ ГРАФІК	ВІДКРИТИ СТОРІНКУ	ПОБУДУВАТИ ГРАФІК	ВІДКРИТИ СТОРІНКУ
<p>Номер петиції №22/048039-еп Мах приріст 1933 Накласти вето на закони 8487 та 8488 про розмитнення авто на іноземній реєстрації Стутус :Триває збір підписів Опубліковано 09.11.2018 Залишилося 53 д. Проголосувало 11264</p>		<p>Номер петиції №22/047348-еп Мах приріст 819 Легалізація маріхуани Стутус :Триває збір підписів Опубліковано 09.10.2018 Залишилося 22 д. Проголосувало 6496</p>	
ПОБУДУВАТИ ГРАФІК	ВІДКРИТИ СТОРІНКУ	ПОБУДУВАТИ ГРАФІК	ВІДКРИТИ СТОРІНКУ
<p>Номер петиції №22/048351-еп Мах приріст 1492 Критична ситуація із заробітною платою і масовим відтоком спеціалістів в газорозподільних підприємствах України!</p>		<p>Номер петиції №22/048273-еп Мах приріст 772 Не допустити збільшення оподаткування на посилки фізичних осіб</p>	

Figure 3: Suspicious petitions highlighting.

“Open page” button leads to the petition webpage. An example is shown on the figure 4.

To compare the signatories of different petitions, it is necessary to select the date on the petition plot from which the signatories will be analyzed. It could be done by clicking on a specific day of the histogram. The minimum number of petitions to compare is two, but it is possible to select more.

After selecting the days, one need to open the comparison Activity. It could be done by clicking “Comparison” in the menu. An example of collecting the lists of signatories is shown on the figure 5.

This activity shows a list of selected petitions, selected dates and number of votes. A long press on the petition removes it from the list. To start the comparison, one should click “Comparison” in the menu, then if necessary, it is possible to export the data by clicking the “Export” item in the menu. An example of the comparison process and its result is shown on the figure 5.

If matches were found, it is possible to export the table with the list in csv format.

The application is similar to a log in which everyone can view a list of petitions and choose



Figure 4: Petition chart activity and a petition webpage.

one to view statistics, as well as go to the webpage where it is possible to vote. The data is updated periodically by timer event, but if one wants to update the list themselves at a convenient time, there is an update button.

When the application is started, the MainActivity is being created and the AppDatabase database is being connected. Afterwards, in the basic global class, OnBootReceiver and Alarm-Receiver broadcast receivers and the intentService service (ForegroundService) are being created. An adapter PetitionListAdapter for communication with the database is being created to load data into the PetitionViewModel through the application observer.

The update algorithm looks like this: the parser performs page-by-page analysis of the petition webpage while there is data. When the information is collected, the analysis of each petition begins separately and the votes data is obtained.

After information accumulation is completed, the data is being written to the database with page number marks, which is necessary to avoid full webpage parsing next time.

Having data from the petitions, namely the number of votes by date and the list of signatories

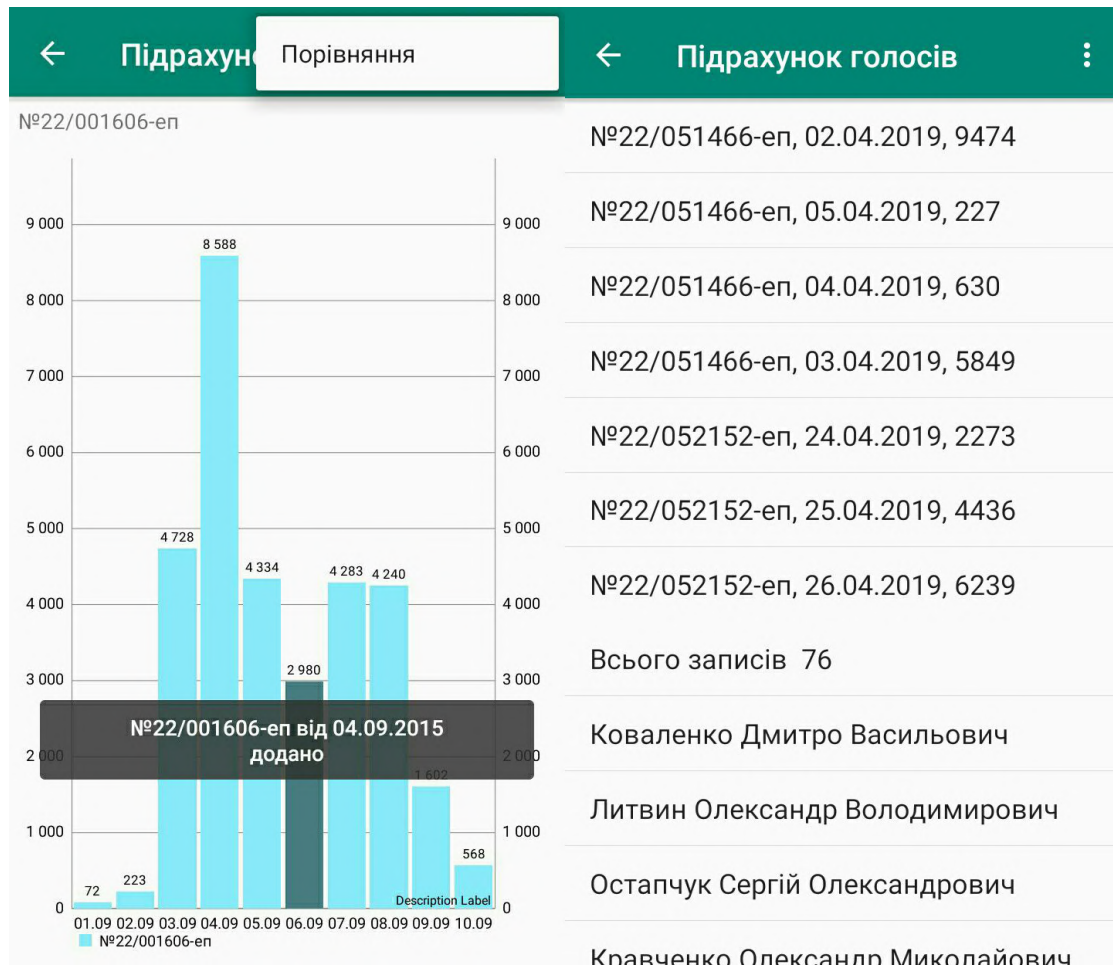


Figure 5: Comparison range selection and comparison results.

who voted for the petition these days, it is possible to compare the lists of people who voted on specific dates for different petitions. If matches were found, the obtained information might be taken into account. For example it might look suspicious if same persons regularly vote for different petitions within short periods of rapid votes bursts. CompareActivity is responsible for all this process.

5. An example of use

Although the research is not finished yet, we would be glad to share and discuss our interim results. The most interesting case is two opposite petitions for and against the resignation of the president Volodymyr Zelenskyj [12, 13]. Our software helped to detect over 500 persons who signed both of them during just few days. About half of these matches were detected in only two most active days of these two petitions (figure 6). Such indicators give reason to think

about the possible cheating and interference in the voting process. It may be a result of personal data stealing or votes trading.

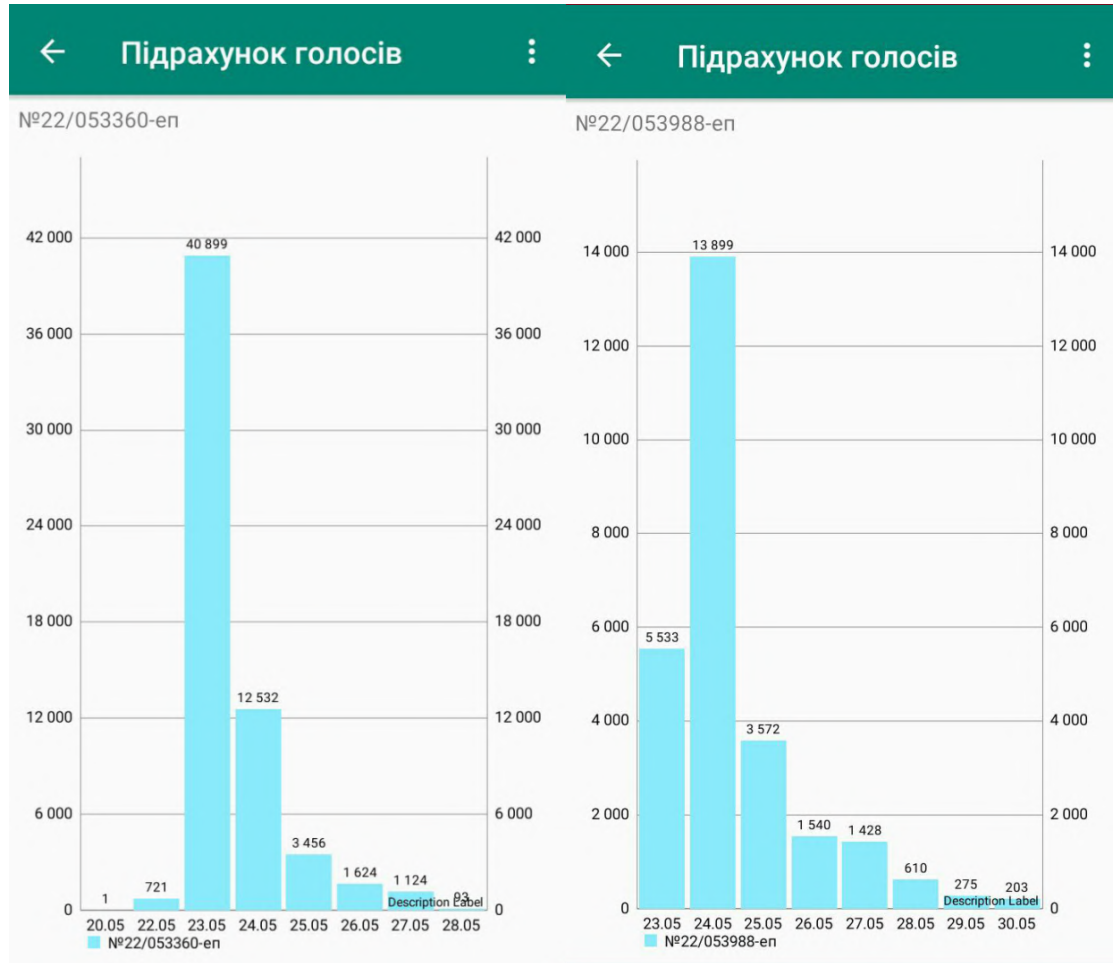


Figure 6: A comparison of vote gain dynamics of petitions 53360 and 53988.

6. Conclusion

Since there are no efficient tools for e-petitions cheating revealing, we developed an application for voting dynamics analysis. We are planning to build a mathematical model to detect suspicious voting gaining intervals, but due to the lack of completed petitions, we currently use a simplified model which might be improved in the future. It is possible to extract names of petitioners who signed petition within time intervals marked as “suspicious” and automatically name-by-name compare these lists for different petitions. The proposed software does not give a final verdict but may be used as a tool for detecting evidences of possible falsifications.

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New approach to switching points optimization for segmented regression during mathematical model building

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Abstract

Mathematical models building is widely used in different branches of human activity to describe statistical data obtained during observation of various phenomena. The main tool for this problem solution is approximation theory, especially ordinary least squares method. Basic goal during approximation is minimizing deviation between observed and estimated data. Analysis showed that providing given accuracy is possible based on usage of segmented regression models. Such models contain one or more switching points for segments connection. This paper deals with a problem of calculation of optimal values of switching point abscissa for segmented regression. Analytical expression for segmented regression was obtained using the Heaviside function. Switching point's determination is based on the usage of multidimensional optimization paraboloid. Paper presents the methodology for optimal segmented regression building. Simulation results and example of data processing proved increasing the accuracy of approximation in case of using the proposed methodology.

Keywords

mathematical model building, approximation, ordinary least squares method, segmented regression, optimization of switching point abscissa

1. Introduction

The mathematical models are used in many applications. Such models give the possibility to determine the mathematical relationship (formulas, logical dependency) for real world objects and phenomena. The one of the main motives to build mathematical models is: a) a greater understanding of researched phenomena, b) to analyze the object mathematically, c) to provide experimentation with model using simulation methods [1, 2].

The mathematical models building starts with experimental investigations and obtaining observations of some system, object or phenomenon. These operations form input data for model. According to these data, at the second stage mathematical formulations are carried out,

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and after those computational simulations are performed. Output data of simulation are used for model validation [3].

During mathematical models building, different models can be utilized. Researcher always tries to choose the best of them [4]. To do this the following criteria can be used: simplicity of mathematical equation with the given level of error, minimum number of coefficients in the mathematical equation, minimum sum of squared deviations between the predicted and empirical values and others [5].

The main algorithmic tool that is used to obtain information from mathematical models contains methods of linear algebra, data analysis, probability theory and mathematical statistics, functional analysis and others [6]. The mathematical models based on statistical data-driven approach can be built using the techniques of the approximation theory [7]. In case of approximation, spline functions or different polynomials are often used [8].

2. Literature review and problem statement

Nowadays, regression analysis becomes popular research tool for mathematical models building [9]. It allows to develop mathematical expressions to describe the behavior of some dependent random variable [10]. Regression analysis can be used to predict the value of dependent variable based on information of its previous realization trend.

The mathematical models building based on regression analysis can be used in different branches of human activity and scientific research:

- in econometrics: to analyze economics behavior for certain country or city dependent on one or more factors [11, 12];
- in biology: to obtain regional models of biological processes [13];
- for electrical engineering: to describe realizations of electrical signals and parameters of electronic devices [14, 15];
- in reliability theory: to build the mathematical model for trends of reliability parameters and diagnostics variables [16, 17];
- in aviation system: to build the mathematical model for Unmanned Aerial Vehicle (UAV) and aircraft flight routes [18, 19], to analyze the possibilities of UAV cyber security hazards [20], to calculate the efficiency of functioning of aviation equipment [21, 22], and others;
- for radar and navigation systems: to solve the problem of efficient target detection [23] and for approximation and prediction of data trends [24, 25, 26];
- during equipment operation: to calculate the optimal maintenance periodicity [27, 28] and to estimate the efficiency of diagnostics process [29, 30];
- for control systems: to find the correlation between statistical data for inertial stabilized platforms of ground vehicles [31] and to analyze possible control actions in case of aircraft departures and arrivals delays [32].

In practice, researchers apply simple linear regression [33] and more realistic nonlinear regression [34]. Considering nonlinear regression, it should be pointed that quadratic, cubic, exponential, segmented and even logistic regressions are widely used [35, 36]. Different software to implement such models was developed [37, 38].

As there are different types of regression curves, let $f_k(x_i, \vec{a}_{m,k})$ is set of k one-dimensional functions, any of them depends on vector $\vec{a}_{m,k}$ of m parameters and gives the estimate value \hat{y}_i for initial data in for two-dimensional array (x_i, y_i) with sample size n . According to existing results [9, 10, 33, 36], regression model with one independent variable can be presented as follows

$$Y = f_k(X, \vec{a}_{m,k}) + \epsilon,$$

where Y and X are the dependent and independent variables, ϵ is an error of evaluation.

For simple linear regression model $f_1(X, \vec{a}_{m,1}) = a_{0,1} + a_{1,1}X$, where $a_{0,1}$ and $a_{1,1}$ are parameters that must be determined [9].

To increase the accuracy of model, on the one hand, researchers use segmented regression techniques with several linear or parabolic sections for approximation empirical data [33]. On the other hand, additional analysis for heteroskedasticity in observed data trend is carried out [39, 40]. Literature analysis showed that unfortunately not enough attention is paid to another way of increasing the accuracy of model that is associated with calculation of optimal switching points (breakpoints or changepoints) between regression segments. To estimate the parameters of regression (including switching points), the maximum likelihood estimator (MLE) can be used [41, 42]. Moreover, paper [42] concentrates on replacing the traditional nonsmooth model with another that transitions smoothly at the switching point. Another approach can be based on Bayesian changepoint models [43, 44]. In some publications, there are attempts to solve this problem based on: 1) statistical simulation results using sequential search [45], 2) inverted F test confidence interval estimate for large sample sizes and bootstrapped confidence intervals estimate for small sample sizes [46]. Analysis of mentioned techniques for calculation of optimal switching points showed: a) MLEs require prior information on error distribution and approximate range of switching point, b) MLEs have bias of estimate, c) in some modifications MLE is the most computationally expensive, both in setup time and in run time, d) Bayesian estimators are more robust for difficult cases, but require additional prior limitations for model parameters. Moreover, the exact mathematical equations for optimal value of switching points in literature are not considered.

The *aim of this paper* is to develop a new approach to switching points optimization in case of segmented regression usage for mathematical models building. The calculation of the optimal values of abscissas of the switching points will give the possibility to increase the approximation accuracy and the possibility to improve the predictive properties.

From mathematical point of view, such problem can be considered as follows. At the first stage, it is necessary to choose the segmented approximation function $f_k(x_i, \vec{a}_{m,k})$ in such a way to minimize standard deviation σ between real values y_i and estimates \hat{y}_i

$$k = \text{inf}(s \forall j : \sigma(f_s(x_i, \vec{a}_{m,s})) \leq \sigma(f_j(x_i, \vec{a}_{m,j}))). \quad (1)$$

At the second stage, it is necessary to carry out optimization of switching points abscissas x_{sw} and to find the corresponding values

$$(x_{swopt_1}, x_{swopt_2}, \dots, x_{swopt_r}) = \text{argmin}(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r}), \quad (2)$$

where r is quantity of switching points in case of $r + 1$ segments for regression usage.

3. Methodology

The best preferred statistical data processing algorithms can be used in the conditions of aprioristic uncertainty [47]. In this research some limitations about aprioristic information was made.

After observation of random phenomenon, the two-dimensional array (x_i, y_i) with sample size n is collected. Initial data are plotted in two-dimensional space in form of dependence. Based on visual analysis of data, researcher can identify geometrical structure of data trend and choose the appropriate approximation function. Assume that only segmented functions can be used. Such function contains two or more segment without discontinuities. The segments are connected in the switching points. The quantity r of switching points or the quantity $r + 1$ of segments is determined by researcher according to the analysis of geometrical structure of plotted data.

At the first step, type of segmented regression for data approximation is chosen. In authors opinion, it is enough to use one of three types of segmented regression:

1. Segmented linear regression

$$f_1(X) = a_{0,1} + a_{1,1}X + \sum_{i=1}^r a_{i+1,1}(X - x_{sw_i})h(X - x_{sw_i}), \quad (3)$$

where $h(X - x_{sw_i})$ is Heaviside step function.

In case of two segments usage, functional dependence (3) contains one switching point and three unknown coefficients. Equation (3) can be presented as follows

$$f_1(X) = a_{0,1} + a_{1,1}X + a_{2,1}(X - x_{sw_1})h(X - x_{sw_1}).$$

Unknown coefficients $a_{0,1}$, $a_{1,1}$ and $a_{2,1}$ are calculated according to ordinary least squares method in such a way

$$a = W^{-1}B, a = \begin{pmatrix} a_{0,1} \\ a_{1,1} \\ a_{2,1} \end{pmatrix}, B = \begin{pmatrix} \sum_{i=1}^n y_i \\ \sum_{i=1}^n x_i y_i \\ \sum_{i=1}^n (x_i - x_{sw_1}) y_i h_1 \end{pmatrix}, h_1 = h(x_i - x_{sw_1}),$$

$$W = \begin{bmatrix} n & \sum_1^n x_i & \sum_1^n (x_i - x_{sw_1}) h_1 \\ \sum_1^n x_i & \sum_1^n x_i^2 & \sum_1^n (x_i - x_{sw_1}) x_i h_1 \\ \sum_1^n (x_i - x_{sw_1}) h_1 & \sum_1^n (x_i - x_{sw_1}) x_i h_1 & \sum_1^n (x_i - x_{sw_1})^2 h_1 \end{bmatrix}.$$

2. Segmented parabolic regression

$$f_2(X) = a_{0,2} + a_{1,2}X + a_{2,2}X^2 + \sum_{i=1}^r a_{i+2,1}(X - x_{sw_i})^2 h(X - x_{sw_i}). \quad (4)$$

In the case of two segments usage, functional dependence (4) contains one switching point and four unknown coefficients. Equation (4) can be presented as follows

$$f_2(X) = a_{0,2} + a_{1,2}X + a_{2,2}X^2 + a_{3,2}(X - x_{sw_1})^2 h(X - x_{sw_1}).$$

Unknown coefficients $a_{0,2}$, $a_{1,2}$, $a_{2,2}$ and $a_{3,2}$ are calculated according to ordinary least squares method in such a way

$$a = W^{-1}B, a = \begin{pmatrix} a_{0,2} \\ a_{1,2} \\ a_{2,2} \\ a_{3,2} \end{pmatrix}, B = \begin{pmatrix} \sum_1^n y_i \\ \sum_1^n x_i y_i \\ \sum_1^n x_i^2 y_i \\ \sum_1^n t_i^2 y_i h_1 \end{pmatrix}, t_i = x_i - x_{sw_1}$$

$$W = \begin{bmatrix} n & \sum_1^n x_i & \sum_1^n x_i^2 & \sum_1^n t_i^2 h_1 \\ \sum_1^n x_i & \sum_1^n x_i^2 & \sum_1^n x_i^3 & \sum_1^n t_i^2 x_i h_1 \\ \sum_1^n x_i^2 & \sum_1^n x_i^3 & \sum_1^n x_i^4 & \sum_1^n t_i^2 x_i^2 h_1 \\ \sum_1^n t_i^2 h_1 & \sum_1^n t_i^2 x_i h_1 & \sum_1^n t_i^2 x_i^2 h_1 & \sum_1^n t_i^4 h_1 \end{bmatrix}.$$

3. Segmented linear-parabolic regression

$$f_3(X) = a_{0,3} + a_{1,3}X + a_{2,3}X^2 p(X) + \sum_{i=1}^r a_{i+2,1}(X - x_{sw_i})^{p(X)+1} h(X - x_{sw_i}), \quad (5)$$

where $p(X)$ is sign function. This function is equal to zero, if the segment is linear, and is equal to one, if the segment is parabolic.

In the case of two segments usage with first parabolic and second linear segment, functional dependence (5) contains one switching point and three unknown coefficients. Equation (5) can be presented as follows

$$f_3(X) = a_{0,3} + a_{1,3}X + a_{2,3}X^2 - a_{2,3}(X - x_{sw_1})^2 h(X - x_{sw_1}).$$

Unknown coefficients $a_{0,3}$, $a_{1,3}$ and $a_{2,3}$ are calculated according to ordinary least squares method in such a way

$$a = W^{-1}B, a = \begin{pmatrix} a_{0,3} \\ a_{1,3} \\ a_{2,3} \end{pmatrix}, B = \begin{pmatrix} \sum_1^n y_i \\ \sum_1^n x_i y_i \\ \sum_1^n x_i^2 y_i - \sum_1^n t_i^2 y_i h_1 \end{pmatrix},$$

$$W = \begin{bmatrix} n & \sum_1^n x_i & \sum_1^n x_i^2 - \sum_1^n t_i^2 h_1 \\ \sum_1^n x_i & \sum_1^n x_i^2 & \sum_1^n x_i^3 - \sum_1^n x_i t_i^2 h_1 \\ \sum_1^n x_i^2 - \sum_1^n t_i^2 h_1 & \sum_1^n x_i^3 - \sum_1^n x_i t_i^2 h_1 & \sum_1^n x_i^4 + \sum_1^n (t_i^4 - 2x_i^2 t_i^2) h_1 \end{bmatrix}.$$

At the second step, the quantity r of switching points and the range of possible values of abscissas of switching points is selected subjectively based on visual analysis of observed data. For this approach, it is necessary to choose at least five possible values for each switching point. So matrix of vectors of possible abscissa values is generated in the following form $(\vec{x}_{sw_1}, \vec{x}_{sw_2}, \dots, \vec{x}_{sw_r})$.

At the third step, regression coefficients and standard deviations σ between real values y_i and estimates \hat{y}_i for all segmented regression types are calculated. Standard deviation is determined according to the equation

$$\sigma = \sqrt{\frac{1}{n-l} \sum_{i=1}^n (y_i - \hat{y}_i)^2}, \quad (6)$$

where l is a degree of freedom for selected model.

The standard deviation is calculated for all combinations of possible values of switching point abscissa. So at this step, the r -dimensional dependence of $\sigma(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r})$ is obtained.

At the fourth step, the obtained dependence is approximated by r -dimensional paraboloid based on ordinary least squares method. The general equation of r -dimensional paraboloid

$$z(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r}) = A_0 + \sum_{i=1}^r A_i x_{sw_i}^2 + \sum_{i=1}^r B_i x_{sw_i} + \sum_{i < j} C_{i,j} x_{sw_i} x_{sw_j}, \quad (7)$$

where $A_i, B_i, C_{i,j}$ are unknown coefficients need to be estimated, the sum is calculated only for $i < j$.

To simplify the calculation, it can be assumed that $C_{i,j} = 0$ and equation (7) will take a form

$$z(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r}) = A_0 + \sum_{i=1}^r A_i x_{sw_i}^2 + \sum_{i=1}^r B_i x_{sw_i}. \quad (8)$$

In this case unknown coefficients can be found according to the following equation

$$a = W^{-1}B, a = \begin{pmatrix} A_0 \\ A_1 \\ B_1 \\ \dots \\ A_r \\ B_r \end{pmatrix}, B = \begin{pmatrix} \sum_1^v \dots \sum_1^v z_{i_1, i_2, \dots, i_r} \\ \sum_1^v \dots \sum_1^v x_{sw_1 i_1}^2 z_{i_1, i_2, \dots, i_r} \\ \sum_1^v \dots \sum_1^v x_{sw_1 i_1} z_{i_1, i_2, \dots, i_r} \\ \dots \\ \sum_1^v \dots \sum_1^v x_{sw_1 i_r}^2 z_{i_1, i_2, \dots, i_r} \\ \sum_1^v \dots \sum_1^v x_{sw_1 i_r} z_{i_1, i_2, \dots, i_r} \end{pmatrix}, g = v^{r-1}$$

$$W = \begin{bmatrix} v^r & g \sum_1^v x_{sw_1 i_1}^2 & g \sum_1^v x_{sw_1 i_1} & \dots & g \sum_1^v x_{sw_r i_1} \\ g \sum_1^v x_{sw_1 i_1}^2 & g \sum_1^v x_{sw_1 i_1}^4 & g \sum_1^v x_{sw_1 i_1}^3 & \dots & g \sum_1^v x_{sw_1 i_1}^2 x_{sw_r i_1} \\ g \sum_1^v x_{sw_1 i_1} & g \sum_1^v x_{sw_1 i_1}^3 & g \sum_1^v x_{sw_1 i_1}^2 & \dots & g \sum_1^v x_{sw_1 i_1} x_{sw_r i_1} \\ \dots & \dots & \dots & \dots & \dots \\ g \sum_1^v x_{sw_r i_1} & g \sum_1^v x_{sw_1 i_1}^2 x_{sw_r i_1} & g \sum_1^v x_{sw_1 i_1} x_{sw_r i_1} & \dots & g \sum_1^v x_{sw_1 i_r}^2 \end{bmatrix}.$$

where v is quantity of chosen points in the range of possible values of abscissas of switching points.

At the fifth step, the minimum of r -dimensional paraboloid is calculated to provide the criterion (2). For this purpose, the theory of optimization is used [48]. To find the minimum, it is necessary to solve the system of equations

$$\begin{cases} \frac{\partial z(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r})}{\partial x_{sw_1}} = 0, \\ \frac{\partial z(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r})}{\partial x_{sw_2}} = 0, \\ \dots \\ \frac{\partial z(x_{sw_1}, x_{sw_2}, \dots, x_{sw_r})}{\partial x_{sw_r}} = 0. \end{cases} \quad (9)$$

In the case of r -dimensional paraboloid (7) usage, the system of equations (9) turns to the system of r linear equations that can be solved by one of known method. In case of simplified

paraboloid (8) usage, the simple solution can be obtained in the following form

$$x_{sw_i, opt} = \frac{-B_i}{2A_i}. \quad (10)$$

At the sixth step, coefficients of segmented regression (3), (4) or (5) are recalculated, and resulting model is obtained.

4. Simulation results and numerical example

Consider the problem of analysis of proposed methodology implementation based on the results of statistical simulation.

The statistical simulation starts with obtaining initial data set with two switching points. The data set contains deterministic and random components. The deterministic component can be presented as follows

$$f_1(X) = a_{0,1} + a_{1,1}X + a_{2,1}(X - x_{sw_1})h(X - x_{sw_1}) + a_{3,1}(X - x_{sw_2})h(X - x_{sw_2}).$$

This dependence is converted into discrete form at the range [1; 100] with sampling interval $\delta = 1$ and sample size $n = 100$. The initial parameters of deterministic model can be different, but in this research, authors used the following initial numerical values: $a_{0,1} = 500$, $a_{1,1} = 10$, $a_{2,1} = -25$, $a_{3,1} = 20$, $x_{sw_1} = 20$ and $x_{sw_2} = 50$.

Random component is generated at each sample point as additive Gaussian noise with zero expected value and standard deviation $\sigma = 30$. The number of procedures reiteration is 1000.

The example of one of data sets is given in table 1. The data in the table 1 present the values of dependent variable Y that was measured at points X separated by sampling interval δ .

The graphical presentation of three examples of initial data set is shown in figure 1.

Visual analysis of data (figure 1) gives possibility to conclude that most convenient regression type for these data approximation is segmented linear regression with two switching points. Let $r = 5$. The range of possible values of abscissas of switching points is

$$x_{sw_1} = (10, 15, 20, 25, 30),$$

$$x_{sw_2} = (40, 45, 50, 55, 60).$$

In this case it is necessary to calculate estimates of regression coefficients $a_{0,1}$, $a_{1,1}$, $a_{2,1}$, $a_{3,1}$ for all combinations of possible values of abscissas of switching points. After that, standard deviation (6) is determined for each option. The results of standard deviation calculation are given in table 2.

Data from table 2 are approximated by two-dimensional paraboloid based on ordinary least squares methods. For paraboloid types (7) and (8) following equations were obtained

$$z(x_{sw_1}, x_{sw_2}) = 364.893 - 6.635x_{sw_1} - 10.012x_{sw_2} + 0.111x_{sw_1}^2 + 0.09x_{sw_2}^2 + 0.047x_{sw_1}x_{sw_2},$$

$$z(x_{sw_1}, x_{sw_2}) = 317.416 - 4.261x_{sw_1} - 9.062x_{sw_2} + 0.111x_{sw_1}^2 + 0.09x_{sw_2}^2,$$

The obtained paraboloids are shown in figure 2 and figure 3, respectively.

Table 1
Example of initial data set.

X	Y	X	Y	X	Y	X	Y	X	Y
1	478.051	21	708.727	41	430.555	61	361.496	81	391.604
2	531.887	22	716.929	42	397.554	62	357.442	82	410.622
3	488.646	23	698.735	43	440.372	63	281.227	83	370.187
4	532.988	24	662.582	44	324.692	64	362.172	84	460.596
5	437.424	25	554.083	45	372.758	65	336.362	85	345.848
6	576.916	26	663.423	46	343.182	66	341.036	86	356.448
7	558.703	27	621.014	47	304.289	67	288.759	87	408.922
8	525.774	28	692.666	48	380.215	68	401.393	88	459.006
9	561.106	29	522.092	49	252.287	69	321.402	89	340.568
10	598.737	30	659.452	50	333.319	70	290.943	90	443.487
11	631.717	31	398.557	51	307.979	71	436.479	91	541.709
12	658.255	32	520.615	52	270.906	72	333.381	92	436.921
13	647.998	33	472.390	53	290.251	73	373.471	93	462.618
14	607.476	34	463.161	54	265.407	74	343.770	94	532.297
15	648.630	35	442.640	55	240.342	75	354.348	95	484.741
16	691.087	36	443.975	56	269.936	76	402.171	96	451.064
17	638.839	37	482.674	57	338.144	77	377.978	97	505.605
18	687.825	38	433.265	58	284.574	78	303.512	98	439.356
19	689.012	39	405.900	59	351.267	79	339.748	99	450.629
20	653.723	40	444.444	60	243.165	80	312.829	100	485.727

Table 2
Standard deviations.

Abscissas	$x_{sw_1} = 10$	$x_{sw_1} = 15$	$x_{sw_1} = 20$	$x_{sw_1} = 25$	$x_{sw_1} = 30$
$x_{sw_2} = 40$	72.179	62.257	56.561	58.777	66.45
$x_{sw_2} = 45$	63.561	53.526	49.227	53.585	62.128
$x_{sw_2} = 50$	57.41	48.362	46.246	52.425	61.318
$x_{sw_2} = 55$	56.026	49.361	49.677	56.532	64.713
$x_{sw_2} = 60$	59.484	55.562	57.516	63.941	70.661

In the case of paraboloid (7) usage, it is necessary to solve system of equations (9) that takes a form

$$\begin{cases} \frac{\partial z(x_{sw_1}, x_{sw_2})}{\partial x_{sw_1}} = 0, \\ \frac{\partial z(x_{sw_1}, x_{sw_2})}{\partial x_{sw_2}} = 0. \end{cases}$$

After derivatives calculation this system of equations turns to system of linear equations

$$\begin{cases} -6.635 + 0.222x_{sw_1opt} + 0.047x_{sw_2opt} = 0, \\ -10.012 + 0.047x_{sw_1opt} + 0.18x_{sw_2opt} = 0. \end{cases}$$

The solution of this system is

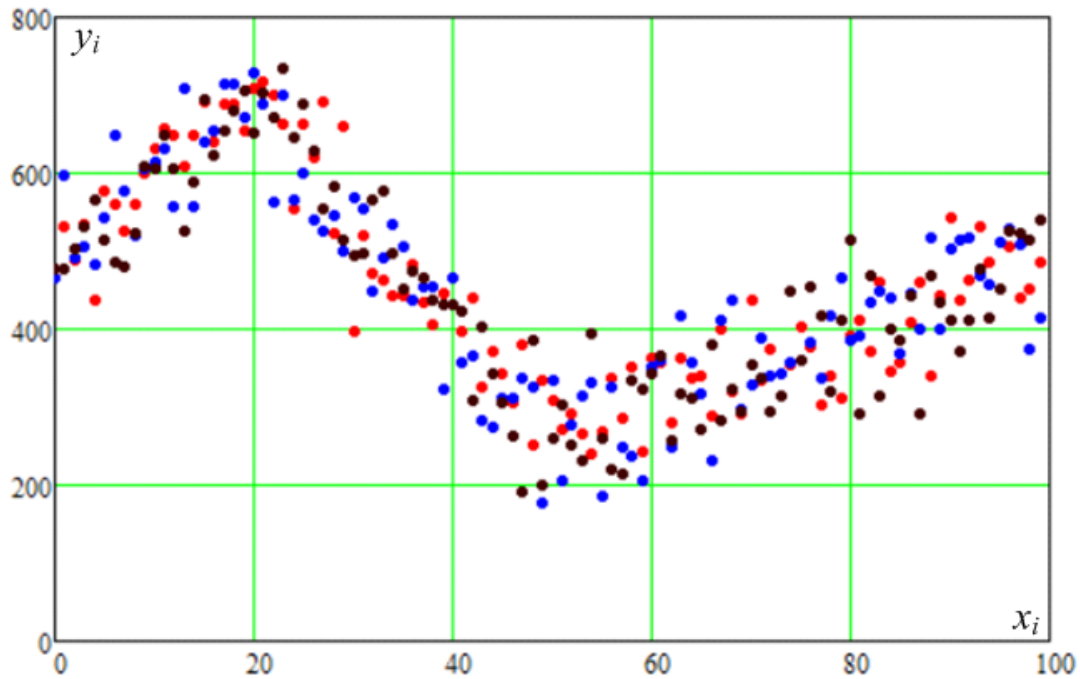


Figure 1: The initial data sets (three realizations).

$$x_{sw1opt} = 18.941,$$

$$x_{sw2opt} = 50.812.$$

In the case of paraboloid (8) usage, the optimal values of abscissas of switching points are calculated according to equation (10). The results of calculation

$$x'_{sw1opt} = 19.113,$$

$$x'_{sw2opt} = 50.532.$$

Analysis showed that for this particular case simplified paraboloid gives greater accuracy of switching point's abscissas estimates (relative error is 4.435 percent and 1.064 percent for the first and second switching points, respectively).

Resulting segmented linear regressions for both optimization options (paraboloids (7) and (8)) are

$$f_1(X) = 484.143 + 11.397X - 25.025(X - 18.941)h(X - 18.941) + \\ + 18.021(X - 50.812)h(X - 50.812),$$

$$f_1(X) = 484.987 + 11.26X - 25.073(X - 19.113)h(X - 19.113) +$$

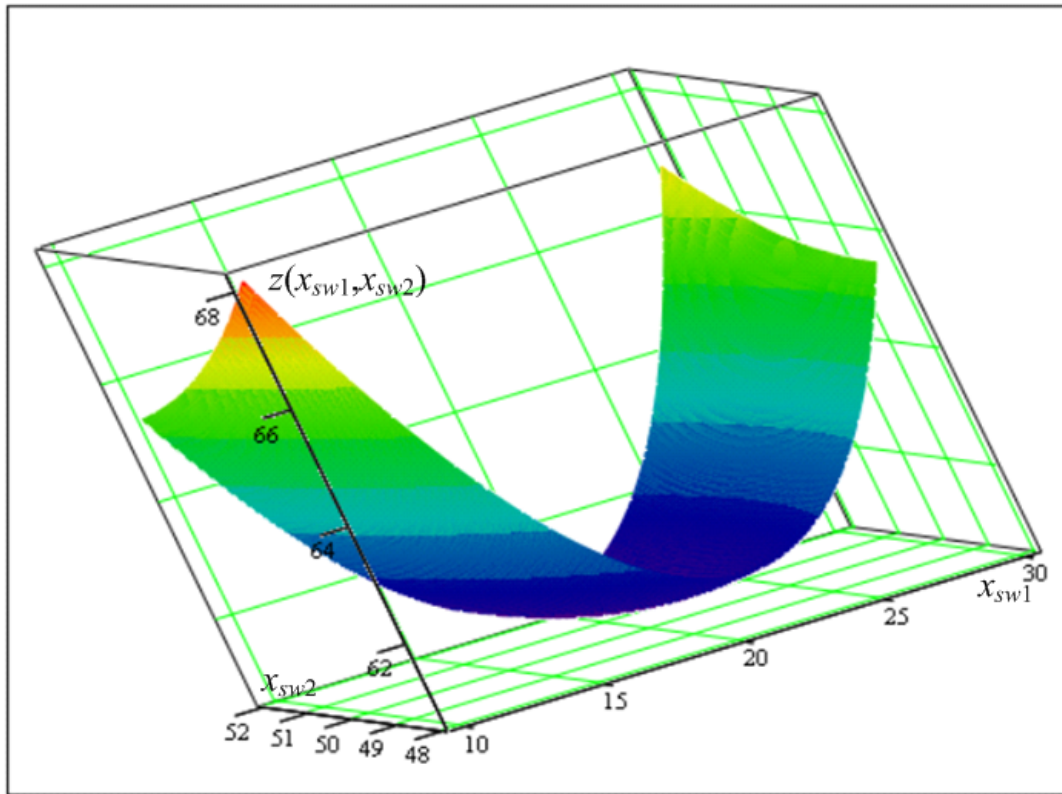


Figure 2: Obtained paraboloid (7) for data set from table 1.

$$+18.155(X - 50.532)h(X - 50.532).$$

The standard deviation for the first and second optimization options is 46.038 and 46.040, respectively. The results of approximation are shown in figure 4.

Resulting segmented linear regressions for both optimization options in figure 4 almost coincide and have approximately equal standard deviation.

Consider the statistical simulation results for 1000 reiteration procedures. Such simulation gives the possibility to build the probability density functions of estimates of switching point's abscissas. Figure 5 shows the histograms for estimate of abscissa of the first (figure 5a) and second (figure 5c) switching point for paraboloid (7), the histograms for estimate of abscissa of the first (figure 5b) and second (figure 5d) switching point for paraboloid (8). Statistical characteristics (expected value, variance, minimum and maximum) of estimates for optimal values of abscissas of switching points using paraboloids (7) and (8) are given in table 3.

Analysis showed that general paraboloid (7) in average has greater accuracy for switching points abscissas estimation. In the case of the first switching points abscissas estimation, relative error is 3.63 and 4.32 percents for paraboloid (7) and (8), respectively. In the case of second switching points abscissas estimation, relative error is 0.968 and 1.376 percents for paraboloid (7) and (8), respectively. In addition, paraboloid (7) has greater scattering of estimate.

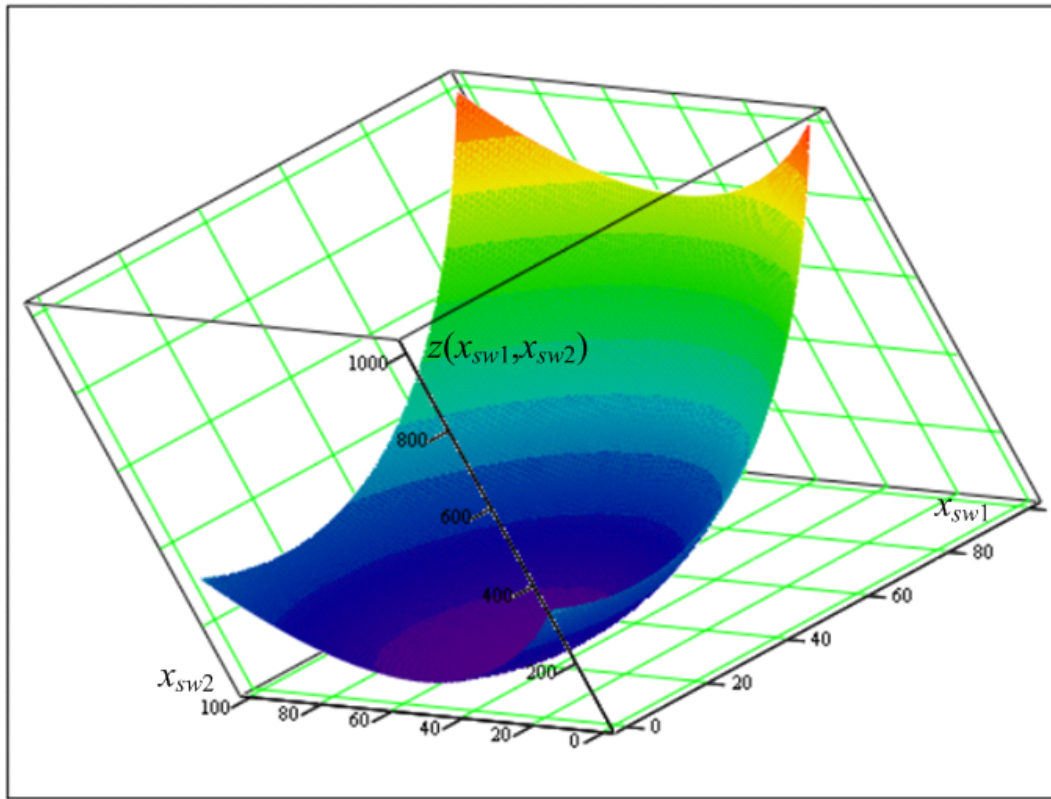


Figure 3: Obtained paraboloid (8) for data set from Table 1.

The simulation results give approximately same efficiency of estimate and accuracy of mathematical model. So to simplify the calculation, optimizational paraboloid (8) can be used as more suitable during mathematical model building.

5. Conclusion

The paper considers new approach to switching point's optimization for segmented regression during mathematical model building. The analytical equations for segmented linear, parabolic and linear-parabolic regressions are presented based on usage of Heaviside step function. To find the optimal values of connection points between regression segments, multidimensional optimization paraboloid is used for describing the dependence of standard deviation on possible values of switching point's abscissa. The proposed methodology, in contrast to the existing ones, allows to obtain the accurate mathematical formula for calculating the abscissa of switching points. Moreover, considered methodology has property of robustness for initial distribution of errors and dataset. The analysis of proposed methodology is carried out based on statistical simulation. The implementation of methodology is explained on numerical example for generated data set. Computations prove feasibility of proposed approach. The research results can be

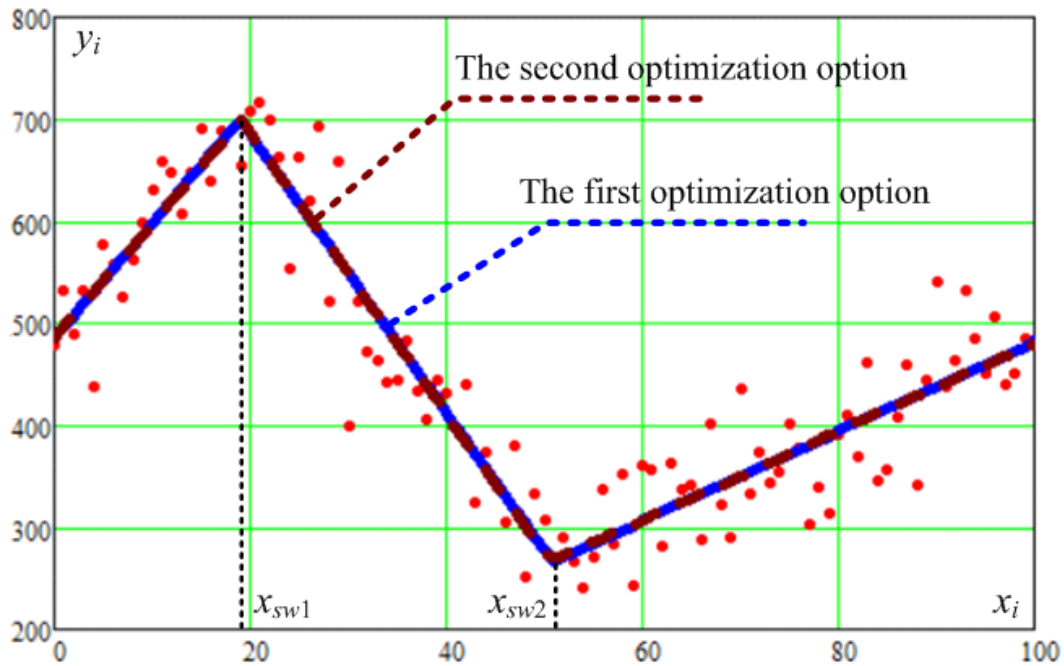


Figure 4: The initial data set and obtained optimal segmented linear regressions.

Table 3

Statistical characteristics of estimates for optimal values of abscissas of switching points using paraboloids (7) and (8)

Statistical characteristic	Paraboloid (7)	Paraboloid (8)
Expected value for x_{sw1}	20.726	20.864
Variance for x_{sw1}	1.427	1.317
Minimum value for x_{sw1}	15.892	16.929
Maximum value for x_{sw1}	25.004	25.026
Expected value for x_{sw2}	50.484	50.688
Variance for x_{sw2}	1.314	1.188
Minimum value for x_{sw2}	45.978	45.914
Maximum value for x_{sw2}	54.883	55.062

used to increase the accuracy of data approximation in mathematical model building.

Further research directions will be associated with a comparative analysis of the efficiency of the proposed methodology with other techniques for determining estimates of the abscissa of switching points (in particular, MLE and estimates based on the Bayesian approach) in the case of different limitations presence.

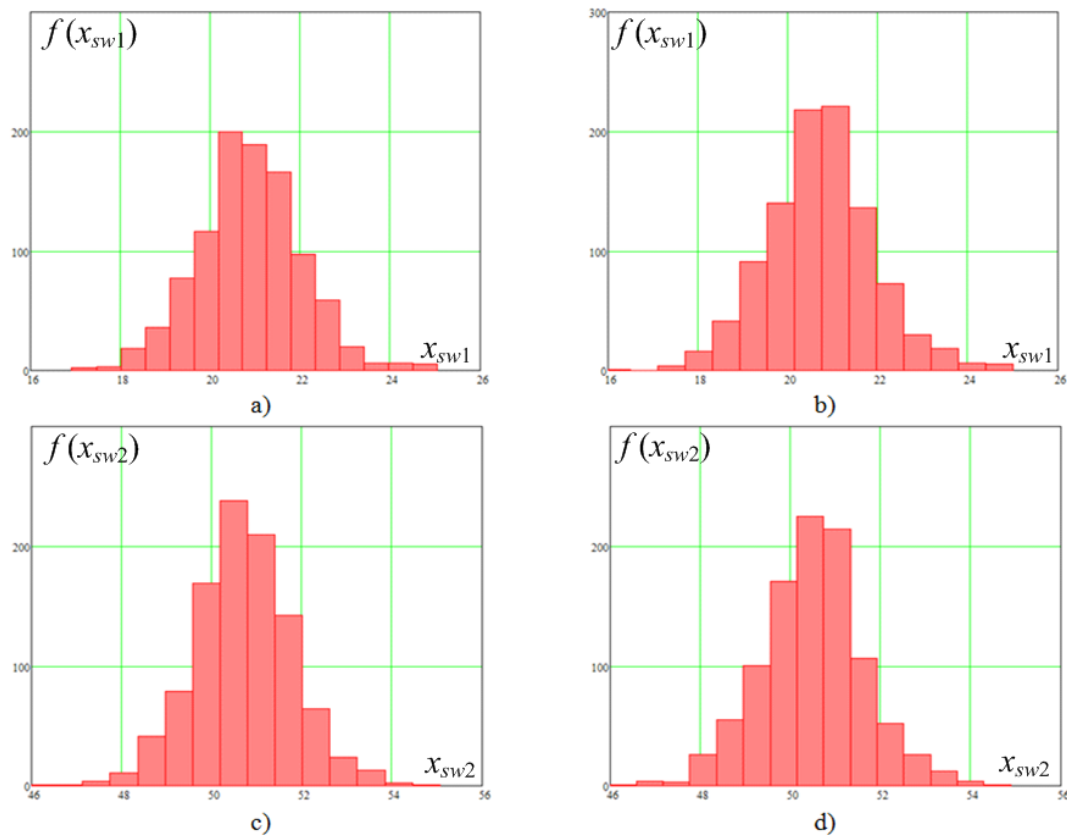


Figure 5: The histograms of estimates of switching point's abscissas.

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Available parking places recognition system

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Abstract

The paper describes algorithms and methods of working of the available parking places recognition system by analyzing the flow of video data, coming from the city cameras. Search an available parking place is usually a significant problem in modern cities, which requires finding new information technologies, approaches to solve it. Therefore, the purpose of this work is to analyze existing solutions and finding new information technologies for the task of optimizing the parking process. In addition, the software implementation of the proposed algorithms and methods has been implemented. The system was developed with Python and PHP programming languages. With Python an algorithm for recognizing free spaces for car parking and a chatbot for Telegram were implemented. PHP was used for the developing of the content management system with MVC (Model-View-Controller) architectural pattern. MySQL was chosen as the database management system. Communication between the chatbot and the script for recognition is carried out using memory-resident NoSQL DBMS Redis. The implemented system allows drivers to search available parking places in the selected parking lot with a minimum of time, providing information via a Telegram chatbot. The system can be deployed on Apache2 Webserver and Linux OS.

Keywords

parking place, parking lot, Mask R-CNN, neural network, edge computing, computer vision

1. Introduction

Analyzing auto-flow in Ukrainian cities, we can mention that it always increases. This situation causes some problems for citizens. The biggest problem is searching for an available parking place near big supermarkets, multi-story buildings or other areas with crowds of people. Implementation of available parking places recognition system will allow users to determine whether the specified parking lot has available parking places and choose which part of the parking lot these places are located. Modern systems are based on artificial intelligence and machine learning, which, combined with edge computing and intelligent technologies, create digital society systems capable of solving several complex problems and automating management

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decisions that improve human life. Therefore, the available parking places recognition system is one of the components of an intelligent city system and a necessary component of modern digital society.

2. The purpose and objectives of the study

The primary purpose of the program system implementation is a minimization of time for searching for an available parking place to park a car. The system must provide quick information about the existence and location of public parking places on a selected parking lot.

The following system components should be implemented:

- chatbot for messenger Telegram;
- website for system management;
- sub-module for searching available parking places in real-time using video cameras installed on this parking lot and connected to the Internet.

Implementation of the objectives for Telegram chatbot consists of the following stages:

1. Creating a possibility for showing a list of available parking lots to search for available parking places.
2. Handling and processing a request for an available parking place searching for a chosen parking lot.
3. Implementation of data processing received from the recognition sub-system and sending these data to the user as text and images.
4. Implementation of the possibility of performing an automatic search of available parking places for a specified parking lot at a limited time.

Implementation of the objectives for the sub-system consists of the following stages:

1. Connection establishment with IP security camera, using required data from a database.
2. Retrieving an image from a video-flow, for the recognition.
3. Car recognition on the image and getting coordinates of cars found by the system.
4. Implementation of an algorithm that determines the availability of a parking place, using the coordinates.
5. Control of input requests from the Telegram bot.
6. Generating a response for the chatbot.
7. Saving of an image with marked available parking places.

3. Analysis of published data

Girshick et al. [1], Hariharan et al. [2, 3], Dai et al. [4] show the efficiency of the Region-Based Convolutional Neural Network (R-CNN). Most approaches for semantic segmentation use information about shape by extraction of CNN functions from masked image regions. In papers

[5, 6] utilized classification of the Fast R-CNN. However, segmentation that precedes recognition, going slowly and is less accurate. The authors of the article [7] have gotten good results. They claim that Mask R-CNN provides a practical foundation for a self-learning strategy. The work's main contribution [8] comprehensively describes region-based convolutional neural networks and their recent improvement. In paper [9], the application of the cutting-edge instance segmentation framework, Mask R-CNN, was demonstrated in cattle counting in different situations. In article [10], a detailed survey of loss combinations was provided and showed improvements on the MS COCO Mask. In a default Mask R-CNN setup, achieved a training speed-up. Today, there are many different companies involved in non-regular passenger transport. Yefimenko et al. [11] consider the possibility of reducing the speed of order processing to improve service delivery but ignore the necessity of quickly finding parking spaces. Cheng et al. [12] consider the conditions for improving the accuracy of mask localization in the process of image segmentation. Huang et al. [13] evaluated the problem of mask quality. They proposed R-CNN with mask scoring, which contains a network block for studying the quality of predicted masks of instances.

4. Materials and methods

We will analyze information technology to find an available parking place. The Region-Based Convolutional Neural Networks architecture has been developed to apply Convolution Neural Networks to object detection tasks.

Mask of R-CNN represents a two-stage structure: at the first stage, an image is scanned, and regions are generated, which can contain an object. At the second stage, suggestions are classified, and bounding boxes and masks are created. Figure 1 shows the Mask R-CNN architecture.

The Mask R-CNN, a deep neural network designed to separate machine learning and computer vision, is used to solve the problem of recognizing cars in a frame obtained from a video stream. An image or video is input, an object frame, an object contour ("mask") and an object class is output.

The Mask R-CNN neural network has proven itself very well in recognizing and distinguishing vehicles in the image. A notable increase in accuracy and performance can be achieved using the Feature Pyramid Network (FPN) as a backbone.

The COCO dataset (Common Objects in Context) is used for data analysis and machine learning [14]. It contains about 330 thousand images, including images of cars, trucks, motorcycles, buses – all types of objects that may be needed to implement this system.

Intersection Over Union (IoU) computes the intersection by joining two bounding rectangles, bounding rectangle for primary truth and bounding rectangle for predicted rectangle by algorithm[15].

When the IoU is 1, it will mean that the predicted box and the confidence bounding box overlap entirely. To detect the object in the image, in case of non-maximum suppression, all bounding boxes with $\text{IoU} > 0,5$ takes into account.

Thus, after analysing the capabilities of these technologies, a general algorithm of the system was created:

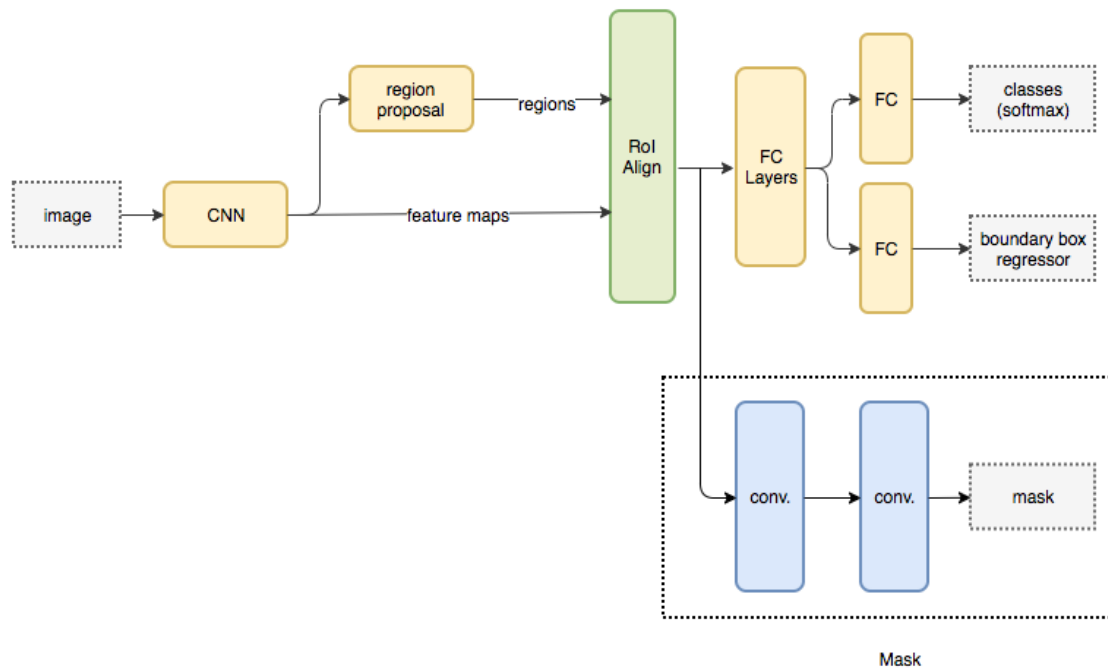


Figure 1: Architecture of the Mask R-CNN.

1. Connection to an IP security camera;
2. Obtaining the initial frame of the parking lot, where all parking places are filled with cars. This frame is used as a basis for determining the availability of the parking space;
3. Recognition of all cars in the initial frame by using the model Mask R-CNN and obtaining their coordinates;
4. Getting the current frame from the video stream;
5. Recognition of all cars in the current frame by using the model Mask R-CNN and obtaining their coordinates;
6. Finding the IoU value (figure 2) between the car at the initial frame and the vehicle at the current frame. This determines the availability of parking space. If this value is less than some constant value (for example, 0.15), then this parking space is considered available;
7. Based on the calculated data, the information is sent to the end-user.

To get more performance on a computer with a 4 GB GPU, the Mask R-CNN settings have been changed. As a result, the best system performance was obtained with the following settings:

```
class MaskRCNNConfig(Config):
    NAME = "coco_pretrained_model_config"
    IMAGES_PER_GPU = 1
    GPU_COUNT = 1
```

```
DETECTION_MIN_CONFIDENCE = 0.7
VALIDATION_STEPS = 10
STEPS_PER_EPOCH = 100
```

The system's main components are a chatbot, an algorithm for recognizing an available parking place, and a control panel. After launching the Telegram chatbot, the user has specific actions available: view information about the bot, show a list of commands on the screen, show available actions in the form of a button menu. When a user selects "Find Free Place" or "Set Up Auto Search", a button menu appears with a list of all available locations. After selecting one of the locations, the user gets the result, and in the second case, he needs to choose the time and days of the week for an automatic search. If the user wants to finish working with the chatbot, he can leave the conversation. Otherwise, he can select any action again.

An equally important component of the system is the script for recognizing available space for car parking. The recognition script is run once and executed access to the video stream from the IP camera. The current frame is taken from the received video, and by using the algorithm, it is checked whether free parking places are available in the given location. At the same time, it is checked whether there are requests from the chatbot. Depending on the combination of these factors, the script either generates a response, then sends it to the chatbot, or takes the next frame and starts the process again. The following is the activity diagram of the recognition script (figure 2).

Figure 3 shows the class diagram of the control panel.

The following classes can be distinguished in this diagram:

- Core – core of the MVC;
- Template – class for the view logic;
- DatabaseSingleton – the class for database queries execution and general working with the database;
- "Admin_Controller" – the main controller for control panel working. This class uses "Admin_Model" – for data processing and "Admin_View" – for showing results;
- "Admin_Model" – a model which defines working with database in the control panel;
- "Admin_View" – an MVC component that takes care of displaying logic. The controller uses class depends on a controller function, shows content to a user.

The following classes and methods have been implemented to create a chatbot and a recognition algorithm using Python (figure 4).

The following classes can be distinguished at this diagram:

- TelegramBot – a category that controls all the logic of the Telegram chatbot;
- FreeParkingDetector – a class that implements an algorithm for recognizing available parking places on video from a video camera and creates a response object to send to the chatbot;
- MaskRCNNConfig – a configuration class for the Mask R-CNN model that sets object recognition parameters on the image. This class is used while creating a model object.
- MysqlClient – a class for implementation of work with DBMS MySQL on the side of Python programming language. Used to insert, edit, delete and retrieve information. It is a "link" between Python scripts and the control panel implemented using PHP.

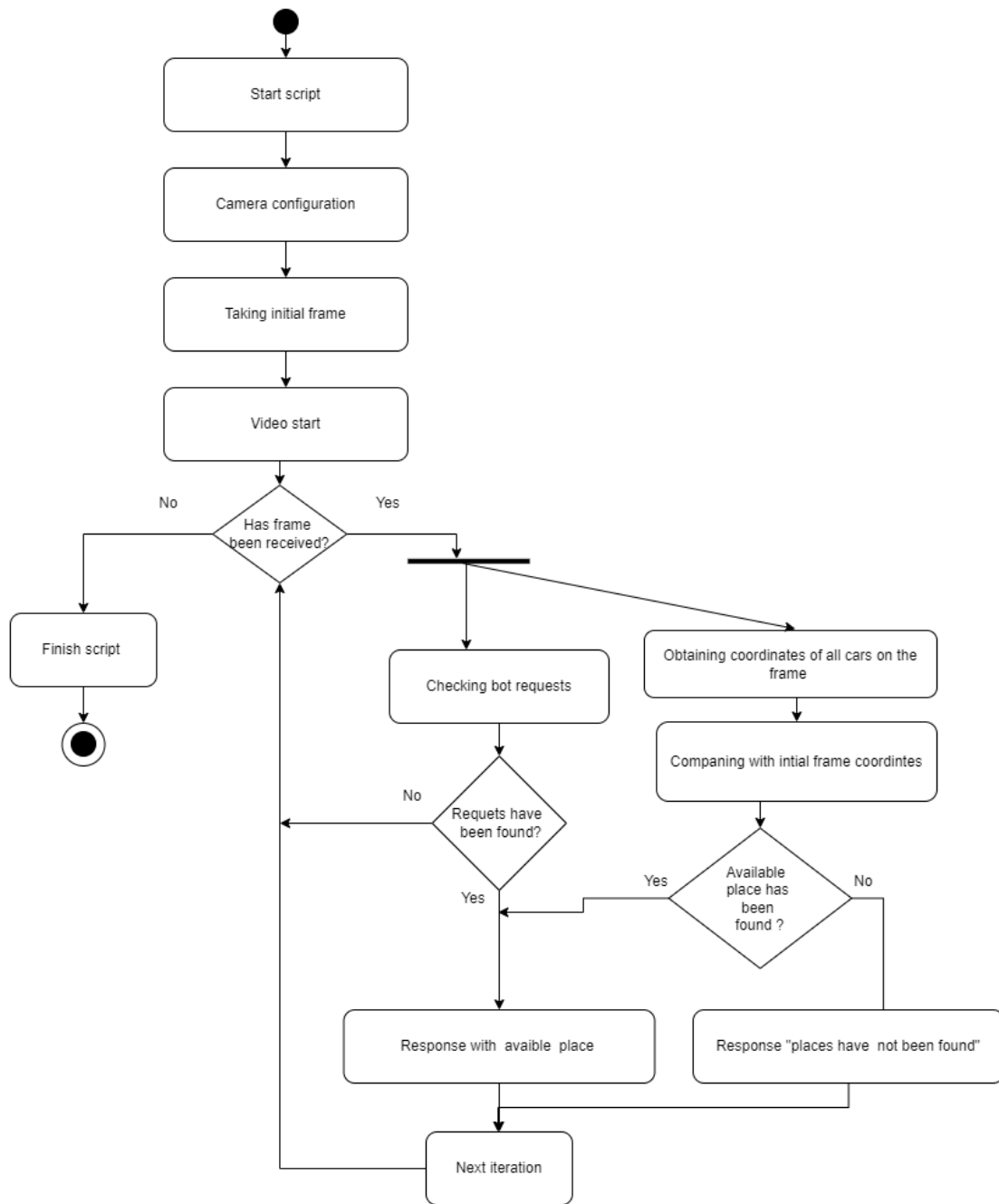


Figure 2: The activity diagram of the recognition script.

- RedisClient – a class for working with NoSQL Redis data warehouse in Python programming language. With Redis, there is constant real-time communication between the Python scripts.

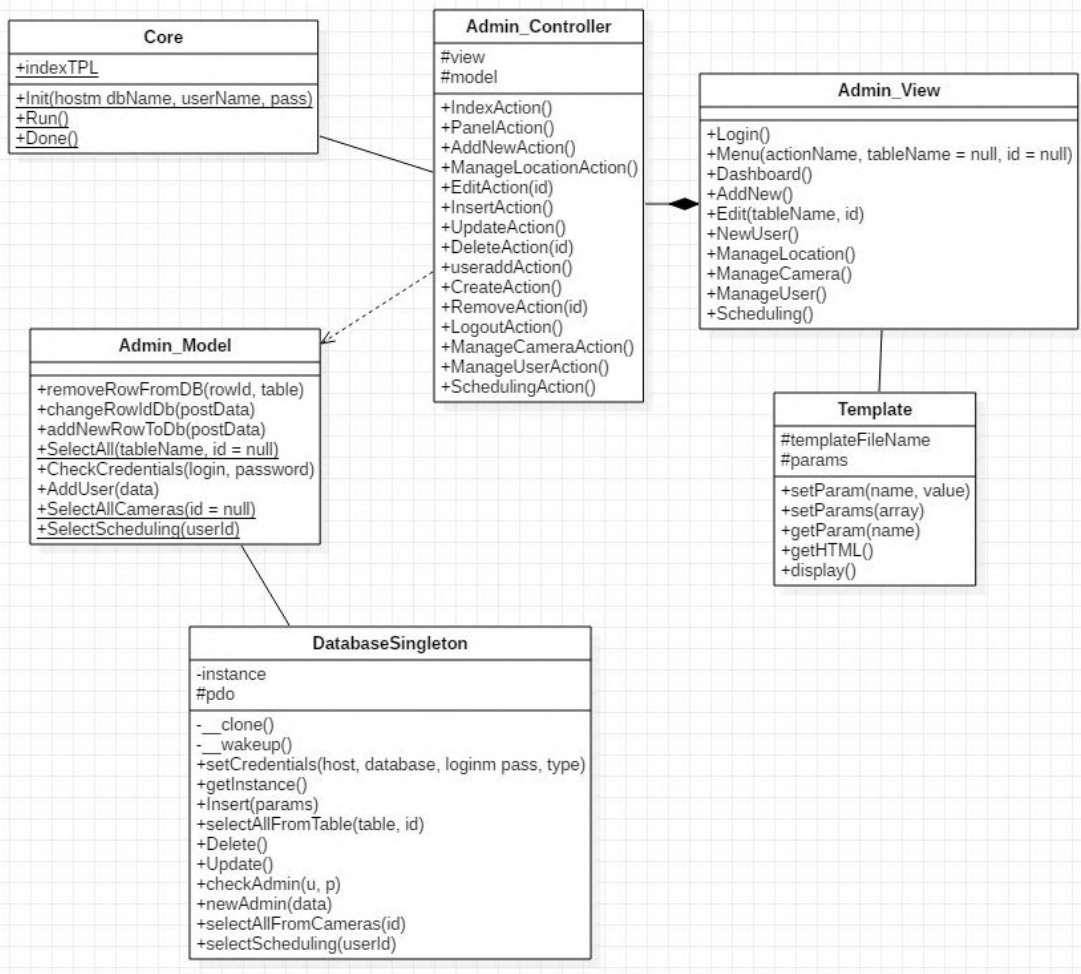


Figure 3: The activity diagram of the recognition script.

The system database “free_parking_detection_database” includes five tables, storing all required information for working the program. The database structure is shown in figure 5.

The “users” table is created to store info about administrators. The “telegram_users” table is used to store data of Telegram chatbot users. The “locations” table is designed to store parking lots and their locations. The “location_camera” table is created to store security camera access settings. This table is related to the “locations” by location identifier. The “detection_scheduling” table is used to store configurations for auto-recognition of a parking place. The table contains time and weekdays, in which the system should search available sites for specified used at a limited time.

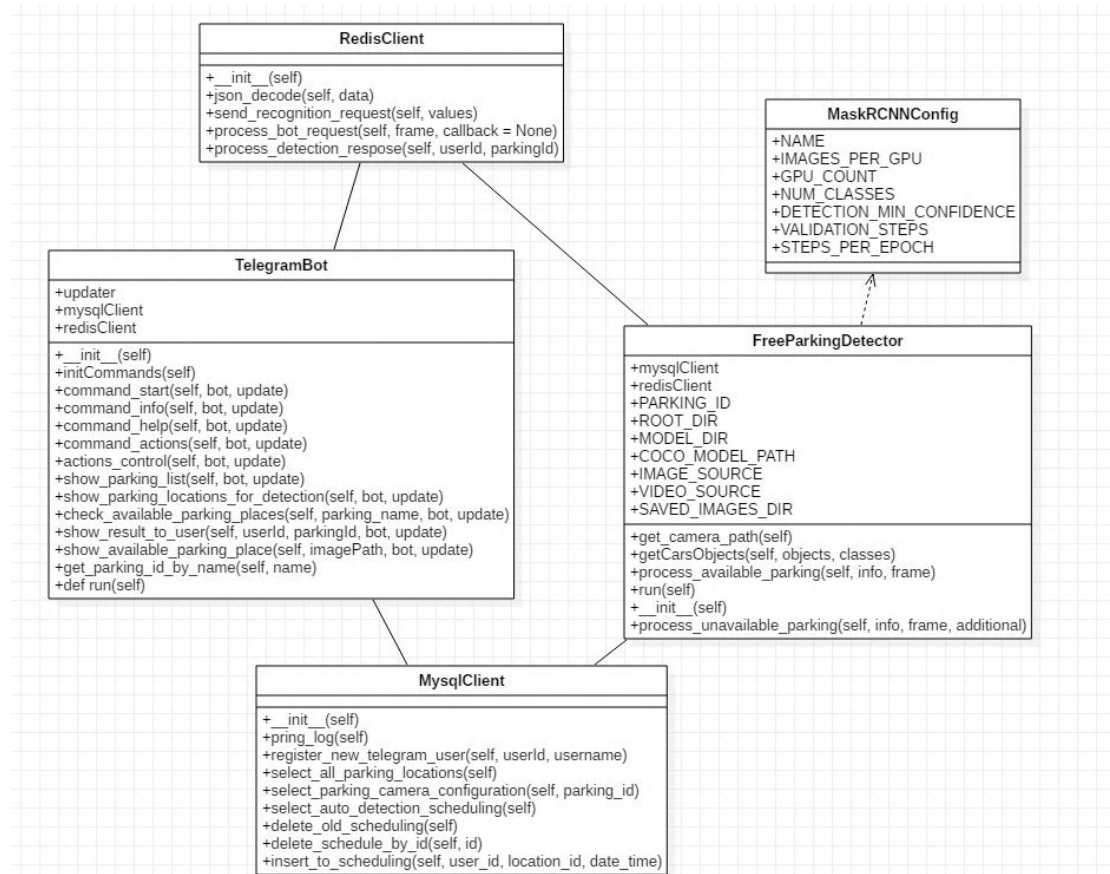


Figure 4: The class diagram of a chatbot and a recognition algorithm.

5. Results

The interface structure of the available parking places recognition system. After logging in, the administrator user sees the main page of the control panel (figure 6). This page has a menu for navigating the admin panel, a welcome message, and an exit button.

Using the menu on the left, the user can choose what he wants to change. If the user selects the “Administrators” menu item, he goes to the admin management page. Here is a form for creating a control panel user that contains login and password fields. There is also a table with current administrators. The table contains all information about administrators and a column with the “Delete” button, with which you can delete an administrator.

To find a bot, you need to search the bot name “Free Parking Recognition” in the Telegram search input. The most important command of the chatbot is “/ actions”. Using this command, a user can open a button menu, which will display the main functionality of the system. Three buttons appear on the screen with the main actions for the user: “Parking list”, “Check availability”, “Set up automatic recognition”.

The “Parking list” button is used to display information about available locations in the

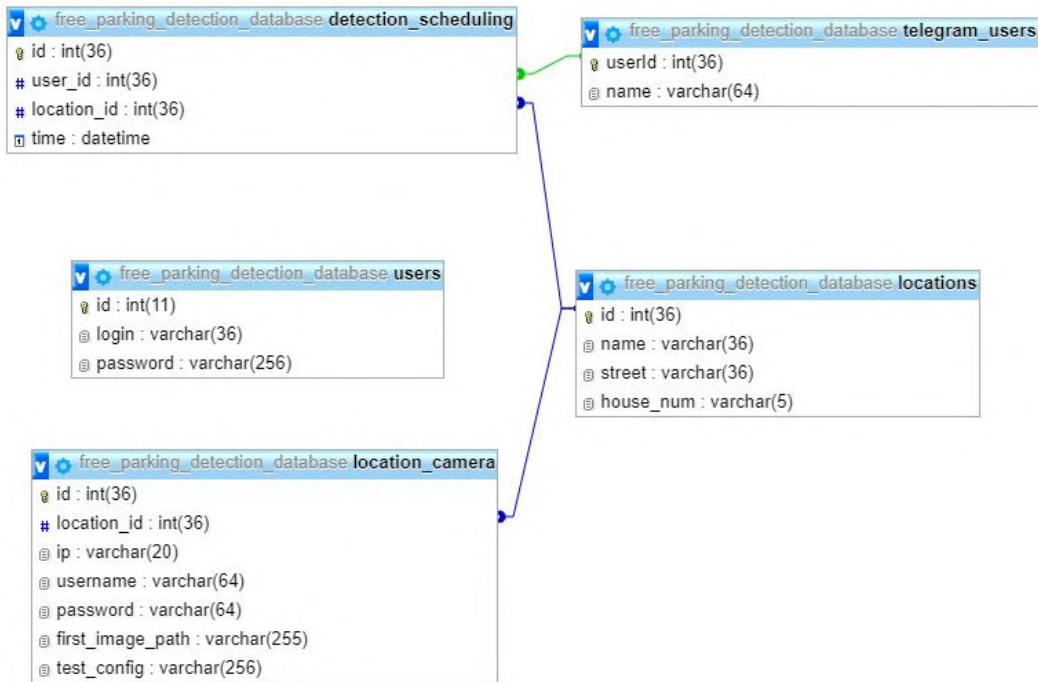


Figure 5: Database structure scheme.

system. This information can be helpful for users who know the address or name of the site but are not sure whether the procedure works in this location. The “Set up automatic recognition” button is needed to adjust the recognition at a specified time. This can be especially useful for Users who plan their trips. After clicking this button, the user must enter the date and time specified in the message. If the date and time are determined correctly, the user will be prompted to select a parking lot for automatic recognition at the specified time.

“Check availability” button allows the user to make sure that there are free parking places in the parking lot he needs at the moment. By clicking on it, the user must select a location from the list of suggested (figure 7).

After the user selects one of the locations, the bot will send a recognition request to the script responsible for recognizing available parking places in this parking lot. If no parking places are found, a message with this information will be displayed. The number of spaces in this parking lot is displayed for users.

If the algorithm at least one available parking place has been recognized, and a corresponding message will be shown (figure 8). The user can view the information about the number of available places, which will allow the user to analyze the situation in more detail and make sure that he will be able to find an open place shortly. A photo of this parking place is attached to the message about the successfully found parking place, which will allow the user to see it in large parking lots quickly.

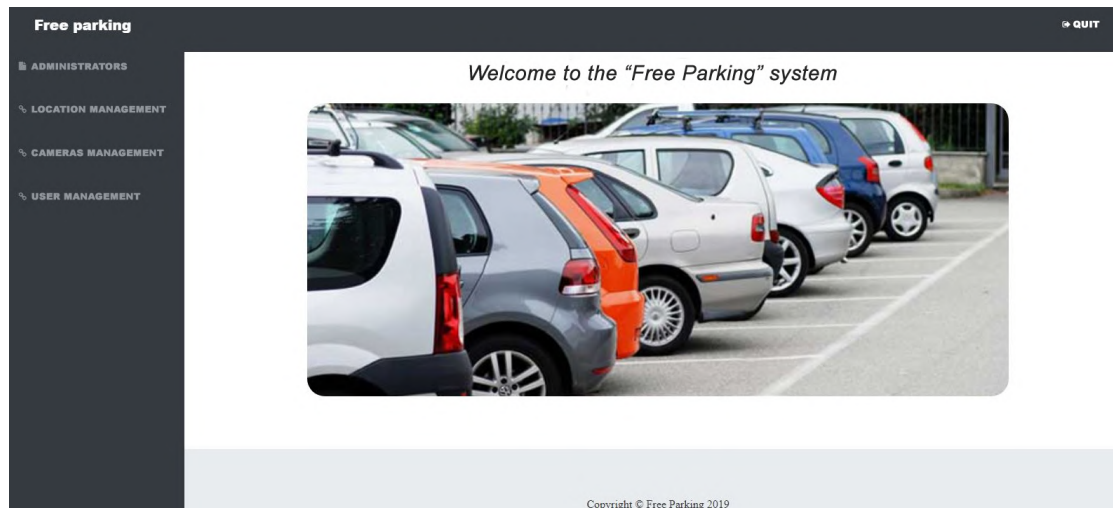


Figure 6: Main page of the control panel.

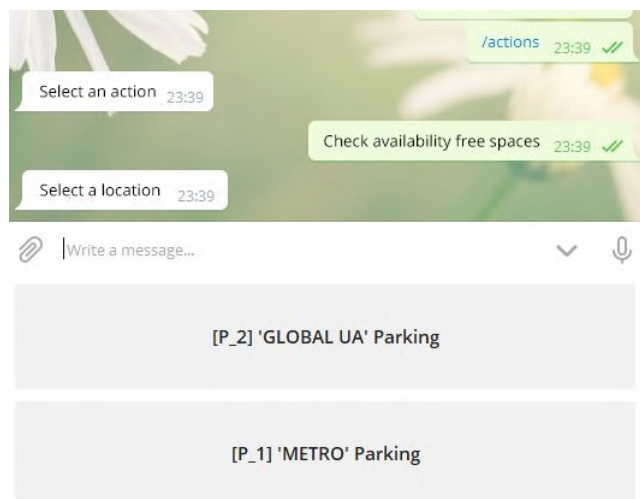


Figure 7: Checking for available places existing.

6. Conclusions

The analysis of neural networks showed that usage of the Mask R-CNN neural network is best suited to solve the problem of recognizing cars from the video flow of a security camera in real-time. This neural network has some advantages over R-CNN and Fast R-CNN. Based on various studies of this neural network, we can say that the main benefits are performance and greater accuracy. In addition, we were able to get the optimal balance between performance and accuracy through the correct selection of network settings.

The general algorithm of working of the system has been offered, and software realization

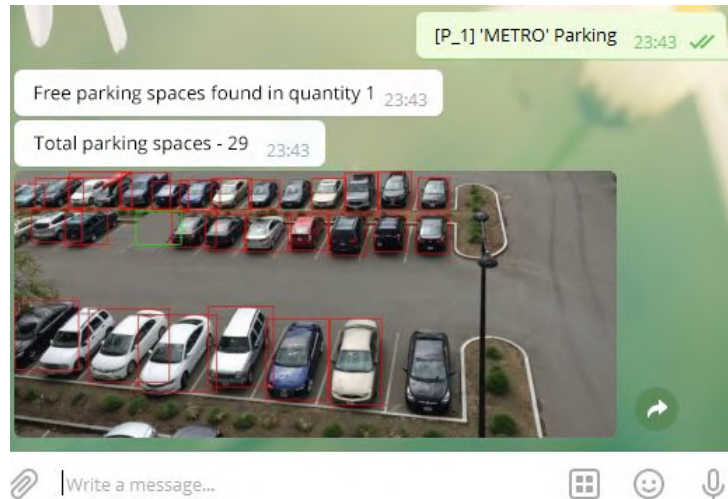


Figure 8: Available place has been found.

of availability for each parking place has been carried out. The maximum balance between productivity and accuracy has been experimentally defined as 0.7.

The activity diagram of the recognition script, the chart of the control panel classes in PHP, the graph of the chatbot classes, and the recognition algorithm in Python, the structure scheme of the database have been offered. Software implementation of the chatbot for Telegram messenger and a script for recognizing an available place for car parking has been developed.

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Research methods and tools for cleaning the system partition of Windows operating systems

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Abstract

Causes and solutions of the problem of free space lack on the system partition during exploitation of Windows (Vista/7/8/8.1/10) operating system are analyzed in this research. Main objects of the file structure, system paths to them, their purpose and role in system partition space usage have been prospected. Some operating system settings that allow to manage relatively large system files and folders and adjust the amount of free space have also been explored. In the course of the research, a set of third-party software was used as an auxiliary tool to compare the cleaning efficiency of individual objects of the system partition and to form own cleaning methods. Commands sets for correct cleaning of such objects are offered. They can be used for writing batch files and scripts, which allows automating the system partition optimizing process in the future.

Keywords

operating operation system, partition, cleanup, Windows, command-line interpreter, batch file, registry

1. Introduction

The latest versions of the Windows OS family require more and more space for file structure storage on hard disk in system volume. New components are added, updates and fixes are installed, users' data is stored, different backup copies fill the system volume, etc. As a result, system volume where OS itself is stored gets filled with non-critical data, resulting in a free space deficit that affects OS performance and functionality and even can affect updates and fixes installation. The simplest solution for that would be extending system volume, but that is not always possible, especially for solid-state drives or due to lack of free space on other partitions. Besides, system volume size increase produces additional inconveniences while working with this volume: it takes more time for backups to complete, its parameters change and restoration,

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because it gets filled with a considerable number of insignificant files and directories taking big size. The optimal solution for that is well-timed cleaning of negligible information. The OS itself should clean such data automatically, but due to misconfiguration and possible periodic failures, this is not always happening [1]. In this research, we will prospect mechanisms and ways to free space on the system volume, which will help us solve this problem. Therefore, the purpose of the work is to determine the system folders, the size of which significantly affects the occupied system partition space, to explore their functions, ways to reduce their size, by identifying and removing redundant information in their content, to identify operating system settings leading to significant use of system partition space, to review the tools for implementing these methods.

2. Updates and fixes

OS gets periodic updates and fixes, which adds new features into the system, fixes bugs or security vulnerabilities [2]. Updates center downloads all required files to keep the operating system up to date into *%windir%\SoftwareDistribution\Download* directory. During package unpacking, documents are placed into *SoftwareDistribution* directory [3]. This means that after the update procedure finishes, these directories could be emptied. All previous file versions are stored in *Windows.\$BT* or *Windows.old* directories in the root of system volume for one month, which helps to rollback in case of any issues. If everything works as expected and more free disk space is required, or the user is confident that rollback will not be required, directory contents could be removed by the “Disk Cleanup” system tool (command name: *cleanmgr*) [3].

..*SoftwareDistribution* directory contains text file *ReportingEvents* – events journal. All events related to update procedure are stored into the journal: downloads, unpacking, installation, integrity checks status, start and end date. In case of any errors, their identifiers are stored [3].

Space reclamation with this method depends on the number and type of updates and can reach a few gigabytes, sometimes even tens of gigabytes.

3. Installer

Directory *%windir%\Installer* (it is hidden) occupies on the system partition relatively large size (several gigabytes). It includes the set of files with extensions *.msi* and *.msp*, and directories with extensions *.tmp*. There are installers required for removing and updating applications, different program components installers, patches, non stabilized system updates files and other data needed for the system and installed software in this system directory. Service “Windows Installer” uses these files. The data in this file are very important when a software package is updated or removed using “Control Panel” – “Programs and Features”. It is used to fix the installation. Mistakes may occur in the process of such tasks implementation [4, 5]

This directory should be cleared in a special way. Operating system Windows includes the list of the current installers and patches, that can be accessed through WMI calls (Windows Management Instruments)[6]. It is possible to review the actual list using the next command in the command shell environment PowerShell:

```
get-wmiobject Win32_Product | Sort-Object -Property Name |Format-Table IdentifyingNumber, Name, LocalPackage -AutoSize.
```

Therefore, it is possible to write a script to automate the cleaning of the Installer directory. All the data in the directory but not is the list named "orphan" files. These data may be removed or deleted without compromising system functionality. The other way of the clearing is using free utilite PatchCleaner [7].

Directories with extensions *.tmp*- are temporary in the studied directory and can be removed in the usual way.

Directory *%windir%\Installer\\${PatchCache}* is special in this directory. This directory may appear during the system upgrade process and remain after it is completed. The base versions of the directories, changing during the software upgrade stored in it. These changes are made with *msp*-patches and help not to use installers during the upgrade process. If the installer will not find these files, it will ask to use the disk or to write the path where the application was installed from [8]. When the upgrade is finished the directory *\${PatchCache}* becomes to be no longer.

4. WinSxS

Another large system directory is located by *%windir%\WinSxS* path. *WinSxS* contains previous versions of system files before updates and more. Thus with every Windows update, information about file changes and backup copies of files are written into that directory, which later can be used for rollback. After some time *WinSxS* directory can consume large space – several gigabytes, and the size of the directory grows with every Windows update installed. In reality, this directory consumes much less space than it appears. Many files in the Windows directory are hard-linked to files in *WinSxS* directory. Therefore this directory cannot be cleaned in the usual way without breaking OS integrity [9].

For safe operations on this directory embedded system must be used – DISM (Deployment Image Servicing and Management). This command-line tool can be used to prepare Windows disk images or to prepare Windows PE images. It also provides the following functionality: adding, removal, and listing of packages and drivers; enabling and disabling of Windows components; Windows update to next release; all platforms support (32-bit, 64-bit, and Itanium); usage of old package manager scenarios and other [10, 11, 12, 13].

DISM can provide detailed report for *WinSxS* storage:

Dism.exe /Online /Cleanup-Image /AnalyzeComponentStore

Example report provided at figure 1, where:

- Windows Explorer Reported Size... – storage size without hard-links;
- Actual Size of Components Store – storage size with hard-links (excluding hard-links pointing into Windows directory);
- Shared with Windows – common files with Windows directory (important and used);
- Backups and Disabled Features – backup copies and disabled components (optional, does not affect system usage);
- Cache and Temporary Data – not required files.

Also, a recommendation is given about cleanup targets – Component Store Cleanup Recommended.

Deployment Image Servicing and Management tool
Version: 10.0.22000.1

Image Version: 10.0.22000.258

[=====99.5%=====]

Component Store (WinSxS) information:

Windows Explorer Reported Size of Component Store : 3.79 GB

Actual Size of Component Store : 3.77 GB

Shared with Windows : 3.13 GB

Backups and Disabled Features : 644.16 MB

Cache and Temporary Data : 0 bytes

Date of Last Cleanup : 2021-10-14 21:54:45

Number of Reclaimable Packages : 0

Component Store Cleanup Recommended : No

The operation completed successfully.

Figure 1: DISM storage report.

Also, DISM can perform Components Store cleanup:

Dism.exe /Online /Cleanup-Image /StartComponentCleanup,

and remove files required for update packages removal:

Dism.exe /online /Cleanup-Image /SPSuperseded,

after that, it will be impossible to remove installed packages.

There is an additional */ResetBase* option for the */StartComponentCleanup* parameter, which will delete all previous components versions.

DISM also performs storage health checks:

Dism.exe /Online /Cleanup-Image /ScanHealth

and restore components in case of damage:

Dism.exe /Online /Cleanup-Image /RestoreHealth.

More detailed information about all DISM features and execution options can be found in [14].

5. System files compression (CompactOs)

Official ability to compress system files appeared in the last versions of OS Windows. It is in contrast with the ability to compress an entire system partition in the NTFS file system, which existed in older Windows operating systems [15]. The system command line utility COMPACT was introduced to do this.

Files in Windows and Program Files are compressing, as well as store applications, which provides a significant share of space saved. It is clear from the DSIM report about the component storage (figure 1). In practice, the “compressed” system will work slower because of the development of hardware (such as new generations of processors, chipsets, solid state drives, etc.). This slowdown is small, but saves a few gigabytes of space. The utility described above is even able to give recommendations on the needs and feasibility of compression (figure 2).

```
a) Listing C:\Users\teacher\  
New files added to this directory will not be compressed.  
  
Of 19 files within 1 directories  
0 are compressed and 19 are not compressed.  
4 784 148 total bytes of data are stored in 4 784 148 bytes.  
The compression ratio is 1,0 to 1.  
  
b) d:\>compact /compactos:query  
The system is in the Compact state. It will remain in this state unless an  
administrator changes it.
```

Figure 2: Information returned by COMPACT utility (a – compression recommendation (Windows 7), b – information that the system is compressed (Windows 10)).

In particular, to find out the compression status and get recommendations, use the key:

/CompactOS:query;

to compress the space:

/CompactOS:always,

to cancel compression:

/CompactOS:never.

It is clear that the results will vary between individual specific operating systems. But it is possible to save about 20% of the space occupied by system files, which in absolute terms can be 2–3 gigabytes.

6. Devices drivers

%Windir%\System32\DriverStore is the path to the storage *FileRepository*. This storage keeps the devices drivers using by the operating system. This storage can use from a few to a few dozen gigabytes of space. The size of the used space depends on the number of the devices and the frequency of their updates. *FileRepository* storage includes not only the current versions of running devices drivers, but their previous versions (which are not in use and intended for operating system rollback). This storage also includes devices drivers, which are not currently

connected with the system, but can be used sometimes. It is, for example, smartphones, cameras, modems etc.

It is impossible just to clear such a directory (*DriverStore*), because this cleansing will cause the entire system to fail or individual devices to shut down. However, cleaning the *FileRepository* will not cause the system to crash, but changing the hardware may require reinstalling the drivers for such devices from external sources.

Therefore the command line utility PNPUTIL is used for such cleansing. The key */e* returns the drivers packages list from *FileRepository* (Fig.3). After analyzing such a list (by data, version, name), it is possible to remove not needed packages using the key */d*.

Example:

```
pnputil.exe /d oemXX.inf
```

where *oemXX.inf* – file, identifying driver package, *XX* – driver number.

```
Published name :          oem26.inf
Driver package provider : Oracle Corporation
Class :                  Мережева служба
Driver date and version : 02/20/2020 6.0.18.0
Signer name :           Oracle Corporation

Published name :          oem16.inf
Driver package provider : Synaptics FP Sensors
Class :                  Біометричні пристрої
Driver date and version : 06/27/2018 4.5.351.0
Signer name :           Microsoft Windows Hardware Compatibility Publisher

Published name :          oem8.inf
Driver package provider : Synaptics FP Sensors
Class :                  Біометричні пристрої
Driver date and version : 07/24/2018 4.5.701.0
Signer name :           Microsoft Windows Hardware Compatibility Publisher

Published name :          oem36.inf
Driver package provider : Intel
Class :                  Software components
Driver date and version : 02/18/2021 7.3.0.33
Signer name :           Microsoft Windows Hardware Compatibility Publisher
```

Figure 3: The fragment of the list generated by the command *pnputil /e*.

The next step – to recognize the currently using device driver. It is possible to complete this operation using Device Manager or device properties. And drivers not conforming to the current version can be removed [16, 17].

Such manipulations are more convenient to perform using external tools, such as Driver Store Explorer, for example [18].

Many software and hardware vendors store device drivers in a directory *%windir%\System32\DriverStore* and duplicate these drivers in the storages non typical for operating systems. Running the device drivers installer, the driver storage duplicates in the native software package, installed in the operating system. For example, directories with drivers

for Xerox or Samsung printers locates not only in the storage `%windir%\System32\DriverStore\`, but in the directories `%windir%\Drivers\Xerox\`, `%windir%\Drivers\Samsung\` and `%systemdrive%\Program Files (x86)\Xerox\` and `%systemdrive%\Program Files (x86)\Samsung\`. Obviously, it was made for the compatibility of the software with operating systems older versions. Therefore, it is worth reviewing certain directories, containing similar directories for later publication, which does not affect the subsequent functions of the devices.

7. Hibernation

Hibernation is powering down a computer while retaining its state: current state of OS, programs and, data will be written into system file in system volume root – `hiberfil.sys`. During the next power-on, the system will read the contents of this file and will boot into its original state with all programs and windows opened, and user can work without spending time on launching applications. This state is similar to suspend mode, but with hibernation mode computer is not consuming any power because all data is written into a hard disk, while in suspend mode, some minimal amount of power is consumed to retain data in RAM. Both modes are equally important when work is temporarily stopped and power consumption should be considerably or completely decreased. Hibernation mode allows somewhat quicker bring the system into operation than its full boot, but slower than with suspend mode. We are interested in `hiberfil.sys` file, the size of which is proportional to RAM size. By disabling hibernation mode (in favor of full boot or suspend mode), we can save a considerable amount of disk space on the system volume consumed by the `hiberfil.sys` file.

It could be done via the OS system settings panel or command line:

```
powercfg /h off
```

To enable hibernation mode:

```
powercfg /h on.
```

8. Swap file

The primary purpose of swap files (for Windows, it's `pagefile.sys`, `swapfile.sys` in system volume root) is to freed RAM from unused at the moment data by writing it into disk storage. In this way, the insufficient memory problem is solved. Often swap file is presented in the system as an addition to RAM and even considered as continuous memory space. In modern times RAM modules are cheap and most users have required, and even more than required, RAM installed, thus swap file usage is not required, but Windows is always creating it by default. Its size is automatically adjusted and is not zero, even if it's not used, and can reach few gigabytes.

In this case, swap file usage can be disabled via the OS system settings panel or command line:

```
wmic pagefileset delete.
```


9. System Volume Information

All disk volumes (and system volume) have automatically created in root hidden directories *System Volume Information*, which can reach a few dozen gigabytes in size.

These directories contain Windows points of recovery (if points of recovery creation is enabled for the current volume), indexing service database, volume's unique identifier, volume shadow copy data (if files history is enabled in Windows [19]). In other words, the *System Volume Information* directory contains data required for services operating with this volume and system recovery data.

This directory on the NTFS file system has not only "system" and "hidden" attributes, but permissions that limit user access to this directory also. To obtain access to that directory, its security properties should be changed in the "Security" tab for that directory. For the FAT, FAT32, exFAT filesystems, any user has permissions to change this directory.

Full access for such directory could be obtained the following command:

```
cacls %systemdrive%\System Volume Information /g <username>:f
```

where <username> – current user name. Or directory owner could be changed, which will grant access automatically:

```
takeown /f "%SystemDrive%\System Volume Information" /r.
```

Points of recovery (which use the most space) could be deleted via the "System properties" panel, "System Protection" tab. This panel could be run the following commands:

```
SystemPropertiesProtection
```

or

```
rundll32.exe shell32.dll,Control_RunDLL sysdm.cpl,,4
```

But this might not be enough to delete this directory completely, as there might be files and directories used by running services, and the system will not allow to delete it. Thus before deletion, such services should be stopped, particularly: "System protection", "Volume Shadow Copy", "File History". "File History" service is disabled by default unless user enabled it explicitly (it requires separate storage) [19]. "System Protection" could be disabled via system registry *DisableSR* parameter change (0 – disabled parameter, 1 – enabled parameter) at the following path [*HKEY_LOCAL_MACHINE\SOFTWARE\Policies\Microsoft\Windows NT\SystemRestore*] (via regedit editor), or by creating text file with .reg extension and following contents:

```
Windows Registry Editor Version 5.00
```

```
[HKEY_LOCAL_MACHINE\SOFTWARE\Policies\Microsoft\Windows NT\SystemRestore]
```

```
"DisableSR"=dword:00000001
```

and executing this file. Value *dword:00000000* – will enable "System protection", *dword:00000001* – will disable. After that, most files could be deleted in the *System Volume Information* directory.

10. Temporary files

There is a list with the paths to the directories with temporary files in the operating system. These directories need to be cleaned periodically. This is the list of such directories:

```
%SystemDrive%\Temp\,
```

`%SystemRoot%\Temp\`,
`%SystemRoot%\System32\DriverStore\Temp\`,
`%SystemDrive%\Users\<user>\AppData\Local\Temp\`,
 where <user> is the user account name.

11. Comparison of software products for the system partition cleaning

It is possible to use third-party software products for the system partition cleaning. There are a sufficient number of them, both, commercial and free. We most often used the following software products in the research process: Patch Cleaner [7], Driver Store Explorer [18], DISM++ [20], Wise Disk Cleaner [21]. Their main purpose is somewhat different from each other, but they contain tools for cleaning. In terms of functionality, their capabilities overlap, but some functions are better implemented in some, worse in others. The short comparison of software on the possibility of interaction with file objects, which were considered in this paper, represented in the table 1.

Table 1

Comparison of system partition cleaning and optimization software (“-” – no such function, “satisfactorily” – insignificant cleaning, “good” – significant cleaning, “excellent” – almost complete cleaning)

Object	Patch Cleaner	Driver Store Explorer	DISM++	Wise Disk Cleaner
Updates and fixes	-	-	good	excellent
Installer	good	-	satisfactorily	satisfactorily
WinSxS	-	-	excellent	satisfactorily
Devices Drivers	-	excellent	good	-
Temporary Files	-	-	excellent	good

Wise Disk Cleaner and DISM++ are most versatile tools, but in practice situations it is necessary to clean system partition space using the first software product and then use the second for a more complete cleaning. Patch Cleaner and Driver Store Explorer – highly specialized tools for thoroughly cleaning the Installer directory and driver repository, respectively.

12. Conclusions

Non complete list of the operating system paths and directories, clearing which makes possible to save a lot of space on the system partition is represented in this research. But these directories occupy the largest repositories on the system partition. The file structure of the system partition is analyzed. The list of commands that can be used to write batch files, scripts, registry files, is the result of this analysis. It is shown that it is possible to automate the process of cleaning system partitions.

During the cleaning system partitions process, users may miss the errors, thereby affecting the operating system and its file structure. In such cases, users should use the system utility SFC. For example, to write in the command line:

sfc /scannow,

It allows the user to check all protected system files and replace crashed files with their cached copies located in a compressed directory `%WinDir%\System32\dllcache` [22]. The system partition cleansing is not the only way to free the space. Moving the "heavy" directories to another (non-system) partition using hard links (*mklink*) [23] or moving the directories with users profiles during the operating system installation and exploitation are the other solutions to this problem [24, 25].

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Game based learning with artificial intelligence and immersive technologies: an overview

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Abstract

The usage of serious games with AI and immersive technologies in education is considered in the paper. We discussed the development of serious educational games with adaptability and personalization based on recognition of the images, human emotions, speech, and intelligent agents usage for the simulation of “being there” effect of a human opponent, and control of the complexity of game levels and game contents. We investigated some tools for teachers and students to allow the creation of the educational games based on AI and immersive technologies without programming skills existence: Aurora Neverwinter Nights toolset, eCraft2Learn tool with visual programming on Snap!, Scratch with AI abilities, Metaverse Studio for AR applications development with computer vision models using Google AI, CoSpaces Edu and EV Toolbox constructors for immersive apps.

Keywords

educational games, AI in education, immersive technologies in education, AR/VR constructors with AI modules

1. Introduction

Game-based learning is the perspective direction in education because the younger generation is involved in computer and mobile games from early childhood and this kind of activity began to be perceived as a normal thing. The games in education are not required adaptation from the younger generation, cause to positive perception and desire to use games for further learning [1]. Serious games are widely used in education, but they are aimed not at entertainment, but at achieving concrete educational goals [2].

There is no single definition of a serious game. Following [3, 4, 5], by serious games we mean digital games with some simulation of processes oriented to knowledge acquisition, its improvement and problem-solving, including the harnessing of innovative technologies, in particular, virtual environment. Games of this kind can help create new curriculums for the adaptation of the learners to the digital age.

Computer games are considered as perspective interactive digital or virtual environments, that allow getting immersive experience and practical skills through engagement, the interest of


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players, and feedback with them [5]. As shown in [6], educational computer games contribute to the improvement of cognitive and social skills.

Modern serious games must satisfy a number of requirements: aimed at problem-solving, must have a spirit of innovation, take into account the personal needs and preferences of the player and his goals, improve cognitive, analytical, mathematical, communication skills, promote the development of new technologies, develop creativity and skills management, ability to take initiative, etc. [7]. For example, Nand et al. [8] considered the characteristics that attract and retain the users in the games and how such characteristics can be used for the development of educational games. So, as a result of the survey, it was revealed that realistic graphics, different levels of difficulty, and feedback in the form of scoring are important for the players. Abdellatif et al. [9] investigated the qualitative characteristics (game design, user's satisfaction, usability, usefulness, understandability, motivation, performance, playability, pedagogical aspects, learning outcomes, engagement, user's experience, efficacy, social impact, cognitive behavior enjoyment, acceptance, user interface) of serious games in the field of education with the help of game Robocode for the teaching of programming and discussed the directions for improving the game that students are noted.

Important features of the development of serious games are the focus on obtaining certain knowledge and skills from students. The development of serious games requires the use of machine learning methods to solve such practically important problems as image recognition, speech-based text recognition, etc. [10]. The recognition of the players' emotions is of particular importance, as it makes it possible to track those parts of the game that cause boredom, fear, etc. Recognition of players' emotions can be used to personalize content in educational games, and the natural language processing techniques in conjunction with neural networks are used to develop dialogues with the learners in real-time and create the effect of the tutor presence for support organization during learning [11]. Tracking and assessing the emotional state of the learners during the use of serious games are important tasks aimed at studying both the emotions themselves and assessing the emotional experience gained during training since it is precisely such emotional experience that further affects the activity and volition in the learning process based on games and is of interest from the point of view of developing educational games aimed at personalizing learning. Anolli et al. [12] considered different approaches for assessment of the emotional state of the player based on facial emotion recognition, voice analysis, and gesture recognition (assessment emotions based on body language analysis).

The purpose of the paper is to study the possibilities and prospects of using immersive technologies and artificial intelligence for gamification of the educational process and tools for the development of educational games based on these technologies.

2. Related works

Serious games in education aim at the acquisition of basic knowledge and skills and academic performance improvement. As shown in table 1, serious games are widely used in police, business, diagnostics, aircrew for educational purposes. Their main distinguishing feature is the focus on the educational aspect and active learning, and the main advantage is maintaining the student's interest-based in cognitive curiosity, plot intrigue, reward system, interactivity,

feedback and gaining professional skills and knowledge through experience of problem solving and high motivation [13].

Table 1

Areas of the serious games usage

Research	Area	Goal	Target group	Results
Binsubaih et al. [14]	Police	Learning of the typical traffic accident investigation experience	56 police officers	Advantages: effective learning, performance improvement, interactive environment for learning Disadvantages: difficulties at the beginning of interaction with virtual environments for students that have not any experience with 3D technology
Martín and Aznar [15]	Business	Learning of business information analysis	58 students	Learning improvement through experience to get different useful skills in the subject area
Chourabi et al. [16]	Information System	Data Modeling, UML learning	24 master I students and 3 teachers	UML understanding and improvement of data modeling skills
Gaggi et al. [17]	Diagnostic	Identification of people with developmental dyslexia	24 children	Classification of children with respect to risk group for developmental dyslexia
Mautone et al. [18]	Aircrew	Aircrew Training	14 male	Improvement of performance and accuracy of carrying out the FMS preflight programming in the proper sequence
Lämsä et al. [19]	Inclusive Education	Reading and math learning for people with disabilities	-	Organizing of special educational support

3. Review of serious learning games

3.1. Games with Artificial Intelligence and for Artificial Intelligent learning

The rapid development of the gaming industry puts forward new requirements from players – the presence in the game of the “being there” of a human opponent, the presence of levels with complex enemies behavior, a variety of scenes, and unexpected dynamically changing scenarios, the replacement of a human enemy who has left the game with an intelligent enemy bot, etc. This led to the need to integrate artificial intelligence modules into games and, in particular,

machine learning based on the use of intelligent agents, including human behavior simulation in games according to styles and skills acquired in games by intelligent agents [20]; the usage of the deep learning, for example, the usage of the value and policy networks for the game Go to generate different random games for self-play [21] and multilayer perceptrons for developing intelligent bots simulated human behavior [22]; the usage of the genetic algorithms for the search of the effective strategy organization without total check of all possible alternatives [23] and simulation of real player behavior playing, for example, in Mario game with the help of genetic operations, fitness function, and subject area knowledge to optimize actions of the player [24].

The criteria for evaluation of users' engagement and their interest is an open problem in game development [25], but some researchers propose methods for assessment based on machine learning. For example, Tadayon and Pottie [26] investigated the ability of the hidden Markov model for student performance assessment after educational game usage.

Serious games are enough effective in education, but require the effect of support presence when learners find it difficult. As support, virtual and intelligent characters are used in games. They are created, for example, with the help of agent-based technology [27].

There are two directions in game-based learning: the development of learning games with artificial intelligence and learning games to teach and learn artificial intelligence itself. Examples of games for AI learning are ArtBot – a game for learning the basics of reinforcement learning and supervised learning methods. It allows investigating how the bot is trained. Machine learning for kids game allows demonstrating the possibilities of machine learning algorithms, and how they transform input to output and can be considered as an introduction to machine learning for kids [28].

3.2. Adaptive learning games

Personalization, personification and adaptability today cover all areas of human activity from Internet technologies, medicine, and economics to education [29, 30] and are associated with understanding human behavior, emotions, states, experiences and desires, cognitive processes.

Development of dynamic adaptive educational games focused on offering educational content, difficulty level, game scenarios, assessment of acquired skills, etc. taking into account personification is one of the innovative approaches in the gaming industry and education. Personification is viewed as a tool for developing adaptive games aimed at understanding the players, their personal needs in order to engage and retain their interests. Many scholars investigate how users or homogenous groups of users interact with the content of the game. The model of educational games based on real-time dynamic adaptivity taking into account learning styles, performance, player's behavior, and profile with personality traits are investigated in [31]. Serhan et al. [32] detected the target groups of players with similar preferences, proposed the serious game development with adaptive learning content for such group, and considered the idea of personal hints in the game depending on rating scores.

Adaptivity in game-based learning is considered as the systems' ability to change learning content according to users' preferences and characteristics [33]. Such type of game's customization usually is based on users' learning styles and tracking their behavior during games (for example, users' eye tracking, face and its emotions recognition, etc.). The game development

based on behavior tracking has to take into account users' affective states changing during the game and the ability to predict users' emotions in the future to generate adaptive content. Lopez and Tucker propose to use the recognition of facial expression in real-time mode for motivation, experience, and performance improvement in the game with the help of SVM algorithm [34]. The search for a balance between skills and game difficulty is a very important factor for serious games development.

Zhu and Ontañón [35] discussed open problems connected with AI usage for personalized serious game development, for example, such as modeling of individual player behavior because often it is not enough to get observed data for the prediction of the users' behavior.

The most well-known approaches for developing adaptive games in education are the use of learning styles that reveal preferences about the way information is perceived (visually, verbally, with the help of "brainstorming", while observing someone, etc.) and machine learning algorithms for embedding adaptive content, taking into account the current behavior of the player and the skills he has acquired. Khenissi et al. [36] found that students with a predominant style of Active in the Felder-Silverman model prefer action games, students with a predominant style of Sequential prefer games based on puzzles. Thus, when developing serious games in education, it is possible to offer educational content adapted to specific target groups.

Some examples of the serious adaptive game in education are presented in table 2.

3.3. Serious learning games with augmented and virtual reality

Augmented and virtual reality technologies aimed at providing interactive experiences in the study of abstract concepts are showing promising results in the field of education. If we add to the interactivity and clarity of learning in a playful form, then this kind of approach can increase the involvement and interest of students. Games with flashcards for entertaining learning of the alphabet, numbers, and words, developed on the basis of Unity, Vuforia, Blender, InkScape are widespread [10].

The interesting direction of immersive technologies is the use of such technologies for hints appears as support in the learning process. Dyulicheva [39] proposed to use hints for students that have trouble in mechanics learning; the hints for people with special needs during learning are discussed in [40]. Drey et al. [41] considered the application of adaptive hints in a virtual environment based on analysis of player behavior.

Game-based learning with immersive technologies is effectively used for teaching and learning mathematics, foreign languages, physics, chemistry, biology, astronomy, etc. AR/VR with gamification is widely used in rehabilitation when people learn to control their body from the start and AI modules are applied for quality assessment of performed exercises by patients [42].

Some examples of serious learning games with immersive technologies are presented in table 3.

3.4. Tools for learning games development with AI and immersive technologies

The usage of serious games in education as their development by students with the management of teachers facilitates to positive effect in education [45]. Annetta et al. [46] noted that serious

Table 2

The examples of the serious games with adaptivity in education

Research	Area	Game genre	Type of content with adaptivity	Specialties	Adaptivity Base	Target group	Results
Soflano et al. [37]	Basics of SQL	3D Role-Playing Game (RPG)	Presentation of learning materials	Game with three modes: non-adaptive, out-of-game (based on questionnaire before game) and in-game (based on historical data) adaptive modes	Felder-Silverman learning style usage	120 higher education students	The learning effectiveness increasing for GBL and strengthening of effectiveness through adaptivity mode
Hooshyar et al. [38]	Computational thinking	maze	Situations in game, feedback, hints, learning materials	Bayesian network usage for decision making or feedback creation for user support	Historical data	79 students an elementary school	Improvement of students' learning attitude

games with immersion in a virtual environment contributed to the self-education of students, stimulated them to learn additional materials, and also developed collaborative skills through interaction with other students or instructors when they created their own games. Carbonaro et al. [47] proposed an approach based on supplementing and adapting the finished game “Neverwinter Nights” by students without programming skills for deeper immersion in the studied subject area. Immersive technologies and artificial intelligence make it possible to transfer the teacher from the role of a passive observer to an active participant who directly interacts in a virtual environment with the subject of study and even creates virtual objects himself and determines how to interact with them. The learner gains important skills through the study of microworlds. A student now is not just a user of a computer game, he is also its developer, who must achieve a certain educational goal. The student’s participation in game development contributes to his self-expression, the development of creativity, and self-education.

The development of tools with interactive and visual software development tools leads to the emergence of new teaching methods and to rethink the possibilities and learning outcomes

Table 3

The examples of the serious games with immersive technologies

Research Area	Game title	Immersive technology	Specialties	Development tools	Target group	Results
Cerqueira et al. [43]	Mathematics (Learning basic functions and their graphs)	FootMath	Augmented reality	3D football to score goals with the help of different function graphs. It uses real teaching scenarios	Unity, Vuforia	22 middle school teachers and 22 middle school students. The interest and engagement improvement
Afyouni et al. [42]	telerehabilitation	RehaBot	Virtual reality	Personalization based on analytics of quality of therapy exercises performance and 3D motion tracking using for rehab bots development	Unity	10 patients with neck pain. Usability and effectiveness experimental proof of online physiotherapy
Zarzuela et al. [44]	kids and handicapped people learning		Augmented reality	Different types of activities	Unity3D, Cinema 4D, Vuforia SDK	5 kids. Knowledge improvement in some field (animals learning)

based on the integration of AI and immersive technologies into education. Consider the tools that teachers can use together with their students to develop educational games with AI modules and/or immersive technologies:

1. Computer role-playing game creation with BioWare Aurora Neverwinter Nights toolset when students play the role of historical character, journalist, ecologist, economist, etc. for expanding the skills of scientific research, or writing story with facts, or creation proposition for save of environment, or studying the conditions of life in some historical epoch is discussed in [47]. Another example of educational game creation for adaptive teaching of SQL base with Aurora toolset is described in [37]. Aurora toolsets allow develop different scenes and characters based on usage of the tiles and library of creatures, create and assign dialogs to characters of the game, and set actions and organize interactivity with characters. Spronck et al. [48] describe the possibilities of introducing adaptive elements into games based on the role-playing game “Neverwinter Nights” using AI and dynamic scripting development.
2. Tool eCraft2Learn allows developing projects with AI blocks and abilities with block visual programming with the help of Snap! [49]. AI blocks are used to create custom projects

involving speech, image recognition, and neural network application development. Any project allows you to add various sprites and functionality based on AI blocks. Study projects contain applications with gesture and speech recognition for learning words in other languages, gaining skills in arithmetic operations with numbers, acquaintance with works of art, and more. For example, you can study the pronunciation of numbers in different languages and the pronunciation of a phrase that a parrot will recognize using AI blocks with the help of Snap!, as shown in figure 1.

3. The block-based visual programming language Scratch with AI abilities is used for learning basic concepts of AI and own games creation with AI. For example, kids easily can create their own chatbot with Alexa functionality, games with hand-written text recognition, games with voice and video recognition [50]. Estevez et al. [51] proposed to use Scratch to understand the principles of cluster analysis algorithms and the functioning of a neuron and a simple neural network. The introduction of tools for visualization of difficult-to-learn concepts into the educational process and familiarity with basic machine learning algorithms in a game form contributes to the growth of students' interest, their involvement, and the study of advanced information technologies.
4. Studio for the creation of AR applications, in particular, AR games with visual tools like storyboard [52]. The button "Create experience" on the web page allows creating a workspace named as a storyboard page with the ability of characters and dialogs, many scenes such as, for example, inserting of photo and video portals, blocks into the scene as shown in figure 2.

MacCallum and Parsons [53] considered the perspectives of Studio usage for learning. The authors point out a number of benefits of using Metaverse in education:

- simplicity and availability of Metaverse in terms of use by both teachers and students, the ability to embed various resources into scenes;
 - Metaverse supports locating and overlaying AR content for exploring the environment and conducting experiments in physical space, proposing hypotheses by students and confirming or refuting them using 3D model tracking;
 - Metaverse allows you to embed pre-trained computer vision models using Google AI and combine the capabilities of immersive technologies with the capabilities of recognition of images, texts, environments, and objects.
5. CoSpaces Edu – interactive development environment for educational AR / VR applications with built-in scripting language CoBlocks for block visual programming. The teacher, together with the students, implement project-based learning, creating AR / VR applications for studying the history of Egypt, Minecraft worlds, different simulators for physics learning, puzzles and mazes, games for acquiring computing skills, etc. [54].
 6. EV Toolbox – AR / VR constructor for creating scenarios by means of visual programming based on the marker and markerless tracking technologies [55].

Examples of the use of tools CoSpaces Edu and EV Toolbox in the classroom at school and university are given in the paper [57]. In particular, the development of a virtual gallery for the study of animals, an application for learning English based on the use of block programming in CoSpace Edu, and the development of an application based on marker technology for studying the history of the university using the EV Toolbox was demonstrated.

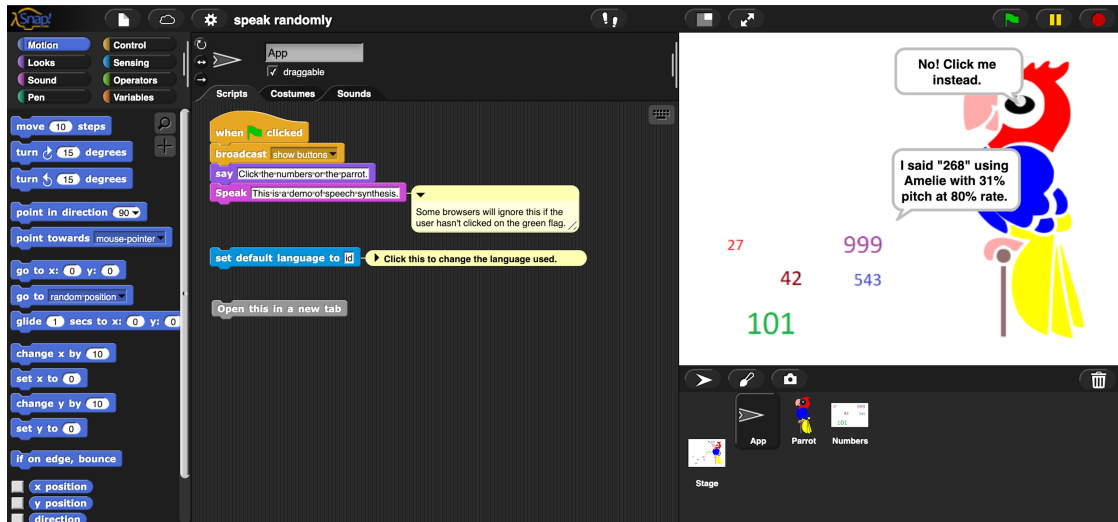


Figure 1: The example of project with AI blocks for speech recognition and block programming on Snap! [56].

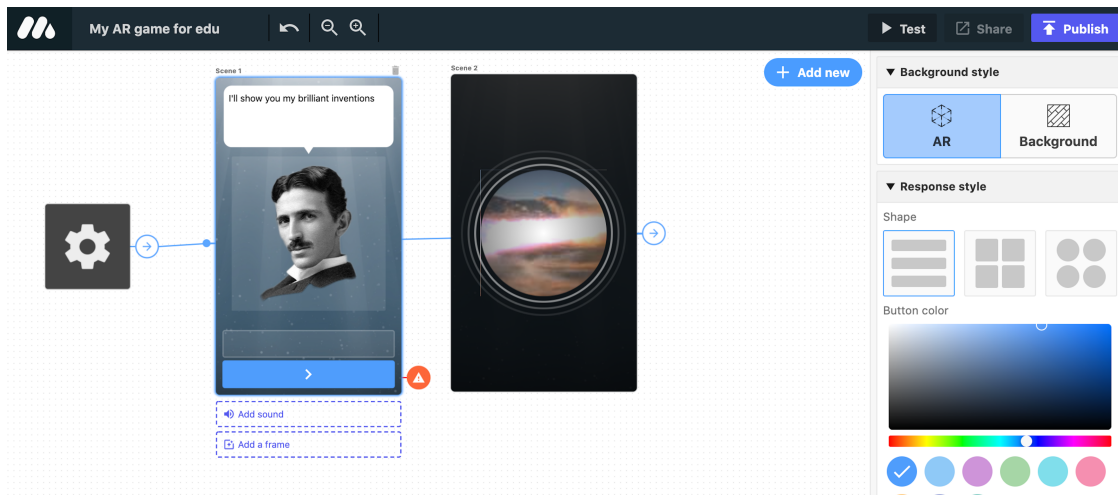


Figure 2: The example of AR-game creation about knowledge of Tesla' inventions.

4. Conclusion

Artificial intelligence and immersive technologies are powerful tools for educational games development. New constructors without programming skills existence open perspectives for the creation of new curriculums for game-based and project-based learning.

A promising area for further research is the study of the development principles of educational games based on immersive technology together with machine learning.

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Classification problem solving using quantum machine learning mechanisms

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Abstract

Due to the similarity of the computational and probabilistic nature of quantum computing and machine learning, the idea arose to optimize the learning process using quantum methods. There are both fundamentally new algorithms, such as HHL, and quantum-improved ones: QPCA, QSVM. In this article, we will look at the QSVM algorithm step by step, starting from the basics described in section 2 and gradually delving into the composition of the algorithm. Thus, after the basics, we will consider the quantum phase estimation, which is part of the HHL algorithm, and then the QSVM algorithm, the component of which is the HHL. We also will consider the QPCA algorithm, which can be applied before the QSVM algorithm to reduce the dimension of the data sample. In this way, we explore the fundamental difference between classical algorithms and their quantum counterparts. We also implement the QSVM method in practice and compare the obtained practical results with theory. As a result, we obtained high quality of accuracy (100 %) compared to the classical SVM (83 %) on a data sample of dimension 72. However, we found out that the learning time on a quantum device is far from ideal (it can reach 5 min for a sample of this size). The study aims to theoretically argue or disprove the hypothesis about the efficiency of quantum computing for machine learning algorithms. The object of research is the programming of quantum computers. The research subject is the study of quantum computing mechanisms for the implementation of machine learning problems. The research result is a software module that allows evaluating the efficiency of the classification task on a quantum computer. It also can be used to compare the results obtained from classical and quantum devices. Research methods: theoretical analysis of the foundations of quantum computing: principles of superposition and entanglement, linear algebra, probability theory over complex numbers; building a model of one qubit and multi-qubit system; research of quantum machine learning algorithms' work principles and their complexity; empirical comparison of quantum machine learning methods with their classical counterparts.

Keywords

quantum machine learning, classification problem, HHL algorithm, quantum principal component analysis, quantum support vector machine

1. Introduction

While building a quantum computer is still a daunting engineering challenge, it already has a long list of areas to be effective [1, 2]:

- data modeling (weather forecast, chemical modeling);

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- creation of drugs (search for new formulas for drugs by studying the spatial structure of protein compounds, diagnostics, and testing of various types of diseases);
- logistics (combinatorial traveling salesman problem);
- search optimization (Google uses quantum technologies to refine search results, taking into account more important ones);
- data security (quantum protocols for encryption and data transmission);
- military engineering (improving the accuracy of radar weapons);
- machine learning (more accurate solutions and faster learning algorithms).

Therefore, the field of quantum computing have met with increasing interest. Governments of countries such as China, the USA, Germany, Switzerland, Russia, and others are investing in quantum computing technologies development to take a leading position in the quantum race. Private companies, including Google, IBM, Microsoft, Intel, Amazon, are not lagging behind.

The number of qubits plays an influential role in quantum superiority achievement, but no less important, one might even say, the decisive factor is the “quantum volume” – a metric that determines the power of a quantum computer in conjunction with the level of computational errors. Today, Honeywell is the leader in these indicators, setting a record of 64 units of quantum volume [3].

However, quantum computers may be useless without appropriate scientific knowledge about their proper use. In this regard, the IBM company has a policy of encouraging interest in research in this area, providing hardware (IBM Q) and software (Qiskit) tools on a costless basis [4]. These tools allow anyone to conduct experiments on real-life quantum installations of the order of 1 to 5 qubits, with a quantum volume from 1 to 32 units.

There are the following technologies for constructing qubits, implemented in practice: quantum dots (Intel), superconducting elements (D-Wave, Google, IBM), vacuum traps (IonQ, AQT, Honeywell), vacancies in the diamond lattice (Quantum Diamond Technologies) [5]. The most popular approach is to build qubits on superconducting elements.

The biggest challenge for building any quantum computer is the problem of overcoming decoherence. Decoherence is the process of destroying the coherence of a coupled qubits system. This phenomenon is created by thermodynamic processes when interacting with the environment. Decoherence disrupts the communication of the system of qubits and destroys their quantum properties, which negates the advantage of a quantum computer over a classical one. This problem is usually solved by combining more physical qubits into a single logical one. This technique is called quantum error correction. Quantum error correction is well developed in theory but not achievable in practice because the noise level of physical qubits is still too high.

There are such fundamental problems associated with the possibility of applying quantum machine learning algorithms [6, 7, 8]:

- input problem;
- output problem;
- problem of calculation;
- the problem of comparative analysis.

Quantum computers are known to provide exponential acceleration in some cases. But data input and output operations are carried out by transferring information from the classical world to the quantum one and vice versa. These operations can be quite time-consuming and, most importantly, can completely negate the benefits of exponential problem solving. The data entry problem can be solved by creating a quantum equivalent memory (QRAM). This problem is another significant engineering problem.

The calculation problem is related to input and output problems. It is impossible to know in advance how many gates a quantum computer will need when working with classical devices. Although quantum computers can solve big tasks better than classical computers, it is still unknown how big a problem must be to gain a quantum advantage.

The problem with the comparative analysis is that it is sometimes difficult to argue that the quantum algorithm is better than all the known classical ones. This claim requires extensive comparative testing with modern heuristic methods. Establishing lower bounds for quantum algorithms would partially solve this problem.

Thus, it is necessary to develop software for quantum machine learning considering all the described technical and algorithmic problems.

2. Quantum computing basics

A quantum computer operates with minimal information units - qubits. A qubit can be represented as a unit vector of a 2-dimensional complex space:

$$|\phi\rangle \in H, \|\phi\| = 1, \dim H = 2. \quad (1)$$

Here $|\phi\rangle$ is a column vector, H is a Hilbert space. A qubit can be 0 and 1, just like a bit:

$$|q_0\rangle = |0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, |q_0\rangle = |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad (2)$$

And also other values that represent the probability of occurrence of zero or one. Such probabilities are called probability amplitudes. In example (3) the qubit $|q_0\rangle$ can take the value of either 0 or 1 (the probability of meeting this or that event is $\frac{1}{2}$). In this case, they say that the qubit is in superposition.

$$|q_0\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{i}{\sqrt{2}}|1\rangle = \begin{bmatrix} \frac{1}{\sqrt{2}} \\ \frac{i}{\sqrt{2}} \end{bmatrix} \quad (3)$$

The sum of the probabilities should always be equal to one. For complex numbers, this means that the vector must be normalized. That is, for the vector:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \alpha, \beta \in \mathbb{C} \quad (4)$$

the following condition has to be met:

$$\sqrt{|\alpha|^2 + |\beta|^2} = 1 \quad (5)$$

To measure the state of a system with one qubit of information, one must first choose an orthonormal basis:

$$|x\rangle, |y\rangle : \langle x|y\rangle = 0, \|x\| = \|y\| = 1, \quad (6)$$

and then take measurements on this basis. Thus, the state $|x\rangle$ encountering probability when measuring the state $|\psi\rangle$ equal to the square of the modulus of the scalar product of the row vector $\langle x|$ and the column vector $|\psi\rangle$:

$$p(|x\rangle) = |\langle x|\psi\rangle|^2 \quad (7)$$

After measurement, the system from the state $|\psi\rangle$ can pass into the state $|x\rangle$ or the state $|y\rangle$ and does not change it after repeated measurement. Therefore, we can say that the measurement process converts quantum information into classical information. That is why measurements are most often at the very end of the algorithm.

Usually, we make measurements in the computational basis $|0\rangle, |1\rangle$. However, we can make measurements in other bases. For example, measuring the qubit from (3) in the Hadamard basis $|+\rangle, |-\rangle$, we obtain $|\langle +|q_0\rangle|^2 = 0$ and $|\langle -|q_0\rangle|^2 = 1$.

The state of a system consisting of more than one qubit can be represented as the tensor product of qubits. For example, the system state consisting of qubits $|a\rangle$ and $|b\rangle$ is described in (8). Thus, a system of n qubits is a vector with dimension 2^n . In this case, the number m , encoded by a vector in its pure form, reflects the state of the system, where the string $m + 1$ takes the value 1.

$$|ab\rangle = |a\rangle \otimes |b\rangle = \begin{bmatrix} a_0 \times \begin{bmatrix} b_0 \\ b_1 \end{bmatrix} \\ a_1 \times \begin{bmatrix} b_0 \\ b_1 \end{bmatrix} \end{bmatrix} = \begin{bmatrix} a_0 b_0 \\ a_0 b_1 \\ a_1 b_0 \\ a_1 b_1 \end{bmatrix} \quad (8)$$

If two qubits are in a superposition state, the system will transition to one of four states during measurement:

$$(\alpha|0\rangle + \beta|1\rangle)(\gamma|0\rangle + \delta|1\rangle) = \alpha\gamma|00\rangle + \alpha\delta|01\rangle + \beta\gamma|10\rangle + \beta\delta|11\rangle \quad (9)$$

In this case, the sum of the squares of all possible states is equal to 1:

$$|\alpha\gamma|^2 + |\alpha\delta|^2 + |\beta\gamma|^2 + |\beta\delta|^2 = 1 \quad (10)$$

However, not all multi-qubit systems can be decomposed into the tensor product of several separate states. For example, for the Bell state $\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$, the measurement of the first qubit will result in the instantaneous measurement of the second: it will no longer be in a superposition state. If the measurement of one qubit leads to the measurement of the second, the state of such qubits is called entangled.

Based on formula (9), the system qubits independence can be verified by the equality of the product of the external and internal coefficients of the system. Thus, if equality is not met (as shown in (11)), then the system is confusing:

$$\alpha\gamma \times \beta\delta \neq \alpha\delta \times \beta\gamma \quad (11)$$

All operators performed on the state vector must be unitary. That is, for the operator U , its adjoint operator must be equal to the inverse:

$$UU^* = U^*U = I \quad (12)$$

Another property of unitary operators is that when they are applied, the scalar product of vectors (the angle between them) has preserved:

$$\forall \phi, \psi \in H |\langle U|\phi\rangle \langle U|\psi\rangle| = |\langle \phi\psi\rangle| \quad (13)$$

In addition to this, the length of the vector has also preserved:

$$\forall \phi \| U|\phi\rangle \| = \| |\phi\rangle \| \quad (14)$$

We can also write the wave function from (5) in the following form:

$$|\psi\rangle = e^{i\gamma} \left(\cos \frac{\theta}{2} |0\rangle + e^{i\phi} \sin \frac{\theta}{2} |1\rangle \right) \quad (15)$$

where $e^{i\gamma}$ is global phase, $e^{i\phi}$ is local phase. The global phase does not affect the calculation results because it is not observable.

Each operator has a finite set of eigenvalues and eigenphases. Eigenstate is a state that is immune to some operations. After applying the operator for such a state, the probability amplitude and the local phase will not change, but the global phase will change. Eigenphase is the global phase acquired by the eigenvalue. The global phase carries information about the applied operator. We can obtain this information by using a phase estimation.

3. Quantum phase estimation

Quantum phase estimation (QPE) is one of the commonly used building blocks of quantum machine learning algorithms. This algorithm helps to extract unobservable information from the global phase θ of the quantum operator U :

$$U|\psi\rangle = e^{2\pi i\theta} |\psi\rangle \quad (16)$$

where $|\psi\rangle$ – is an eigenvector and $e^{2\pi i\theta}$ – is an eigenvalue.

As we can see from (16), each eigenphase θ_j is associated with eigenstate u_j . Worth noticing the eigenphase θ_j is a fraction of 360° in the output quantum register. Looking ahead, the value of the output register R with size m will take the value:

$$R = \forall \theta_j 360 \times 2^m \quad (17)$$

The QPE algorithm writes the eigenphase of the U operator in the Hadamard basis. Then, using inverse QFT, we convert the value from the Hadamard basis to the computational basis. In other words, using the QPE algorithm, information is converted from the global phase to

its own one. Then the information is decoded to produce the result with a READ operation. Algorithm description:

- system initialization where $|\psi\rangle$ has stored in one register and the value $2^n\theta$ in another register:

$$|\psi_0\rangle = |0\rangle^{\otimes n}|\psi\rangle; \quad (18)$$

- obtaining a superposition by applying the n -bit operation $H^{\otimes n}$ on the second register:

$$|\psi_1\rangle = \frac{1}{2^{\frac{n}{2}}}(|0\rangle + |1\rangle)^{\otimes n}|\psi\rangle; \quad (19)$$

- creates a supervised CU statement that applies only if the control bit is $|1\rangle$. Based on (15):

$$U^{2^j}|\psi\rangle = U^{2^{j-1}}|\psi\rangle = U^{2^{j-1}}e^{2\pi i\theta}|\psi\rangle = \dots = e^{2\pi i2^j\theta}. \quad (20)$$

Now it is necessary to apply controlled operations $CU^{2^{j-1}}$ in the range $0 \leq j \leq n-1$:

$$\begin{aligned} |\psi_2\rangle &= \frac{1}{2^{\frac{n}{2}}}(|0\rangle + e^{2\pi i\theta 2^{n-1}} + |1\rangle) \otimes \dots \otimes (|0\rangle + e^{2\pi i\theta 2^1} + |1\rangle) \otimes \\ &\otimes (|0\rangle + e^{2\pi i\theta 2^0} + |1\rangle) \otimes |\psi\rangle = \frac{1}{2^{\frac{n}{2}}} \sum_{k=0}^{2^n-1} e^{2\pi i\theta k} |k\rangle \otimes |\psi\rangle \end{aligned} \quad (21)$$

where k is an integer representation of n -bit numbers.

- perform inverse Fourier transform:

$$|\psi_3\rangle = \frac{1}{2^{\frac{n}{2}}} \sum_{k=0}^{2^n-1} e^{2\pi i\theta k} |k\rangle \otimes |\psi\rangle \xrightarrow{QFT_n^{-1}} \frac{1}{2^n} \sum_{x=0}^{2^n-1} \sum_{k=0}^{2^n-1} e^{-\frac{2\pi ik}{2^n}(x-2^n\theta)} |x\rangle \otimes |\psi\rangle \quad (22)$$

- measure the system and get the answer in the auxiliary register:

$$|\psi_4\rangle = |2^n\theta\rangle \otimes |\psi\rangle \quad (23)$$

Thus, you can get reliable information about the global phase if $2^n\theta$ is an integer. Otherwise, reliable information will be received with a probability of about 40%. We can improve this probability by increasing the number of qubits. If you need to get your eigenphase by p bits of accuracy and the probability does not exceed ϵ , you can determine the number of qubits m in the following way:

$$m = p + \lceil \log 2 + \frac{1}{\epsilon} \rceil \quad (24)$$

The considered algorithm is irreplaceable for some QML algorithms. For example, the HHL algorithm uses QPE to obtain critical information about the matrix to be inverted.

4. Quantum machine learning algorithms

Systems of linear equations (SLE) in machine learning are the foundation of many algorithms. In general, a system of n equations is written as follows:

$$A|x\rangle = |b\rangle \quad (25)$$

To get a matrix form solution, it is necessary to find the inverse matrix A^{-1} :

$$|x\rangle = A^{-1}|b\rangle = \sum_{j=0}^{N-1} \lambda_j^{-1} b_j |u_j\rangle \quad (26)$$

where $|u_j\rangle$ is the j^{th} eigenvector of A and λ_j id eigenvalue.

Among the traditional algorithms for finding the solution vector x , the nonlinear conjugate gradient method can be distinguished as the most optimal algorithm. Matrix A . in this case, must be valid and meet the condition:

$$A = A^T > 0 \quad (27)$$

The HHL algorithm is used to solve SLN on a quantum computer. Since only unitary operators can be used in quantum algorithms, the matrix A must be Hermitian.

The HHL algorithm (figure 1) is effective in such cases:

- if one uses it as a structural element of a quantum machine learning algorithm;
- when it's necessary to check the equality of vectors $|x\rangle$ and $|y\rangle$;
- when one needs to find some derivative characteristic (sum, average, frequency component) of the vector $|x\rangle$.

Figure 1 shows an example of a quantum circuit that implements the HHL algorithm. Here are three quantum registers, initialized to $|0\rangle$. The n_l register stores the binary representation of the eigenvalues of A . The rest of the registers are used as service registers for storing intermediate calculations.

A step-by-step description of the algorithm [9]:

- we put $N = 2^{n_b}$
- loading the vector $|b\rangle$ through a transformation of the form $|0\rangle_{n_b} \mapsto |b\rangle_{n_b}$
- application of Quantum Phase Evaluation (QPE):

$$U = e^{iAt} = \sum_{j=0}^{N-1} e^{i\lambda_j t |u_j\rangle\langle u_j|} \quad (28)$$

The quantum state of the register, expressed in its own basis A :

$$\sum_{j=0}^{N-1} b_j |\lambda_j\rangle_{n_l} |u_j\rangle_{n_b} \quad (29)$$

where $|\lambda_j\rangle_{n_l}$ – is n_l -bit binary representation of λ_j .

- adding an auxiliary qubit and applying rotation under the condition $|\lambda_j\rangle$

$$\sum_{j=0}^{N-1} b_j |\lambda_j\rangle_{n_l} |u_j\rangle_{n_b} \left(\sqrt{1 - \frac{C^2}{\lambda_j^2}} |0\rangle + \frac{C}{\lambda_j} |1\rangle \right) \quad (30)$$

where C – is a normalization constant and, as expressed in the current form above, should be less than the smallest eigenvalue λ_{min} in magnitude $|C| < \lambda_{min}$;

- applying the QPE \dagger operation. In this case, ignoring QPE errors will be displayed in the following form:

$$\sum_{j=0}^{N-1} b_j |0\rangle_{n_l} |u_j\rangle_{n_b} \left(\sqrt{1 - \frac{C^2}{\lambda_j^2}} |0\rangle + \frac{C}{\lambda_j} |1\rangle \right) \quad (31)$$

- measurement of the auxiliary qubit on a computational basis. If the result is 1, then the register is following after measurement:

$$\left(\sqrt{\frac{1}{\sum_{j=0}^{N-1} |b_j|^2 / |\lambda_j|^2}} \right) \sum_{j=0}^{N-1} \frac{b_j}{\lambda_j} |0\rangle_{n_l} |u_j\rangle_{n_b} \quad (32)$$

- applying the observable M to calculate $F(x) = \langle x|M|x\rangle$.

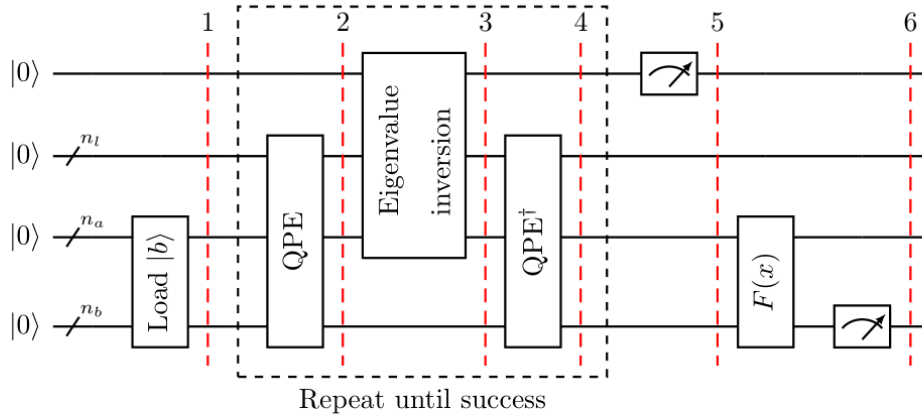


Figure 1: HHL algorithm schematic.

The following parameters affect the performance of the SLN solution: n is the size of the SLN, k is the condition number of the matrix A , s is the sparsity of the matrix A , ϵ , is the accuracy of the solution.

The computational complexity for the conjugate vector method is $O(nsk \log 1/\varepsilon)$. The HHL algorithm has a computational complexity of $O(k^2 s^2 \varepsilon^{-1} \log n)$, which provides exponential acceleration depending on the size of the SLN n . However, one should remember that this algorithm does not provide an exact solution. By analogy with numerical methods, HHL gives an approximate solution with an accuracy ε .

Principal component analysis (PCA) is used to filter out correlated features and dimensionality reduction. We can achieve this by projecting the data point onto a new, lower-dimensional basis. The vectors covering this basis are called principal components and are the eigenvectors of the covariance matrix. The most costly action of PCA algorithm is considered to be the proper decomposition of the covariance matrix σ :

$$\sigma = \frac{1}{n-1} X^T X \quad (33)$$

where X is an $m \times n$, m is data points, n is features. As with the HHL algorithm, the QPCA algorithm should help us speed up the costly process of decomposing the covariance matrix.

The algorithm consists of two steps:

- 1) the QPCA algorithm requires reusable SWAP operations on $\rho \otimes \sigma$ for representation of the covariance matrix. The density operator is:

$$\rho = \sum_j \rho_j |\psi_j\rangle \langle \psi_j|, \quad \sum_j \rho_j = 1 \quad (34)$$

where ρ_j is the probability of encountering a mutually orthogonal state ψ_j . This view requires reusable SWAP operations;

- 2) phase estimation to determine the eigenvalues of σ . The representation of σ in the density operator ρ form makes it possible to obtain the phase estimates of the eigenvector at the output and the associated eigenvalue (variance value) in the output register. The principal component with an eigenvalue and a vector is determined randomly but depends on the magnitude of the variance. Most likely, it will be the component with the greatest variance. Using ρ as the initial state, we get the state with the highest rank value:

$$\sum_j r_j |\chi_j\rangle \langle \chi_j| \otimes |\tilde{r}_j\rangle \langle \tilde{r}_j| \quad (35)$$

where χ_j – eigenvector of ρ operator, \tilde{r}_j – estimate of the corresponding eigenvalue r_j . This state will be decomposed into an eigenvector/eigenvalue pair. Then we can get the mathematical expectation of an eigenvector with an eigenvalue r_j using the measurement operation $\langle \chi_j | M | \chi_j \rangle$.

The traditional PCA algorithm has a computational complexity of $O(d)$, where d is the number of features. The quantum analogue of this method is performed in time $O(R \log d)$, where R is the smallest rank of the approximation of the covariance matrix. In this case, the exponential acceleration by the quantum algorithm is achieved under the condition $R < d$ [10]. Support vector machine allows you to find a hyperplane maximizing the distance between two

hyperplanes:

$$\sum_i a_j y_i - \frac{1}{2} \sum_i \sum_j a_i \vec{x}_i \times a_j \vec{x}_j \quad (36)$$

where x_i is the i^{th} - point in the feature space, y_j is the tagged class and a_j - parameter of the model. Thus, to find the optimal hyperplane, it is necessary to find $\vec{a} = [a_1, \dots, a_m]$. Unlabeled data can be classified by the formula:

$$sign(\sum_i a_i \vec{x}_i \times \vec{x} - b) \quad (37)$$

The QSVM method allows you to speed up the calculation of the dot product $\vec{x}_i \times x$. This product is also known as the kernel matrix K .

Let us rewrite the problem of finding the vector \vec{a} in the LS-SVM form of a system of linear equations to apply the HHL algorithm:

$$\begin{bmatrix} b \\ \vec{a} \end{bmatrix} = F^{-1} \begin{bmatrix} 0 \\ \vec{y} \end{bmatrix} \quad (38)$$

Matrix F consists of scalar products of the kernel matrix K of the training sample:

$$\begin{bmatrix} 0 & i^T \\ 1 & K + \frac{1}{\gamma} I \end{bmatrix} \quad (39)$$

where i is the unit vector, I is the unit matrix, γ is the hyperparameter.

We use HHL to find F^{-1} . At the same time, we pass the amplitude-encoded $|\vec{y}\rangle = [0, \vec{y}]$ classes' vector to the input register of the phase estimation eigenstate. Moreover, we regard $|\vec{y}\rangle$ as a superposition of eigenstates of F . As a consequence, $|F^{-1}\vec{y}\rangle$ exactly coincides with the desired solution $|b, \vec{a}\rangle$.

It remains us only to classify the data by obtaining a sign. If we store the superposition of the training data amplitudes a_i in one QRAM quantum register and the new data point \vec{x} in the other, we will be able to apply the SWAP test procedure. This procedure is constructed so that the probability p becomes $p < 0.5$ for the +1 sign and $p \geq 0.5$ for the -1 sign. By repeating the SWAP test, it is possible to estimate the value of the probability p to the desired accuracy.

In the best case, the implementation of the SVM algorithm has a complexity of $O(poly(m, n))$, where m is the amount of data used for training, and n is the number of features. The quantum analog of the SVM algorithm allows you to obtain a logarithmic acceleration of $O(\log mn)$.

5. Research results

It was decided to use the QSVM algorithm using the Qiskit public library and the IBM Quantum Experience cloud service to solve the assigned task. For comparison, the original classic SVM algorithm and the Google Colaboratory cloud development environment were used. It was significant to check the practical applicability of quantum machine learning algorithms. As well as the existing algorithms' ability to correctly perform the task of not only binary but

also multiple classifications have been checked. The dataset "ElectricalFaultDetection.csv" was selected to detect electrical faults at various locations on the power line. This dataset has six features and six classes. Since the maximum number of qubits in the free-for-all IBM machines is five, only the first five features participated in the training. The number of data points in this dataset is 7861. As it turned out, using all the data for training and testing would take at least a couple of days on a quantum device (without waiting in the queue). For this reason, we use a sample of shuffled data with a dimension of 72 for the quantum algorithm training. However, we used all data to train the classical SVM. Each sample has been divided into 75 % of the training data and 25 % of the test data. With the optimal selection of parameters, the classical SVM algorithm has been trained in 2.64 s. with an accuracy of 73.25 %. Let us consider in more detail the results obtained by execution on different quantum devices.

First, let's look at why training on large data sets on today's quantum devices is not desirable. Figure 2 shows how long it takes a model to train in a quantum simulator. As we can see, the time increases with the growth of the size of the training and test samples with a polymodal rate. It makes sense since we are only simulating quantum behavior.

If you perform the same actions on the real quantum device, the time will grow less and less with the growth of the sample according to the logarithmic law (figure 3). This result is in line with theory, but if one pays attention, the execution time for a sample size of 72 reaches almost 5 minutes. The classical method only needs about 3 seconds. Of course, as the size of the qubit increases, it will be possible to train the data in parallel, which will give a greater speedup. However, one cannot ignore the fact that the need to run the same circuit many times, external noise, and the time spent on error correction influence the total program execution time.

In terms of accuracy, it ranges from 61 % to 94 % on a training set of up to three data points. For the training set with a dimension of four and higher, we got an accuracy of 100 %. The accuracy of the classical SVM with the same training and test sample size was 83 %. Consider now the time it took for the program to execute on various quantum devices: qasm_simulator 474 s, lima 481 s, quito 352 s and belem 347 s. As we see, the runtime on real quantum devices ultimately does not differ much from the runtime on the simulator.

From the results obtained earlier, we can conclude that quantum devices are not efficient for small datasets. However, QPU needs more qubits for large datasets and, of course, more quantum volume. When QPUs achieve this condition, quantum computers can become an indispensable assistant in machine learning.

6. Conclusion

In the problem studying process using a quantum computer to solve the classifying machine learning problem from the theoretical side, the high advantage of quantum computing algorithms over classical ones was substantiated. It was written a module that allows you to perform the classification task on a classical and quantum device to check the current state of quantum computing. This module enables performing the classification task on a classical and quantum device. It has been proven that a quantum computing device can solve both binary and multiclass classification tasks. Empirical research has shown that the current state of quantum computing is far from quantum superiority in accelerating classical teaching methods. However, this does

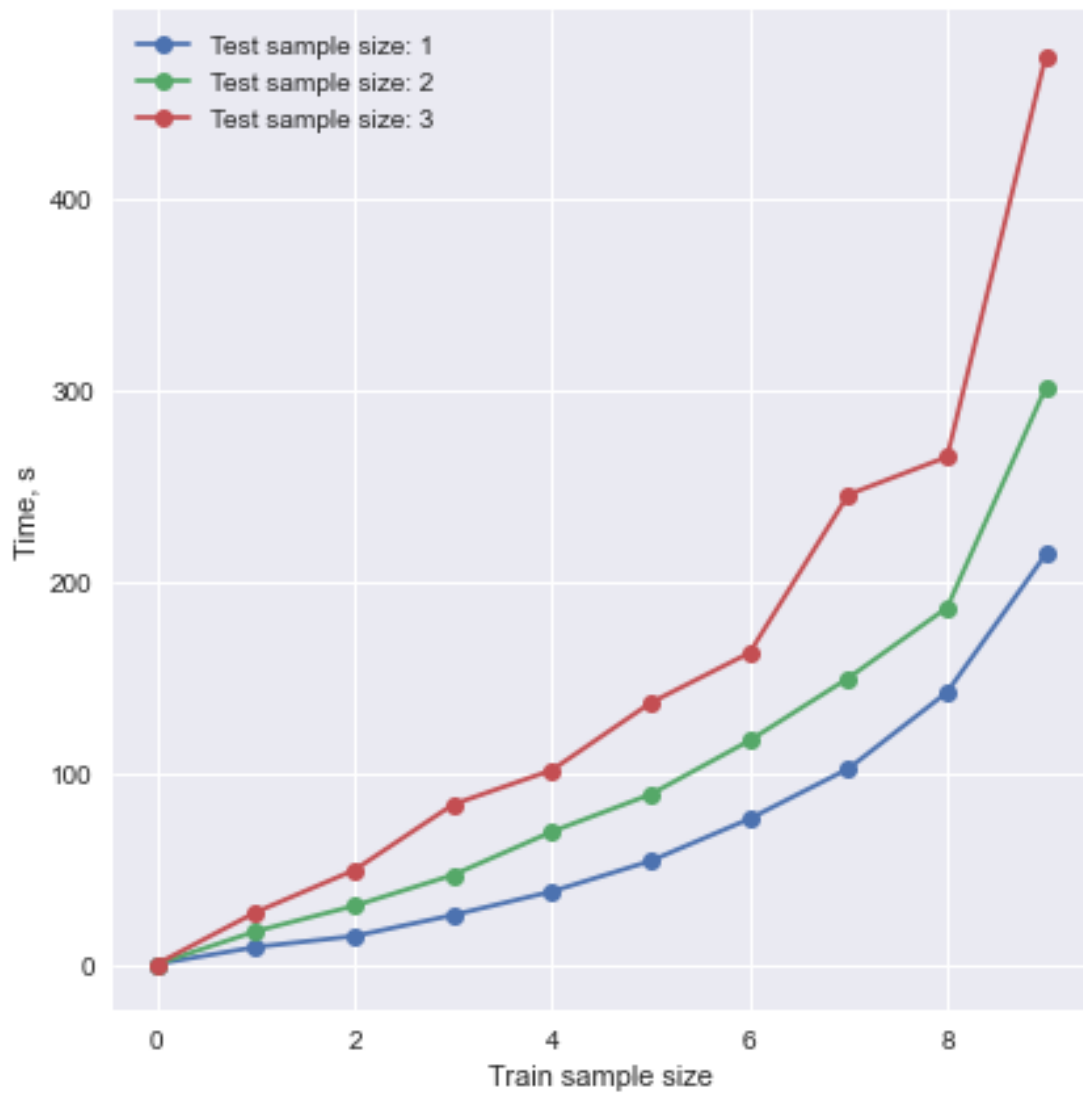


Figure 2: Training of the model on the IBM quantum simulator.

not negate the importance of research in this area. When the stable quantum computer is invented with sufficient computational resources to perform real-world tasks, the need for theoretically based quantum algorithms will increase. Therefore, an important task is to build fundamentally new algorithms for quantum machine learning. In the future, it is planned to study the possibility of using quantum machine learning to increase the forecasting accuracy of short-term time series.

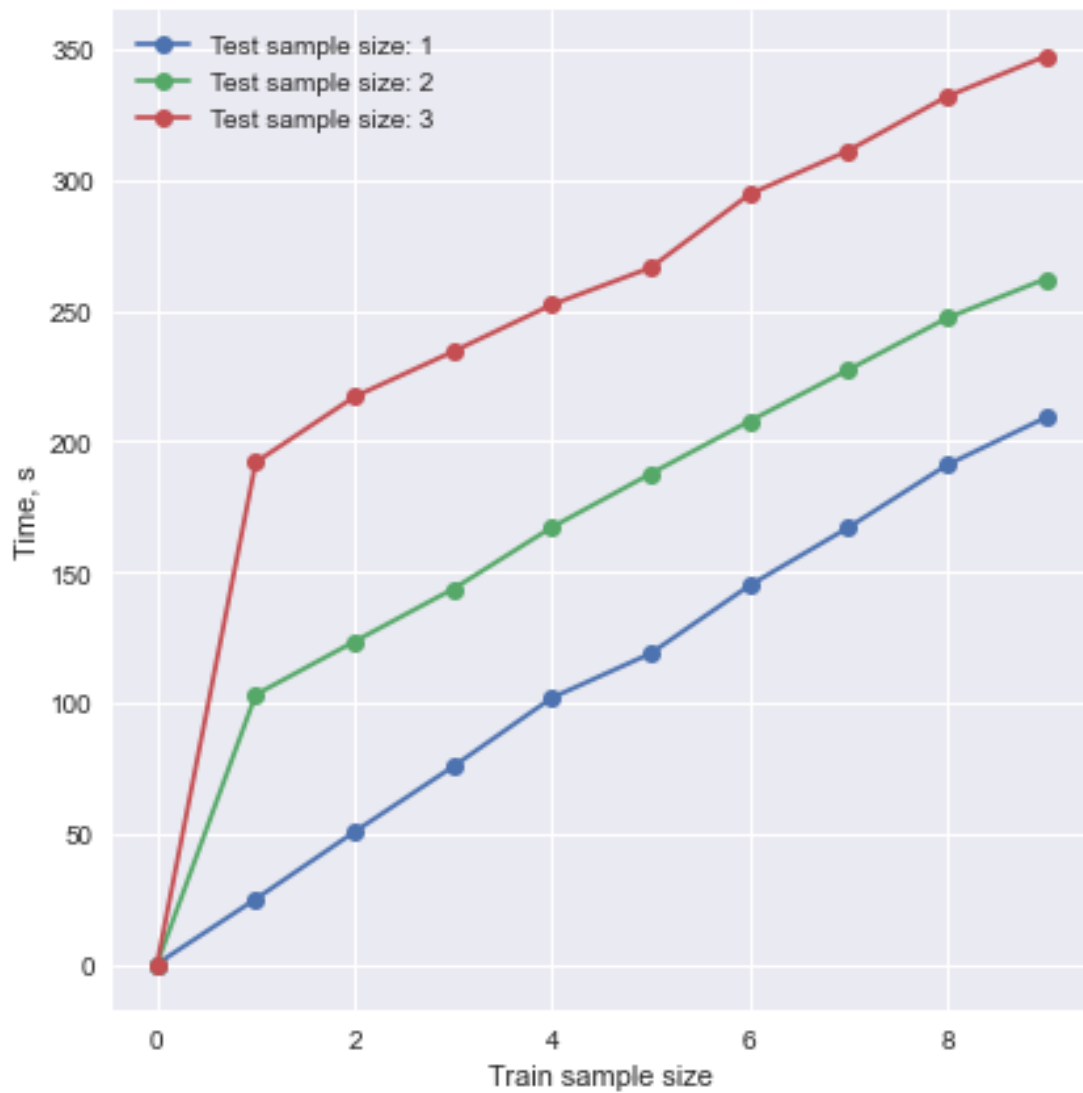


Figure 3: Training of the model on the IBM quantum belem device.

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System and method of automatic collection of objects in the room

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Abstract

A system and method of automatic collection of objects in a room focused on the minimum energy consumption is proposed in this paper. This result is achieved by the implementation of an improved method of automatic collection of items in the room and mathematical method for calculating the desired motion trajectory; development and implementation of algorithms that implement the proposed method; software and hardware implementation of the system for automatic collection of items with minimal energy consumption, including the small number of system components and an improved movement trajectory. The system's main component is the Arduino Uno, which acts as a controller. The developed software makes it possible to evaluate the implemented method's effectiveness in a real-life system. An application example of the proposed method is given.

Keywords

robotplatform, Alhabet, Arduino, optimization, evolutionary method

1. Introduction

Humanity is on the verge of a new era of technological development. Already now, robotics is rapidly being introduced into people's daily lives, helping them to interact more effectively with automated systems, improve existing jobs and, in general, give people more time to focus on what interests them, it is important and fun. We are talking about cyber-physical systems for modeling complex sociotechnical systems that largely control themselves.

The principle of operation of such systems is to combine physical production processes or any other processes that require continuous control in real-time using software [1] and electronic systems.

The robot differs from a conventional automatic system in its multipurpose purpose, versatility, and ability to be reconfigured to perform various functions. Automation of robotic systems

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requires the development of robots capable of intellectual activity, using a pre-prepared program or artificial intelligence technologies [2, 3, 4].

Today, the use of robots covers almost all industries and tasks. With the rapid development of robotics, human-machine interaction will soon become a common daily practice. Moreover, today technological advances are increasing the adaptability and flexibility of robots. Most people in developed countries prefer home automation, allowing control of lighting, air conditioning, audio content, security systems, and home appliances. Much attention is paid to the creation of mobile robots that are used in home conditions or in situations where the presence of a person is dangerous and optional. Modern robotics focuses on the complete automation and autonomy of robots and robotic systems. A characteristic feature of work is the ability to partially or completely fulfill the mechanically motor and intellectual functions of a person.

Additional support is provided by connected jobs that apply to all types of services, such as robotic vacuum cleaners. Modern companies are actively developing this area, developing new assistant robots. The number and popularity of home robotic assistants in homes are growing at a high rate, due to the increase in the functions that provide work and the decrease in the price of them.

Most robotic home assistants are entertaining in nature, such as a voice assistant built into a music speaker. Another group of robots is designed to free humans from doing household chores, they can guardhouses, wash windows, clean pools and do small household chores. Work greatly improves the quality of our life at home, at work and during leisure. They are adapted to recognize objects, distinguish objects of the environment, repeat simple human movements, coordinate with other works. Such functionality has become possible thanks to the use of innovations in the development of robotics, as well as due to the improvement of algorithms that control perception, thinking, control and coordination of work.

The purpose of the study is to organize the automatic collection of items in the room by developing a system and collection method that allow assessing not only the results of the work, but also implementing the collection process with minimal energy consumption.

The objective of the research is to develop a robotic autonomous system for collecting objects in a room with increased requirements for energy saving due to the developed method.

2. System structure

The basis of the collection system is represented by the AlphasBot double-deck robotic platform, which allows you to remotely control the development via Bluetooth or WiFi. The robotic platform is equipped with two motors, contains mounting holes for mounting various sensors, controllers and power supplies. The main component of the aforementioned system is the Arduino Uno hardware and software complex, which acts as a control controller. It is a board that houses the microcontroller and other electronic components.

The MG995R servo motor is used for automatic remote control of the claws, which assists in the opening (closing) functions. The operation of the wheels is provided by DC motors with a gearbox, the rotation speed of the motors is helped to determine the photo-interrupting sensors. To determine the distance, the HC-SR04 ultrasonic sensor is connected to the robot platform [5, 6].

The robotic claw is made of light metal. The claw opens approximately 55 mm and, depending on the servo used, can lift heavy objects.

The main connections to the Arduino board are shown in figure 1. In this case, the Board is connected in a standard way to the Alfabot platform, according to the documentation [5].

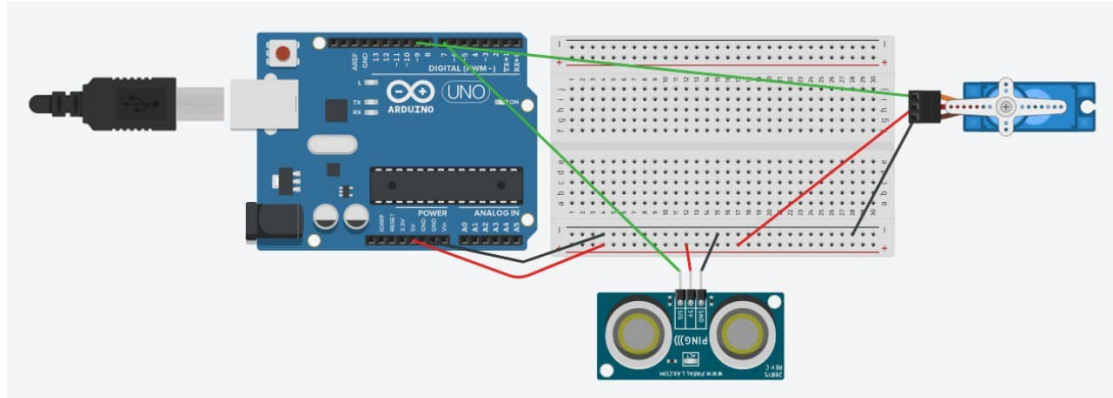


Figure 1: Connections to the Arduino board.

Optimization of energy consumption in this work is considered from the point of view of minimizing the trajectory of the robot's movement. Changing the component base, in the future, is planned as the next stage of research in terms of energy consumption optimization.

3. System operation

For the effective functioning of the system, a method for collecting items from the floor of the room was developed, which allows collecting with minimal energy consumption. In order for the energy consumption to be minimal, it is necessary that the time of the task being performed is also minimal. This result can be achieved by moving the robot along the minimum path along the total distance.

Thus, the developed method of collecting objects from the floor is as follows. The room where the robot moves to collect items is a matrix of points, each of which is equal to the length of the robot platform with a claw. The robot is installed in those points where it can turn to the left. With the help of an ultrasonic sensor, it is determined how far it can travel forward, that is, to a wall or an object [7, 8].

As soon as the system reaches the obstacle and it turns out to be a wall, then this point becomes a "basket" where objects will be collected. Then the robot makes a 180-degree turn and continues to go to the next obstacle. If there is an object on the way, he tries to grab it and, if successful, determines the shortest path to the "basket" from the point at which he stopped, and begins to move in this direction.

Having reached the point of collecting objects, he leaves the object and returns to the point where he picked it up, and continues to search for the following objects. If the robot was unable to grip the object, because the dimensions differ from the permissible parameters, it makes a detour around the object. When the robot reaches the other end of the room, it looks for the

shortest route back to the starting point. As soon as the robot is at the starting point of the room, it turns off.

The algorithm for the functioning of the system that implements the developed method of collecting items, based on the above, is as follows:

1. The robot scans the distance to the obstacle using an ultrasonic sensor.
2. The robot moves towards an obstacle.
3. Having stopped at an obstacle, the object is gripped: the claw opens, the robotic platform travels 4 cm and the claw is closed.
4. The robot moves backward 8 cm and checks the distance:
 - if the distance does not change and the “basket” is indicated, then go to step 8;
 - if the distance does not change and the “basket” is not indicated, then the robot turns in place by 180 degrees, moves to the wall with the help of obstacle sensors and makes a reverse turn;
 - if the distance changes and the “basket” is indicated, then go to step 6;
 - if the distance changes and the “basket” is not indicated: the robot defines this point as a collection point. Then step 6 is performed.
5. The robot opens the claw, moves forward 4 cm, closes the claw. Then step 9 is performed.
6. Turn left.
7. If the distance allows movement, a 90-degree turn is performed, then step 1 is performed, otherwise, the robot is at the end of the room: step 10 is performed.
8. The shortest path to the “basket” is determined. A movement is made towards it and step 5 is carried out.
9. The shortest path to the capture point of the object is determined. When the robot arrives at this point, step 1 is performed.
10. The shortest path to the starting point is determined.
11. The movement to the starting point is carried out, and the robot finishes its work.

4. Mathematical justification

To prove that energy consumption will be minimal, with the smallest distance traveled by the robot and with the minimum number of devices, we will construct the following mathematical model.

First, let's prove that a device with fewer connected devices should use less power.

Let S – be the distance that the robot will cover when moving around the room, while collecting all possible objects. Then we will designate the energy that he will spend as E_{np} . Value N – the number of connected devices powered from one source.

The energy of each i -th device is denoted as E_i , where $i = (1, N)$. Then the energy that will be spent by the robot for the entire path traveled is determined as follows: $E_{np} = \sum_1^N E_i$.

Considering that the value E_i cannot be less than zero, then according to the mathematical law of additivity, the lower the value of the energy of the i devices E_i , the lower the value of

the energy that is spent by the robot while covering the entire distance E_{np} . This means that the fewer devices connected to the robotic platform, the less energy they will spend during a certain operating time. Thus, it has been proved that the device developed in this scientific work meets the requirements of energy saving.

Secondly, we will prove that the energy consumption will be the least, with the minimum distance traveled by the robot. Suppose that the robot moves uniformly, because the time for gripping the object does not depend on the path of movement of the robot, but remains unchanged regardless of which path was traversed by the robot. Then the following formula for determining the distance is valid: $S = vt$, where t – the time during which the movement is carried out at a given speed of robot v .

Then $v = \frac{S}{t}$. Taking into account the energy of motion $E = \frac{mv^2}{2}$, we get that $E = \frac{m(\frac{S}{t})^2}{2}$. This means that the less the path traveled by the robot, the less energy will be spent by the device. Which it was necessary to prove. Thus, at this point of work, it was proved that the developed system meets the requirements of energy saving and has significant advantages in this.

5. Analysis of similar systems

Minimizing energy costs is always an urgent problem. Many scientists are dealing with this issue, and among robotics, not least. Naturally, there are many studies on similar topics, some of which can be considered as distant analogs of the developed system.

So, for example, Taniguchi et al. [9] considers autonomous planning based on spatial concepts for guidance in the house using service robots. To complete the tidying task, the robot must recognize the environment, evaluate objects to clean while moving, and determine where to place objects in three-dimensional (3D) space.

The proposed tidy up planning method is formulated to first select the object whose tidied place is the most defined. In the spatial concept model learned in the tidied environment, the likelihood is the highest when each object position is tidied. Therefore, when tidying up one object from scattered objects, the object with the highest likelihood is selected first. In this study, tidying up implies moving the positions of the observed objects to increase the likelihood of the spatial concept mode.

First, the robot detects cluttered objects while moving. Next, if multiple scattered objects are detected, the robot decides on an object and a place to be tidied up. The robot estimates simultaneously the order and positions of the objects to tidy up from the multiple objects it observed in the cluttered environment. Moreover, the robot can determine if the tidied position of the object is unknown from Equation. If unknown, the robot can ask where to move the object.

Finally, the robot performs motion planning. After both estimating the tidied positions and planning the object order by Equation, the robot is required to accurately manipulate the objects to move them. The developed system uses the MoveIt! framework for the motion planning of the robot arm when grasping an object. Furthermore, the robot moves to the appropriate search positions while performing self-localization based on its map and observations.

When the robot finishes tidying an object, the state of the other objects may have changed

owing to external factors. To deal with such scenarios, it is possible to sequentially plan the tidy up task by redoing the object detection after tidying each object.

Approach is divided into learning and planning phases. In the learning phase, the robot observes the tidied environment. Spatial concepts are formed from observed data regarding objects and their 3D positions by multimodal learning. In the planning phase, the robot observes scattered objects in the environment, and estimates the order and positions of objects to be tidied up based on the spatial concepts formed in the learning phase.

According to the above flow, the robot tidies up a selected object to the target position repeatedly. In the case of an unknown object, the robot tidies it up by asking the user about its place name.

In contrast to the developed system, the reduced one is much more advanced, a robot that has undergone machine learning scans the surrounding space using a camera and builds the shortest paths based on the data obtained and built-in algorithms. On the one hand, such a system is more profitable in terms of finding goals and shortest paths in advance, on the other hand, it requires much higher development costs, in contrast to the one given in the article.

In a large number of works, the construction of trajectories for robots with obstacle detection is considered. So, for example, in work [10] for the study of space, an algorithm is used, based on the algorithms of the robot's movement "Spiral" and "Movement along the wall".

Algorithm "Spiral" is a movement along a circle with increasing radius. "Movement along the wall" is an algorithm in which the robot moves along the perimeter of space. Unlike the "Spiral" algorithm, in this algorithm the robot can go around obstacles. The proposed algorithm for learning a mobile robot in order to detect obstacles is a modified combination of the two algorithms described above. The learning algorithm consists of three parts. The first part can be called the main one – it is an algorithm for passing one circle (figure 2). The robot begins its exploration of space from a possible perimeter, and with each circle it narrows it down to a radius less by one. In order for the robot to narrow the radius with each passed circle, the second part of the algorithm is needed – the algorithm for starting the study of a new circle (figure 3).

After the end of the movement according to this algorithm, the robot needs to check the space for unexplored areas (figure 4). In the case when there are few obstacles and their shape is simple, the robot explores the space in one pass. Otherwise, there will be dark areas unknown to the robot. To prevent the robot from spending a lot of time on the way to such a site, it is necessary to use the algorithm for finding the shortest path. There are many obstacle avoidance algorithms. The most efficient is Dijkstra's algorithm if we consider the classical algorithms for solving the problem.

In [11], to solve the trajectory planning problem, an approach is used based on artificial neural networks of Hopfield, which belongs to intelligent algorithms – fuzzy and genetic algorithms, the main advantage of which is the speed of calculation with a moderate load on onboard computing complexes. However, the use of the specified mathematical apparatus imposes significant restrictions on the minimum system requirements of the MR computing platform, which excludes the possibility of implementing the method on devices with limited computing resources. For example, AVR or STM microcontrollers with a processor capacity of less than 32 bits, which are also a significant drawback.

Based on everything discussed above, we can conclude that the developed system is really

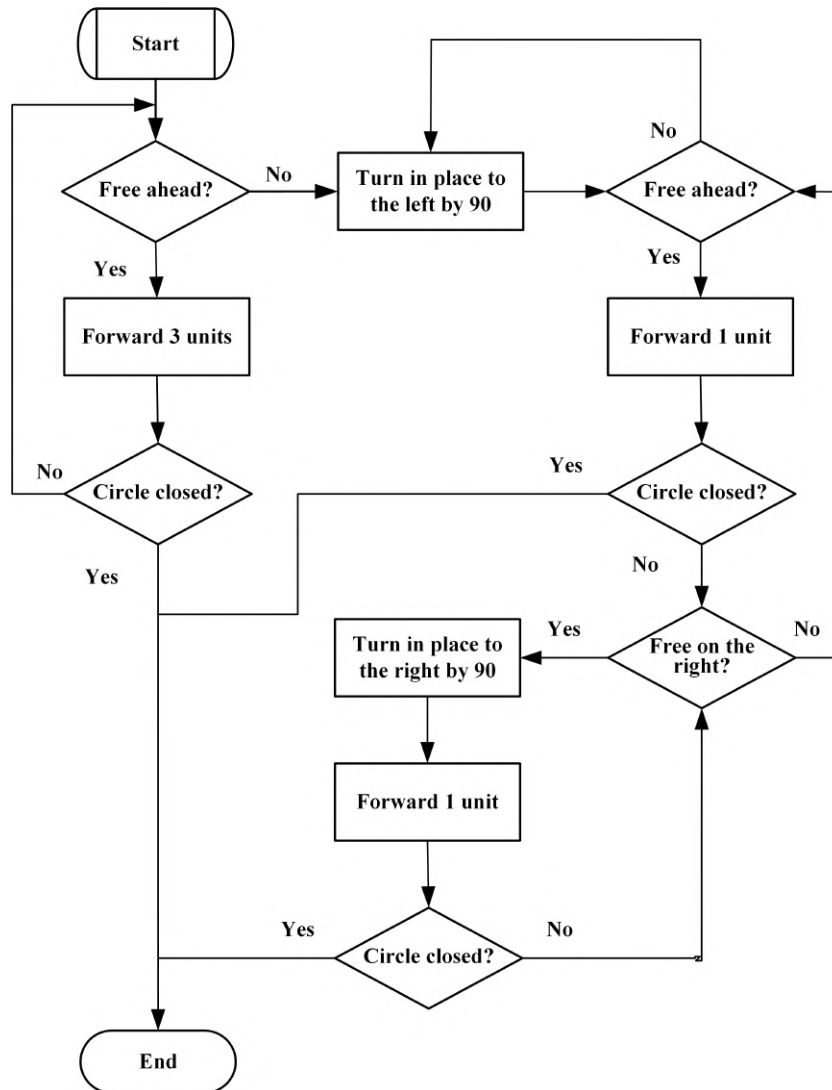


Figure 2: Algorithm for passing one circle.

relevant, having no exact analogs and showing an advantage over others for the set goals.

6. System implementation

By connecting the Arduino board to power, the firmware starts to actively execute. The microcontroller is configured so that the bootloader is responsible for the control functions at system startup. First, the loader checks for 1-2 seconds, the user will not start sending a new program. If the reprogramming process is started, the sketch is loaded into memory and control is transferred to it. If there are no new programs, the loader executes the previously saved program [12].

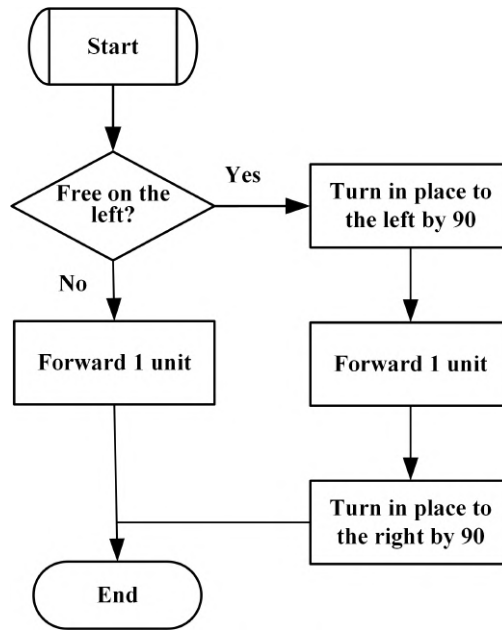


Figure 3: Algorithm for starting the study of a new circle.

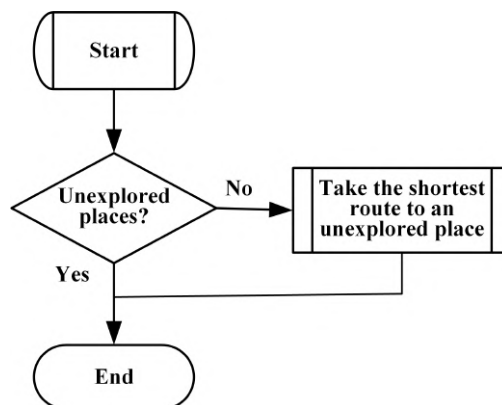


Figure 4: Algorithm for check the space for unexplored areas.

After starting the execution of the program, the Arduino performs a number of routine operations of initializing and setting up the environment, and only then proceeds to execute the same code that is contained in the sketches. Thus, Arduino eliminates the need to remember all the details of the microprocessor architecture and concentrate on the tasks at hand.

The robotic platform contains a large number of sensors and actuators, which can be controlled by the AlphaBot.h library, which can be downloaded from the official AlphaBot website [13]. The instance used to send commands from the sketch is Car1, and the method implemented by the sketch is: SetSpeed(), Forward(), Brake(), Backward(), Left(), Right(), LeftCircle(), RightCircle(), MotorRun().

A set of functions for controlling a servo drive is provided by the Servo.h library:

- servo.attach() – indicates the pin to which the servo control wire is connected;
- servo.write() – set the turning angle;
- servo.writeMicroseconds(uS) – a value is passed to control the servowrite in microseconds (uS), setting the rotation angle to this value;
- servo.read() – reads the current angle of rotation of the servo;
- servo.attached() – determines if there is a binding to the servo via pin;
- servo.detach() – disconnect a pin from the Servo library.

By downloading the program, the Arduino allows the code to participate in the initialization of the system. To do this, the microcontroller is given commands that it will execute at the time of the boot and will no longer return to them (that is, these commands are executed only once at system startup). And it is for this purpose that a block is allocated in the program in which such commands are stored – void setup() [14, 15]. In the function, the necessary properties are set for connecting the configuration of the ultrasonic sensor, setting the speed of the robot, specifying the pin for connecting to the servo drive.

```
void setup()
{
  ProximityConfig();
  UltrasonicConfig();
  myservo.attach(9);
  Serial.begin(9600);
  Car1.SetSpeed(150);
}
```

Variables that are used in the program for the functioning of the robot:

- run – to set the start of the robot’s functioning;
- side – to determine the side to which the robot is returning;
- distance – to determine the distance to the obstacle at the present time;
- spacing – to save the old value of the distance to the obstacle;
- cart – to determine the presence of a “basket”;
- pos_last_point – to save the distance to the point where the object was taken;
- time_turn – to save the time for which the reversal is carried out;
- pos_cart – to save the distance to the “basket”.

Be sure to after setup() there is a loop() function – the entry point to the program, which ensures the execution of commands while the Arduino board is turned on. This function contains all commands that will be executed cyclically. Starting from the first command, the microcontroller performs all subsequent steps to the very end and immediately returns to the beginning to repeat the same instruction. Checking the distance in the program is performed by the check distance() function. It allows you to check the driving distance in the range from 2 to 30 cm.

```

int check_distance()
{
    if((1 < Distance) && (Distance < 38))
    {
        return false;
    } else {
        return true;
    }
}

```

The capture of objects is carried out by the Servo() function.

```

void Servo()
{
    for (pos = 0; pos <= 180; pos += 1) {
        myservo.write(pos);
        delay(15);
    }
    delay(1000);
    Distance_test();
    spacing = Distance;
    Car1.MotorRun(10,10);
    Car1.Brake();
    delay(1000);
    Car1.MotorRun(0,0);
    Car1.Brake();
    for (pos = 180; pos >= 0; pos -= 1) { myservo.write(pos);
    delay(15);
    }
}

```

A cycle is started that opens the claw 180 degrees. Next, a delay is called to start the motors. The robot moves forward 4 cm. The next cycle is responsible for closing the claw.

The object_check() function checks the delight of the subject.

```

int object_check()
{
    Distance_test();
    if (spacing > Distance)
    {
        return true;
    } else {
        return false
    }
}

```

If the distance to the object is less than the value of the distance that was before the capture, then it is considered that the object was taken by the robot. Otherwise, the object defines the wall.

To leave an item in the “basket”, the program calls the leave_object() method. Obstacle sensors are controlled by the sensor_check() function. The movement of the robot backward is set and a cycle is performed until the sensors notify about the object. Upon completion, the system performs a 180-degree turn in place.

```

void sensor_check()
{
  Car1.Motor(-150,-150);
  Car1.Brake();
  while(true)
  {
    RSensor = digitalRead(RSensorPin);  LSensor = digitalRead(LSensorPin);
    if (LSensor == HIGH && RSensor == HIGH)
    { Car1.Motor(0,0);
      Car1.Brake();
      delay(1000);
      Car1.RightCircle(2000);
      Car1.Brake();
      break;
    }
  }
}

```

The Distance_test() function writes the distance to the obstacle in the Distance variable.

```

void Distance_test()
{
  digitalWrite(TRIG, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG, LOW);
  float Fdistance = pulseIn(ECHO, HIGH);
  Fdistance = Fdistance / 58;
  Distance = Fdistance;
}

```

The definition of the shortest path to the “basket” is provided by the road_to_busket() function. Changing side determines the side to return to (1 – left, 2 – right).

The road_to_last_point() function returns the work to the point along the shortest path where the item was taken.

To return to the starting position of the work, the road_to_start_point() function is called.

The turn() function determines the side in which to turn and carries out movement in a certain direction.

```

int turn(){
  if (side == 1) {
    Car1.RightCircle(1000);
    Car1.Brake();
    Distance_test();
    if (check_distance() == true) {
      Car1.RightCircle(1000);
    }
  }
}

```

```

Car1.Brake();
side = 2;
return true;
} else {
return false;
}} else {
Car1.LeftCircle(1000);
Car1.Brake();
Distance_test();
if (check_distance() == true) {
Car1.LeftCircle(1000);
Car1.Brake();
side = 1;
return true;
} else {
return false; }}}

```

7. Conclusion

On the basis of the Arduino family platform, an object collection system was created that is able to: estimate the distance to an obstacle using an ultrasonic sensor; perform the movement to a given point; grab an object no larger than 5.5 cm; deliver the item to the item collection point; determine the shortest path to a certain point. The movement to the right is performed in the same way as the algorithm of movement to the left.

There are limitations associated with the use of an ultrasonic distance sensor:

1. Partial displays can distort the measurement results (this can be caused by curved or inclined surfaces with respect to the direction of emission of the signal).
2. Objects made of sound-absorbing, insulating materials, with a woolen surface can weaken the signal.
3. The size of the object affects the signal quality. The smaller it is, the weaker the reflected signal.
4. High humidity (rain, snow) contributes to signal distortion.

The system can be improved with a movable ultrasonic sensor stand, which will help determine the width of the object in order to calculate the distance to avoid an obstacle.

The scientific novelty of the work lies in the fact that a new method of collecting objects in the room and a system have been developed that allows organizing the collection process with minimal energy consumption.

The practical significance of the work lies in the fact that the software has been developed, which makes it possible to assess the adequacy and effectiveness of the developed method in the real work of the system.

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Learning analytics of MOOCs based on natural language processing

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Abstract

The perspectives of application of machine learning, especially, decision trees, random forest and deep learning for educational data mining problem solving, and learning analytics tools development are considered in the paper. The abilities of sentiment analysis with BERT deep model, clustering based on kMeans with the different approaches to the text vectorization are investigated for the development of learning analytics tools on the example of the learning analytics of some programming MOOCs from Udemy. We analyze 300 titles of MOOCs and proposed their clustering for better understanding the directions of learning and skills, and 1150 sentences that contain the word “teacher” or its synonyms and 2365 sentences about the course for sentiments detection of students and top of words that describe opinions with positive and negative polarities and the issues during learning.

Keywords

MOOC, sentiment analysis, BERT deep model, learning analytics

1. Introduction

Recently MOOCs and various e-learning environments propose Big Data connected with students and tutors activities in form of clickstreams, sequences of video watching, and interactions with different types of learning content, video streams from the camera during learning for facial students’ expressions recognition, and students’ comments on various social media platforms. The diversity of data in education requires special approaches to handling and data recognition. Machine learning algorithms are widely used in learning analytics (LA) and educational data mining (EDM) [1]. EDM is considered as a methodology for mining regularities from big educational data that are gathered in educational environments [2]. LA is aimed at tools development for analyzing and optimization learning [3, 4].

During the COVID-19 pandemic, when distance learning became the only possible form of education, the development of tools for solving the problem of assessing the quality of education and analyzing feedback from students in the form of answers to questions of google-forms, comments and reviews on various media platforms attracted the attention of many researchers as one of the most pressing tasks of learning analytics [5].

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There are different problems in LA and EDM formulated as supervised learning, unsupervised learning, or reinforcement learning problems connected with the extraction of qualitative regularities from educational data for understanding students' and tutors' behavior and activities.

The following purposes are stated in the paper

- studying the effectiveness of the machine learning algorithms application for solving learning analytics problems;
- the development of the learning analytics tool for extracting the regularities from some programming language MOOCs using python libraries.

2. Literature review

Consider some machine learning algorithms and their usage for educational data mining and learning analytics tools development.

2.1. The decision trees and random forest for EDM and LA

Social influences, math achievements and students engagement (their interests and beliefs) impact acceptance or vice versa rejection from engineering specialities choice. It is important to develop tools for monitoring the causes of negative relationships to engineering specialities and specialities that required high-quality math knowledge. Tan et al. [6] noted the perspective of the linear regression model and random forest usage to investigate how demographic and family background factors, high school factors and students' academic achievements with their non-cognitive behaviour influence their involvement in engineering learning choice.

The task of predicting student performance is one of the primary tasks in e-learning systems aimed at identifying factors that affect student performance; assessing the quality of learning; identifying groups of lagging and successful students, etc. Ahmed and Elaraby [7] considered the problem of academic performance prediction as a supervised learning problem in the case of the target function with discrete values. Authors constructed decision tree on feature space like faculty, average score with intervals (excellent rating with score $\geq 85\%$, very good rating with score $\geq 75\%$ & $< 85\%$, good rating with score $\geq 65\%$ & $< 75\%$, bad rating with score $\geq 50\%$ & $< 65\%$, very good rating with a score $< 50\%$); results of the tests; assessing of learning in seminars, students' activity as a binary value (yes or no), homework availability as a binary value (yes or no), and received decision rules for decision making about students final score results. The hybrid approach based on the decision tree together with a genetic algorithm was used for identifying the successful students' groups with a description of the professional skills that will be useful for employers [8].

Decision trees can be used to describe the key characteristics of certain groups of students – listeners of MOOCs. Identifying such target groups can help the tutor better understand the target audience of online courses. Topîrceanu and Grossec [9] allocated the following target groups of students according to their archetypes:

- 1) egocentric learners (interested in getting the skills they need on a regular basis);
- 2) short-term learners (focused on short quick courses);

- 3) comfort-oriented learners (focused not only on short but also easy-to-learn online courses);
- 4) interactive learners (focused on short courses and the possibility of active interaction in communities, and among these learners there are those who seek to obtain the certain competencies and those who use online courses for fun);
- 5) learners in order to distract themselves (the duration of the course is not important for them);
- 6) learners aimed at competencies searching (focused on the rapid acquisition of professional skills, but unable to complete the course);
- 7) curious initiators (learners who attend courses out of curiosity with a probability of completing them approximately 0.5);
- 8) limited learners focus on the shortcomings of online courses and are frustrated by the lack of personalized approach;
- 9) optimistic learners (learners that always set to success);
- 10) learners with the Pygmalion effect, justifying their personal failures on the course by the fact that most of the learners did not complete online courses.

2.2. Deep learning for EDM and LA

2.2.1. Sentiment analysis in education

The challenges of this area are closely related to identifying the mood of students in relation to this course, teacher, university, etc., based on the analysis of text content in the form of reviews, comments, posts on various media platforms, including social networks. Analysis of students' communities and content of students' profiles are also a very important challenge for aggressivity identifying [10].

Sentiment analysis and analysis of opinions allow us to identify the emotional component (boredom, aggression, fear, antipathy, frustration, inspiration, joy, lively interest, etc.) associated with learning, to understand the reasons for student behavior (loss of interest in the learning process, involvement in the educational process, etc.), to detect their interests and needs, as well as the expectations of students and their perception of reality. Another application of sentiment analysis in education is the development of systems for the qualitative assessment of the work of teachers and universities, teaching methods, and the quality of the educational process based on the analysis of feedback from students. Sutoyo et al. [11] noted the similarities between understanding behavior and strategies developing for customer and learner retention when using e-learning environments. Strategies for retaining learners are closely related to improving learning content, teaching styles, curriculum personalization, and individual learning trajectories development, development of tools for monitoring and estimation of teachers and students activity. For individual learning trajectories construction, it is important to understand students' characteristics of personality that can be extracted with the help of students' opinion mining from social media data [12].

The main stages of the study of text content in educational analytics include text understanding based on natural language processing (NLP) methods with subsequent vectorization (BoW, one hot embedding, CoVe embedding, word2vec, etc) and the use of machine learning methods (SVM, neural networks, Random Forest, etc) for classifying or clustering educational text data. Dsouza et al. [13] investigated the effectiveness of various machine learning methods for the

sentimental analysis of student feedback and note that the most accurate was Multinomial Naive Bayes Classifier versus SVM and Random Forest.

Of particular interest is the development of text mining together with deep learning for extraction regularities from students' feedback. [11] proposed the usage of convolutional neural networks with three types of layers for classification students' comments by sentiments. For feature extraction from texts, authors used a convolution layer with different kernels sizes, pooling layer, and fully connected layer with softmax activation function for result interpretation as sentiments class. [14] used sentiment analysis for teacher performance assessment based on LSTM architecture with embedding layer (word2vec and pre-trained model based on it), LSTM layer, Dense layer, and softmax activation function for final classification, and achieved about 90% accuracy.

The results of learning analytics can be used to develop intelligent systems for monitoring activity, involvement, and changes in the emotional states of students, for example, math anxiety [15]. Barron-Estrada et al. [16] investigated CNN together with LSTM and achieved 88.26% accuracy. Besides, the authors noted the effectiveness of CNN for secondary emotions detection.

2.2.2. Academic performance and students' dropout prediction

Academic performance research is crucial for universities, MOOCs, and students themselves because it detects the prestige of universities or MOOCs, forms their reputation, and influences on future careers of students. Besides, the development of learning analytics tools for detecting students from the category "at dropout risk" is very important for teachers/tutors/instructors and courses/curriculums creators. Mondal and Mukherjee [17] proposed the usage of Recurrent Neural Networks with only one hidden layer with 40 neurons and the ReLu activation function to analyze data about 480 students with 17 features to predict the students' performance and achieved an accuracy of around 85%. The same dataset xAPI-Edu-Data on Kaggle for analysis was used by Bendangnuksung and Prabu [18]. The authors considered deep neural network (DNN) for students' performance prediction based on data about 500 students described with the help of 16 features (gender, nationality, grades, topic, and different types of students and parents activities). They used two hidden layers of DNN with ReLu and softmax activation function for the layers respectively and achieved up to 84.3% accuracy. The students' grade prediction was investigated by Yousafzai et al. [19] based on the hybrid deep neural network such as network with bidirectional long short-term memory (BiLSTM) with four types of layers: embedding layer, dropout layer, bidirectional LSTM layer, attention layer with tanh and softmax activation functions, output layer with sigmoid activation function, and special procedure for choice of the significant feature that more influence on students' grade. Such architecture of BiLSTM with significant feature extraction allows achieving the accuracy of 90.16%.

The research of students' sequence of clicks and the sequence of video content watching usually is done based on RNN architecture. Jeon and Park investigated the influence of clicks during learning video watching on students' dropout. For a description of students' activity authors proposed to analyze the n-grams of clicks and video embedding together with the gated recurrent unit (GRU) and achieved 78.3% accuracy of students' dropout [20]. The effectiveness of deep neural network with 5 hidden layers and ReLu activation function after each hidden fully-connected layers and softmax activation function for output layer and achieved 90.2% accuracy

was demonstrated in [21]. Xiong et al. [22] used RNN-LSTM for prediction next behavior of learners based on their previous behavior such as the sequences of previous observable actions of learners in form of the responses, comments, posts, and achieved about 90% accuracy.

2.2.3. Recognition of students' facial expressions

The development of approaches to assessing the emotional state of students and teachers during classes can be used to improve the educational process, which is especially important for distance learning, the quality of interaction between students and teachers, the atmosphere within the student team, and identifying content that causes difficulties. D'Errico et al. [23] note the importance of recognizing the cognitive emotions of students for the formation of a positive perception of the educational process, creativity, and success of students.

The development of learning analytics tools based on the recognition of cognitive emotions of students contribute to the creation of systems for tracking student engagement, assessing the complexity of tasks and their impact on academic performance. Lee and Lee [24] considered a deep neural network with three convolutional layers, max-pooling between them, and finally, a fully connected layer with softmax activation function for students' expressions classifying according to difficulties level (easy, neutral, hard) during exams. Sharma and Mansotra [25] proposed the usage of a convolutional neural network for recognition of students' facial emotions such as sad, happy, neutral, angry, disgust, surprise, and fear for moods and psychological atmosphere detection.

Many researchers note the importance of studying not only the emotional state of students but also teachers, since the perception of a teacher as a person who confidently demonstrates his knowledge has a significant impact on the perception of the discipline and can create a stable positive or negative attitude towards the discipline throughout life. In particular, a deep neural network with a convolutional layer, pooling layer with dense blocks, and RELM classifier for final detection of instructors' facial expressions from one of 5 classes: awe, amusement, confidence, disappointment and neutral was described in [26].

3. Dataset and methodology

We investigate the data of 300 MOOCs on the studying of most popular programming languages for machine learning such as Python and R and scrapped 6000 reviews on them and extracted 1150 sentences that describe teacher, tutor, or instructor and 2365 sentences that describe the course or tutorial.

Consider the main steps of the research.

1. Clustering titles of MOOCs with the help of a bag of words for vectorization and simple cosine measure with the dot product of two vectors in numerator and product of two Euclidean norms of vectors in the denominator for detection of similarity of titles and, additionally, clustering kMeans method.
2. The sentiment analysis of 1150 sentences that contain the word "teacher" or its synonyms and 2365 sentences about course, tutorial or its synonyms was performed. We used model BERT for the sentiment analysis of each group. BERT model (Bidirectional Representation

for Transoformers) based on transfer learning and has a complex architecture with 12 or 24 encoder stack layers with 12 or 24 bidirectional heads realized self-attention and 768 or 1024 hidden units [27]. We used python-library PyTorch and encode method for text vectorization based on pre-train model BERT. The received tensor with five scores we transformed into convenient polarities from 1 to 5: the score 1 and 2 – for negative polarity, 3 – neutral, 4 and 5 – for positive polarity.

3. Frequency analysis of reviews based on polarities. We extracted the top of words with high frequency for each group of sentences with different polarities.

4. Results

According to the main steps of our methodology we received the following results.

4.1. The titles clustering of MOOCs

The results of clustering of 300 MOOCs from Udemy based on kMeans and cosine similarity measure are presented in figure 1.

Cluster	Size	Top of words
1	10	complete, bootcamp, flask
2	34	machine learning, A-Z, analytics, data science
3	8	django, web, backend, REST API
4	28	deep learning, neural networks, tensorflow, keras
5	42	complete, course, zero, hero, advanced
6	47	absolute, beginner, learn, introduction, goide
7	21	selenium, web, driver, scrapping
8	18	computer vision, openCV, deep learning, GANs
9	15	networks, engineering
10	14	time series, forecasting
11	22	regression, statistics, cluster, unsupervised ...
12	13	video games, GDScript
13	12	PostgreeSQL, SQL, database
14	16	natural language, processing, NLP

Figure 1: The results of 14 clusters detection based on the titles of MOOCs.

The top of words from 14 clusters allows listeners to understand the presence of MOOCs and the main directions of learning. Such words agree well with the extraction of key skills and basics that are learned during the online course and will be used to match popular job

vacancies in the labor market. The most presented courses on UdeMy are the courses aimed at beginner and advanced levels for machine learning, in particular, deep learning, web scrapping, forecasting, computer vision, natural language processing.

4.2. Sentiment analysis of reviews of MOOCs based on BERT

We investigated three aspects of MOOCs: relationship to teacher and course, and description of issues during the learning and used python-library transformers and pre-trained text pre-processing for text vectorization and sentiments of texts detection. The results of sentiment analysis with BERT deep model are presented at figure 2.

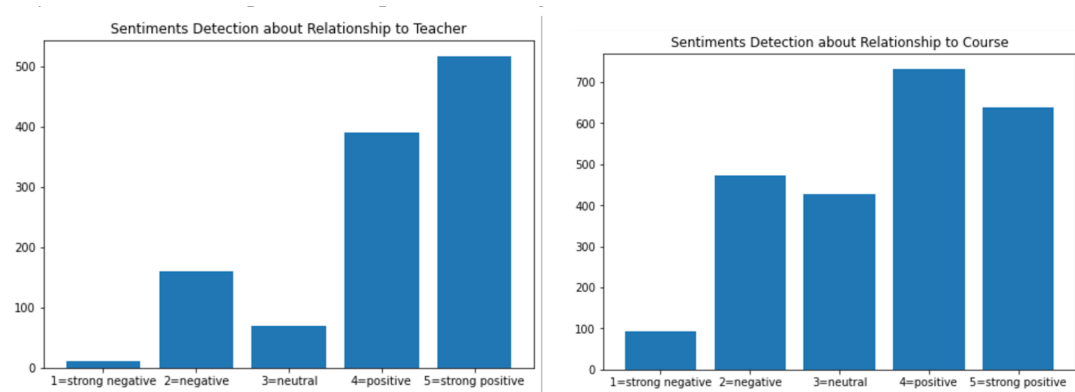


Figure 2: The Sentiments Detection about Relationship to Teacher (right) and Course (left) based on BERT.

The distribution of opinions by groups, taking into account the polarity, shows that students of MOOCs in programming are more demanding on the course than on the teacher, but in general, they show a positive attitude.

4.3. Frequency analysis of reviews based on polarities and aspects

Let's create clouds of words based on frequency analysis and wordcloud python-library, taking into account sentiments and the aspects under study. The results of a frequency analysis are shown in table 1.

Frequency analysis can be used as an additional tool for understanding the causes of students' issues, for example, we extracted such troubles as installation of libraries, settings, development of apps with GUI, hard understanding of two programming languages at the same time, etc. for programming MOOCs. We have highlighted words that well describe the positive and negative emotions of MOOCs listeners. The most frequently positive words that MOOCs listeners were used for positive emotions description about the relationship to instructors were knowledgeable, clear, talented, great, patient, etc., and for the description of negative emotions the words boring, bad, hard, unprofessional, etc. were used. The positive emotions to course learners of MOOCs expressed in words great, good, complete, amazing, friendly, etc., and for negative emotion description they used such words as difficult, bad, confused, expected deep, uninformative, lacked, etc.

Table 1
The cloud of words with polarities and aspects

Aspects	Positive polarity	Negative polarity
teacher		
course		
issue	-	

We demonstrate that even the usage of the simple tool developed based on python natural language processing libraries gives an understanding of the advantages and disadvantages of MOOCs that will be used by developers, experts, and instructors for better quality MOOCs creation that oriented on preferences of each listener of MOOC based on listener feedback analytics.

5. Conclusion

We demonstrated that text mining approaches based on the deep BERT model and clustering can be considered as instruments for learning analytics. Such instruments are aimed at the creation of personalized MOOCs and their contents and understanding the issues, preferences, and needs of students. The feedback from students in form of comments, reviews, and posts can be used for assessing the quality of education and detecting the direction for its improvement. We demonstrated that learners of MOOCs are more demanding to the course and its content, and their opinions, in general, have a positive sentiment.

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Web application for facial wrinkle recognition

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Abstract

Facial recognition technology is named one of the main trends of recent years. It's wide range of applications, such as access control, biometrics, video surveillance and many other interactive human-machine systems. Facial landmarks can be described as key characteristics of the human face. Commonly found landmarks are, for example, eyes, nose or mouth corners. Analyzing these key points is useful for a variety of computer vision use cases, including biometrics, face tracking, or emotion detection. Different methods produce different facial landmarks. Some methods use only basic facial landmarks, while others bring out more detail. We use 68 facial markup, which is a common format for many datasets. Cloud computing creates all the necessary conditions for the successful implementation of even the most complex tasks. We created a web application using the Django framework, Python language, OpenCv and Dlib libraries to recognize faces in the image. The purpose of our work is to create a software system for face recognition in the photo and identify wrinkles on the face. The algorithm for determining the presence and location of various types of wrinkles and determining their geometric determination on the face is programmed.

Keywords

pattern recognition, wrinkles, facial landmarks, the Viola-Jones algorithm, the Haar-Like features, OpenCV, DLib, image filters

1. Introduction

It's no secret that today cloud computing has become available to everyone. They combine supercomputer computing power with the accessibility and ease of managing software complexes, and the wide possibilities of modern programming languages and stable software complexes create all the necessary conditions for the successful implementation of even the most complex tasks.

For 50 last years the technology of computer vision evolved from the decision of simple tasks of recognizing symbols to creation of the augmented reality [1]. The most significant examples of using computer vision systems are: 3D-cameras and 3D-sensors; remote control devices; facilities of treatment and recognition of visual patterns and symbol information; deep learning on terminal devices and in the cloud; SLAM (Simultaneous Localization and Mapping)

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in cars, robots, drones; augmented /virtual reality and perception calculation; the systems for monitoring and security; systems of medical diagnostics and biometrical control.

Face Detection Technology is one of the main trends of recent years. The most ambitious practical application of face recognition with the help of a computer is the creation of anthropomorphic robots that can read the emotional state of the interlocutor.

Algorithms for recognizing a human face are different in complexity. The simplest systems that can establish a person's personality on a photo are looking at the image of the nodal points that form the basic features of the face, and then measure the distances between them. The main parameters are the distance between the eyes, the width of the nose, the depth of the eye, the shape of the cheek-bones, the length of the jaw line. Key indicators in digital terms are a unique code or "face print" that represents a person in the database. For example, to identify a suspect's person, his photo is uploaded to the system and compared to the database.

In modern recognition systems, complex biometric algorithms that analyze unique skin texture, iris, and even vein patterns are used. The process of surface texture analysis works by its very nature similar to facial recognition. The image of a person (namely, her face) is divided into smaller blocks, and algorithms distinguish the fine lines, wrinkles, pores, birthmarks and even the structure of the skin on the texture and iris of the eye – all this appears in the form of a mathematical model. Thanks to this system it is easy to determine the differences even between identical twins.

So, identifying a person in a photo using a computer means solving two different tasks: the first one – to find a face in a photo, the second – to find in the image those features that distinguish a particular person from other people from the database. Face detection algorithms contain at the input of the image, at the output - the coordinates of the found rectangles of the person in the coordinate system of the image. This approach is used in the analysis of photo and video content.

Attempts to teach a computer to find faces in photos began in the early 1970's. But the most important step forward was the creation in 2001 by Viola and Jones [2] of the cascade boost method, which was called the Viola-Jones object detection. Historically, algorithms that work only with the intensity of the image (for example, the value of RGB in each pixel), have a high computational complexity. Papageorgiou et al. [3] considered a set of features based on the Haar wavelets. Viola and Jones [2, 4] adapted this idea and developed the hallmarks of Haar.

Biometric features of a person are unique, therefore identification of an individual is an interesting and difficult task. Face Detection is one of the methods of identifying a person. But over time, the process of aging and changing facial features requires the updating of existing databases, which is a cumbersome procedure. To solve this problem, it is necessary to apply a method that identifies a person, regardless of the effects on the face of aging processes.

In our time, it is necessary to establish personal identification systems, in particular, in educational institutions, in order to protect the lives and health of people, in order to prevent the loss or damage to property in the form of crime agents and intruders. It is known that the cost of personal identification systems from leading soft-ware developers is significant. In addition, technical support is also quite expensive for budget organizations.

The purpose of our work is to create a software system for face recognition in the photo and identify wrinkles on the face.

2. Related work

Facial wrinkles and emotions are often closely related. Researchers claim that people can express 7 basic emotions: anger, joy, surprise, fear, sadness, disgust, and neutrality. But there are also mixed emotions, which are composed of different combinations of the main emotions. Emotions are short-term manifestations of feelings. A person's face has a great ability to show different emotional shades. During the onset of these feelings, the muscles on the face move and noticeable changes in the image occur, for example, wrinkles, a change in the position of the shapes of the eyebrows, eyes, and other parts of the face.

There are three types of facial signals: static (skin tone), long lasting (wrinkles), and instant (raising the eyebrows). The researchers conditionally divided the face into three parts, which have the ability to move independently of other areas of the face (eyebrows; eyes; lower part of the face), and with a combination of the expression of these areas, a mask of each emotion is compiled. Automatic identification of images using a computer is one of the most important directions in the development of artificial intelligence technologies, which allows you to give a key to understanding the peculiarities of the work of human intelligence. Research into methods of automatic emotion recognition allows the computer to assess a person's mood. Facial expression analysis is a challenging area of research in the field of pattern recognition, mainly due to the difficulty in obtaining accurate facial features and facial expressions.

Emotion recognition methods are divided into four large classes: holistic, local recognition, dynamic, geometric. Holistic recognition methods analyze emotions in the face as a whole to find differences between images: Independent Component Analysis (ICA), Principal Component Analysis (PCA), Fisher's Linear Discriminants, Hidden Markov Models, cluster analysis. Local recognition methods are based on the analysis of individual parts of the face: PCA, Neural Networks, Facial Actions Code System (FACS). Dynamic methods take as a basis the changes in the location of parts of the face, while changing various expressions: Point Distribution Model (PDM), Active Shape Model (ASM). Geometric methods take as a basis the shape and position of various parts of a person's face to extract characteristic vectors that convey geometric features of the face. However, the above methods do not always allow us to recognize the user's emotions with a sufficient level of accuracy. Therefore, in this work, the task was set to develop a new combined method for recognizing emotions and detecting wrinkles.

Kazemi and Sullivan [5], Dollár et al. [6], Cao et al. [7] show that the task of determining the face detection on the image can be solved by means of a cascade of regression functions. In the paper of Kazemi and Sullivan [5], which is based on a large number of studies, the methodology for using the regression trees is described to determine the location of key points on the face.

Wrinkles on the face are important signs of aging of the human skin. Wrinkles are three-dimensional imperfections of the skin and are manifested in the form of thin inhomogeneities or cracks in the skin texture. But wrinkles on the face can be masked by the conditions of illumination / reception on 2D images due to the specific nature of the surface texture of the skin and its properties to reflect light. Existing approaches to the study of skin aging on the basis of images are based on the analysis of wrinkles as a texture, rather than as curvilinear cracks.

Jana and Basu [8] propose a methodology for evaluating the real age of a person by analyzing the areas of facial wrinkles. Depending on the location of the wrinkles, an algorithm for c-

average clustering was applied to each facial image. Then, the estimated age was determined based on the analysis of values and average age calculated for each cluster.

Batool and Chellappa [9], Mawale and Chaugule [10] proposed an effective algorithm based on Gabor filters and the morphology of the image to improve the results of locating wrinkles on the face. The authors carried out numerous experiments on sets of different images and the results suggest that the proposed algorithm provides visually better results than other existing systems.

Analyzing the results of many studies, one can conclude that it is convenient to determine wrinkles using filters. The small wrinkles in the corners of the mouth are calculated by the degree of scattering of the brightness of the pixels: the Gauss smoothing filter is applied, and then the received image is compared to the output. If wrinkles were present, they would disappear during smoothing and the difference between the images would be larger. If there was no wrinkle, smooth skin will remain smooth while smoothing. For well-known wrinkles that are quite pronounced (for example, wrinkles on the forehead or on the wings of the nose), the Gabor filter is better suited. This filter is a two-dimensional sinusoid, which is smoothed by a Gaussian window, and very “reacts” to the inherent great wrinkles of sharp changes in brightness in a certain direction.

3. The choice of programming tools

3.1. Select a programming language Python

The reasons to choose Python are: cross-platform; language supports the main programming paradigms used in solving problems; has a large set of useful libraries [11]. In addition, as a complement to Python, there are several popular and feature rich packages that extend the functional language for the full control of clouds. The cloud system itself looks like this: the programmer runs the program code via Django [12] (as in our application) or another framework that is stored along with the web application itself on the server of the cloud service provider, such as Google AppEngine. The control of Django and AppEngine can be done using an accessible interface, but the application itself is configured using Python.

3.2. OpenCV library

The implementation of computer vision can be done using the OpenCV library (Open Source Computer Vision Library) [13, 14]. The library provides tools for processing and analyzing the contents of images, including the identification of objects in photographs (for example, persons and figures of people, text, etc.), object tracking, image transformation, application of machine learning methods, and the discovery of common elements on various images. In this paper, the following functions of the described library were used: the Viola-Jones approach to face detection [2, 4] and functions for working with images, their filtration and transformation.

Recently, the Viola-Jones method, which has long been the main method for detecting objects in an image, has given way to new and improved algorithms. Nevertheless, the relevance of this method remains at the present time.

Of course, the Haar-based cascade classifier (Viola-Jones method) is inferior in performance to the LBP cascade classifier. It is less accurate than a detector based on HOG functions, and even more so a detector based on convolutional neural networks. And yet it has a certain niche when an accuracy higher than that of the LBP cascade is required, but the speed of operation of more accurate detectors is not high enough. The decisive factor for our choice of method was the fact that there are a large number of already trained cascades for the Haar cascade classifier, including in the OpenCV library. Therefore, the speed of this algorithm is very important. This prompted us to choose this particular algorithm as the basis for detecting a face in an image.

The Viola-Jones algorithm (figure 1) can be divided into four main stages:

1. Translate the image into an integral representation.
2. Use the Haar attributes as descriptors.
3. Use the AdaBoost as the classifier.
4. Use the cascade from the classifiers.

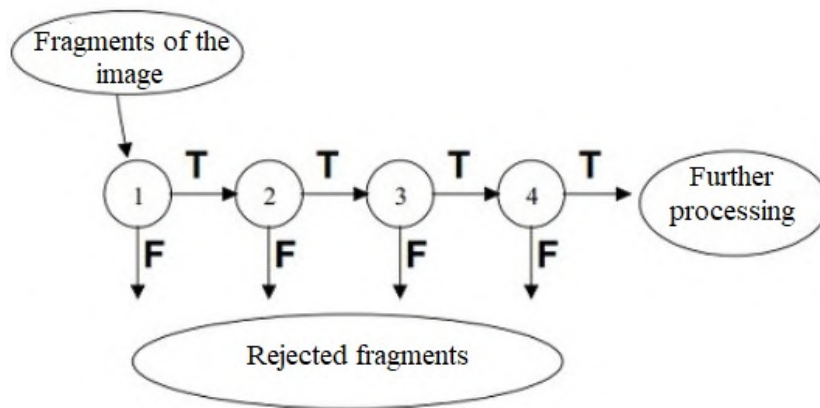


Figure 1: The scheme of the Viola-Jones algorithm.

Let's consider each of these stages in more detail.

In order to reduce the number of operations for computing the Haar-like features, the original image is translated into its integral representation. This view allows you to quickly calculate the total brightness of the rectangle in the image regardless of the size of this rectangle. Integral representation images is a matrix whose size is equal to the original image, and the value of its elements is calculated in the following way:

$$L(x, y) = \sum_{i=0, j=0}^{i \leq x, j \leq y} I(i, j), \quad (1)$$

where $I(i, j)$ is the brightness of the pixel of the original image. Each element of the matrix $L(x, y)$ is the sum of pixels in a rectangle $(0, 0) (0, x) (x, y) (0, y)$.

The calculation of such a matrix takes linear time, which is proportional to the number of pixels in a given image. Therefore, the integral representation is calculated completely in one pass.

Let us demonstrate visually the calculation of the area of a rectangle in an integral image using the following example (figure 2).

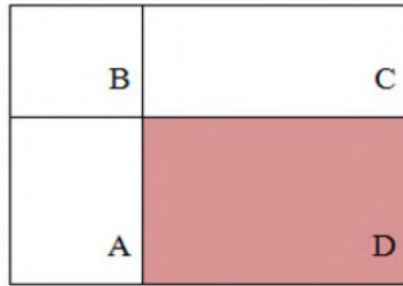


Figure 2: Finding the area of the rectangle $ABCD$ in the integral representation of the image.

Suppose that in the integral image you need to find the area of the rectangle with vertices $ABCD$. This calculation can be reduced to just three operations:

$$S(ABCD) = L(D) - L(A) - L(C) + L(B) \quad (2)$$

In the classical Viola-Jones method, the Haar-like features are used, which are presented in figure 3.

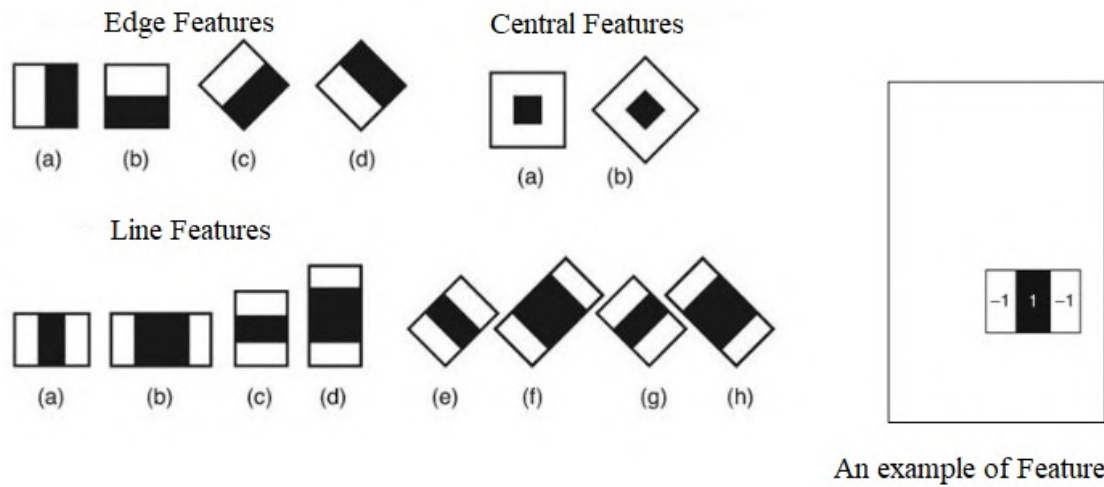


Figure 3: The Haar-like features.

These features are calculated in the following way:

$$F = X - Y \quad (3)$$

where X is the sum of the brightness values of the image pixels covered by the white area, and Y is the black area. Actually, for this purpose the integral representation of the image,

considered above, is used.

The number of different feature variations, calculated for a 24x24 window, is approximately 160,000+, and very many of them are useless for detecting an object. The AdaBoost algorithm is used to select useful features.

Boosting is a complex of methods that contributes to improving the accuracy of analytical models. A model is called “strong” if it admits a small number of classification errors. The “weak” model, on the contrary, makes a large number of errors and does not allow for the reliable separation of classes. Therefore, boosting is a procedure that, as a result of the consistent construction of the composition of machine learning algorithms, seeks to eliminate the shortcomings of all previous algorithms in each new algorithm

The most advanced algorithm for boosting is AdaBoost (Adaptive Boosting), proposed in 1999 by Freund and Schapire [15]. AdaBoost adaptive algorithm because every next the classifier is based on the objects that were incorrectly classified by the past. This algorithm is sensitive to noise in data and outliers, and also less susceptible to retraining

A cascade of “strong” classifiers is a kind of decision tree in which each node is built in such a way as to recognize almost all objects of interest in the image and reject areas in which these objects do not exist. In addition, the nodes of this decision tree are arranged in such a way that the closer the node is to the root of the tree, the smaller the number of descriptors it contains, therefore, it requires less time to make a decision.

This cascade model of classifiers is very well suited for processing images that contain relatively small detected objects. In this case, the classifier constructed in this way can quickly decide that this area does not contain an object and proceed to the next one.

So, summing up the above, the Viola-Jones algorithm involves the sequential execution of four steps:

1. Remove the color and convert the image to the matrix of brightness.
2. Impose one of the square black and white masks on the resulting matrix (the Haar-like features). Inspect the entire image with the mask by changing the position and size.
3. Add the numerical values of the brightness of those matrix cells that fall under the white part of the mask and subtract the values that fall under the black part. If at least in one case the difference between white and black areas is above a certain threshold, take this area of the image for further work, and if not – forget about it, – there is no face here.
4. Repeat from step 2 with a new mask – but only in the area of the image that passed the first exam.

3.3. The method based on localization of the facial landmarks

DLib contains methods of machine learning and various additional tools. Also, this library contains a ready-to-learn model, in this work it is used to find key points on the person’s face. Our work uses a face detector from the Dlib library [16]. The detector is used to estimate the location of 68 (x, y) coordinates that are displayed on the face. Indices 68 coordinates are indicated in figure 4. These points are part of the data set on which the face detector predictor was taught.

Finding the key points of the face in the image consists of two stages:

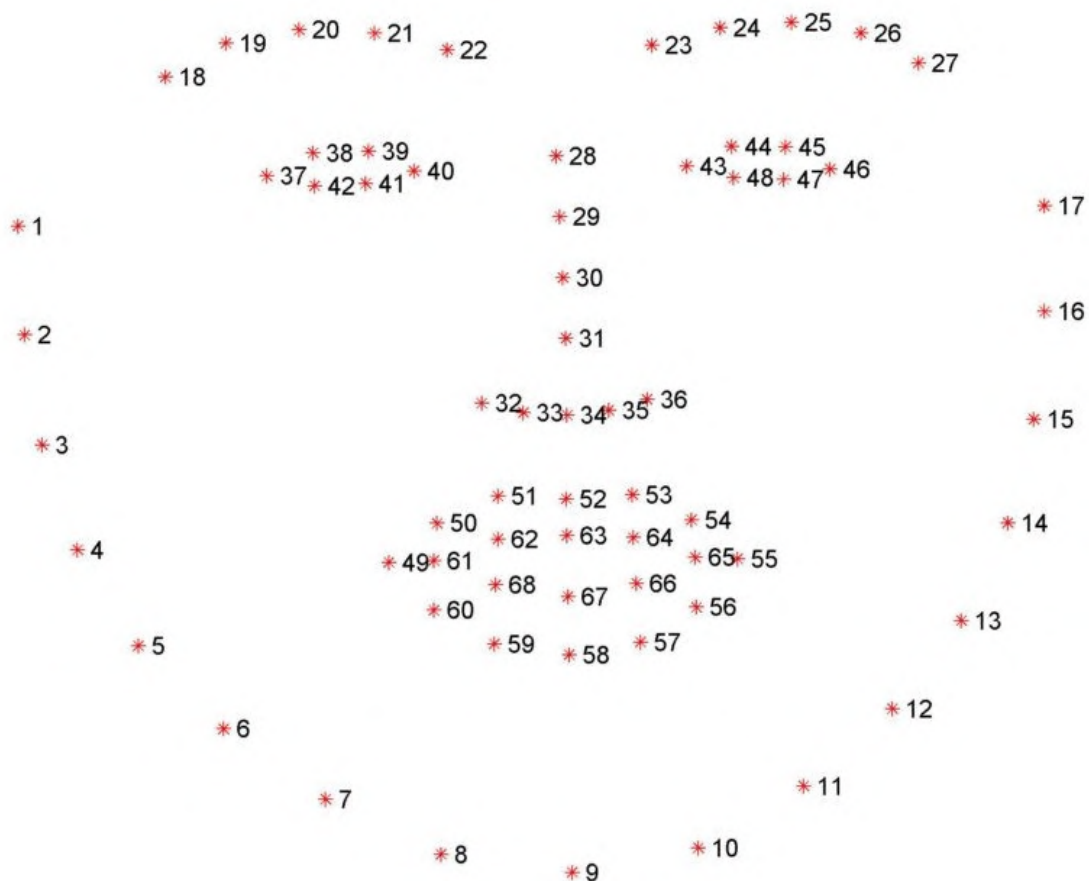


Figure 4: The facial landmarks.

1. First you need to localize the face in the image. This can be done using different methods, it is enough to use an approach that creates a limiting frame around the face.
2. Apply the shape predictor, in particular, the key point detector to get (x, y) coordinates of the faces.

3.4. Algorithm for recognizing wrinkles on the face, depending on their type

Anatomical guidelines were used to implement the wrinkle detection algorithm on the face image to evaluate different types of wrinkles (figure 5).

The texture information method is based on wrinkles, shadows, and other texture elements on the face. Various methods and ways of image filtering were used to calculate texture features on facial areas. To detect fine wrinkles (for example, the forehead area), we used the calculation of a measure of the root mean square dispersion of pixel values over a given area. Two-dimensional Gabor filters were used to detect large wrinkles (for example, nasolabial folds). The two-dimensional Gabor transforms are a harmonic function smoothed by a Gaussian window.

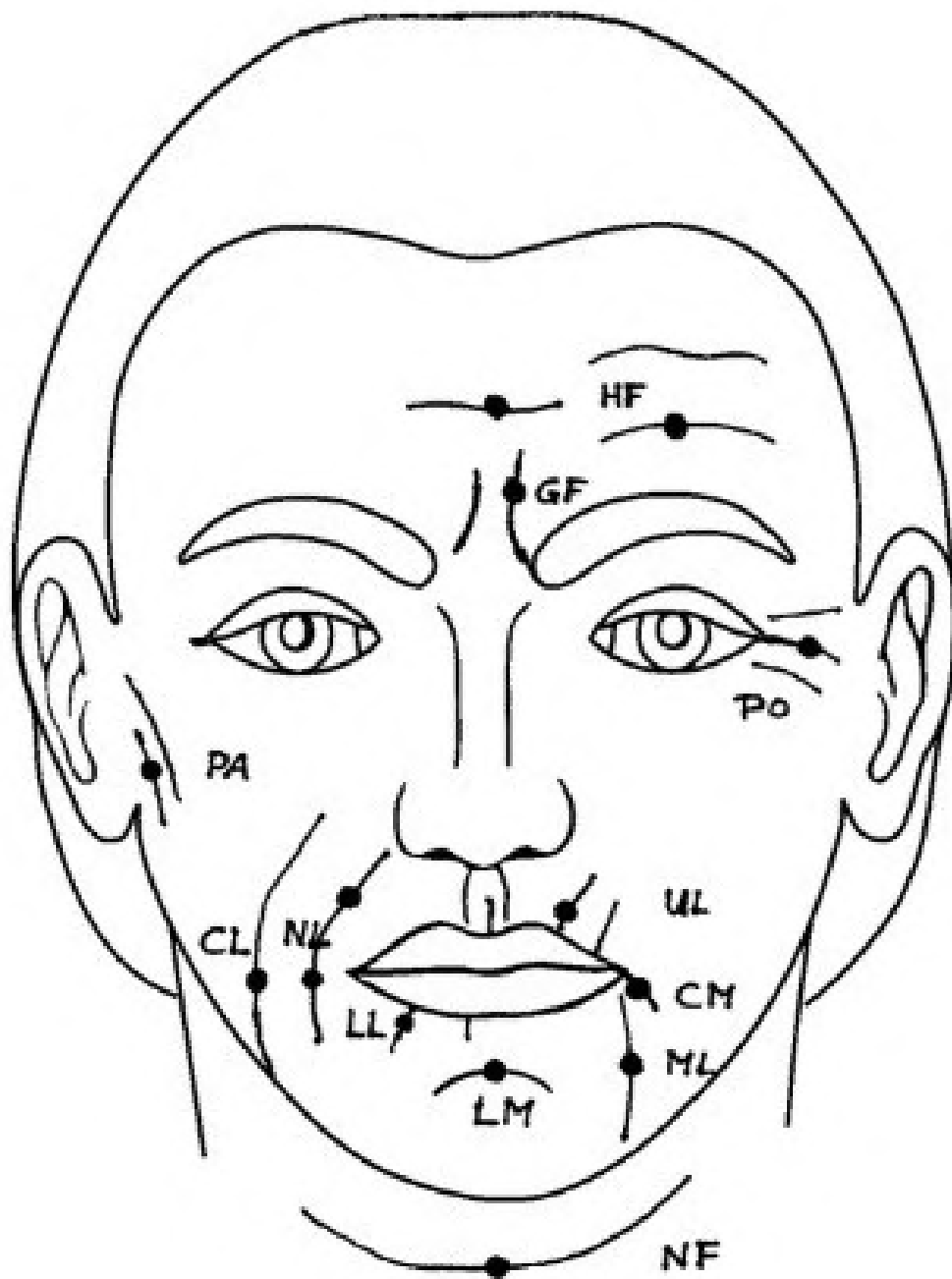


Figure 5: Anatomic reference points for assessment and measurement of wrinkle depth. HF, horizontal forehead lines; GF, glabellar frown lines; PO, periorbital lines; PA, preauricular lines; CL, cheek lines; NL, nasolabial folds; UL, upper radial lip lines; LL, lower radial lip lines; CM, corner of the mouth lines; ML, marionette lines; LM, labiomental crease; NF, horizontal neck folds [17]

Filter and spatial frequencies are calculated depending on the orientation of the wrinkle and its size. According to the control points, the faces are divided into parts where wrinkles are to be found. The filtered area applies to the area under consideration, depending on the location of the area on the face. At the next stage, the contours are determined and their geometric parameters are analyzed. Wrinkle is considered valid (detected) if the contour parameters meet the requirements for each type of wrinkles. For symmetrical wrinkles, an additional double-sided check is used. The results are shown in figure 6.

To train the model, we use the standard Dlib dataset – iBug 300W, which consists of over 6,000 images of different dimensions. The official Dlib dataset consists of a combination of four main datasets: afw, helen, ibug, and lfpw. It is possible to select custom images from social networks and news. The total dataset for training the model was 20,000 images.

Django accepts incoming messages for a request for face recognition and its characteristics in the image. Django sends an image for recognition to one of 20 streams (adjustable in the settings). If there are no free engine threads, then the incoming request is put on hold until the free thread is released or the client is disconnected by timeout. The larger the image, the longer it takes to process, so a normalize function is used to “normalize” the image to the desired size. Models work in shades of gray. The Dlib library processes the file using a trained model. After processing, an array with key points is returned. The wrinkle recognition module geometrically detects the location of the wrinkles and stores an array of coordinates for the lines on the recognized face. The FaceRecognizing class is the entry point to recognition. As soon as it is created, the class initiates a pool of separate recognition threads. A stream is captured for recognition by calling the getFacetRecognizer or getProfileRecognizer methods, which will return the recognition object. Methods can take two parameters: selfRelease = True, callBack = None. If the selfRelease = True, then upon completion of recognition the object will return itself to the free thread pool; otherwise, the parent script must do this by calling the releaseFacetRecognizer or releaseProfileRecognizer method. Through the callBack parameter, you can pass a callback function that will be called at the end of recognition.

Link to the archive of materials for this application, located in the repository on GitHub [18]. Fragment of the module code for filling an array of points of different areas of the face (for example, the bridge of the nose) to find wrinkles:

```
#PARRIER WRINKLES
#left nose bridge wrinkle
delta = int(
round((dict(res['left_eye'])[43][0] - dict(res['nose'])[28][0]) / 4, 0))
x1 = dict(res['right_eye'])[40][0]
x2 = dict(res['nose'])[28][0] - delta
# y1 - top point of the eyebrow minus the height of the eye
y1 = dict(res['right_eyebrow'])[20][1] -
(dict(res['right_eye'])[42][1] - dict(res['right_eye'])[38][1])
y2 = dict(res['right_eye'])[40][1]
roi = self.getRectFromGrayImage(x1, x2, y1, y2)
res['nosebridgeWrinkleLeft'] = self.__getNosebridgeWrinkle__('left',
roi, dict(res['nose'])[28][0], dict(res['nose'])[28][1], x1, y1,
```

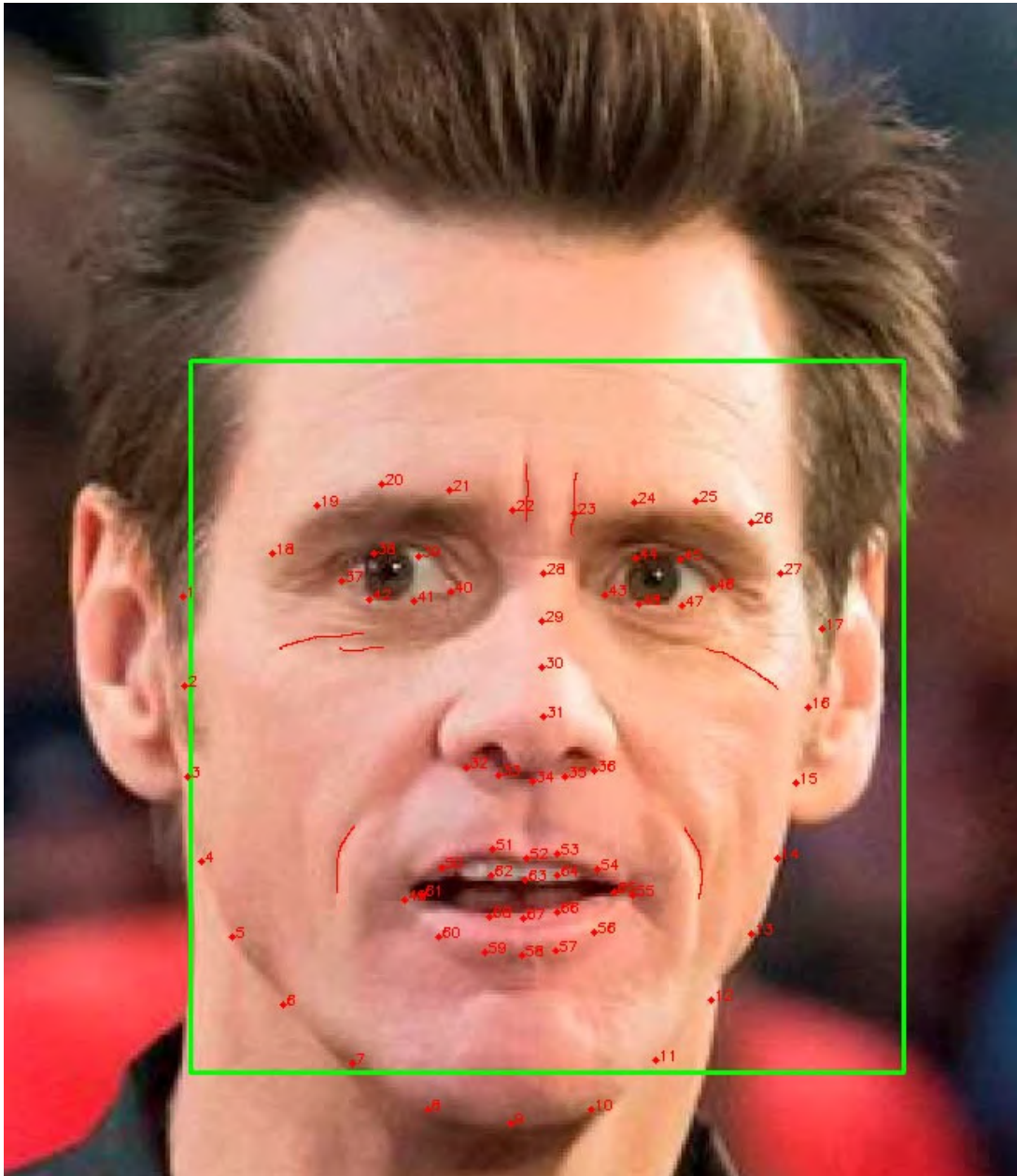


Figure 6: The result of the algorithm for finding wrinkles on the lines of CL-cheeks and CL-nasolabial folds.

```
dict(res['nose'])[28][0], dict(res['nose'])[28][1],
cannyParam1=const.config.getint('Wrinkle.NosebridgeWrinkle',
'cannyparam1', fallback=const.NOSEBRIDGE_WRINKLE_CANNYPARAM_1),
cannyParam2=const.config.getint('Wrinkle.NosebridgeWrinkle',
'cannyparam2', fallback=const.NOSEBRIDGE_WRINKLE_CANNYPARAM_2))
```

4. Conclusions

Consequently, in this paper, we have shown that different types of wrinkles on the face image are conveniently recognized by using special filters. For example, to detect small wrinkles using the Gaussian filter. For strong wrinkles it is better to use a Gabor filter. In our work an algorithm for determining the presence and location of various types of wrinkles and determining their geometric location on the face is implemented. We created a web application using the Django framework, Python language, OpenCv and Dlib libraries to recognize faces in the image. Using the program you can get geometric parameters of wrinkles. This development can be used to develop a face-to-face identification system for research in the field of cosmetology as the basis for creating a system for recognizing emotions.

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