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IDENTIFICATION OF DANGEROUS SITUATIONS IN THE ROAD INFRASTRUCTURE USING UNMANNED AERIAL VEHICLES

The object of the research is the developed automated computational model (AI-driven system) for real-time monitoring and analysis of road traffic, focusing on the identification and assessment of dangerous situations (traffic violations, congestion, and accident risks). This paper examines how the increased number of people moving to cities and their vehicles increases the likelihood of traffic accidents on public roads. It is also noted that traditional inspections are carried out very slowly and do not fully detect violations of traffic rules. To overcome these limitations, it is proposed a novel automated computational model for vehicle and accident tracking, based on UAVs combined with computer vision and artificial intelligence technologies. The proposed model allows for real-time threat detection and evaluation. The study, modeled in the MATLAB environment using real traffic data from drone-captured video. This model demonstrates significant improvements in operational metrics, an average detection achieved accuracy 89% for vehicles and critical events (e. g., congestion, deviations). The model successfully visualizes risk areas with heat maps and predicts short-term traffic pattern changes, increasing the reliability of traffic management and expanding the possibilities of traffic risk forecasting. The results obtained during the simulation can be used in practice by transport services, road, and maintenance organizations, particularly at difficult intersections and on highly accident-prone highways in urban, heavily built-up areas.

Keywords: *infrastructure, security, risks, monitoring, traffic, incidents, drones, aircraft, damage, urbanization.*

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1. Introduction

In recent years, the very rapid growth of traffic and the enormous increase in urbanization have increased the demands on the quality and safety of road infrastructure in general. In almost all countries of the world, reducing road accidents, as well as effective traffic management and ensuring the safety of absolutely all road users have become the main tasks of the state. In this regard, there is a need to introduce new technologies that will allow timely identification and assessment of dangerous situations at highway infrastructure facilities.

Unmanned aerial vehicles (UAVs) are now widely used in many areas, such as building roads and other infrastructure [1]. Compared to traditional control methods, modern technologies make it easier to quickly check the technical condition of roads and find dangerous areas, while also saving time, money, and labor [2]. These devices allow to monitor the condition of infrastructure facilities (bridges, crossings, signs, etc.), as well as analyze traffic flows by collecting high-quality images and photographic materials that help identify violations on the roads [3]. The data obtained by the UAV can help identify dangerous situations in advance and take the necessary precautions.

Compared to traditional methods, UAV monitoring makes it faster to find dangerous things on the road and gives more accurate information. The ability to automatically process data collected by UAS will make risk assessment of road infrastructure more effective and cut down on the number of accidents on the road [4]. Similar methods of artificial intelligence, such as models for predicting how much soil can be polluted based on Ann, turned out to be very accurate [5]. Multicopters with sensors and methods for processing large amounts of data were also useful for monitoring the environment [6]. In addition, the use of unmanned aerial vehicles for systematic monitoring makes it possible to determine how the road will change, assess the degree of infrastructure wear and tear, and plan the optimal time for carrying out repair work [7]. Drones are not only used to monitor transport and the environment. They are also used in extreme sports to make things safer, plan routes, and make players feel better mentally [8]. However, the short flight times and energy inefficiency of onboard systems are still problems that keep UAVs from being widely used for monitoring [9]. Recent advances in power electronics, like compact switched-capacitor multilevel inverters (SC-MLIs) with high voltage gain and efficiency [9], have opened up new ways to make UAVs more autonomous and connect them to renewable-powered systems. Most of the cited scientific sources talk about the technical characteristics and advantages of UAVs, or how they can be used in certain areas, such as security or environmental monitoring. These studies do not pay enough attention to carefully identify dangerous situations in road infrastructure. Our study combined UAV data with artificial intelligence algorithms to automatically search and assess risks.

The article discusses the theoretical and practical aspects of the use of UAV technologies to identify dangerous situations in road infrastructure. In particular, in accordance with modern requirements in the

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field of road safety, methods for identifying dangerous zones, ways to process data obtained by aircraft and enter them into the risk management system will be studied.

In particular, the methods of their use for the timely detection and assessment of hazardous situations at road infrastructure facilities (bridges, crossings, signs, etc.) and the analysis of traffic flows are studied. The main problem addressed by the study is the increasing demands on the quality and safety of road infrastructure against the backdrop of increasing traffic and urbanization, as well as the need to reduce the number of road accidents (RA) and ensure the safety of road users. The study involves a comprehensive study of the possibility of using UAVs for operational detection of threats in road infrastructure, as well as the impact of these technologies on road safety [10]. The high efficiency and efficiency of using monitoring with the help of UAVs in comparison with traditional methods of detecting threats and analyzing the technical condition of roads has been established. The relevance of developing algorithms and methodological approaches for the automatic processing of UAV data in order to improve the efficiency of risk assessment is determined.

Timely and accurate identification of dangerous situations in the road infrastructure will prevent road accidents, reduce human losses and material damage [11]. Therefore, the widespread use of the capabilities of modern technologies, including unmanned aerial vehicles, is one of the most important directions in the development of the transport system and its security [12]. In addition, UAV-based strategies have moreover appeared productivity in biological observing assignments when prepared with dispersed estimation sensors and optimized planning calculations [13]. On the contrary, UAVs can be used for malicious purposes such as smuggling, surveillance or carrying explosives, thus making UAV detection, and classification methods very important [14]. The unusual rise in the number of UAVs has also made it necessary to quickly develop new counter-UAS frameworks that combine RF analysis, deep learning, auditory detection, and multi-sensor fusion to provide dependable protection against possible threats [15].

UAVs are used as a very effective solution to identify dangerous situations and improve safety in the road transport infrastructure. Being one of the latest modern technologies, drones can take high-resolution videos and photographs, as well as independently monitor in real time. Due to mobility, it is possible to quickly cross large territories. Thanks to such devices, it becomes possible to quickly identify malfunctions in the transport infrastructure, such as failures in traffic lights and lighting systems. as well as other life-threatening situations related to road accidents [12].

The data obtained by the UAV is analyzed by high-precision systems and processed using artificial intelligence, machine learning and computer vision technologies. These technologies can independently determine the low quality of illumination of images, poor visibility of road signs and other life-threatening factors. Thanks to real-time monitoring functions, dangerous situations can be detected at an early stage and, depending on the situation, prompt measures can be taken to prevent them and ensure the safety of all road users [16].

The use of drones makes dangerous situations on public roads much more effective than traditional control methods. Because it reduces the chance of human error. This allows to explore vast territories in a much shorter time. These gadgets allow to inspect hard-to-reach and life-threatening areas, reducing risks for employees themselves [16]. The use of unmanned aerial vehicles in the field of road safety is a modern and promising area for researchers to study in many areas.

Unmanned aerial vehicles are autonomous and fully remotely controlled devices. They are controlled using special software and are equipped with various sensors, cameras and navigation systems [17]. The main advantages of drones include high maneuverability, the ability to quickly collect data, and conduct monitoring in hard-to-reach places for people. Due to this, they have low operating costs [18]. With the help of drones, it is possible to obtain up-to-date and accurate information about the intensity of traffic flow and other road users [19].

Identification of dangerous road conditions has always been considered one of the key elements of ensuring road safety [20]. This concept includes factors such as malfunction of lighting and road patrol systems, high concentration of traffic flow, insufficiency and damage to road signs. It is also possible to damage the road infrastructure as a result of natural disasters [21]. Identification of such dangerous situations and natural disasters at an early stage almost completely and always makes it possible to prevent traffic accidents at an early stage and reduce their consequences.

The detection of security threats using UAVs consists of the following stages: first, good-quality video and photographic materials are collected from the air, then the data obtained is processed using special software and the condition is assessed using artificial intelligence [22].

These technologies make it possible to quickly and accurately identify dangerous situations on the roads [23]. This approach is considered more effective than traditional control methods, as it minimizes errors caused by the human factor. This in turn makes it possible to check a large area in a very short time [24].

Obtaining operational data from unmanned aerial vehicles makes it possible to predict the current state of the road infrastructure [24]. Due to the integration of information data into the hardware traffic management system, road safety is improved. It becomes possible to introduce additional safety measures in dangerous areas of the road and optimize traffic flow. Another important factor in detecting dangerous situations using drones is the ability to quickly collect data and further respond promptly in emergency situations [24]. The use of UAVs also plays a major role in scientific research aimed at improving road traffic safety [25]. Currently, practical methods for early detection and assessment of life-threatening situations in road infrastructure are being developed and successfully implemented in many countries of the world [26]. Thanks to the use of UAVs, it is possible to improve the quality of road safety [27] and increase the service life of road infrastructure facilities [28].

Based on data obtained with the help of UAV, new methods of traffic management are being developed, which in turn plays an important role in ensuring the reliability and safety of transport [29].

The object of research is the developed automated computational model of unmanned aerial vehicles working in conjunction with artificial intelligence and computer vision, the processes of identifying dangerous situations in road infrastructure and assessing them.

The aim of research is to validate the effectiveness and robustness of the developed AI-driven computational model for automated detection, analysis, and forecasting of hazardous situations in road infrastructure to improve safety and optimize maintenance strategies.

Research objectives are goal-based:

1. To develop a conceptual model for recognizing dangerous situations in road infrastructure using data from UAVs and artificial intelligence algorithms.
2. To use the proposed model in a MATLAB environment and show hazardous areas using spatial and heat maps.
3. To evaluate the practical usefulness of observations with UAVs for a systematic assessment of the situation in urban transport systems and preliminary safety planning.

2. Materials and Methods

This study provided an overview of the algorithms and methodological approaches used to conduct a comprehensive assessment and monitoring of road infrastructure on the basis of the UAV. The standard operating model of UAV is shown in Fig. 1.

In order to obtain high-quality data for traffic modeling, a comprehensive work on traffic monitoring using UAVs was carried out. However, due to weather conditions, it was not possible to process the obtained data, so it is possible to load video materials obtained in previous experiments. Drone flights were distributed among regulated intersections, critical pedestrian crossings and main connections to record the flow of the urban transport system. In this way, the most suitable video materials with different numbers of moving and stationary vehicles were sorted (Fig. 2).

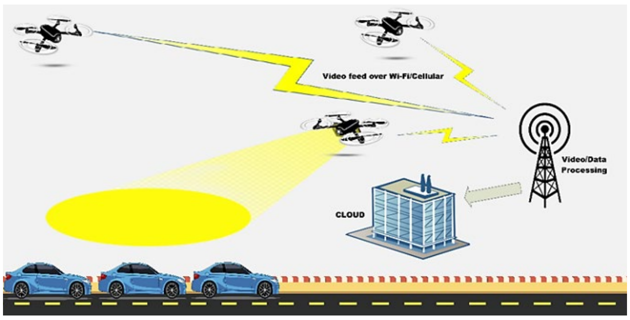
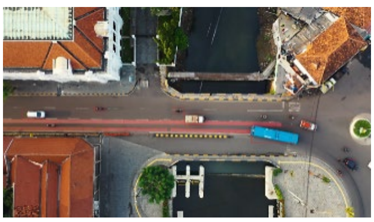


Fig. 1. Typical UAV model



a

b

c

Fig. 2. Examples of traffic vehicle detection using UAVs: *a* – monitoring at low traffic intensity; *b* – monitoring at medium traffic intensity; *c* – monitoring at high traffic intensity

The core of the proposed system is a deep learning model for vehicle detection and tracking. It can process data both in real time and saved from unmanned aerial vehicles (Fig. 1). However, the main focus of the model is the analysis of traffic flow in real time.

The architecture of convolutional neural networks (CNNs) (such as YOLOv7, YOLOv8, YOLOv9, RetinaNet) was used to detect objects (vehicles, cars, trucks, buses, motorcycles and pedestrians). This architecture was chosen because of the high speed of real-time data processing, as well as the accuracy of aerial photographs. At the output, the proposed model is able to show the bounding boxes and the intended classifications for each vehicle found. The computational model and simulation of the system's operational metrics were conducted in the MATLAB environment.

3. Results and Discussion

The principle of operation of the drone is as follows: collects data, analyzes, detects a threat, and sends a signal (Fig. 3). This process can be fully automated using artificial intelligence and machine learning methods.

After reviewing the surveys of other researchers in recent years, it is possible to identify the weaknesses of UAV data collection methods as shown in Table 1. And let's aim to address most of the shortcomings cited by other authors.

Dangerous zones in the road infrastructure are modeled in the MATLAB environment (Fig. 4).

This diagram shows dangerous places along the road as green dots on a simple map. In this study model the places found by the UAV scan in the program.

Based on the data, the red areas are the most dangerous. It is possible to create such a map based on the data collected by the cameras of UAVs. Fig. 5 shows how UAVs have used smart optical sensors to collect the spatial tracking signal. The X and Y axes show the area seen by the sensor, and the color scale shows the signal strength as the Z value. The red areas on the heat map indicate where the signal is strong, and the blue areas indicate where the signal is weak or not at all. It is possible to use this map to accurately display the data collected by sensors in space. It also serves as the basis for the accurate detection of obstacles, targets or critical areas during an autonomous drone flight. Such graphs help intelligent control systems determine what is happening in the environment so that they can perform certain actions.

Thanks to the proposed model, it is possible to identify congestion, disorderly movement and potential violations of the rules, which are combined into risk maps (Fig. 4, 5).

As mentioned above, the model was trained on a specific dataset with annotated video frames from saved video streams. There are different traffic densities on video frames (Fig. 2).

In addition to the dataset, notes have been added for various classes of vehicles (for example, cars, trucks, buses, motorcycles). Generally accepted standards in the field of computer vision (Average Precision (mAP) and F1-score) were used to assess the quality and reliability of the developed vehicle detection model and possible violations. During testing in the MATLAB environment, the model showed high performance: its detection accuracy was 89%. This high indicator confirms that the developed system meets the strict requirements for automated data processing.

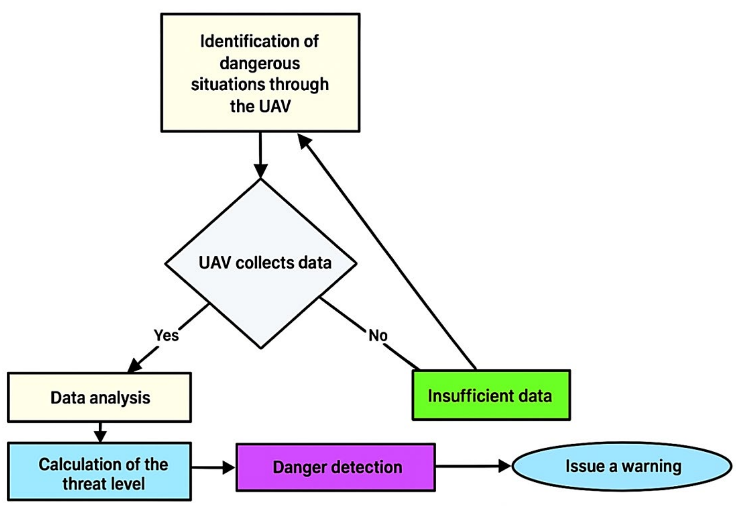


Fig. 3. Flowchart: threat detection process using UAVs

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Table 1

Comparison of UAV survey works

Surveys	Energy efficiency	Security	Optimization	Routing protocols	AI-based learning	UAV communication	Trajectory	IRS/WPT	Advance AI approach
[22]	–	–	+	+	–	+	–	–	–
[23]	+	–	–	–	–	–	–	+	–
[24]	–	+	–	–	–	–	–	+	–
[25]	+	–	–	–	+	–	–	–	–
[26]	+	–	+	–	–	+	+	–	–
[27]	–	–	+	+	–	–	–	–	–

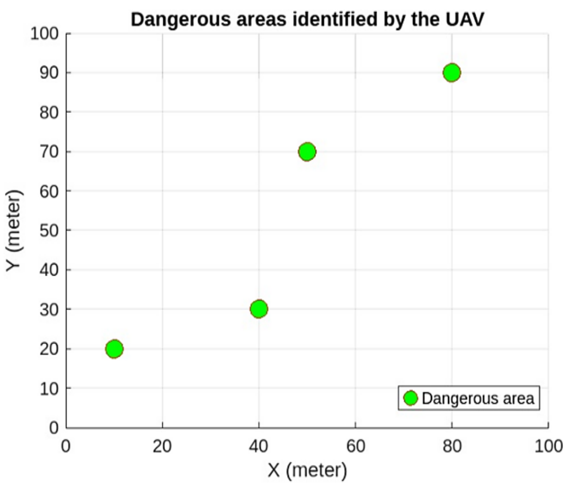

Fig. 4. Map showing dangerous areas in road infrastructure

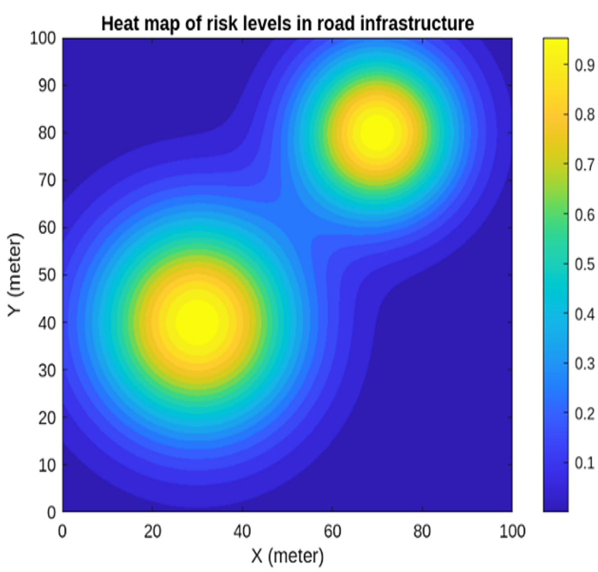

Fig. 5. Heatmap of risk level

The heat map visualization model developed and tested in the MATLAB environment provides operational traffic management centers with meaningful information about critical areas. Allowing emergency and rescue services and repair teams to quickly head to these areas. The developed model using UAVs and AI makes it possible to fully automate the process of infrastructure maintenance. The actual data from real observations, presented in the form of a heat map (Fig. 4), can be used as a basis for the development of reliable navigation algorithms for autonomous vehicles.

The use of UAVs to detect non-standard and sometimes even life-threatening situations in the road infrastructure is one of the most important tools for improving the safety of the transport system. The study showed that the use of UAV technology increases the level of high-quality and reliable information. These methods of monitoring and detecting (especially in cases of urgency) traffic jams and infrastructure deficiencies greatly facilitate this process. The use of artificial intelligence to automate control processes will help reduce the number of traffic accidents, ensure the safety of road users and reduce the cost of materials. This makes it possible to ensure uninterrupted and efficient operation of the road network services for a long time. The use of unmanned aerial vehicles to ensure the safety of road infrastructure is a critically important area of innovative development for the transport sector. Further improvements in these technologies include improved algorithms for processing input data. That is, improving the technical characteristics of an unmanned aerial vehicle. Due to this, road safety standards are being improved. Therefore, additional research in this area would not be superfluous to improve the model.

Practical value: following the results of this study, it can be noted that it is of great practical importance in the areas of smart city infrastructure and road traffic safety management.

Research limitations: although the simulation results show the potential of this system, there are a number of limitations that hinder the practical implementation and generalization of the results. The main limitation is the factor of weather conditions in video and photographic materials, which makes it impossible to soberly evaluate the data obtained in real time. Data collection is only possible under favorable weather conditions, which limits the use of the system as round-the-clock monitoring. Implementing our model in the MATLAB environment and further integrating computer vision and machine learning requires significant computing resources and financial costs. This, in turn, may become an obstacle to the practical implementation of this study.

In future research, it is possible to combine radar and multispectral sensors with optical sensors. This tandem can provide reliable data retrieval regardless of weather conditions or site illumination. Potential research should focus on migrating the model from the MATLAB environment to scalable platforms, as well as further developing APIs for integration with existing municipal GIS and traffic management systems. At this stage, it is very important to understand that such an improvement attracts additional costs.

4. Conclusions

1. The integration of artificial intelligence and computer vision, coupled with UAVs, has increased the detection rate. This feature provides early detection of dangerous situations and provides the opportunity for operational solutions with minimal operator intervention, eliminating human error.

2. In addition to the simulation, thermal and route maps were developed that determine the level of danger at specific geographical coordinates (for example, a color scale expressing the intensity of the threat). This improvement directly increases the clarity and speed of decision-making by the heads of traffic safety services.

3. The created monitoring model for unmanned aerial vehicles has made it possible to automate and significantly speed up the system cycles of data collection and subsequent analysis. Compared to traditional methods, the time for error control when detecting non-standard situations has been significantly reduced.

Conflict of interest

The authors declare that they have no conflicts of interest related to this research, including financial, personal, authorship, or any other form that could have influenced the research and its reported results.

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Data availability

The manuscript does not contain associated data.

Use of artificial intelligence

The authors used Yandex GPT 5.1 Pro artificial intelligence technologies within permissible limits during the initial drafting of certain text fragments of the article, particularly in the sections "Introduction", "Materials and Methods". The use of AI was aimed at finding sources for a literature review, preliminary methodology development, preliminary structuring of the material and enhancing the logical consistency of the presentation with strict compliance with the journal's AI policy. All AI-generated suggestions were carefully reviewed, supplemented, or corrected by the authors before being included in the final version of the article.

Authors' contributions

Nurzhigit Smailov: Conceptualization, Resources, Supervision; ***Yerzhan Nussupov***: Methodology, Writing – original draft, Writing – review and editing; ***Kyrmyzy Taissariyeva***: Software, Validation, Data Curation; ***Aidar Kuttybayev***: Project administration, Supervision, Investigation; ***Baigulbayeva Moldir***: Formal analysis, Data Curation, Methodology; ***Mukhit Turumbetov***: Conceptualization, Methodology, Formal analysis; ***Yulian Hryhoriev***: Writing – original draft, Resources, Project administration; ***Serhii Lutsenko***: Writing – review and editing, Visualization, Software.

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