electronics

Editorial

Control and Applications of Intelligent Unmanned Aerial Vehicles

Yunda Yan [1,*], Dewei Yi [2], Hao Lu [3] and Lan Gao [4]

1 Department of Computer Science, University College London, London WC1E 6BT, UK
2 Department of Computing Science, University of Aberdeen, Aberdeen AB24 3FX, UK; dewei.yi@abdn.ac.uk
3 School of Automation and Electrical Engineering, University of Science and Technology Beijing, Beijing 100083, China; haolu@ustb.edu.cn
4 School of Information Science and Technology, Hangzhou Normal University, Hangzhou 311121, China; langaouc@gmail.com
* Correspondence: yunda.yan@ucl.ac.uk

Received: 6 January 2025
Accepted: 16 January 2025
Published: 19 January 2025

Citation: Yan, Y.; Yi, D.; Lu, H.; Gao, L. Control and Applications of Intelligent Unmanned Aerial Vehicles. *Electronics* **2025**, *14*, 375. https://doi.org/10.3390/electronics14020375

1. Introduction

Embedding intelligence into the control design of unmanned aerial vehicles (UAVs) has become increasingly critical as these systems are deployed in complex and uncertain environments, often requiring them to adapt dynamically to unpredictable events. Intelligent control systems not only enhance operational efficiency, but also ensure safety and reliability when executing challenging missions. In this context, optimization, and machine learning techniques are emerging as transformative tools, fuelled by the rapid development of artificial intelligence and computational technologies. These approaches provide new pathways for designing UAV systems capable of handling uncertainties, optimizing performance, and learning from data to improve over time.

UAVs have demonstrated remarkable success across a wide range of interdisciplinary applications, including remote sensing, precision agriculture, environmental monitoring, disaster management, and offshore asset inspection. In remote sensing, UAVs provide high-resolution, real-time data collection for mapping and analysis. In precision agriculture, they enable site-specific management through crop health monitoring, irrigation optimization, and yield prediction. Similarly, their role in inspecting offshore assets, such as wind turbines and oil rigs, has become indispensable, offering safer and more cost-effective alternatives to traditional methods. These examples highlight the vast potential of UAVs to transform industries and address critical global challenges.

However, as UAV missions grow in complexity, new challenges emerge, especially in areas such as trajectory and path planning, control in adverse environments, and autonomous decision-making under constraints. For example, strong winds, turbulence, and rapidly changing conditions can jeopardize the safety and success of UAV operations. Machine learning techniques, coupled with advanced optimization methods, offer innovative solutions to these problems by enabling UAVs to predict and adapt to environmental changes, optimize resource allocation, and ensure robust performance.

This Special Issue aims to bring together a diverse and articulate collection of research papers that advance the understanding and application of intelligent control systems for UAVs. The topics of interest include, but are not limited to:

- Trajectory and path planning: innovations in spatial-temporal mission planning, including algorithms that account for dynamic obstacles, environmental uncertainties, and multi-agent coordination.

- Advanced control design: techniques for maintaining stability and performance in adverse environments, such as high winds, sudden temperature changes, or other challenging operational conditions.
- Machine learning integration: the use of reinforcement learning, neural networks, and data-driven methods for adaptive control, fault detection, and predictive maintenance.
- Real-world applications: case studies demonstrating the implementation of intelligent UAV systems in various fields, such as agriculture, environmental science, and industrial inspection.
- Modern guidance systems: the design and deployment of intelligent guidance systems that combine sensing, decision-making, and control to enhance UAV autonomy and efficiency.

The timing of this Special Issue is particularly relevant, as recent years have witnessed significant progress in both theoretical and experimental aspects of UAV technology. Pioneering work in areas such as machine learning-driven optimization, robust control under uncertainty, and intelligent guidance systems, has laid the groundwork for addressing many long-standing challenges in UAV development.

By showcasing cutting-edge research and practical applications, this Special Issue seeks to inspire further advancements in the field of intelligent UAVs. The goal is to bridge the gap between theory and practice, fostering collaborations across disciplines to unlock the full potential of UAVs in addressing real-world problems.

2. Review of Published Papers

UAV-assisted mobile edge computing (MEC) networks are gaining prominence for air–ground communications, addressing the need for extensive coverage and computational support. The first contribution (Wang et al.) proposes an energy-efficient scheme for non-orthogonal multiple access (NOMA)-based UAV-assisted MEC systems, tackling energy constraints and massive mobile terminal (MT) access. By jointly optimizing transmission power, computation resources, and UAV trajectory scheduling, the authors minimize system-weighted energy consumption using an iterative successive convex approximation (SCA) algorithm. Simulation results demonstrate significant energy savings and highlight the trade-off between energy and delay. This work provides a foundation for future advancements in hybrid access strategies and user scheduling mechanisms.

The accurate and rapid prediction of longitudinally available overloads under actuator faults is essential for fault-tolerant control and trajectory planning in commercial subsonic aircraft. The second contribution (Krichen) proposes a novel multi-model approach that integrates an analytical model for non-fault conditions with deep learning networks to predict overload variations under actuator faults. Combining the multi-layer perception (MLP), categorical boosting (CatBoost), and light gradient boosting machine (LightGBM) networks, the method achieves high accuracy, with a maximum relative error below 5%, and delivers predictions within 500 ms. The study demonstrates that integrating multiple machine learning models significantly reduces prediction error, and improves speed compared to individual networks. These advancements facilitate precise real-time evaluations of longitudinal manoeuvring capabilities, supporting reliable trajectory planning. While the approach shows promise, limitations such as high memory demands and a focus on a single aircraft type highlight areas for future work, including optimizing the network architecture and validating the model on diverse aircraft.

Ensuring safe and efficient drone operations in critical zones is essential for various applications, from logistics to surveillance. The third contribution (Bechlioulis) presents a novel strategy for controlling drone access to such zones using timed automata and

UPPAAL, a powerful tool for modelling and verifying real-time systems. The system includes six drones, a controller, and a buffer, all modelled as timed automata. The proposed approach ensures that only one drone can enter the critical zone at a time, preventing collisions and ensuring orderly access. Timed automata provide a formal framework to model time-sensitive systems and analyse key properties such as safety, liveness, and deadlock prevention. The strategy is verified through UPPAAL simulations, demonstrating its effectiveness in managing drone access while maintaining system safety and reliability. However, the complexity of modelling larger systems with timed automata presents challenges, particularly as the number of components increases. The results underscore the capability of timed automata and UPPAAL to provide rigorous, formal analysis for drone access control, contributing to the development of robust and safe strategies for managing drone operations in dynamic environments.

The forth contribution (Bechlioulis) addresses the containment control problem for multi-agent systems, focusing on developing a distributed control strategy to guide a subgroup of followers within the convex hull formed by autonomous leaders. The proposed solution comprises two key components: a cyber layer for achieving consensus on a reference trajectory that converges exponentially within the leaders' convex hull, and a physical layer for ensuring each agent tracks the trajectory while avoiding collisions with other agents. The main contributions of this work lie in the robustness of the control framework in both trajectory estimation and tracking, as well as the guaranteed collision avoidance, even in the presence of dynamic leaders and bounded unstructured disturbances. A simulation study with a multi-agent system composed of five followers and four leaders demonstrates the effectiveness of the proposed scheme, validating its robustness against external disturbances and dynamic leader motion. Furthermore, the comparison with existing methods highlights the advantages of the proposed approach in maintaining system stability and efficiency. This research provides a reliable and robust framework for distributed containment control in multi-agent systems, offering a strong solution for real-world applications with dynamic environments and uncertainties.

Autonomous UAVs hold great promise for reducing human involvement in hazardous tasks, such as urban search and rescue (USAR) missions, especially in navigating complex environments like damaged buildings. The fifth contribution (Surojaya et al.) focuses on developing a deep learning model for real-time detection of building openings, a critical task for UAVs transitioning from outdoor to indoor environments. The study introduces a novel dataset of damaged building openings, including image and mask annotations, and compares the performance of single-task and multi-task learning-based detectors. The detector architecture is built on YOLOv5, with performance evaluated across various versions (small, medium, and large). Additionally, a multi-task learning (MTL) model is developed by augmenting the YOLOv5 framework with a segmentation branch, allowing for joint optimization of detection and segmentation tasks. The results show that the MTL-based YOLOv5 outperforms the single-task version, achieving a significant increase in mean average precision (mAP) by 0.167, with an inference speed of 73 frames per second. This work demonstrates the potential of multi-task learning to enhance UAV navigation capabilities in search-and-rescue missions, contributing to safer and more efficient disaster response operations.

Coastal environments, essential from both natural and economic perspectives, are undergoing continuous changes due to climate change, human activities, and natural risks. Remote sensing techniques, particularly from UAV and satellite platforms, offer significant potential for monitoring these areas. The sixth contribution (Figliomeni et al.) focuses on evaluating the accuracy of coastline extraction using multiple datasets, including UAV-RGB imagery and satellite data from Landsat-9 and Sentinel-2. The extraction method involves the application of the normalized difference water index (NDWI) on satellite images, followed by maximum likelihood classification and automatic vectorization. The results are compared with a coastline obtained from a field survey using a global navigation satellite system (GNSS). The findings demonstrate that both the UAV and Sentinel-2 data meet the international hydrographic organization's (IHO) S-44 requirements, with total horizontal uncertainty (THU) of 5 m and a confidence level of 95%. In contrast, Landsat-9 data achieves a THU of 10 m, placing it in a lower accuracy category. This work highlights the effectiveness of remote sensing techniques in accurately monitoring coastal boundaries, contributing to improved environmental management and risk assessment.

The construction industry is increasingly adopting innovative technologies to improve efficiency, reduce costs, and enhance safety. UAVs have emerged as a key tool in this transformation, particularly in data collection and site management. The seventh contribution (Kim et al.) presents a novel approach to automating the path generation of rollers—essential equipment for road construction and large-scale infrastructure projects—using UAVs. The proposed solution leverages UAVs equipped with computer vision technology to capture high-resolution topographical data of construction sites. These data are then processed through a custom algorithm developed by the authors to automatically generate optimized roller paths, streamlining the process and improving efficiency. This work highlights the potential of UAVs to revolutionize construction workflows, offering a more automated and cost-effective solution for path generation in infrastructure projects.

The eighth contribution (Xu et al.) presents an improved potential rapidly exploring random tree star (P-RRT*) algorithm for UAV path planning, addressing the slow convergence and large random sampling issues of the standard P-RRT* algorithm. The proposed enhancements include using the artificial potential field (APF) direction for greedy expansion, rejecting high-cost nodes and sampling points based on heuristic cost, and pruning redundant nodes to improve search efficiency and convergence speed. Simulation results show that the improved P-RRT* algorithm significantly reduces path cost, inflection points, and convergence time, offering an optimized solution for UAV path planning in dynamic environments.

Safe and accurate landing is a critical challenge for UAVs, especially in adverse conditions like strong, rapidly changing winds at coastal sites. Traditional landing algorithms often fail to handle such disturbances effectively. The ninth contribution (Ge et al.) proposes a vision-based autonomous landing strategy for UAVs landing on a multi-level platform mounted on an Unmanned Ground Vehicle (UGV). The strategy enables reliable visual detection even in the presence of strong gusts, ensuring robust landing accuracy despite complex ground effects. Experimental flight tests conducted in farm fields validate the effectiveness and robustness of the proposed method under real-world conditions.

The tenth contribution (Song et al.) addresses the challenges of air defence against large-scale enemy aircraft attacks by proposing a plan generation algorithm for rapid interception. The key contribution is the modification of the standard A* algorithm, integrated with optimization techniques tailored for air-defence missions. The algorithm models the enemy's attack and defence platform, constructs kinetic equations and interception efficiency functions, and establishes interception criteria. A mixed optimal function is developed to define system objectives. The modified A* algorithm, known for its fast convergence, is then used to quickly generate optimal interception plans. Numerical simulations validate the proposed method's effectiveness.

The eleventh contribution (Bai et al.) presents a lightweight multi-scale, multi-branch hybrid convolutional network aimed at improving small-sample hyperspectral image (HSI) classification. The proposed network addresses the challenge of underutilizing spatialspectral features in HSI data by introducing two innovative modules: the pruning multi-scale multi-branch block (PMSMBB) and the 3D-PMSMBB. These modules incorporate multi-branch convolutions of different scales to enhance feature extraction and pruning to reduce model complexity. Tested on three datasets (Indian Pines, Pavia University, and Salinas), the proposed PMSMBN outperforms other advanced models, achieving exceptional classification accuracy with as little as 1% training data. For instance, the method achieved 99.70% accuracy on the Salinas dataset.

The twelfth contribution (Jung et al.) proposes an extremum-seeking-based radio signal strength optimization (ES-RSSO) algorithm to ensure safe and energy-efficient autonomous operations of UAVs and ground control stations (GCS). The algorithm optimizes UAV landing by utilizing radio communication signals to find optimal positions, maintaining sufficient received signal strength indication (RSSI) capacity in obstacle-rich environments. Simulation results demonstrate significant improvements in link capacity, with a 2.37% decrease in mean, 62.08% improvement in variance, and 3.72% decrease in integration strength. The proposed approach shows how minor UAV repositioning can enhance communication links, ensuring robust autonomous operations.

The thirteenth contribution (Specht et al.) presents the 4DBatMap system, an innovative approach for dimensioning and predicting changes in coastal zone topography using UAVs and unmanned surface vehicles (USVs). The system consists of four modules: data acquisition, multi-sensor geospatial data fusion, prediction of topographic changes, and imaging these changes over time. UAVs equipped with GNSS/INS, LiDAR, and photogrammetric cameras, alongside USVs with GNSS RTK receivers and MultiBeam EchoSounders, will collect detailed bathymetric and photogrammetric measurements. The integrated data will enable the creation of accurate 4D bathymetric charts to visualize topographic changes, offering valuable insights for coastal management.

Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions

1. Wang, S.; Luo, Z. An Energy-Efficient Scheme Design for NOMA-Based UAV-Assisted MEC Systems. *Electronics* **2024**, *13*, 4240. https://doi.org/10.3390/electronics13214240.
2. Shan, S.; Cheng, Y.; Jiang, B.; Xu, C.; Guo, K.; Lin, X. A Multi-Model Architecture Based on Deep Learning for Longitudinal Available Overload Prediction of Commercial Subsonic Aircraft with Actuator Faults. *Electronics* **2024**, *13*, 3723. https://doi.org/10.3390/electronics13183723.
3. Krichen, M. Timed Automata-Based Strategy for Controlling Drone Access to Critical Zones: A UPPAAL Modeling Approach. *Electronics* **2024**, *13*, 2609. https://doi.org/10.3390/electronics13132609.
4. Bechlioulis, C.P. Robust Distributed Containment Control with Adaptive Performance and Collision Avoidance for Multi-Agent Systems. *Electronics* **2024**, *13*, 1439. https://doi.org/10.3390/electronics13081439.
5. Surojaya, A.; Zhang, N.; Bergado, J.R.; Nex, F. Towards Fully Autonomous UAV: Damaged Building-Opening Detection for Outdoor-Indoor Transition in Urban Search and Rescue. *Electronics* **2024**, *13*, 558. https://doi.org/10.3390/electronics13030558.
6. Figliomeni, F.G.; Specht, M.; Parente, C.; Specht, C.; Stateczny, A. Modeling and Accuracy Assessment of Determining the Coastline Course Using Geodetic, Photogrammetric and Satellite Measurement Methods: Case Study in Gdynia Beach in Poland. *Electronics* **2024**, *13*, 412. https://doi.org/10.3390/electronics13020412.
7. Kim, H.J.; Kim, J.Y.; Kim, J.W.; Kim, S.K.; Na, W.S. Unmanned Aerial Vehicle-Based Automated Path Generation of Rollers for Smart Construction. *Electronics* **2024**, *13*, 138. https://doi.org/10.3390/electronics13010138.
8. Xu, X.; Zhang, F.; Zhao, Y. Unmanned Aerial Vehicle Path-Planning Method Based on Improved P-RRT* Algorithm. *Electronics* **2024**, *12*, 4576. https://doi.org/10.3390/electronics12224576.

9. Ge, Z.; Jiang, J.; Pugh, E.; Marshall, B.; Yan, Y.; Sun, L. Vision-Based UAV Landing with Guaranteed Reliability in Adverse Environment. *Electronics* **2024**, *12*, 967. https://doi.org/10.3390/electronics12040967.
10. Song, X.; Li, Z.; Feng, S.; Li, Y.; Sun, L.; Jiang, J. Air Defense Interception Plan Generation Method Based on Modified A* Optimization Algorithm. *Electronics* **2024**, *12*, 719. https://doi.org/10.3390/electronics12030719.
11. Bai, Y.; Xu, M.; Zhang, L.; Liu, Y. Pruning Multi-Scale Multi-Branch Network for Small-Sample Hyperspectral Image Classification. *Electronics* **2024**, *12*, 674. https://doi.org/10.3390/electronics12030674.
12. Jung, S.; Kim, Y.J. Extremum Seeking-Based Radio Signal Strength Optimization Algorithm for Hoverable UAV Path Planning. *Electronics* **2024**, *13*, 4064. https://doi.org/10.3390/electronics13204064.
13. Specht, O.; Specht, M.; Stateczny, A.; Specht, C. Concept of an Innovative System for Dimensioning and Predicting Changes in the Coastal Zone Topography Using UAVs and USVs (4DBatMap System). *Electronics* **2024**, *12*, 4112. https://doi.org/10.3390/electronics12194112.