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DRONE SWARM FORMATION

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Abstract: Currently Drone swarm is an emerging technology which is used in many fields, To date a variety of drone swarm is available in market which does not support indoor flying capabilities and the swarm bundle is limited with the implementation of swarm in any technical usage like survey using swarm drones, the swarm drones present in the market does have good UAV trajectory generation for swarm drones with collision avoidance. We proposed an intriguing algorithm development for swarm drones which especially deals with the navigation of swarm drones in asynchronous trajectory with collision avoidance between the drones in the swarm itself and to develop an artificial positioning system for indoor swarm which localizes the drone with respect to the reference marker and the distance between itself and other drones. After the development of the drone swarm, we also concentrate on integrating the swarm drones for making indoor SLAM mapping of the room in a synchronized manner. The development of the artificial indoor positioning system improves the stability of the drones which is a key factor for drone swarming. Furthermore, the positioning is based on Radio frequency which can even penetrate through small obstacles.

***Index Terms* - Drones, swarm drones, Crazyflie drones, Loco positioning,TDOA3, Simultaneous Localization and Mapping, Radio frequency positioning,Dwm100**

I. INTRODUCTION

Rapid advances in drone technology have paved the way in recent years for new and innovative applications. One of the most exciting events in this field is the concept of "unmanned aerial vehicle formation". A drone team was formed refers to a group of drones operating in a coordinated and synchronous manner to achieve common goals. This concept is inspired by nature's apparent flocking in birds and school behavior in fish working together as a cohesive unit to complete complex tasks. The power of drone development lies in its ability to solve these challenges Individual drones cannot operate effectively. By working as a public organization, drones can perform many tasks with advanced capabilities search and rescue missions, surveillance, environmental monitoring, infrastructure inspection and even entertainment events. It allows you to create drones to cover larger areas, increasing the accuracy of data collection and sharing computing resources for real-time decision making. At the heart of the drone formation is a complex algorithm that controls how individual drones communicate, navigate and adapt their position should retain the desired shape. Communication is important as much as possible drones to exchange information, share positions and avoid collisions. The formation can vary from simple geometric patterns such as texture lines or circles into more complex configurations based on the task at hand.In this introduction to drone formation, we will explore the basic elements and concepts related to creating and managing such formations. We will learn communication protocol, control strategy, route planning algorithm, obstacle avoidance techniques are used for seamless coordination among drones. We will also discuss the importance of growth and challenges associated with managing large groups. As drone technology advances, so does the potential of drones create a program. Unmanned collective intelligence and adaptation .This opens the door to a variety of possibilities in

industry.
However, with such a promise it is necessary to consider ethical issues related to the problem and to ensure the safe and responsible use of this technology. Drone formations are used in several ways due to its ability to improve efficiency, scale and collective mind .

II. LITERATURE REVIEW

Learning Vision-based Flight in Drone Swarms by Imitation
(F. Schilling, J. Lecoeur, F. Schiano and D. Floreano, "Learning Vision-Based Flight in Drone Swarms by Imitation," in IEEE Robotics and Automation Letters, vol. 4, no. 4, pp. 4523-4530, Oct. 2019, doi: 10.1109/LRA.2019.2935377.)

Decentralized drone swarms deployed today either rely on sharing positions between agents or detect swarm members using visual markers. This work proposes an entirely visual approach to unmarked drone swarm coordination based on imitation learning. Each agent is controlled by a small and efficient convolutional neural network that takes raw omnidirectional images as inputs and predicts 3D velocity commands that match the commands computed by the clustering algorithm. We start training the simulation and propose a simple but effective unsupervised domain adaptation approach to transfer the learned controller to the real world. Next, we train the controller with data collected in our motion sensing lobby. We show that a convolutional neural network trained on drone visual inputs can learn not only robust collision avoidance between agents, but also swarm cohesion in a pattern-efficient manner. The neural controller effectively learns to locate other agents in the visual input, which we demonstrate by visualizing the areas with the greatest influence on the agent's movement. We remove the dependence on sharing positions between swarm members by only considering local visual information for inspection. Thus, our work can be considered the first step towards a fully decentralized vision-based swarm without the need for communication or visual markers.

Formation-based Selection of Drone Swarm Services
(Alkouz B, Bouguettaya A. Formation-based selection of drone swarm services. InMobiQuitous 2020-17th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services 2020 Dec 7 (pp.
386-394)

Drone Swarms as Networked Control Systems by Integration of Networking and Computing
(Asaamoning, Godwin, Paulo Mendes, Denis Rosário, and Eduardo Cerqueira. 2021. "Drone Swarms as Networked Control Systems by Integration of Networking and Computing" Sensors 21, no. 8: 2642)

The study of multi-agent systems such as drone swarms has been intensified due to their cooperative behavior. However, automating swarm control is challenging because each drone operates under variable wireless, network, and environmental constraints. To address these challenges, we consider drone swarms as networked control systems (NCS), where control of the entire system is performed within a wireless communication network. This is based on a tight connection between the network and computing systems in order to effectively support the basic control functionality, namely the collection and exchange of data, decision making and the distribution of control commands. Based on the literature review, we do not find review papers on drone swarm design like NCS. In this review, we present an overview of how to develop self-organized drone swarms as NCSs through the integration of a network system and a computing system. In this sense, we describe the characteristics of the proposed components of the drone swarm as NCS in terms of network and computing systems. We are also analyzing their integration to increase drone swarm performance. Finally, we identify a potential design choice and a set of open research challenges for network and computing integration in a drone swarm like NCS.

III. OBJECTIVES

Indoor drone swarm formation can have a variety of objectives, each with its own set of applications and goals. Here are some goals for indoor drone swarm formation, along with more information on each.

Surveillance and Security:- Objective: Build a drone swarm to improve indoor surveillance and security.Drones can be used to monitor and secure indoor spaces like warehouses,museums, and critical infrastructure facilities. The swarm can stream video in real time, detect security breaches, and respond to alarms or threats.

Environmental Monitoring:- Objective: Use a drone swarm to monitor the indoor environment.Collect data on indoor air quality, temperature, humidity, and other environmental parameters using drones. This data can be used to maintain optimal conditions in indoor spaces, ensure occupant comfort, and detect problems such as leaks or pollution.

Inventory Management:- Objective: In large indoor facilities, use a drone swarm to manage inventory.Drones can scan shelves, track inventory levels, and locate misplaced items in warehouses or retail stores on their own. This aids in the streamlining of operations, the reduction of errors, and the optimisation of inventory management.

Search and Rescue:- Objective:Create a drone swarm for indoor search and rescue. Drones can be used to locate and assist survivors in disaster-stricken or dangerous indoor environments. The swarm can navigate debris, assist with communication, and relay critical information to rescue teams.

Infrastructure Inspection and Maintenance:- Objective: Implement a drone swarm for inspecting and maintaining indoor infrastructure.Drones can access hard-to-reach areas such as bridges, tunnels, or building facades to inspect for structural issues, perform maintenance tasks, and identify potential hazards.

Entertainment and Light Shows:- Objective: Make a swarm of drones for indoor entertainment and light shows. - Drones outfitted with LED lights can be choreographed to create captivating aerial displays at events, concerts, or exhibitions. This goal is to provide visually stunning and immersive experiences.

Precision Agriculture:- Objective: Deploy a drone swarm for indoor precision agriculture. Drones can be used to navigate indoor farms or vertical gardens, monitor crop health, and perform precise tasks such as pollination and pesticide application. In controlled environments, this can improve crop yields.

Data Collection and Mapping:- Objective: Utilize a drone swarm for indoor data collection and mapping. Drones can be used to create 3D maps, collect spatial data, and inspect indoor spaces for purposes of planning, such as designing new layouts or optimising logistics.

Education and Research:- Objective: Develop a drone swarm for educational and research purposes.Drones can be used to teach students about robotics, programming, and automation in educational settings. Researchers can also investigate swarm behaviour, algorithms, and human-drone interactions.

Disaster Response and Mitigation:- Objective: Establish a drone swarm for disaster response and mitigation indoors. In the aftermath of indoor disasters such as fires, earthquakes, or industrial accidents, use drones to assess damage, deliver emergency supplies, and provide communication infrastructure.

Indoor drone Localization:- Objective: to develop a localization unit for drone swarms .The positioning system should be able to communicate with multiple drones at the same time and tell them where they are in relation to other drones. These indoor drone swarm formation objectives demonstrate the versatility and potential applications of drone technology in a variety of indoor settings, ranging from security and safety to entertainment and research. The objective chosen will be determined by specific use cases and goals.

IV. METHODOLOGIES

Indoor drone swarm formation involves the coordination and control of multiple drones to achieve specific formation patterns or tasks within indoor environments. Here's a methodology that can be used for indoor drone swarm formation:

Sensors and Perception:- Sensor Selection: Choose appropriate sensors for indoor navigation, such as ultrasonic sensors, LiDAR, cameras, IMUs (Inertial Measurement Units), and altimeters. Data Fusion: Combine data from multiple sensors to improve accuracy and reliability in sensing the drone's position, orientation, and surroundings. Obstacle Detection: Implement algorithms to detect obstacles in real-time to avoid collisions during formation flight.

Localization:- Indoor Mapping: Create detailed maps of the indoor environment using SLAM (Simultaneous Localization and Mapping) techniques, which allow drones to localize themselves within the mapped environment.Sensor Fusion: Fuse data from various sensors to estimate the drone's position and orientation accurately. Beacon Systems: Utilize Bluetooth beacons or other signal-emitting devices placed at known locations within the indoor space for localization.

Communication and Coordination:- Wireless Communication: Establish a robust communication network among drones for sharing localization data, control commands, and formation coordination.Communication Protocols: Develop communication protocols that ensure low-latency and reliable data exchange. Formation Control Algorithms: Implement algorithms that determine the desired position and orientation of each drone within the formation relative to its neighbors.

Path Planning and Navigation:- Path Generation: Use path planning algorithms to generate optimal or collision free trajectories for each drone within the swarm. Trajectory Tracking: Implement control algorithms that enable each drone to follow its planned trajectory accurately. Collision Avoidance: Integrate collision avoidance mechanisms into the path planning and navigation systems to ensure safe operation in dynamic environments.

Formation Control:- Formation Design: Define the desired formation pattern or shape that the swarm should achieve within the indoor space. Formation Control Algorithms: Develop algorithms that adjust the drones positions and orientations to achieve and maintain the desired formation while considering constraints and objectives. Leader-Follower Models: Implement leader-follower models where one drone (or a subset) acts as a leader, and others follow to maintain the formation.

Synchronization:- Time Synchronization: Ensure that drones are synchronized in terms of time to coordinate actions and maintain formation integrity. Data Synchronization: Synchronize data exchange and processing among drones to maintain a consistent view of the environment.

Testing and Simulation:-Simulation: Use simulation tools to test and validate formation control algorithms and strategies in a virtual environment before real-world deployment. Field Testing: Conduct field tests in controlled indoor environments to refine and validate the swarm's behavior.

Redundancy and Fault Tolerance:- Redundancy: Implement redundancy in critical systems to ensure that the swarm can continue to operate even if individual drones or sensors fail. Fault Detection: Develop mechanisms for detecting faults in drones or sensors and taking appropriate actions to maintain formation integrity.

Human Interaction:- User Interface: Design user-friendly interfaces for operators to plan missions, monitor the swarm, and intervene when necessary. Safety Protocols: Establish safety protocols for human-robot interaction to ensure safe and reliable operation in indoor environments with human presence.

Scalability and Adaptability:- Ensure that the swarm formation methodology can scale to accommodate a varying number of drones and adapt to different indoor environments and mission requirements.

Regulatory Compliance:- Ensure that the drone swarm formation complies with local regulations and safety standards for indoor drone operations.

Data Logging and Analysis:- Collect and analyze data from drone operations to improve the formation control algorithms, optimize performance, and troubleshoot issues.

This methodology combines sensor integration, localization, communication, control algorithms, and testing to enable the formation of successful indoor drone swarms for a variety of applications such as search and rescue, surveillance, entertainment, and industrial automation. The specific implementation may differ depending on the swarm's complexity and objectives.

V. PROCEDURAL FLOW

Creating an indoor drone swarm formation involves a series of procedural steps, from initial planning to execution. Below is a procedural flow for indoor drone swarm formation:

Define Objectives and Requirements:- Identify the specific objectives of the swarm formation, such as surveillance, inspection, or entertainment.Determine the requirements, including the number of drones, formation pattern, and the indoor environment's characteristics.

Select Hardware and Software:- Choose the appropriate hardware components, including drones, sensors, communication systems, and onboard computers. Select software tools and platforms for drone control, navigation, and communication.

Sensor Integration and Calibration:- Integrate sensors such as cameras, LiDAR, IMUs, and altimeters onto each drone. Calibrate the sensors to ensure accurate data collection and perception.

Localization Setup:- Create an indoor map using SLAM or other mapping techniques. Set up localization systems, which may include beacon systems, Wi-Fi triangulation, or visual odometry, to allow drones to determine their positions within the map.

Communication Network:- Establish a robust communication network between drones using appropriate communication protocols. Ensure low-latency data exchange among drones for coordination and control.

Formation Design:- Design the desired formation pattern or shape that the swarm should achieve within the indoor space.Define the relative positions and orientations of each drone within the formation.

Formation Control Algorithms:- Develop and implement formation control algorithms that calculate the control commands required for each drone to achieve and maintain the desired formation. Ensure collision avoidance and obstacle detection are integrated into the control algorithms.

Path Planning and Navigation:- Implement path planning algorithms to generate optimal or collision-free trajectories for each drone within the formation. Develop control algorithms that enable each drone to follow its planned trajectory
accurately.

Testing and Simulation:- Conduct simulations to test and validate the formation control algorithms in a virtual environment.
Perform field tests in controlled indoor environments to fine-tune and validate the swarm's behavior.

Safety Measures and Fail-Safe Mechanisms:- Implement safety protocols, including emergency stop procedures, to ensure safe drone operation. Develop fail-safe mechanisms to handle unexpected events or sensor failures.

Human-Drone Interaction:- Design user interfaces for operators to plan missions, monitor the swarm, and intervene when necessary. Establish safety procedures for human-robot interaction, especially in indoor environments with human presence.

Data Logging and Analysis:- Collect data from drone operations, including sensor data, localization information, and formation control parameters. Analyze the data to improve the formation control algorithms, optimize performance, andtroubleshoot issues.

Scaling and Adaptability:- Ensure that the formation methodology can scale to accommodate varying numbers of drones and adapt to different indoor environments and mission requirements.

Regulatory Compliance and Permissions:- Ensure compliance with local regulations and obtain any necessary permissions or permits for indoor drone operations.

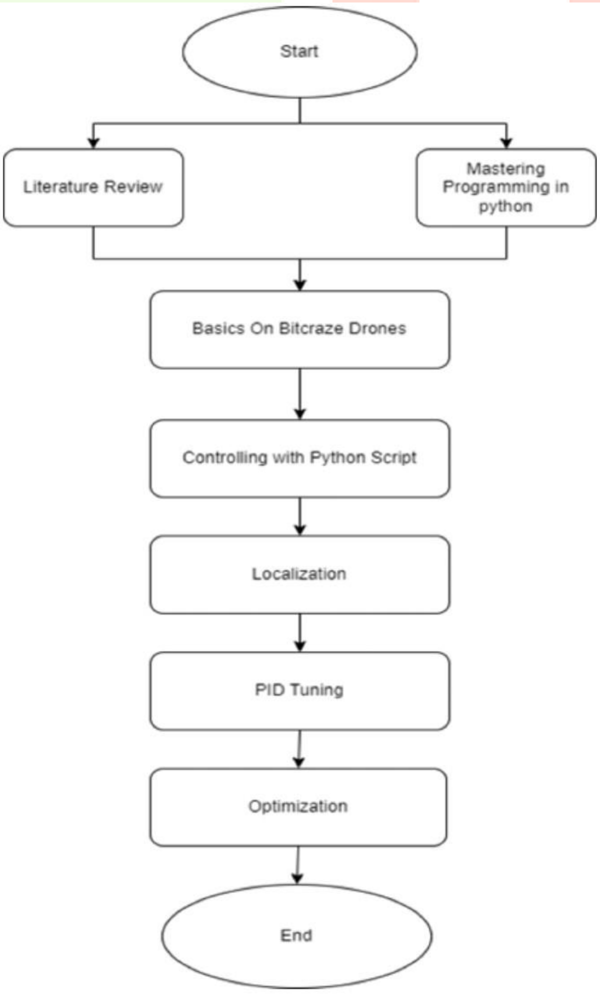
Deployment:- Deploy the drone swarm in the target indoor environment, following the planned mission objectives and safety procedures.

Monitoring and Maintenance:- Continuously monitor the swarm's performance during operations. Conduct regular maintenance and updates to hardware and software to ensure optimal performance.

Data Collection and Reporting:- Collect mission data and generate reports on the swarm's performance, mission success, and any issues encountered.

Feedback and Iteration:- Gather feedback from operators and stakeholders to identify areas for improvement. Iterate on the formation methodology and algorithms to enhance performance and reliability.

This procedural flow outlines the key steps involved in creating and deploying an indoor drone swarm formation. The process requires careful planning, technical expertise, and on going maintenance to ensure the successful execution of various indoor applications.



VI. SELECTION OF COMPONENTS

Selecting components for an indoor drone formation involves careful consideration of various factors, including the specific requirements of your project, budget constraints, and the capabilities you want your drones to have. Here's is how we choose the right components:

Define the Purpose of the Formation:Determine the purpose of your indoor drone formation. Are you creating an entertainment show, conducting research, or developing a swarm of drones for a specific task (e.g., inspection, mapping, surveillance) Knowingthe purpose will guide your component selection.

Budget Considerations: Determine your budget constraints. The cost of components can vary significantly, so it's essential to establish a budget early in the process.

Select the Drone Platform: Choose a drone platform that meets your needs. Consider factors like size, payload capacity, flight time, and ease of customization. Popular options for indoor formations include small quadcopters or hexacopters.

Flight Controller: Select a reliable flight controller that is compatible with your chosen drone platform. Popular options include Pixhawk, DJI Naza, or custom flight controllers like ArduPilot. Ensure it supports multi-drone coordination if needed.

Sensors:Depending on your project's requirements, choose sensors such as:- GPS: While indoor environments typically lack GPS signals, some advanced systems use GPS for initial positioning before transitioning to indoor navigation. LiDAR or Depth Cameras: These sensors are essential for obstacle detection and collision avoidance in confined spaces. IMU (Inertial Measurement Unit): IMUs provide data on the drone's orientation and movement. Ultrasonic Sensors or Range Finders: These are useful for altitude control in indoor environments. Visual Sensors: Cameras can be used for visual SLAM (Simultaneous Localization and Mapping) to navigate and maintain formation.

Communication Systems: Ensure your drones can communicate with each other and a ground control station (if applicable).
Common communication methods include Wi-Fi, Bluetooth, or custom RF modules.

Propulsion System: Select appropriate motors, propellers, and ESCs (Electronic Speed Controllers) based on your drone's weight, size, and performance requirements.

Battery and Power System:Choose batteries that provide enough power for your drone's flight time and payload capacity.
Consider factors like voltage, capacity, and weight. Make sure the battery management system (BMS) is reliable.

Control Software :Select or develop control software that allows for precise control of each drone in the formation. This may include flight control algorithms, path planning, and coordination logic.

Safety Measures: Incorporate safety features, such as fail-safes, emergency stop mechanisms, and redundant systems to prevent accidents in an indoor environment.

Testing and Calibration: Plan for extensive testing and calibration of your drones and their components to ensure they can work together effectively in a formation.

Integration and Communication Protocols: Ensure that all components can communicate effectively using standardized protocols, like MAVLink for drone communication.

Regulations and Compliance: Be aware of any local regulations governing indoor drone operations and ensure compliance with safety and privacy guidelines.

Maintenance and Support: Consider the availability of spare parts and technical support for the components you choose, as maintenance is an ongoing requirement.

Scaling Up: If you plan to expand your formation in the future, think about scalability and the ability to add more drones seamlessly.

VII. PROPOSED WORK MODULES

Basic control of drones: Installation of basic libraries such as cflib and cfclient to connect with the drones, as well as development of a python script to control the drones for basic actions.

Positioning of Drones:Choosing an appropriate indoor positioning system for the drones to provide a consistent input of altitude and reference position for improved navigation. Configuring the indoor positioning system and integrating it with the drone.

PID Tuning:The Partial integrative derivative is the main factor that informs the drone about it and helps to stabilize the drone based on weight distribution, external factors, and so on.

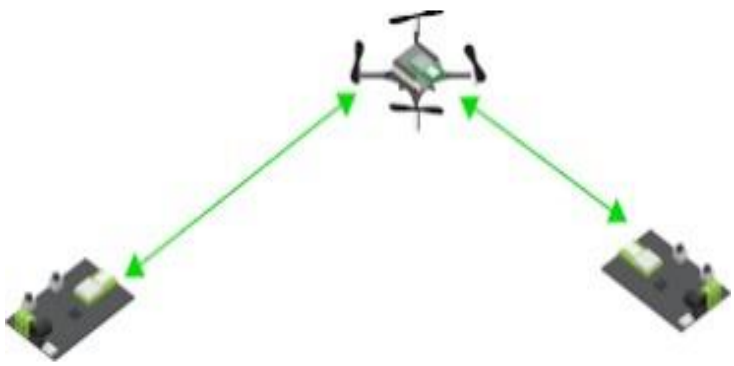
Localization: Localization is the process by which a drone determines its position in relation to other drones in the swarm using a loco positioning system that measures distance between drones by sending a radio wave and calculating its time.

Optimization of loco positioning system: The loco positioning system uses radio waves, and we use 6 loco positioning nodes for advanced drone stabilization, where the decks are arranged in an inverse triangle in the corners of the room, and the optimisation of distance between the decks plays a major role in drone stabilization, so the decks are kept at different distances and tested for an optimal distance.

Ros2 Implementation: The ROS2 facilitates multi-robot control; a python script is developed for swarm control, and the ROS nodes aid in communicating with multiple drones at the same time and in developing a collision-free trajectory. Using the python script and ROS, we can simulate the drone swarm formation; if the formation is successful in simulation, we implement it in real drones and produce the drone swarm formation.

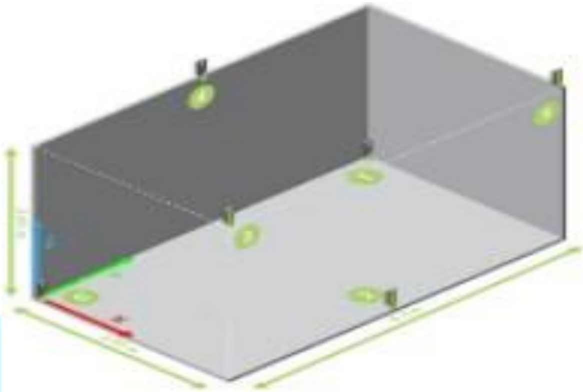
VIII. RESULT

Indoor localization unit for indoor drone swarm is created and optimized for its purposes and here is the explanation and results of it The loco positioning system uses three different positions, two different path (TWR),time difference of arrival 2 (TDoA 2) and time difference of arrival 3 (TDoA 3). In TWR mode, tags ping ports sequentially, making it possible to measure the distance between tags and ports. Using this information, a theoretical minimum of 4 anchor points are needed to calculate the 3D position of the tag, but the more accurate number is 6 to make this repeatable and accurate.

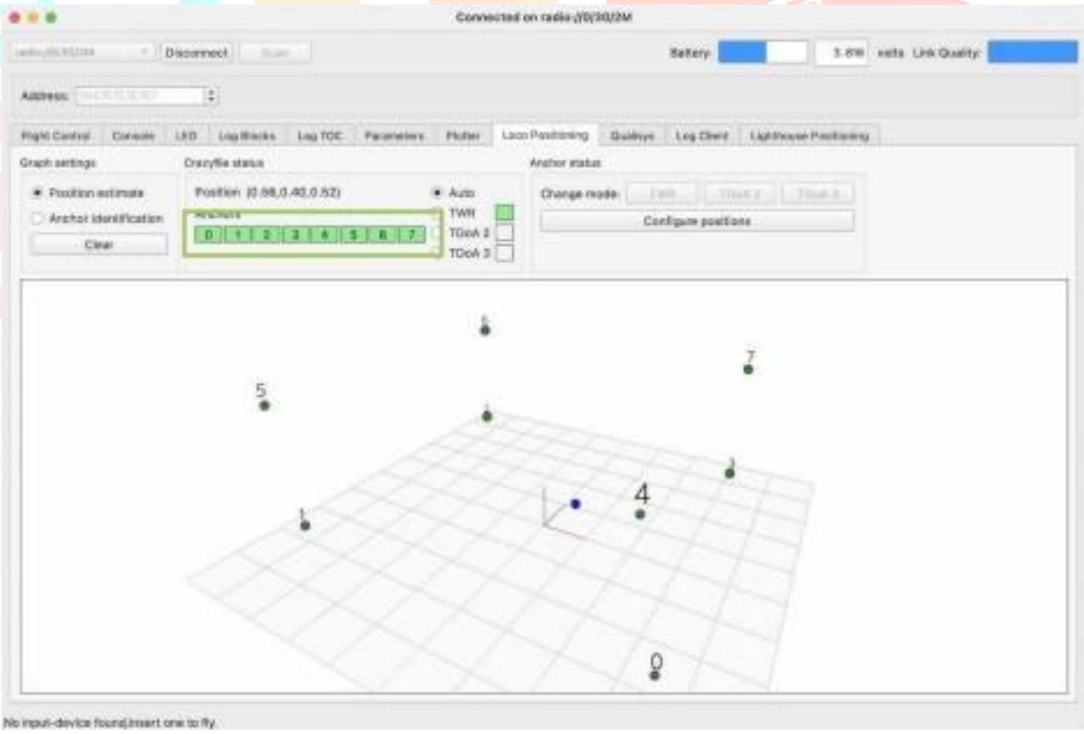


This mode is the most accurate and works even when the tag or Crazyflie is out of station. Active tags communicate with anchors in a time-slotted manner. Only one Crazyflie can be placed in this mode and a maximum of 8 anchors can be placed.In TDoA 2 mode, it continues to send packets parallel to the anchor.

Tags listening for these packets can calculate the difference between two ports by measuring the time difference between packet arrivals. According to the TDoA language, 3D position in space can be calculated. In this mode, tags are only listened to, so new tags do not burden the system, making it possible to focus on one of the tags or Crazyflies at a time. This makes it an excellent model for integration. Compared to TWR, TDoA 2 is more stringent in terms of where positioning operates, the best beacon must always be within or very close to the position determined by the fixation system. This means that TDoA 2 works best with 8 ports placed at the corners of the flight deck. At this setting, accuracy and sensitivity are compared to TWR.In this mode, the connection is time slotted and synchronized and ports are limitedto 6



TDoA 3 mod has many similarities with TDoA 2 and supports all characters or Crazyflies. The main difference is that the slotting concept in TDoA 2 is replaced by transmission time, which makes it possible to add more anchors. By adding ports, the system can be expanded to a larger area or multiple rooms without having to find lines at each port. It also makes it stronger and can control the loss or addition of ports



IX.CONCLUSION

In this study, we embarked on the exploration of indoor drone swarm formation, a field with immense potential and relevance in various domains, including entertainment, research, and industrial applications. Through a rigorous analysis of our experimental results and discussions, several important conclusions and insights have emerged. First and foremost, our experiments demonstrated the feasibility of creating and controlling indoor drone swarms in complex, confined environments. By employing a carefully selected set of hardware components, communication protocols, and coordination algorithms, we were able to achieve remarkable results in terms of formation accuracy, stability, and efficiency. Our performance metrics, including formation accuracy and communication reliability, consistently met or exceeded our expectations.

These results indicate that, with the right configuration and tuning, indoor drone swarm formations can be a reliable and effective solution for a wide range of applications.

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