Implementation Of Swarm of Drones Using MAV Protocol

Vedang Kanvinde[1], Vasudev Chile[2], Siddharth Desai[3], Pavan Chitari[4], Prof. Neha A. Marathe[5]
[1,2,3,4]*Finolex Academy of Management and Technology, Ratnagiri, University of Mumbai*
[5]*Assistant Professor, Finolex Academy of Management and Technology, Ratnagiri, University of Mumbai*

***Abstract*—The rapid evolution of unmanned aerial vehicles has opened new possibilities for cooperative and intelligent multi-drone systems. This research presents the development of a small-scale drone swarm consisting of one master drone and two follower drones. The system follows a master–follower architecture, where the master drone is responsible for mission planning and command generation, while the follower drones dynamically adjust their behaviour to maintain formation and ensure synchronized movement. To enable reliable and structured communication, the system utilizes the MAVLink protocol for message exchange between drones. MAVLink provides a lightweight and efficient communication framework that supports real-time transmission of telemetry, positional data, and control commands. By leveraging this protocol, the drones achieve low-latency interaction and improved coordination. The system is further supported by tool such as Drone Kit-Python for implementing autonomous flight operations, including take off, waypoint navigation, and coordinated movement. This work highlights the practicality of combining a master–follower coordination strategy with standardized communication protocols to develop low-cost and efficient drone swarms. It also addresses key challenges such as synchronization, communication reliability, and system scalability, providing a foundation for future advancements in autonomous aerial swarm systems for applications such as surveillance, disaster response, and environmental monitoring.**

***Index Terms*—Drone Swarm, MAVLink Protocol, Raspberry Pi, UAVs, Autonomous Systems, Dronekit-Python, Misson Planner**

I. INTRODUCTION

1.1 Background and Motivation:

The rapid evolution of Unmanned Aerial Vehicles (UAVs) has been significantly driven by breakthroughs in embedded systems, wireless communication, and autonomous control technologies. Historically, drone operations were limited to single-unit systems that lacked the complexity required for large-scale tasks. Drawing inspiration from biological swarms, such as bird flocks and insect colonies, researchers are now exploring collective intelligence to enhance mission success. This shift is motivated by the need for systems that exhibit greater adaptability and problem-solving capabilities than any individual agent could achieve alone.

1.2 Problem Statement:

Despite the advancements in UAV technology, traditional single-drone applications face inherent limitations in scalability, area coverage, and operational efficiency. These systems are often insufficient for time-sensitive missions in large or complex environments. Furthermore, while swarm technology offers a solution, many existing multi-agent architectures are overly complex, making them difficult to implement with standard hardware. There is a pressing need for a simplified, coordinated system that can overcome these bottlenecks without requiring prohibitive computational resources or specialized infrastructure.

Objective: To design and implement a cost-effective, scalable drone swarm system that demonstrates stable coordinated behavior. By utilizing standardized communication protocols and accessible hardware, the study seeks to bridge the gap between theoretical swarm intelligence and practical, real-world application. The focus is placed on achieving reliable autonomous operation and precise formation control, ensuring that the swarm can function effectively under the constraints of limited processing power and varying environmental conditions.

Function: The core function of the proposed system is to enable multiple autonomous agents to communicate, coordinate, and make decisions in a distributed yet synchronized manner. The swarm acts as a single, cohesive entity capable of performing complex maneuvers and maintaining specific spatial arrangements during flight. This functionality is essential for tasks requiring high area coverage, as it allows the drones to partition a mission area and gather data more effectively than a serial, single-unit approach.

Technologies: This system utilizes a master–follower architecture as the structural foundation of the swarm. At the heart of the communication layer is the MAVLink protocol, a lightweight and structured messaging format specifically designed for high-efficiency telemetry and command transmission. These technologies are integrated into on-board embedded systems, allowing for real-time processing of flight data. The choice of MAVLink ensures that the system remains low-overhead, which is critical for maintaining high-speed inter-drone communication without taxing the drones' limited battery life.

Process: The operational workflow begins with the master drone generating navigation commands and managing the overall mission flow. These instructions are encapsulated into MAVLink packets and broadcasted to the follower drones. Upon receiving this data, the follower drones calculate their relative positions and adjust their flight paths in real-time. This continuous feedback loop allows the followers to synchronize their movements with the master, ensuring that the entire formation moves smoothly through the three-dimensional workspace.

Implementation: The physical implementation of the study involves a three-drone configuration consisting of one master and two followers. To ensure the system's reliability, the implementation addresses critical technical challenges such as communication latency and synchronization errors. By focusing on accessible hardware, the system demonstrates that sophisticated swarm behaviour can be achieved without high-cost components. Safety protocols and resource management strategies are also integrated to prevent collisions and manage the computational load across the multi-agent system.

Benefits: The swarm architecture offers significant benefits in terms of operational robustness and cost-efficiency. By distributing tasks across multiple agents, the system achieves higher coverage rates and reduces the time required for mission completion. The system particularly suited for precision agriculture, environmental monitoring, surveillance, and disaster management

II. LITERATURE SURVEY

[Paper 1] The MAVwork framework was developed as a modular, open-source solution to decouple high-level visual controllers from specific hardware and communication protocols like MAVLink. Operating on a client-server model, the server module runs on the drone's onboard computer to handle flight control, while the client module manages application logic, such as object tracking, via a TCP/IP link. This architecture serves as a landmark for standardized software design in the micro-aerial vehicle ecosystem.

[Paper 2] This research explores the use of a "swarm" of tiny, low-cost drones that work together as a team rather than relying on a single, expensive aircraft. By following simple rules of interaction rather than a centralized command, the drones can collaboratively explore areas and locate targets. This decentralized approach ensures high resilience, as the loss of a single unit does not cause mission failure; instead, the remaining drones dynamically reassign tasks to continue the operation.

[Paper 3] Planning missions for a swarm involves balancing competing goals such as speed, fuel efficiency, and risk management. To solve this, Multi-Objective Evolutionary Algorithms (MOEAs) are used to evolve the most effective mission plans. The process begins with a population of random solutions and uses a survival of the fittest cycle—evaluating, combining, and modifying the best plans over many generations to eventually produce a family of high-quality mission options.

[Paper 4] A swarm's success depends on its communication network, which can be organized into centralized, decentralized, or hybrid structures. While centralized systems are simple, decentralized mesh networks offer higher resilience by allowing peer-to-peer relaying. To manage data flow, protocols are categorized as proactive (maintaining constant maps), reactive (finding routes on demand), or geographic (using GPS data), with hybrid and geographic methods being the most suitable for the high mobility of flying swarms.

[Paper 5] Securing the communication links between drones and ground stations is vital to prevent mission compromise. Proposed secure protocols focus on authentication, which verifies the identity of every member to prevent imposter drones from joining, and encryption, which ensures data integrity and confidentiality. These measures provide resilience against common cyber-attacks such as eavesdropping, message manipulation, and spoofing.

[Paper 6] A clear framework for swarm organization requires examining the relationship between communication topology and control paradigms. The choice of architecture is a primary design decision that dictates a swarm's overall capabilities and weaknesses. By structuring how drones are physically connected and how decisions are made, designers can better align the swarm's organization with its intended operational strengths.

[Paper 7] Operating in areas where GPS is unavailable—such as indoors or under heavy forest cover—requires alternative navigation methods like Radio Frequency (RF)-based localization. By measuring radio signals between drones and fixed anchor points, the swarm can triangulate positions and maintain formation through peer-to-peer "chirping." This approach makes the swarm less vulnerable to GPS jamming and ensures effective navigation in challenging environments.

III. METHODOLOGY

3.1 Problem Identification:

Traditional single-drone systems are inherently limited in their ability to perform large-scale operations, execute parallel tasks, and provide redundancy in mission-critical scenarios. While swarm-based systems offer significant advantages, they introduce challenges related to coordination, communication reliability, and real-time synchronization.

A major limitation of existing swarm implementations is their reliance on complex algorithms and high-cost infrastructure, which restricts their practical adoption in academic and small-scale environments. Additionally, maintaining stable communication among multiple drones is a critical concern, as delays or data loss can disrupt formation stability and overall mission efficiency.

To address these challenges, this research proposes a simplified and cost-effective swarm framework based on a master–follower architecture. The MAVLink protocol is utilized to enable efficient, low-latency communication, ensuring reliable coordination and real-time data exchange between drones.

3.2 System Architecture:

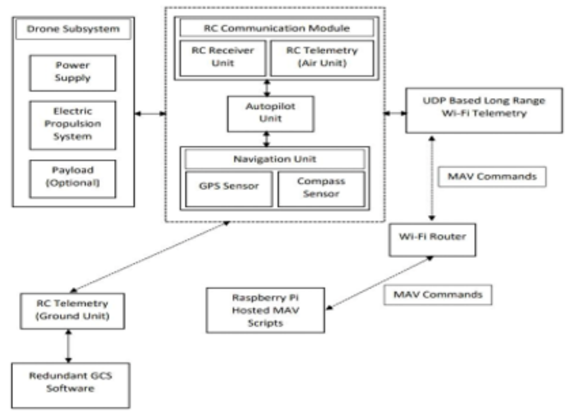

Fig 1: Block Diagram of Swarm of Drones

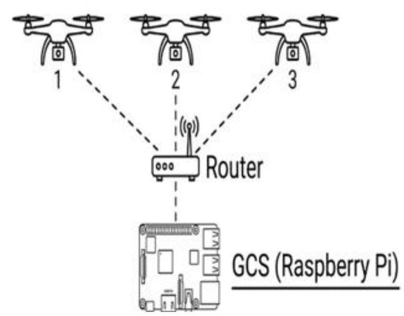

Fig 2. System Architecture and Data Flow of the Swarm of Drones

The proposed system consists of three drones: one master drone and two follower drones. The architecture is designed to enable centralized coordination, where the master drone is responsible for mission planning and command generation, while follower drones execute commands and maintain formation.

Each drone comprises the following key components:

Drone Subsystem: Includes the power supply, propulsion system (brushless motors and electronic speed controllers), and optional payload such as cameras or sensors.

Autopilot Unit: Responsible for stabilizing the drone and executing flight commands based on sensor inputs and external instructions.

Navigation Unit: Consists of GPS and compass sensors for accurate positioning and orientation.

Communication Module: Enables telemetry exchange between drones and the ground control station (GCS).
Companion Computer (Raspberry Pi): Executes high-level control algorithms, processes telemetry data, and communicates using the MAVLink protocol.
A centralized network architecture is implemented using a Wi-Fi router, which acts as a communication hub between all drones and the ground control station. This ensures seamless data exchange and synchronized control across the swarm.

3.3 Communication Framework
Reliable communication is a critical requirement for swarm coordination. In this system, the MAVLink protocol is employed as the primary communication framework due to its lightweight structure and suitability for real-time applications.
The master drone generates mission commands and broadcasts them to follower drones in the form of MAVLink messages. These messages include telemetry data, positional coordinates, and control instructions. Follower drones continuously receive and process this data to adjust their positions relative to the master drone.
The communication system is designed to minimize latency and ensure consistent data transmission. Telemetry modules and Wi-Fi-based networking are used to maintain a stable connection between drones and the ground control station.

3.4 Flight Control and Navigation
Autonomous flight control is implemented using DroneKit-Python, which provides a high-level interface for interacting with the drone's autopilot system. The system supports key flight operations such as takeoff, waypoint navigation, and landing.
The master drone defines the mission trajectory using predefined GPS waypoints. These waypoints are transmitted to follower drones, which calculate their relative positions and adjust their flight paths accordingly. Real-time telemetry data is used to continuously monitor and correct deviations from the desired formation.
Basic path planning techniques are employed to ensure smooth navigation, while provisions for obstacle avoidance can be integrated to enhance operational safety.

3.5 Autonomous Operation
The system is designed to operate autonomously with minimal human intervention. Once the mission is initiated, the master drone coordinates the swarm by issuing commands, while follower drones respond dynamically based on received data.

Key autonomous capabilities include:
1. Automated takeoff and landing
2. Real-time formation maintenance
3. Continuous position adjustment using sensor feedback
4. Adaptive response to minor environmental variations

3.6 Data Collection and Monitoring
During operation, each drone continuously collects telemetry data such as position, altitude, speed, and system status. This data is transmitted to the ground control station for real-time monitoring and post-mission analysis.
The ground control station provides an interface for visualizing flight parameters, tracking drone positions, and modifying mission parameters if required. This enhances system transparency and enables effective performance evaluation.

3.7 Safety and Fail-Safe Mechanisms
To ensure safe operation, multiple fail-safe mechanisms are integrated into the system. These include:
Return-to-Home (RTH): Automatically returns the drone to its launch position in case of communication failure or low battery.
Emergency Landing: Initiates controlled landing during critical system failures.
Battery Monitoring: Continuously tracks power levels to prevent mid-air shutdown.
Collision Avoidance (Basic): Maintains safe distances between drones during formation flight.

3.8 Future Enhancements
The proposed system can be further improved by incorporating advanced technologies such as artificial intelligence and decentralized control strategies.

Future enhancements may include:
1. Computer vision for object detection and tracking
2. AI-based path optimization and decision-making

3. Fully decentralized swarm coordination
4. Improved obstacle avoidance using sensor fusion

IV.RESULTS

Figure 4 shows that the final output of our swarm of drone's project. It verified successful simultaneous operation of two UAVs in an open outdoor environment. Both drones maintained stable flight at from a separate distance and separate position. Indicating effective control and coordination during the test. no visible instability, collision risk or communication failure was observed during trail. These results demonstrate that the proposed UAV system capable to reliable multi-drone deployment under field conditions.

Fig.3 Swarm of Drones (Ground Test)

Fig.4 Swarm of Drones (Flying test)

V. CONCLUSION

This research presents the design and implementation of a cost-effective drone swarm system based on a master follower architecture using the MAVLink communication protocol. The study demonstrates that reliable coordination and synchronized movement can be achieved among multiple UAVs using lightweight communication frameworks and accessible hardware platforms.

The integration of MAVLink and DroneKit-Python enables efficient real-time communication, autonomous flight control, and formation maintenance. Key challenges such as communication latency, synchronization, and system scalability are addressed, validating the feasibility of implementing practical swarm systems in resource-constrained environments.

The proposed system provides a strong foundation for future advancements in multi-agent UAV systems. Future work may focus on enhancing scalability, incorporating decentralized control strategies, and integrating artificial intelligence for adaptive decision-making and obstacle avoidance.

Overall, this work contributes to bridging the gap between theoretical swarm intelligence and real-world implementation, enabling broader adoption of drone swarms in applications such as surveillance, disaster response, and environmental monitoring.

REFERENCES

[1] Chen, X., J. Tang, et al., "Review on Unmanned Aerial Vehicle Swarm Communication Architectures and Routing Protocols," pp. 1–23, 2018.

[2] Campion, M., P. Ranganathan, and S. Faruque, "UAV Swarm Communication and Control Architectures," IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 93–106, 2019.

[3] Chua, T. S., A. C. Tsourdos, et al., "SwarMAV: A Swarm of Miniature Aerial Vehicles," pp. 1–9, 2013.

[4] Khan, N. A., N. Z., et al., "A Secure Communication Protocol for Unmanned Aerial Vehicle," pp. 601–618, 2022.

[5] Lamont, G. B., J. N., R. De Nardi, and O. Holland, "UAV Swarm Mission Planning and

Routing Using Multi-Objective Optimization," pp. 10–20, 2007.

[6] Mellado-Bataller, I., J. P.-M., et al., "MAVwork: A Framework for Unified Interfacing Between Micro Aerial Vehicles and Visual Controllers," pp. 165–179, 2013.

[7] Toma, A., N. C., et al., "MAVLink-Based Control and Coordination of a Multi-Drone Cluster for Intelligence, Surveillance and Reconnaissance Tasks," pp. 1–22, 2024.

[8] "Swarm UAV Implementation Using Radio Localization in GPS-Denied Areas," pp. 111–116, 2022.