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APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES FOR ENSURING SAFETY ON CONSTRUCTION SITES

ПРИМЕНЕНИЕ ТЕХНОЛОГИЙ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ОБЕСПЕЧЕНИЯ БЕЗОПАСНОСТИ НА СТРОИТЕЛЬНЫХ ПЛОЩАДКАХ

ҚҰРЫЛЫС АЛАҢДАРЫНДА ҚАУІПСІЗДІКТІ ҚАМТАМАСЫЗ ЕТУ ҮШІН ЖАСАНДЫ ИНТЕЛЛЕКТ ТЕХНОЛОГИЯЛАРЫН ҚОЛДАНУ

S. Akhazhanov[1*], **O. Bibalayev**[1], **R. Muratkhan**[1], **D. Mikhailov**[2], **A. Montaeva**[2]
[1]Karaganda Buketov University, Karaganda, Kazakhstan
[2]Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan
*Corresponding author: Akhazhanov Sungat Berkinovich, e-mail: stjg@mail.ru

Keywords:
artificial intelligence, construction site, U.S. Bureau of Labor Statistics, personal protective equipment, monitoring, predictive analytics, automation.

ABSTRACT
In the context of the rapid development of the construction industry, safety issues on construction sites are becoming increasingly relevant. According to various sources 60 to 80% of accidents at construction sites are related to safety violations. This is due to the challenging working conditions, the high degree of interaction with heavy machinery and the shortcomings of existing control methods, which largely rely on human factors. In response to these challenges, the project proposes the development of an intelligent monitoring system for construction sites using artificial intelligence (AI) and computer vision technologies. The primary function of the system is the automatic detection of safety violations, including the absence of personal protective equipment (helmets, vests, goggles, etc.), as well as facial recognition for employee identification and access control. Additionally, the system will incorporate alcohol level monitoring for workers before they are permitted to begin their shifts. The implementation of this system is expected to provide continuous and objective monitoring of safety compliance, minimize the impact of the human factor, increase the responsiveness to incidents, and ultimately lead to a significant reduction in injuries and accidents. This interdisciplinary development integrates advancements in AI, construction technologies, and safety management. The system's deployment will also promote the digitalization of the construction industry, enhance its competitiveness, and establish a scientific and technological foundation for further research and innovative solutions in the field of industrial safety.

Түйінді сөздер:
жасанды интеллект, құрылыс алаңы, АҚШ

ТҮЙІНДЕМЕ
Құрылыс саласының қарқынды дамуы жағдайында құрылыс алаңдарындағы қауіпсіздікті қамтамасыз ету мәселелері күн сайын

Еңбек статистикасы бюросы, жеке қорғаныс құралдары, мониторинг, предиктивті аналитика, автоматтандыру

өзектілігін арттыруда. Түрлі дереккөздердің мәліметінше, құрылыс нысандарында орын алатын жазатайым оқиғалардың 60–80 %-ы еңбек қауіпсіздігі ережелерінің бұзылуымен байланысты. Бұл жағдайлар жұмыс жағдайларының күрделілігімен, ауыр техникалармен тығыз әрекеттесумен және адам факторына негізделген бақылау әдістерінің кемшіліктерімен түсіндіріледі. Осы сын-қатерлерге жауап ретінде жоба аясында құрылыс нысандарын интеллектуалды бақылау жүйесін жасау ұсынылады, ол жасанды интеллект (ЖИ) пен компьютерлік көру технологияларын қолдануға негізделген. Жүйенің негізгі мақсаты – қауіпсіздік техникасының бұзушылықтарын автоматты түрде анықтау, соның ішінде жеке қорғаныс құралдарының (каска, жилет, көзілдірік және т.б.) жоқтығын анықтау және жұмысшыларды тану мен нысандарға кіруді бақылау үшін фейс-контроль жүргізу. Сонымен қатар, жүйеге қызметкерлердің жұмысқа кірісер алдындағы алкоголь деңгейін бақылау функциясы енгізіледі. Жүйенің енгізілуі қауіпсіздік нормаларын сақтауды үздіксіз және объективті бақылауды қамтамасыз етіп, адам факторына тәуелділікті азайтады, оқыс оқиғаларға әрекет ету жеделдігін арттырады және жарақаттар мен апаттар санын айтарлықтай қысқартуға әкеледі деп күтілуде. Бұл әзірлеме пәнаралық сипатқа ие болып, ЖИ, құрылыс технологиялары және қауіпсіздікті басқару салаларындағы жетістіктерді біріктіреді. Жүйенің енгізілуі құрылыс саласын цифрландыруға, оның бәсекеге қабілеттілігін арттыруға және өнеркәсіптік қауіпсіздік саласындағы болашақ зерттеулер мен инновациялық шешімдерге арналған ғылыми-техникалық база қалыптастыруға ықпал етеді.

Ключевые слова:
искусственный интеллект, строительная площадка, бюро статистики труда США, индивидуальные средства защиты, мониторинг, предиктивная аналитика, автоматизация

АННОТАЦИЯ

В условиях активного развития строительной отрасли вопросы обеспечения безопасности на строительных площадках приобретают всё большую актуальность. По данным различных источников, от 60 до 80% несчастных случаев на строительных объектах связаны с нарушениями техники безопасности. Это обусловлено сложными условиями труда, высокой степенью взаимодействия с тяжёлой техникой, а также недостатками в существующих методах контроля, основанных на человеческом факторе. В ответ на данные вызовы в рамках проекта предлагается создание интеллектуальной системы мониторинга строительных объектов с использованием технологий искусственного интеллекта (ИИ) и компьютерного зрения. Основная задача системы – автоматическое выявление нарушений техники безопасности, включая отсутствие индивидуальных средств защиты (каски, жилета, очков и т.д.), а также проведение фейс-контроля для идентификации сотрудников и контроля доступа на объекты. Кроме того, в систему будет интегрирована функция контроля уровня алкоголя у работников перед допуском к работе. Предполагается, что внедрение данной системы обеспечит непрерывный и объективный контроль за соблюдением норм безопасности, минимизирует влияние человеческого фактора, повысит оперативность реагирования на инциденты и, как следствие, приведёт к значительному снижению числа травм и несчастных случаев. Разработка носит междисциплинарный характер и объединяет достижения в области ИИ, строительных технологий и управления безопасностью. Внедрение системы также будет способствовать цифровизации строительной отрасли, росту её конкурентоспособности и формированию научно-технического задела для дальнейших исследований и инновационных решений в сфере промышленной безопасности.

INTRODUCTION

Modern construction is associated with numerous risk factors, including interaction with heavy machinery, working at heights, exposure to adverse weather conditions, and high personnel density on construction sites. Despite the presence of regulations and standards, traditional safety methods based on periodic inspections and visual monitoring often prove ineffective in the face of the high dynamism and complexity of construction processes. These methods rely heavily on the human factor and are unable to provide continuous monitoring. According to estimates by international and national organizations, 60 to 80% of workplace accidents occur due to non-compliance with occupational safety regulations. Data from the U.S. Bureau of Labor Statistics indicate that the fatality rate among construction workers is nearly six times higher than in other sectors of the economy, highlighting the urgent need for fundamentally new approaches to ensuring safety. Amid the rapid digitalization of the economy, including the construction industry, there is an urgent need for intelligent systems capable of operating in real time and effectively identifying potential threats before critical situations arise. This study proposes an innovative AI-based approach that integrates predictive analytics, computer vision, and Internet of Things (IoT) sensors, aimed at establishing a new paradigm in safety management. Predictive analytics enables the analysis of large datasets related to incidents, weather conditions, and technical failures, identifying patterns and allowing for the prediction of potentially hazardous scenarios. AI-powered cameras in real time detect the absence of personal protective equipment, equipment misuse, and abnormal personnel behavior, automatically notifying management for prompt response. IoT sensors track environmental parameters, such as dust levels, noise, temperature, and vibrations and trigger safety protocols when thresholds are exceeded. The integration of all system components into a unified digital platform ensures continuous monitoring, minimizes human error, enhances workers' situational awareness, and fosters a strong safety culture. As part of the project, the development and pilot implementation of the software platform Futurism Sentinel Sphere is being carried out. The platform is adapted to various types of construction projects, including residential, industrial, and infrastructure construction. The system is capable of automatically detecting violations, performing facial recognition, registering employee entry and exit, and monitoring workers' conditions, including alcohol testing. The implementation of this technology aims to significantly reduce the number of emergency situations, optimize safety management processes, increase transparency, reduce time and financial costs, and improve the overall quality of construction work. The interdisciplinary approach combining advancements in artificial intelligence, construction technologies, occupational safety standards, and engineering informatics, makes the project particularly relevant for the Republic of Kazakhstan. It supports the development of national technological capacity, strengthens the position of domestic companies in the construction market, and contributes to the training of highly qualified specialists in digital technologies and industrial safety. Thus, the application of AI as both a research and practical tool for safety in construction opens new horizons for transforming the industry and building a more sustainable, secure, and technologically advanced future.

According to data from the U.S. Bureau of Labor Statistics, the fatality rate among construction workers is nearly six times higher than that of workers in other sectors of the economy (Figure 1) (International Labour Organization, 2018). This striking statistic underscores the urgent need for decisive solutions to improve safety on construction sites. Under current conditions, traditional monitoring methods often fail to timely identify and prevent hazardous situations, necessitating the use of innovative technologies such as artificial intelligence and computer vision to automate monitoring and minimize risks (International Labour Organization, 2018). Fatalities Among Workers by Major Industry Sectors, 2022-2023. The construction, agriculture, and fishing sectors continue to account for the highest number of worker fatalities due to accidents each year.

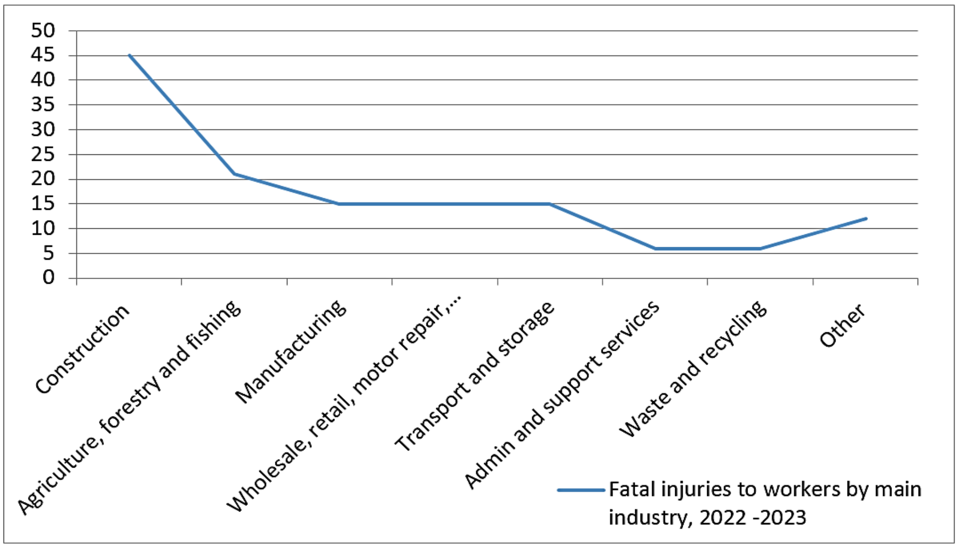

Figure 1. Worker Fatalities by Major Industry Sectors, 2022-2023 (USA)
Note – compiled by the authors

In Kazakhstan, the level of occupational injuries remains high: approximately 1,500 individuals are injured at work each year, and around 200 die, with real numbers likely higher due to underreporting of incidents. The causes of workplace accidents include both systemic management issues, such as lack of oversight, cost-cutting on safety measures, and hiring without official contracts and individual negligence among workers. Despite a gradual decline in injuries and fatalities since 2012, the situation remains alarming: over one million Kazakhstani citizens work in unfavorable and hazardous conditions. Amid systemic corporate irresponsibility and the limited authority of labor inspections, the burden increasingly falls on the workers themselves, who are often left unprotected due to informal employment and ineffective institutional mechanisms. Trade union representatives emphasize the need for collective agreements and greater worker involvement in defending their rights. At the same time, the positive experience of foreign companies operating in Kazakhstan demonstrates that safe labor is achievable through strict compliance with procedures and employer accountability. European practices show significantly lower injury rates, attributed to effective institutions, oversight, and a strong occupational safety culture, an area Kazakhstan still has to develop (Jung et al., 2022).

This research direction is promising and rapidly evolving. Publications in this field, as well as the number of citations in the Web of Science database, show steady annual growth, indicating increasing interest from the scientific community in this topic (Figure 2).

Globally, the construction industry is marked by a high number of both fatal and non-fatal accidents. According to the International Labour Organization, construction workers in developed countries face nearly four times the risk of fatal incidents compared to workers in other professions (International Labour Organization, 2018). Fatal and permanently disabling accidents occur at an alarmingly high rate in the construction sector (Jung, 2022; Hussain, 2023; Park, 2023). For example, South Korea reports the highest average fatality rate 17.9, compared to 9.4 in the United States and 5.3 in China (Choi et al., 2019). The construction industry, known for its complexity, heavily relies on manual labor to perform control and supervisory functions.

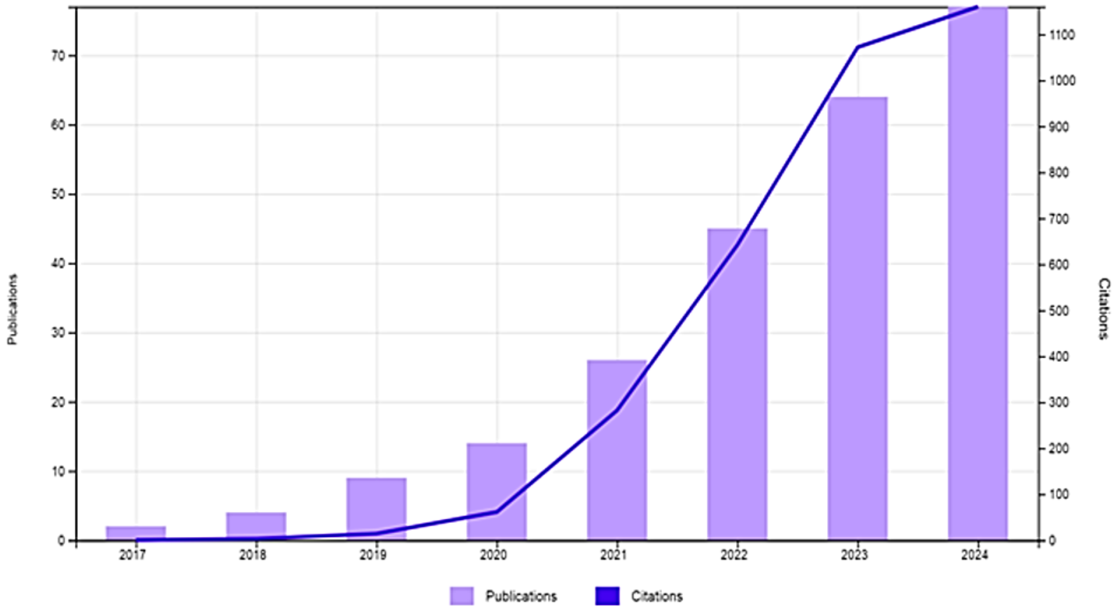

Figure 2. Number of Publications and Citations in Web of Science
Note – compiled by the authors

However, relying on human labor for safety monitoring has proven to be costly, labor-intensive, and prone to errors, which reduces overall efficiency. At the same time, ensuring employee safety remains a key responsibility of construction companies, necessitating accelerated processes, increased productivity, and rapid resolution of safety issues on construction sites (Xiao, 2021; Chen, 2022; Suh, 2023; Hussain, 2024; Soltani, 2024). Zheng and Li analyzed studies conducted between 1991 and 2021, emphasizing the importance of utilizing information technologies, including computer vision, virtual reality, and simulation to enhance risk awareness and safety measures in the construction sector (Zeng, 2022). In recent years, computer vision technologies have been widely adopted across various industries, including construction, where they play a critical role in improving safety and monitoring operations (Wang, 2024).

Significant contributions have been made through the development of personal protective equipment (PPE) detectors, which help monitor compliance with safety regulations (Fang, 2018; Fang, 2018; Huang, 2021; Han, 2022; Hung, 2019; Wu, 2019). Most research in construction safety monitoring has focused on helmet detection. For example, Bo et al., (2019) proposed a YOLOv3-based method demonstrating high accuracy; Gu et al., 2021 developed a helmet detection approach using YOLOv4; and Zhou et al., 2021 introduced a YOLOv5-based method noted for its high precision and real-time performance. In addition to YOLO-based technologies, Long et al., 2019, Wu et al., 2019, and Li et al., 2020 proposed solutions using the Single Shot Multibox Detector (SSD), which also yielded promising results. Furthermore, several studies employed convolutional neural networks (CNNs) to recognize workers' safety vests (Hung, 2019; Jeon, 2020; Ali, 2021). However, despite their successful application in controlled environments, these methods have not yet been implemented or tested on real construction sites in real-time scenarios (Khan, 2023). They also do not always ensure accurate detection in every frame, leading to false positives or missed detections due to occlusion or object overlap (Li, 2023), which in turn reduces the effectiveness of automated monitoring systems. According to a bibliometric study by Luo et al., 2022, both developed and developing countries have adopted artificial intelligence (AI) technologies to address safety issues on construction sites. In the Republic of Kazakhstan, research on the application of AI for construction site safety monitoring is still at an early stage. Most existing studies focus on the implementation of digital technologies and intelligent construction management systems; however, there is a lack of research specifically dedicated to automatic safety violation detection using AI. Studies by Turlybayev (2022) and Sarsenbayev (2021) emphasize the need to implement digital technologies and automation systems to enhance safety at construction sites in Kazakhstan, highlighting persistent issues such as high injury rates and the low effectiveness of traditional safety control systems. Concurrently, research analyzing the causes of construction site accidents has revealed significant shortcomings in the current safety system (Sukhachev, 2025), underlining the need for modern solutions such as breathalyzers and worker condition monitoring systems. Currently, most existing safety systems on construction sites use fragmented elements, such as video surveillance and access control, but comprehensive solutions that integrate safety violation detection, facial recognition, and alcohol level monitoring have been scarcely studied or implemented. Moreover, such systems often suffer from limited response speed and accuracy, which reduces their practical effectiveness. The new project aims to address these shortcomings by developing an integrated system that automates monitoring, reduces the burden on inspectors, and minimizes human error. Based on AI and computer vision technologies, the system will operate continuously, with scalability and adaptability for different construction sites. The key distinguishing feature of the proposed solution lies in its comprehensiveness for the first time in Kazakhstan, a single system will integrate automatic detection of safety violations, worker identification, and health status monitoring, including alcohol testing, thereby significantly enhancing overall safety levels. The project holds strong commercialization potential and may contribute to the digitalization of the construction sector and the development of intelligent risk management systems. The scientific novelty of the project lies in the development of a unique integrated platform that combines AI, computer vision, facial recognition, and sensor technologies, an approach not previously applied in the construction industry of Kazakhstan. The project promotes the advancement of interdisciplinary research in machine learning, automation, and industrial safety. Its outcomes may serve as a foundation for new approaches to risk management amid ongoing urbanization and growth in the construction sector. Thus, the implementation of such a system will contribute to reducing accidents and injuries, saving costs for employers, enhancing the industry's public image, and improving working conditions. Taken together, these factors make the project relevant, innovative, and socially significant.

MATERIALS AND METHODS

To date, most existing safety systems on construction sites are limited to the use of individual components such as surveillance cameras or access control systems. However, comprehensive solutions that integrate safety violation detection, facial recognition, and alcohol level monitoring remain largely underexplored and have not been widely implemented. Moreover, current systems are prone to false alarms and often fail to respond promptly to changes in work processes, creating serious barriers to ensuring reliable and timely worker protection. In response to these challenges, an innovative project is being developed to address current shortcomings by integrating all control elements into a single intelligent platform designed to significantly enhance safety on construction sites. A key advantage of the proposed system is its automated monitoring capability, which reduces the burden on inspectors and minimizes human error. The system will operate continuously, using artificial intelligence and computer vision technologies to perform real-time video stream analysis and detect potential violations. An important feature of the project is its scalability and adaptability to the specific needs of various construction companies. Unlike existing solutions in Kazakhstan and abroad, this project is based on a comprehensive approach that simultaneously performs three key functions: automatic detection of safety violations, biometric identification of workers through facial recognition systems, and condition monitoring via alcohol level sensors. This integrated functionality is being implemented for the first time within a single system, lending the project both scientific novelty and high practical significance. AI and computer vision technologies will enable the recognition of critical situations, such as the absence of protective equipment, workers' presence in hazardous zones, and the execution of risky actions. Meanwhile, facial recognition and sobriety checks will ensure access control and prevent incidents related to human factors. The development of this system is especially relevant for large-scale construction projects with high personnel density and intensive workflows, where the risk of accidents is significantly elevated. The project contributes to the advancement of interdisciplinary research in automation, machine learning, and intelligent data analysis, while also offering new approaches to safety management in the context of increasing urbanization and the development of Kazakhstan's construction sector. The scientific and technological demands of the project stem from the need to create adaptive AI-based automated solutions for effective monitoring and timely response to hazardous situations, making its contribution to improving occupational safety particularly valuable. The socio-economic impact includes reductions in injury and fatality rates, preservation of workers' health, lower costs associated with incident response, and overall gains in labor productivity. The project's innovativeness and competitiveness are grounded in its use of advanced technologies in multisensor analysis, machine vision, and intelligent control systems, which help minimize risks, accelerate decision-making, and enable integration with other safety infrastructures, making this solution both timely and in high demand in the construction technology market.

The project hypothesis posits that the implementation of an intelligent monitoring system incorporating facial recognition and alcohol level detection will significantly improve the effectiveness of identifying and preventing safety violations on construction sites. To test this hypothesis, a comprehensive research strategy will be employed, combining descriptive, correlational, and experimental methods. First, data on the current state of safety and the technologies in use will be collected and analyzed. Then, the relationship between safety levels and the use of integrated systems will be examined, followed by pilot testing of the developed system under real-world conditions. The research sequence includes a literature review, field studies, system modeling, experimental implementation, pre- and post-deployment analysis, and the development of recommendations for scaling. This approach will provide a thorough assessment of the system's effectiveness and validate the scientific soundness of the hypothesis.

The project's key experiments are designed to evaluate the effectiveness of the intelligent monitoring system under real construction site conditions. The first experiment focuses on testing facial recognition to assess the accuracy and speed of worker identification, including cases where workers are wearing helmets and safety glasses. Cameras will be installed at entry points and key zones, and recognition results will be compared with actual employee data. The second experiment targets the automatic detection of safety violations using AI algorithms trained on video footage from real construction sites and tested in scenarios involving simulated infractions. The third experiment involves deploying breathalyzers at construction sites and integrating them with access control systems to monitor workers' conditions before shifts, with the expectation of reducing the number of individuals granted access while over the legal alcohol limit. The final stage entails the pilot implementation of the complete system on a construction site, where all components will be tested together over a defined period to assess their combined effectiveness and to collect data for further optimization. The expected outcome of the pilot implementation is the confirmation of the integrated system's functionality and the collection of empirical data for its subsequent optimization. The experiments described will allow for a comprehensive validation of the project's hypotheses and provide a foundation for scaling and successful deployment of the developed technology. The proposed system is a comprehensive solution that integrates real-time video surveillance modules, intelligent data processing using AI algorithms, and a user-friendly interface for efficient safety management. The system's structure is detailed in Figure 3.

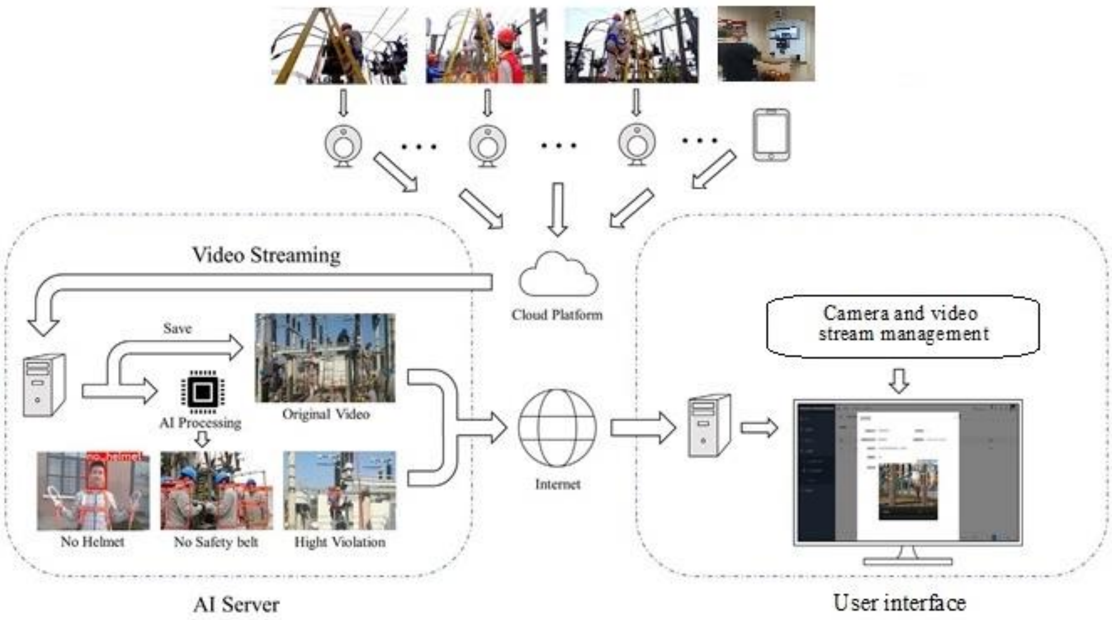

Figure 3. Automated Safety Violation Monitoring on Construction Sites Using AI
Note – compiled by the authors

This figure illustrates the architecture and workflow of the AI-powered construction site monitoring system developed for automatic detection of safety violations. The system is equipped with multiple surveillance cameras installed across the construction site to capture real-time video streams. The cameras are positioned to cover different zones of the site and record potential safety violations. The video streams are continuously collected and transmitted to the system for processing. These streams are sent to a central AI server, where real-time analysis is performed. AI algorithms process the incoming footage to detect the following types of violations: absence of helmets and personal protective equipment (PPE), and non-compliance with regulations for working at heights. Additionally, the system includes a feature for detecting workers' blood alcohol levels. Entry terminals equipped with breathalyzers are installed at the site’s access points to measure employees' alcohol levels before they begin work. If the detected level exceeds the permissible threshold, the system issues a warning and denies access to the site. The server processes the video streams using computer vision algorithms and stores both the original and processed footage for future use. Processing occurs in parallel with the live stream, allowing for immediate detection of violations. The processed data and video streams are transmitted to a cloud platform, where they are securely stored. The platform enables remote access to the data, ensuring scalability and reliable backup. The platform also synchronizes data between the system and user interfaces in real time. Through this interface, system operators can control cameras, adjust video stream settings, monitor detected violations, manage alcohol level checks, and generate reports. Camera and stream control allows users to view live video feeds, access archived footage, and configure violation alerts or inspection intervals. The interface also displays data from the alcohol detection terminals, enabling monitoring of test results and preventing access for individuals who exceed the permissible alcohol threshold. The system automatically generates snapshots of violations with detailed event information, including the time, type of violation, and the personnel involved. These reports are stored on the server for subsequent analysis and audit purposes. All system components are connected via the internet, ensuring continuous interaction between the AI server, cloud platform, and user interface. Authorized users can conduct real-time remote monitoring from any device. This system provides a comprehensive solution for enhancing safety on construction sites. The integration of artificial intelligence and computer vision enables timely detection of safety violations, reduces human error, and improves overall construction site management. This approach increases inspection efficiency and helps prevent incidents through early identification of potential risks. The project will employ object and violation detection methods using YOLO (You Only Look Once), real-time monitoring, and model accuracy enhancement and adaptation techniques. The project will include two core components: an analysis stands and a monitoring and verification system. In the initial research phase, the architecture will be developed to ensure interaction between these systems and to optimize data storage and processing on the server. The server will manage camera video streams, process employees' biometric data, and store information on detected violations. The artificial intelligence system responsible for monitoring compliance with safety regulations will also operate on this server. The safety violation recognition system is based on a machine learning model, specifically using the Ultralytics library with the YOLO architecture. These technologies will be trained on real data collected from surveillance cameras to enable the system to automatically detect violations such as the absence of helmets, lack of personal protective equipment, or the presence of employees on site while under the influence of alcohol. The Ultralytics library is one of the most popular deep learning libraries, providing an implementation of the YOLO model for object detection tasks. YOLO (You Only Look Once) is a neural network architecture designed for fast and accurate object recognition in images. The model divides an image into a grid and, for each cell, determines whether an object is present, its boundaries, and its class. For this project, YOLO will be trained to recognize the following objects: people (construction workers), safety helmets and protective clothing (presence or absence), and potentially hazardous actions or zones (e.g., being in a danger zone without a helmet). To ensure the effective operation of the system, information will be collected from various sources, including live video streams from cameras, violation snapshots with detailed descriptions, biometric data of employees, and alcohol test results from the verification stand. The data will be systematized and prepared for further processing. To improve training quality, data augmentation is used a method in which images are altered (e.g., changes in lighting or camera angles) to increase the model's robustness under various operating conditions. The YOLO model will be trained on annotated data for object classification and localization. Each type of violation will be assigned a specific class: absence of a helmet, presence in a hazardous zone, improper wearing of protective clothing, and others. After training, the model will be integrated with the construction site's video surveillance system, where it will analyze live video streams in real time to detect safety violations. All video streams will be processed at low intervals to efficiently utilize server resources and computational accelerators, enabling timely safety compliance checks. A pre-trained artificial intelligence model will be used to detect safety violations. The model will be trained on frames collected from the construction site using the Ultralytics library and the YOLO architecture, which is designed for identifying and classifying objects in images. Training the model will allow the system to target specific objects and actions for monitoring (Figure 4).

The entire system will include a control panel with a web interface, allowing administrators to add cameras, set inspection intervals, and view the history of violations. This interface will be developed with a focus on usability and accessibility of information for users. The analysis stand will consist of a computer with a touchscreen, a camera, and a breathalyzer sensor. The stand's software will perform employee identification based on biometric data stored on the server. Once identification is successful, a step-by-step verification process will follow, using an intuitive user interface. After the system's pilot deployments at several construction sites, model retraining on new data may be conducted to improve accuracy and adapt the system to the specific characteristics of each site.

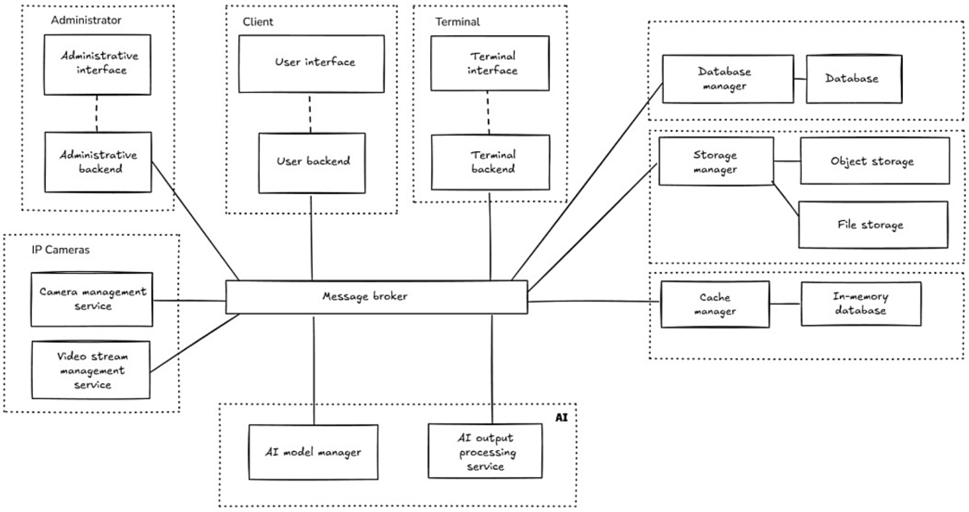

Figure 4. Field Data Processing System

Note – compiled by the authors

During system operation, ongoing analysis of false positives cases where the system erroneously detects a violation will be conducted, followed by adjustments to algorithms and model parameters to enhance recognition accuracy. At the final stage of the study, comprehensive testing of the system is planned under real construction site conditions, including assessments of violation detection accuracy, information processing speed, and the coordination of all components. The test results will be used to identify bottlenecks, eliminate deficiencies, and optimize functionality. After the system is deployed, user feedback will be collected to evaluate its effectiveness, identify strengths and weaknesses, and implement improvements based on practical experience. The use of the YOLO model and the Ultralytics library in this project ensures high performance and reliability of real-time safety monitoring, which will significantly enhance worker protection, reduce the number of incidents, and enable timely responses to potential threats.

DISCUSSION

One of the key challenges of the project was ensuring high recognition accuracy in construction site environments, where workers' faces may be partially obscured by helmets, goggles, or other protective equipment. To address this issue, data augmentation and model retraining under specific conditions were employed. Particular attention was also given to the speed of video stream processing, as the system is required to operate in real time. It is important to note that even with high accuracy, false positives may still occur, especially in atypical situations. This necessitates continuous adaptation of the algorithms and regular updates to the training dataset. Furthermore, the project highlighted the need for flexible system configuration and effective interaction with personnel, both in terms of how alerts are perceived and in protecting personal data. Future development of the project envisions expanded functionality, including predictive analytics and integration with construction process management systems. Continued efforts are also recommended to reduce the number of false alarms and to increase model robustness under varying weather and lighting conditions typical of construction sites.

CONCLUSION

One of the primary challenges of the project was achieving high recognition accuracy in construction site environments, where workers' faces may be partially obscured by helmets, protective goggles, or other personal protective equipment. To address this, data augmentation and model retraining were applied using specially curated image datasets that reflect real-world operational conditions. Particular emphasis was also placed on ensuring high-speed video stream processing, as the system is required to function in real time. Despite achieving high accuracy, false positives may still occur, especially in non-standard or rapidly changing situations, necessitating regular algorithm adaptation and training data updates. Moreover, the project underscored the importance of flexible interaction between the system and personnel, both in terms of interpreting and responding promptly to alerts and in protecting employees' personal data. Future development of the project is expected to involve expanding the system's functionality, including the implementation of predictive analytics and integration with construction process management platforms. Further efforts should also focus on reducing the number of false alarms and improving the model's resilience to various weather conditions and lighting changes typical of construction sites. The expected outcome of the pilot implementation is to confirm the functionality of the integrated system in real-world conditions and to gather empirical data necessary for further optimization. The proposed experiments will enable a comprehensive validation of the project's working hypotheses and will lay the foundation for scaling and effective implementation of the developed technology. The presented system is a comprehensive solution that integrates real-time video surveillance modules, intelligent data processing based on AI algorithms, and an intuitive user interface for efficient safety management on construction sites.

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Авторлар туралы мәліметтер
Информация об авторах
Information about authors

Ахажанов Сунгат Беркинович – PhD, қауымдастырылған профессор, Академик Е.А. Бөкетов атындағы Қарағанды университеті, Қарағанды қ., Қазақстан,

Ахажанов Сунгат Беркинович – PhD, ассоцированный профессор, Карагандинский университет имени академика Е.А. Букетова, г. Караганда, Казахстан,

Akhazhanov Sungat Berkinovich – PhD, Associate professor, Karaganda Buketov University, Karaganda, Kazakhstan,
e-mail: stjg@mail.ru,
ORCID: https://orcid.org/0000-0002-0903-3517

Бибалаев Олжас Досанұлы – техника ғылымдарының магистрі, инженер-программист, Е.А. Бөкетов атындағы Қарағанды университеті, Қарағанды қ., Қазақстан,
Бибалаев Олжас Досанұлы – магистр технических наук, инженер-программист, Карагандинский университет имени академика Е.А. Букетова, г. Караганда, Казахстан,
Bibalayev Olzhas Dosanuly – Master of technical sciences, software engineer, Karaganda Buketov University, Karaganda, Kazakhstan,
e-mail: oljaktl@gmail.com
ORCID: https://orcid.org/0000-0002-6821-4932

Муратхан Райхан – PhD, қауымдастырылған профессор, Академик Е.А. Бөкетов атындағы Қарағанды университеті, Қарағанды қ., Қазақстан,
Муратхан Райхан – PhD, ассоцированный профессор, Карагандинский университет имени академика Е.А. Букетова, г. Караганда, Казахстан,
Muratkhan Raikhan – PhD, Associate professor, Karaganda Buketov University, Karaganda, Kazakhstan,
e-mail: rai-81@mail.ru,
ORCID: https://orcid.org/0000-0002-2030-8948

Михаилов Даниел Михаилович – техника ғылымдарының магистрі, докторант, Қорқыт Ата атындағы Қызылорда университеті, Қызылорда, Қазақстан,
Михаилов Даниел Михаилович – магистр технических наук, докторант, Кызылординский университет имени Коркыт Ата, Кызылорда, Казахстан,
Mikhailov Daniel Mikhailovich – Master of technical sciences, PhD Student, Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan,
e-mail: daniel_mihailov@mail.ru
ORCID: https://orcid.org/0009-0007-9052-8552

Монтаева Айнур Сарсенбековна – PhD, ғылыми зерттеулерді үйлестіру бөлімінің басшысы, Қорқыт Ата атындағы Қызылорда университеті, Қызылорда қ., Қазақстан,
Монтаева Айнур Сарсенбековна – PhD, начальник отдела координации научных исследований, Кызылординский университет имени Коркыт Ата, г. Кызылорда, Казахстан,
Montayeva Ainur Sarsenbekovna – PhD, Head of the Department of Scientific Research Coordination, Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan,
e-mail: montayeva_ainur@mail.ru,
ORCID: https://orcid.org/0000-0001-9536-3442