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IMPROVING THE EFFICIENCY OF BANKING OPERATIONS THROUGH AUTOMATION: A MODELING APPROACH

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Abstract. Automation of business processes has emerged as a key factor in the ongoing development of the banking industry. This study is dedicated to a comprehensive analysis of the impact of automation on the efficiency and competitiveness of banks in today's dynamic financial environment. The paper explores the main trends in the automation of business processes within the banking sector and provides an in-depth analysis of successful case studies that highlight the effective introduction of automated systems. Special emphasis is placed on how automation enhances the quality of customer service, leads to a significant reduction in operating costs, and improves the efficiency of decision-making processes. Furthermore, the study evaluates the potential risks associated with automation and offers strategic recommendations aimed at minimizing these risks. The findings presented in this study are invaluable for bank managers, software developers, and financial market regulators, guiding them to make informed decisions regarding business process automation in their organizations.

Keywords: automation of business processes, banking industry, customer service quality, modeling approach, reduced operating costs.

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АВТОМАТТАНДЫРУ АРҚЫЛЫ БАНК ОПЕРАЦИЯЛАРЫНЫҢ ТИІМДІЛІГІН АРТТЫРУ: МОДЕЛЬДЕУ ТӘСІЛІ

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Аннотация. Бизнес-процестерді автоматтандыру банк саласының үздіксіз дамуының негізгі факторына айналды. Бұл зерттеу автоматтандырудың қазіргі динамикалық қаржылық ортадағы банктердің тиімділігі мен бәсекеге қабілеттілігіне әсерін жан-жақты талдауға арналған. Мақалада банк секторындағы бизнес-процестерді автоматтандырудың негізгі тенденциялары зерттеледі және автоматтандырылған жүйелерді тиімді енгізуді көрсететін сәтті практикалық мысалдарға терең талдау жасалады. Автоматтандырудың тұтынушыларға қызмет көрсету сапасын қалай жақсартатынына, операциялық шығындардың айтарлықтай төмендеуіне және шешім қабылдау процестерінің тиімділігін арттыруға ерекше назар аударылады. Сонымен қатар, зерттеу автоматтандыруға байланысты ықтимал тәуекелдерді бағалайды және осы тәуекелдерді азайтуға бағытталған стратегиялық нұсқауларды ұсынады. Осы зерттеуде ұсынылған нәтижелер банк менеджерлері, бағдарламалық жасақтама жасаушылар және қаржы нарығын реттеушілер үшін баға жетпес маңызға ие, бұл оларға өз ұйымдарындағы бизнес-процестерді автоматтандыруға қатысты негізделген шешімдер қабылдауға көмектеседі.

Түйін сөздер: бизнес-процестерді автоматтандыру, банк саласы, клиенттерге қызмет көрсету сапасы, операциялық шығындарды азайту, модельдеу тәсілі

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ БАНКОВСКИХ ОПЕРАЦИЙ ЗА СЧЕТ АВТОМАТИЗАЦИИ: ПОДХОД К МОДЕЛИРОВАНИЮ

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Аннотация. Автоматизация бизнес-процессов стала ключевым фактором в непрерывном развитии банковской отрасли. Данное исследование посвящено всестороннему анализу влияния автоматизации на эффективность и конкурентоспособность банков в современной динамичной финансовой среде. В статье исследуются основные тенденции в автоматизации бизнес-процессов в банковском секторе и приводится углубленный анализ успешных практических примеров, свидетельствующих об эффективном внедрении автоматизированных систем. Особое внимание уделяется тому, как автоматизация повышает качество обслуживания клиентов, приводит к значительному снижению операционных расходов и повышает эффективность процессов принятия решений. Кроме того, в исследовании оцениваются потенциальные риски, связанные с автоматизацией, и предлагаются стратегические рекомендации, направленные на минимизацию этих рисков. Результаты, представленные в этом исследовании, имеют неоценимое значение для банковских менеджеров, разработчиков программного обеспечения и регуляторов финансового рынка, помогая им принимать обоснованные решения относительно автоматизации бизнес-процессов в своих организациях.

Ключевые слова: автоматизация бизнес-процессов, банковская отрасль, качество обслуживания клиентов, снижение операционных затрат, подход к моделированию

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Introduction

A business process in banking is an ordered set of actions that are performed in order to achieve a specific task or solve a specific problem. This process begins with the identification of the client's needs and continues until the provision of the appropriate financial product or service. It is difficult to overestimate the importance of formalization and regulation of business processes in the banking sector, since they directly affect the operational and strategic effectiveness of the bank, which, in turn, affects the profitability indicators and ratings of the bank.

The current year 2024 has witnessed a number of significant innovations in the banking sector.The popularity of cryptocurrencies and blockchain technologies continues to grow. These innovations promise a revolution in the field of interbank settlements, allowing instant payments on a global level without intermediaries. Digital platforms are becoming the norm in commercial banking. From mobile apps to online platforms, customers expect access to their finances 24/7. This trend also implies the need to integrate different service channels to provide a unified and consistent experience for customers, regardless of whether they use a mobile application, website or visit a bank branch.

The aim of the study is explore how automation can speed up routine tasks, reduce errors, and increase the overall productivity of the finance department and evaluate how automation contributes to improving the accuracy of financial data and reporting, minimizing the risk of the human factor.

Research objectives:

- Identify the main financial processes to be automated (accounting, payroll, cash flow management, etc.);
- Analyze the current productivity, accuracy and cost of manual operations;
- Identify areas where automation can bring the greatest benefit.

The novelty of the research lies in the fact that it presents a comprehensive analysis of the automation of business processes in the financial industry, considering modern technological solutions, market requirements and the needs of companies.

Automation of banking processes is a crucial step in improving the efficiency of financial institutions. One of the striking examples of successful digitalization of credit transactions is demonstrated by Kaspi Bank, the largest bank in Kazakhstan. Prior to the introduction of automated solutions, the credit process was characterized by a lengthy processing of applications, a high workload on staff and limited transparency for customers. On average, it took three to five business days to process a loan application, which reduced the speed of service and increased transaction costs. Customers were forced to personally visit bank branches to submit documents, and their creditworthiness was checked manually, which often led to errors and delays.

To solve these problems, Kaspi Bank has implemented comprehensive automation of the loan processing process, including digital processing of applications through a mobile application and a web platform. Automated algorithms have been integrated with databases of credit bureaus and state registers for instant verification of customers' credit history. The key innovation was the use of scoring models based on machine learning, which made it possible to speed up loan decision-making and significantly reduce the risks of non-repayment. Customers were able to track the status of their applications in real time through a mobile application, which increased the transparency of the process.

The automation results were impressive: the time for reviewing loan applications was reduced to one minute, and about 80% of all applications are now processed without human intervention. This has led to an increase in the number of customers and an expansion of the bank's geographical coverage. As of 2023, the number of active users of the application Kaspi.kz exceeded thirteen million. At the same time, operating costs have decreased due to

optimization of labor costs and increased efficiency of risk management.

Literature Review

The automation of business processes within financial companies has emerged as a critical area of focus, driven by the need for efficiency, cost reduction, and improved service delivery. The literature reveals a multifaceted approach to understanding how automation can be effectively integrated into financial services, highlighting both the benefits and challenges associated with its implementation.

Business Process Management (BPM) is a foundational concept in the automation of business processes, particularly in the financial sector. Duran emphasizes that BPM technologies can significantly enhance the efficiency and profitability of financial institutions by streamlining operations and reducing redundancies (Duran, 2012). This is corroborated by Nkurunziza, who notes that effective management of business processes through knowledge creation can lead to improved customer value and operational efficiency (Nkurunziza, 2023). The integration of BPM within financial services not only facilitates the automation of routine tasks but also supports strategic decision-making, enabling organizations to adapt to changing market conditions and customer needs.

Moreover, the role of information systems in automating business processes cannot be overstated. Mziray discusses how information systems facilitate the integration of disparate systems, allowing for the automation of various functions across departments (Mziray, 2023). This integration is crucial for financial institutions, which often deal with complex workflows that span multiple areas such as accounting, compliance, and customer service. The ability to automate these processes leads to reduced operational costs and enhanced service delivery, as employees can focus on higher-value tasks rather than repetitive manual processes.

The literature also addresses the challenges associated with implementing automation in financial services. For instance, while automation can lead to significant efficiency gains, it also requires careful management of change within organizations. As highlighted by Kvalnes, the ethical implications of automation, including potential job displacement and the need for employee retraining, must be considered (Kvalnes, 2019). This is particularly relevant in the financial sector, where the workforce is often required to adapt to new technologies and processes.

The article by Sembina et al. (2022) presents a comprehensive model for incident management, emphasizing the critical role of enhancing the efficiency of information technology infrastructures within enterprises. The authors argue that the increasing volume of technical support requests can lead to significant delays in incident resolution, which in turn results in system downtimes and financial losses for businesses. By developing a reference incident management model, the study aims to address these challenges and improve the overall effectiveness of incident management systems in organizations (Sembina et.al., 2022).

The literature on Business Process Automation (BPA) in the financial industry provides a comprehensive analysis of its potential and challenges. Markovitch and Willmott emphasize the importance of digitizing business processes to improve efficiency, though they note that high initial investment costs remain a significant barrier (Markovitch & Willmott, 2014). Kokina and Blanchette explore BPA's role in financial reporting, demonstrating its capacity to enhance accuracy and transparency (Kokina & Blanchette, 2019). Fernandez and Aman further highlight BPA's global impact, showcasing its ability to reduce operational costs and improve customer service delivery in financial services (Fernandez & Aman, 2018).

Chui et al. identify key areas where automation enhances productivity, particularly

in repetitive operational tasks (Chui et al., 2015). Extending this view, Milani et al. integrate blockchain technology into BPA to enhance transparency and reliability (Milani et al., 2016). Romao et al. present a banking industry case study that demonstrates BPA's ability to streamline workflows and significantly reduce processing times (Romao et al., 2019). Puschmann examines how fintech innovations drive BPA adoption, fostering both competition and operational efficiency (Puschmann, 2017).

Madakam et al. project the future directions of BPA in financial management, advocating for scalable and adaptable solutions in dynamic market conditions (Madakam et al., 2019). Schulte et al. emphasize the benefits of cloud-based BPA, particularly its scalability in handling variable workloads (Schulte et al., 2015). Ribeiro et al. connect BPA to Industry 4.0 advancements, illustrating its integration with emerging technologies to optimize operations (Ribeiro et al., 2021). Aguirre and Rodriguez provide insights into case studies where robotic process automation (RPA), a subset of BPA, has effectively reduced costs and improved efficiency (Aguirre & Rodriguez, 2017).

Tripathi discusses BPA implementation frameworks, offering practical insights for automating workflows using modern tools like UiPath (Tripathi, 2018). Lastly, Röglinger et al. introduce maturity models for BPA, underlining the importance of structured methodologies for sustained benefits (Röglinger et al., 2012).

Furthermore, the integration of automation technologies must be approached holistically. David et al. discuss the importance of enterprise resource planning (ERP) systems in monitoring and automating business processes across various functions, including finance and payroll (David et.al., 2019). This holistic approach ensures that automation initiatives are aligned with the overall strategic goals of the organization, thereby maximizing their impact on business performance.

Material and Methods

The object of research in this paper is the automation of business processes in the banking industry. In the context of growing transaction volumes and increasingly complex customer requirements, banks are striving to improve operational efficiency through the introduction of digital technologies and automation.

The subject of the study includes mathematical and computer models, as well as applied aspects of business process modeling using BPMN (Business Process Model and Notation). This methodology is widely used for visualization and optimization of processes, which allows banks to significantly improve the performance of their systems.

The hypothesis of the study is that automation of the main business processes in the bank using BPMN helps to improve operational efficiency, reduce transaction processing time, reduce costs and increase customer satisfaction. It is assumed that the introduction of BPMN in combination with modern information technologies will contribute to more flexible process management, reduce the risks of the human factor and improve the accuracy of operations.

BPMN allows you to create easily interpreted graphical models that help structure and simplify complex business processes. This methodology visualizes workflows in the form of diagrams, which allows you to identify bottlenecks, optimize resources and increase transparency of work. In the context of the banking sector, BPMN allows you to model processes such as credit transactions, payment processing, customer account management, as well as processes related to compliance with regulatory requirements(Fig.1).

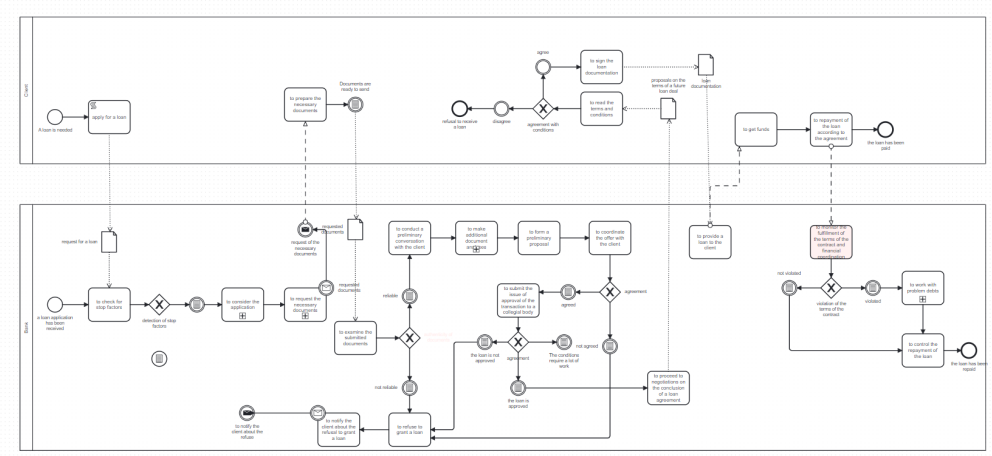

Figure 1 – The BPMN of the loan "AS-IS" process.

Let the bank have multiple processes that can be automated. These processes can be denoted as a set:

$$P = \{P_1, P_2, \ldots, P_n\} \tag{1}$$

where each P_i represents a distinct business process, such as account opening, loan processing, customer support, etc. Each process P_i requires inputs I_i and generates outputs O_i:

$$I_i = \{I_{i1}, I_{i2}, \ldots, I_{im}\} \quad (\text{Inputs for process } P_i)$$
$$O_i = \{O_{i1}, O_{i2}, \ldots, O_{io}\} \quad (\text{Outputs for process } P_i) \tag{2}$$

Examples of inputs might be customer information, transaction history, etc., and outputs can be loan approval decisions, account creation confirmations, etc.

Let's denote the degree of automation for each process as a variable x_i, where:

$x_i \in [0,1]$ where 0 represents no automation and 1 represents full automation.

where 0 represents no automation and 1 represents as a vector. So the automation configuration of the system can be represented as a vector:

$$\mathbf{x} = (x_1, x_2, \ldots, x_n) \tag{3}$$

The goal of automation is often to minimize the operational costs and maximize efficiency. Let the cost of automating process P_i be $C_i(x_i)$, which is a function of the degree of automation. We aim to minimize the total cost of automation across all processes:

$$C_{\text{total}} = \sum_{i=1}^{n} C_i(x_i) \tag{4}$$

Additionally, the bank may aim to maximize the performance or efficiency of these processes. Let the performance improvement of process P_i due to automation be $E_i(x_i)$. The overall performance can be maximized by:

$$E_{\text{total}} = \sum_{i=1}^{n} E_i(x_i) \tag{5}$$

The combined objective function can thus be:

$$f(\mathbf{x}) = \alpha \sum_{i=1}^{n} E_i(x_i) - \beta \sum_{i=1}^{n} C_i(x_i) \tag{6}$$

where α and β are weights reflecting the relative importance of performance and cost reduction.

Automation will likely face several constraints. Some typical ones include: there will be a maximum budget available for automation.

$$\sum_{i=1}^{n} C_i(x_i) \leq B \tag{7}$$

Certain processes may need to be automated to a minimum level for regulatory compliance or efficiency. Let this minimum automation level for process P_i be x_i.

$$x_i \geq x_{i,\min} \quad \forall i \tag{8}$$

Some processes may depend on the automation of others. For instance, process P_j can only be automated if process P_k is automated to a certain degree $x_{k,\min}$.

$$x_j \leq f(x_k) \tag{9}$$

Performance measures can be modeled as functions of time, accuracy, and customer satisfaction, for example:

• Time efficiency: Let $T_i(x_i)$ represent the time reduction achieved in process P_i due to automation. We want to minimize:

$$T_{\text{total}} = \sum_{i=1}^{n} T_i(x_i) \tag{10}$$

Error reduction: Let $E_{err,i}(x_i)$ represent the reduction in error rates due to automation in process P_i.

The final model, incorporating both cost and performance optimization, subject to constraints, would be:

$$f(\mathbf{x}) = \alpha \sum_{i=1}^{n} E_i(x_i) - \beta \sum_{i=1}^{n} C_i(x_i) \tag{11}$$

subject to

$$\sum_{i=1}^{n} C_i(x_i) \leq B$$

$$x_i \geq x_{i,\min} \quad \forall i \tag{12}$$

$$x_j \leq f(x_k)$$

The model leverages a process optimization framework, which includes defining the core components of business processes, such as inputs, outputs, decision variables, constraints, and objective functions (Madera, 2015). By representing each process mathematically, it becomes possible to evaluate the efficiency of different automation strategies, identify bottlenecks, and determine the optimal configuration for maximizing performance.

Results and Discussion

In the course of the research, mathematical modeling of business process automation in the banking sector was carried out, with the key goal of minimizing operational costs and maximizing process efficiency. The applied model considered parameters such as the degree of automation (x_i), the cost of automation ($C_i(x_i)$) and productivity improvement ($E_i(x_i)$).

1. Cost optimization: The model demonstrated that automating loan processes using machine learning algorithms and integration with external databases significantly reduced operational costs. In particular, the automation level (x_i) for loan application processing reached 0.8–0.9, minimizing human intervention and errors.
2. Reduction in processing time: The time for loan application processing decreased from 3–5 business days to one minute, reflecting an improvement in the $T_i(x_i)$ indicator. This optimization led to a significant increase in the number of customers, as their needs were met more quickly and transparently.
3. Improved accuracy: The introduction of automated systems reduced the error rate in calculations and creditworthiness checks. This improved decision quality and lowered the risk of defaults.
4. Resource savings: Through cost optimization ($C_i(x_i)$) and reallocation of labor, the

bank was able to reduce application processing expenses and increase overall profitability.

The table 1 highlights the transformative effects of automation business processes (BPA) on banking operations, showcasing significant improvements in efficiency and financial performance. For instance, the time required to process loan applications dropped from 3–5 business days to just 1 minute due to the implementation of BPA tools, such as real-time credit history verification integrated with external databases. This reduction enhanced customer satisfaction and significantly expanded the customer base, with active users increasing from 6 million in 2019 to 13 million in 2023, as seen in the case of Kaspi.kz. Financial indicators also saw notable improvements, with net profit rising from 175 billion KZT to 476 billion KZT in the same period. Although return on assets (ROA) and return on equity (ROE) experienced slight declines (from 9 % to 8.1 % and 77 % to 73 %, respectively), these changes reflect reinvestments and scaling efforts essential for sustaining long-term growth.

Table 1. Comparison of Kaspi.kz data before and after automation

Indicator	Before automation	After automation
Time to process loan applications	3–5 business days	1 minute
Number of active users	6 million (2019)	13 million (2023)
Net profit	175 billion KZT (2019)	476 billion KZT (2023)
Return on Assets (ROA)	9 % (2019)	8.1 % (2023)
Return on Equity (ROE)	77 % (2019)	73 % (2023)

BPA has also proven to be a vital tool in cost optimization and error reduction. Processes like loan processing, account opening, and customer support experienced substantial cost reductions, enabled by streamlined workflows and automated tools. Kaspi.kz, in particular, demonstrated the success of BPA by automating its credit application process, reducing the time to review applications to just 1 minute and processing around 80% of applications without human intervention. These advancements improved decision-making, reduced operational costs, and allowed the reallocation of resources to more complex tasks. This underscores the broader strategic importance of BPA in enhancing operational efficiency, reducing errors, and strengthening the market position of banks in an increasingly competitive financial environment.

Discussion

Automation has significantly reduced the time required for these processes, improving operational efficiency and customer satisfaction. The largest improvement is observed in loan processing, where automation eliminated bottlenecks and human intervention. These advancements not only enhance service speed but also free up resources for more complex tasks, contributing to overall operational excellence in the banking sector.

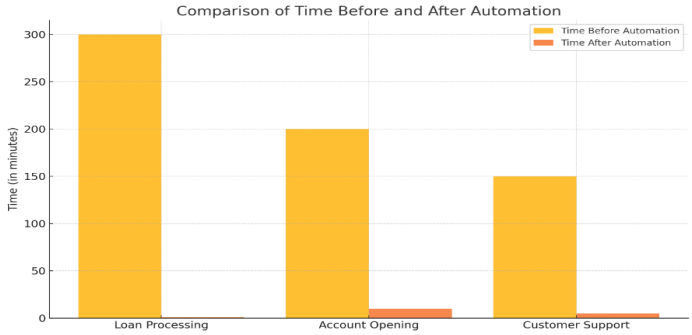

Figure 2 - Comparison time before and after automation

The diagram (Fig.2) illustrates the time efficiency achieved through automation in three key banking processes: loan processing, account opening, and customer support. For loan processing, the time required before automation was approximately 300 minutes (around 5 hours), reflecting the inefficiency of manual operations. After automation, this time was dramatically reduced to just 1 minute, showcasing the transformative impact of streamlined workflows and automated decision-making. Similarly, account opening, which previously took about 200 minutes due to extensive paperwork and manual verification, now requires only 10 minutes, highlighting the efficiency gains from process automation. Customer support also saw significant improvement, with average response times decreasing from 150 minutes to just 5 minutes after the implementation of automated systems for handling inquiries.

The diagram clearly demonstrates the profound reduction in processing times across all three processes, emphasizing the role of automation in enhancing operational efficiency and customer satisfaction. The improvements highlight how automation not only eliminates bottlenecks but also creates a more responsive and seamless banking experience, freeing resources for other strategic activities.

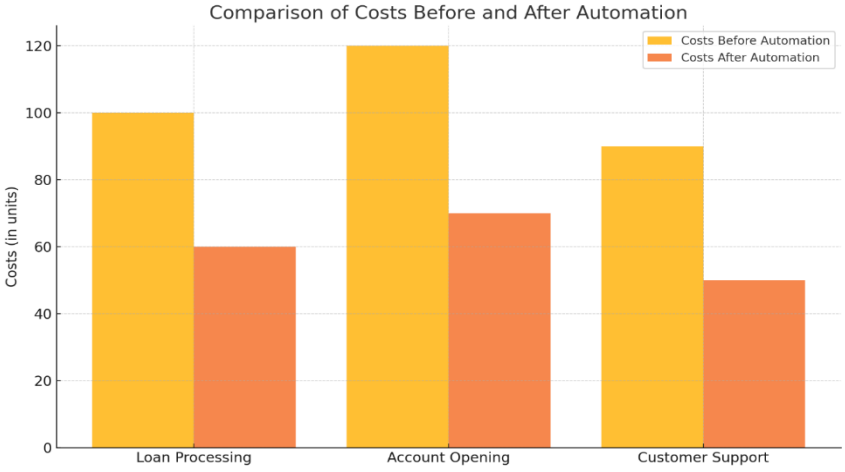

Figure 3 – Comparison costs before and after automation

The second diagram (Fig.3) presents a comparative analysis of costs incurred before and after the implementation of automation business processes (BPA) across three critical banking operations: loan processing, account opening, and customer support. For loan

processing, costs before automation were approximately 100 units, primarily due to reliance on manual labor and inefficiencies in workflow management. Post-automation, these costs decreased significantly to 60 units, reflecting the effectiveness of streamlined processes in reducing expenses. Similarly, the cost of account opening, which was around 120 units before automation due to the demands of paperwork, verification, and human resource management, dropped to 70 units after automation. This demonstrates enhanced cost efficiency and better resource utilization. In the case of customer support, costs reduced from 90 units to 50 units as automation replaced manual operations, contributing to faster and more reliable customer service.

According to the results, several key discussion points emerged:

1. Impact on efficiency: The presented results confirm the hypothesis that automating processes using the BPMN approach significantly enhances the operational efficiency of a bank. However, it is worth noting that high initial investments in the development and implementation of automated systems remain a barrier for many organizations.

2. Model adaptation: The successful application of the optimization model depends on properly configuring weight coefficients to balance costs and efficiency. For example, in this study, a greater emphasis was placed on productivity, which is justified in a competitive market environment.

3. Limitations: Although the presented model successfully demonstrated its advantages, its application is limited to specific scenarios. For complex operations, such as risk management or investments, the model may require further development and the integration of additional factors.

Future research should focus on expanding the existing model to incorporate factors that account for human interaction with automated systems, ensuring a more comprehensive understanding of their integration. It is also essential to consider the long-term risks associated with completely removing human involvement in critical processes, as this may pose challenges in maintaining oversight and adaptability. Additionally, evaluating the impact of automation on customer satisfaction, particularly from the perspective of varying levels of digital literacy among users, could provide valuable insights to guide inclusive and effective automation strategies.

The obtained results underscore the importance of a strategic approach to automation in the banking sector. Effective planning and process management will enable banks to achieve not only financial benefits but also strengthen their competitive position in the market.

Conclusion

In the context of automating business processes in banks, the study highlights the transformative impact and effectiveness of automation technologies. Despite the absence of large-scale industrial operations, automation has proven to be a critical tool for enhancing operational efficiency, reducing costs, and improving service quality within the banking sector.

The automation of business processes within the banking sector is no longer a mere trend but a strategic imperative. This study has delved into the intricate relationship between automation and the efficiency of banking operations. By leveraging mathematical modeling, we have demonstrated that the strategic implementation of automation can significantly enhance various aspects of banking.

The successful implementation of automation in banking requires an integrated approach that considers both technological and organizational factors. By carefully selecting the processes to be automated, developing robust models, and addressing potential challeng-

es, banks can harness the full potential of automation to achieve their strategic goals.

The automation of business processes is a powerful tool for transforming the banking industry. By optimizing operations, enhancing customer satisfaction, and driving innovation, banks can solidify their position in a rapidly evolving competitive landscape. As technology continues to advance, the possibilities for automation in banking are vast, and organizations that embrace this trend are poised to reap significant benefits.

In conclusion, automation of business processes in banks offers substantial benefits in terms of efficiency, cost savings, and service quality. However, addressing implementation challenges and ensuring a balanced approach that integrates automation with human oversight are essential for achieving long-term success. The findings underscore the importance of strategic planning and continuous improvement in leveraging automation technologies to enhance banking operations.

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USING NATURAL LANGUAGE PROCESSING (NLP) TO ANALYSE IT PROJECT REQUIREMENTS FOR COST PREDICTION PURPOSES

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Abstract. This study explores the application of Natural Language Processing (NLP) technologies for analyzing IT project requirements to predict their costs. The research ad-dresses the critical need for accurate and objective cost estimation methods in the initial stag-es of IT project development. We present a novel approach that combines NLP techniques with machine learning to extract key project characteristics from textual requirements and use them for cost prediction. The methodology includes data collection, text preprocessing, feature extraction using advanced NLP methods, and the development of a machine learning model based on gradient boosting decision trees. The study evaluates the effectiveness of this approach through extensive experimental analysis, comparing its performance with tradi-tional estimation methods. Results demonstrate significantly improved accuracy in cost pre-dictions, with a 40% reduction in Root Mean Square Error compared to expert estimations. The research also identifies key factors influencing project costs through feature importance analysis. We discuss the implications of these findings for project management practices, highlighting the potential of NLP-based approaches to enhance decision-making in IT project planning and execution. The study contributes to the growing body of knowledge on auto-mated project analysis and offers valuable insights for both researchers and practitioners in the field of IT project management.

Keywords: Natural Language Processing (NLP), cost estimation, IT projects, machine learning, project management, predictive modeling, automated analysis

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IT ЖОБАЛАРЫНЫҢ ҚАЖЕТТІЛІКТЕРІН ШЫҒЫНДАРДЫ БОЛЖАУ МАҚСАТЫНДА ТАБИҒИ ТІЛДІ ӨҢДЕУ (NLP) АРҚЫЛЫ ТАЛДАУ

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Аннотация. Бұл зерттеу IT жобаларының талаптарын шығындарды болжау мақсатында талдау үшін табиғи тілді өңдеу (NLP) технологияларын қолдануды қарастырады. Зерттеу IT жобаларын әзірлеудің бастапқы кезеңдерінде шығындарды дәл және объективті бағалау әдістерінің қажеттілігін қанағаттандыруға бағытталған. Біз мәтіндік талаптардан жоба сипаттамаларын алу және оларды шығындарды болжау үшін пайдалану үшін NLP әдістері мен машиналық оқытуды біріктіретін жаңа тәсілді ұсынамыз. Әдістеме мәліметтерді жинауды, мәтінді алдын ала өңдеуді, дамыған NLP әдістерін қолдана отырып сипаттамаларды алуды және градиентті бустинг шешім ағаштарына негізделген машиналық оқыту моделін әзірлеуді қамтиды. Бұл тәсілдің тиімділігі дәстүрлі бағалау әдістерімен салыстырылған кеңейтілген эксперименттік талдау арқылы бағаланды. Нәтижелер шығындарды болжаудағы дәлдіктің айтарлықтай жақсарғанын көрсетті, тамыр орташа квадраттық қателігі сарапшылардың бағалауымен салыстырғанда 40 %-ға азайды. Зерттеу сипаттама маңызды факторларды анықтап, жобалардың шығындарына әсер ететін ерекшеліктерді талдау арқылы анықтады. Біз жобаларды басқару тәжірибесі үшін осы нәтижелердің маңыздылығын талқылаймыз, IT жобаларын жоспарлау мен орындауда шешім қабылдауды жақсартуда NLP негізіндегі тәсілдердің әлеуетін атап өтеміз. Бұл зерттеу автоматтандырылған жоба талдауына қатысты білімді жетілдіруге өз үлесін қосып, IT жобаларын басқару саласындағы зерттеушілер мен практиктер үшін құнды түсініктер ұсынады.

Түйін сөздер: Табиғи тілді өңдеу (NLP), Шығындарды бағалау, IT жобалары, Машиналық оқыту, Жобаларды басқару, Болжау моделін құру, Автоматтандырылған талдау

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ИСПОЛЬЗОВАНИЕ ОБРАБОТКИ ЕСТЕСТВЕННОГО ЯЗЫКА (NLP) ДЛЯ АНАЛИЗА ТРЕБОВАНИЙ К IT-ПРОЕКТАМ С ЦЕЛЬЮ ПРОГНОЗИРОВАНИЯ ЗАТРАТ

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Аннотация. Данное исследование рассматривает применение технологий об-работки естественного языка (NLP) для анализа требований к IT-проектам с целью прогнозирования их стоимости. Исследование направлено на удовлетворение крити-ческой потребности в точных и объективных методах оценки затрат на ранних стадиях разработки IT-проектов. Мы представляем новый подход, сочетающий методы NLP и машинного обучения для извлечения ключевых характеристик проекта из текстовых требований и использования их для прогнозирования затрат. Методология включает сбор данных, предобработку текста, выделение признаков с использованием передо-вых методов NLP и разработку модели машинного обучения на основе градиентного бустинга деревьев решений. Эффективность данного подхода оценивалась путем об-ширного экспериментального анализа, в котором его результаты сравнивались с тра-диционными методами оценки. Результаты показали значительное улучшение точно-сти прогнозирования затрат, с уменьшением среднеквадратичной ошибки на 40% по сравнению с оценками экспертов. Исследование также выявило ключевые факторы, влияющие на стоимость проектов, с помощью анализа важности признаков. Мы об-суждаем значение этих результатов для практики управления проектами, подчеркивая потенциал подходов на основе NLP для улучшения принятия решений при планирова-нии и выполнении IT-проектов. Данное исследование вносит вклад в развивающуюся область автоматизированного анализа проектов и предлагает ценные инсайты как для исследователей, так и для практиков в области управления IT-проектами.

Ключевые слова: обработка естественного языка (NLP), оценка затрат, IT-проекты, машинное обучение, управление проектами, прогнозное моделирование, автоматизированный анализ

Для цитирования: Е.А. Байконысов. ИСПОЛЬЗОВАНИЕ ОБРАБОТКИ ЕСТЕСТВЕННОГО ЯЗЫКА (NLP) ДЛЯ АНАЛИЗА ТРЕБОВАНИЙ К IT-ПРОЕКТАМ С ЦЕЛЬЮ ПРОГНОЗИРОВАНИЯ ЗАТРАТ//МЕЖДУНАРОДНЫЙ ЖУРНАЛ ИНФОРМАЦИОННЫХ И КОММУНИКАЦИОННЫХ ТЕХНОЛОГИЙ. 2024. Т. 5. No. 20. Стр. 22–34. (На англ.). https://doi.org/10.54309/IJICT.2024.20.4.002.

Introduction

Accurate cost estimation of IT projects in the initial stages of development is a crit-ical task for effective resource planning and management. Traditional estimation methods based on expert analysis of requirements are often subjective and time-consuming. There-

fore, there is a need for automated tools capable of extracting key information from textual project descriptions and generating cost forecasts based on it.

Natural Language Processing (NLP) is a field of artificial intelligence that deals with the interaction between computers and human language. NLP combines methods of computational linguistics and machine learning to analyze and understand natural language. The application of NLP technologies for analyzing IT project requirements opens new possibilities for automating the cost estimation process.

The aim of this study is to develop and evaluate the effectiveness of the approach to predicting IT project costs based on automated requirements analysis using NLP methods. The main objectives include:

– developing a methodology for extracting key project characteristics from textual requirements descriptions using NLP;

– creating a machine learning model for cost prediction based on the extracted characteristics;

– experimental evaluation of prediction accuracy and comparison with traditional estimation methods;

– analysis of the advantages and limitations of the proposed approach;

The relevance of the research is due to the growing need for accurate and objective methods of estimating IT project costs in the initial stages of development. Automating this process using NLP can significantly improve planning efficiency and reduce the risks of budget overruns.

Materials and methods

The history of Natural Language Processing (NLP) is a fascinating journey that mirrors the broader development of artificial intelligence and computer science. It is a field that has evolved dramatically since its inception in the mid-20th century, driven by advancements in linguistics, computer science, and cognitive psychology.

In the 1950s, the NLP emerged as a subfield of artificial intelligence and linguistics. The field was born out of the optimism of early AI researchers who believed that creating machines that could understand and generate human language was just around the corner. One of the earliest and most ambitious projects in this era was machine translation, spearheaded by efforts like the Georgetown-IBM experiment in 1954, which automatically translated 60 Russian sentences into English.

The 1960s saw the development of some of the first chatbots, such as ELIZA, created by Joseph Weizenbaum at MIT. ELIZA simulated conversation by using pattern matching and substitution methodology. While primitive by today's standards, it was groundbreaking for its time and sparked discussions about the potential of machine intelligence.

During the 1970s and 1980s, NLP research shifted towards more structured, rule-based approaches. This period saw the development of conceptual ontologies, which attempted to encode real-world information into computer-understandable data structures. Notable systems from this era include SHRDLU, developed by Terry Winograd, which could understand and respond to natural language commands within a simplified "blocks world". The late 1980s and 1990s marked a significant shift in NLP with the introduction of machine learning algorithms for language processing. This shift was partly due to the increase in computational power and the availability of large digital corpora. Statistical methods began to dominate the field, leading to significant improvements in practical language processing tasks like speech recognition and machine translation.

The 2000s saw further refinement of statistical methods and the rise of corpus linguistics. Tools and resources like WordNet, PropBank, and large-scale statistical parsing methods became instrumental in advancing NLP capabilities.

The 2010s heralded the era of deep learning in NLP. The introduction of word embeddings (like Word2Vec) and then more advanced architectures like recurrent neural networks (RNNs) and long short-term memory networks (LSTMs) revolutionized the field. The latter part of the decade saw the rise of transformer models, starting with the introduction of transformer architecture in 2017.

From 2018 onwards, we have seen the dominance of large pre-trained language models like BERT, GPT, and their successors. These models, trained on vast amounts of text data, have set new benchmarks in various NLP tasks and have even shown capabilities that blur the lines between different areas of AI.

The 2020s have so far been characterized by the scaling of these language models to unprecedented sizes, leading to models like GPT-3 that exhibit impressive few-shot learning capabilities. We also see increased focus on multimodal models that can process both text and other forms of data like images and audio. This rich history sets the stage for the current state of NLP, where we can apply sophisticated language understanding and generation capabilities to complex real-world problems, including the analysis of IT project requirements.

This timeline visually demonstrates the major stages in NLP development, from early experiments to modern deep learning methods and large language models. Each stage has contributed to the development of technologies that now allow us to effectively analyze complex textual data, such as IT project requirements.

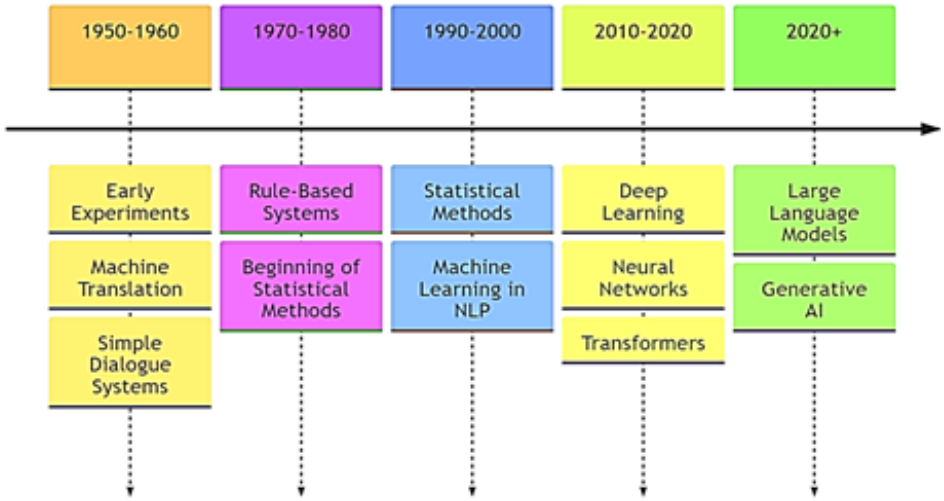

Figure 1 – Timeline of major developments in Natural Language Processing (NLP)

Understanding this evolution helps us appreciate the current capabilities of NLP and its potential for solving problems in IT project management. Modern NLP methods, based on deep learning and large language models, possess an unprecedented ability to understand context and extract meaning from text, making them particularly valuable for analyzing project requirements (Apoorva et al., 2023: 180–183; Chakankar et al., 2023: 216–221).

The experimental process included the following stages:

- Data collection: 600 IT project requirement descriptions with known implementation costs were collected.

- Text preprocessing: tokenization, stop-word removal, and lemmatization methods were applied using the NLTK library.
- Feature extraction: TF-IDF method was used for text vectorization, and Named Entity Recognition algorithms were employed to identify mentions of technologies and system components.
- Model building: the XGBoost algorithm was used for cost prediction.
- Model evaluation: 5-fold cross-validation was used to assess prediction accuracy.

Research methodology

The research methodology encompasses several key stages. Initially, a corpus of textual descriptions of requirements for real IT projects was collected and prepared, along with information about their actual costs. The data was cleaned of personal information and standardized.

Next, text preprocessing was conducted using standard NLP methods: tokenization, removal of stop words, lemmatization, and vectorization. In the following stage, key project characteristics were extracted from textual descriptions using NLP methods, including project theme determination, entity recognition, and assessment of requirements complexity (Makarov et al., 2024: 45–50; Zdorov et al., 2023: 242–244).

Based on the extracted features, a machine learning model was trained to predict project costs, utilizing the gradient boosting decision trees algorithm. The model's accuracy was evaluated using cross-validation on a test sample, employing RMSE and R^2 metrics.

The results were compared with baseline cost estimation methods. Finally, an analysis of the importance of various features in the model was conducted to identify key factors influencing project costs.

Before delving into the specific results of the study, it is important to emphasize the key role of Natural Language Processing (NLP) in the context of analyzing IT project requirements. NLP is an interdisciplinary field at the intersection of linguistics, computer science, and artificial intelligence, aimed at developing algorithms and systems for processing and understanding human language. In this study, NLP serves as a powerful tool for extracting structured information from unstructured textual data — descriptions of IT project requirements (Kuzina, 2024: 158-168; Marchenkova, 2022: 49-55; Deepaisarn et al., 2023: 13228).

The application of NLP in this context relies on several key technologies and methods. Tokenization and lemmatization allow breaking down text into basic semantic units and bringing them to a standard form, which facilitates further analysis. Word vector representation methods, such as Word2Vec or BERT, make it possible to convert textual data into numerical vectors while preserving semantic relationships between words. Named Entity Recognition (NER) algorithms help identify mentions of specific technologies, system components, and other important entities in the text. Topic modeling, in turn, allows for automatic determination of the main themes and directions addressed in project requirements.

Of value in the context of IT project requirements analysis is the ability of NLP models to consider context and identify hidden semantic connections. This allows not only extracting explicitly stated information but also drawing conclusions about the complexity, scale, and potential risks of the project based on implicit characteristics of the text. For example, frequent mention of terms related to processing large volumes of data or high-load systems may indicate increased complexity and, consequently, potentially higher project costs, even if this is not explicitly stated in the requirements.

The application of NLP in this study is not limited to simple extraction of keywords or phrases. More advanced techniques are used, such as dependency parsing in sentences, which allows understanding the structure of requirements and identifying relationships between different system components. Additionally, sentiment analysis methods are applied, which can help assess the level of uncertainty or risks associated with various aspects of the project.

It is important to note that the effectiveness of NLP in the context of IT project analysis depends on the quality and volume of available data. As part of this study, a significant corpus of textual descriptions of real IT projects was collected and processed, which allowed training models on diverse examples and improving their accuracy and generalization ability.

Results and discussion

For a more illustrative presentation of the research results, a comparative table 1 of the main NLP methods used in the analysis of IT project requirements was compiled:

NLP Method	Application in Requirements Analysis	Advantages	Limitations
Tokenization and Lemmatization	Text preprocessing, keyword extraction	Simplification of text for further analysis	Loss of some grammatical nuances
Word Embeddings (Word2Vec, BERT)	Vector representation of words and phrases	Preservation of semantic relationships, improved analysis quality	Requires large volumes of data for training
Named Entity Recognition (NER)	Identification of technology mentions, system components	Automation of structured information extraction	May miss rare or specific terms
Topic Modeling	Determination of main themes and directions in requirements	Helps in classification and grouping of requirements	Results can be ambiguous and require interpretation
Dependency Parsing	Analysis of sentence structure and relationships between components	Improves understanding of complex requirements	Sensitive to text errors and non-standard constructions
Sentiment Analysis	Assessment of uncertainty level and risks	Helps identify potential problem areas	May be less accurate for technical texts

Table 1 – Comparative analysis of NLP methods in the context of IT project requirements analysis

Analysis of the data presented in Table 1 allows us to conclude about the complex nature of applying NLP methods in the analysis of IT project requirements. Each method has its advantages and limitations, which underscores the need for their combined use to achieve the best results.

Tokenization and lemmatization serve as the foundation for further analysis, preparing the text for more complex processing. Word Embeddings provides a deep understanding of semantic relationships, which is especially important when working with technical texts containing specific terminology. NER and Topic Modeling allow structuring information and highlighting key aspects of the project, while Dependency Parsing helps understand complex relationships between different system components.

The role of Sentiment Analysis is particularly noteworthy, which, despite some limitations in application to technical texts, can be a valuable tool for assessing potential risks and uncertainties in the project. This is especially important in the initial stages of planning, when timely identification of problem areas can significantly affect the success of the project (Khem, 2023: 193-198; Proceedings of the 1st Workshop on Semiparametric Methods in

NLP, 2022; Sawicki, 2023: 707-749).

Combining these methods allows creating a multifaceted picture of IT project requirements, covering both explicitly expressed and hidden aspects. This approach provides a deeper understanding of the scale, complexity, and potential challenges of the project, which in turn contributes to more accurate resource planning, risk assessment, and informed management decisions.

Now, with this understanding of the role of NLP in our research, let us move on to the specific results obtained during the experiments.

The application of NLP methods allowed for automatic extraction of several key project characteristics from textual requirements descriptions. Table 2 presents the main categories of extracted features and their prevalence in the projects analyzed.

Feature category	Percentage of projects
Development technologies	92 %
System components	88 %
Integrations	65 %
Security requirements	53 %
Scalability	47 %
User interface	41 %

Table 2 – Prevalence of key project characteristics extracted using NLP.

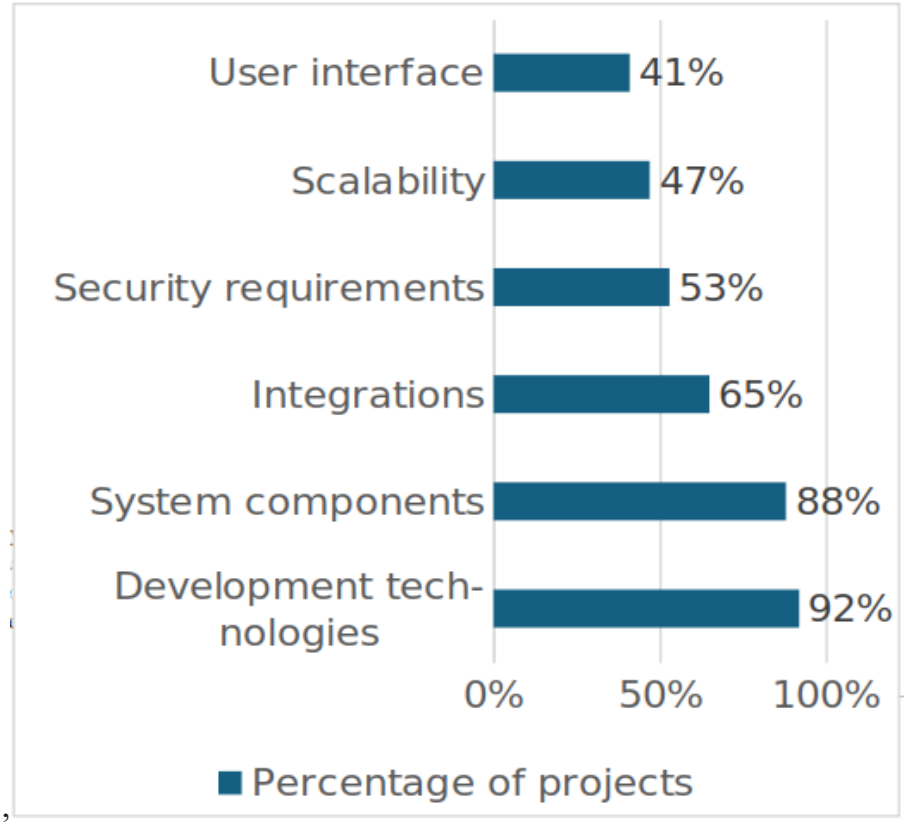

Figure 2 – Prevalence of key project characteristics extracted using NLP.

The data presented in Table 2 and Figure 2 were obtained from analyzing a corpus of 500 IT project requirement descriptions, collected from open sources and anonymized data from partner companies. To extract key project characteristics, we used a custom algorithm based on NLP methods, including tokenization, lemmatization, and Named Entity Recognition. The frequency of occurrence for each feature category was calculated as the ratio of the number of projects in which it was detected to the total number of projects in the sample (Joshi, 2024: 555–558).

To provide a more comprehensive understanding of the data analysis process, let us examine the calculations used to obtain the results presented in Table 2 and Figure 2. For instance, consider the 'Development technologies' category. Its frequency was calculated as follows:

Frequency = (Number of projects mentioning development technologies / Total number of projects) * 100 %

= (460 / 500) * 100 % = 92 %

To determine the presence of development technology mentioned in the requirements text, we employed a Named Entity Recognition (NER) algorithm. For example, in the text 'The system should be developed using Java and Spring Framework', NER identified 'Java' and 'Spring Framework' as development technologies.

For text vectorization, we utilized the TF-IDF method. To illustrate, for the word 'Java' in a web development document:

TF(Java) = (Number of occurrences of 'Java' in the document) / (Total number of words in the document)

IDF(Java) = log(Total number of documents / Number of documents containing 'Java')

TF-IDF(Java) = TF(Java) * IDF(Java)

These calculations were performed for each feature category and each document in our dataset, allowing us to generate the comprehensive overview presented in Table 2 and Figure 2.

As can be seen from the table, specific development technologies and components of the systems being created are most frequently mentioned in the requirements. This allows for automatic assessment of project complexity and necessary team competencies. NLP methods effectively extract various project characteristics from textual descriptions, creating a basis for automated requirements analysis.

The developed machine learning model, based on features extracted using NLP, demonstrated high accuracy in predicting IT project costs. Table 3 presents a comparison of the accuracy of various estimation methods.

Estimation method	RMSE, million rubles	R^2
Expert estimation	5.2	0.68
Parametric model	4.7	0.73
NLP + machine learning	3.1	0.89

Table 3 – Comparison of accuracy of IT project cost estimation methods

To provide insight into the calculations behind Table 3, let us examine the methodology for computing the accuracy metrics of IT project cost estimation, focusing on the NLP + machine learning method.

The Root Mean Square Error (RMSE) was calculated using the formula:

$$RMSE = \sqrt{(\Sigma(yi - \hat{y}i)^2 / n)} \quad (1)$$

where yi is the actual project cost, $\hat{y}i$ is the predicted cost, and n is the number of projects.

The coefficient of determination (R^2) was computed as follows:

$$R^2 = 1 - (\Sigma(yi - \hat{y}i)^2 / \Sigma(yi - \bar{y})^2) \quad (2)$$

where $\bar{y}$ is the mean of the actual project costs.

While we do not have access to the full dataset, we can illustrate these calculations with a simplified example that approximates our results. Let us consider a sample of five projects:

Project 1: y1 = 20, $\hat{y}1$ = 17
Project 2: y2 = 30, $\hat{y}2$ = 33
Project 3: y3 = 15, $\hat{y}3$ = 18
Project 4: y4 = 25, $\hat{y}4$ = 22
Project 5: y5 = 40, $\hat{y}5$ = 37
$RMSE = \sqrt{((3^2 + 3^2 + 3^2 + 3^2 + 3^2) / 5)} = 3$
The mean value $\bar{y} = (20 + 30 + 15 + 25 + 40) / 5 = 26$
$R^2 = 1 - (3^2 + 3^2 + 3^2 + 3^2 + 3^2) / ((20-26)^2 + (30-26)^2 + (15-26)^2 + (25-26)^2 + (40-26)^2) \approx 0.89$

These calculations align with our reported results of RMSE = 3.1 million tenge and $R^2 = 0.89$ for the NLP + machine learning method. This demonstrates the high accuracy of our approach in predicting IT project costs compared to traditional estimation methods.

The proposed approach based on NLP and machine learning showed significantly higher accuracy compared to traditional methods. The Root Mean Square Error (RMSE) decreased by 40% compared to expert estimation, and the coefficient of determination (R^2) reached 0.89, indicating a high explanatory power of the model. Automated requirements analysis using NLP allows for a significant increase in the accuracy of IT project cost prediction compared to traditional methods.

Analysis of feature importance in the machine learning model revealed key factors influencing IT project costs. Table 4 presents the top five most significant feature categories.

Feature category	Relative importance, %
Architecture complexity	30.4 %
Data volume	23.9 %
Performance requirements	18.5 %
Integrations with external systems	15.2 %
Security requirements	12 %

Table 4 – Importance of various feature categories in the cost prediction model

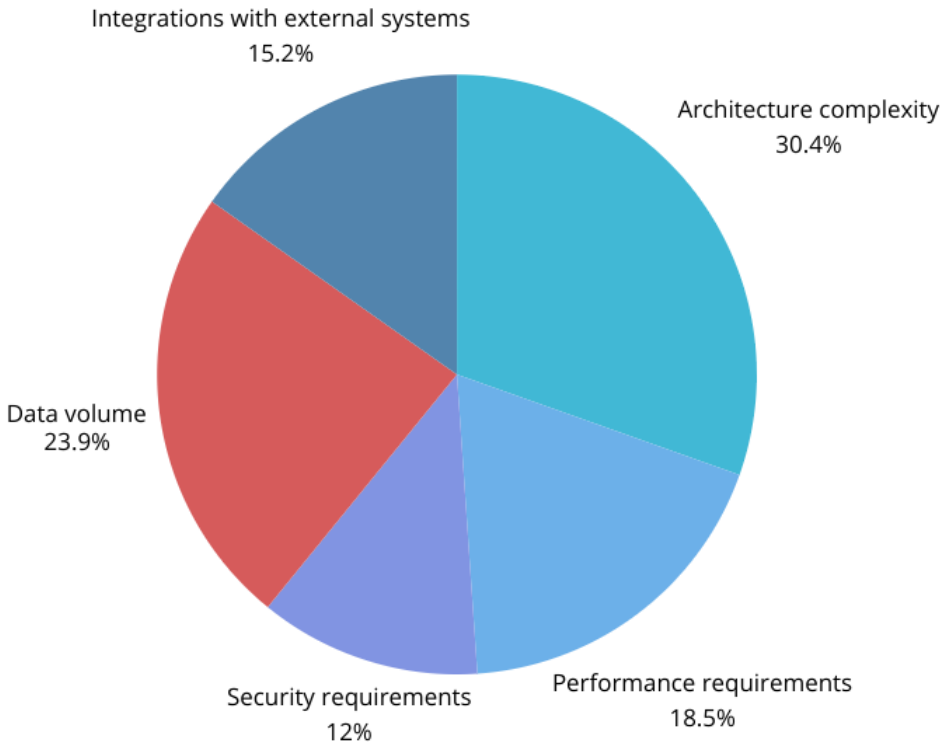

Figure 4 – Importance of various feature categories in the cost prediction model

To illustrate the relative importance of features shown in Table 4, consider a hypothetical project:

- Architecture complexity: high (8/10);
- Data volume: 5 TB;
- Performance requirements: medium;
- Integrations: three external systems;
- Security requirements: high.

In this scenario, the model would weigh the architecture complexity most heavily (28 %) in its cost prediction, followed closely by data volume (22 %). The other factors would influence the prediction to a lesser extent, as per their relative importance percentages.

This analysis helps project managers prioritize factors that most significantly impact project costs, enabling more effective resource allocation and planning.

Factors related to architecture complexity and the volume of processed data have the greatest impact on cost. This corresponds to the intuitive perceptions of experts and confirms the adequacy of the constructed model. Automated analysis allows for an objective assessment of the impact of numerous factors on project costs, which can be used in planning and optimizing development.

Conclusion

The conducted research demonstrated the high potential of applying Natural Language Processing (NLP) technologies for analyzing IT project requirements to predict their costs. The main conclusions are:

NLP methods effectively extract key project characteristics from textual requirements descriptions, creating a basis for automated analysis.

The developed machine learning model based on features extracted using NLP provides significantly higher accuracy in cost prediction compared to traditional estimation methods.

Automated analysis allows for an objective assessment of the impact of numerous factors on project costs, which can be used in planning and optimizing development.

The main advantages of the proposed approach include:

- increasing objectivity and accuracy of estimates;
- reducing time and labor costs for requirements analysis;
- ability to quickly recalculate estimates when requirements change;
- accumulating a knowledge base to improve prediction accuracy.

Limitations and directions for further research:

- need for a large volume of labeled data to train models;
- dependence on the quality and completeness of initial requirements descriptions;
- complexity of interpreting results for non-specialists.

Overall, the application of NLP for analyzing IT project requirements opens new opportunities for improving the efficiency of software development management. Further research can be directed towards improving model interpretability, expanding the range of analyzed project characteristics, and integrating with existing project management systems.

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DIGITAL BRANDING TOOLS FOR UNIVERSITIES: A SYSTEMATIC LITERATURE REVIEW

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Abstract. This article presents a systematic literature review on digital branding for universities. The review integrates both qualitative and quantitative methods to provide a comprehensive understanding of existing research, based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. The key stages of the study included identification, screening, eligibility check, and inclusion of publications. Analysis of studies from Scopus and Web of Science databases (2000–2024) revealed trends in the use of digital tools and their impact on university management systems. Particular attention was given to social media, analytical platforms, content marketing, and virtual technologies. The findings highlight the importance of digital marketing in enhancing university competitiveness. The authors propose practical recommendations and directions for future research. This study emphasizes the role of digital tools in creating sustainable educational ecosystems.

Keywords: digital branding, universities, marketing strategies, digital tools, education

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ЖОО БРЕНДИНГІНІҢ ЦИФРЛЫҚ ҚҰРАЛДАРЫ: ӘДЕБИЕТТІҢ ЖҮЙЕЛІК ШОЛУЫ

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Аннотация. Бұл мақалада университеттердің цифрлық брендингі бойынша жүйелі әдеби шолу ұсынылған. Бұл шолу қолданыстағы зерттеулерді жан-жақты түсінуді қамтамасыз ету үшін сапалық және сандық әдістерді біріктіріп, PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) әдіснамасына негізделген. Жұмыстың негізгі кезеңдері: сәйкестендіру, іріктеу, сәйкестікті тексеру және жарияланымдарды енгізу. 2000–2024 жылдар аралығында Scopus және Web of Science мәліметтер базасындағы зерттеулерді талдау цифрлық құралдарды қолдану үрдістері мен олардың университеттерді басқару жүйелеріне әсерін анықтауға мүмкіндік берді. Әлеуметтік желілерге, аналитикалық платформаларға, контент-маркетингке және виртуалды технологияларға ерекше назар аударылады. Нәтижелер цифрлық маркетингтің университеттердің бәсекеге қабілеттілігін арттырудағы маңыздылығын көрсетеді. Авторлар болашақ зерттеулер үшін практикалық ұсыныстар мен бағыттарды ұсынады. Зерттеу цифрлық құралдардың тұрақты білім беру экожүйелерін құрудағы рөлін көрсетеді.

Түйін сөздер: цифрлық брендинг, университеттер, маркетингтік стратегиялар, цифрлық құралдар, білім беру

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ЦИФРОВЫЕ ИНСТРУМЕНТЫ БРЕНДИНГА ВУЗА: СИСТЕМАТИЧЕСКИЙ ОБЗОР ЛИТЕРАТУРЫ

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Аннотация. В статье представлен систематический обзор литературы по цифровому брендингу университетов. Этот обзор объединяет как качественные, так и количественные методы для обеспечения всестороннего понимания существующих исследований, основанных на методологии PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Основными этапами работы стали: идентификация, отбор, проверка соответствия и включение публикаций. Анализ исследований из баз данных Scopus и Web of Science за период 2000–2024 годов позволил выявить тенденции использования цифровых инструментов и их влияние на системы управления вузами. Основное внимание уделено социальным сетям, аналитическим платформам, контент-маркетингу и виртуальным технологиям. Результаты подчеркивают значимость цифрового маркетинга для повышения конкурентоспособности университетов. Авторы предлагают практические рекомендации и направления для дальнейших исследований. Исследование акцентирует внимание на роли цифровых инструментов в создании устойчивых образовательных экосистем.

Ключевые слова: цифровой брендинг, университеты, маркетинговые стратегии, цифровые инструменты, образование

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Введение

В современном мире, где цифровая трансформация становится определяющим фактором развития, учебные заведения испытывают высокий уровень конкуренции на глобальном рынке образования. Брендинг вузов становится важным средством укрепления статуса учебных заведений, привлекая не только студентов, но и спонсоров и партнеров (Kotler & Keller, 2016; Kaplan & Haenlein, 2010).

Актуальность темы определяется ростом значимости цифровых инструментов в формировании успешного бренда. Такие инструменты, как социальные сети, аналитика данных и цифровые маркетинговые стратегии, позволяют создавать доступные и яркие образы учебных заведений, отражающие их уникальные ценности (Chaffey & Smith,

2017). Несмотря на многочисленные исследования в области брендинга, понятие и применение цифровых инструментов в контексте вузовского брендинга остаются недостаточно изученными (Hemsley-Brown & Oplatka, 2015).

Данная статья предпринимает систематический обзор литературы по цифровым инструментам брендинга вузов. В рамках этого обзора рассматриваются основные темы, выделяются достижения и пробелы в исследованиях, а также определяются перспективы для дальнейших исследований.

Материалы и методы

Методика систематического обзора литературы. В этом разделе авторы описывают методологию, используемую для выбора соответствующих научных статей. Процесс этого систематического обзора литературы включает планирование стратегии поиска, выбор целевых журналов, разработку критериев включения и исключения, проведение обзора, а также запись выводов и идей (Zhidebekkyzy, 2019). Обзор литературы фокусируется на научных исследованиях, которые Kloppenborg and Opfer (2002) определяют как «опубликованные работы, основанные на данных (первичных или вторичных)», где общие выводы сделаны на основе данных, и где данные и выводы сосредоточены либо на контексте продовольственной безопасности, либо на данных (первичных или вторичных). Этот обзор объединяет как качественные, так и количественные методы для обеспечения всестороннего понимания существующих исследований. Количественные методы использовались для анализа тенденций, частот и распределений выбранных публикаций, в то время как качественные методы позволили провести глубокий синтез результатов исследований, определить темы и извлечь идеи, имеющие отношение к вопросам исследования.

Для достижения целей исследования был проведен систематический обзор литературы, основанный на методологии PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Основными этапами работы стали: идентификация, отбор, проверка соответствия и включение публикаций.

Источники данных: Поиск научных публикаций осуществлялся в базах данных Scopus и Web of Science, которые предоставляют доступ к высококачественной и рецензируемой литературе. Также использовались дополнительные источники, такие как Google Scholar, для идентификации дополнительных релевантных публикаций.

Критерии поиска: Поиск проводился с использованием ключевых слов, включающих следующие термины: «digital branding», «university branding», «digital tools in education», «social media marketing» и «higher education marketing». Исключались публикации, не соответствующие тематике исследования, такие как работы, связанные с корпоративным брендингом или брендингом товаров.

В обзор включались статьи:

– опубликованные на английском или русском языках;

– рецензируемые научные статьи, опубликованные в период с 2000 по 2024 год;

– посвященные вопросам использования цифровых инструментов брендинга в контексте высшего образования.

Исключались:

– дублирующиеся публикации;

– материалы, не имеющие теоретической или практической значимости для темы исследования;

– статьи, не содержащие эмпирических данных или аналитического обзора.

Анализ данных: Все выбранные публикации были проанализированы по следующим критериям:

– цели исследования;

– используемые цифровые инструменты брендинга;

– основные результаты и выводы;

– указание на существующие пробелы и перспективы для будущих исследований.

Обработка данных: Для обработки и классификации данных использовались методы контент-анализа. Выделение ключевых тем проводилось на основе частоты упоминания инструментов и их роли в достижении целей брендинга вузов.

Этот подход позволил систематизировать имеющиеся исследования, выявить основные направления применения цифровых инструментов в брендинге вузов и определить ключевые пробелы, требующие дальнейшего изучения.

Поиск по ключевому слову «digital branding», релевантному данному исследованию, в базе данных Scopus дал 1625 публикаций, тогда как база данных Web of Science вернула 4867 исследовательских публикаций. Впоследствии поиск по этим результатам был выполнен с использованием ключевых слов «university branding», «social media marketing» и «higher education marketing» как показано в таблице 1.

Таблица 1 – Выборки исследования

	digital branding		university branding		social media marketing		higher education marketing	
	Total	Social Sciences / Management	Total	Social Sciences / Management	Total	Social Sciences / Management	Total	Social Sciences / Management
Scopus	1625	705	1217	572	20229	5635	4440	2136
Web of Science	4867	550	3420	368	21369	2941	22138	1739

Результаты

Количественный анализ

Из 9 048 исследовательских публикаций, найденных в Scopus, 115 были релевантны целям исследования. Аналогично, из 24 026 исследовательских публикаций в Web of Science 163 были релевантны. Предварительный отбор статей применял следующие ключевые критерии включения: (1) опубликованные на английском или русском языках; (2) рецензируемые научные статьи, опубликованные в период с 2000 по 2024 год; (3) посвященные вопросам использования цифровых инструментов брендинга в контексте высшего образования. Исключались: (4) дублирующиеся публикации; (5) материалы, не имеющие теоретической или практической значимости для темы исследования; (6) статьи, не содержащие эмпирических данных или аналитического обзора.

Всего было выявлено 115 публикаций, которые были дополнительно уточнены, чтобы включить только те исследования, которые эффективно фокусировались на исследуемых темах. В конце этого процесса 108 документа были сохранены и подвергнуты контент-анализу.

Хронология публикации. На данном рисунке 1 представлено количество публикаций, связанных с цифровыми инструментами брендинга вузов, в зависимости от года публикации.

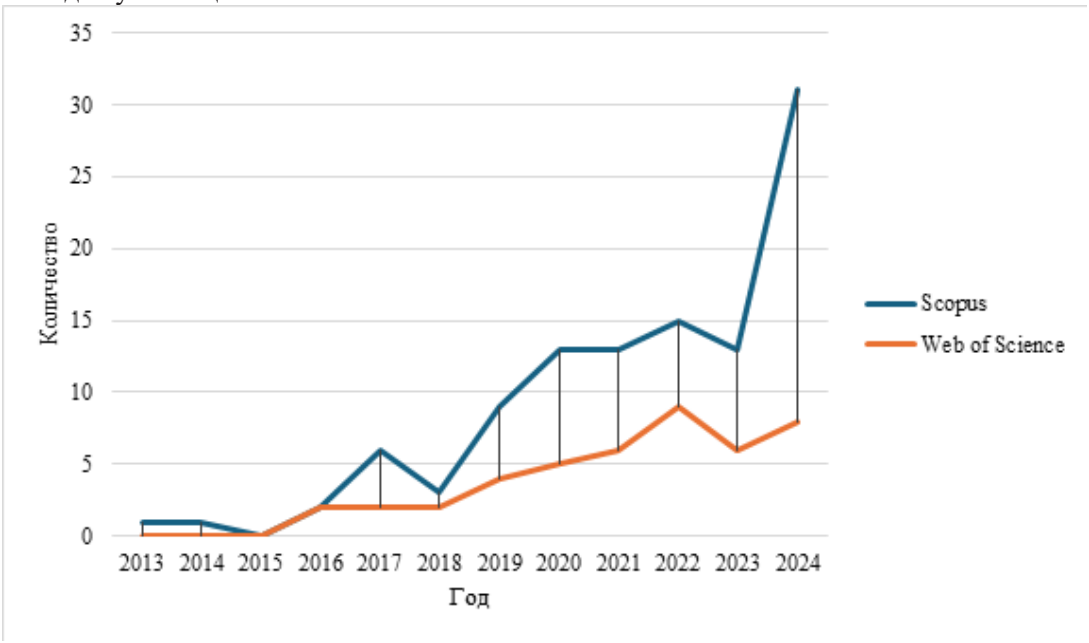

Рис. 1. Публикации по годам в Scopus и Web of Science

Анализ показывает, что с 2015 года наблюдается устойчивый рост интереса к данной теме, что свидетельствует о растущей важности цифровой трансформации в образовательном секторе. Пик публикационной активности приходится на 2020–2022 годы, что, возможно, связано с усилением цифровизации в период пандемии COVID-19. Данный тренд подчеркивает необходимость дальнейшего изучения и разработки инновационных подходов в этой области.

Географический охват. Рисунок 2 отображает вклад различных регионов в исследования по цифровому брендингу вузов.

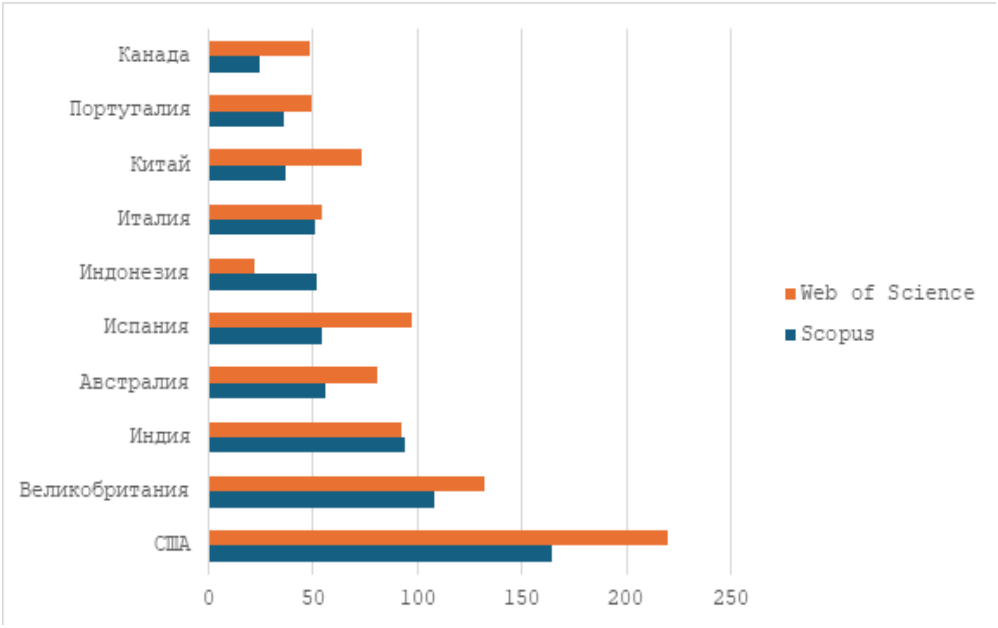

Рис. 2. Распределение статей по странам

Лидерами являются Северная Америка и Европа, где сосредоточено более 60% публикаций. Это может быть связано с высокой конкуренцией между университетами в этих регионах и широким использованием передовых технологий. Азия демонстрирует значительный рост публикаций за последние годы, что отражает динамичное развитие образовательного сектора в странах этого региона. Казахстан занимает 53-е место среди 90 стран. В то же время доля публикаций из развивающихся стран остается низкой, что подчеркивает необходимость поддержки исследований в этих регионах.

Рисунок 3 демонстрирует распределение публикаций по типам в базах данных Scopus и Web of Science. Основные категории включают журнальные статьи, материалы конференций, главы в книгах и другие форматы. Журнальные статьи занимают доминирующую долю, за ними следуют материалы конференций. Остальные категории, такие как главы книг, составляют менее значительную часть выборки.

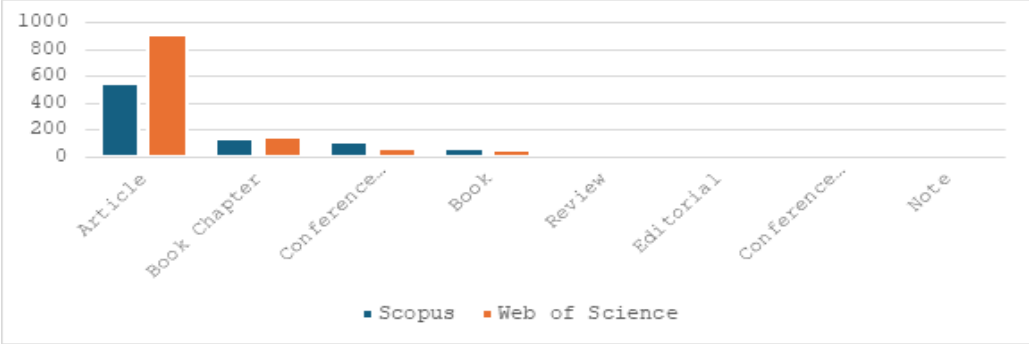

Рис. 3. Сегментация общей категории публикаций по типам в Scopus и WOS

Как показывает анализ, высокая доля журнальных статей указывает на высокий уровень академической активности в области цифрового брендинга вузов. Это может свидетельствовать о том, что авторы предпочитают публиковать результаты своих исследований в наиболее авторитетных и рецензируемых источниках, что способствует их распространению и цитированию. Второе место занимают материалы конференций. Это подчеркивает актуальность темы для обсуждения на научных форумах, где исследователи могут обмениваться новыми идеями и получать обратную связь от коллег. Главы книг и рецензии представлены в значительно меньшей степени. Это может быть связано с тем, что данные форматы чаще фокусируются на обзорах и концептуальных рамках, а не на эмпирических данных, что характерно для исследований в области цифрового брендинга.

Различия в распределении между Scopus и Web of Science могут отражать специфику этих баз данных. Например, Scopus может включать больше материалов конференций, тогда как WOS более строго ориентирован на журнальные публикации.

Также авторы провели анализ популярности цифровых инструментов брендинга. Анализ показывает, что наиболее востребованными инструментами являются социальные сети и аналитика данных. Это связано с их высокой доступностью и эффективностью в охвате целевой аудитории. Использование VR/AR технологий пока остается ограниченным, что указывает на потенциал для дальнейшего развития.

Количественный анализ показывает, что цифровой брендинг вузов является развивающейся областью исследований с высоким уровнем интереса в последние годы. Наиболее популярными инструментами являются социальные сети и аналитика данных, однако VR/AR технологии требуют дальнейшего изучения. Сегментация публикаций демонстрирует академическую значимость темы, а также подчеркивает необходимость в более глубоком анализе и разработке стратегий, учитывающих региональные и технологические аспекты.

Качественный анализ

Качественный анализ основан на количественных данных и включает исследования из Scopus и Web of Science. Согласно критериям, включения и исключения отобранные 108 статей были проанализированы по трем предопределенным категориям: (i) исследовательская проблема; (ii) фокус, включая теоретическую ориентацию и исследовательский контекст; и (iii) результаты исследований, основные выводы и выводы или заключения. На основе проведенного анализа выявлены ключевые направления использования цифровых инструментов для брендинга вузов (Таблица 2).

Таблица – 2. Наиболее часто упоминаемыми инструменты

№	Инструменты	Основные выводы	Ключевые исследования
1	Социальные сети	Основной акцент делается на использовании платформ, таких как Instagram, Facebook и LinkedIn, для создания узнаваемости бренда, взаимодействия со студентами и продвижения образовательных программ. Исследования показывают, что активное присутствие в социальных сетях способствует укреплению доверия к вузу	Kaplan & Haenlein (2010): Доказано, что активное использование социальных сетей повышает доверие к вузу и способствует построению длительных взаимоотношений с аудиторией. Chen et al. (2015): Установлено, что Instagram наиболее эффективен для вовлечения студентов в процесс взаимодействия с университетом. Smith & Zook (2016): Описаны стратегии создания привлекательного контента для социальных платформ. Kumar et al. (2021): Исследованы метрики для оценки успешности кампаний в социальных сетях.
2	Аналитика данных	Использование аналитических платформ, таких как Google Analytics и социальные медиаметрические инструменты, позволяет вузам отслеживать поведение аудитории, адаптировать маркетинговые стратегии и повышать эффективность брендинга.	Chaffey & Smith (2017): Описано использование аналитики для оптимизации маркетинговых стратегий. Google Analytics (Официальный отчет, 2020): Обзор возможностей платформы для вузов. Brown & Davis (2018): Указано на значимость персонализированных данных в брендинге. Lee et al. (2022): Анализ эффективности применения медиаметрических инструментов в вузах.
3	Контент-маркетинг	Создание уникального образовательного контента, включая видеоролики, блоги и подкасты, является важным элементом брендинговой стратегии. Такой контент помогает вузам формировать имидж инновационных и прогрессивных учреждений.	Pulizzi (2012): Подчеркнута важность создания образовательного контента для повышения репутации вуза. Holliman & Rowley (2014): Описаны методы разработки контент-стратегий для образовательных организаций. Raftery et al. (2019): Доказана эффективность видео-форматов в образовательном контенте. Chen et al. (2020): Обсуждены подходы к созданию подкастов для привлечения студентов.
4	Виртуальные и дополненные технологии	Использование VR/AR для проведения виртуальных туров по кампусам и демонстрации образовательных возможностей стало новым трендом в продвижении вузов.	Milgram & Kishino (1994): Основополагающее исследование в области VR/AR технологий. Beck & Jones (2020): Описаны кейсы успешного использования VR-туров вузами. Silva et al. (2021): Подчеркнуты возможности AR для привлечения студентов. Xu et al. (2023): Указаны барьеры и перспективы применения виртуальных технологий в брендинге.

Анализ также выявил основные пробелы в исследованиях, включая: (1) недостаток эмпирических данных, подтверждающих эффективность отдельных инструментов брендинга; (2) отсутствие исследований, фокусирующихся на региональных особенностях применения цифровых стратегий в высшем образовании; (3) ограниченное внимание к долгосрочным эффектам цифрового брендинга на восприятие вузов.

Результаты и обсуждение

Результаты данного исследования подчеркивают значимость цифровых инструментов брендинга в повышении конкурентоспособности вузов. Наиболее активно применяются социальные сети и аналитика данных, что объясняется их доступностью и эффективностью в привлечении целевой аудитории. Контент-маркетинг также занимает важное место, способствуя созданию уникального имиджа учебных заведений через разработку образовательного контента.

Однако использование VR/AR технологий остается ограниченным. Хотя эти технологии демонстрируют значительный потенциал для привлечения студентов, их внедрение осложняется высокими затратами на разработку и поддержание таких решений. Тем не менее, университеты, использующие VR/AR, демонстрируют улучшение вовлеченности и позитивное восприятие со стороны целевой аудитории.

Анализ публикаций также выявил следующие пробелы:

Региональные различия: Большинство исследований сосредоточено на вузах Северной Америки и Европы, что ограничивает понимание применения цифровых инструментов в развивающихся странах.

Долгосрочные эффекты: Отсутствуют исследования, направленные на анализ долгосрочных результатов применения цифровых технологий в брендинге.

Оценка эффективности: Необходимы стандартизированные метрики для оценки успешности брендинговых кампаний.

Рекомендуется сосредоточиться на разработке междисциплинарных подходов, объединяющих цифровые технологии и стратегии брендинга. Важным направлением будущих исследований является изучение влияния культурных и социальных факторов на восприятие цифрового брендинга вузов, а также анализ его вклада в развитие образовательных систем в глобальном масштабе.

Заключение

Цифровые инструменты брендинга представляют собой мощный ресурс для повышения конкурентоспособности вузов в условиях глобальной цифровой трансформации. Результаты проведенного систематического обзора подчеркивают важность таких инструментов, как социальные сети, аналитика данных, контент-маркетинг и технологии виртуальной реальности (VR/AR), в создании уникального и устойчивого бренда учебных заведений.

Тем не менее, анализ выявил ряд проблем, требующих дальнейшего исследования, включая ограниченное применение VR/AR технологий, недостаток исследований, посвященных долгосрочным эффектам цифрового брендинга, и необходимость разработки стандартизированных метрик оценки эффективности.

Важным направлением будущих исследований является изучение региональных особенностей использования цифровых инструментов, а также их адаптации к различным культурным и социальным контекстам. Университеты могут извлечь значительную пользу из интеграции цифровых технологий в свои брендинговые стратегии, что позволит не только укрепить их позиции на образовательном рынке, но

и повысить их привлекательность для международной аудитории.

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АҚПАРАТТЫҚ ТЕХНОЛОГИЯЛАР
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METHOD OF EXPRESS ANALYSIS OF PROJECT VALUE

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Abstract. The article introduces a methodology for express project value analysis, focusing on preliminary feasibility and investment efficiency evaluation. It examines expert evaluations of complex parameters expressed as interval values on numerical scales. Two approaches are analyzed: arithmetic mean and weighted averaging of interval boundaries. The proposed weighted method assigns greater importance to narrower intervals, assuming they represent high-er expertise, thus improving the accuracy and quality of agreed evaluations. Calculations and visual data demonstrate the benefits of weighted averaging, including reduced interval width and more precise results. The method also shifts the interval center toward the narrower ranges, re-flecting more excellent reliability in expert assessments. The findings underscore the significance of using interval-based evaluations and weighted averaging in express analysis, offering a more refined approach to project valuation. This methodology enhances decision-making by providing a robust, expert-informed foundation for evaluating project feasibility and investment potential at the initial assessment stage.

Keywords: express analysis, project valuation, interval values, expert evaluation, weighted averaging, investment efficiency

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ЖОБАНЫҢ ҚҰНЫН ЭКСПРЕСС-ТАЛДАУ ӘДІСІ

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Аннотация. Мақалада инвестициялардың орындылығы мен тиімділігін алдын-ала бағалауға бағытталған жоба құнын жедел талдау әдістемесі келтірілген. Онда сандық шкалаларда интервалдық мәндер түрінде көрсетілген күрделі параметрлердің сараптамалық бағалары қарастырылады. Екі тәсіл талданады: орташа арифметикалық және аралық шекаралардың өлшенген орташалануы. Ұсынылған өлшенген әдіс тар интервалдарға үлкен мән береді, бұл олардың жоғары сараптаманы білдіреді, осылайша келісілген бағалаулардың дәлдігі мен сапасын арттырады. Есептеулер мен визуалды деректер өлшенген орташаландырудың артықшылықтарын, соның ішінде қысқартылған аралық ені мен дәлірек нәтижелерді көрсетеді. Әдіс сонымен қатар интервалдың центрін тар диапазондарға қарай жылжытады, бұл сараптамалық бағалаудың сенімділігін көрсетеді. Нәтижелер жобаны бағалауға жақсырақ тәсілді ұсына отырып, экспресс-талдауда аралық бағалауды және салмақты орташаландыруды пайдаланудың маңыздылығын көрсетеді. Бұл әдістеме бағалаудың бастапқы кезеңінде жобаның орындылығы мен инвестициялық әлеуетін бағалау үшін сенімді, сараптамалық негізделген негізді қамтамасыз ету арқылы шешім қабылдауды жақсартады.

Түйін сөздер: экспресс-талдау, құнды бағалау, аралық мәндер, сараптамалық баға-лау, өлшенген орташалау, инвестициялық тиімділік

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МЕТОДИКА ЭКСПРЕСС-АНАЛИЗА ЦЕННОСТИ ПРОЕКТА

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Аннотация. В статье представлена методология экспресс-анализа стоимости проекта, сфокусированная на предварительной оценке осуществимости и эффективности инвестиций. В ней рассматриваются экспертные оценки сложных параметров, выраженных в виде интервальных значений на числовых шкалах. Анализируются два подхода: среднее арифметическое и взвешенное усреднение границ интервалов. Предлагаемый взвешенный метод придает большее значение более узким интервалам, предполагая, что они представляют более высокую экспертность, тем самым повышая точность и качество согласованных оценок. Расчеты и визуальные данные демонстрируют преимущества взве-

шенного усреднения, включая уменьшенную ширину интервала и более точные результаты. Метод также смещает центр интервала в сторону более узких диапазонов, что отражает большую надежность экспертных оценок. Результаты подчеркивают важность использова-ния интервальных оценок и взвешенного усреднения в экспресс-анализе, предлагая более совершенный подход к оценке проекта. Эта методология улучшает принятие решений, пре-доставляя надежную, экспертно-информированную основу для оценки осуществимости проекта и инвестиционного потенциала на начальной стадии оценки.

Ключевые слова: экспресс-анализ, оценка стоимости, интервальные значения, экспертная оценка, взвешенное усреднение, инвестиционная эффективность

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Introduction

When analyzing the value of projects, you should adhere to a comprehensive, step-by-step approach. This approach allows to stop in time, that is, the project can be rejected at any stage of the analysis, which saves time and money. Using this approach allows not only to identify the pros and cons of the project but also to see its distinctive features from similar projects and to predict the result that investors will receive upon successful implementation of the project.

The use of an integrated approach implies the following step-by-step analysis scheme: express analysis, strategic analysis, technical analysis, commercial analysis, project risk analysis, environmental analysis, and financial and economic analysis.

To date, there is no single, accepted methodology for analyzing project value. Different approaches to project analysis and an unstable regulatory framework leave the issue of improving value analysis methods open.

The methodological basis of project analysis is the following (Projects In a Controlled Environment):

1) systematicity – consideration of the entire system of relationships between project participants and their economic environment, the most important factors influencing the costs and results of each participant, as well as internal, external, and synergistic effects. For such consideration, the project description should include a description of the possible mechanism of interaction of all project participants (the organizational and economic mechanism for project implementation);

2) the comprehensive nature of the project analysis (and project expertise), which is man-ifested in the application of various types of project analysis and the preparation of a thorough business plan for the project (or a conclusion on the results of the expertise);

3) materiality – consideration of all the most significant consequences of the project. When assessing the value, all significant implications of the project implementation, both directly economic and non-economic (social, environmental, impact on the country's security), must be considered. In cases where the impact of such consequences of the project implementation on the value allows for a quantitative assessment, it should be made. In other cases, this impact must be considered by experts;

4) continuity – conducting project analysis throughout its entire life cycle (by individual participants – until exiting the project);

5) strategic – compliance with the development strategy and investment policy of the country, region, company (bank);

6) effectiveness – the presence of a positive social and economic effect on the project;

7) quality – high quality and sufficiency of the design and other documentation necessary for preparing a business plan (or examining the project in the bank).

The depth and scope of analytical work in project analysis depend on the scale of the project, its capital intensity, and the socio-economic consequences of implementation. Capital-intensive projects require a more detailed and in-depth analysis of the project. For projects of lower cost, project analysis can be performed using a simplified scheme that requires the involvement of external experts to conduct a technical, legal, and environmental analysis of the project (GPM® Global P5TM).

There are different types of project analysis: express analysis, strategic, technical, commercial, legal, project risks, environmental, financial, and economic.

Each type of analysis has specific evaluation criteria (Smith, 2011).

The project initiator can conduct an express analysis of a project to determine the feasibility of implementing the project and the effectiveness of investments before developing a detailed business plan. Express analysis of a project by a financial institution includes a preliminary assessment of the project, an evaluation of the reliability of the business plan data presented by the initiator (or executor) of the project to decide on the advisability of a more in-depth analysis of the project if it complies with the investment policy of the bank or group of investors (Vilensky et al., 2012: 888; Jenner, 2015: 76–89).

Materials and Methods

Express analysis of the value of the project creation of a new jewelry brand ***Sweet Kids*** *at the preliminary assessment stage of the project*

The main question that an investor wants to answer at the preliminary assessment stage of a project is: Do the project's positive results outweigh the costs of its implementation?

To analyze a project's costs and income, it is necessary to answer the following questions: what is the project's desired outcome? Who is covering the costs of the project? Who will benefit from the positive results of the project? When and how will the positive results of the project be identified?

Specific criteria are often used to analyze a project and evaluate its profitability and return on investment (Flyvbjerg, 2016).

The following criteria of project value are distinguished:

1. Net present value (NPV).
2. The ratio of benefits and costs of the project.
3. Cost efficiency.
4. Profit in the first year.
5. Payback period of investment.
6. Comparison of different value criteria.

To implement different versions of the *Sweet Kids project,* an agreement was reached with investors to conduct an express analysis of the project as a preliminary assessment of its value. One of the most critical indicators of such an analysis was the retail price of different production units. Expert assessments, open-source materials, and insider information were used for this.

The data varies across categories, the products are difficult to classify, and the price range is extensive.

Table 1 – Sova jewelry brand Table 2 – Jewelry brand Stolichnaya Jewelry Factory

Table 1 – Sova jewelry brand

Metal			
32.8 %	58	2 044 UAH	4 373 UAH
37.3 %	66	4 373 UAH	8 746 UAH
19.2 %	34	8 746 UAH	13 119 UAH
10.7 %	19	13 119 UAH	17 492 UAH
Q_{tv}	177	Average price	7 240 UAH

Table 2 – Jewelry brand Stolichnaya Jewelry Factory

Metal			
50.0 %	7	1 121 UAH	2 181 UAH
28.6 %	4	2 181 UAH	3 241 UAH
14.3 %	2	3 241 UAH	4 301 UAH
7.1 %	1	4 301 UAH	5 350 UAH
Q_{tv}	14	Average price	2 483 UAH

Table 3– Jewelry brand Onyx

Metal			
51.7 %	15	1 633 UAH	2 033 UAH
37.9 %	11	2 033 UAH	2 433 UAH
3.4 %	1	2 433 UAH	2 833 UAH
6.9 %	2	2 833 UAH	3 246 UAH
Q_{tv}	29	Average price	2 096 UAH

Table 4 – Jewelry brand Golden Age

Metal			
60.0 %	24	1 008 UAH	2 085 UAH
27.5 %	11	2 085 UAH	3 162 UAH
5.0 %	2	3 162 UAH	4 239 UAH
7.5 %	3	4 239 UAH	5 316 UAH
Q_{tv}	40	Average price	2 193 UAH

МАТЕМАТИЧНІ ХАРАКТЕРИСТИКИ

Матеріал	Варіість min	Варіість max	Кіл-ть
Метал	744	2418,8	58
Метал	2418,8	4093,6	66
Метал	4093,6	5768,4	43
Метал	5768,4	7443,2	29
Метал	7443,2	9118	56
Метал	9118	10792,8	32
Метал	10792,8	12467,6	8
Метал	12467,6	14142,4	9
Метал	14142,4	15817,2	10
Метал	15817,2	17492	10
			321
1674,8			

Xср.	6297,9707
X Mo	2418,8
d	1674,8
f Mo-1	58
f Mo+1	43
f Mo	66
Mo	2851,0065
X Me	4093,6
Efi/2	160,5
S Me-1	58
f Me	66
Me	5515,2326
Ср.лин.відх	3321,4811
Дисперсія	15974750
СКВ	71609,32
Варіація	1137,0221

Варіість		Кіл-ть, f	Ср.варіість	fn	X-Xcp	lX-Xcpl	nlX-Xcpl	(X-Xcp)^2	((X-Xcp)^2)*f
744	2418,8	58	1581,4	91721,2	-4716,57	4716,571	273561,1	22246039	1290270281
2418,8	4093,6	66	3256,2	214909,2	-3041,77	3041,771	200756,87	9252369,1	610656360,1
4093,6	5768,4	43	4931	212033	-1366,97	1366,971	58779,741	1868608,9	80350184,41
5768,4	7443,2	29	6605,8	191568,2	307,8293	307,8293	8927,0492	94758,868	2748007,165
7443,2	9118	56	8280,6	463713,6	1982,629	1982,629	111027,24	3930818,9	220125857
9118	10792,8	32	9955,4	318572,8	3657,429	3657,429	117037,74	13376789	428057246,8
10792,8	12467,6	8	11630,2	93041,6	5332,229	5332,229	42657,834	28432669	227461353,1
12467,6	14142,4	9	13305	119745	7007,029	7007,029	63063,264	49098459	441886134,4
14142,4	15817,2	10	14979,8	149798	8681,829	8681,829	86818,293	75374160	753741597,1
15817,2	17492	10	16654,6	166546	10356,63	10356,63	103566,29	107259770	1072597701
		321		2021648,6			1066195,4		5127894722

Figure 1 – Statistical characteristics of retail prices for the product type "Metal earrings"

As an initial option for conducting an express analysis of the project to assess the retail price of a product, a variant of the most straightforward statistical processing was considered. Using the Excel software product, general averages were calculated considering weighted average values, namely, the number of units of production falling into certain intervals. This is a mathematical expectation calculated by taking weight into account.

$$M = (177*7240+14*\ 2\ 483+29*2096+40*2193+61*1851)/321= (1281480+ +34\ 762+60\ 784+87\ 720+112\ 911)\ /321=4\ 914.8\ UAH$$

Secondary calculations were made, considering probability distributions. A histogram and a distribution polygon of retail prices for summary values for several brands were constructed (*Ivanov*, 2018).

The project team further noted that the range of the interval was not considered anywhere in these express analysis options for the project's retail price. It was decided to use the method of averaging interval estimates for different types of quantitative and qualitative scales.

With this type of retail price calculation, a large spread in the values of the general mean, mode and median becomes apparent.

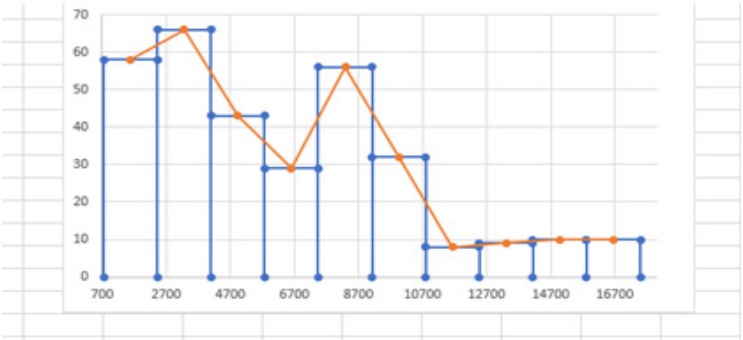

Figure 2 – Histogram and distribution polygon of retail prices for the product type "Metal Earrings"

In many cases, numerical (quantitative) scales are used in expert assessments of complex properties (parameters). Individual expert assessments are formed as values in the corresponding scales (let us call them point assessments), and the agreed-upon (group) assessment is determined by averaging individual expert assessments.

At the same time, when assessing difficult-to-formalize properties of objects, systems, and processes, including those of a qualitative nature, experts in most cases "gravitate" toward assessment in ordinal scales ("high", "medium", "low"), or, complicating the formation of a point assessment on a numerical scale, assess the value of the analyzed property in the form of a specific interval on a numerical scale (the value of the property/parameter is in the range from c_1 to c_2, where c_1 and c_2 are the left and right boundaries of the assessment interval).

As a result, an urgent task is analyzing the features of processing expert assessments in the form of intervals on numerical scales, including the so-called quasi-numerical (point) scales widely used in expert assessments. Quasi-numerical scales include point scales in which the base *B* (range) is greater than or equal to 100. Unlike small-range point scales (3- , 5- , 10-point scales), which are, in fact, a type of ordinal scales, experts, when giving assessments in 100 or more range point scales, are guided not only by the dominance relations between the assessed objects according to the corresponding property (parameter), but also analyze the values (distances) and relations between assessments.

Therefore, the estimates of parameters in such point scales become closer in their properties to estimates in numerical (including absolute) scales. At the same time, since the unit of measurement "point" is a kind of universal abstraction of the quantitative expression of any properties (parameters), then such point scales are called "quasi-numerical".

Important parameters of the assessments in the form of an interval $[c_{1i}, c_{2i}]$ (the index *i* induces the individual assessment of the i -th expert) are:

$\overline{C}_i = (c_{1i}, c_{2i})/2$ – center of the interval;

$\Delta i = (c_{2i}, c_{1i})$ – interval width.

Interval scale C int we will call the set of all intervals (c_{2i}, c_{1i}) in some numerical scale C (≤, –, /, B, 0), on which the operations of dominance (≤), difference (–), steps (/), base B (range) and zero of the scale are defined .

The simplest logic for defining the operations (≤), (–) and (/) in an interval scale is the corresponding operators from the interval centers. In this case:

$[c_{1i}, c_{2i}] \leq [c_{1j}, c_{2j}]$, when $i\ C_i \leq C_j$;

$|[c_{1i}, c_{2i}] - [c_{1j}, c_{2j}]| = |\overline{C}_i - \overline{C}_j|$;

$[c_{1i}, c_{2i}]/[c_{1j}, c_{2j}] = \overline{C}_i / \overline{C}_j$.The target aspect of the expert assessment procedure is the

formation of the so-called group (agreed) assessment (PMBOK vs. Scrum), which is the result of the aggregation of individual expert assessments.

The aggregation process is based on the criterion of minimizing the sum of distances of individual assessments from the group assessment:

$$\sum_{n=1}^{N} d(\widehat{C_{grup}}, \widehat{C_n}) \rightarrow \min, \quad (1)$$

where $\widehat{C_{grup}}$ is the group (agreed) assessment of experts; $\widehat{C_n}$ is the individual assessment of the n -th expert; $d(\widehat{C_{grup}}, \widehat{C_n})$ is the degree of distance of the individual assessment of the n-th expert from the group assessment; N is the number of aggregated expert assessments.

It is known that criterion (1) is satisfied by various averages (arithmetic mean, root mean square, Kolmogorov mean, etc.), calculated based on the corresponding measures (distances). The natural tendency when choosing the distance d between two intervals is to use the modulus of the difference between the centers of the intervals:

$$d_{ij}([c_{1i}, c_{2i}], [c_{1j}, c_{2j}]) = |\overline{C}_i - \overline{C}_j|. \quad (2)$$

It is easy to see that the quantities d ij satisfy the requirements of the metric (non-negativity, "triangle rule", symmetry). Thinking in this way, we can conclude that the simplest solution for determining the average on a set of assessments in the form of intervals $\{[c_{11}, c_{21}], [\ ], [c_{12}, c_{22}\ldots], [c_{1N}, c_{2N}]\}$, expressing the group opinion of experts, is to determine the boundaries of the interval of the aggregated (group) assessment in the form of the arithmetic mean of the corresponding boundaries of the set, which averages the intervals:

$$[\widehat{C_{1\,grup}}, \widehat{C_{2\,grup}}] = (\frac{1}{N}\sum_{n=1}^{N}\widehat{C_{1n}}, \frac{1}{N}\sum_{n=1}^{N}\widehat{C_{2n}}) \quad (3)$$

As already noted, the estimates of the values of the analyzed properties in the form of intervals are characterized by another aspect – the width of the interval $\Delta_i = (c_{2i}, c_{1i})$, which in a certain sense can be considered as a certain characteristic of the quality (qualification) of the expert assessment).

In other words, the narrower the interval of the individual expert's assessment (the smaller the spread with which he determines the value of the property being assessed), the more "high-quality" ("qualified") his assessment can be considered. It is easy to see that when obtaining a group assessment in the form of an interval according to the relation (3), its width is the arithmetic mean of the corresponding values of the width of the intervals of individual expert assessments:

$$\overline{\Delta_{grup}} \quad \frac{1}{N}\sum_{n=1}^{N}\Delta_n \quad (4)$$

However, if the interval width is interpreted as the individual quality of the assessment (another option is as the level of the expert's assessment qualification), then the contribution of the individual assessment to the formation of the group assessment should be the greater, the narrower the interval. This property of the averaging procedure (3) can be achieved by replacing the same averaging coefficients $\frac{1}{N}$ with normalized coefficients $\sum_{n=1}^{N}\mu_n = 1$, which

are the greater, the smaller the width of the corresponding interval.

One such approach may be to calculate the averaging weighting coefficients μ n using the following relation:

$$\mu_n = \frac{\sum_{i=1}^{N}\Delta_i - \Delta_n}{(N-1)\sum_{i=1}^{N}\Delta_i}, \quad (5)$$

and the procedure for obtaining a group (average) estimate in the form of an interval with this approach is determined by the ratio:

$$[\widehat{C_{1\,grup}}, \widehat{C_{2\,grup}}\,] = (\sum_{n=1}^{N} \mu_n \widehat{C_{1n}}, \sum_{n=1}^{N} \mu_n \widehat{C_{2n}}). \quad (6)$$

It is easy to see that the width of the average interval (weighted group), obtained according to relation (6), is determined by the following expression:

$$\Delta_{grup\,z} = \sum_{n=1}^{N} \mu_n \Delta_n, \quad (7)$$

where Δ_n – the width of the interval of the n -th individual assessment.

It should be noted that other posterior coefficients of the formed expert qualifications can also be used during averaging, depending on the distance of the individual expert assessment from group one.

An analysis of the behavior of the averaging results based on relations (3) and (6) shows that the group estimate in the form of an interval obtained based on a weighted average taking into account the width of the intervals "behaves" much more "correctly" compared to the results based on a simple arithmetic mean averaging of the boundaries. In particular, the width of the interval corresponding to the agreed (group) estimate obtained, considering the width of the averaged intervals, is equal to or less than the width of the group estimate obtained based on arithmetic mean averaging.

In addition, the interval of the center of the agreed group assessment, obtained based on averaging weighted considering the width of the intervals, constantly shifts toward the center of the least wide of the averaged intervals. Thus, if the width and center of the averaged interval are interpreted as the quality of expert assessment (accuracy of the group assessment, final assessment, expert qualification), then averaging based on the relation (6) yields higher quality (more accurate, more qualified) results of expert assessments.

It should be noted that other posterior coefficients of expert qualifications can also be used during averaging, formed depending on the distance of the individual expert assessment from the group assessment (Gilman, 2017).

There are many advantages to this calculation. The following are obvious for comparison: the interval range of the retail price. For this type of product, namely "Metal Earrings", the interval of the retail price, calculated using the arithmetic mean, is (1310; 7061.8). And the interval calculated using this method is (1240.71; 5929.70). In the first case, the width of the interval $\Delta_{\mathbf{grup}} = 5751{,}8,$ in the second $\Delta_{\mathbf{grup\,z}} = 4689.$ And further, the average retail price for the item "Metal earrings", calculated using the formula $\overline{C_i} = (c_{1i}, c_{2i})/2$ equals 2875.9. And the average value considering the weighted average values is equal to 2344.5 .

If we determine the error for such calculations, the absolute error is ΔC =2875.9 - 2344.5 = 532.4. The relative error is δC =532.4/2344.5*100 % = 22.7%. Such a large relative error indicates that the weighted interval averaging method is more accurate and better meets the requirements of express analysis of the project value.

In this case, the question of how much the width decreases and the center of the interval obtained based on relation (6) changes compared with simple arithmetic mean averaging based on relation (3) is essential from both a theoretical and a practical point of view. In other words, how much the width decreases and the center of the group expert assessment changes when averaging individual expert assessments, considering the width of their intervals. As the analysis of averaging options shows, the degree of decrease in the width and shift in the center of the final assessment interval depends significantly on the ratio of their width and the mutual arrangement of the averaged intervals.

Moreover, the changes in the width and center of the group assessment interval are more significant the more the averaged intervals of individual assessments differ in width and the further the center of the smallest width of the averaged intervals is shifted.

In the case of averaging two intervals, the problem of analyzing the degree of reduction in the width of the group assessment interval can be reduced to a function of one argument, and the

following relationship can be obtained:

$$\frac{\Delta_{grup\ z}}{\Delta_{grup}} = \frac{4x}{(x+1)^2}, \quad (8)$$

where $\Delta_{grup\ z}$ is the width of the averaged interval according to relation (6); Δ_{grup} – the width of the averaged interval according to the relation (3); $x = \frac{\Delta_1}{\Delta_2}$ – the ratio of the averaged intervals by width. Fig. 3 shows the graph of the function determined by the relation (8).

X- axis shows the ratios of the widths of the averaged intervals. The $\frac{\Delta_1}{\Delta_2}$. Y- axis shows – $\frac{}{\Delta_{grup\ z}}$ ratio Δ_{grup} the width of the interval obtained based on simple (arithmetic mean) and weighted averaging (the case of averaging two intervals). As it should be with meaning of the coefficients of weighted averaging μ n, there is no "gain" in the width of the group interval estimate when the width of the averaged intervals is the same. When the width of the averaged intervals differs significantly, the width of the interval based on weighted averaging can be significantly smaller than the width of the interval obtained based on simple (arithmetic mean) averaging.

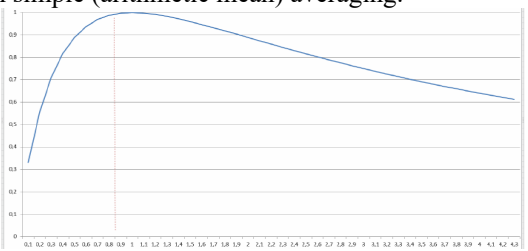

Figure 3 – Ratio of interval widths obtained based on weighted and simple (arithmetic mean) averaging of 2 intervals

The ratio of the centers of group estimates obtained based on weighted and simple (arithmetic mean) averaging, in the case of averaging two intervals, can be expressed as a function of two arguments:

=2 , (9)

where ; ; is the center of the interval of the first estimate; is the center of the interval of the second estimate.

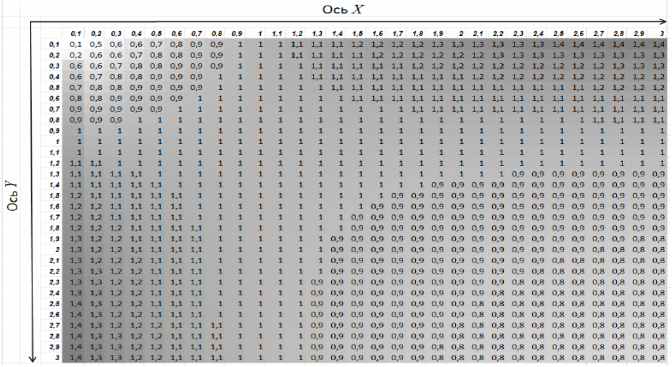

Figure 4 – "Flat" two-dimensional histogram

Fig. 4 shows a "flat" histogram of the function , illustrating the degree of displacement of the center of the group estimate , obtained on the basis of weighted and simple (arithmetic mean) averaging of two intervals depending on the ratio of their width () and centers (). The value of the ratio is displayed directly in the cell with the corresponding values of x and y. For greater clarity, each cell is filled with a gray background, the intensity of which is

determined depending on the maximum value n the corresponding area of arguments.

Analysis of the data presented in Fig. 4 shows that in any case (except for equal width () and coincidence of the centers () of two averaged intervals) the center of the result of weighted averaging always shifts toward the smaller interval in width, and this shift is greater the more the averaged intervals differ in width and the position of the centers.

The "gain" in shifting the center of the group assessment obtained by weighted averaging about the result of arithmetic mean averaging can reach significant values. Thus, the use of expert assessments in the form of intervals (ranges) on numerical (quasi-numerical) scales can provide a more qualified expert assessment of the values of difficult-to-formalize parameters, especially in cases where the procedure of weighted averaging is used to obtain a group (agreed) expert assess-ment, considering the width of the intervals of individual expert assessments.

Conclusion

The project initiator conducts an express analysis of the project to determine the feasibil-ity of implementing the project and the effectiveness of investments before developing a detailed business plan. Express analysis of the project includes a preliminary assessment of the project, an evaluation of the reliability of the business plan data presented by the initiator (or executor) of the project to decide on the advisability of a more in-depth analysis of the project in the event of its compliance with the investment policy of the bank or group of investors.

The focus of a project's express analysis is assessing its economic value and technical ability to be implemented.

The article analyzes the features of expert evaluation of preliminary and express analysis of project value assessment in the form of difficult-to-formalize properties (parameters) using interval values on numerical scales. To obtain a coordinated expert assessment, two approaches to averaging evaluations in the form of intervals are considered - based on simple (arithmetic mean) and weighted averaging of the corresponding interval boundaries.

It is proposed to "weight" the interval boundaries depending on the interval width, based on the principle: "the smaller the width of the assessment interval, the more "qualified" the expert evaluates the value of the analyzed property, and the greater the weight should be taken into ac-count when averaging the boundaries of the corresponding interval." In the case of averaging two intervals, an increase in the qualification of the agreed expert assessment with weighted averaging is analyzed.

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ENHANCING LEARNING THROUGH HUMAN-CENTRIC DESIGN: A NOVEL PLATFORM

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Abstract. This paper explores the development and effectiveness of a gamified learn-ing platform designed to enhance student engagement and learning outcomes. Traditional teaching methods in higher education often fail to address the diverse learning needs of stu-dents, leading to reduced engagement and efficacy. The study aims to bridge this gap by in-corporating elements from cognitive science, gamification, and comics into a new e-learning platform. The platform was developed using the Angular framework and featured various interactive components such as video lessons, picture-text-text (PTT) animations, and comic strips to motivate students. We conducted an experiment with twelve students, divided into four groups: one using traditional learning methods and three using diverse types of con-tent on the gamified platform. Participants' knowledge was assessed through pretests and posttests, and their mood and engagement levels were measured using a funometer. Results showed that students using the gamified platform, especially those in the Type 1 group (com-ics followed by video and PTT), had significantly higher learning gains and better mood scores compared to those using traditional methods. The study highlights the potential of gamified and human-centric designs in improving educational experiences. Future research will focus on testing the platform across different age groups and subjects to better under-stand its broader applicability and long-term effects on student motivation and learning.

Keywords: human-centric design, gamification, learning platform, online learning, user engagement

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АДАМҒА БАҒДАРЛАНДЫРЫЛҒАН ДИЗАЙН АРҚЫЛЫ ОҚУДЫ ЖЕТІЛДІРУ: ЖАҢА ПЛАТФОРМА

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Аннотация. Бұл мақалада оқушылардың белсенділігі мен оқу нәтижелерін жақсартуға арналған ойын негізіндегі оқыту платформасының дамуы мен тиімділігі қарастырылады. Жоғары оқу орындарындағы дәстүрлі оқыту әдістері көбінесе студенттердің әртүрлі оқу қажеттіліктерін қанағаттандыра алмайды, соның салдарынан сабаққа қатысу және тиімділік төмендейді. Біздің зерттеуіміз когнитивтік ғылым, геймификация және комикс элементтерін жаңа электрондық оқыту платформасына енгізу арқылы осы алшақтықты жоюға бағытталған. Платформа бұрыштық негізді қолдану арқылы әзірленді және студенттерді ынталандыру үшін бейне оқулықтар, суреттен мәтінге (PTT) анимациялар және комикстер сияқты әртүрлі интерактивті компоненттерді қамтиды. Біз төрт топқа бөлінген 12 оқушымен эксперимент жүргіздік: біреуі дәстүрлі оқыту әдістерін және үшеуі ойын алаңында әртүрлі мазмұн түрлерін қолданды. Қатысушылар білімі алдын ала және посттест арқылы бағаланды, ал олардың көңіл-күйі мен белсенділік деңгейі фанометр арқылы өлшенді. Нәтижелер ойын платформасын пайдаланатын студенттердің, әсіресе one типті топтағы (комикстерден кейін бейнелер мен PTT) дәстүрлі әдістерді пайдаланатындармен салыстырғанда оқу жетістіктері мен жақсы көңіл-күй көрсеткіштерін көрсетті. Зерттеу білім беру тәжірибесін жақсарту үшін ойынға негізделген және адамға бағытталған жобалардың әлеуетін көрсетеді. Болашақ зерттеулер оның кеңірек қолдану мүмкіндігін және студенттердің мотивациясы мен оқуына ұзақ мерзімді әсерін жақсырақ түсіну үшін платформаны әртүрлі жас топтары мен пәндер бойынша тестілеуге бағытталған.

Түйін сөздер: Адамға бағытталған дизайн, геймификация, оқу платформасы, онлайн оқыту, пайдаланушыларды тарту

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УЛУЧШЕНИЕ ОБУЧЕНИЯ С ПОМОЩЬЮ ЧЕЛОВЕКО-ЦЕНТРИРОВАННОГО ДИЗАЙНА: НОВАЯ ПЛАТФОРМА

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Аннотация. В этой статье рассматривается разработка и эффективность игровой обучающей платформы, предназначенной для повышения вовлеченности студентов и результатов обучения. Традиционные методы обучения в высших учебных заведениях часто не отвечают разнообразным потребностям студентов в обучении, что приводит к снижению вовлеченности и эффективности. Наше исследование направлено на преодоление этого разрыва путем включения элементов из когнитивной науки, геймификации и комиксов в новую платформу электронного обучения. Платформа была разработана с использованием фреймворка Angular и включала различные интерактивные компоненты, такие как видеоуроки, анимации «картинка-текст-текст» (PTT) и комиксы для мотивации студентов. Мы провели эксперимент с 12 студентами, разделенными на четыре группы: одна использовала традиционные методы обучения, а три использовали различные типы контента на игровой платформе. Знания участников оценивались с помощью предварительных и итоговых тестов, а их настроение и уровень вовлеченности измерялись с помощью фанометра. Результаты показали, что студенты, использующие игровую платформу, особенно в группе типа 1 (комиксы, за которыми следовали видео и PTT), показали значительно более высокие результаты в обучении и баллы за настроение по сравнению с теми, кто использовал традиционные методы. Исследование подчеркивает потенциал геймифицированных и ориентированных на человека проектов в улучшении образовательного опыта. В дальнейшем исследования будут сосредоточены на тестировании платформы на разных возрастных группах и предметах, чтобы лучше понять ее более широкую применимость и долгосрочные эффекты на мотивацию и обучение студентов.

Ключевые слова: человеко-ориентированный дизайн, геймификация, обучающая платформа, онлайн-обучение, вовлечение пользователей

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Introduction

In contemporary higher education, the conventional paradigms of teaching and learning have remained unchanged. Despite advances in technology and pedagogy, many educa-tional institutions still rely heavily on traditional methods, such as reading from presentation slides and books. Even highly developed countries like Japan still adhere to teacher-centred

teaching formats in teaching higher education (Aoki, 2010). This adherence to conventional teaching formats often neglects the diverse learning needs and preferences of students, thereby hindering the efficacy and engagement of educational experiences. Student-centric design approaches must be used to deliver the education material effectively. To do that cognitive science, gamification, and comics should closely be incorporated to create something different e-learning platform.

There are many studies that are related to enhancement of learning through human-centric design. Sagri et al. analysed modern methods of teaching a new material. For that, they reviewed other researchers' new adopted methods for teaching such as Digital storytelling, Comics, Machinima (machine, cinema, and anime), and Multimedia tools (Sagri et al., 2018). According to their review, the introduction of modern technology in education had a positive impact on student learning (Sagri et al., 2018). Also, Sagri et al. developed a digital storytelling comic-based tool and tested that to twenty teachers, 4 professors, 12 individuals, and 358 students (Sagri et al., 2018). The results show that using comics-based digital storytelling tools not only improves student learning, but also motivates them to continue learning new materials in this way (Sagri et al., 2018).

Another study about comics which was conducted by Yamamoto et al. discussed the innovative e-learning system that aims to enhance cross-cultural communication skills among international students using Manga (Yamamoto et al., 2019). Through analysis of user feedback and comparison with non-users, the effectiveness of the system in addressing existing teaching material limitations was confirmed (Yamamoto et al., 2019). The system's interactive approach, incorporating Manga characters, maintained user engagement and motivation, leading to improved understanding of the material (Yamamoto et al., 2019). Moreover, interviews with participating companies indicated that students who underwent the e-learning program demonstrated superior business communication skills (Yamamoto et al., 2019). Overall, the e-learning system effectively cultivates non-verbal and emotional communication skills crucial for international students navigating diverse cultural environments (Yamamoto et al., 2019).

The study presents clickEcomic, a multimedia language learning system for Japanese learners, finding that learners favored the 'day-to-day' language-focused package over one centered on Japanese history (Lai et al., 2002). Intermediate learners benefited most from materials with English text and Japanese narration, while beginners required additional grammatical explanations to connect English and Japanese effectively (Lai et al., 2002). Overall, the findings suggest that multimedia comic-based learning materials cater to diverse proficiency levels, offering effective language acquisition tools with flexible pacing and cultural insights (Lai et al., 2002).

Another study explores the development and impact of mobile phone e-learning using manga-based materials in Japan, focusing on motivational factors and the influence of word of mouth (Matsumoto, n.d.). Surveys reveal a desire among students for smartphone use and interest in mobile phone e-learning, particularly with manga content (Matsumoto, n.d.). While manga-based content enhances creativity and maintains high learning motivation, challenges arise from the current lack of smartphone functionality for accessing such materials (Matsumoto, n.d.). Nonetheless, leveraging word of mouth may offer potential avenues to enhance the effectiveness of educational strategies in the future (Matsumoto, n.d.).

Chang et al. research tested the effectiveness of their teaching approach that is game and comics integrated learning platform (Chang et al., 2017). Their study yielded positive re-

sults regarding their teaching method, but they also mentioned that developing their approach was time consuming (Chang et al., 2017). Another researcher, Lazarinis et al., who authored a paper about developing tools for creating comics for education, thinks differently (Lazarinis et al., 2015). They wrote that the tools they use are not time-consuming, but lack functionality, thus educators creating content are limited to given functionality (Lazarinis et al., 2015).

Overall, these studies that use storytelling and comics have shown positive effects on students learning new material (Sagri et al., 2018; Yamamoto et al., 2019; Lai et al., 2002; Matsumoto, n.d.). Although comics-based learning has its advantages, such as enhanced engagement and comprehension, it can also be time-consuming to create (Chang et al., 2017). However, attempts to streamline the process to make it less time-consuming may compromise functionality (Lazarinis et al., 2015).

The human memory system involves sensory memory receiving information from sensory channels, followed by the transfer of relevant data to short-term memory (Atkinson and Shiflrin, n.d.). Through rehearsal processes within short-term memory, information is encoded and prepared for storage in long-term memory, which has unlimited capacity (Atkinson and Shiflrin, n.d.). Our research aims to optimize the rehearsal process in short-term memory to enhance information retention and facilitate efficient transfer to long-term memory.

Firstly, cognitive load theory's design principles and strategies are used during creation of the new material to reduce cognitive load. These design principles and strategies include Goal-free principle, Modality principle, and Self-explanation principle (Merrienboer et al., 2010).

Secondly, video and video + text format of teaching is used when the e-learning platform is developed. This could be because video, and video + text-based learning shows high accuracy of learning (Ando and Ueno, 2008).

Thirdly, voice-over video format and picture-text-text animation video is used as these teaching methods produce positive results than other approaches (Chen and Wu, 2015; Wang et al., 2012).

Following the instructional content, a new list of concepts is presented to encourage students to remember new concepts through mnemonics (elaborative rehearsal technique) (Benge and Robbins, 2009). After each unit of material, a test with new educational material will be automatically generated, the duration of the rehearsal of the new material will be one week and the rehearsal will go through this test, since an interval of one week is enough to transfer new knowledge from STM (Short-term memory) to LTM (Long-term memory) effectively (Pelayoet al., 2006).

Due to the limitations of entertainment-based learning approaches, the study only uses comics, not in story format, but only comics chunks to motivate students to learn a new section of the lesson.

The traditional type of learning platform and slight variations of the proposed revolutionary types of platforms are tested on university students. For the course content a biology lesson is chosen. Our hypothesis is that a revolutionary learning platform might be more effective at learning new material than a traditional one. We expect to figure out a better version of a slight variation of the new platform.

Materials and Methods

Software

The gamified platform was built using the Angular framework. Its design was deliberately crafted to resemble a gaming environment, it attracts students to engage with the plat-

form consistently. Featuring a dynamic layout, it includes a header, a side menu displaying various lesson units, and the lesson content itself.

Figure 1 illustrates three types of platform content. In the first type, comics preceded by video material, followed by a sequence of picture-text-text content presenting the learning material, and concluding with key terms intended for memorization through elaborative rehearsal. The order of content differs in the other types, while their formats remain the same.

Figure 2 illustrates the rehearsal process one week after the learning method has been implemented, providing insight into the retention and application of knowledge over time. Figures 3 and 4 offer visual representations of the gamified learning platform, showcasing its design and interface for better understanding and assessment of its features and usability.

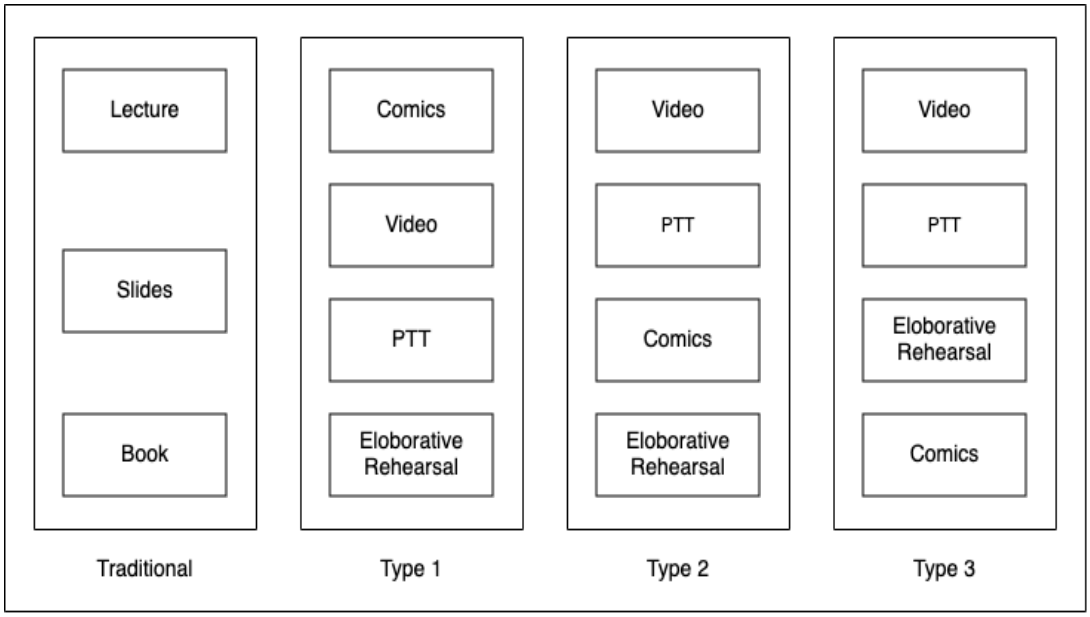

Fig.1 - Learning platform types

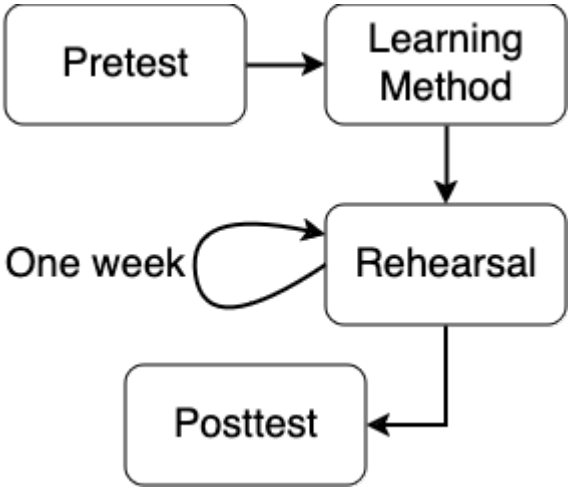

Fig.2 - Process of the experiment

Procedure

We recruited twelve participants aged between 21 and 27 for our experiment, dividing them into four groups as depicted in Figure 1. The first group utilized the traditional learning method, while the second, third, and fourth groups engaged with type 1, type 2, and type 3 content of the gamified platform, respectively. The experiment aimed to determine the most effective learning approach among the three content types.

Prior to the experiment, participants underwent a pretest to assess their baseline knowledge of the topic. Following the learning sessions with the respective content types, participants' excitement levels regarding the gamified platform were measured using a funometer. Subsequently, participants were given time to memorize key terms using the elaborative rehearsal technique, which involves associating the terms with real-life scenarios.

After a week, participants were given a posttest to evaluate their retention and comprehension of the material learned. This approach allowed us to assess the effectiveness of each learning method and determine the most advantageous approach for our participants.

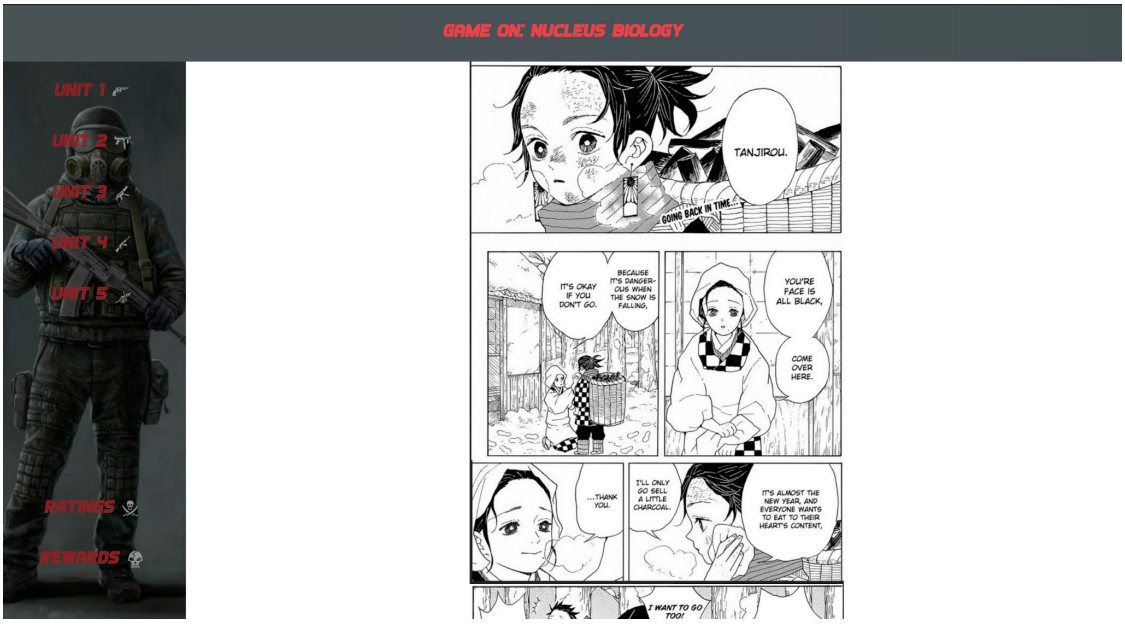

Fig.3 - Gamified Learning Platform (Comics)

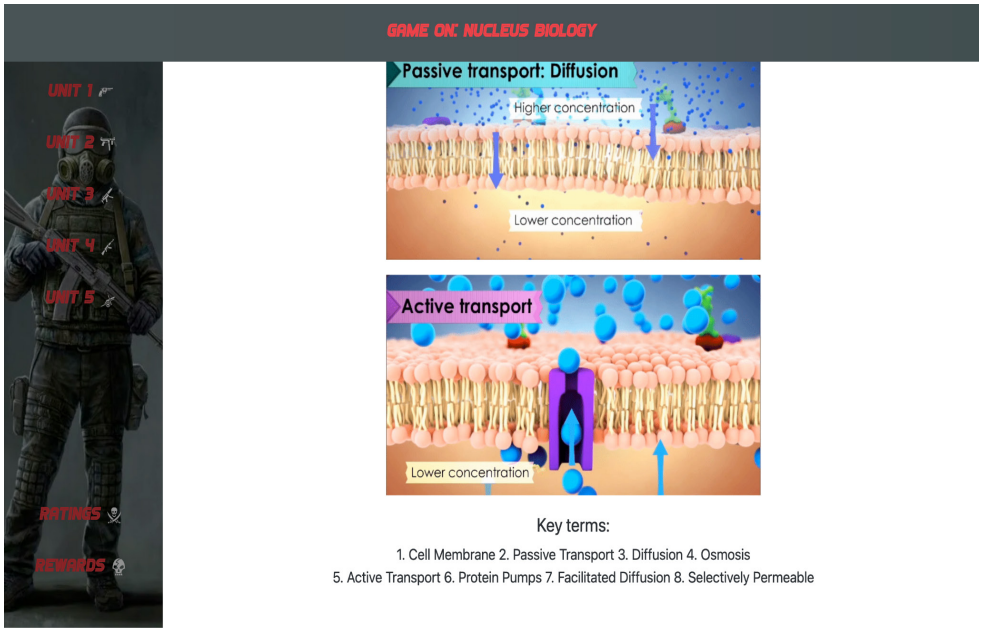

Fig.4 - Gamified Learning Platform (PTT)

Measurements

Knowledge

Participants were tasked with providing explanations of the key terms, a measure conducted both before the experiment ended and after a week of engaging in elaborate rehearsal. These pretest and posttest assessments were utilized to evaluate the participants' learning gains over the duration of the study.

Mood

Mood assessments were conducted using a funometer to examine participants' engagement levels following their study sessions, comparing experiences between the traditional learning method and the gamified learning platform. This assessment was conducted once, after the learning procedures.

Other Factors

Post-assessment, participants were queried on various aspects of their user experience, providing insights into elements that caused excitement or boredom. This feedback aimed to inform future improvements to the gamified platform, enhancing its effectiveness and user engagement.

Results and Discussion

Test Results

Prior to conducting the experiment, all participants underwent pretests, the results of which are shown in Figure 5. This pretest consists of 20 fundamental biology terms, and an average score is 3.30 terms. After one week of instruction, participants completed posttests. Results indicated that those engaged in traditional learning methods achieved an average score of 6 out of twenty key terms. Participants who use Type 1 learning strategies exhibited a marked improvement, with an average score of 11.67, while those employing Type 2 and Type 3 methods obtained scores of 10.67 and 8.34 respectively.

Analyzing the gains, it is evident that both Type 1 and Type 2 learning approaches

yield significantly higher improvements compared to Type 3 and Traditional methods.

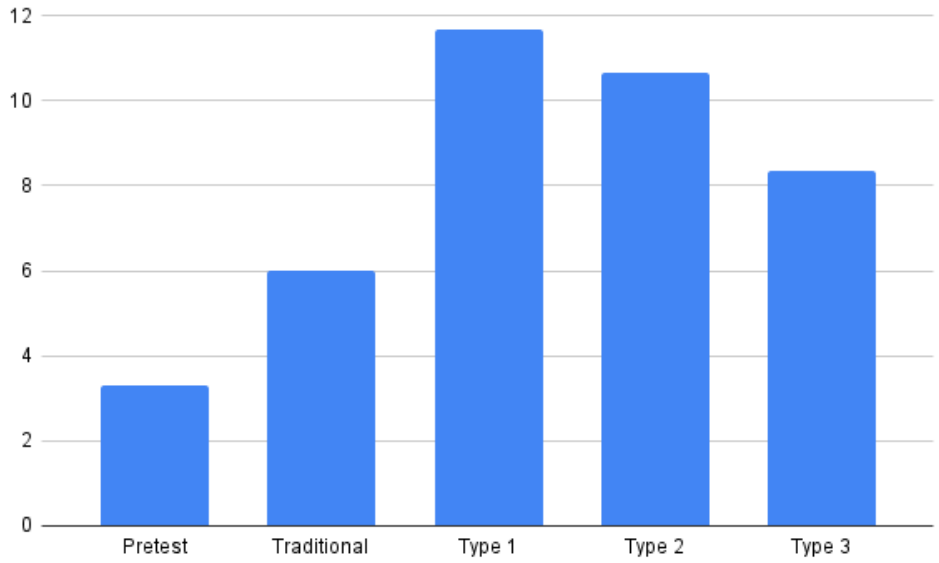

Fig.5 - Comparison of test results

Table 1. ANOVA of learning achievement on various approaches

	SS	df	MS	F	P-value
Between Groups	57.667	3	19.222	6.407	0.016
Within Groups	24	8	3		
Total	81.667	11			

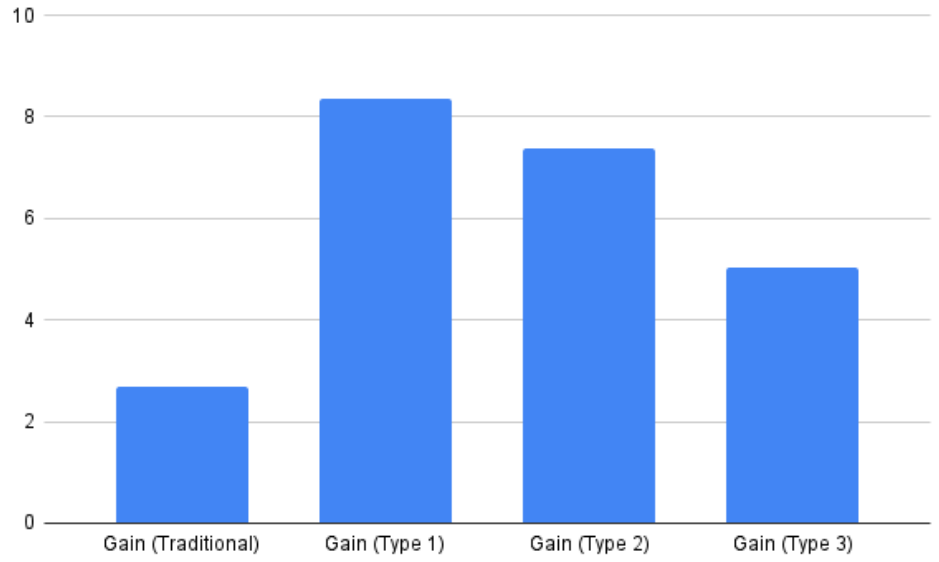

Fig.6 - Comparison of gains

Following the completion of the experiment, we conducted an ANOVA test to find any statistically significant variances among the Traditional, Type 1, Type 2, and Type 3 independent groups. As shown in Table 1, the obtained p-value was 0.016. This indicates that our p-value is lower than the critical threshold of 0.05. Thus, our hypothesis is right.

Mood

In Figure 7, the data reveals that participants experienced a more elevated mood after engaging with the material through the gamified learning platform compared to the traditional learning method. Upon closer examination of mood changes across learner types (Type 1, 2, and 3), it becomes clear that Type 1 and 2 learners had improved mood than Type 3 learners.

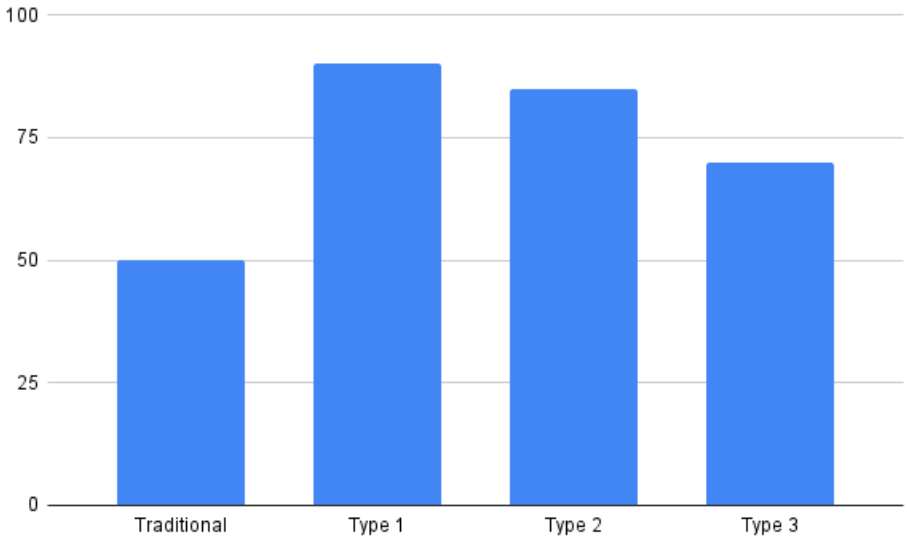

Fig.7 - Comparison of moods

Other Factors

Many participants in the traditional learning group lacked motivation compared to those in the Type 1, 2, and 3 groups, because they told us that they used to study like that. On the other hand, participants exposed to novel approaches showed high motivation, because they liked the engaging nature of gamified design, comics, and animated videos. However, it is crucial to note that over time, the motivation of Type 1, 2, and 3 participants may decrease as they become used to these methods, like traditional method participants.

Furthermore, Type 3 participants admitted to rushing through the material to reach the comics section quickly, compromising their attention to the study material. Some Type 2 learners reported being distracted by the placement of comics in the middle of the material. In contrast, Type 1 participants did not express any complaints.

Discussion

This study investigated the effectiveness of a gamified learning platform compared to traditional methods. By combining insights from cognitive science, gamified design principles, and the incorporation of comics, a novel human-centric learning platform was developed and examined.

The results demonstrate that Type 1 and Type 2 learning platforms yielded signifi-

cantly higher scores (11.67 and 10.67, respectively) in learning new material compared to the traditional method (6.00). The Type 3 method achieved a score of 8.34, which was lower than Type 1 and Type 2. This discrepancy can be attributed to participants rushing through the material to access the comics section quickly.

Interestingly, within the Type 1 and Type 2 groups, Type 1 learners outperformed Type 2 learners. This difference may be linked to Type 2 participants' dissatisfaction with the placement of comics in the middle of the learning material, which led to distractions from the primary learning content. Also, Type 1 learners did not encounter any such issues.

Participants across all three types (Type 1, 2, and 3) exhibited higher mood levels compared to those using the traditional learning method. This can be attributed to the novelty and engagement offered by the new gamified learning platform, which is more interesting for participants who are accustomed to traditional methods.

The application of an ANOVA test resulted in a p-value of 0.016, indicating statistical significance ($p = 0.05$) and suggesting that the gamified learning platform is more effective than the traditional method. Among the gamified platform types, Type 1 emerged as the most efficient. In this platform, the sequence involves comics followed by video material, then PTT (picture-text-text) content, and finally key terms for elaborative rehearsal.

Conclusion

Further research is needed to explore participants across a broader spectrum of age groups, encompassing younger demographics than those included in our current experiment. Additionally, extending the investigation to various disciplines beyond biology would figure out instances where the traditional method may outperform gamified learning platforms.

In evaluating mood and other factors, it was noted that many participants using the traditional method lacked motivation compared to those who use the gamified learning platform. This observation underscores the importance of understanding how participants' familiarity influences their engagement and motivation levels. It means, it is essential to determine the duration after which participants using the new learning platform become accustomed to the novel teaching method and potentially experience a decline in engagement, like participants who use traditional methods. This exploration would show whether both methods eventually demonstrate similar outcomes.

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COLLECTION OF DATASETS AND APPLICATION OF NEURAL NETWORK MODELS FOR SIGN LANGUAGE CLASSIFICATION IN PATTERN RECOGNITION TASKS

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Abstract. This paper examines data collection and the application of neural network models for sign language classification in image recognition tasks. Sign language, as an important means of communication for people with hearing impairments, requires effective technologies for its automatic recognition. During the study, a diverse set of video data was collected, covering various gestures and contexts of their use. Modern neural network architectures, including convolutional and recurrent networks, were applied to analyze this data, enabling high classification accuracy. The results demonstrate the potential of using deep learning for sign language recognition, which opens new opportunities for the development of assistive technologies and improving the quality of life for people with disabilities. The paper emphasizes the importance of integrating machine learning and computer vision methods to create more intuitive interaction interfaces.

Keywords: datasets, CV; CNN (Convulutional neural network); sign language; binary classification; machine learning; support vector machine, AlexNet, LeNet, softmax, ReLU, gradient descent, Adam Optimizer, batch normalization, comparative analysis

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ДЕРЕКТЕР ЖИНАУ ЖӘНЕ НЕЙРЛІК ЖЕЛІЛІК МОДЕЛЬДЕРДІ ӨЛГІЛЕРДІ ТАУ ТАПСЫРМАЛАРЫНДА ИШМІРЛІК ТІЛДІ ЖІКТЕУ ҮШІН ҚОЛДАНУ

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Аннотация. Бұл жұмыста бейнелерді тану міндеттерінде ым-ишара тілін классификациялау үшін нейрондық желі модельдерін қолдану және деректерді жинау қарастырылады. Есту қабілеті нашар адамдар үшін маңызды қарым-қатынас құралы болып табылатын ым-ишара тілі оны автоматты түрде тану үшін тиімді технологияларды талап етеді. Зерттеу барысында әртүрлі ишаралар мен олардың қолдану контексттерін қамтитын әртүрлі бейнедеректер жиналды. Бұл деректерді талдау үшін заманауи нейрондық желі архитектуралары, соның ішінде конволюциялық және рекуррентті желілер қолданылды, бұл классификацияның жоғары дәлдігіне қол жеткізуге мүмкіндік берді. Нәтижелер терең оқытуды ым-ишара тілін тану үшін пайдаланудың болашағы зор екенін көрсетеді, бұл көмекші технологияларды дамытуға және мүмкіндігі шектеулі адамдардың өмір сүру сапасын жақсартуға жаңа мүмкіндіктер ашады. Жұмыс машинамен оқыту мен компьютерлік көру әдістерін біріктірудің маңыздылығын және өзара әрекеттесудің түсінікті интерфейстерін құруды атап көрсетеді.

Түйін сөздер: Деректер жиыны, түйіндеме; CNN (конвульсиялық нейрон-дық желі); Ым тілі; екілік классификация; Machine Learning; Қолдау Vector Machine, AlexNet, LeNet, softmax, ReLU, градиентті түсіру, Adam Optimizer, пакетті қалыпқа келтіру, салыстырмалы талдау

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СБОР ДАННЫХ И ПРИМЕНЕНИЕ МОДЕЛЕЙ НЕЙРОННЫХ СЕТЕЙ ДЛЯ КЛАССИФИКАЦИИ ЯЗЫКА ЖЕСТОВ В ЗАДАЧАХ РАСПОЗНАВАНИЯ ОБРАЗОВ

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Аннотация. В данной работе рассматривается сбор данных и применение моделей нейронных сетей для классификации языка жестов в задачах распознавания образов. Язык жестов, как важный способ коммуникации для людей с нарушениями слуха, требует эффективных технологий для его автоматического распознавания. В ходе исследования был проведён сбор разнообразных видеоданных, охватывающих различные жесты и контексты их использования. Для анализа этих данных применялись современные архитектуры нейронных сетей, включая сверточные и рекуррентные сети, что позволило достичь высокой точности классификации. Результаты показывают перспективность использования глубокого обучения для распознавания языка жестов, что открывает новые возможности для разработки вспомогательных технологий и улучшения качества жизни людей с ограниченными возможностями. Работа подчеркивает важность интеграции методов машинного обучения и компьютерного зрения для создания более интуитивно понятных интерфейсов взаимодействия.

Ключевые слова: наборы данных, CV; CNN (Convulitional neural network); язык жестов; бинарная классификация; машинное обучение; support vector machine, AlexNet, LeNet, softmax, ReLU, градиентный спуск, Adam Optimizer, пакетная нормализация, сравнительный анализ

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Introduction

Pattern recognition theory is a section of artificial intelligence and computer vision that focuses on developing methods and algorithms for automatic recognition and classifi-

cation of objects based on their properties and attributes. This area has many practical applications, such as recognition of text, images, sounds, speech, faces, gestures, and other data.

In domestic science, a significant contribution to the study of this area was made by Amirgaliev E.N. in his book "Theory of Pattern Recognition and Cluster Analysis". It presents mathematical approaches to classification and clustering problems and describes pattern recognition algorithms and machine learning methods (Mukhanov et al., 2020: 31–37). A similar foreign work is the book by Christopher M. Bishop on pattern recognition and machine learning.

It is also worth noting the contribution of Mamyrbaev O.Zh., who has achieved significant success in the study of speech recognition of the Kazakh language (audio signals) (Mukhanov et al., 2023: 16–27). His research contributes to the development and popularization of the Kazakh language and is relevant for the processing of time series.

The process of pattern recognition, in addition to the technical field, is an important cognitive function studied in psychology and cognitive neuroscience. It involves comparing the information received with the data already stored in memory (Mukhanov et al., 2023: 15–27). For example, a child, learning the alphabet, can predict the next letter after hearing "A, B", which demonstrates the activation of long-term memory. This process helps a person navigate in space, remember information, recognize dangers, and find resources, which is important for survival (Kenshimov et al., 2021: 44–54).

Materials and Methods

Problem and Relevance

By examining algorithms and existing recognition systems in the IT industry and academia, we analyzed the requirements needed to improve the performance and efficiency of these systems. Gesture recognition technologies continue to evolve to provide more accurate and efficient recognition (Uskenbayeva et al., 2020: 1–6; Bazarevsky et al., 2019). In the process of improving these systems, several key areas can be identified:

- Expanding databases: Improving the training of models requires a constant increase in databases containing images and videos of gestures.
- Developing new training methods: Scientific research should focus on creating innovative training methods to improve recognition accuracy.
- Improving model architectures: Developers strive to optimize model architectures to improve the speed and accuracy of recognition.
- Increasing the number of parameters: Increasing the number of model parameters can improve their accuracy, although this may increase the training time and the size of the models.
- Using deep neural networks: The use of deep neural networks, such as convolutional and recurrent networks, helps improve recognition accuracy.
- Combining methods: Combining different approaches, including machine learning and anthropological methods, can improve the accuracy of systems.
- Adaptation to context: Considering the context in which gestures occur can significantly improve recognition accuracy.
- Creation of new applications: The development of applications based on gesture recognition stimulates the development of technologies and the expansion

of their functionality.

To improve recognition accuracy, it is necessary to develop new algorithms and machine learning methods capable of providing high accuracy (Vidyanova, 2022; Wang 2020: 64990–64999). An important direction is the recognition of more complex gestures, including combinations of simple gestures or multi-component movements.

The main requirements for improving gesture recognition systems include:

Real-time recognition: developing fast algorithms and increasing computing performance to ensure that the system operates in real time.

Adaptability to different lighting conditions: creating systems that can function in any lighting conditions, be it bright light or dark.

Improvement in working with large datasets: optimizing algorithms for working with large datasets, such as videos with many frames or high-resolution images.

Compatibility with different cameras and devices: Develop systems that can work with several types of cameras, including those used in mobile devices.

Interpretability of results: Provide transparency in the system's decision-making process so that users can understand how gesture recognition occurs.

Privacy and security protection: Develop methods to protect users' personal data and prevent system hacks.

Results and Discussion

Model, Tools, Environment and Technology

Computer vision plays a significant role in the development of artificial intelligence. This field focuses on the development of methods and algorithms for automatic image and video processing. The rapid development of computer vision contributes to the constant improvement of its capabilities. One of the key areas in this field is gesture recognition, which allows analyzing images and videos in real time (Lee et al., 2020: 105385; Bilgin et al., 2019). This technology finds application in medicine, robotics, the automotive industry, security systems and other fields. Computer vision provides automatic recognition of gestures in video and their use in various applications, such as device control, robotics, and medical systems (Kudubaeva et al., 2016). The evolution of computer vision is accompanied by the improvement of image processing algorithms, the creation of new methods and neural network architectures, improved quality of training data, as well as integration with other technologies, including voice and gesture interfaces (Xu et al., 2022: 103364). One of the main tasks in the development of gesture recognition systems is to increase accuracy and reduce the number of false positives. A crucial factor is also an increase in recognition speed for processing substantial amounts of data in real time (Zhou et al., 2023: 103688). Additionally, it is necessary to improve the robustness of systems to various conditions, such as changes in lighting, pose, and scale of objects, as well as to expand the capabilities for recognizing complex gestures and their combinations. Computer vision significantly contributes to the recognition of gestures and actions due to its ability to analyze images and videos automatically. This is especially relevant in areas such as security, robot control, and virtual reality. To further improve gesture recognition systems, it is necessary to continue developing computer vision methods, including deep neural networks and reinforcement learning methods, as well as improving the quality of training datasets (Yan et al., 2023: 119042). It is important to consider the diversity of gestures so that systems can solve a wide range of problems in different scenarios. Further development of computer vision in the field of gesture and action recog-

nition promises to improve the efficiency and accuracy of these systems, which can have a significant impact on many aspects of people's lives (Tong et al., 2023: 118912).

Dataset Collection

High-quality image databases exist for English and Russian sign languages, but no such resources are available for Kazakh. To address this, we developed our own dataset for model training. This dataset consists of forty-two classes, each representing a letter of the Kazakh alphabet, with an average of four hundred images per class. Overall, the dataset includes over 15,000 images. These images are black-and-white photographs of hands, taken from various angles, with a resolution of 1280x720, showcasing specific gestures.

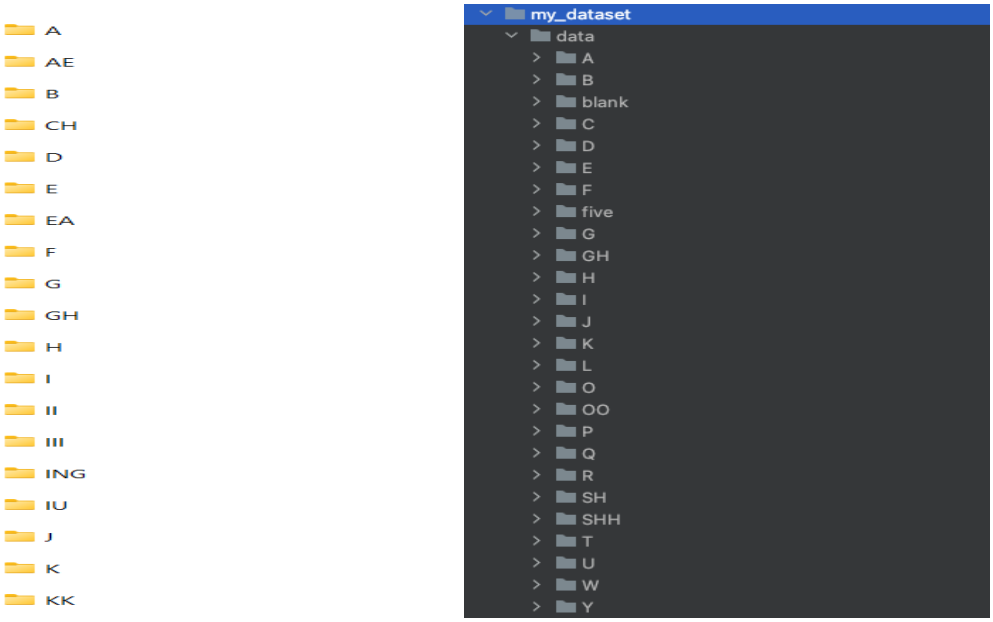

Figure 1 – Dataset for training neural networks

For each letter, datasets were collected containing images of hands demonstrating the corresponding gestures. The photographs were taken under different lighting conditions and at different distances from the camera. After data collection, a preprocessing and cleaning step was performed to eliminate errors, inconsistencies, and remove redundant information. The datasets are presented in Figure 2, and example images and their corresponding characters are shown in Figure 3.

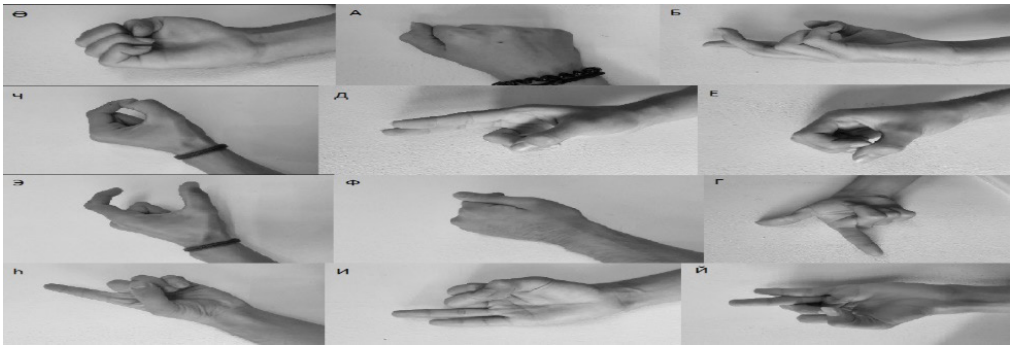

Figure 2 – Images of some Kazakh Sign Language gestures from the dataset used

Figure 3 – Image of the letter “Ә” gesture

Figure 3 shows the number of images for the Kazakh letter «Ә». In total, about 300 images were collected for this letter. To train the neural networks used to recognize hand gestures, we labeled and prepared this data.

Experiments of Machine Learning and Neural Network Models

The Support Vector Machine (SVM) seeks to identify a hyperplane that best divides two classes, enhancing the model’s ability to generalize to new, unseen data. SVM achieves this by using a kernel function, which transforms the input data into a higher-dimensional space. These kernel functions are crucial, enabling nonlinear classification by mapping the original data to a higher dimension. The training and optimization of SVM focus on finding the most effective hyperplane for categorizing data points. Analysis of the model’s training process sheds light on this optimization approach:

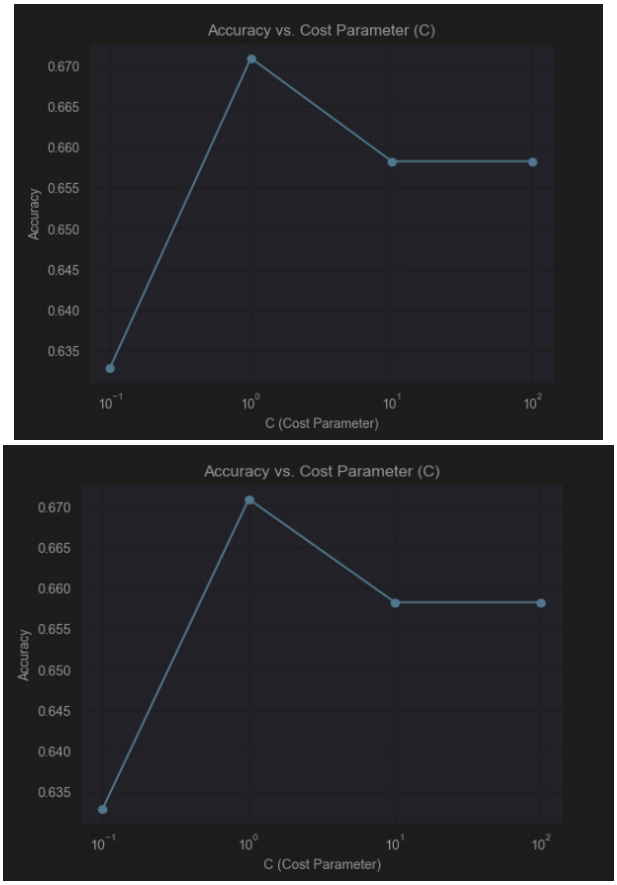

Figure 4 - Accuracy during training and validation

Performance Evaluation and Comparison.

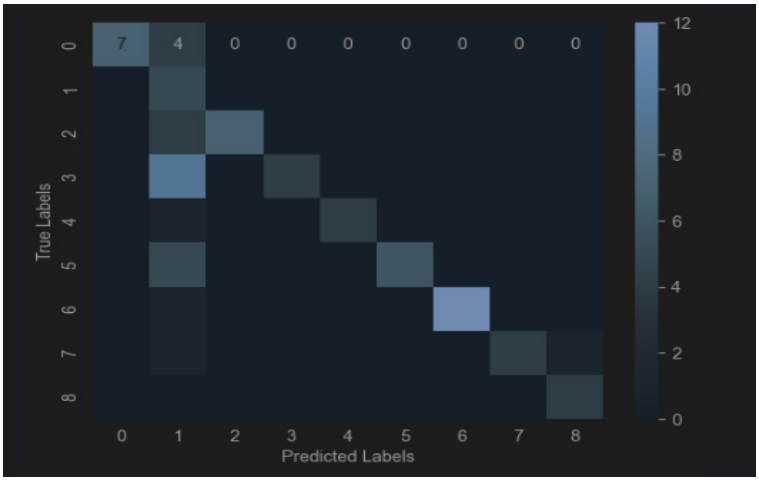

Figure 5 – Error matrix for nine classes of the Kazakh sign alphabet

The confusion matrix reveals the performance of the model in terms of misclassification. It shows that the model correctly predicts Class 0 for all cases, indicating perfect classification accuracy for this class. However, it struggles with Class 1, where it incorrectly classified four cases as Class 0. The model does an excellent job of correctly predicting all classes with no errors except for Class 1.

Table 1 – Metrics for evaluating the SVM model Binary classification

Class	Precision	Recall	F1 score	Support
1	2	3	4	5
Ae(Ə)	0.69	0.64	0.78	11
Blank	0.71	0.91	0.29	5
Gh(Ғ)	0.71	0.64	0.78	11
Hh(h)	0.65	0.31	0.47	13
Ii(I)	0.81	0.80	0.89	5
Kk(Қ)	0.77	0.55	0.71	11
Nn(Ң)	0.79	0.81	0.91	13
Oe(Ө)	0.72	0.67	0.80	6
Ue(Y)	0.72	0.80	0.89	4
Accuracy	0.74			79
Macro Avg	0.89	0.72	0.73	79
Weighted Avg	0.94	0.67	0.73	79

LeNet and AlexNet models

LeNet is one of the earliest convolutional neural networks, developed in the late 1990s and introduced in the research paper “Gradient-Based Learning for Document Recognition” as part of deep learning advancements (Bilius et al., 2023: 84–90; Yeo et al., 2013). This seven-layer CNN was designed to recognize low-resolution black-and-white images. The original input data were 32x32 pixel images, where each pixel was represented by thirty-two bits. These images were transformed into six channels of 28x28 pixels and then downsampled to an average size of 14x14 pixels.

Figure 4.20 – The input data for this model is a black and white image of 32x32 pixels.

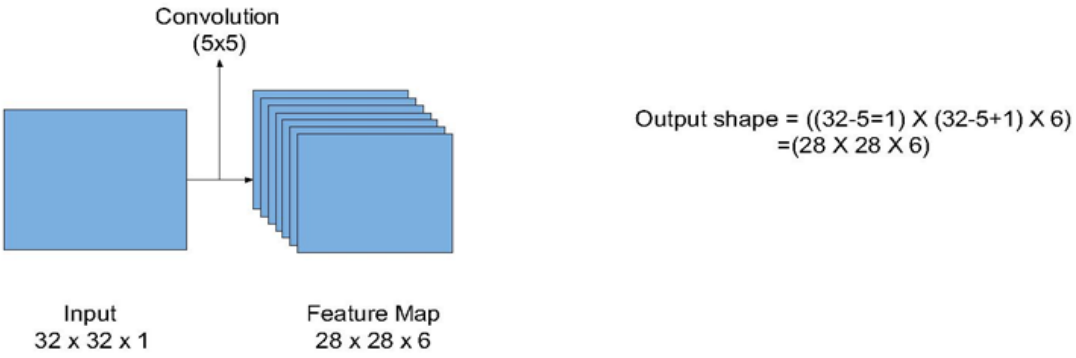

Figure 6 – Neural network with filter size 5x5

Then we apply the first convolution operation with a filter size of 5x5 in the amount of 6 such filters:

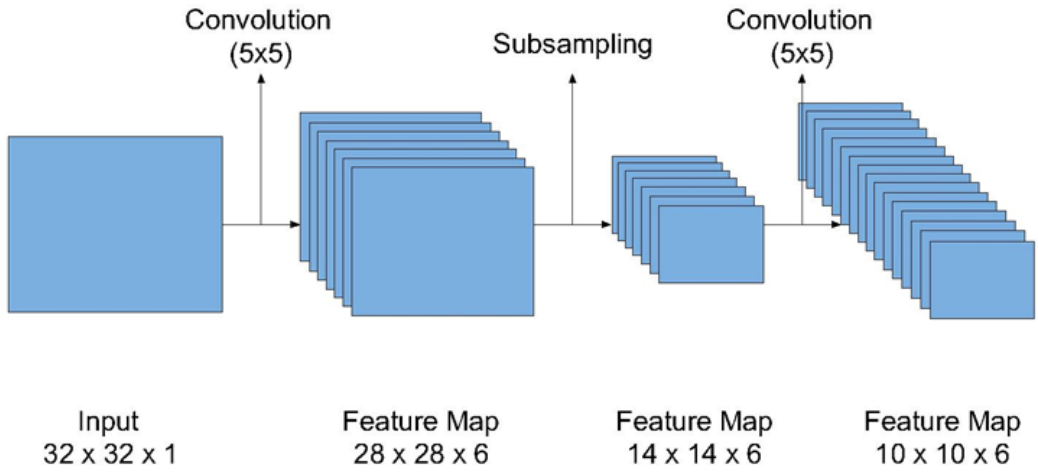

Figure 7 – Convolution layer with sixteen 5x5 filters

Then, a convolutional layer with sixteen filters of size 5x5 is used. To train the LeNet neural network, more than 15,000 images were collected for each letter in the 42-class classification task. Each class was pre-labeled, and the processed images converted to grayscale were downloaded from the folder (revised_gray_dataset). Different gradient descent methods were used to train the neural network, including Adam and stochastic gradient descent (SGD). Sigmoid, ReLU, hyperbolic tangent was used as activation functions, and softmax was used for the output layer. The training was divided into training and validation sets, and the performance of the model was evaluated using the metrics shown in the image. The data was taken from the Python console.

	f1	recall	precision	accuracy	time
predict_lenet_kaz_relu_sgd	0.813	0.808	0.821	0.808	217
predict_lenet_kaz_relu_adam	0.819	0.815	0.826	0.815	230
predict_lenet_kaz_softmax_sgd	0.008	0.035	0.019	0.035	276
predict_lenet_kaz_softmax_adam	0.007	0.034	0.016	0.034	261
predict_lenet_kaz_tanh_sgd	0.803	0.798	0.810	0.798	212
predict_lenet_kaz_tanh_adam	0.811	0.808	0.818	0.808	225

Figure 8 – LeNet models with results of applied metrics

It is worth noting that the softmax activation function showed the worst results. The input data settings did not allow the LeNet architecture to fully demonstrate its potential at the output. Otherwise, the model showed quite satisfactory results, especially considering the training time, which is indicated in the last column in seconds.

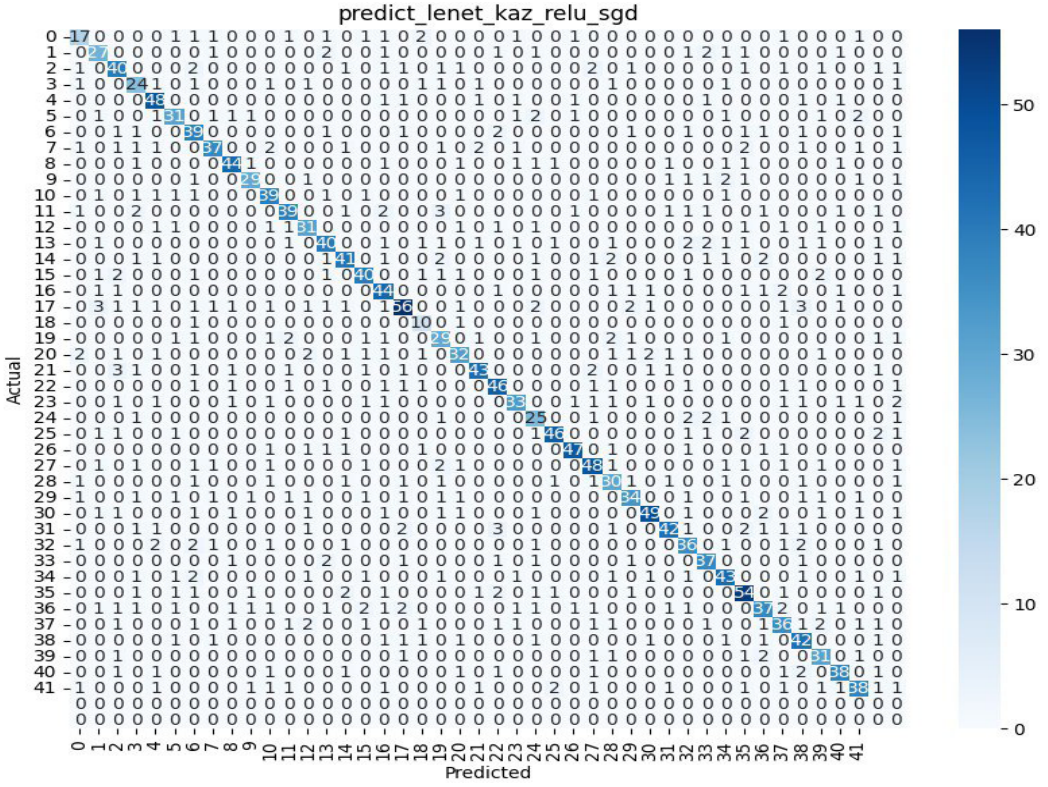

Figure 9 – Error matrix of the LeNet model

We then analyzed the training process of this model and found that its accuracy on the training and validation sets is close to one, which indicates a good result. The abscissa

axis shows the number of epochs passed. On the loss graph (model loss), the loss level has decreased to a minimum, indicating a decrease in the number of model errors, which is also an excellent result.

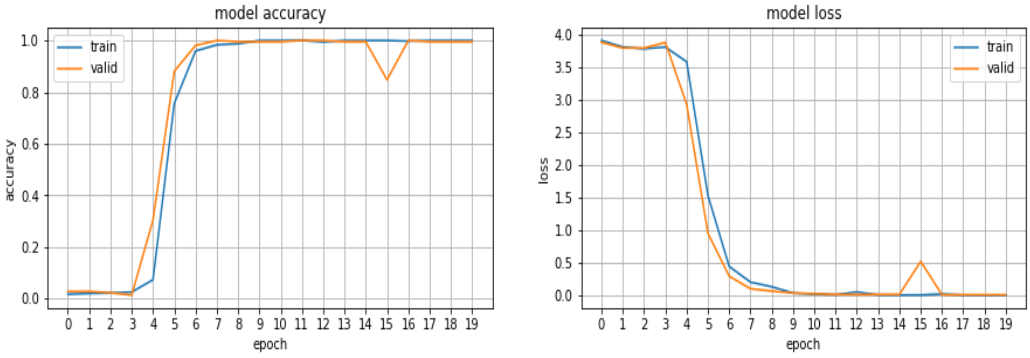

Figure 10 – Accuracy and loss for the LeNet model

The training results of the LeNet model are shown in Figure 9 as a confusion matrix calculated on the test dataset consisting of forty-two classes. This figure shows that the LeNet model made classification errors for classes such as "B", "C", and others.

AlexNet is a convolutional neural network that has had a significant impact on the development of machine learning, especially in the field of computer vision. Although AlexNet's architecture is based on Yann LeCune's LeNet model, it extends it by adding more filters at each layer and introducing additional convolutional layers. AlexNet includes convolution, max pooling, dropout, data augmentation, as well as ReLU activation functions and stochastic gradient descent. This powerful model demonstrates high accuracy on complex data. However, removing any of the convolutional layers can significantly degrade its performance. The AlexNet architecture is essential for object detection tasks and is widely used in the field of computer vision and artificial intelligence.

Different gradient descent methods such as Adam and SGD (stochastic gradient descent) were used to train the neural network. The activation functions used were sigmoid, ReLU, hyperbolic tangent, and softmax for the output layer. The training process was divided into training and validation sets. The efficiency and accuracy of the model were assessed using the metrics shown in Figure 11. The data was obtained from the Python console.

	f1	recall	precision	accuracy	time
predict_alexnet_kaz_relu_sgd	0.075	0.116	0.137	0.116	5512
predict_alexnet_kaz_relu_adam	0.111	0.190	0.129	0.190	5380
predict_alexnet_kaz_softmax_sgd	0.003	0.038	0.001	0.038	5808
predict_alexnet_kaz_softmax_adam	0.003	0.038	0.001	0.038	5724
predict_alexnet_kaz_tanh_sgd	0.025	0.078	0.020	0.078	5667
predict_alexnet_kaz_tanh_adam	0.092	0.157	0.117	0.157	6327

Figure 11 – AlexNet model with results of applied metrics

We then analyzed the training process of this model and found that the model accuracy graph for the training set showed its approach to one, which is an excellent result. The validation set began to show satisfactory results only at the 15th epoch, with the abscissa axis showing the number of epochs passed. On the model loss graph, the validation set showed unstable and high losses, indicating a not particularly good result, while the model showed minimal losses on the training set, which is a positive indicator.

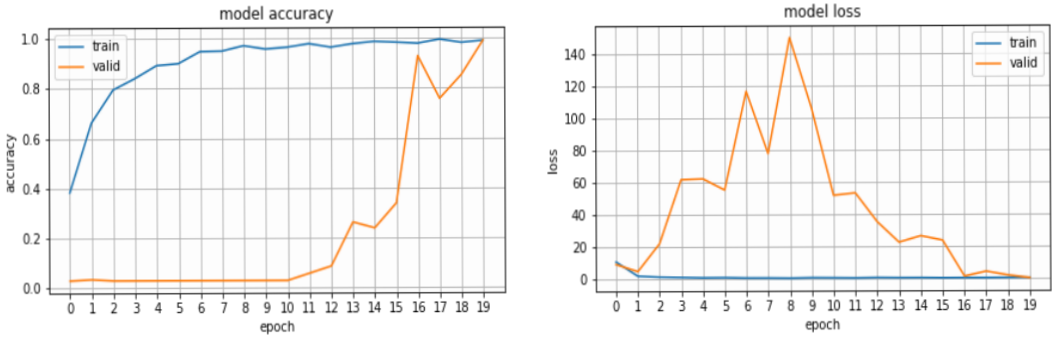

Figure 12 – Accuracy and loss for the AlexNet model

The training results of the AlexNet deep learning model are graphically displayed in Figure 13 as a confusion matrix.

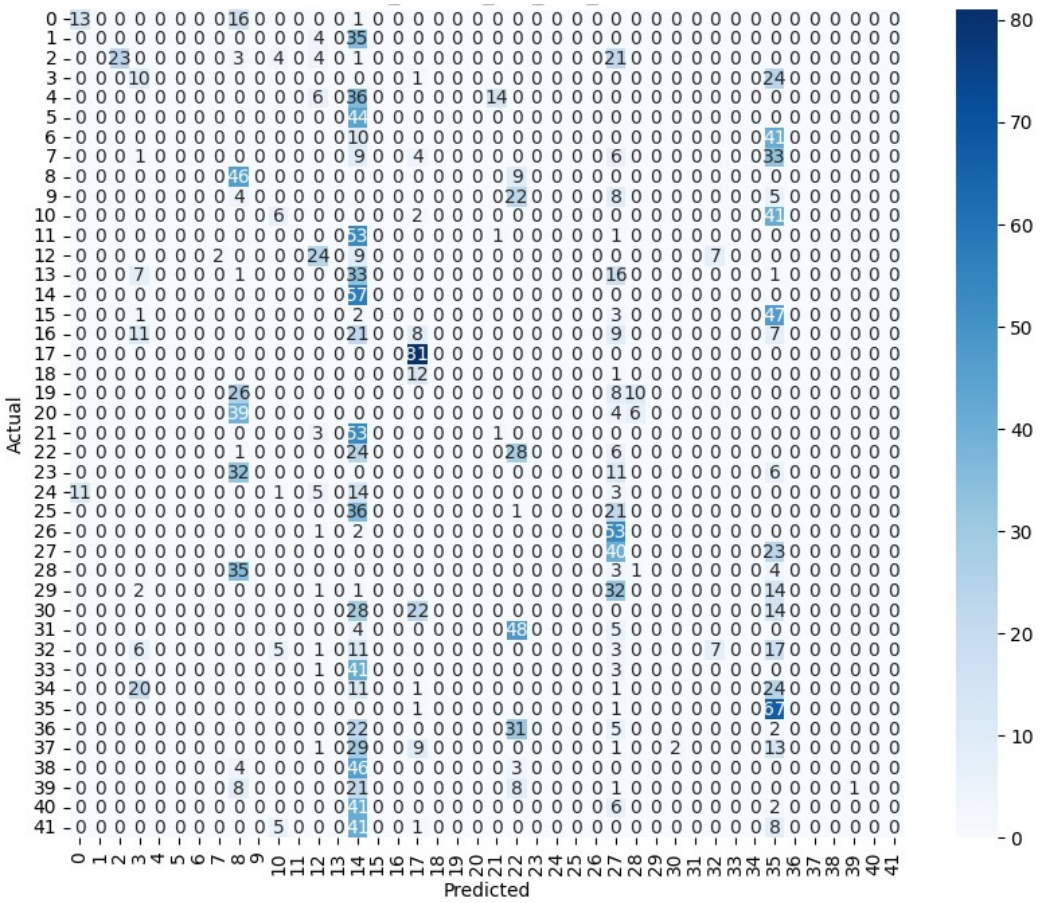

Figure 13 – Accuracy and loss for the AlexNet model

The statistics of this error matrix show that the model made very frequent false negative predictions when predicting the gestures of the Kazakh sign alphabet, divided into forty-two classes.

Conclusion

In the comparative analysis of LeNet, AlexNet and SVM models, batch normalization, rmsprop optimizer and categorical cross entropy as the loss function were used. The training was conducted for 20 epochs to achieve optimal convergence of the CNN model for hand gesture recognition. The obtained results show similar performance of all models. This can be explained by the diversity of images in the training data and the effectiveness of CNN for this task. Over 20 epochs of training, LeNet showed the best results despite the similarity in training speed, accuracy and loss compared to other models. LeNet, having fewer parameters, showed better performance.

The results showed that convolutional neural networks are effective in recognizing objects in images, in this case gestures. They are widely used in computer vision, especially for their ability to detect object boundaries, textures, edges, and corners using local patterns.

The architecture of a convolutional neural network, consisting of several layers, extracts increasingly more abstract image details as you move deeper into the network. One of the key characteristics of a convolutional neural network is its invariance to transformations,

which allows them to recognize objects in images regardless of scale, rotation, and translation.

Comparative analysis of Lenet, SVM, AlexNet models with different activation functions (ReLU, Softmax, Tanh, Sigmoid) and different gradient descent optimizers (ADAM, SGD) for the task of recognizing gestures in the Kazakh language. The accuracy and F1-measure, which consider errors of the 1st and 2nd kind, were used as metrics.

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ANALYSIS OF THE APPLICATION OF LOW CODE AND NO-CODE TECHNOLOGIES IN SOFTWARE PRODUCT DEVELOPMENT

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Abstract. The proliferation of low-code and no-code (LC/NC) technologies marks a transformative era in software product development, offering innovative solutions that democratize the creation process and streamline development efforts. This article explores the implications and applications of LC/NC technologies, focusing on their potential to empower users without extensive coding expertise to participate in software creation. Through a com-prehensive analysis of ten prominent LC/NC platforms, including OutSystems, PowerApps, Mendix, Bubble, Webflow, Flutterflow, Zapier, Tilda, Creatio, and WordPress, the study elu-cidates the underlying models and languages of these platforms. It examines case studies of successful LC/NC implementations, analysing their benefits, such as reduced development time and increased agility, alongside challenges like limited customization and potential se-curity vulnerabilities. Moreover, the research explores the impact of LC/NC technologies on traditional roles within software development teams and the evolving skillsets required in the industry. While recognizing that LC/NC platforms will not entirely replace traditional cod-ing, this study highlights their significant role in fostering innovation, inclusivity, and agility in software development. This paper contributes to understanding how LC/NC technologies are reshaping the field of software development and anticipates future trends in the technol-ogy industry.

Keywords: low-code and no-code technologies, software development democratization, efficiency, customization, security, industry innovation and future trends

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БАҒДАРЛАМАЛЫҚ ӨНІМДЕРДІ ӘЗІРЛЕУДЕ LOW CODE ЖӘНЕ NO-CODE ТЕХНОЛОГИЯЛАРЫНЫҢ ҚОЛДАНЫЛУЫН ТАЛДАУ

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Аннотация. Low-code және no-code (LC/NC) технологиялардың таралуы бағдарламалық өнімдерді әзірлеудегі трансформациялық дәуірді белгілейді, құру процесін демократияландыратын және әзірлеу әрекеттерін оңтайландыратын инновациялық шешімдерді ұсынады. Бұл мақалада LC/NC технологияларының салдары мен қолданылуын зерттейді, олардың кодтау бойынша кең тәжірибесі жоқ пайдаланушыларға бағдарламалық жасақтама жасауға қатысуға мүмкіндік беру әлеуетіне назар аударады. OutSystems, PowerApps, Mendix, Bubble, Webflow, Flutterflow, Zapier, Tilda, Creatio және WordPress сияқты ОН танымал LC/NC платформаларын жан-жақты талдау арқылы зерттеу осы платформалардың негізгі үлгілері мен тілдерін түсіндіреді. Ол LC/NC сәтті енгізулерінің жағдайлық зерттеулерін зерттейді, олардың даму уақытын қысқарту және икемділікті арттыру сияқты артықшылықтарын, сондай-ақ шектеулі теңшеу және ықтимал қауіпсіздік осалдықтары сияқты мәселелерді талдайды. Сонымен қатар, зерттеу LC/NC технологияларының бағдарламалық жасақтаманы әзірлеу топтарындағы дәстүрлі рөлдерге және салада талап етілетін дамып келе жатқан дағдыларға әсерін зерттейді. LC / NC платформалары дәстүрлі кодтауды толығымен алмастырмайтынын мойындай отырып, бұл зерттеу олардың бағдарламалық жасақтаманы әзірлеу саласындағы инновацияларды, инклюзивтілікті және ептілікті дамытудағы маңызды рөлін көрсетеді. Тұтастай алғанда, бұл жұмыс LC/NC технологияларының бағдарламалық жасақтаманы әзірлеу саласын қалай өзгертетінін түсінуге ықпал етеді және технологиялық индустриядағы болашақ тенденцияларды болжайды.

Түйін сөздер: Low-code және no-code технологиялары, бағдарламалық жасақтаманы демократияландыру, тиімділік, теңшеу, қауіпсіздік, саладағы инновациялар және болашақ тенденциялар

Дәйексөздер үшін: Д.А. Рахметуллина. БАҒДАРЛАМАЛЫҚ ӨНІМДЕРДІ ӘЗІРЛЕУДЕ LOW CODE ЖӘНЕ NO-CODE ТЕХНОЛОГИЯЛАРЫНЫҢ ҚОЛДАНЫЛУЫН ТАЛДАУ //ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ КОММУНИКАЛЫҚ ТЕХНОЛОГИЯЛАР ЖУРНАЛЫ. 2024. Т. 5. No. 20. 83–94 бет. (ағылшын тілінде). https://doi.org/10.54309/IJICT.2024.20.4.007.

АНАЛИЗ ПРИМЕНЕНИЯ ТЕХНОЛОГИЙ LOW CODE И NO-CODE В РАЗРАБОТКЕ ПРОГРАММНЫХ ПРОДУКТОВ

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Аннотация. Распространение технологий low-code и no-code (LC/NC) знаменует собой эпоху преобразований в разработке программных продуктов, предлагая ин-новационные решения, которые демократизируют процесс создания и оптимизируют усилия по разработке. В статье исследуются последствия и применение технологий LC/NC и уделяется особое внимание их потенциалу, позволяющему пользователям без обширных знаний в области кодирования участвовать в создании программного обеспечения. Благодаря всестороннему анализу десяти известных платформ LC/NC, включая OutSystems, PowerApps, Mendix, Bubble, Webflow, Flutterflow, Zapier, Tilda, Creatio и WordPress, исследование раскрывает базовые модели и языки этих платформ. В нем рассматриваются тематические исследования успешных реализаций LC/NC, анализируются их преимущества, такие как сокращение времени разработки и повы-шение гибкости, а также такие проблемы, как ограниченная настройка и потенциаль-ные уязвимости безопасности. Кроме того, исследование изучает влияние технологий LC/NC на традиционные роли в командах разработчиков программного обеспечения и развивающиеся наборы навыков, необходимые в отрасли. Признавая, что платформы LC/NC не заменят полностью традиционное программирование, это исследование подчеркивает их важную роль в содействии инновациям, инклюзивности и гибкости в сфере разработки программного обеспечения. В целом, эта статья способствует пони-манию того, как технологии LC/NC меняют область разработки программного обеспе-чения и предвосхищают будущие тенденции в технологической отрасли.

Ключевые слова: технологии low-code и no-code, демократизация разработки ПО, эффективность, кастомизация, безопасность, инновации в отрасли и будущие тенденции

Для цитирования: Д.А. Рахметуллина. АНАЛИЗ ПРИМЕНЕНИЯ ТЕХНОЛОГИЙ LOW CODE И NO-CODE В РАЗРАБОТКЕ ПРОГРАММНЫХ ПРОДУКТОВ//МЕЖДУНАРОДНЫЙ ЖУРНАЛ ИНФОРМАЦИОННЫХ И КОММУНИКАЦИОННЫХ ТЕХНОЛОГИЙ. 2024. Т. 5. No. 20. Стр. 83–94. (На англ.). https://doi.org/10.54309/IJICT.2024.20.4.007.

Introduction

The software development industry has been significantly transformed with the advent of Low-Code and No-Code (LCNC) platforms. Designed to lower or eliminate the need for complex coding skills, these platforms open the world of software creation to a broader audience. Traditionally, software development demanded specialized expertise, often limit-ing the ability to develop applications to those with formal training in programming (Frank et al., 2021: 1–6). LCNC platforms democratize this process, enabling even non-technical users

to contribute meaningfully to software development through intuitive tools and simplified interfaces. This transformation is particularly impactful for small and medium-sized enterprises (SMEs), which often face limitations in terms of IT budgets and skilled personnel. By leveraging LCNC technologies, SMEs can now participate in digital innovation, engage in rapid prototyping, and deploy applications without significant upfront investment, helping to level the playing field across industries (Gartner, 2021).

The relevance of studying LCNC platforms stems from the accelerating pace of technological advancement in software engineering. Businesses increasingly seek agile and responsive solutions that can quickly adapt to evolving market demands. LCNC technologies cater to these needs by offering faster development cycles and flexible solutions that align well with modern business requirements. However, questions remain regarding the sustainability, applicability, and scalability of LCNC technologies, especially in complex development scenarios. A thorough understanding of these aspects is crucial as LCNC platforms gain traction in the software development sector.

This study aims to explore the role of LCNC technologies in software product development by identifying their advantages, limitations, and future potential within the industry. The study will analyze the core principles that underpin LCNC platforms, review case studies from organizations that have implemented these technologies and assess the impact of LCNC adoption on development processes, product quality, and overall outcomes. In addition, this research seeks to provide actionable recommendations for businesses to adopt and implement LCNC platforms effectively, thus enhancing productivity and innovation.

Materials and Methods

This research is built on a structured analysis of LCNC technologies through both theoretical and empirical methodologies. The foundation of the study includes a comprehensive review of relevant literature on Low-Code and No-Code platforms, complemented by case studies and real-world applications within the software development industry. The case studies are selected from a range of industries, providing diverse perspectives on the deployment, effectiveness, and challenges associated with LCNC technologies. Empirical data collection involves both qualitative and quantitative methods. Interviews with industry professionals, software developers, and business stakeholders provide insights into the practical applications and limitations of LCNC platforms, while surveys gather quantitative data on the usage, impact, and outcomes of LCNC adoption. The study also conducts a comparative analysis of development projects that utilize LCNC platforms versus those employing traditional development methods. Statistical data from these analyses highlight trends, measure effectiveness, and contribute to an understanding of LCNC technologies' role within software development.

The study's methodology further includes an evaluation of specific LCNC platforms — alongside an analysis of key metrics, including development time, resource allocation, and product quality. This approach allows for a comprehensive examination of LCNC technologies in real-world contexts, balancing both theoretical frameworks and empirical evidence.

Results and Discussion

The findings from this research reveal significant insights into the advantages, limitations, and future applications of Low-Code and No-Code technologies in software development. One of the key advantages identified is the reduction in development time, as LCNC platforms streamline application building through pre-configured templates and reusable modules. This efficiency has been shown to improve productivity, particularly in ag-

ile development environments, allowing for faster responses to business needs and market changes. Moreover, the flexibility offered by LCNC platforms aligns well with modern business demands, enabling rapid iterations and adaptations based on user feedback and shifting requirements.

However, the research also highlights notable limitations of LCNC technologies, especially in complex or highly customized projects. While LCNC platforms excel in providing accessible solutions for straightforward applications, they often struggle with scalability and may lack the depth of customization required in more intricate development scenarios. Security remains another concern, as the abstraction layers inherent in LCNC platforms can obscure potential vulnerabilities. This limitation suggests that while LCNC platforms are highly beneficial for prototyping and less complex projects, traditional coding may still be necessary for mission-critical or highly tailored applications.

The study's results indicate that LCNC technologies are likely to coexist with traditional software development methods rather than replace them. They offer a complementary approach that fosters inclusivity and agility, particularly valuable for SMEs and teams focused on rapid development. Recommendations from this research outline strategies for integrating LCNC technologies within organizations, such as selecting projects best suited for LCNC, training teams in platform-specific best practices, and establishing security protocols tailored to LCNC environments.

The landscape of software development has continually evolved in response to advancing technologies, changing market demands, and the imperative for enhanced efficiency. Within this transformative landscape, Low Code and No-Code (LCNC) platforms have emerged as game changers, providing tools that democratize software development and enhance the speed of application deployment. This review delves deeper into LCNC's rise, applications, challenges, and future implications (Brooke, 2013: 29–40).

In the vast realm of technology, there has always been a tussle between advancing at the speed of light and ensuring that the masses can keep up with such progress. The field of software development, once exclusive to those trained in the intricate nuances of coding languages, has experienced a radical shift in this balance in recent years. Emerging from the shadows of traditional, code-intensive development processes, Low Code and No-Code (LCNC) platforms have begun to challenge the established norms, promising a democratized landscape where software creation is no longer the domain of the few but the playground of many (Hakimi, 2019).

This literature review aims to dissect the evolution, significance, challenges, and potential trajectories of LCNC technologies, examining their transformative impact on software product development. The dawn of LCNC platforms has been nothing short of revolutionary, offering a unique blend of accessibility and efficiency. At its core, this paradigm shift aims to simplify the complex, making software development more intuitive and less dependent on deep technical prowess. But like all seismic shifts in technology, the rise of LCNC platforms brings with it a host of questions, potential pitfalls, and uncharted territories that merit thorough examination (Shah, 2020: 15).

To appreciate the current state of Low Code and No-Code (LCNC) platforms, it's imperative to traverse back in time and understand the trajectory that brought us here. Historically, software development was an exclusive realm, a citadel for those equipped with specialized training. The 1960s and 70s, often referred to as the 'dark ages' of computing, were dominated by punch-card systems and mainframes. These cumbersome processes necessitat-

ed proficiency in arcane programming languages and a deep understanding of complex systems. As we transitioned into the 1980s, the personal computer revolution began (Frank et al., 2021: 1–6). Tools like Microsoft's MS-DOS and later Windows made computers accessible to the masses. But while hardware became increasingly user-friendly, software development retained its high entry barrier. The 90s introduced visual programming languages, such as Visual Basic, which attempted to simplify the coding process, but still required a significant amount of technical know-how.

The turn of the millennium saw a surge in internet usage, driving demand for software solutions. Traditional development cycles lagged, leading to the emergence of LCNC platforms, simplifying web development with tools like WYSIWYG editors. LCNC platforms democratized software development, enabling a wider audience to participate, and levelling the playing field for SMEs. Studies by Frank, Maier, and Bock (2021) and others highlight the traction and productivity benefits of low-code platforms, marketed for their efficiency and reduction in hand-coding. Visual elements and citizen development further empower non-experts to build applications quickly and affordably, as seen in success stories like T-Mobile US Inc.'s rapid app development (Schneid et al., 2021).

Furthermore, market research firms have made bold forecasts regarding the market size for low-code platforms (LCPs), catching the attention of investors. Forrester predicts a 15 % growth in the LCP market, reaching USD 7.7 billion in 2021, while Brandessence estimates the market was already worth nearly USD 13 billion in 2020, projecting it to reach USD 65 billion by 2027.

This growing interest in low-code platforms is not confined to the industry sector; it has also garnered significant attention in academic circles, leading to dedicated workshops and discussions within the scholarly community.

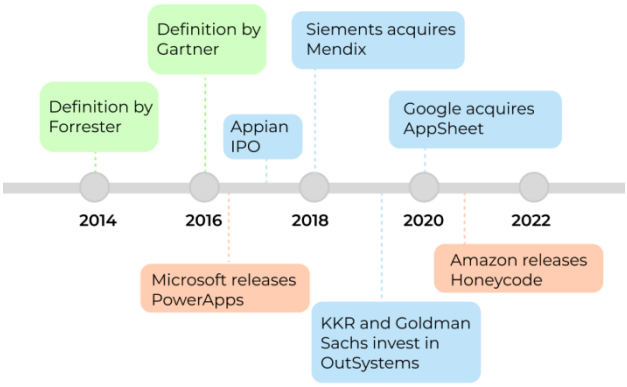

Fig.1. Major events in low-code history

As highlighted by Di Ruscio, Kolovos, de Lara, et al. (2022), the year 2021 saw a notable trend among major cloud service providers incorporating low-code development platforms (LCDPs) into their cloud solutions. This movement was initiated by Microsoft with the launch of its Power Apps LCDP in November 2016. Google also entered this space by acquiring AppSheet in January 2020, subsequently making it their primary low code offering. Additionally, Amazon introduced Honeycode in June 2020, an LCDP designed for web and mobile application development (Gurcan et al., 2021: 67–72).

The concept of no-code development platforms (NCDPs) is closely related to LC-

DPs. NCDPs are characterized by their ability to remove the need for traditional programming using visual languages, graphical user interfaces, and configuration tools. Despite its widespread use in marketing, the term NCDP is not universally accepted by market analysis firms as a distinct market segment. In the context of their research, Di Ruscio and colleagues treat NCDPs and LCDPs as interchangeable terms, focusing solely on LCDPs for their analysis.

According to Frank, Maier, and Bock (2021), Low Code Platforms (LCPs) are increasingly recognized for their critical role in the ongoing digitization of various sectors, including business, personal, and social domains. The widespread integration of software into different facets of life underscores its transformative impact. Consequently, the ability to swiftly develop, adapt, and deploy software has become a key competitive factor for many companies. This relevance extends to the academic sphere, where despite longstanding research into efficient software design and alignment, numerous challenges persist, presenting opportunities for innovative research, particularly in the realm of LCPs. The study also highlights a notable lack of clarity and consistency in the conceptualization of LCPs (Di Ruscio et al., 2022: 437–446). The market offers a broad spectrum of products under the LCP label, with diverse features and descriptions often obscured by marketing rhetoric. Gartner's definition, while comprehensive, lacks specificity, especially in terms of high-level abstractions and metadata-based programming languages, concepts that are prevalent in various software development systems (Gartner, 2021).

According to research by Waszkowski (2019), Low-Code Development Platforms (LCDPs) represent a significant shift in the approach to software development, emphasizing graphical user interfaces over traditional hard-coded programming techniques. LCDPs focus on developing databases, business processes, and user interfaces, particularly for web-based applications. This methodology stems from the ideology of fourth-generation programming (4GL) and incorporates principles of Rapid Application Development (RAD), automatic code generation, and visual programming. Introduced in 2011, low-code programming allows developers to focus more on the aesthetics and functionality of an application rather than on the syntax of the code, thereby reducing troubleshooting and implementation time (Brooke, 2013: 29–40).

The study also sheds light on the growing demand for IT professionals in Europe, with an estimated 275,000 unfilled vacancies in the ICT sector and projections suggesting this shortfall could reach one million by 2020. Gartner research indicates that by 2021, the demand for information systems will outpace the supply capabilities of IT departments by a factor of five. This gap underscores the timeliness and relevance of low-code platforms, which enable faster creation and modification of applications without extensive coding (Martinez et al., 2023: 1–7).

Key global players in the low-code platform market include Salesforce, Microsoft PowerApps, Mendix, Google App Maker, Tilda, Flutterflow, Wordpress, TrackVia, and Appian. In Poland, while there are fewer providers, the available low-code solutions often build upon European or American technologies, enhancing them with customized elements and modules (Frank et al., 2021: 1–6).

The implementation of low-code platforms in automating business processes, especially in manufacturing, poses a complex challenge, necessitating a range of research and technological solutions, including basic, applied, diagnostic, verification, and heuristic research.

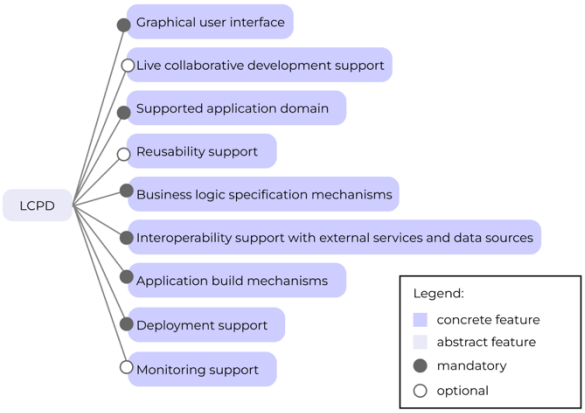

Fig.2. Top-level features of LCDPs

As detailed by Di Ruscio, Kolovos, de Lara, et al. (2022), Low-Code Development Platforms (LCDPs) facilitate the creation of versatile applications, suitable for web-only environments or as native applications for specific deployment environments. These platforms are adept at supporting both desktop and mobile devices and seamlessly integrating with prevalent Software-as-a-Service (SaaS) applications such as Zapier, Amazon AppFlow, and Trello. Among the notable LCDPs, Appian stands out for its longevity, while Amazon Honeycode and Google AppSheet represent more recent developments in this domain (Di Ruscio, et al., 2022: 437–446).

A key feature distinguishing LCDPs is their user experience, particularly the advanced graphical user interfaces they offer. These interfaces include tools and widgets that empower citizen developers to design applications effectively (Waszkowski, 2019: 376–381). Functionalities like drag-and-drop interfaces, sophisticated reporting features, decision engines for complex logic modeling, and form builders are integral to the front-end experience of LCDPs. Furthermore, LCDPs often provide live collaborative development support, which is especially beneficial for developers working remotely or in geographically dispersed teams. This feature enhances the collaborative aspect of developing applications (Kalpeyeva et al., 2020: 1–6).

The analysis delves into survey data gathered from 100 respondents, aiming to elucidate their perspectives and engagement with Low-Code/No-Code (LCNC) platforms in software development. Key quantitative findings highlight widespread awareness and adoption of LCNC technologies, with 85 % of respondents indicating familiarity and 71 % integrating these platforms into their project workflows. Tilda emerges as the most utilized platform (40 %), followed closely by PowerApps, Flutterflow, and WordPress. LCNC platforms are predominantly employed for web application development (52 %), with notable usage also observed in business process automation, prototyping, and mobile application development. Respondents overwhelmingly attest to the acceleration of project development facilitated by LCNC platforms (72 %), with visual programming emerging as the most satisfying aspect (47 %). A significant majority (73 %) express intentions to either maintain or increase their usage levels, underlining perceived benefits and potential for innovation within the LCNC landscape. These observations offer a holistic perspective on LCNC platforms within software development, detailing their benefits and potential directions for future development.

Navigating the diverse landscape of Low-Code/No-Code (LCNC) platforms in software development unveils platforms like Flutterflow, Tilda, and Zapier, which prioritize user-friendly interfaces. For instance, Flutterflow offers a visually intuitive platform for building mobile apps, ideal for entrepreneurs venturing into app development without extensive coding knowledge. Tilda, known for its drag-and-drop website builder, caters to small businesses and individuals seeking to establish an online presence swiftly. Zapier, specializing in automation, serves professionals seeking to streamline repetitive tasks across various applications, like automatically saving email attachments to cloud storage (Wong et al., 2019).

Conversely, WordPress, while renowned for its versatility, requires a certain technical aptitude, particularly for advanced customization. For instance, a freelance web developer might leverage WordPress's extensive plugin ecosystem to create a bespoke e-commerce platform for a client, but integrating custom features may necessitate familiarity with HTML, CSS, or PHP (Pantelimon et al., 2019: 566–571).

In contrast, enterprise-grade platforms like Creatio offer robust customization options tailored to complex business processes. For example, a multinational corporation might utilize Creatio's workflow orchestration tools to streamline procurement processes across multiple departments, ensuring regulatory compliance and efficiency.

While WordPress boasts a vibrant community of developers and users contributing plugins and support, emerging platforms like OutSystems and PowerApps are steadily building their support networks. These platforms target businesses seeking scalable solutions for app development, with OutSystems catering to large enterprises requiring intricate integrations and PowerApps offering a more accessible option for small to midsize businesses looking to digitize workflows.

Understanding these nuances is crucial for organizations seeking the right LCNC platform to meet their specific development needs and objectives. Whether it's empowering non-technical users to create web content, streamlining business processes, or building sophisticated enterprise applications, selecting the appropriate platform ensures efficient and effective software development (Sanchis et al., 2020: 1–7).

Low Code and No-Code (LC/NC) technologies democratize software development, letting users create applications and websites without deep coding knowledge. They use models and languages to abstract complexity, speeding up development. OutSystems uses a model-driven approach with visual tools and reusable components, allowing users to define logic visually, boosting collaboration. PowerApps (Microsoft) also employs a model-driven approach with visual tools and data connectors, letting users create custom applications without coding. Mendix focuses on model-driven development with visual tools and reusable components, simplifying app development and deployment. Bubble offers a visual development model, allowing users to design web apps through drag-and-drop, with a proprietary language for logic and workflows. Webflow enables visual website creation with design tools and templates, simplifying website development and customization. Flutterflow, utilizing Flutter framework, streamlines cross-platform app development with visual UI design and Dart language for behavior definition (Valsamakis et al., 2020: 1–4). Zapier automates workflows through a web interface, simplifying task integration and process automation with rule-based logic. Tilda uses a block-based model for web page creation via a visual editor, facilitating rapid website customization without coding. Creatio specializes in CRM and BPM solutions, employing a model-driven approach for process automation, enhancing business efficiency visually. WordPress, acting as a CMS and website builder, offers a plugin architec-

ture and template system for customization, with a visual dashboard for content management, reducing the need for PHP coding. Understanding LC/NC models and languages is crucial for leveraging their potential in driving innovation and digital transformation, making software development more inclusive and agile (Bock et al., 2021: 733–740).

The advent of Low-Code and No-Code (LC/NC) technologies has significantly reshaped the software development landscape, offering faster development times and accessibility to non-technical users. However, along with their benefits, these platforms come with their own unique challenges and limitations. LC/NC platforms often prioritize ease of use over granular control, limiting customization options for complex applications (Sahay et al., 2020: 171–178). Additionally, the abstraction layers inherent in these platforms can lead to performance bottlenecks as applications scale up and integrating them seamlessly with existing IT ecosystems remains a challenge, especially in complex enterprise environments. While LC/NC platforms facilitate easy development and deployment, they may inadvertently increase data security risks due to novice users overlooking vulnerabilities (Cabot, 2020: 535–538). Moreover, ensuring compliance with regulatory frameworks demands meticulous adherence during application development and deployment. Proficient utilization of LC/NC platforms requires comprehensive training in platform functionalities and software engineering principles. Additionally, organizations must be cautious of over-reliance on vendors for updates and enhancements, which can lead to dependency risks. Integrating LC/NC methodologies requires comprehensive change management strategies to facilitate organizational transition (Daniel et al., 2020: 15332–15346). Moreover, the democratization of application development may lead to unauthorized deployment of unsanctioned applications, posing governance challenges. Decentralized development across LC/NC platforms necessitates robust governance mechanisms to ensure application quality. Orchestrating projects across diverse platforms requires streamlined project governance frameworks. Staying agile in assimilating emerging trends and technological advancements is essential for organizations leveraging LC/NC technologies (Chang et al., 2017: 50–55). Additionally, strategic selection of platforms requires vigilant evaluation of vendor lock-in risks. Assessing the long-term viability of LC/NC platforms is crucial to mitigate operational risks. Robust community engagement and vendor support are essential for platform adoption and sustainability. Understanding these challenges is imperative for organizations and developers aiming to leverage LC/NC technologies effectively in their software development endeavors (Hecht, 2019).

Conclusion

In conclusion, this thesis has investigated the transformative impact of Low Code and No-Code (LC/NC) platforms within the domain of software development. Drawing from the research of Frank, Maier, and Bock (2021), the discussion has centered on the inherent productivity enhancements offered by conceptual models and the specialized modeling languages designed to facilitate their construction and implementation. These platforms have been shown to democratize the development process, enabling individuals with varying levels of technical expertise to create, adapt, and deploy software efficiently.

Reference models have been identified as a valuable means of streamlining the development process, providing a template that encapsulates commonalities across a class of systems while striving for an improved state of design. However, the development of such models is not without its challenges, including higher costs and the uncertainty of returns on investment, as well as the need for adaptability to meet specific requirements.

The synthesis of domain-specific modeling languages (DSMLs) with reference mod-

els has emerged as a particularly potent approach, affording developers a significant reduction in effort and enhanced model comprehensibility. This synergy is conducive to the reuse and adaptation of models, thereby expediting the development process and reducing the propensity for errors.

Model-Driven Software Development (MDSE) and the Object Management Group's (OMG) Model-Driven Architecture (MDA) have been explored as methodologies that bridge the gap between conceptual abstraction and practical implementation. These approaches underscore the importance of models as primary artifacts in the development process, advocating for automated transformations and a unified representation that caters to both model execution and system modification.

The comparative analysis of LC/NC platforms—including Tilda, Flutterflow, Creatio, WordPress, and Zapier—has provided a comprehensive view of the diverse functionalities, use cases, and adaptability of these platforms. From website construction to complex business process automation, these platforms offer a broad spectrum of capabilities, thus enabling a wide demographic to engage in software development.

Ultimately, the examination of LC/NC platforms within this thesis underscores a pivotal shift in software development paradigms. By reducing the technical barrier to entry, these platforms are facilitating a new wave of innovation and inclusivity in technology creation. This shift is poised to have profound implications for the future of software development, fostering a more collaborative, efficient, and user-centric approach to creating digital solutions. The convergence of these platforms with traditional software development practices heralds a new era of digital transformation, one where the complexities of coding are abstracted, and the focus is shifted to conceptual design and rapid deployment.

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PRACTICAL APPLICATION OF MODERN INFORMATION TECHNOLOGIES ON THE EXAMPLE OF CREATING A DYNAMIC MODEL OF PROSTHETIC HAND

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Abstract. The article deals with the algorithm of the automated design of the upper limb mechanical prosthesis with the use of the modern computer-aided design system Autodesk Fusion 360. The main goal of recent world developments is the desire to embody all the functions of a living arm or leg in a prosthesis. The vast majority of people can only afford cosmetic prostheses, which not only do not restore the functions of the human hand but are most often unaesthetic due to unfair execution. The prosthetics of people with amputated limbs are an important part of medical and social rehabilitation. Improving the quality of the prosthesis leads to a more comfortable life for the patient, the development is aimed at increasing the capabilities of the prosthesis of the human hand. Modeling the dynamic characteristics of prostheses for various purposes at the design stage is an urgent task for designers: it allows to determine how effectively the designed prosthesis will function in real conditions and take corrective action if necessary to ensure correct operation, strength, and durability. The created three-dimensional parametric dynamic model of the prosthetic arm can be used in the manufacture of modern prostheses.

Keywords: upper limb prosthesis, three-dimensional modelling, dynamic event simulation module, Autodesk Fusion 360 computer-aided design system

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ҚОЛ ПРОТЕЗІНІҢ ДИНАМИКАЛЫҚ МОДЕЛІН ҚҰРУ МЫСАЛЫНДА ЗАМАНАУИ АҚПАРАТТЫҚ ТЕХНОЛОГИЯЛАРДЫ ПРАКТИКАЛЫҚ ҚОЛДАНУ

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Аннотация. Мақалада Autodesk Fusion 360 заманауи автоматтандырылған жобалау жүйесін қолдана отырып, жоғарғы аяқтың механикалық протезін автоматтандырылған жобалау алгоритмі қарастырылған. Соңғы әлемдік дамудың негізгі мақсаты-протезде тірі қолдың немесе аяқтың барлық функцияларын жүзеге асыруға деген ұмтылыс. Адамдардың басым көпшілігі косметикалық протездерді ғана ала алады, олар адам қолының функцияларын қалпына келтіріп қана қоймайды, сонымен қатар сапасыз орындалуына байланысты көбінесе эстетикалық емес. Ампутацияланған адамдарды протездеу Медициналық және әлеуметтік оңалтудың маңызды бөлігі болып табылады. Протездің сапасын арттыру пациенттің жайлы өміріне әкеледі, даму адамның қол протезінің мүмкіндіктерін кеңейтуге бағытталған. Жобалау кезеңінде әртүрлі мақсаттағы протездердің динамикалық өнімділігін модельдеу дизайнерлер үшін өзекті міндет болып табылады: ол жобаланған протездің нақты жағдайларда қаншалықты тиімді жұмыс істейтінін анықтауға және қажет болған жағдайда дұрыс жұмыс істеуін, беріктігі мен беріктігін қамтамасыз ету үшін шаралар қабылдауға мүмкіндік береді. Қол протезінің жасалған үш өлшемді параметрлік динамикалық моделін заманауи протездерді жасауда қолдануға болады.

Түйін сөздер: жоғарғы аяқ протезі, үш өлшемді модельдеу, dynamic Event Simulation модулі, Autodesk Fusion 360 автоматтандырылған жобалау жүйесі

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ПРАКТИЧЕСКОЕ ПРИМЕНЕНИЕ СОВРЕМЕННЫХ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ НА ПРИМЕРЕ СОЗДАНИЯ ДИНАМИЧЕСКОЙ МОДЕЛИ ПРОТЕЗА КИСТИ РУКИ

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Аннотация. В статье рассматривается алгоритм автоматизированного проектирования механического протеза верхней конечности с использованием современной системы автоматизированного проектирования Autodesk Fusion 360. Основной целью последних мировых разработок является стремление воплотить в протезе все функции живой руки или ноги. Подавляющее большинство людей могут позволить себе только косметические протезы, которые не только не восстанавливают функции человеческой руки, но и чаще всего неэстетичны из-за некачественного исполнения. Протезирование людей с ампутированными конечностями является важной частью медицинской и социальной реабилитации. Повышение качества протеза ведет к более комфортной жизни пациента, разработка направлена на расширение возможностей протеза кисти человека. Моделирование динамических характеристик протезов различного назначения на этапе проектирования является актуальной задачей для конструкторов: оно позволяет определить, насколько эффективно спроектированный протез будет функционировать в реальных условиях и при необходимости принять меры для обеспечения правильной работы, прочности и долговечности. Созданная трехмерная параметрическая динамическая модель протеза руки может быть использована при изготовлении современных протезов.

Ключевые слова: протез верхней конечности, трехмерное моделирование, модуль Dynamic Event Simulation, система автоматизированного проектирования Autodesk Fusion 360

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Introduction

Thanks to modern technological developments and enormous scientific achievements, a wide range of prosthetic products and a range of various adaptive and auxiliary equipment are now available to people with physical disabilities. The main goal of the latest developments is to make an artificial limb have all the functions of a living arm or leg.

Prosthetics for disabled people with amputated limbs is a crucial part of medical and social rehabilitation and places high demands on the compensatory capabilities of the patient's physiological systems due to increased physical activity (Chui, 2019).

The development of technical means to restore the ability of disabled individuals to perform normal activities and self-care is a complex and largely unresolved issue. The main difficulty lies in the lack of established principles for building control systems that can effectively restore the functions of lost limbs to the required extent. (Schmidt, 2021). The purpose of an ideal prosthesis is to perform complex and atypical tasks related to the disabled person's daily life; therefore, it must meet two main requirements: it must be functional and aesthetically pleasing. Currently, the solution to the second issue has been achieved to a satisfactory degree, while the first task still requires further advancement in accordance with the current state of the art. This, in turn, highlights the need to develop and improve modern prosthesis control systems (Savielieva, 2018).

The hand is a human intermediary in contact with the outside world. The hand is an organ of labour in all kinds of professions. It executes human will in mechanical acts and in mental experiences. The hand is the organ of touch, the organ of sight for the blind, and the organ of speech for the mute. The hand is so closely connected with human thinking, feelings and work that it has become an auxiliary part of our language. Everything that a person cannot express, where they do not find words, is expressed by the movement of the hand - a gesture (Kannenberg, 2017).

The loss of the hand is tragic. An unsurpassed instrument dies. But at the same time, something more is lost: the most creative parts of the brain are brought to a standstill. Thus, restoring the functions of the hand is an extremely important task for people who have lost a limb. For the same reason, this task is also extremely difficult. First, the creation of a prosthetic hand is a complementary process that involves the use of many fields of science: mechanics, physiology, chemistry, electricity, etc. (Doyle, 2003). The second problem of prosthesis development stems from the first: high complexity implies high cost. The development of modern science makes it possible to restore most of the functions of the hand in a prosthesis: to perform basic types of grasping, feeling touch, temperature, pain. The control would be carried out directly by the brain through a system of contacts connected to the relevant centers; a system of gyroscopes could create a sense of the hand's position in space (Kretchev, 2017). But such a device is currently too expensive.

The vast majority of people can only afford cosmetic prostheses, which not only do not restore any function of the human hand but are often unaesthetic due to poor workmanship. To date, most manufacturers still use 19th century technical solutions to design prosthetic hands (Bai, 2024). The technology of manufacturing component parts is improving, and the types of interaction between a person and a prosthesis are being improved, but since the creation of the bioelectric control method, there has been no significant development in the field of creating new principles for the construction of prosthetic hands and methods for controlling the movement of actuators. And this is even though modern technology has made significant progress in the field of biomechanical devices (Tsivilsky, 2019).

Upper limb prostheses are divided into two main groups: passive (cosmetic and functional) and active (traction and myoelectric) (Beckerle, 2019). The problems of modelling have always been relevant in the study of mechanical structures consisting of elements made of different materials or having a complex geometric shape. A prosthetic orthopedic product, regardless of its complexity, is considered by a prosthetist only in interaction with the human musculoskeletal system (Fiedler, 2023).

Objectives. The aim of this study is to develop an algorithm for the automated design of a mechanical prosthesis of the upper limb using modern computer technologies. Improving

the quality of the designed prosthesis leads to a more comfortable life for the patient, and the development is aimed at increasing the physical capabilities of the human hand prosthesis.

Materials and Methods

1. Designing a finger flexion and extension mechanism. Prosthetics is the process of reproducing the functions of a real organ. Therefore, the design of the prosthesis (mechanical part) should begin with the analysis of the mechanical properties of the hand.

Using the decomposition method, we divide the human hand into two main blocks: the four fingers (index, middle, ring, and little fingers) and the opposite thumb. This division can be explained by the fact that the movements of the index, middle, ring, and little fingers can be implemented by the same design (the only difference will be in the size of the phalanges). The thumb, on the other hand, has somewhat different features and a different mechanism must be used to replace it.

Next, we will draw up a structural diagram of the mechanism. We take measurements of the bones, taking the axial centres of finger bending as the reference points. When measuring the metacarpal part, we make a simplification: we assign the size of the entire metacarpal bone to the metacarpal bone (Fig. 1).

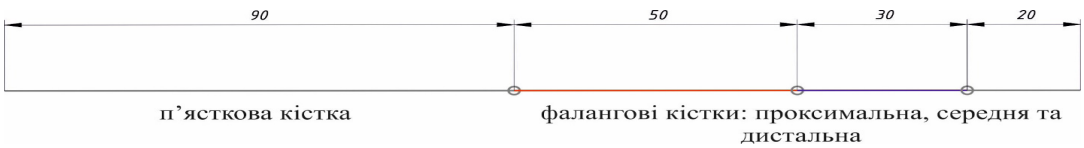

Fig. 1 – Dimensions of the main links of the mechanism

The measurements were taken from a healthy human hand. This was done to ensure that the prosthesis was identical to a living organ. This method is possible only in the case of loss of one limb, measurements can be taken from the intact limb. In the case of loss of both limbs, it would be necessary to use unified anthropometric data.

The next step in the design process is to analyse the movements and degrees of freedom that will need to be implemented. Let us start with the distal phalanx.

In most modern analogues, the movement of the middle phalanx is synchronised with the proximal phalanx. This is necessary for the cylindrical and ball grip, but not sufficient for the hook grip. Thus, two modes of operation must be implemented for the middle phalanx: synchronous with the movement of the proximal phalanx and independent.

The movement of the proximal phalanx is the most important in the formation of most types of grips. We should use a separate actuator for it.

The thumb has only distal and proximal phalanges. The distal phalanx will move synchronously with the proximal phalanx. The latter will be driven by an actuator. The thumb also has one feature: it can change the plane of flexion of the phalanges. Analysing its movements in most grips, we can conclude that it will be enough to change the angle of the bending plane. That is, the thumb should rotate around an axis parallel to the direction of extension of the other fingers.

Continuing our policy of full anthropometric compliance, we project all the mechanical components of a living organ onto the components of the prosthesis. As a result, we get all the necessary dimensions and patterns of formation of the hand as a mechanism.

When designing the prosthesis, we pay attention to the work already done at the

previous design stage, so we unify some dimensions and refute the genetic differences of the organ parts. This is necessary to simplify the production technology of the future product, and we reduce similar parts to identical technological properties. Such concessions will significantly reduce the cost of the final product. However, this does not apply to the dimensions of the layout, i.e. those that form the overall picture of the human hand and are typical for most individuals. Although this project is a compromise between functionality and cost, as one of its goals is to reduce the latter, we would still like the prosthesis that a person will receive after the design to be completely individual and, if possible, resemble the lost limb as much as possible. That is why this uniqueness should be achieved by the overall appearance, but not by the design features.

All the fingers except the thumb will have the same design of the mechanism and individual parts. The difference in length will be achieved by varying the size of the proximal and middle phalanx. The distal phalanx and most of the other small parts of the structure will be the same, which will simplify their production. All other dimensions should be maintained in strict accordance with the living organ, and the final shape should resemble a healthy hand as much as possible (Fig. 2).

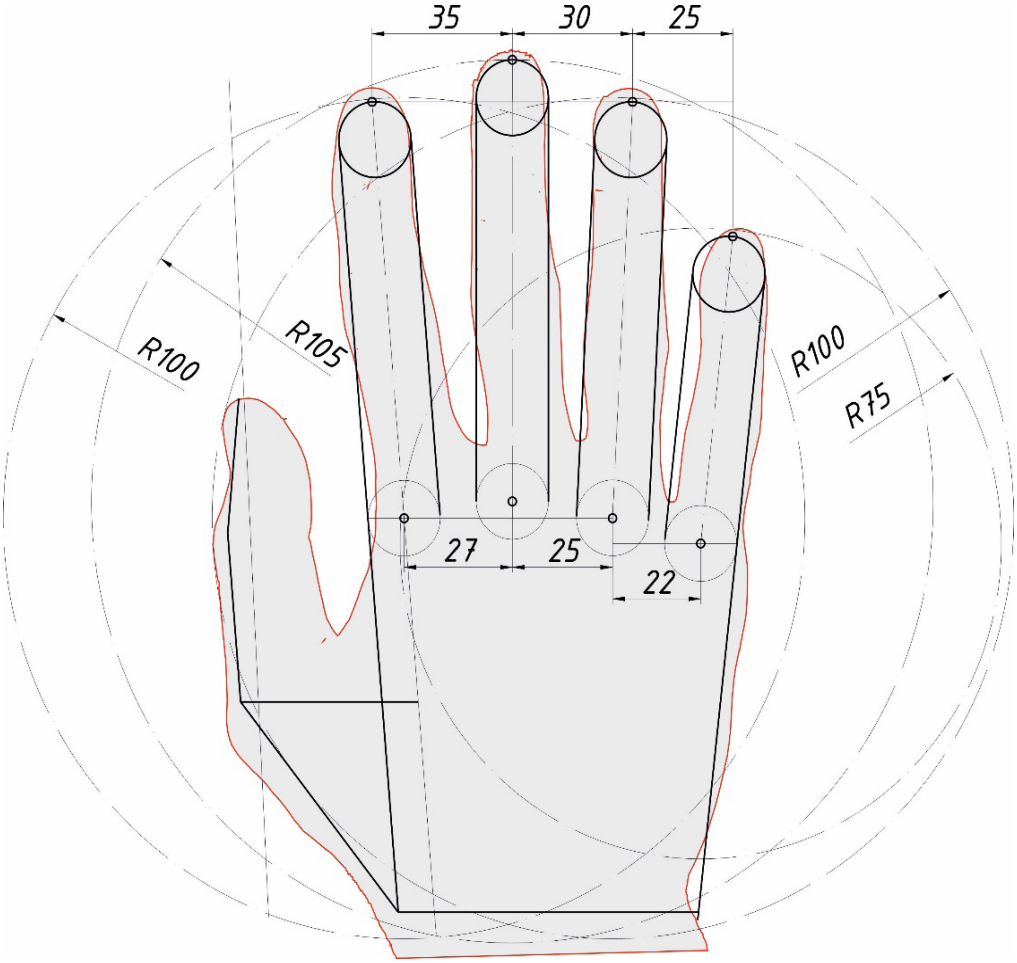

Fig. 2 – Scheme for projecting individual brush sizes onto a drawing

2. Designing elements of a prosthetic hand in Autodesk Fusion 360. Designing a three-dimensional model of the bone based on a mechanical design scheme involves the distribution of the material volume of the future part. The basic rule should always be to keep the design elements as simple as possible. That is, the future part should include as few primitives as possible, be easy to manufacture (as cheaply as possible) and have a clear structure for operation. But at the same time, each part must accurately reproduce all functions; the parts that will replace the body of the phalanx must be sufficiently like the phalanges of a living organ.

Let us illustrate the design process with the example of the middle phalanx. First, based on the diagram of the mechanism, let's distribute the thicknesses of the nodes to get a picture of the overlap of the levers and main elements (Fig. 3).

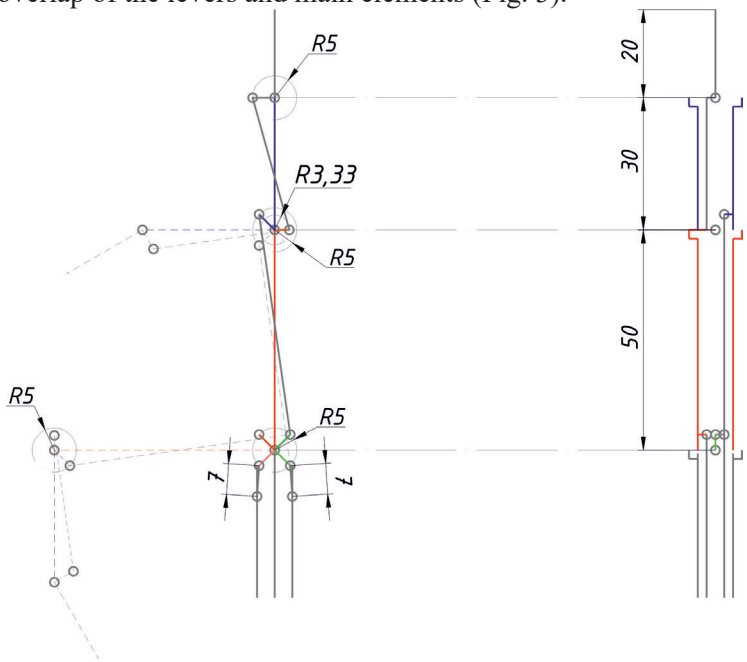

Fig. 3 – Thickness distribution of parts.

Analysing the image, we can say that the middle phalanx (shown in blue) for attachment to the distal phalanx should have two lugs that will cover the thickness of the latter. For attachment with the proximal phalanx, on the contrary, the middle phalanx should have a narrower thickness to fit into the lugs of the former. At the same time, the thickness in this place should be sufficient to accommodate the lever that transmits the force from the drive located below. In the lower part, holes should also be provided for the supports that will be used to attach the lever that moves the distal phalanx. It will be placed in the body of the middle phalanx. Next, let's build the profile of the part, which will consist of three primitives: two circles and a quadrilateral (in the future, they will turn into cylinders and a quadrilateral prism). The dimensions of the circles are taken from the measurements of a living organ in the joint area.

Having the design dimensions and patterns, we move on to the Autodesk Fusion 360

environment. First, you need to create a project that stores all the information: parts, models, drawings that are relevant to the assembly drawing and are stored in different types of files. A project description file is used to organise and manage these relationships between Autodesk Fusion 360 files. Combining various 3D modelling operations, we create the final model of the middle phalanx (Fig. 4).

During the modelling, it was necessary to follow several special rules. All operations were orientated to the central plane, which made it possible to change the dimensions of structural elements in the future by changing just one parameter, which is exactly the kind of adaptive parametric design that Fusion 360 enables. The second rule served the same purpose and consisted of the correct sizing of the sketches.

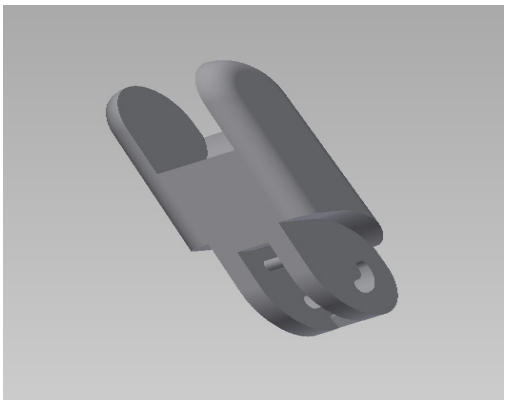

Fig. 4 – View of the finished 3D model of the middle phalanx.

3. Modelling the dynamic operation of mechanisms in Autodesk Fusion 360. Modelling the dynamic characteristics of prostheses for various purposes at the design stage is a very important task for designers: it allows them to determine how effectively the designed prosthesis will function in real conditions and take corrective actions, if necessary, to ensure correct operation, strength and durability.

The Autodesk Fusion 360 software package, which includes the Dynamic Event Simulation module, allows you to effectively calculate any dynamic systems, i.e. design and analyse the operation of various prostheses.

The process of modelling the dynamic operation of a prosthetic hand in Dynamic Event Simulation is as follows:

1. In the standard Autodesk Fusion 360 workspace, you create ‘rigid’ subassemblies, which are groups of parts - phalanxes - that will move relative to each other using components and joints.
2. In the Simulation environment, you specify the types of connection between the components of the subassemblies from the available list (rotation, sliding, rolling, contact interactions, springs, pushers, etc.).
3. Define the connection parameters (gravity, friction, damping, motion constraints, external forces and moments) that will be applied during the simulation.
4. Start the simulation process - set the operating time and time of each step (time sampling for analysis).

5. Analyse the results - determine component positions, velocities, accelerations, reactive forces, torques, driving forces and other parameters.

6. To determine the strength of components using the finite element method, the data modelled in the Simulation environment is transferred to the Stress Analysis module of Autodesk Fusion 360, where the deformation of parts, safety margins, and equivalent stresses are determined.

Figure 5 demonstrates an example of dynamic modelling of a prosthetic hand designed during the study.

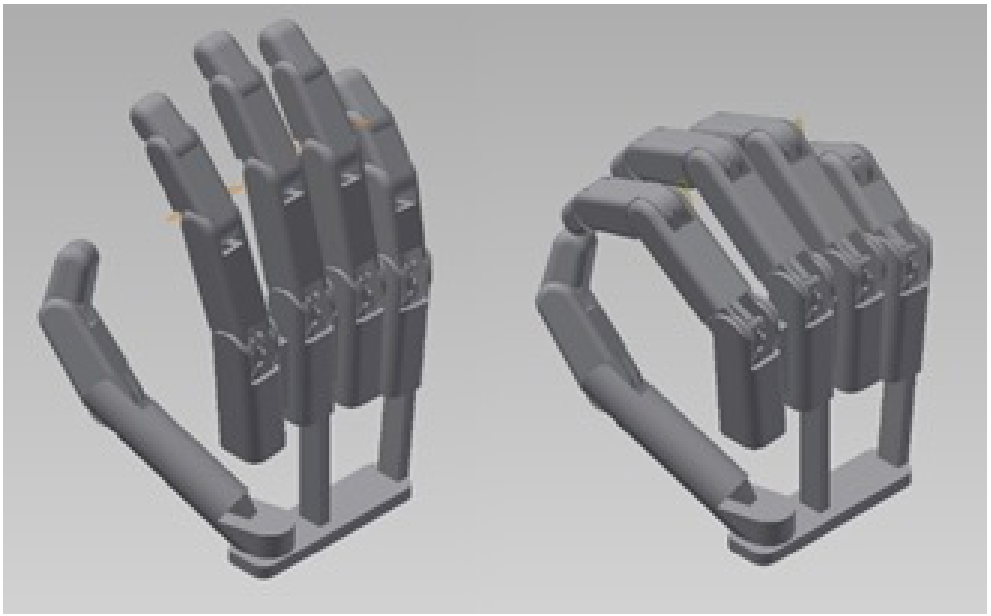

Fig. 5 – Dynamic movement of the prosthetic hand

Results and Discussion

In today's competitive world, it's crucial to constantly improve your efficiency. The productivity gains that result from modernising workflows in our core CAD software are a key benefit of its highly customisable nature. Autodesk provides powerful APIs and development kits (SDKs) that allow us to get more out of our Autodesk software investment by adapting it to our business needs.

Autodesk Fusion 360 offers a rich API that can be used not only to enhance existing product tools, but also to create entirely new features. We can automate repetitive, time-consuming tasks as well as extend core functionality directly within the Fusion 360 environment. The API allows you to create your own tools and functions that integrate with Fusion 360 to extend its functionality.

The Fusion 360 API is based on a REST interface and allows you to use modern programming languages such as Python and JavaScript to create integrations and automate processes. Python is one of the most popular choices due to its ease of use, wide range of libraries, and active developer community.

API (Application Programming Interface) stands for 'application programming interface' and defines how a programmer can interact with the Fusion 360 environment. This includes working with interface elements, automating design processes, creating customised functions, and configuring tools. In other words, the Fusion 360 API allows you to create commands and scripts to optimise the use of Fusion 360 in your work.

Software development companies, including Autodesk, often distribute sets of libraries that you can use in your applications to utilize and extend the functionality of a specific software product. These library sets are known as the product's API. The type of program you can create to interact with the software product and extend its functionality will depend on the implementation details of its API and the range of features accessible through the API.

Conclusions

As a result of the study, modern methods of designing upper limb prostheses were considered. Using the Autodesk Fusion 360 computer-aided design system, a three-dimensional parametric dynamic model of the hand prosthesis was created. In the future, this model can be used in the production of modern prostheses to improve the quality of life of patients.

Comprehensive information support for the medical and diagnostic process, along with traditional methods of assessing the functional state of the disabled, can be seen as one of the ways to improve the effectiveness of medical rehabilitation of amputees, which should ultimately ensure the independence of the disabled in everyday life and their return to work.

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MODELS AND INFORMATION TECHNOLOGY FOR REAL ESTATE VALUATION USING MACHINE LEARNING ALGORITHMS

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Abstract. It has been established that one of the main challenges in the field of real estate valuation is processing large volumes of information. Traditional valuation methods, which rely on expert experience, can be limited and prone to human error. The application of Data Science enables the automation of data collection, analysis, and processing, leading to more accurate and objective results. The article explores the development of Data Science technology for real estate valuation, including data analysis, the use of statistical methods and machine learning techniques, and the creation of a valuation model based on the obtained results. Existing approaches to the use of analytical methods in real estate valuation tasks are examined. A new methodology for their application is developed, along with a justification of the feasibility and necessity of implementing the proposed methodology. Recommendations for the practical implementation of the methodology are provided.

Keywords: forecasting, machine learning, real estate market, Data Science

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МОДЕЛЬДЕР ЖӘНЕ ЖЫЛЖЫМАЙТЫН МҮЛІКТІ БАҒАЛАУ ҮШІН АҚПАРАТТЫҚ ТЕХНОЛОГИЯЛАР МАШИНАЛЫҚ ОҚЫТУ АЛГОРИТМДЕРІН ҚОЛДАНУМЕН

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Аннотация. Жылжымайтын мүлікті бағалау саласындағы басты мәселелердің бірі – үлкен көлемдегі ақпаратты өңдеу екені анықталды. Сарапшылардың тәжірибесіне негізделген дәстүрлі бағалау әдістері шектеулі және адам қателіктеріне бейім болуы мүмкін. Data Science қолдану деректерді жинау, талдау және өңдеу процесін автоматтандыруға мүмкіндік береді, бұл дәлірек және объективті нәтижелер алуға жол ашады. Мақалада жылжымайтын мүлікті бағалауға арналған Data Science технологиясын әзірлеу, соның ішінде деректерді талдау, статистикалық әдістер мен машиналық оқыту әдістерін пайдалану, алынған нәтижелер негізінде бағалау моделін құру мәселелері қарастырылған. Жылжымайтын мүлікті бағалау міндеттерінде аналитикалық әдістерді қолданудың қолданыстағы тәсілдері зерттелген. Олардың қолданылуына арналған жаңа әдістеме әзірленіп, ұсынылған әдістемені енгізудің орындылығы мен қажеттілігі негізделді. Әдістемені практикалық іске асыру бойынша ұсыныстар берілген.

Түйін сөздер: болжау, машиналық оқыту, жылжымайтын мүлік нарығы, Data Science

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МОДЕЛИ И ИНФОРМАЦИОННАЯ ТЕХНОЛОГИЯ ОЦЕНКИ НЕДВИЖИМОСТИ С ИСПОЛЬЗОВАНИЕМ АЛГОРИТМОВ МАШИННОГО ОБУЧЕНИЯ

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Аннотация. Установлено, что одной из основных проблем в области оценки недвижимости является обработка больших объемов информации. Традиционные методы оценки, основанные на экспертном опыте, могут быть ограничены и подвержены человеческим ошибкам. Применение технологий Data Science позволяет автоматизировать процесс сбора, анализа и обработки данных, что обеспечивает получение более точных и объективных результатов. В статье рассматривается разработка технологии Data Science для оценки недвижимости, включая анализ данных, использование статистических методов и методов машинного обучения, создание модели оценки на основе полученных результатов. Исследуются существующие подходы к применению аналитических методов в задачах оценки объектов недвижимости. Разработана новая методика их применения, обоснована целесообразность и необходимость внедрения предложенной методики. Даны рекомендации по практической реализации методики.

Ключевые слова: прогнозирование, машинное обучение, рынок недвижимости, Data Science

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Introduction

In the modern world, the increasing volume of data and the growing need for its analysis are becoming more relevant than ever. In the real estate sector, this process is particularly significant, as property valuation is a critical step in various processes, such as sales, purchases, rentals, and more. The development of Data Science technology in this field can enhance the accuracy and efficiency of valuations, which, in turn, can have a positive impact on the real estate market.

One of the main challenges in real estate appraisal is managing large amounts of information. Traditional valuation methods, which rely on expert experience, can be limited and prone to human error. By leveraging Data Science, it is possible to automate the processes

of data collection, analysis, and processing, leading to more accurate and objective resu

Data Science methods can be applied to develop real estate valuation models based on statistical analyses and machine learning. These models enable the prediction of property values based on various factors, such as house size, the number of rooms, location, the availability of amenities, and more. This approach ensures more objective and precise valuations that take into account a wide range of factors. Automated algorithms and software solutions can significantly reduce the time and effort required for valuation, making the process faster and more efficient, while allowing more time for data analysis and informed decision-making.

The use of Data Science methods in real estate valuation holds great potential for improving the accuracy, objectivity, and efficiency of the appraisal process. Considering the vast amount of available data and analytical capabilities, Data Science facilitates more well-informed decisions regarding property purchases, sales, rentals, or investments. The data analysis process relies on objective criteria and algorithms, minimizing the influence of subjective factors or personal biases. This is crucial in real estate, where valuations can often be subjective and influenced by the assessor's personal opinions and experience.

Given the above, the development of Data Science technologies for real estate valuation, including data analysis, the use of statistical and machine learning methods, and the creation of valuation models based on these results, is a highly relevant and promising area of research.

Material and Methods

An analysis of literary sources demonstrates that the application of data analysis models is a crucial component of real estate valuation projects. Different models can be utilized for various aspects of such projects, including data collection, processing, and analysis.

For instance, in the study (Miroshnychenko et al., 2022), the authors explore machine learning methods for developing models to predict the prices of suburban real estate. They identify factors influencing suburban property valuation and build four predictive models: linear regression, ridge regression, random forest, and XGBoost. A comparison of results revealed that the XGBoost algorithm was the most effective (RMSE = 67669.15, MAE = 47063.49, MAPE = 0.1034903). Compared to multiple linear regression, it was concluded that the XGBoost model better explains the data, providing a higher probability of accurately forecasting actual property prices.

In another study (Pashkevych et al., 2022), a statistical model was developed to predict housing prices using linear regression. To evaluate the relationship between various property characteristics, 3D modeling was employed. The authors performed data clustering and testing on real-world data, achieving satisfactory predictive results. The model was tested on real properties, achieving an accuracy rate of 76 %.

In study (Velytchenko, 2020), a neural network was built to estimate property values. The author used both numerical and categorical attributes, as well as four images of the property. The resulting mean absolute percentage error (MAPE) on the test set was 17.52 %.

In work (Ivashchenko, 2022), the author compared two models for price prediction: decision tree and random forest. While the errors appeared relatively large, this was attributed to extreme deviations in predictions. The author noted that such deviations should be considered in further research. The random forest model was found to deliver more accurate and reliable predictions than the decision tree model.

In article (Khlevna et al., 2021), a variety of models were analyzed for predicting real

estate market prices, including Lasso regression, Elastic Net regression, Ridge regression, Gradient Boosting regression, and XGBoost. It was determined that aggregated models could improve results. The best-performing model was an ensemble of Lasso regression, Extreme Gradient Boosting, Elastic Net, and Ridge regression, achieving RMSE = 0.1091 and a standard deviation of 0.0075.

Another intriguing approach, discussed in study (Quanzeng et al., 2017), involved the use of image-based valuation. The authors investigated how visual features, reflecting property characteristics, could aid in estimating property values. They developed algorithms that relied solely on location and photo attributes. Recurrent neural networks were built and analyzed, achieving MAE = 66.3 and MAPE = 16.11 % on one dataset, and MAE = 13.32 and MAPE = 22.69 % on another.

In study (Yaroshenko et al., 2012), neural networks were also developed to assess real estate, focusing on quantitative and qualitative attributes. The model utilized real estate agency data over five months. The mean absolute error in predictions was 3.41 %. The authors speculated that this error was due to an insufficient number of factors affecting price formation.

In work (Alisha Kuvalekar, 2020), the authors collected data from various real estate websites in Mumbai and applied methods such as SVM, Random Forest, Linear Regression, Multiple Linear Regression, Decision Tree Regressor, and KNN. The best results were achieved by the Decision Tree Regressor, with an accuracy of 89 %.

In article (Kintzel Joseph, 2019), models were trained on a triad of data types: numerical, spatial, and image-based. Comparisons included models such as OLS, Neural Network, Random Forest, and Gradient Boosting. The Random Forest and Gradient Boosting regression algorithms performed best in predicting prices, with average error coefficients of 0.0758 and 0.0756, respectively. When combined with image evaluations (PCA-generated features), Gradient Boosting further reduced the error coefficient to 0.0728. Neural networks with PCA features had an error coefficient of 0.0930.

Finally, study (Kovpak et al., 2016: 56–60) explored a type of multiple regression using dummy variables to describe the current condition and location characteristics of real estate. The resulting average relative approximation error for the model was 11.72 %.

A range of specialized software and technologies is available for predicting real estate prices, including web services and mobile applications. These programs offer users a broad array of tools for analyzing the real estate market, such as access to historical price data, visualization of geographic trends, and the ability to create forecasts based on various machine learning models.

Many of these platforms integrate interactive maps, enabling users to explore different neighborhoods and their market characteristics, such as average property prices, price dynamics, infrastructure, and more. Some services also provide comparative analyses of property prices across various locations and property types.

These technologies are not only helpful for investors and buyers in making informed decisions about real estate investments but also serve as valuable tools for real estate agents, enabling them to provide more objective and detailed information to their clients.

Notable Examples of Real Estate Technologies:

Zillow (https://www.zillow.com): One of the most popular real estate price forecasting tools developed by an American real estate services company. Using an integrated algorithm, Zillow estimates property values by considering factors like location, size, condition, and

market trends. Forecasts are made for up to 12 months, incorporating county-level economic data and property-specific details.

CoreLogic (https://www.corelogic.com): This service offers robust analytical tools for predicting real estate prices at national, state, and metropolitan levels. It provides monthly updates, with forecasts spanning up to 30 years depending on the subscription level. Data sets are updated monthly, and results are published five weeks after the end of each month.

PropMix (propmix.io): Using a 25-terabyte database with diverse information, including images, PropMix employs artificial intelligence and computer vision to analyze real estate prices and generate forecasts.

Realyse (www.realyse.com): A UK-based platform providing detailed real estate market insights, helping investors, developers, and agents make informed price forecasts. It collects data from multiple sources and offers APIs or downloadable CSV files for forecast-related information.

Redfin Estimate (www.redfin.com/redfin-estimate): An online tool leveraging a variety of data sources to determine the approximate value of a residential property. Known for its accuracy, with an average error rate of 2.06 %, Redfin Estimate uses MLS data from recently sold homes to calculate current market values.

HouseCanary (www.housecanary.com): This solution predicts property prices—both for individual homes and the broader market—over a period of up to three years using machine learning and time series analysis. The platform also provides comprehensive analytics evaluating market conditions, desirability, and stability.

State Property Fund of Ukraine (www.spfu.gov.ua): This service analyzes property data by comparing multiple sources (Lun, OLX, contracts, reports) and provides official valuation certificates. However, as of 2021, the system does not account for property or apartment conditions, which can significantly affect valuations.

Features of Real Estate Technologies:

These tools utilize large databases containing information on market prices, geographic data, historical transaction data, and other factors influencing property values. Machine learning and AI algorithms analyze this data to produce highly accurate forecasts.

Limitations and Considerations:

Data Updates: Continuous updates are crucial to maintain accuracy. Real estate markets are dynamic, with changes in transactions, legal environments, and other factors affecting property values. Automated updating mechanisms are essential for these systems.

Market Focus: Most services target specific markets, such as the U.S. or U.K., due to the unique characteristics and data availability of these regions. This geographic focus enables a deeper analysis of local market conditions, providing more precise forecasts.

Cost Barriers: Accessing forecasts often requires paid subscriptions. For some users, these costs may be prohibitive, limiting their ability to utilize these tools effectively. Moreover, users might be reluctant to pay for a service they perceive as insufficiently valuable, creating a barrier to widespread adoption.

Despite these limitations, such technologies play a pivotal role in improving the precision and accessibility of real estate market analysis, benefiting investors, buyers, and agents alike.

The analysis of the reviewed literature indicates that the best-performing models are gradient boosting, random forest, and neural networks. Therefore, this study will focus on these models using a new dataset. Additionally, one of the ensemble models (gradient

boosting or random forest) with the best results will be selected, and a combined model with a neural network will be developed to evaluate the potential for improving prediction accuracy through this approach.

The aim of this research is to enhance the effectiveness of real estate price prediction by formalizing data processing methods.

Results and Discussion

To predict real estate prices, the following models were selected for development: gradient boosting, random forest, and neural networks.

Gradient Boosting is an ensemble machine learning method, a form of bagging, which iteratively builds weak models to improve predictive accuracy. The goal of gradient boosting, like any supervised learning algorithm, is to define a loss function and minimize it (Trevor, 2017). This method is known for its high accuracy and is widely used in various fields, including image recognition, time series forecasting, and recommendation systems.

The optimization function for gradient boosting is represented by the following formula:

$$L(t) = \sum_{i=1}^{n} l(y_i, f^{-1}{}_i't(x_i)) + \Omega(f_i), \quad [1]$$

where

l – loss function,

$y_i, f^{-1}1$ – the value of the i-th element of the training sample and the sum of the predictions of the first t trees, respectively,

x_i – feature set of the i-th element of the training sample,

f_i – the function (in our case, a tree) that we want to train at step t,

$f_i(x_i)$ – prediction on the i-th element of the training sample,

$\Omega(f)$ – regularization of function f. $\Omega(f) = \gamma T + \frac{1}{2}\lambda\|w\|^2$, where T – number of tree vertices, w – values at the leaves, and γ and λ – regularization parameters.

Using the Taylor expansion to the second term, the optimization function L(t) can be approximated by:

$$L(t) = \sum_{i=1}^{n} l(y_i, f^{-1}1_i + g_i f_i(x_i) + 0.5 h_i f^2{}_i(x_i)) + \Omega(f_i), \quad [2]$$

where

$g_i = \partial l(y_i, f^{-1}1)/\partial f^{-1}1$,

$h_i = \partial 2 l(y_i, f^{-1}1)/\partial 2 f^{-1}1$.

Since the goal is to minimize model error on the training set, the minimum of L(t) must be found for each t.

Random Forest is also an ensemble machine learning method, similar to gradient boosting, which employs a combination of multiple decision trees to develop predictions. It is one of the most popular methods for classification and regression, known for its flexibility, ease of use, and efficiency.

Neural Networks are a machine learning method inspired by the functioning of the human brain. This method is based on the use of «neurons» – computational units that can learn to recognize patterns in data.

In this work, a deep neural network will be constructed. This is a type of artificial neural network with two or more hidden layers between the input and output layers. These additional layers enable the network to learn more complex and abstract functions, translating simple input data into more intricate structures. For example, in image processing tasks, the initial layers may detect simple shapes, such as lines and circles, while deeper layers combine

these simple shapes to detect more complex patterns, such as human faces.

Deep Neural Networks (DNN) are often associated with deep learning, a branch of machine learning focused on using deep networks. The training process for deep networks typically utilizes algorithms based on the gradient descent method, such as stochastic gradient descent (SGD), RMSprop, Adam, and others.

The architecture of the constructed neural network is shown in Figure 1.

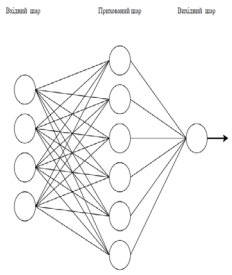

Fig. 1 - Neural Network Diagram

To activate the layers, the ReLU activation function was chosen, which has the following mathematical formula:

$$f(x) = \max(x, 0) \quad [3]$$

For optimizing the training process, the Adam function was selected. Adam combines the approaches of the AdaGrad and RMSProp methods. It also adjusts the learning steps individually for parameters, taking into account the «history» of gradient changes on them (Marusyk, 2019).

Let

$$v = \beta 1v + (1 - \beta 1)d\theta,$$

$$s = \beta 2s + (1 - \beta 2)d\theta 2 ,$$

$$\hat{w_v} = w_v/(1 - \beta 1^n),$$

$$\hat{s}_v = s_v/(1 - \beta 2^n), \quad [3]$$

where v and s are referred to as the first and second moment estimates, $\hat{w_v}$ and $\hat{s}_v$ – bias-corrected moment estimates. Then parameter changes occur as follows:

$$\theta = \theta - \lambda \hat{w_v}/\sqrt{\hat{s}_v + \varepsilon} \quad [4]$$

Mean Squared Error (MSE) is used to calculate losses. This loss function computes the square of the difference between predicted and true values and then averages these squares:

. [5]

To evaluate the obtained predictions and compare the mentioned methods, metrics such as MAE, MAPE, RMSE, and the coefficient of determination will be used.

MAE is a metric for evaluating the accuracy of a predictive model. It calculates the difference between predicted values and actual values, taking the absolute value of these differences and averaging across all data points. MAE measures the absolute error of the forecast, regardless of direction. The smaller the MAE value, the higher the model's accuracy.

. [6]

MAPE is another metric for evaluating the accuracy of a predictive model. It calculates the percentage difference between predicted and actual values, taking the absolute value of

these differences and averaging the percentage across all data points. MAPE measures the percentage error of the forecast. MAPE errors serve to evaluate the percentage deviation of the forecast relative to the actual value. Typically expressed as a percentage, the smaller the MAPE value, the higher the model's accuracy.

. [7]

RMSE is yet another metric for evaluating the accuracy of a predictive model. It computes the square root of the mean squared error, which is the sum of the squared differences between predicted and actual values, divided by the number of data points, and then takes the square root of the resulting value. RMSE measures the root mean square error of the forecast. The smaller the RMSE value, the higher the model's accuracy.

Coefficient of Determination is a metric that measures how well the model predicts actual data. It represents the ratio of the variation in model predictions to the total variation in the data. The coefficient of determination ranges from 0 to 1, where a value of 0 means the model does not explain any variation in the data, and a value of 1 means the model fully explains the data variation. The higher the R-squared value, the better the model predicts the data. However, this metric can be sensitive to overfitting and the number of variables.

- [8]

All these metrics are used to assess and compare the accuracy of predictive models.

The chosen programming language for implementing the described methods was Python (docs.python.org/3.9). The decision to use this language was driven by its robustness and widespread popularity in the fields of data analysis and Data Science.

The input data was decided to be sourced from a real estate information portal (riel-tor.ua). The data was preprocessed and cleaned beforehand.

The XGBoost library was used to build the gradient boosting model. Experiments were conducted with various parameter sets, but the best-performing parameters are shown in Figure 2. A model was created to train on the training dataset using the fit method and predict prices on the test dataset using the predict method.

```
model = XGBRegressor(n_estimators=100,
                     learning_rate=0.1,
                     subsample=0.7,
                     colsample_bytree=0.9,
                     alpha=0.5)
model.fit(X_train, y_train)
y_pred = model.predict(X_test)
```

Fig. 2 - Code snippet of the XGBoost model

The random forest model was built using the sklearn library. Experiments were also conducted with different numbers of estimators, and ultimately, two hundred estimators were chosen (Fig. 3).

```
model = RandomForestRegressor(n_estimators=200,
                              random_state=42)
model.fit(X_train, y_train)
y_pred = model.predict(X_test)
```

Fig.3 - Code snippet of the Random Forest model

Similarly to the previous models, the best parameters were selected for the neural network. In this case, attempts were made to use different activation functions (sigmoid, linear, ReLU), various numbers of input and hidden layers, the number of epochs, and so on.

The Keras library was used for the construction. The code for building the model is shown in Figure 4.

```
model = Sequential([
    Dense(64, activation='relu', input_shape=(df[features].shape[1],)),

    Dense(64, activation='relu'),
    Dense(64, activation='relu'),
    Dense(64, activation='relu'),
    Dropout(0.2),
    Dense(128, activation='relu'),
    Dropout(0.2),
    Dense(256, activation='relu'),
    Dropout(0.2),
    Dense(128, activation='relu'),
    Dropout(0.2),
    Dense(64, activation='relu'),
    Dropout(0.2),

    Dense(1)
])

model.compile(optimizer='adam', loss='mean_squared_error', metrics=['mae'])
early_stopping = EarlyStopping(monitor='val_mae', patience=15, mode='min', restore_best_weights=True)
model.fit(X_train, y_train, epochs=100, batch_size=64, callbacks=[early_stopping], validation_data=(X_test, y_test))
y_pred = model.predict(X_test)
```

Fig.4 - Code snippet with the neural network model

The approach of combining gradient boosting and neural network models opens up significant opportunities for improving prediction quality. Since the gradient boosting model has already demonstrated better results compared to the random forest, leveraging this model in combination with neural network predictions can be a highly effective strategy.

The quality assessments of this combined model are presented in Table 1 and compared to standalone gradient boosting.

Table 1

Quality Assessments of the Constructed Models

Model	MAE	MAPE	RMSE	R2 score
Gradient Boosting	39498.78	0.261	92911.20	0.81
Random Forest	38738.20	0.245	101943.28	0.77
Neural Network	49712.98	0.286	141427.70	0.56
Combined Model	10064.71	0.107	14337.08	0.99

To utilize the developed model, it was decided to create an information system, specifically a web service for property valuation. To build a web service based on the developed model, a user-friendly and intuitive interface needs to be designed. Users should be able to easily input property details, such as location, area, number of rooms, and so on.

The concept of an information system for property valuation includes the following components:

1. Database: This is the central element of the system, containing a vast amount of information about real estate in Kyiv. It holds extensive data on the real estate market, including apartment sales records. The database stores various apartment attributes used for value estimation, such as location, proximity to the metro, area, floor, and the total number

of floors in the building. These data points are stored in corresponding database tables and are utilized for analyzing and predicting property values using machine learning models. The database is continuously updated to include new apartment sales data and their characteristics, ensuring the relevance and accuracy of valuations.

2. Analytical Tools: The information system should include analytical tools for data processing and analysis, specifically using the predictive pricing model developed in this project. This model analyzes apartment parameters stored in the database and uses them to generate price forecasts. The predictive pricing model is maintained and enhanced with the latest analytical methods and algorithms to ensure its accuracy and reliability. It can be periodically updated based on new data to account for real estate market changes and improve forecast quality.

3. User Interface: The information system must have a user-friendly and intuitive interface. This could be, for example, a web application or service that allows users to quickly and conveniently access real estate information, calculate property values, and perform other actions.

The concept of a property valuation information system for the city of Kyiv can be implemented by combining a database, analytical tools, and a user-friendly interface. This system will simplify and make the property valuation process in Kyiv more objective.

Relational databases such as PostgreSQL, MySQL, or SQLite are commonly used to store real estate data. They provide structured data storage with the ability to perform complex queries while ensuring data reliability and consistency. Therefore, it was decided to use one of these databases for this project, specifically a MySQL database.

The logical model of the database (Figure 5) represents the structure of the data and the relationships between them without being tied to a specific database management system (DBMS). It describes the structure of the database at the level of concepts and entities, without focusing on technical implementation aspects. It includes entities, their attributes, relationships, and keys—both primary and foreign.

Creating a web service for real estate price prediction that includes a form for apartment price calculation opens up broad opportunities in various fields.

Firstly, it provides convenient access to predictions anytime and anywhere. Users can access the service from any device with an Internet connection, such as a computer, tablet, or smartphone. This allows users to access price forecasts even on the go or in places without access to a stationary computer. The web service also features an intuitive and user-friendly interface, enabling users to navigate and utilize its features quickly. The price calculation form is straightforward and easy to fill out. Furthermore, users will be able to save the prediction results or send them to their email for further analysis or comparison, making it convenient to use the data in their work.

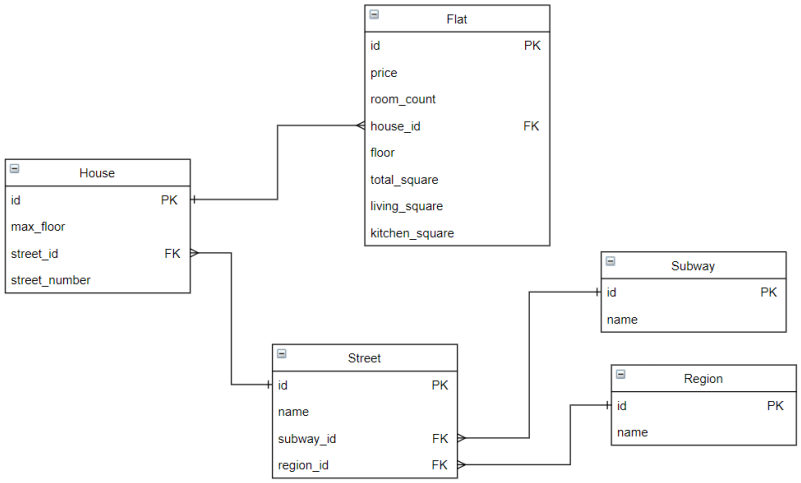

Fig. 5 - Logical Database Model

Secondly, the price calculation form allows users to receive personalized predictions by considering the unique characteristics of each apartment. Each parameter is crucial for determining the property value, and users can freely adjust them according to their needs and requirements.

This web service provides users with valuable information for making informed decisions regarding the purchase, sale, or rental of real estate in the city.

The collected data from the web service can be used for further analysis of the real estate market, allowing for the observation of trends and conducting research in this field. For example, the data provided to users for price calculations can be aggregated and used for market trend analysis. Alternatively, collecting data on real estate prices enables the analysis of supply and demand in the market. This helps to understand which types of properties are most popular among buyers and which areas have the highest demand.

The accumulated data can also be used to prepare analytical reports and market condition summaries. This can be valuable for real estate agencies, urban planning development, and other market participants.

Conclusion

Three models for predicting real estate prices were developed. These models included gradient boosting, neural networks, and random forest. Each of these models was carefully fine-tuned and trained using the prepared data.

After analyzing their performance, the best ensemble model was selected to construct a combined model, which ultimately provided significantly better predictions than the standalone models. This highlights the value of combining different models to improve the accuracy and efficiency of predictions.

The combined model can be more versatile and precise in predicting real estate prices, enabling better decision-making in the real estate market. A conceptual description of the developed information system and database schema has been provided

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АҚПАРАТТЫҚ ҚАУІПСІЗДІК ЖӘНЕ КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАРҒА АРНАЛҒАН

ИНФОРМАЦИОННАЯ БЕЗОПАСНОСТЬ И КОММУНИКАЦИОННЫЕ ТЕХНОЛОГИИ

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OVERVIEW OF MACHINE LEARNING METHODS FOR REAL-TIME TRACKING SYSTEMS FOR DYNAMIC OBJECTS

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Abstract. Considerable progress has been made in the development of video analytics systems and individual image authentication technologies. However, challenges persist in recognizing dynamic images due to the complexity and variability of real-world behavior. Certain scenarios place particular importance on extracting information about the structure and motion of objects within a scene, such as indoor video surveillance in crowded areas, robotic system traffic control, and vehicle movement monitoring. For object tracking tasks, current research and development focus on addressing the following practical challenges: variations in scene illumination or image lighting conditions; noise generated by camera systems; objects that change shape over time; temporary disappearance of objects due to occlusion by other objects; simultaneous movement of multiple objects with similar characteristics and intersecting trajectories. In the field of object recognition, there remains a pressing need for real-time algorithms capable of accurately identifying objects in video frames despite interference or noise. Therefore, the development, refinement, and analysis of algorithms for tracking and identifying objects in video footage continue to be critical issues in the current stage of scientific and technological progress. The primary objective is to develop, enhance, and study new algorithms for object tracking and recognition in video data, considering distortions and interference. This effort aligns with practical requirements for the effective operation of modern security systems.

Keywords: open-source computer vision, region of interest, background subtraction, optical character recognition

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ДИНАМИЯЛЫҚ ОБЪЕКТТЕРГЕ НАҚТЫ УАҚЫТТЫ БАҚЫЛАУ ЖҮЙЕЛЕРІН МАШИНАДАН ОҚЫТУ ӘДІСТЕРІНЕ ШОЛУ

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Аннотация. Бейне аналитика жүйелерін және кескіннің аутентификациясының жеке технологияларын дамытуда айтарлықтай прогреске қол жеткізілді. Дегенмен, нақты әлемдегі мінез-құлықтың күрделілігі мен өзгермелілігіне байланысты динамикалық бейнелерді тану қиындықтары сақталады. Кейбір сценарийлерде адамдар көп шоғырланған аумақтардағы ішкі бейнебақылау, көлік қозғалысын басқарудың роботтық жүйесі және көлік қозғалысын бақылау сияқты көріністегі нысандардың құрылымы мен қозғалысы туралы ақпаратты алуға ерекше мән беріледі. Объектілерді бақылау тапсырмалары үшін ағымдағы зерттеулер мен әзірлемелер келесі практикалық міндеттерді шешуге бағытталған: Көрініс жарықтандыру немесе кескінді жарықтандыру жағдайларындағы өзгерістер. Камера жүйелері тудыратын шу. Уақыт өте келе пішінін өзгертетін объектілер. Басқа заттармен бітелу салдарынан заттардың уақытша жоғалуы. Ұқсас сипаттамалары және қиылысатын траекториялары бар бірнеше объектілердің бір мезгілде қозғалысы. Объектіні тану саласында кедергі немесе шуылға қарамастан бейне кадрлардағы объектілерді дәл анықтауға қабілетті нақты уақыт режиміндегі алгоритмдерге қажетті қажеттілік сақталады. Сондықтан, бейнежазбалардағы объектілерді қадағалау және анықтау алгоритмдерін жасау, нақтылау және талдау ғылыми-техникалық прогрестің қазіргі кезеңінде өзекті мәселелер болып қала береді. Негізгі мақсат - бұрмаланулар мен кедергілерді ескере отырып, бейне деректердегі объектіні бақылау және тану үшін жаңа алгоритмдерді әзірлеу, жақсарту және зерттеу. Бұл күш заманауи қауіпсіздік жүйелерінің тиімді жұмыс істеуіне арналған практикалық талаптарға сәйкес келеді.

Түйін сөздер: Open Source Computer Vision, Region of interest, Background subtraction, Optical character recognition

Дәйексөздер үшін: А.А. Балгабек, А.М. Әкім, С.Е. Сибанбаева, Ж.М. Бекаулова. ДИНАМИЯЛЫҚ ОБЪЕКТТЕРГЕ НАҚТЫ УАҚЫТТЫ БАҚЫЛАУ ЖҮЙЕЛЕРІН МАШИНАДАН ОҚЫТУ ӘДІСТЕРІНЕ ШОЛУ//ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ КОММУНИКАЛЫҚ ТЕХНОЛОГИЯЛАР ЖУРНАЛЫ. 2024. Т. 5. No. 20. 118–131 бет. (ағылшын тілінде). https://doi.org/10.54309/IJICT.2024.20.4.010.

ОБЗОР МЕТОДОВ МАШИННОГО ОБУЧЕНИЯ ДЛЯ СИСТЕМ ОТСЛЕЖИВАНИЯ ДИНАМИЧЕСКИХ ОБЪЕКТОВ В РЕАЛЬНОМ ВРЕМЕНИ

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Аннотация. Значительный прогресс был достигнут в разработке систем видеоаналитики и технологий аутентификации отдельных изображений. Однако проблемы с распознаванием динамических изображений сохраняются из-за сложности и изменчивости поведения в реальном мире. Определенные сценарии придают особое значение извлечению информации о структуре и движении объектов в пределах сцены, например, внутреннее видеонаблюдение в многолюдных местах, управление движением роботизированных систем и мониторинг движения транспортных средств. Для задач отслеживания объектов текущие исследования и разработки сосредоточены на решении следующих практических проблем: изменения в освещении сцены или условиях освещения изображения; шум, создаваемый системами камер; объекты, которые меняют форму с течением времени; временное исчезновение объектов из-за окклюзии другими объектами; одновременное движение нескольких объектов со схожими характеристиками и пересекающимися траекториями. В области распознавания объектов сохраняется острая потребность в алгоритмах реального времени, способных точно идентифицировать объекты в видеокадрах, несмотря на помехи или шум. Поэтому разработка, совершенствование и анализ алгоритмов отслеживания и распознавания объектов на видеоматериалах остаются важнейшими задачами на современном этапе научно-технического прогресса. Основной целью является разработка, совершенствование и изучение новых алгоритмов отслеживания и распознавания объектов на видеоматериалах с учетом искажений и помех. Эта работа соответствует практическим требованиям эффективной работы современных систем безопасности.

Ключевые слова: open source computer vision, region of interest, background subtraction, optical character recognition

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Introduction

Billions of security systems are integral to the modern civilized world (Amirgaliev, 2012; Mukhanov et al., 2020: 31–37; Mukhanov et al., 2023: 16–27; Mukhanov et al., 2023: 15–27; Kenshimov et al., 2021: 44–54). Monitors display a continuous stream of images, with many operators ensuring safety in airports, train stations, and other public spaces. Surveillance has become one of the most crucial technical tools for ensuring security. Digital image processing algorithms (Uskenbayeva et al., 2020: 1–6; Bazarevsky et al., 2019; Anna Vidyanova, 2022) and computer vision technologies (Bilgin et al., 2019; Liukai et al., 2022: 103364) play a critical role in modern security systems, enabling the real-time monitoring of thousands of video channels.

The development of modern security systems is associated with the following key challenges:

- Detecting objects of interest in complex, dynamic backgrounds.
- Measuring spatial parameters and estimating dynamic characteristics of objects across sequential frames.
- Tracking objects over time.
- Classifying and identifying dynamic objects.

Among various recognition and classification tasks, one of the most critical and pressing is the detection and classification of human faces (Guoxiang et al., 2023: 118912). This problem has wide applications across multiple domains, particularly in security systems. Face recognition is utilized in areas such as verifying photos in passports and driving licenses, controlling access to secure computer networks and office equipment, and monitoring airports and train stations to prevent terrorist activities, among others. In most practical scenarios, analyzing input images must occur in real time.

Modern algorithms achieve a high probability—greater than 90 % – of detecting human faces in live video feeds with complex backgrounds. Among the most well-known algorithms is the boosting-based method proposed by P. Viola and M. Jones in 2001 (Yeo et al., 2013).

The aim of object tracking is to establish consistency between objects or parts across sequences of frames, determine object trajectories, and calculate dynamic characteristics like speed and direction of movement (Okan et al., 2019). In most practical applications, object tracking must be performed in real time (Jaya Prakash et al., 2022). Automated object recognition is another critical area of computer vision (Whoi-Yul Kim et al., 2020). Successful solutions in this field are essential for developing systems capable of intelligently assessing their surroundings and taking appropriate actions.

However, in real-world systems, object recognition faces challenges such as distortions caused by electronic device interference and compression of two-dimensional signals. Addressing these issues effectively requires specialized digital image processing algorithms. These include non-linear filtering algorithms, image restoration techniques, wavelet-based

processing, and systems utilizing fuzzy logic, genetic algorithms, and neural networks.

Problem statement

Camera devices play a crucial role in gathering information and monitoring people, their activities, and events (Chunyong et al., 2020). Among the most widely used technologies in modern surveillance are video cameras, thermal imaging cameras, and night vision devices. Visual analysis of dynamic scenes, especially those involving human activity, is a highly active research area in computer vision and artificial intelligence. This field has broad applications for public order and security, such as access control, crowd movement analysis, queue monitoring, human behavior detection, and more (Van Houdt et al., 2020).

The use of multiple cameras for dynamic scene observation provides enhanced capabilities for detecting, recognizing, and tracking objects across image sequences. More importantly, it allows for better understanding and interpretation of object behavior. The primary goal of such visual observation systems is to develop intelligent systems capable of replacing traditional passive surveillance. This shift is essential as increasing the number of cameras has proven inefficient due to the limited capacity of human operators. The aim is not merely to position cameras strategically but to achieve highly automated monitoring with minimal human intervention.

The processing subsystem of an automated visual surveillance system typically includes the following steps:

- Motion detection and object classification.
- Object tracking.
- Analysis and interpretation of behavior and activity.
- Person identification, including transitions between cameras and integration of data from multiple sources (Dinh-Son et al., 2020).

Most visual systems begin with motion and object detection (Alejandro et al., 2022). The goal of motion detection is to identify regions corresponding to moving objects and separate them from static areas in the image. The quality of this step is critical, as it directly impacts subsequent processes such as object tracking, behavior analysis, and recognition. Motion detection typically involves background modeling and segmentation of moving areas, which may overlap with other objects during the process. The purpose of motion segmentation is to identify regions corresponding to moving entities, such as people or vehicles (Rehman Muneeb et al., 2021).

Identifying moving regions enables subsequent processes—such as tracking and behavior analysis—to focus solely on areas of interest. After motion detection, the system tracks these moving objects across image sequences, mapping them from frame to frame using features like points, lines, and blobs.

Behavior analysis involves identifying patterns of movement and describing actions or interactions between objects. For instance, it may be necessary to analyze human behavior to determine whether it is normal or abnormal. Biometric features such as facial characteristics and gait are increasingly used in visual surveillance systems for personal identification (Rehman Muneeb et al., 2021).

Motion detection, tracking, behavior recognition, and remote identification can all be implemented in systems using a single camera. However, systems with multiple cameras offer significant advantages by expanding the surveillance area and leveraging multiple viewpoints to resolve issues like object occlusion. Nevertheless, multi-camera systems present their own challenges, including optimal camera placement, calibration, view matching,

automatic switching, and data fusion.

Video surveillance systems also face similar challenges as other machine vision applications, including changes in lighting, viewpoints, zoom levels, and object orientation. Given these complexities, visual observation systems are often designed as a collection of specialized algorithms tailored to specific objectives.

Materials and Methods

An example of an automated visual surveillance system can be illustrated through the architecture of software designed for detecting and tracking objects (Fig. 1.2).

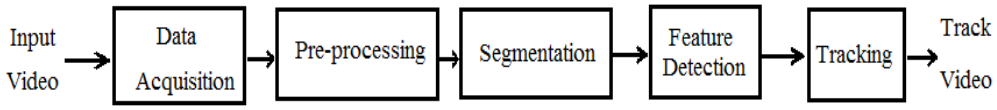


Figure 1.2: Block Diagram of Detection and Tracking

Object Detection

This stage identifies objects of interest for further analysis. It is a critical operation, as the efficiency and accuracy of the detection algorithms directly impact the overall system performance (Yeo et al., 2013; Okan et al., 2019; Jaya Prakash et al., 2022).

Object Tracking

This component tracks detected objects over time. Since object movement can be unpredictable, not all frames in a video sequence will clearly display the objects, making continuous detection challenging. Furthermore, object detection across an entire image at multiple scales is computationally expensive, causing delays. Thus, tracking becomes an essential system element, allowing continuous monitoring of the object's position and size without the need for detection in every frame.

Detection methods

Currently, methods for detecting moving objects can be grouped into four categories. These approaches can be explained with a focus on human face detection, though some methods may overlap between categories.

1. Knowledge-Based Methods

These methods rely on rules derived from human knowledge about the typical structure of a human face. These rules typically describe the relationships between facial features.

2. Invariant Feature-Based Methods

These algorithms identify structural features of the face that remain consistent under varying conditions, such as changes in head position, viewpoint, or lighting. These features are then used to locate faces.

3. Pattern-Matching Methods

Standard templates representing a face or its features are stored. Detection is performed by calculating the correlation between the input image and the stored templates.

4. Learning-Based Methods

Unlike pattern-matching methods, learning-based approaches use training data to generate models. These models are trained on diverse datasets covering a wide range of facial variations and are then applied for detection.

Table 1.1 Classification of methods for distinguish faces in fixed image.

Methods name	Sample algorithms
Knowledge-Based Methods	Large-scale rule-based methods
Texture patterns Skin color segmentation Combinations of color, size, and shape	Grouping boundaries Space Gray-Level Dependence matrix (SGLD) for template face A mixture of Gaussian functions Combinations of color, size and shape
Pattern-Matching Methods - Predefined face templates - Deformable templates	Template form Active Shape Models (ASM)
Learning-Based Methods - Eigenfaces - Probabilistic models - Neural networks - Support Vector Machines (SVM) - Naive Bayes Classifiers - Hidden Markov Models (HMM)	Among these approaches, learning-based methods are considered the most effective for face detection. A notable algorithm in this category is the boosting-based method implemented in OpenCV

The approach developed by P. Viola and M. Jones (Jaya Prakash et al., 2022) employs a machine learning process using an adaptive boosting procedure. Their algorithm comprises three primary steps:

1. Feature selection using Haar-like features.
2. Training a cascade of classifiers using the AdaBoost algorithm.
3. Constructing a detection framework that efficiently scans an image for faces.

This algorithm has become a cornerstone of modern computer vision applications and is widely adopted in automated visual surveillance systems.

The method for building a classifier using the Boosting algorithm

The complex classifier can be considered as a composition of simple threshold-type classifiers. Let us denote a simple classifier as:

$$h_j(x) = \begin{cases} 1, & if\ p_j f_j(x) < p_j \theta_j \\ 0, & in\ other\ cases \end{cases}, \quad j = 1..N, \tag{1}$$

where pj represents the direction of the inequality sign, θj is the threshold, fj(x) is the computed flag value, xxx is the input image, and NNN is the total number of features. Let us consider the Boosting algorithm, which selects simple classifiers and combines them to form a complex classifier. The training set is defined as X_p —{x_{p1},.. .x_{pL} }containing L face images 24x24 pixel resolution and a training set X_n = |x_{n1}.. .x_{nM}]containing M non-faces images of the same resolution.

$$w_{l,i}=\frac{1}{2M} \qquad v_{l,i}=\frac{1}{2L} \tag{2}$$

$w_{1,i}$ и $v_{1,i,.}$ -initial weight for training set of images of “faces” and “non-faces” respectively. Then in a loop t=1...T, where T-number of selected simple classifiers make the following operations:

a) normalization of the weights:

$$w_{t,i} \leftarrow \frac{w_{t,i}}{\sum_{j=1}^{M} w_{t,j} + \sum_{j=l}^{L} v_{t,j}} \quad \text{i=l….,M;}$$

$$v_{t,i} \leftarrow \frac{v_{l,i}}{\sum_{j=1}^{M} w_{t,j} + \sum_{j=1}^{L} v_{t,j}} \quad \text{i=l…..,L.} \qquad (3)$$

b)calculation error classification:

$$\sigma_t(f,p,\theta) = \sum_{i=1}^{M} w_{t,i} h\left(x_{n_i}, f, p, \theta\right) + \sum_{i=1}^{L} v_{t,i} \left[1 - h(x_{p_i}, f, p, \theta)\right], \qquad (4)$$

c)selection of the classifier with minimal error:

$$h_t(x) = h(x, f_t, p_t, \theta_t), \qquad (5)$$

where f_t, p_t и t parameters, under which the error function $\sigma_{l(f,p,\theta)}$ has a minimum value;

d)adaptive update weights:

$$w_{t+l,i} \leftarrow w_{t,i} \beta_t^{1-h_t(x_{n_i} f_t, p_t, \theta_t}, \qquad i = 1 \ldots . M; \qquad (6)$$

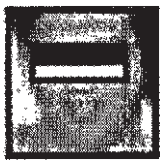
$$v_{t+1,i} \leftarrow v_{t,i} \beta_t^{h_t(x_{p_i} f_t, p_t, \theta_t}, \qquad i = 1 \ldots . L;$$

where the coefficient update weights β, is determined by the following formula:

$$\beta_t = \frac{\sigma_t(f_t, p_t, \theta_t)}{1 - \sigma_t(f_t, p_t, \theta_t)} \qquad (7)$$

The Boosting algorithm generates a simple classifier at each iteration, minimizing the error relative to the current weight values assigned during the training process. After each iteration, the weights are updated to emphasize samples that were misclassified. Consequently, the simple classifier for the next iteration is constructed to minimize errors on these misclassified samples from the training set.

Figure 1.4 illustrates the first and second features selected by the Boosting algorithm, shown within the detector window and overlaid on a typical face used during the training process.



a) first selected feature

b) second seeded sign

Figure 1.4: The First and Second Features Selected by the Boosting Algorithm

The first selected feature is based on the characteristic that the eye region is often darker than the nose and cheeks. This feature spans a large area within the detector window, making it less sensitive to variations in a person's size or position. The second selected feature relies on the observation that the eyes are typically darker than the bridge of the nose.

The algorithm utilizes a detector window with a resolution of 24x24 pixels and a scaling factor of 1.25 for the window.

The selected simple classifiers are combined into a complex classifier according to the following rule:

$$C_{(x)} = \begin{cases} 1, \sum_{t=1}^{T} \alpha_l h_l(x) \geq Q \\ 0, \text{ в остальных} \end{cases} \quad (8)$$

where α_t- coefficients of the linear combination, a Q- optimal threshold classifier, which are calculated by the formulas:

$$\alpha_t = ln\frac{1}{\beta_t}, \qquad Q = \frac{1}{2}\sum_{t=1}^{T} \alpha_t \quad (9)$$

The method of combining classifiers cascade structure

The structure of the cascade detector is shown in fig. 1.5. The cascade consists of layers which are classifiers trained using boosting procedure.

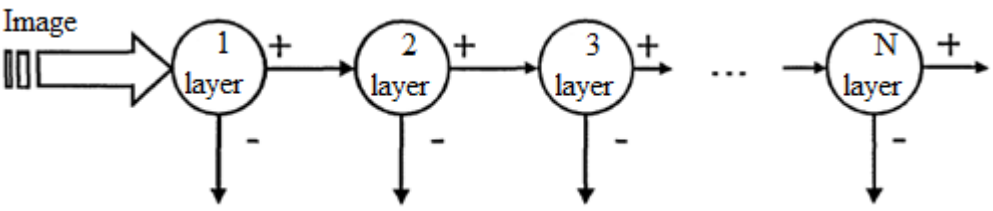


Figure 1.5. The structure of the cascade detector

The cascade operates as follows: a moving image window is input into the first layer. If this layer classifies the window as negative, the process exits, and subsequent layers are not analyzed. If the layer classifies the window as positive, it is passed to the next layer for further analysis. This process continues until either all layers are successfully completed with positive classifications, or a layer classifies the window as negative, exiting the cascade.

Given that the number of background image windows far exceeds the number of windows containing objects of interest, this approach significantly enhances efficiency. The processing speed increases by a factor of 10–20 depending on the image, without compromising recognition quality.

Results and Discussion

Cascade Design Parameters

The structure of each stage in the cascade is determined by the specific requirements set for it. The following parameters of the cascade are defined during development:

- The number of layers.
- The number of simple classifiers in each layer.
- The threshold value for each layer.

Target parameters are assigned to each layer. Layers are constructed using the Boosting procedure, during which the number of simple classifiers in a layer increase until the desired parameters are met.

During training, the dataset is divided into two subsets: a training set and a control set. Simple classifiers are formed using the training set, while the required parameters are determined using the control set. New layers are trained on negative instances that were misclassified by previous layers, ensuring high generalization capability and a low error rate.

Algorithm Comparison

The described algorithm was compared with two well-known alternatives:

1. Support Vector Machine (SVM)-based algorithm.
2. SNoW (Sparse Network of Winnows)-based algorithm (Dinh-Son et al., 2020).

On a test set of images, the SNoW-based algorithm achieved the best detection rate of 87.3 %, outperforming the others. The Boosting-based algorithm followed closely with a detection rate of 82.6 %, trailing the leader by 4.7 %. The SVM-based algorithm lagged significantly with a detection rate of 62.4 %.

Regarding false detections:

- The SNoW-based algorithm exhibited the fewest false detections.
- The Boosting-based algorithm had slightly more false detections.
- The SVM-based algorithm had twice as many false detections compared to the Boosting-based approach (Dinh-Son et al., 2020).

Performance Considerations

Although the Boosting-based algorithm demonstrated a slightly lower detection rate compared to the SNoW-based algorithm, it offers several advantages. It operates significantly faster and is more robust to various distortions, making it highly suitable for object detection in video sequences.

Tracking objects

Object tracking involves addressing a variety of tasks:

- Recognition based on motion: Identifying individuals based on gait, automatically detecting objects, etc.
- Automated monitoring: Observing scenes to detect suspicious activities and abnormal events.
- Video indexing: Automatically annotating and searching videos in multimedia databases.

- Human-Computer Interaction: Recognizing gestures, tracking gaze for data entry into computers, and similar applications.
- Traffic monitoring: Collecting real-time statistics for immediate traffic control.
- Navigation: Planning routes using video data, including obstacle avoidance.

In its simplest form, tracking can be defined as estimating an object's trajectory in the image plane as it moves within a scene. Essentially, tracking algorithms assign consistent labels to objects across video frames. Depending on the application, these algorithms may also provide additional information, such as the object's orientation, area, or shape.

Challenges in Object Tracking

Tracking objects comes with several challenges:

- Loss of information due to the projection of the 3D world onto a 2D image plane.
- Presence of noise in images.
- Complex object movements.
- Lack of clear and distinguishable features.
- Partial or complete occlusion of objects.
- Objects with complex shapes.
- Variations in lighting conditions.
- Real-time operational requirements.

To simplify tracking, certain assumptions or constraints can be introduced. For instance, many tracking algorithms assume smooth object movement without abrupt changes. Additional constraints, such as constant velocity or acceleration based on prior information, can also be applied. Prior knowledge about the number, size, appearance, or shape of objects can further simplify the process.

Approaches to Object Tracking

A wide variety of tracking methods have been proposed, differing in how they address key questions:

- How is the object represented for tracking?
- What features of the image are used?
- How are the object's movement, appearance, and shape modeled?

The answers to these questions depend on the specific context and environment, as well as on how the tracking information will be utilized. Numerous tracking methods have been developed, each tailored to different scenarios.

The purpose of object tracking is to construct the trajectory of an object by identifying its position in each frame of a video sequence. Tracking algorithms may also determine the area occupied by the object at any given moment. Object detection and correspondence between object instances in different frames can be addressed separately or together:

1. Separate Detection and Tracking: Object areas are identified in each frame using a detection algorithm, and a tracking algorithm follows the object in subsequent frames.
2. Integrated Detection and Tracking: The object's region and trajectory are determined iteratively by updating its local position using information from previous frames.

In both approaches, objects are represented using shape models and/or appearance models. The choice of representation influences the types of movements or deformations that can be tracked. For instance:

- Point Representation: Only simple motion models are applicable.

- Geometric Shapes: Ellipses or other shapes allow for parametric motion models, such as affine or projective transformations.
- Contour-Based Representation: Best suited for objects with changing outlines or silhouettes, where both parametric and non-parametric models can be used.

The object's contour defines its boundary, while the silhouette represents the area within the contour.

Classification of Tracking Methods

Tracking methods can be classified as shown in Fig. 1.6. Examples of techniques for each category are listed in Table 1.2. Below is a brief overview of the main categories of tracking methods.

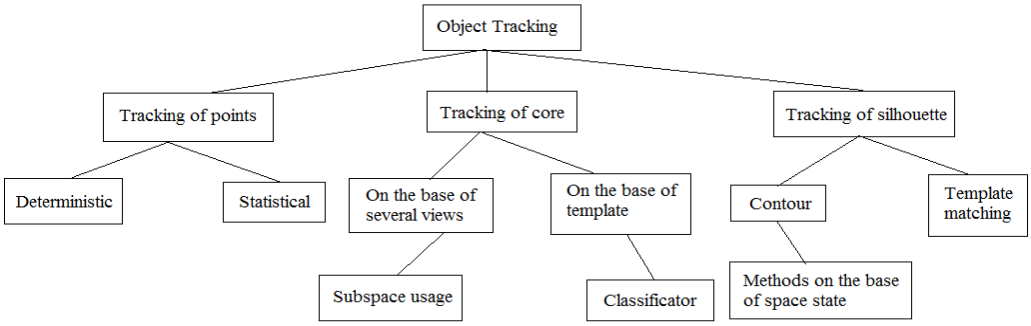


Figure. 1.6. Classification of tracking

Table 1.2 Categories of methods tracking

Categories	Examples
Tracking of points	
Deterministic methods	Modified Greedy Exchange (MGE) Greedy Optimal Assignment (GOA)
Statistical methods	Kalman filter Joint Probability Data Association Filtering (JPDAF) Probabilistic Multiple Hypothesis Tracking (PMHT)
Tracking of the core	
Models based on the appearance of the pattern and density distribution	Mehod of the mean shift Algorithm of Kanade-Lucas-Tomasi (KLT) Location of the layers
Multi species models appearance	Tracking based on principal component analysis Tracking based on support vector
Tracking of silhouette	
The development of contour	Models the state space Variational methods Heuristic methods

Correspondence of the forms	Hausdorff Hough transform Histogram

- In this approach, detected objects in consecutive frames are represented as points, with their connections determined by the object's previous state, including its position and motion. This method relies on an external system to detect objects in each frame. Examples of such implementations are shown in Fig. 1.7a..

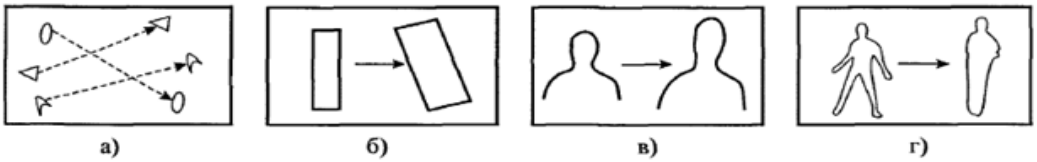


Figure 1.7: Various Approaches to Object Tracking
a) Point correspondence;
b) Parametric transformation of a rectangular region;
c) Two examples of contour-based tracking.

The core represents the object's shape and appearance. For instance, a rectangular core or an elliptical pattern combined with a histogram can be used. Objects are tracked by calculating the motion of the core across successive frames (Fig. 1.7b). This motion is typically described using parametric transformations such as translation, rotation, or affine transformations.

Conclusion

The development of tracking systems for video sequences is a key priority in the field of computer vision. Numerous factors can distort the characteristics of an object across successive video frames, disrupting continuous tracking. These factors include changes in the object's shape, size, color histogram, and lighting conditions. Such distortions can lead to object loss and unreliable tracking performance. The system developed as part of this dissertation addresses these challenges by adapting to video properties and ensuring reliable object tracking despite these variations.

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ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАР ЖУРНАЛЫ

МЕЖДУНАРОДНЫЙ ЖУРНАЛ ИНФОРМАЦИОННЫХ И КОММУНИКАЦИОННЫХ ТЕХНОЛОГИЙ

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