

THE TRANSFORMATIVE EFFECTS OF ARTIFICIAL INTELLIGENCE AND UNMANNED AERIAL VEHICLES ON NATIONAL DEVELOPMENT PARADIGMS

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Abstract:

In recent years, the integration of artificial intelligence (AI) with unmanned aerial vehicles (UAVs) has led to significant advancements across various fields. This comprehensive analysis explores the dynamically evolving landscape of AI-enabled UAVs, as well as the concept of "friendly" (environmentally conscious) applications and computing within the context of their use. The work encompasses promising trends, futuristic concepts, and the associated challenges inherent in this domain. This study examines the role of AI in enabling navigation, object detection and tracking, wildlife monitoring, enhancing agricultural precision, facilitating rescue operations, and carrying out surveillance activities and establishing communication between UAVs using environmentally oriented computing methods. By analyzing the interaction between AI and UAVs, this work highlights the potential of these technologies to radically transform sectors such as agriculture, surveillance systems, and emergency management strategies. Beyond predicting opportunities, the review also considers ethical considerations, safety concerns, the necessity of developing regulatory frameworks, and the responsible deployment of AI-enhanced UAV systems. By summarizing the research findings in this area, this review contributes to an understanding of the evolving landscape of AI-powered UAVs and establishes a foundation for further research in this promising field.

Keywords: Artificial intelligence, unmanned aerial vehicles (UAVs), monitoring, surveillance, computing

INTRODUCTION

Unmanned aerial vehicles (UAVs) have become widely popular as efficient tools for performing tasks related to observation, mapping, and remote sensing¹. Their proliferation is driven by several factors, including relative cost-effectiveness, ease of operation, personnel safety, and the accessibility of operator training². The combination of these advantages with

¹ S.A.H. Mohsan, N. Q. H. Othman, Y. Li, M. H. Alsharif, and M. A. Khan, "Unmanned aerial vehicles (uavs): practical aspects, applications, open challenges, security issues, and future trends," *Intelligent Service Robotics*, pp. 1–29, 2023.

² S. Manfreda, M. F. McCabe, P. E. Miller, R. Lucas, V. Pajuelo Madri- gal, G. Mallinis, E. Ben Dor, D. Helman, L. Estes, G. Ciraolo,

the high resolution of the acquired data and reliable object tracking capabilities is contributing to the expansion of their application in various fields. In particular, UAVs are actively used for environmental monitoring, including assessing air pollution levels, measuring land surface temperature, predicting flood risks, detecting forest fires, identifying road surface defects, monitoring terrain relief, analyzing pedestrian traffic, and managing evacuations in emergency situations³. Furthermore, the application of UAVs in geoinformation technologies for providing data tailored to professionals in the construction industry has made them a sought-after tool for information gathering. Modern advancements in automotive technologies also allow for assisting drivers by providing timely and accurate information about road conditions. There is a growing trend of utilizing UAVs in road construction for traffic monitoring and traffic flow management⁴.

Significant advancements in computer hardware and software have made artificial intelligence (AI) a key component in virtually all research areas related to engineering⁵. AI represents a powerful tool for solving complex problems for which there are no definitive answers or for which traditional methods require significant human intervention⁶. A fundamental distinction between AI and standard cognitive algorithms is the ability to automatically extract features, which avoids the time-consuming manual feature engineering⁷.

In general terms, the tasks solved using AI can include identifying anomalies, predicting future outcomes, adapting to changing conditions, forming an understanding of complex problems requiring the processing of large volumes of data, and discovering patterns that might be overlooked by humans⁸. AI can effectively utilize and analyze large volumes of data to optimize UAV management. Compared to traditional optimization methods, AI is also capable of rationally allocating resources⁹.

Automation of functions, both partial and complete, is a defining characteristic of unmanned aerial vehicles (UAVs) utilizing artificial intelligence (AI). The implementation of AI enables UAV manufacturers to efficiently use data from devices connected to the drone for gathering and analyzing information about the environment and visual perception¹⁰. AI can be applied to automatically control drones, including their movement and navigation. Various methods, such as GPS monitoring, computer vision, and machine learning algorithms, are used to achieve these goals. Speech recognition, scene identification, object detection, and image classification

et al., "On the use of unmanned aerial systems for environmental monitoring," *Remote sensing*, vol. 10, no. 4, p. 641, 2018.

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⁴ A. Alamouri, A. Lampert, and M. Gerke, "An exploratory investiga- tion of uas regulations in europe and the impact on effective use and economic potential," *Drones*, vol. 5, no. 3, p. 63, 2021.

⁵ L. Cao, "AI science and engineering: A new field," *IEEE Intelligent Systems*, vol. 37, no. 1, pp. 3–13, 2022.

⁶ Y. Xu, X. Liu, X. Cao, C. Huang, E. Liu, S. Qian, X. Liu, Y. Wu, F. Dong, C.-W. Qiu, *et al.*, "Artificial intelligence: A powerful paradigm for scientific research," *The Innovation*, vol. 2, no. 4, p. 100179, 2021.

⁷ C. Janiesch, P. Zschech, and K. Heinrich, "Machine learning and deep learning," *Electronic Markets*, vol. 31, no. 3, pp. 685–695, 2021.

⁸ M. E. Morocho-Cayamcela, H. Lee, and W. Lim, "Machine learning for 5g/b5g mobile and wireless communications: Potential, limita- tions, and future directions," *IEEE access*, vol. 7, pp. 137184–137206, 2019.

⁹ S. Razzaq, C. Xydeas, A. Mahmood, S. Ahmed, N. I. Ratyal, and J. Iqbal, "Efficient optimization techniques for resource allocation in uavs mission framework," *PloS one*, vol. 18, no. 4, p. e0283923, 2023.

¹⁰ T. Alladi, V. Chamola, N. Sahu, and M. Guizani, "Applications of blockchain in unmanned aerial vehicles: A review," *Vehicular Communications*, vol. 23, p. 100249, 2020.

are just some of the areas in which AI demonstrates significant advancements, especially in the context of deep learning techniques¹¹. Deep learning aims to identify hidden patterns in raw data at various levels¹².

These characteristics provide the possibility of modeling the real world. According to forecasts, the UAV market size will grow from USD 26.2 billion in 2022 to USD 38.3 billion by 2027, at a compound annual growth rate (CAGR) of 7.9% during the forecast period. The increasing use of small drones for military purposes, such as intelligence, surveillance, and reconnaissance (ISR), is expected to contribute to the growth of the small drone market during the forecast period¹³.

Despite the growing interest in unmanned aerial vehicles (UAVs), there are several limitations faced by developers and users. Many issues associated with UAVs, such as high energy consumption and the need for real-time data processing, can be partially addressed through edge computing and edge AI, which are characterized by low power consumption and minimal latency¹⁴. The integration of deep learning with UAVs unlocks new horizons for revolutionary changes in traffic monitoring within the transportation sector¹⁵. This research aims to provide an in-depth analysis and exploration of the optimal application of artificial intelligence and deep machine learning methods in already existing UAVs, as well as to identify potential avenues for their further development. AI-equipped UAVs require powerful computing systems and sensors that consume a significant amount of energy. The use of energy-efficient components and algorithms is a key aspect of “green” computing. Researchers are working on optimizing AI algorithms to reduce the computational resource requirements and energy consumption of UAVs¹⁶ [16].

The application of renewable energy sources, such as solar panels or wind turbines, can provide a more environmentally friendly way to charge UAV batteries. Artificial intelligence also plays an important role in ensuring the autonomy and navigation of UAVs. AI algorithms enable the optimization of flight paths, which contributes to reduced fuel consumption and decreased emissions of harmful substances. Scientists, specialists in the field, and government organizations can join forces to develop «green» computing solutions for AI-equipped UAVs. Scientific research is aimed at creating environmentally friendly technologies and methods that contribute to the development of more advanced “green” UAVs¹⁷.

¹¹ W. Budiharto, A. A. Gunawan, J. S. Suroso, A. Chowanda, A. Patrik, and G. Utama, “Fast object detection for quadcopter drone using deep learning,” in *2018 3rd international conference on computer and communication systems (ICCCS)*, pp. 192–195, IEEE, 2018.

¹² A. Carrio, C. Sampedro, A. Rodriguez-Ramos, and P. Campoy, “A review of deep learning methods and applications for unmanned aerial vehicles,” *Journal of Sensors*, vol. 2017, 2017.

¹³ P. Butterworth-Hayes and J. Beechener, “Uav market projected to grow from usd26.2b in 2022 to usd38.3b by 2027, at 7.9% cagr,” May 2023.

¹⁴ Y. Yazid, I. Ez-Zazi, A. Guerrero-González, A. El Oualkadi, and M. Arioua, “Uav-enabled mobile edge-computing for iot based on ai: A comprehensive review,” *Drones*, vol. 5, no. 4, p. 148, 2021.

¹⁵ C. Chen, Z. Zheng, T. Xu, S. Guo, S. Feng, W. Yao, and Y. Lan, “Yolo- based uav technology: A review of the research and its applications,” *Drones*, vol. 7, no. 3, p. 190, 2023.

¹⁶ A. H. Kelechi, M. H. Alsharif, O. J. Bameyi, P. J. Ezra, I. K. Joseph, A.-A. Atayero, Z. W. Geem, and J. Hong, “Artificial intelligence: An energy efficiency tool for enhanced high performance computing,” *Symmetry*, vol. 12, no. 6, p. 1029, 2020.

¹⁷ G. Wu, Y. Miao, Y. Zhang, and A. Barnawi, “Energy efficient for uav- enabled mobile edge computing networks: Intelligent task prediction and offloading,” *Computer Communications*, vol. 150, pp. 556–562, 2020.

The analysis of deep learning methods applied in the context of unmanned aerial vehicles (UAVs) has revealed limitations at the current stage of their development. In particular, insufficient attention is given to the discussion of algorithms and potential applications of UAVs in specialized industries¹⁸. The study analyzed communication systems for UAVs based on machine learning (ML) using various algorithms. Only some of the many possible applications of UAVs were considered. A navigation system for UAVs using computer vision and various artificial intelligence technologies was also studied. Various aspects of the application of computational intelligence, including search and rescue operations and surveillance, were discussed¹⁹. A review of the application of intelligent UAV base stations for sharing information about rescue operations, resource allocation, and trajectory design was conducted. Promising rescue strategies based on AI were analyzed.

Researchers are also analyzing computer vision methods based on machine learning algorithms and unmanned aerial vehicle (UAV) platforms for their potential application in the early detection and treatment of agricultural diseases, taking into account factors such as weeds, pests, and environmental conditions²⁰. In addition, the possibility of using UAV systems equipped with artificial intelligence (AI) for traffic management, as well as for monitoring, controlling, and identifying traffic violations is being considered²¹. Most modern review studies focus on a narrow range of applications of UAVs using AI. These works provide only a limited number of examples and do not cover a significant portion of the diversity of AI and machine learning (ML) algorithms. The proposed review aims to assess various uses of UAVs where the application of AI is appropriate, as well as to analyze the various learning algorithms that researchers are currently using.

The study of AI-enabled UAVs presents a fascinating exploration of cutting-edge technologies. This detailed review examines current trends, forecasts a future where UAVs can transform several sectors, and discusses challenges that require solutions. The research analyzes the transformative impact of AI, «green» computing, and UAVs on society, as well as their potential to stimulate innovation and achieve positive outcomes. This systematic review also includes a discussion of potential datasets for each relevant application area of UAVs.

APPLICATION OF ARTIFICIAL INTELLIGENCE IN UAVS FOR TRAFFIC MONITORING

Unmanned aerial vehicles (UAVs) have the ability to observe and determine parameters such as the location, speed, and direction of vehicles, as well as the number of crossings through specific points, such as gates, intersections, or pedestrian crossings. These parameters are

¹⁸ A. Carrio, C. Sampedro, A. Rodriguez-Ramos, and P. Campoy, "A review of deep learning methods and applications for unmanned aerial vehicles," *Journal of Sensors*, vol. 2017, 2017.

¹⁹ Y. Lu, Z. Xue, G.-S. Xia, and L. Zhang, "A survey on vision-based uav navigation," *Geo-spatial information science*, vol. 21, no. 1, pp. 21–32, 2018.

²⁰ A. Bouguettaya, H. Zarzour, A. Kechida, and A. M. Taberkit, "A survey on deep learning-based identification of plant and crop diseases from uav-based aerial images," *Cluster Computing*, vol. 26, no. 2, pp. 1297–1317, 2023.

²¹ S. Srivastava, S. Narayan, and S. Mittal, "A survey of deep learning techniques for vehicle detection from uav images," *Journal of Systems Architecture*, vol. 117, p. 102152, 2021.

typically recorded by a UAV positioned above the observed area. Changes in the values of these parameters can be used to identify specific events. For example, speeding can be recorded when a vehicle's speed exceeds a set limit. Similarly, a traffic jam can be detected if the average speed of several cars falls below a certain threshold. A camera mounted on the UAV, as part of the monitoring system, collects images of the current road situation, using technologies related to route planning. An identification system integrated into the UAV automatically processes these images. The main task of the identification system is to assess traffic congestion. The recognition results are transmitted to the traffic management center, where traffic managers can conduct further analysis based on the data obtained.

The classification system installed on the UAV can be divided into two main parts: one for feature extraction and the other for characteristic recognition. Recorded images are transmitted to the component of the system responsible for extracting high-level information. The results of the final recognition are determined by the element of the system responsible for recognition, and these conclusions are based on the extracted characteristics.

The main architecture of the system component for feature extraction is based on a reconstructed network using convolutional layers. In most cases, the introduction of a residual block reduces the time required for training and also reduces the complexity of the model. Currently, several variations of ResNet networks, such as ResNet-50, ResNet-101, and ResNet-110, are used as trainable layers for the neural network. Recent studies have demonstrated that training a 110-layer ResNet with arbitrary depth provides better results compared to training networks of fixed depth and requires significantly less preparation time.

The YOLO technology, based on neural networks, is a real-time object identification method²². The widespread adoption of this approach is attributed to its high speed and accuracy. YOLO finds application in traffic monitoring tasks, pedestrian recognition, and parking space control²³. During the evolution of the YOLO algorithm, version V3 abandoned the use of Darknet-19 as a base network, switching to Darknet-53. Furthermore, multi-scale object estimation was implemented in V3. It should be noted that spatial pyramid pooling (SPP) in combination with YOLO V3 for traffic sign recognition is used by only a limited number of researchers²⁴.

In traffic monitoring systems, YOLO is applied for counting, detecting, and classifying vehicles, as well as for identifying traffic signs. The YOLOv4-tiny model is used to determine the location of a vehicle. Recently, an enhanced efficiency algorithm, TSR-YOLO, was developed, specifically designed for recognizing traffic signs in the context of traffic monitoring. To improve the accuracy of identifying small traffic signs, a system capable of performing global feature extraction using a multi-component lightweight detection head was created. This approach demonstrates resilience to challenging weather conditions and various

²² R. Chandana and A. Ramachandra, "Real time object detection system with yolo and cnn models: A review," *arXiv preprint arXiv:2208.00773*, 2022.

²³ Q. Xu, R. Lin, H. Yue, H. Huang, Y. Yang, and Z. Yao, "Research on small target detection in driving scenarios based on improved yolo network," *IEEE Access*, vol. 8, pp. 27574–27583, 2020.

²⁴ S.-K. Tai, C. Dewi, R.-C. Chen, Y.-T. Liu, X. Jiang, and H. Yu, "Deep learning for traffic sign recognition based on spatial pyramid pooling with scale analysis," *Applied Sciences*, vol. 10, no. 19, p. 6997, 2020.

types of environments. YOLOv5 (STC-YOLO) is an improved version of YOLO, characterized by increased performance in conditions of smog, snowfall, noise, occlusion, and blur. This version is optimized for monitoring small traffic signs and vehicles²⁵.

In the field of traffic monitoring using artificial intelligence-based unmanned aerial vehicles (UAVs), the principles of «green» computing are being actively implemented. Strategies aimed at achieving this goal include the use of energy-efficient equipment, the integration of renewable energy sources into ground stations, the optimization of artificial intelligence (AI) algorithms to reduce computational load, the simplification of data processing on the device itself, as well as the application of dynamic resource allocation. These methods aim to reduce energy consumption, decrease carbon emissions, and support environmentally sustainable aerial traffic monitoring, combining technological progress with environmental protection.

It should be noted that all systems have certain shortcomings and potential for further development. Despite its potential advantages, traffic monitoring using machine learning faces limitations that are actively being researched. Machine learning algorithms can provide inaccurate results when counting vehicles due to partial correctness [26]. Complex environmental conditions increase the likelihood of monitoring errors in extreme weather conditions. To improve the accuracy and reliability of traffic monitoring, researchers are focused on developing methods aimed at overcoming these limitations.

CONCLUSION

The analysis of unmanned aerial vehicles (UAVs) equipped with artificial intelligence (AI) demonstrates the dynamic and promising development of this technological field. The study examines key trends indicating the deep integration of AI into the functionality of UAVs, which allows for achieving a new level of autonomy, efficiency, and versatility in their application across various sectors of the economy and public life. The review forms a vision of the future in which AI-powered UAVs can significantly transform areas such as environmental monitoring, object detection and identification, reconnaissance, cargo transportation, and emergency management. These technologies can provide a higher degree of precision and efficiency in performing tasks, which, in turn, can lead to improved decision-making and enhanced safety.

Nevertheless, significant obstacles exist on the path to realizing this vision, including regulatory restrictions, ethical considerations, and technical complexities. Regulatory barriers may hinder the implementation of UAVs in civil and commercial spheres, while ethical aspects related to the use of AI require careful consideration to avoid potential negative consequences. Technical complexities, such as the need for reliable communication and data processing systems, can also pose a serious challenge.

Given the parallel development of AI and UAV technologies, overcoming these obstacles will be a necessary condition for fully unlocking the potential of AI-equipped UAVs for the benefit

²⁵ Chu, C. Zhang, M. Yan, H. Zhang, and T. Ge, "Trd-yolo: a real-time, high-performance small traffic sign detection algorithm," *Sensors*, vol. 23, no. 8, p. 3871, 2023.

of society. This requires the combined efforts of researchers, developers, regulators, and the public to create a safe and efficient ecosystem in which UAVs can function at their best.

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