Journal of
Engineering Education
and Practice

Https://journaleep.com
Editor@journaleep.com
ISSN (Print) : 3080-6747
ISSN (Online) : 3080-6755

CURRENT TRENDS AND FUTURE DIRECTIONS IN THE DESIGN, DEVELOPMENT, AND SIMULATION OF NEXT-GENERATION UAV NAVIGATION SYSTEMS: ADVANCING AUTONOMY, PRECISION, AND RELIABILITY

Nida Hafeez [1*], **Nida Arshad**[2]

[1]Department of Computer Science, Bahria University Lahore

[2]Department of Electrical Engineering, Islamia University Bahawalpur, Pakistan

*Corresponding Author E-mail: nidah.bulc@bahria.edu.pk

Article History

Received:
January 10, 2024

Revised:
February 07, 2024

Accepted:
March 20, 2024

Available Online:
June 30, 2024

Abstract

The automatic navigation system represents an essential factor in drone technology while continuously growing important within modern technological applications. Modern navigation systems requiring independent operation have become critical due to the rising importance of drones in multiple industries. The cutting-edge technologies expand drone usages across agricultural, logistics, military along with environmental surveillance sectors and strengthen their combat prowess. The understanding of drone automated navigation development together with current technology status in this dynamic industry serves as key elements for predicting industry directions and driving innovation. This essay presents a comprehensive analysis of drone autonomous navigation progress while treating different industrial applications in detail. The analysis evaluates existing systems to present their current benefits and flaws and recommends ways to improve future versions of these technologies. The paper predicts and investigates future advancements in drone navigation systems as it works to develop and spread their wider utilization. This research serves as a resourceful document for developers and practitioners of drone automated navigation technology while they investigate potential new application fields.

Keywords:

Uav; Automatic Navigation Technology; Application Areas; Future Trends

1. INTRODUCTION

The fast-paced development of science along with technology has made drone systems practical for various fields of operation. The ability of drones to execute autonomous flights without human remote-control stems from drone automated navigation systems. Operation effectiveness grows while labor costs decrease alongside the ability to access dangerous or unreachable areas due to this capability. This technology creates opportunities for drones to perform complex missions which allows them to contribute to environmental monitoring and disaster response and logistics and agricultural tasks. Research aims to deliver extensive information regarding current autonomous navigation systems that operate unmanned aerial vehicles (UAVs). The evaluation identifies problems found in current technologies together with an analysis of their deficient performance domains (A. Copiaco, Y. Himeur, A. Amira,2023). The research investigates future work directions to identify sectors requiring additional innovation that will help address these challenges. An evaluation of the existing body of work for this subject and technological trends follows research perception interpretation throughout this study to provide industrial practitioners and researchers with beneficial information. Transportation drones have advanced rapidly and are widely applied thus generating various essential research concerns. Multiple disciplines present one of the main obstacles in drone research. Three main domains that underpin drones include robotics alongside computer science and remote sensing and aeronautical engineering.

LITERATURE REVIEW

Drone technology advancement relies on establishing the mutual interplay of different professional fields as well as creating efficient connecting methods. Assessing both restrictions and potential of drone systems constitutes an essential area of academic inquiry (Y. Himeur, M. Elnour, F. Fadli, N. Meskin,2022). Drone applications provide enhanced efficiency while delivering better financial returns and enabling better data collection however they create new issues because of privacy problems and security challenges and regulatory requirements that drone operators must follow. Drones will successfully and ethically integrate into society through the research and findings of solution methods for these issues. Researchers in drone development recognize the importance of solving the existing research problems. You will find a comprehensive guide in this manual which successfully guides you through the extensive domain of drone research. We aim to curate a comprehensive resource tool that serves academics and researchers of this dynamic field through consolidation of latest findings across multiple disciplines (M. Elnour, F. Fadli, Y. Himeur, I. Petri,2022). The development of drone technology and its complete application across various fields becomes achievable through idea exchange between all stakeholders.

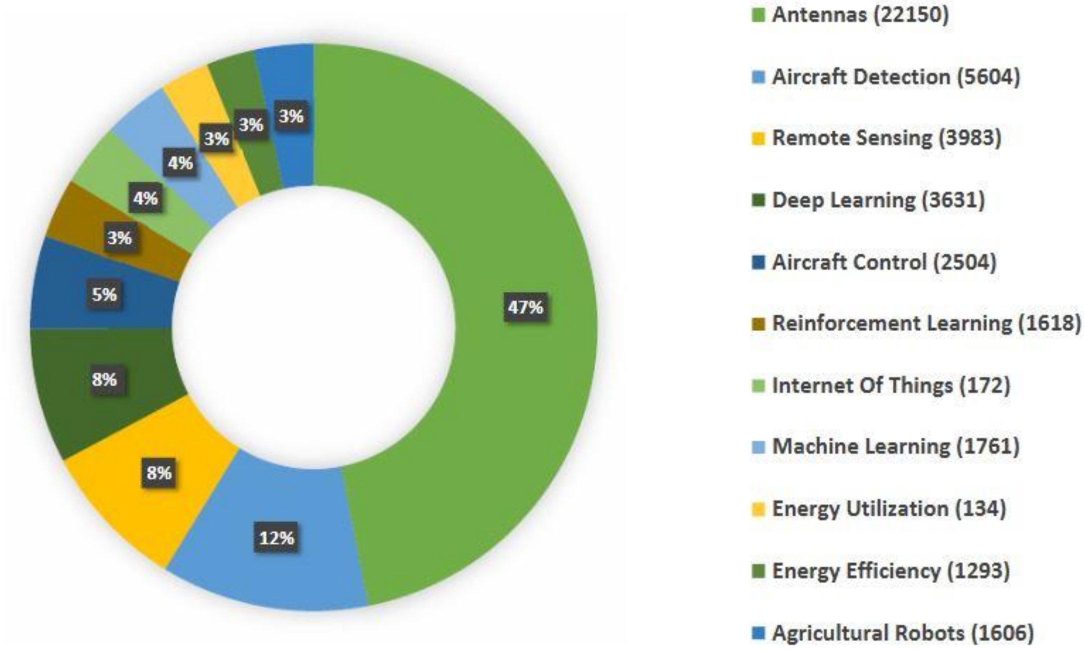


Fig. 1: Chart of last three years research directions in UAV filed

TABLE I: Charting the Course of UAV Research: Exploring Emerging Directions and Inter-Interaction

Research Direction	Antennas	Aircraft Detection	Remote Sensing	AI	IoT	Aircraft Control
Antennas	2,215	3,749	2,176	3.38	1,092	1,707
Aircraft Detection	3,749	5,604	0,462	0.777	1,343	0,758
Remote Sensing	2,176	0,462	3,983	0.707	0,063	0
AI	4,231	2,203	0,777	5,789	0,512	0.294
IoT	1,092	0,133	0,063	0.365	1,720	0.043
Aircraft Control	1,707	1,152	0	0.311	0,043	2,504

UAV Applications

The fast-shipping solution enables Meituan alongside other businesses to deliver packages using drone transportation in urban areas because of instant delivery requirements. Effective autonomous navigation skills are essential for drones to deliver accurate and timely services in complex urban delivery tasks (H. Kheddar, Y. Himeur, S. Al-Maadeed,2023). The rapid growth of e-commerce allows express logistics to implement drones for distribution services across the sector. The implementation of autonomous navigation allows drones to perform independent warehouse-to-destination flights thus reducing labor expenses and boosting operational efficiency.

Precision Agriculture

Farming operations benefit primarily from drone usage through exact monitoring of their land fields. By integrating automated navigation systems drones can perform regular agricultural assessments through multispectral sensors and high-definition cameras which track crop development together with soil water content (S. Atalla, S. Tarapiah,2023). Farming operations become more productive through precise water management as well as pest and illness control which leads to greater efficiency in agricultural production by using the data gathered from drones. Through drone technology farmers can achieve pesticide spraying and seeding operations and other operational tasks in addition to conducting monitoring duties. Autonomous navigation systems equipped on drones enable uniform seed planting and spraying operations along predetermined flight paths thereby raising production levels at reduced labor expense and material outlays (T. M. Al-Hasan, A. S. Shibeika,2022).

Military Applications

Drones serve as real-time data collection devices which provide video feed for combat reconnaissance operations and border surveillance objectives. Thanks to automatic navigation technologies drones perform precise attack operations while also detecting targets with high accuracy (J. Khalife and Z. M. Kassas,2022). Customer personnel gain networked communication through drones that steer themselves towards intended field locations under demanding conditions. Drone systems that utilize automatic navigation capabilities function as wildfire surveillance platforms while providing fire services with direction. The swift detection of disaster-affected people or areas by drones leads to improved rescue performance.

Technical Challenges and Future Trends

The drone sensors must accurately sense and understand surrounding environments while avoiding obstacles to maintain constant flight safety in complicated and dynamic areas such as urban canyon and woodland zones. The drone perception system needs ideal real-time functionality and precision for dynamic environment adaptability to handle swiftly moving targets and changing terrain conditions (O. Elharrouss, S. Al-Maadeed,2021). Vehicle positioning problems can arise when GPS signals experience restrictions inside bridges as well as locations with high signal interference or areas where signals drop altogether. The reflecting nature of surfaces including urban buildings in cities leads GPS signals to become erroneous.

Sensor limitations.

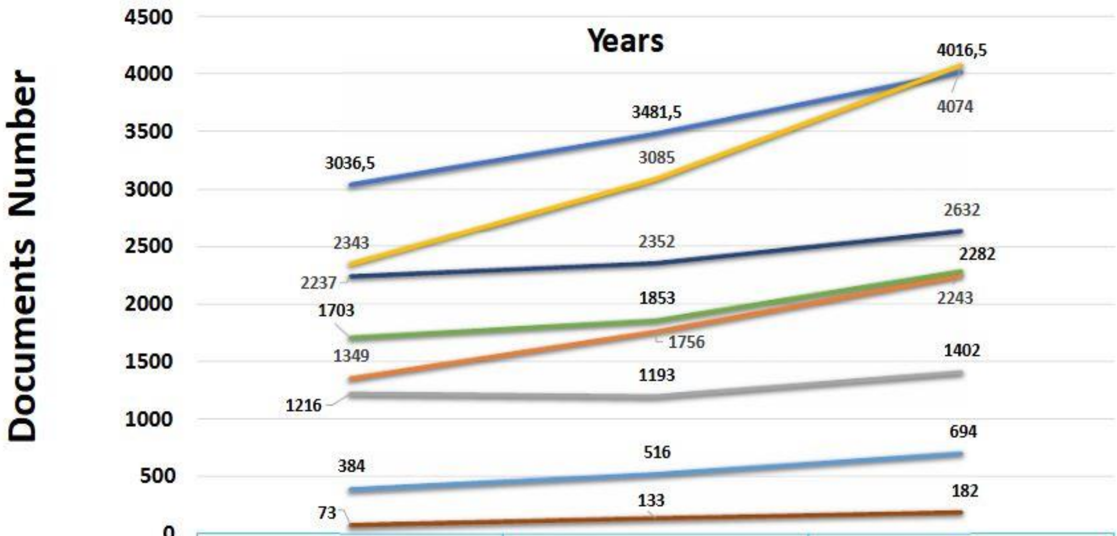
Existing sensors affect navigation performance because of changes in weather conditions and illumination problems and additional factors. Operating difficulties stem from the fact that various sensors create unreliable navigational data when data fusion occurs. The onboard computing needs increase in parallel with sensor count growth and implementation of advanced navigation algorithm systems. UAVs need to analyze and decide on flight maneuvers in real-time because this process taxes the efficiency of their algorithms significantly (W. Liu, T. Zhang, S. Huang, and K. Li,2022).

Human-UAV Interaction

Human-drone interaction represents an emerging academic field which investigates drone-human interactions throughout research exploration and educational teaching and recreational entertainment contexts (F. Ahmed, J. Mohanta, A. Keshari,2022). The technology possesses the power to entirely revamp multiple business sectors. The process of inventing new technology and interfaces to facilitate natural drone interaction by humans is termed human-drone interaction. Several human-machine interface systems along with gestural controls and virtual augmented reality form the base of these technologies (S. N. Ghazbi, Y. Aghli, M. Alimohammadi,2016). Real-time human control reactions present a fundamental challenge for drones to maintain both stability and responsive operation in human-drone interaction systems. The advancement of human-machine interface systems coupled with complex control systems through sensor integration remains essential for human-drone interaction. The challenge in human-drone interaction emerges from drone safety needs and dependability standards especially during instances of limited human control (M. S. Ismail, A. Ahmad,2022). Researchers (G. Macrina, L. D. P. Pugliese, F. Guerriero, and G. Laporte,2020) have developed several approaches which utilize body language and gestures and natural language to control drones. Intelligent human-drone systems based on machine learning and related techniques operate drones and detect gestures efficiently. Various research articles presented new drone operational systems which enable users to control drones through their physical movements. The challenges involving human operators and their interface systems alongside training requirements and workload alongside technological approaches are all subjects of study alongside other human issues within drone research (R. Zhang, J. Zhang, and H. Yu,2018). The choices drone operators make particularly in search and rescue duties need additional examination because they represent an essential domain of study for human-drone interaction. The development of adaptable and intuitive human-drone interface systems becomes vital because they need application to diverse fields. Two survey articles review the state of the art in human-drone interaction by describing control interfaces and gesture recognition methods and autonomous operation techniques in addition to public safety and transportation and entertainment sections. The written works investigate both human factors and the user challenges which emerge when deploying drones along with interface complications and operational workload and required training. The development of research regarding drone controller decision-making remains active particularly for search and rescue missions (H. Liang, S.-C. Lee, W. Bae,2022). The development of usable and efficient human-drone interface platforms stands vital because they need to apply across multiple professional domains and application areas.

Integration of AI

The use of artificial intelligence algorithms creates a revolution in drone operational systems. Autonomous flying and decision-making abilities gain improvement through drone integration of these advanced algorithms thus ensuring operational safety and effectiveness. Advanced sensor technology represents one method drones use artificial intelligence and machine learning algorithms concurrently. The AI system receives live data through drones which deploy lidar and computer vision systems (B. Fan, Y. Li, R. Zhang,2020). Drones use these capabilities to decide directions based on their environmental adjustments. The ability of drones to detect objects through computer vision enhances safety operations by lowering the odds of accidents. Through lidar input drones receive exact environmental information about sizes and speeds and distances of surrounding objects that enable better navigating through challenging terrain conditions. Artificial intelligence acts as a tool for enhancing drone flight route optimization. Through machine learning algorithms drones extract knowledge from previous flight data to enhance operational efficiency by modifying their routes for reduced energy consumption (J. Pasha, Z. Elmi, S. Purkayastha,2022). The evaluation of environmental factors such as temperature and wind speed combined with other variables can lead to this achievement.



	2020	2021	2022
Antenna x 0.5	3036,5	3481,5	4016,5
Aircraft Detection	1349	1756	2243
Remote Sensing	1216	1193	1402
AI	2343	3085	4074
IoT	384	516	694
Energy-Efficient	1703	1853	2282
Control	2237	2352	2632
Swarm Behavior	73	133	182

UAV Research Direction growth trajectories last three years view

2. METHODOLOGY

Pushing the Boundaries of UAV Control: Exploring Advanced Techniques

Several complex control approaches complement PID control strategies within UAV control domains with the goal to improve overall stability and functionality. Sophisticated UAV systems operate optimally with these methods applied to their control systems. Model predictive control (MPC) stands as one of the leading sophisticated control approaches applied to UAV control systems. The UAV's future movement patterns become predictable through mathematical simulations controlled by MPC. The control system generates optimized inputs using expectation-based calculations to maximize performance criteria that might include stability, power consumption and trajectory tracking precision. The future path of the UAV serves as a key factor in making MPC superior to basic control approaches (J. Mészarós,2021). The control method known as adaptive control stands as a crucial advanced control technique. Adaptive control intervenes during runtime to adapt both environmental influences and UAV dynamics. The control system becomes steadily better at performance under all circumstances due to this ability. The innovative control methods enable engineers to construct dependable and efficient controller systems for UAVs. SMC stands as one of the advanced control systems which frequently enables UAV control. SMC functions effectively to handle both uncertain system conditions and disruptive disturbances because it represents a nonlinear control approach (E. Ebeid, M. Skriver,2018). SMC promotes reliability through its ability to keep UAV states inside the gliding mode that represents the target operational area. Technical control techniques which incorporate both machine learning algorithms and artificial intelligence include neural network-based control and REINFORCEMENT LEARNING and DISTRIBUTED REINFORCEMENT LEARNING systems. Through these methods drones acquire experience which leads to progressive development in their operational control systems. In conclusion, the area of drone control employs a number of sophisticated control strategies (L. O. Rojas-Perez and J. Martínez-Carranza,2023). The advanced control techniques show higher stability and better performance than traditional control systems which make them perfect for drone systems with their complex and evolving requirements. Cooperative control functions as a method which allows numerous drones to unite their efforts toward shared mission objectives. Cooperative control provides substantial advantages to drones performing sophisticated joint operations with multiple drones including surveillance and search and rescue tasks.

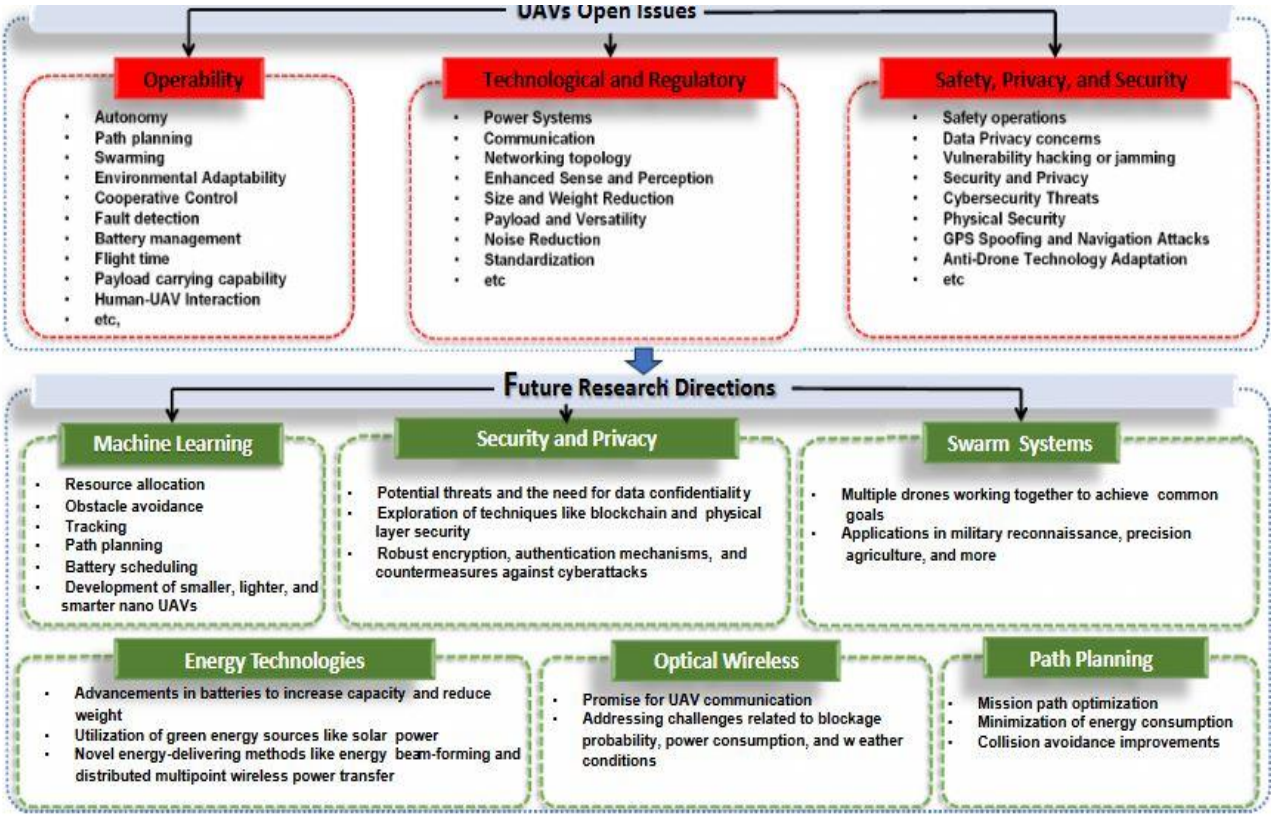
FINDINGS

The Hardware Architecture of UAVs

Each unmanned aerial vehicle (UAV) consists of hardware components such as sensors along with actuators and batteries and payloads and flight computers and controllers as well as structural elements. The UAV flight path with its stability functions under control of the flight computer and controller. Actuators operate as the controlling mechanism of movement for UAVs yet sensors deliver data about navigation systems along with altitude levels and orientation conditions. The UAV operates with batteries which match application requirements (A. Aabid, B. Parveez, N. Parveen,2022). The system comprises cameras together with sensors along with application-specific devices as payloads and provides interfaces for remote control and data exchange. The UAV achieves optimal performance in every application through its supporting structural components consisting of arms and frames. The way UAVs operate in different situations strongly depends on how hardware design affects their performance capabilities. Various researchers scrutinized standard UAV hardware system designs in their studies (A. Aabid, B. Parveez, N. Parveen,2022). Researchers have proposed various multi-level UAV design approaches in published documents. Scientists have intensively analyzed all features of modern UAV technology. The text covers several topics related to micro UAVs and demonstrates how to achieve real-time UAV control through software elements. The hardware configurations of UAVs remain similar regardless of size and these devices get modifications based on their practical usage (M. Galimov, R. Fedorenko,2020).

The Software Architecture for UAVs

The drone requires this functionality to achieve success alongside operational efficiency. The layers which create drone architecture as an autonomous system include firmware, operating system and middleware, and application components. The hardware management functions of the drone including flight controller and sensor operation are encoded within its firmware programming layer (R. Amin, L. Aijun, and S. Shamshirband,2016). A required software connection between firmware and upper-level programs exists through the operating system layer. Data communication software that helps different system elements share information is placed under the middleware layer. Data processing protocols together with transmission and storage software libraries are integrated within this layer. Software applications dedicated to achieving drone system functions belong in the application layer (M. Campion, P. Ranganathan, and S. Faruque,2018). The application layer in a UAV system hosts software solutions for payload management together with data analysis capabilities alongside navigation functions and flight planning operations.



UAVs Open Issues and Future Research Directions

3. CONCLUSION

UAVs get comprehensive analysis throughout this paper to determine research directions and open development pathways and aircraft control systems together with hardware and software architecture designs and practical applications as well as key field developments from past three years. This report establishes UAV research patterns from the past few years while explaining research connections between various lines by using Scopus database analysis with expert involvement. Developing UAVs requires integration of modern technologies such as artificial intelligence and environmental monitoring alongside Internet of Things and deformable capabilities and autonomous flight mechanisms, perception and detection methods, miniature systems, aircraft sensors, swarming systems and advanced communication protocols. This article examines UAV control boundaries alongside relevant control algorithm selection and it presents knowledge of classical and contemporary and intelligent and adaptive control approaches. The publication contains descriptions of UAVs' essential hardware and software structures. Each UAV comprises software and hardware elements that include flight processors and controllers with sensors, actuators as well as batteries, payloads and communication interfaces and structural elements. This work presents an analysis of main open-source UAV hardware and software initiatives while discussing multiple aerial vehicles uses together with their main implementation barriers. The article serves as a valuable research resource for researchers and practitioners and developers who seek to understand the modern trends in UAV development work. The manuscript delivers a detailed analysis of UAV development aspects while presenting potential open development axes and evaluating aircraft control development and describing various applications alongside essential problems in the field. The study provides essential knowledge to the UAV scientific domain while establishing foundational direction for continued investigation into this active field of study.

4. REFERENCES

Copiaco, Y. Himeur, A. Amira, W. Mansoor, F. Fadli, S. Atalla, and S. S. Sohail, “An innovative deep anomaly detection of building energy consumption using energy time-series images,” Engineering Applications of Artificial Intelligence, vol. 119, p. 105775, 2023.

Aabid, B. Parveez, N. Parveen, S. A. Khan, J. Zayan, and O. Shabbir, “Reviews on design and development of unmanned aerial vehicle (drone) for different applications,” J. Mech. Eng. Res. Dev, vol. 45, no. 2, pp. 53–69, 2022.

Fan, Y. Li, R. Zhang, and Q. Fu, “Review on the technological development and application of uav systems,” Chinese Journal of Electronics, vol. 29, no. 2, pp. 199–207, 2020.

E. Ebeid, M. Skriver, K. H. Terkildsen, K. Jensen, and U. P. Schultz, “A survey of open-source uav flight controllers and flight simulators,” Microprocessors and Microsystems, vol. 61, pp. 11–20, 2018.

F. Ahmed, J. Mohanta, A. Keshari, and P. S. Yadav, “Recent advances in unmanned aerial vehicles: A review,” Arabian Journal for Science and Engineering, vol. 47, no. 7, pp. 7963–7984, 2022.

G. Macrina, L. D. P. Pugliese, F. Guerriero, and G. Laporte, “Drone-aided routing: A literature review,” Transportation Research Part C: Emerging Technologies, vol. 120, p. 102762, 2020.

H. Kheddar, Y. Himeur, S. Al-Maadeed, A. Amira, and F. Bensaali, “Deep transfer learning for automatic speech recognition: Towards better generalization,” arXiv preprint arXiv:2304.14535, 2023.

H. Nawaz, H. M. Ali, and A. A. Laghari, “Uav communication networks issues: a review,” Archives of Computational Methods in Engineering, vol. 28, pp. 1349–1369, 2021.

H. Liang, S.-C. Lee, W. Bae, J. Kim, and S. Seo, “Towards UAV’s in construction: Advancements, challenges, and future directions for monitoring and inspection,” Drones, vol. 7, no. 3, p. 202, 2023. P. Pina and G. Vieira, “Uavs for science in antarctica,” Remote Sensing, vol. 14, no. 7, p. 1610, 2022.

J. Khalife and Z. M. Kassas, “On the achievability of submeter accurate UAV navigation with cellular signals exploiting loose network synchronization,” IEEE Transactions on Aerospace and Electronic Systems, vol. 58, no. 5, pp. 4261–4278, 2022.

J. Pasha, Z. Elmi, S. Purkayastha, A. M. Fathollahi-Fard, Y.-E. Ge, Y.-Y. Lau, and M. A. Dulebenets, “The drone scheduling problem: A systematic state-of-the-art review,” IEEE Transactions on Intelligent Transportation Systems, 2022.

J. Mészarós, “Aerial surveying uav based on open-source hardware and software,” The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 38, pp. 155–159, 2012.

L. O. Rojas-Perez and J. Martínez-Carranza, “On-board processing for autonomous drone racing: an overview,” Integration, vol. 80, pp. 46–59, 202

M. Elnour, F. Fadli, Y. Himeur, I. Petri, Y. Rezgui, N. Meskin, and A. M. Ahmad, "Performance and energy optimization of building automation and management systems: Towards smart sustainable carbon-neutral sports facilities," Renewable and Sustainable Energy Reviews, vol. 162, p. 112401, 2022.

M. S. Ismail, A. Ahmad, S. Ismail, and N. M. M. Yusop, "A review on unmanned aerial vehicle (uav) threats assessments," in AIP Conference Proceedings, vol. 2617, no. 1. AIP Publishing LLC, 2022, p. 050007.

M. Galimov, R. Fedorenko, and A. Klimchik, "Uav positioning mechanisms in landing stations: Classification and engineering design review," Sensors, vol. 20, no. 13, p. 3648, 2020.

M. Campion, P. Ranganathan, and S. Faruque, "Uav swarm communication and control architectures: a review," Journal of Unmanned Vehicle Systems, vol. 7, no. 2, pp. 93–106, 2018.

O. Elharrouss, S. Al-Maadeed, N. Subramanian, N. Ottakath, N. Almaadeed, and Y. Himeur, "Panoptic segmentation: a review," arXiv preprint arXiv:2111.10250, 2021.

Q. T. Do, D. S. Lakew, A. T. Tran, D. T. Hua, and S. Cho, "A re- view on recent approaches in mmwave uav-aided communication networks and open issues," in 2023 International Conference on Information Networking (ICOIN). IEEE, 2023, pp. 728–731.

R. Zhang, J. Zhang, and H. Yu, "Review of modeling and control in uav autonomous maneuvering flight," in 2018 IEEE International Conference on Mechatronics and Automation (ICMA). IEEE, 2018, pp. 1920–1925.

R. Amin, L. Aijun, and S. Shamshirband, "A review of quadrotor uav: control methodologies and performance evaluation," International Journal of Automation and Control, vol. 10, no. 2, pp. 87–103, 2016.

S. N. Ghazbi, Y. Aghli, M. Alimohammadi, and A. A. Akbari, "Quadrotors unmanned aerial vehicles: A review," International journal on smart sensing and Intelligent Systems, vol. 9, no. 1, pp. 309–333, 2016.

S. Atalla, S. Tarapiah, A. Gawanmeh, M. Daradkeh, H. Mukhtar, Y. Himeur, W. Mansoor, K. F. B. Hashim, and M. Daadoo, "Iot-enabled precision agriculture: Developing an ecosystem for optimized crop management," Information, vol. 14, no. 4, p. 205, 2023.

T. M. Al-Hasan, A. S. Shibeika, U. Attique, F. Bensaali, and Y. Himeur, "Smart speed camera based on automatic number plate recognition for residential compounds and institutions inside qatar," in 2022 5th International Conference on Signal Processing and Information Security (ICSPIS). IEEE, 2022, pp. 42–45.

W. Liu, T. Zhang, S. Huang, and K. Li, "A hybrid optimization framework for uav reconnaissance mission planning," Computers & Industrial Engineering, vol. 173, p. 108653, 2022.

Y. Himeur, M. Elnour, F. Fadli, N. Meskin, I. Petri, Y. Rezgui, F. Bensaali, and A. Amira, "Next-generation energy systems for sustainable smart cities: Roles of transfer learning," Sustainable Cities and Society, p. 104059, 2022.