SATBAYEV UNIVERSITY

Computing & Engineering

Volume 3 (2025), Issue 2, 28-33

https://doi.org/10.51301/ce.2025.i2.05

Monitoring Urban Road Infrastructure Using Unmanned Aerial Vehicles (UAVs): Challenges and Solutions

N.K. Smailov[1*], P. Komada[2], K.N. Taissariyeva[1], E. Tashtay[1], M.B. Turumbetov[3]

[1]Satbayev University, Almaty, Kazakhstan

[2]Lublin University of Technology, Lublin, Poland

[3]Military Engineering Institute of Radio Electronics and Communications, Almaty, Kazakhstan

**Corresponding author: n.smailov@satbayev.university*

Abstract. Effective management and monitoring of urban road infrastructure require the adoption of new technologies and approaches. Today, Unmanned Aerial Vehicles (UAVs) are widely used for these purposes. UAVs provide enhanced capabilities for monitoring urban roads, traffic flow, pavement conditions, and other infrastructural elements. However, the deployment of UAVs in urban environments presents unique challenges. Tall buildings, dense traffic, radio frequency interference, and weather conditions can hinder UAV performance. Additionally, flight operations in city areas raise concerns related to safety, data privacy, and legal restrictions. This article extensively discusses the features and possibilities of monitoring urban road infrastructure using UAVs. It explores solutions to the technical and organizational difficulties associated with urban UAV flights. For instance, the implementation of automated flight systems, precise monitoring using specialized devices and sensors, and addressing legal and data protection concerns to improve operational safety. Considering viable UAV deployment strategies in urban areas enables full utilization of technological potential. This research proposes solutions aimed at enhancing the efficiency of urban infrastructure and contributes to the future development of urban transport systems.

Keywords: *Unmanned Aerial Vehicle, urban road infrastructure, monitoring, urban environment, technical challenges, automated systems, safety, legal regulation, traffic flow, data protection, flight systems, urban infrastructure management, innovative solutions, sensors, urban transport systems.*

1. Introduction

Urban road infrastructure is a crucial component of modern cities, and its efficient operation contributes to the resolution of numerous social and economic challenges. Issues such as road conditions, traffic efficiency, public transport accessibility, and pedestrian safety remain highly relevant in urban environments [1]. Traditional methods used to monitor and analyze these issues may prove insufficient, as they often require significant time, lack efficiency, and may lead to the absence of accurate, up-to-date information. In this context, Unmanned Aerial Vehicles (UAVs) emerge as a promising new technology [2]. UAVs enable real-time data collection for urban infrastructure monitoring, making them an effective tool for assessing road conditions, analyzing traffic flow, and quickly detecting potential violations or malfunctions [3].

However, the use of UAVs in urban environments comes with specific challenges and limitations. High-rise buildings, noisy radio frequencies, and weather conditions such as wind can create serious obstacles during flight. Buildings and other structures may force changes in flight paths, complicate control, and reduce accuracy. Moreover, heavy traffic, high population density, and crowded urban spaces can impede the efficient operation of UAVs [4]. These issues may compromise the safety of UAV flights and negatively affect the effectiveness of urban infrastructure monitoring.

Another set of difficulties in applying UAVs in cities is related to legal and regulatory constraints. Comprehensive laws and regulations governing UAV flights are still in development. As a result, concerns regarding data security and privacy protection play a significant role. In addition, the environmental impact of UAV operations should also be considered, with efforts made to minimize harm to the surrounding ecosystem [5].

This article provides an in-depth analysis of the obstacles and difficulties encountered when monitoring urban road infrastructure using UAVs. Furthermore, it explores proposed solutions and innovative technologies aimed at enhancing the efficiency of UAV operations in urban areas, addressing challenges, and optimizing the monitoring process. The paper also presents strategies for processing, analyzing, and managing data obtained through UAVs and offers practical recommendations for improving infrastructure conditions. This study focuses on ensuring effective monitoring and control of urban road networks through the application of new, advanced approaches.

2. Materials and methods

2.1. Data Sources

Monitoring and managing urban road infrastructure is currently a complex and significant task. To address this challenge, the integration of advanced technologies is essential — among them, Unmanned Aerial Vehicles (UAVs) offer unique capabilities [6]. UAVs enable the observation of various components of urban infrastructure, facilitate data collection, help identify problems, and support timely intervention. While this technology presents effective solutions for addressing critical urban issues, it also faces several operational challenges [6].

The primary advantage of using UAVs in urban infrastructure lies in their ability to collect highly accurate and rapid data. UAVs monitor road conditions and traffic flow in real time, enabling data-driven decision-making processes [7]. Additionally, UAVs have the capacity to cover large urban areas, making them an efficient tool for surveying and monitoring vast regions. For example, they can effectively perform tasks such as road inspections, assessment of bridge and tunnel conditions, and monitoring traffic congestion levels [7].

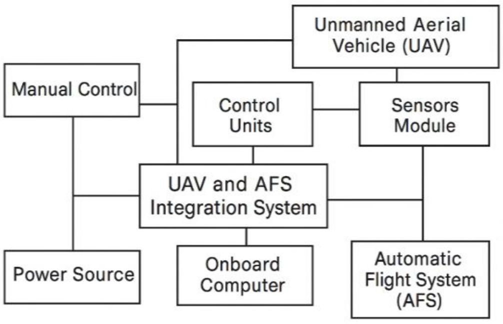

Figure 1. UAV System Diagram

Figure 1 illustrates the general structure of an Unmanned Aerial Vehicle (UAV) control system. The control is implemented in two main modes: manual and automatic. Control signals are transmitted to the UAV via control units, which are coordinated through the UAV and Automatic Flight System (AFS) integration system. The automatic control system includes an onboard computer and a sensor module that collect data about the environment and the condition of the UAV. All subsystems are powered by a central power source.

However, the use of UAVs in urban environments presents several challenges and limitations. Due to the dense layout of urban infrastructure, UAV flight operations face multiple obstacles. Firstly, the abundance of buildings and structures in cities can affect the accuracy and stability of flight. High-rise buildings and multi-story structures can interfere with UAV navigation, forcing changes in direction and complicating control [7]. In such scenarios, the weakening or loss of GPS signals can further compromise flight safety. Moreover, the high presence of electrical and radio frequencies in urban areas can disrupt UAV performance and cause interference during flight.

Another significant issue in urban environments is weather conditions. Frequent occurrences of rain, snow, wind, or cloudy weather in cities can negatively impact UAV flights [8]. These factors can reduce UAV stability and complicate flight operations. Given the rapidly changing weather in urban areas, there is a growing need to implement specialized weather monitoring systems to ensure flight safety [8].

Legal and regulatory restrictions are also critical factors in the use of UAVs within urban environments. At present, many countries still lack fully developed and comprehensive laws and regulations governing UAV operations [9]. Issues such as the potential impact of UAVs on personal privacy, the protection of personal data, and concerns regarding public safety necessitate clear legal oversight [10]. UAV flights may result in the collection of personal data or violations of individual privacy, potentially leading to public distrust. Therefore, it is essential to improve the legal and regulatory frameworks governing UAV deployment [11].

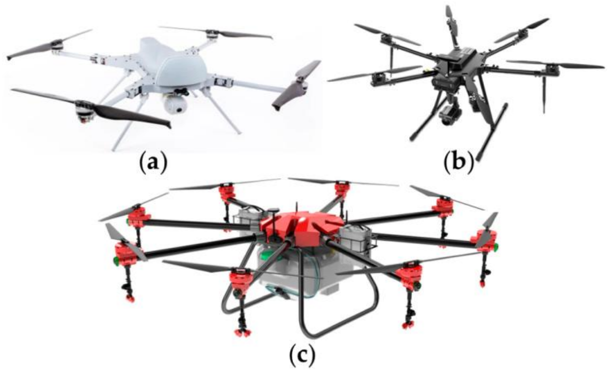

Figure 2. Examples of Multirotor UAVs: (a) Quadcopters; (b) Hexacopters; and (c) Octocopters

Another major challenge in urban UAV usage involves technical limitations and power constraints [12]. The presence of electromagnetic fields between high-rise buildings can disrupt UAV operations. Additionally, the limited battery life and power capacity of UAVs pose significant challenges during extended missions [13]. To ensure safe flight, UAVs must be equipped with high-quality sensors and advanced control systems. Evaluating the technical capabilities and constraints of UAVs in relation to varying urban infrastructure conditions is also vital [14].

Identifying practical solutions and strategies for UAV use in urban settings is a key issue. Automating UAV flights, pre-defining flight paths, and integrating sensor systems tailored for urban environments are some of the proposed solutions [15]. Furthermore, inspection and monitoring systems for UAVs should be established to ensure operational safety [16]. In particular, the development of robust UAV data processing and management systems is crucial in urban environments. These systems help improve flight accuracy, efficiency, and safety [17].

Despite the numerous challenges, monitoring urban road infrastructure via UAVs provides significant potential. Through a combination of technical and organizational solutions, UAV efficiency can be greatly enhanced. The pursuit of improved methods for using UAVs in urban monitoring continues, aiming to optimize the control and management of city infrastructure [17].

3. Results and discussion

To effectively monitor urban road infrastructure using Unmanned Aerial Vehicles (UAVs), various intelligent algorithms are employed. First, trajectory planning algorithms are used to determine the shortest and safest path for the UAV. Commonly used methods such as A* and Rapidly-exploring Random Trees (RRT) construct optimal routes to the target point while accounting for map-based obstacles. Since avoiding obstacles during flight is critical, real-time dynamic algorithms are utilized.

These algorithms can detect moving or previously unknown obstacles and automatically adjust the UAV's path accordingly. Additionally, data collected from UAV-mounted cameras and sensors is processed using computer vision and artificial intelligence techniques to identify road surfaces, vehicles, and structural defects.

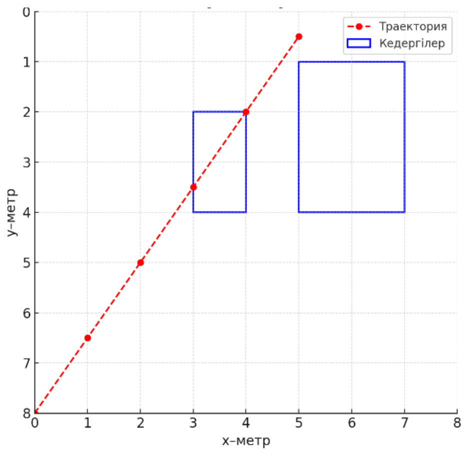

Figure 3. UAV Flight Trajectory

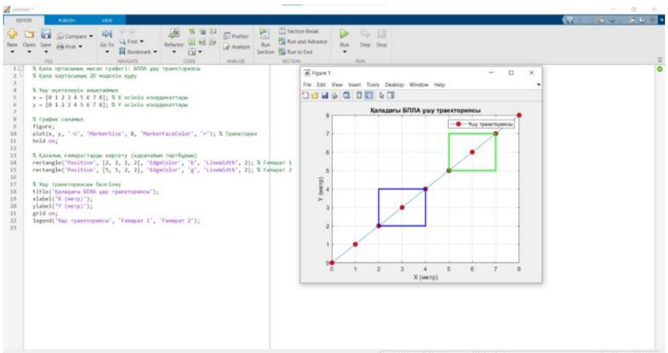

Figure 4. UAV Flight Trajectory in an Urban Environment

This code visualizes the UAV flight trajectory (Figures 3-4) along with urban buildings in a city environment. It is designed to simulate urban infrastructure and buildings for the purpose of visualizing UAV flight paths in urban areas.

Defining the flight path:

The x and y arrays contain the coordinates of the UAV's flight trajectory. These coordinates represent the path of the UAV as it flies through the urban environment. Plotting the flight path:

The plot function is used to draw the UAV flight trajectory as a red line. Each waypoint (0, 1, 2, 3, etc.) indicates the UAV's movement, marked with red circles ('-o') for visibility. Visualizing buildings:

The rectangle function is used to display two buildings within the city. The first building is shown with a blue edge ('EdgeColor', 'b'), and the second building with a green edge ('EdgeColor', 'g'). The dimensions of the buildings are specified using the format [x, y, width, height].

This code adds an altitude (z) coordinate to the UAV flight trajectory. A 3D representation of an Unmanned Aerial Vehicle's (UAV) flight path in an urban environment reflects the complex and dynamic nature of its movement. In such environments, the presence of buildings, bridges, power lines, and other obstacles requires the UAV to maintain a precise and safe route.

The 3D trajectory (Figure 5) is typically visualized along three axes — X, Y, and Z — where the X and Y plane represents horizontal movement, and the Z axis reflects changes in altitude. UAV operations take place at different levels within urban space: at lower altitudes — flying along streets or avoiding traffic flows — and at higher altitudes — passing over buildings.

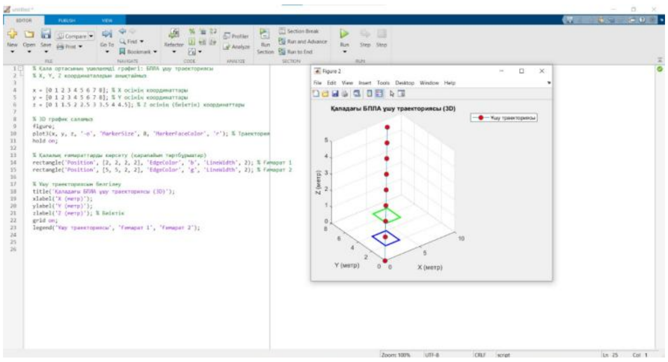

Figure 5. 3D View of UAV Flight Trajectory in an Urban Environment

The 3D trajectory clearly illustrates turns, ascents and descents, and obstacle avoidance maneuvers. Such visualization allows for a comprehensive understanding of UAV motion dynamics and plays a crucial role in real-time trajectory correction, route optimization, and ensuring safe flight.

A 3D model of the flight path in urban environments serves as a foundation for enhancing key UAV capabilities such as autonomous navigation, obstacle avoidance, and precision landing.

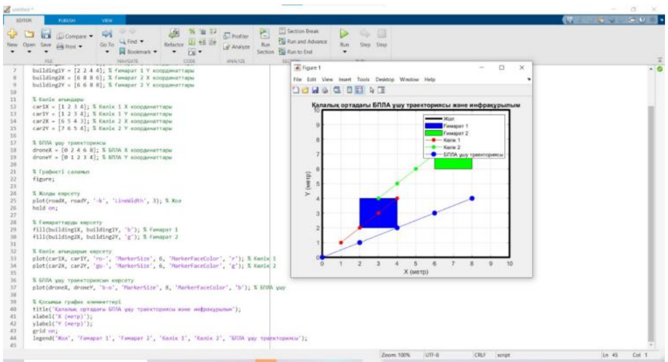

Figure 6. Diagram Showing UAV Flight Trajectory and Buildings Over Urban Roads

Authors proposes creating a 2D diagram to represent the UAV flight trajectory, buildings, traffic flows, and roads in an urban environment. This diagram allows for comparison between vehicle movements, infrastructure, and the UAV's flight path. A diagram showing the UAV flight trajectory and buildings over city roads provides a detailed and realistic spatial representation of a complex urban environment.

In this diagram, urban infrastructure elements—such as buildings, roads, and other structures—are depicted as polygonal volumes placed at specific heights within the space. The UAV flight trajectory is shown as a winding line navigating through and over these structures. The trajectory reflects the UAV's complex navigation, sometimes flying at low altitudes along roadways and other times ascending to avoid obstacles.

The relationship between the UAV's flight path and the placement of buildings is clearly illustrated, showing precise distances between the UAV and surrounding obstacles to ensure flight safety. The UAV's movement directions, turns, ascents, and descents are vividly represented by the trajectory line, while buildings are portrayed as blocks of varying height and form.

Such a diagram is a vital tool for planning UAV missions in urban areas, allowing for the prediction of obstacles and the selection of safe and efficient routes.

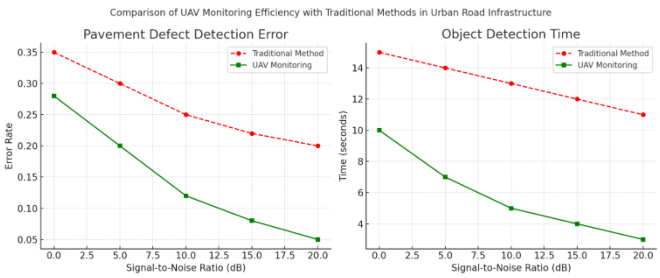

Figure 7. Advantages of UAV Monitoring in Urban Road Infrastructure: Comparative Analysis with Traditional Methods

This comparative graph (Figure 7) demonstrates the effectiveness of unmanned aerial vehicle (UAV) monitoring in urban road infrastructure compared to traditional methods. The graph consists of two parts: the first shows pavement defect detection error, and the second shows the time required to detect an object. The horizontal axis represents the signal-to-noise ratio (in dB), which reflects the clarity and reliability of the conditions. In the first part, the traditional method is shown with a red line, while the UAV monitoring results are represented by a green line. The use of UAVs significantly reduces the detection error: for example, at 0 dB, the error rate for the traditional method is 0.35, whereas it drops to 0.28 with UAVs—and the gap continues to widen as the signal quality improves. The second part displays the time taken to detect an object. UAV-based monitoring identifies objects much faster than traditional methods: starting at 10 seconds and decreasing to just 3 seconds at 20 dB, while the traditional approach only improves from 15 to 11 seconds. This graph clearly illustrates the advantage of UAV technology in terms of accuracy and speed, supporting its application as a reliable and efficient tool for real-time urban road infrastructure monitoring.

4. Conclusions

Monitoring urban road infrastructure using Unmanned Aerial Vehicles (UAVs) is one of the innovative solutions of the modern era. This technology enables the execution of critical functions such as monitoring road conditions, preventing accidents and traffic incidents, and inspecting the technical condition of infrastructure. The complexity and diversity of the urban environment present unique opportunities for UAVs, yet their deployment also involves numerous challenges and obstacles. Addressing these challenges can enhance UAV effectiveness and unlock new capabilities in urban infrastructure monitoring.

The primary difficulties in using UAVs in urban settings are associated with the density of the flight zone and the specific characteristics of the environment. High-rise buildings, multi-story structures, and various obstacles may hinder UAV operations by disrupting GPS signals, causing communication failures, and complicating accurate flight path navigation. In addition, weather factors such as wind, rain, and cloudy skies can significantly affect UAV flight performance, especially during missions requiring precision and stability in the air.

Data collection, processing, and storage also pose important challenges. Monitoring urban infrastructure generates large volumes of data, necessitating specialized systems and software for analysis and processing. Real-time access to and effective use of this data require dedicated infrastructure and technological solutions. Automating systems that utilize UAV-generated data is essential to improving the integration and operational efficiency of urban systems.

For municipal authorities and local governments, legal regulation plays a crucial role in maximizing the effectiveness of UAV use. It is necessary to establish rules governing UAV flight zones, ensure the safety of individuals, and regulate operations in private and public spaces. Addressing these issues requires updates to international and national standards and regulations.

In the future, UAV-based monitoring of urban road infrastructure may become a key tool in urban planning and management. Effective utilization of UAVs demands advanced technologies, improved infrastructure, and appropriate legislative measures. With the help of UAVs, new opportunities emerge for monitoring infrastructure, preventing incidents, and ultimately improving the quality of urban life. Despite the challenges, expanding the use of UAVs represents an important step toward enhancing the safety and efficiency of urban environments.

References

[1] Cheng, L., et al. (2021). Urban Infrastructure Monitoring Using UAVs: Challenges and Solutions. *International Journal of Urban Science, 25(4), 535-550.* https://doi.org/10.1080/12265934.2021.1881832

[2] Zhang, Y. & Liu, F. (2020). Applications of UAVs for Urban Road Monitoring and Management. *Journal of Transportation Engineering, 146(2), 04019054.* https://doi.org/10.1061/JPEODX.0000172

[3] Zhang, J. & Wang, T. (2019). Urban Traffic Monitoring Using UAVs: Challenges and Future Directions. *Transportation Research Part C: Emerging Technologies, 102, 15-30.* https://doi.org/10.1016/j.trc.2019.02.004

[4] Dandois, J., et al. (2020). The Use of Drones for Urban Infrastructure and Traffic Management. *Smart Cities, 3(2), 102-115.* https://doi.org/10.3390/smartcities3020007

[5] Balz, T., et al. (2022). Impact of UAVs on Urban Mobility and Infrastructure: A Comprehensive Review. *Urban Technology Journal, 14(3), 108-123*

[6] Khan, Z., et al. (2020). Urban Air Mobility: Advancements and Challenges for Drone-Based Monitoring Systems. *Transportation Science, 54(6), 1721-1740.* https://doi.org/10.1287/trsc.2020.0987

[7] Li, S. & Wang, X. (2021). Integration of UAVs in Smart City Infrastructure Management. *Journal of Civil Engineering and Management, 27(5), 352-366.* https://doi.org/10.3846/jcem.2021.14536

[8] Pirotti, F., et al. (2018). Drone-Based Infrastructure Inspection and Monitoring: The Role of UAVs in Urban Planning. *Urban Studies Journal, 55(8), 1602-1615.* https://doi.org/10.1177/0042098017709419

[9] Zhang, Z. & Chen, L. (2019). Challenges in Urban Infrastructure Monitoring Using UAVs. *International Journal of Civil Engineering, 17(4), 419-431.* https://doi.org/10.1007/s40999-019-00412-3

[10] Zha, Y., et al. (2020)."High-Precision Monitoring of Urban Roads Using UAV-Based Remote Sensing Systems. *Geocarto*

International, 35(7), 811-824. https://doi.org/10.1080/10106049.2018.1520922

[11] Kase, T. & Takahashi, S. (2021). Urban Monitoring and Infrastructure Management with UAVs: Case Studies and Lessons Learned. *Smart City Journal, 11(6), 345-356*

[12] Xu, S., et al. (2021). Advances in UAV-Based Urban Monitoring: Applications, Challenges, and Solutions. *IEEE Transactions on Intelligent Transportation Systems, 22(4), 2491-2504.* https://doi.org/10.1109/TITS.2020.2992113

[13] Bassi, R., et al. (2020). The Potential of UAVs in Urban Transport and Infrastructure Analysis. *Transport Research Review, 39(2), 58-70*

[14] Liu, Y., et al. (2019). Urban Infrastructure Monitoring Using UAVs: A Survey of Applications and Solutions. *Automation in Construction, 105, 220-234.* https://doi.org/10.1016/j.autcon.2019.05.011

[15] Lu, W., et al. (2019). UAV-Based Monitoring of Urban Roads and Traffic: A Review. *Journal of Intelligent Transportation Systems, 23(1), 72-85.* https://doi.org/10.1080/15472450.2018.1445822

[16] Zhao, X. & Wang, Y. (2020). Applications and Challenges of UAVs in Urban Road Infrastructure Surveillance. *Urban Planning and Development, 146(4), 04020025.* https://doi.org/10.1061/(ASCE)UP.1943-5444.0000595

[17] Qi, X., et al. (2018). Urban Transportation Systems Monitoring Using UAVs: Technological Challenges and Future Prospects. *Urban Mobility Review, 11(3), 153-165*

Ұшқышсыз Ұшу Аппараттарын (ҰҰА) пайдалана отырып, қалалық жол инфрақұрылымын бақылау: мәселелер мен шешімдер

Н.К. Смайлов[1*], П. Комада[2], К.Н. Тайсариева[1], Е. Таштай[1], М.Б. Турумбетов[3]

[1]Satbayev University, Алматы, Қазақстан
[2]Люблин Технологиялық Университеті, Люблин, Польша
[3]Радиоэлектроника және байланыс әскери-инженерлік институты, Алматы, Қазақстан

**Корреспонденция үшін автор:* n.smailov@satbayev.university

Аңдатпа. Қалалық жол инфрақұрылымын тиімді басқару және бақылау жаңа технологиялар мен тәсілдерді енгізуді талап етеді. Бүгінгі таңда бұл мақсаттарда Ұшқышсыз Ұшу Аппараттары (Ұшқышсыз ұшу аппараттары) кеңінен қолданылады. Ұшқышсыз ұшу аппараттары қалалық жолдарды, көлік ағынын, тротуар жағдайларын және басқа да инфрақұрылымдық элементтерді бақылау үшін кеңейтілген мүмкіндіктерді қамтамасыз етеді. Дегенмен, Қалалық жерлерде Ұшқышсыз Ұшу аппараттарын орналастыру бірегей қиындықтарды тудырады. Биік ғимараттар, тығыз қозғалыс, радиожиілік кедергілері және ауа райы жағдайлары ұшқышсыз ұшу аппараттарының жұмысына кедергі келтіруі мүмкін. Сонымен қатар, қалалық жерлерде рейстерді орындау қауіпсіздікке, деректердің құпиялылығына және заңды шектеулерге қатысты алаңдаушылық туғызады. Бұл мақалада Ұшқышсыз Ұшу аппараттарының көмегімен қалалық жол инфрақұрылымын бақылаудың ерекшеліктері мен мүмкіндіктері жан-жақты талқыланады. Ол қалалық ұшқышсыз ұшу аппараттарының ұшуына байланысты техникалық және ұйымдастырушылық қиындықтардың шешімдерін зерттейді. Мысалы, автоматтандырылған ұшу жүйелерін енгізу, мамандандырылған құрылғылар мен датчиктерді қолдана отырып дәл бақылау, сондай-ақ пайдалану қауіпсіздігін арттыру мақсатында деректерді қорғаудың құқықтық және құқықтық мәселелерін шешу. Қалалық жерлерде ұшқышсыз ұшу аппараттарын орналастырудың өміршең стратегияларын қарастыру технологиялық әлеуетті толық пайдалануға мүмкіндік береді. Бұл зерттеу қалалық инфрақұрылымның тиімділігін арттыруға бағытталған шешімдерді ұсынады және қалалық көлік жүйелерінің болашақ дамуына ықпал етеді.

Негізгі сөздер: *ұшқышсыз ұшу аппараттары, қалалық жол инфрақұрылымы, мониторинг, қалалық орта, техникалық мәселелер, автоматтандырылған жүйелер, қауіпсіздік, құқықтық реттеу, қозғалыс ағыны, деректерді қорғау, ұшу жүйелері, қалалық инфрақұрылымды басқару, инновациялық шешімдер, сенсорлар, қалалық көлік жүйелері.*

Мониторинг городской дорожной инфраструктуры с помощью беспилотных летательных аппаратов (БПЛА): проблемы и решения

Н.К. Смайлов[1*], П. Комада[2], К.Н. Тайсариева[1], Е. Таштай[1], М.Б. Турумбетов[3]

[1]Satbayev University, Алматы, Казахстан
[2]Люблинский технологический университет, Люблин, Польша
[3]Военно-инженерный институт радиоэлектроники и связи, Алматы, Казахстан

*Автор для корреспонденции: n.smailov@satbayev.university

Аннотация. Эффективное управление и мониторинг городской дорожной инфраструктуры требуют внедрения новых технологий и подходов. Сегодня для этих целей широко используются беспилотные летательные аппараты (БПЛА). БПЛА предоставляют расширенные возможности для мониторинга городских дорог, транспортных потоков, состояния дорожного покрытия и других элементов инфраструктуры. Однако использование беспилотных летательных аппаратов в городских условиях сопряжено с особыми трудностями. Высокие здания, плотное движение транспорта, радиочастотные помехи и погодные условия могут препятствовать работе беспилотных летательных аппаратов. Кроме того, полеты в городских районах вызывают опасения, связанные с безопасностью, конфиденциальностью данных и юридическими ограничениями. В этой статье подробно рассматриваются особенности и возможности мониторинга городской дорожной инфраструктуры с помощью беспилотных летательных аппаратов. В ней рассматриваются пути решения технических и организационных трудностей, связанных с полетами беспилотных летательных аппаратов в городах. Например, внедрение автоматизированных систем управления полетами, точный мониторинг с использованием специализированных устройств и датчиков, а также решение юридических вопросов и проблем защиты данных для повышения эксплуатационной безопасности. Рассмотрение эффективных стратегий развертывания беспилотных летательных аппаратов в городских районах позволяет в полной мере использовать технологический потенциал. Это исследование предлагает решения, направленные на повышение эффективности городской инфраструктуры и способствующие будущему развитию городских транспортных систем.

Ключевые слова: *беспилотные летательные аппараты, городская дорожная инфраструктура, мониторинг, городская среда, технические проблемы, автоматизированные системы, безопасность, правовое регулирование, транспортные потоки, защита данных, системы управления полетами, управление городской инфраструктурой, инновационные решения, датчики, городские транспортные системы.*

Received: 13 March 2025
Accepted: 15 June 2025
Available online: 30 June 2025