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Intelligent 360° Panoramic UAV Surveillance Platform Using AI Vision and IoT Networking

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Abstract: *Unmanned Aerial Vehicle (UAV) surveillance is a growing field of use but also of issues which include small field of view, high delay from cloud processing, and unreliable communication, which in turn reduce performance in real-time applications. To address this, we present our proposed intelligent 360-degree panoramic UAV surveillance system, which is designed to improve situational awareness and response time. The system uses a multi-camera approach for better coverage along with an onboard edge computing unit for real-time object detection, which has been improved using YOLO-based models, thereby reducing the dependence on cloud-based processing. Additionally, MQTT is used for efficient data transfer, and mesh networking is incorporated to ensure reliable communication between UAVs. The proposed approach offers a scalable and efficient solution for applications such as defence, disaster management, and smart city monitoring.*

Keywords: UAV Surveillance, 360° Panoramic Imaging, Edge AI, Real-Time Analytics, YOLO-based Detection, IoT Networking, MQTT, Mesh Communication, Low-Latency Systems, Intelligent Monitoring

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have seen use in a variety of applications, including disaster management, border surveillance, and infrastructure monitoring. However, many present-day UAV systems still face significant challenges. One major issue is the limited field of view, which is a characteristic of typical cameras and results in blind spots, requiring multiple passes to cover the same area.

Another critical issue is the delay caused by cloud-based processing. In such systems, data must be sent to remote servers before analysis, which leads to increased latency and negatively impacts real-time performance. To address these challenges, recent research has explored the use of edge computing, where data processing is performed directly on the UAV. This approach enables faster decision-making and supports the use of models such as YOLO for real-time object detection [1][4].

In addition, communication systems have been improved through the use of lightweight protocols such as MQTT [11] and mesh networking, which provide more reliable connectivity in areas with poor network coverage [8]. In this work, we present an intelligent 360-degree panoramic UAV surveillance platform that utilizes a multi-camera setup for wide-area coverage along with an onboard AI module for real-time analysis. The system also includes a scalable communication framework for coordination between multiple UAVs, aiming to provide a more reliable and low-latency solution for modern surveillance needs.

II. LITERATURE REVIEW

The development of modern UAV surveillance systems is mainly driven by the combination of aerial mobility, computer vision, and communication networks. However, existing systems still face several technical challenges that limit their overall performance.

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A. UAV Architecture and Limitations: UAVs provide flexibility in the monitoring of large and complex areas which we see in disaster and security situations. But most present systems use a single camera which in turn produces a narrow field of view and also creates blind spots. To that end multi camera panoramic systems have been put forth which do well to increase coverage and improve situation awareness. Although this is an improvement, we see that such systems also bring in greater hardware complexity, power consumption and data processing requirements for embedded platforms.

B. AI-Based Vision Techniques: Computer vision in UAVs has transitioned from basic recording to real time object detection and analysis. Past approaches which did see success with Faster R-CNN [2] had issues with high computation which made real time deployment a problem. In that regard we see that YOLO based models [1] do better, in particular the more recent versions like YOLOv8 [4] which we note for their fast single pass approach and which are more suited for UAV use. At the same time, we still see issues of large variation in object size, motion blur, and handling of multiple camera streams.

C. IoT-Based Communication Systems: Efficient communication is a key element for successful UAV operations in large scale settings. Presently we see that traditional point to point communication models do not scale. To that end we have seen adoption of IoT based solutions which we report to use MQTT [11] a very light weight and low bandwidth protocol. Also, we report on mesh networking techniques [12] which we found to be very useful in improving reliability which in turn allows UAVs to talk to each other in a distributed fashion and also perform in areas which have poor connection.

TABLE I: COMPARISON BETWEEN TRADITIONAL UAV MONITORING SYSTEMS AND THE PROPOSED INTELLIGENT PANORAMIC SURVEILLANCE ARCHITECTURE.

Feature	Traditional UAV Surveillance	Proposed Panoramic UAV System
Field of View	Limited (~90° forward view)	Panoramic (360° horizontal coverage)
Visual Awareness	Directional observation	Full environmental awareness
Processing Location	Cloud-based processing	Edge AI processing on UAV
Detection Latency	High due to network delays	Low due to onboard processing
Communication Model	Direct UAV-to-ground link	IoT-based publish–subscribe network
Scalability	Limited	Supports multi-UAV coordination
Network Architecture	Centralized	Mesh-enabled distributed network

In addition to the above, several studies have explored UAV-based monitoring, communication models, and deep learning techniques in related domains. Previous works have highlighted the role of UAVs in smart city applications and wireless communication challenges [6], [7] as well as network-level issues in aerial systems [8], [9]. Research in IoT frameworks [10] and UAV-based mapping and search operations [13], [14] further supports the importance of integrating sensing, intelligence, and communication in modern surveillance systems.

III. PROPOSED SYSTEM ARCHITECTURE

The UAV hardware platform which includes a multi-camera panoramic vision system, an on board AI processing module, and an IoT based communication framework. These elements work together to capture, process and transmit surveillance data efficiently. We may also present the system's operation in terms of three primary stages. In the first, we see the use of many cameras to capture images from various angles which in turn present us with a wide area view. Then the collected data is processed on board with the use of AI models for the purpose of object detection and analysis Finally, the processed information is transmitted to the ground station using a lightweight communication protocol.

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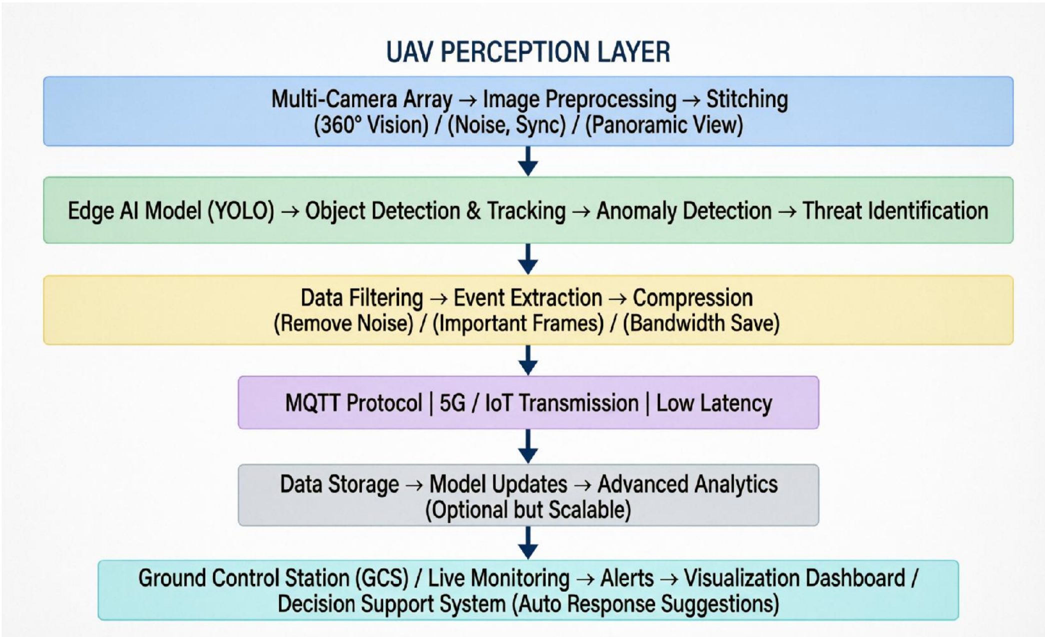

Fig. 1 Architectural Block Diagram

A. Panoramic Vision System

Traditional UAV systems typically use a single forward-facing camera, which limits their field of view. To overcome this limitation, we propose a multi-camera approach in which cameras are placed around the UAV to achieve near 360-degree coverage. This design enables the system to observe the environment from all angles simultaneously.

Furthermore, the captured video from each camera can be processed either individually or combined to generate a panoramic view. This approach significantly reduces blind spots and improves overall situational awareness, especially in complex environments.

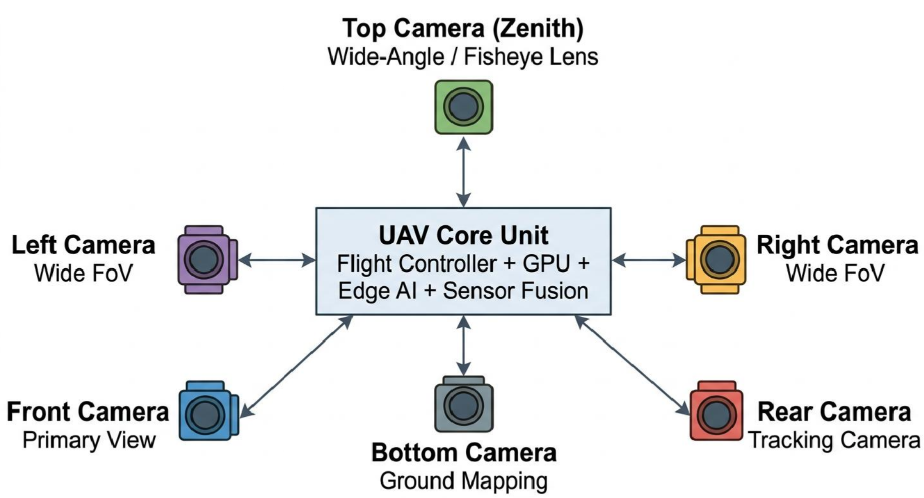

Fig. 2 Vision System

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B. AI-Based Vision Processing

To enable intelligent surveillance, the system incorporates an onboard AI module that processes visual input in real time. The processing pipeline begins with pre-processing steps such as image resizing and noise reduction to prepare the input data. Following this, object detection is performed using a YOLO-based model [1][4] to identify targets such as people and vehicles. The detected objects are then tracked across frames to analyse their movement and behaviour over time. This approach allows the UAV to perform analysis locally rather than relying on cloud servers, thereby reducing latency and improving response time.

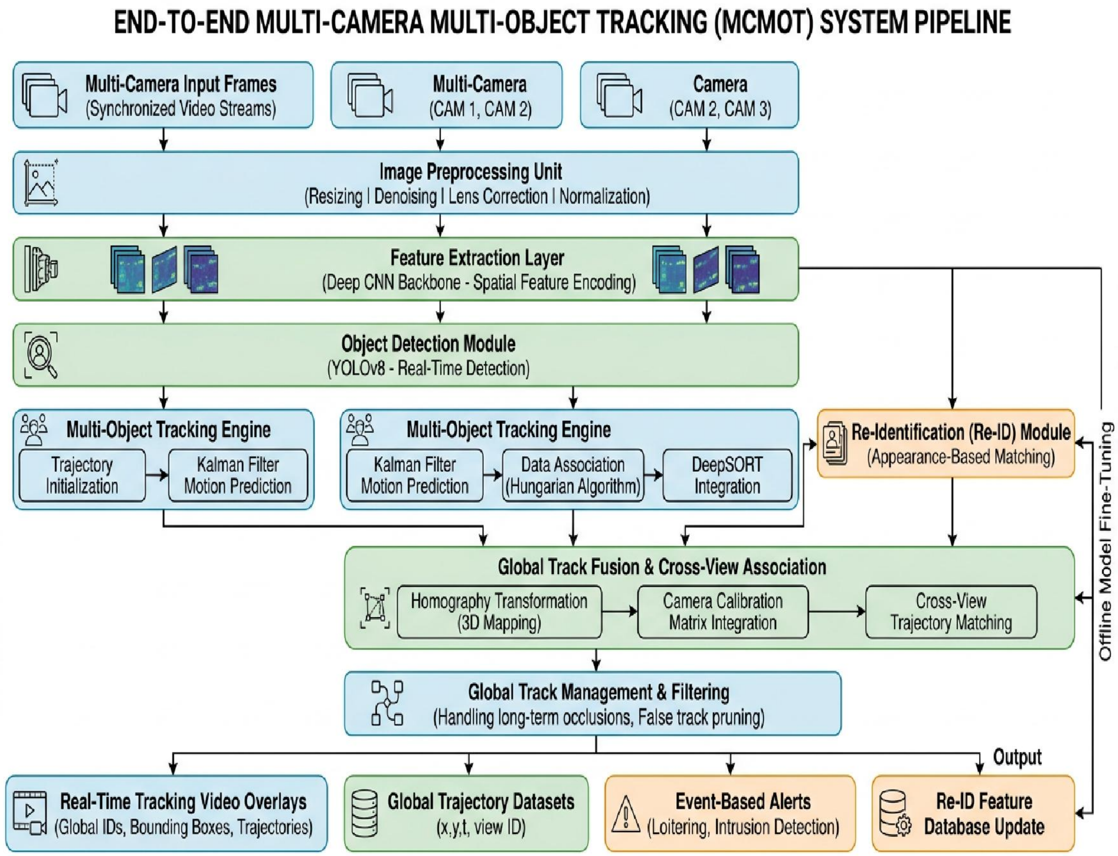

Fig. 3 AI-Based Vision Processing

C. IoT-Based Communication Framework

In the field of data transmission, the system utilizes an IoT-based communication model. Instead of relying on traditional point-to-point connections, a publish–subscribe architecture is adopted using the MQTT protocol [11], where UAVs publish data to a central broker that can be accessed by the ground control station. Additionally, mesh networking [12] is incorporated to enable communication between multiple UAVs. This approach extends the overall network range and improves reliability, particularly in areas with limited or no direct connectivity.

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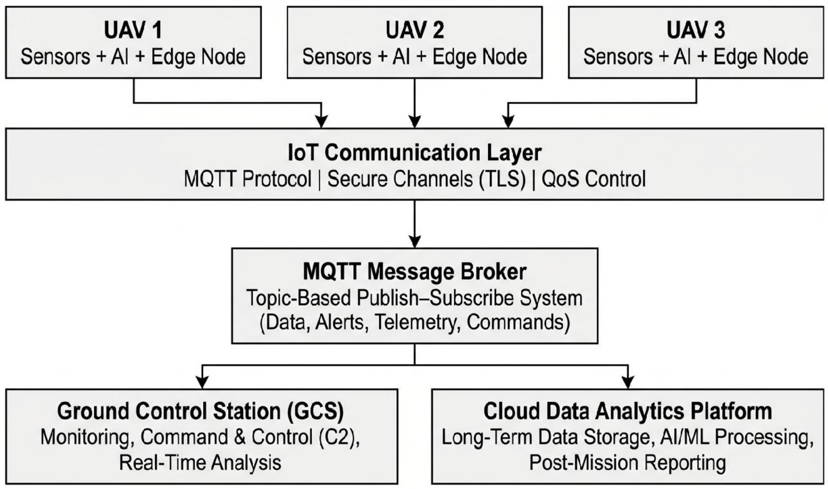

Fig. 4 IOT Based Communication Framework

IV. PERFORMANCE EVALUATION

Since the proposed system is conceptual, its performance is evaluated using theoretical comparisons with existing UAV and edge-AI based systems. The evaluation focuses on three main parameters: detection accuracy, processing latency, and communication efficiency.

A. Detection Accuracy

The accuracy of the system is measured using Mean Average Precision (mAP), which is commonly used in object detection tasks:

$$\text{mAP} = \frac{1}{N}\sum_{i=1}^{N}\text{AP}_i$$

where, N represents the number of classes and APi is the average precision for each class.

Modern YOLO based models do present very good performance in aerial detection tasks [1][4]. That said performance does break down in the presence of motion blur, poor lighting, and varying object sizes. We have put forth a system which improves on this by way of a 360-degree multi camera setup that in turn gives us continuous target coverage and sees to it that we reduce the issue of missed detections which is a result of limited field of view.

B. Processing Latency

The proposed system offers the advantage of reduced latency compared to traditional UAV systems. Existing systems often rely on cloud-based processing, which introduces delays due to data transmission and remote analysis. In contrast, the proposed system utilizes onboard edge computing to perform real-time inference. This approach enables processing speeds of approximately 20–40 frames per second, allowing for faster detection and more immediate response. As a result, the UAV performs more effectively in time-sensitive situations.

C. Communication Efficiency

Efficient communication is achieved by minimizing unnecessary data transmission and utilizing lightweight protocols. Instead of transmitting full raw video streams, the system sends only essential information, including object labels, coordinates, and movement data. The MQTT protocol [11] is used to enable low-bandwidth communication through a publish–subscribe model. In addition, mesh networking [12] allows UAVs to act as relay nodes and communicate with

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each other. This approach improves network reliability and extends the operational range, particularly in areas with limited or no direct connectivity.

V. LIMITATIONS

Although the proposed 360-degree panoramic UAV surveillance system offers several advantages, it also presents certain challenges that must be considered. One major issue is the increased power requirement. The use of multiple cameras and onboard processing units demands higher energy consumption, which reduces the overall flight time of the UAV. This becomes a critical limitation, especially in long-duration missions. Another challenge lies in the performance of AI-based detection models. While models such as YOLO perform well under normal conditions, their accuracy tends to decrease in challenging environments such as low light, fog, or heavy rain. This affects the quality of the collected data and the reliability of detection results.

In addition, handling multiple camera streams in a panoramic setup requires significant computational resources. Tasks such as image processing and data aggregation from multiple cameras place a heavy load on embedded systems, making optimization essential for smooth real-time operation. Communication between UAVs and ground systems also remains a concern, particularly in environments with signal interference or poor network coverage. In such cases, maintaining stable and reliable data transfer becomes difficult. Overall, these challenges highlight the need for improvements in power management, model robustness, system optimization, and communication reliability in future implementations.

VI. FUTURE WORK

• Then we put forth that which may be made better in a number of areas which in turn will improve the system's performance and real into which it can be taken out.

• One such area is the application of swarm intelligence, which is the implementation of many UAVs that work as a team in a coordinated way. This will afford better area coverage and also reduce redundancy in large scale surveillance.

• Also into the picture is the issue of what I would term the added value of different sensors like thermal, infrared, or LiDAR. These in the right environment will see the system do that which it does better in low light or in environments with poor visibility.

• We see a large play for the growth of autonomous navigation into the mix. By which we are talking about the combination of GPS info with the AI that the UAV has, to get it to make real time decisions, to change flight paths, to track moving targets, or avoid obstacles all by itself.

• Also, we see that the system may be put forward by using predictive analytics. We may use more complex machine learning models which will look at trends instead of just what is present which will in turn improve the early warning for critical issues.

• we may look at better battery management methods and improving hardware design which will in turn increase flight time and raise the overall system's dependability.

VII. CONCLUSION

In this paper, an intelligent 360° panoramic UAV surveillance platform has been proposed to address key limitations of traditional UAV systems, including limited field of view, high latency, and inefficient communication. The proposed system integrates a multi-camera setup for wide-area coverage, an onboard AI module utilizing YOLO-based models, and an IoT-based communication framework. This enables real-time detection while reducing dependency on cloud-based processing.

As a result, the platform improves situational awareness, reduces response time, and supports more reliable operation in dynamic environments. Compared to existing methods, the proposed system demonstrates improvements in coverage, processing performance, and communication efficiency.

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Furthermore, the system is designed to be scalable, providing a foundation for future expansion into multi-UAV coordination for large-area monitoring. Overall, the proposed approach represents a practical step toward the development of advanced UAV surveillance systems, with strong potential for applications in disaster management, defence, and smart city monitoring, where real-time performance and high reliability are critical.

VIII. AUTHORS AND AFFILIATIONS

Mr. Mukul Kumar is pursuing his B.Tech degree in Computer Science and Engineering from Sunder Deep Engineering College, Ghaziabad, affiliated to Dr. A.P.J. Abdul Kalam Technical University. His area of interest includes Machine Learning, Data Science, Artificial Intelligence, and IOT.

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