Design and Implementation of a Semi-Intelligent UAV with Real-Time Video Streaming, Obstacle Detection, and Payload Control

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Abstract- *This paper presents the design and implementation of a semi-intelligent Unmanned Aerial Vehicle (UAV) that combines manual flight control with autonomous features using low-cost embedded hardware. The system utilizes an ESP32-CAM module for real-time video streaming and basic image processing, while a Pixhawk or similar flight controller manages stabilization and navigation. A telemetry module ensures continuous data exchange between the UAV and the ground station, providing live updates of altitude, GPS coordinates, battery status, and system health. Integrated ultrasonic sensors enable obstacle detection and avoidance, improving flight safety during semi-autonomous operations. Additionally, a servo mechanism supports payload release or adjustable camera control for multi-purpose missions. The proposed UAV architecture demonstrates how affordable microcontrollers and sensors can be integrated to create a versatile, semi-intelligent drone platform suitable for surveillance, agricultural monitoring, disaster management, and rescue operations.*

Key Words: UAV, ESP32-CAM, Telemetry, Autonomous Drone, Obstacle Detection, Flight Controller.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have undergone significant transformation over the past decade, evolving from exclusive military assets into versatile platforms widely adopted across civilian, commercial, and academic domains. Applications in precision agriculture, environmental surveillance, disaster response, and real-time monitoring increasingly depend on UAVs for their ability to access remote or hazardous environments and deliver timely, high-resolution data.

The growing demand for intelligent UAV systems has catalyzed the integration of advanced sensing technologies, embedded computing modules, and semi-autonomous control mechanisms into compact and cost-effective aerial platforms. These innovations aim to enhance operational efficiency, situational awareness, and decision-making capabilities while maintaining affordability and ease of deployment.

Despite the proliferation of commercial drones, many research-grade UAV systems remain prohibitively expensive or lack onboard real-time processing capabilities. Emerging low-cost microcontrollers, such as the ESP32-CAM, present promising alternatives by enabling lightweight image acquisition and wireless streaming without the need for high-performance processors like the Raspberry Pi. However, achieving an optimal balance between cost, flight stability, sensing precision, and autonomous functionality remains a persistent challenge.

This review synthesizes recent advancements in UAV development, with a focus on autonomous navigation, obstacle avoidance, intelligent video transmission, and payload management. It critically examines existing architectures, identifies limitations in current implementations, and explores how semi-intelligent UAV frameworks can deliver robust performance while remaining accessible to researchers and developers with constrained resources.

2. LITERATURE REVIEW

Vision-based navigation has become essential for UAV operation in GPS-denied and complex environments. Arafat et al. [1] comprehensively reviewed visual localization, mapping, obstacle avoidance, and path planning techniques, highlighting their importance for autonomous navigation. Intelligent decision-making approaches using reinforcement learning were surveyed by Al Mahamid et al. [2], who classified RL algorithms for UAV navigation tasks. Increasing autonomy levels impose higher computational demands, and Mejias et al. [3] analyzed UAS task classifications and autonomy levels, emphasizing suitable embedded computation architectures. Semi-autonomous navigation concepts have also been applied to practical use cases such as medical delivery, where Praveena et al. [23] demonstrated ESP32-CAM–based live video streaming, GPS tracking, and telemetry-enabled semi-autonomous drone operation.

Vision-based autonomous landing, surveillance, and obstacle avoidance systems have been widely explored using low-cost embedded platforms. Xin et al. [4] reviewed vision-based autonomous landing techniques across static, dynamic, and complex scenarios. Embedded vision-based obstacle avoidance using camera and ultrasonic sensors was demonstrated by Rahman and Sasonko [21], employing PID control for real-time navigation. Smart surveillance applications combining AI and IoT were presented by Anis et al. [22], enabling object detection and remote monitoring using embedded controllers. Van Hoa [24] further demonstrated an ESP32-CAM–based system capable of live video streaming and ultrasonic obstacle avoidance, reinforcing the feasibility of low-cost real-time vision-based navigation.

Advanced UAV applications further extend vision-based autonomy to outdoor navigation, inspection, delivery, and cooperative operations. Wang et al. [7] proposed a low-cost outdoor navigation framework using stereo vision, Octomap mapping, and ground-assisted computation. UAV-based inspection accuracy was improved by Hebbache et al. [9] using deep learning–based defect detection, while Chang et al. [10] demonstrated ESP32-based edge computing for low-latency object detection. Beyond navigation, UAVs have been applied to abandoned mine assessment and education by Yang et al. [8] and Chatzopoulos et al. [11]. Delivery-oriented UAV systems and cooperative payload transport were explored by Arora et al. [17], Young et al. [18], and James et al. [19], while Huang et al. [20] showed that semi-autonomous vision-based navigation can effectively assist human operators during teleoperation.

3. CONCLUSIONS

This review highlights the substantial progress achieved in UAV research, particularly in the domains of autonomous navigation, sensing, and real-time data acquisition. However, a critical gap persists in the development of semi-intelligent UAV platforms that are both cost-effective and energy-efficient, while supporting real-time visual monitoring and basic autonomous functionalities.

The proposed UAV architecture—featuring ESP32-CAM–based video streaming, ultrasonic obstacle detection, telemetry communication, and payload control—offers a practical and scalable solution to address this gap. By leveraging lightweight and affordable components, the system achieves a balance between functionality and accessibility, making it well-suited for educational, agricultural, and surveillance applications.

This framework establishes a robust foundation for future advancements in smart UAV systems, including enhanced autonomy, AI-driven perception, and mission-specific payload integration. Continued research in this direction will enable broader adoption of intelligent aerial platforms across diverse operational environments.

REFERENCES

[1] Arafat, M.Y.; Alam, M.M.; Moh, S. Vision-Based Navigation Techniques for Unmanned Aerial Vehicles: Review and Challenges.Drones2023,7,89. https://doi.org/10.3390/drones7020089

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[3] Mejias, L.; Diguet, J.-P.; Dezan, C.; Campbell, D.; Kok, J.; Coppin, G. Embedded Computation Architectures for Autonomy in Unmanned Aircraft Systems (UAS). Sensors 2021, 21, 1115. https://doi.org/10.3390/s21041115

[4] Xie, N.; Ouyang, S.; Liao, K.; Wang, H.; Jiang, J. Near-Field Multiple Target Localization in Frequency Diverse Array Based on Tensor Decomposition. Remote Sens. 2022, 14, 4392. https://doi.org/10.3390/rs14174392

[5] Xin, L.; Tang, Z.; Gai, W.; Liu, H. Vision-Based Autonomous Landing for the UAV: A Review. Aerospace 2022, 9, 634. https://doi.org/10.3390/aerospace9110634

[6] Ortega, L.D.; Loyaga, E.S.; Cruz, P.J.; Lema, H.P.; Abad, J.; Valencia, E.A. Low-Cost Computer-Vision-Based Embedded Systems for UAVs. Robotics2023, 12, 145. https://doi.org/10.3390/robotics12060145

[7] Abbas, Muhammad & Hanif, Farrukh & Affiliations, [2]. (2025). Design and Control of an Autonomous Drone Navigation System Using Embedded AI. 2025.

[8] Wang, Hanzhang & Liu, Yisha. (2020). A low-cost autonomous navigation system for a quadrotor in complex outdoor environments. International Journal of Advanced RoboticSystems.17.172988142090515. 10.1177/1729881420905150

[9] Yang, Y.; Cui, C. Which Provincial Regions in China Should Give Priority to the Redevelopment of Abandoned Coal Mines? A Redevelopment Potential Evaluation Based Analysis. Sustainability 2022, 14, 15923. https://doi.org/10.3390/su142315923

[10] Hebbache, L.; Amirkhani, D.; Allili, M.S.; Hammouche, N.; Lapointe, J.-F. Leveraging Saliency in Single-Stage Multi-Label Concrete Defect Detection Using Unmanned Aerial Vehicle Imagery. Remote Sens. 2023, 15, 1218. https://doi.org/10.3390/rs15051218

[11] Chang, Y.-H.; Wu, F.-C.; Lin, H.-W. Design and Implementation of ESP32-Based Edge Computing for Object Detection. Sensors 2025, 25, 1656. https://doi.org/10.3390/s25061656

[12] Chatzopoulos, A.; Kantaros, A.; Zacharia, P.; Ganetsos, T.; Papoutsidakis, M. A 3D-Printed, Open-Source, Low-Cost Drone Platform for Mechatronics and STEM Education in an Academic Context. Drones 2025, 9, 797. https://doi.org/10.3390/drones9110797

[13] A. Singh, U. Singh, A. Srivastava, G. Yadav, and P. Verma, "Surveillance drone using ESP32," Dept. of Electronics and Communication Engineering, Babu Banarasi Das Institute of Technology and Management, Lucknow, India, UG Project / Paper.

[14] A. Pradeep Kumar, K. Meghana, C. Sunil Kumar, and N. Jeevan Kumar, "Advanced surveillance system using ESP32," Dept. of Electronics & Communication Engineering, CMR College of Engineering & Technology, Hyderabad, India.

[15] R. Muthukumar, M. Dharsan, A. Alex, K. Kaviya, and T. Kirthick Saran, "Face tracking mini drone," Dept. of Electrical and Electronics Engineering, Erode Sengunthar Engineering College, Erode, India.

[16] K. Kamaraj, R. Dutta, U. Vij, M. Moiuddin, and B. K. Agarwal, "Review paper on real-time collision avoidance system using quadcopter," Amity Institute of Aerospace Engineering, Amity University, Uttar Pradesh, India.

[17] S. Arora and E. L. Ntantis, "Customisation and payload integration of hexacopter for enhanced grocery delivery," Conference/Journal name not specified.

[18] A. James, A. Seth, E. Kuantama, R. Han, and S. Mukhopadhyay, "Cooperative drone delivery via push-based lift with payload stabilization," School of Engineering and School of Computing, Macquarie University, Australia.

[19] L. A. Young, "A multi-modality mobility concept for a small package delivery UAV," Aeromechanics Office, NASA Ames Research Center, Moffett Field, CA, USA.

[20] E. Y. C. Huang, "A semi-autonomous vision-based navigation system for a mobile robotic vehicle," M.Eng. thesis, Dept. of Electrical Engineering and Computer Science, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, June 2003.

[21] M. F. Rahman and R. A. Sasonko, "Obstacle Avoiding Quadcopter Using Camera and Ultrasonic Sensor," Journal of Physics: Conference Series, vol. 1005, no. 1, 2018. [Online]. Available:https://doi.org/10.1088/1742-6596/1005/1/012037

[22] H. Anis, A. H. I. Fadhillah, S. Darma, and S. Soekirno, "Smart Drone Surveillance with AI and IoT," arXiv preprint, 2023. [Online]. Available: https://arxiv.org/abs/2209.08258

[23] A. Praveena et al., "Development of Semi-Autonomous Drone for Medical Delivery," International Journal of Scientific Research in Science, Technology and Engineering (IJSRST), vol. 11, no. 2, pp. 112–118, 2025. [Online].

[24] T. Van Hoa, "ESP32-CAM Smart Car with Obstacle Avoidance and Live Streaming," GitHub Repository, 2023. [Online].Available: https://github.com/thaivanhoa37/ESP32-CAM-Smart-Car-with-Obstacle-Avoidance-and-Live-Streaming