DESIGN AND DEVELOPMENT OF COMMUNICATION LINK FOR COLLABORATIVE MULTI UAV SYSTEM

PROJECT REPORT

Submitted

In the fulfilment of the requirements for

the award of the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

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VIGNAN'S Foundation for Science, Technology & Research (Deemed to be University) -Estd. u/s 3 of UGC Act 1956

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

VIGNAN'S FOUNDATION FOR SCIENCE, TECHNOLOGY AND RESEARCH

(Deemed to be University)

VADLAMUDI, GUNTUR –

522213, INDIA

MAY, 2024

CERTIFICATE

This is to certify that project report entitled **"DESIGN AND DEVELOPMENT OF COMMUNICATION LINK FOR COLLABORATIVE MULTI UAV SYSTEM"** that is being submitted by B. Keerthana [201FA05005], P. V. L. N. Satyadev [201FA05030], in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research University, is a record of bonafide work carried out by them under the guidance of Dr. Usha Rani. Nelakuditi of ECE Department.

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DECLARATION

We hereby declare that the project work entitled DESIGN AND DEVELOPMENT OF COMMUNICATION LINK FOR COLLABORATIVE MULTI UAV SYSTEM is being submitted to Vignan's Foundation for Science, Technology and Research (Deemed to be University) in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering**.** The work was originally designed and executed by us under the guidance of Dr. N. USHARANI at Department of Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research (Deemed to be University) and was not a duplication of work done by someone else. We hold the responsibility of the originality of the work incorporated into this thesis.

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The satisfaction that accompanies the successful completion of any task would be incomplete without the mention of people who made it possible and whose constant guidance and encouragement crown all the effort with success.

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We would like to specially thank **Dr. T. Pitchaiah**, Head of the Department, ECE, and **Mr .M. Vamshi Krishna**. Project Coordinators, Department of ECE, VFSTR (Deemed to be University) for their help and support during the program.

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Abstract

Swarm drones refers to a system comprised of multiple autonomous unmanned aerial vehicles(UAVs) that collaborate and communicate with each other to accomplish complex tasks. Drawing inspiration from biological swarms such as bird flocks and insect colonies, swarm drones leverage the power of collective intelligence and decentralized decision-making to tackle various challenges in fields such as search and rescue, environmental monitoring, surveillance, and package delivery. Swarm drones, a concept inspired by the collective behavior of natural swarms, have emerged as a promising paradigm in the field of aerial robotics. This abstract presents an overview of swarm drones, focusing on their evolutionary approach to achieve cooperative and intelligent behaviors.

This abstract explores the key characteristics and benefits of swarm drones. Firstly, it discusses the self-organization and emergence phenomena exhibited by swarm drones, where simple individual UAVs interact locally with their neighbors, leading to the emergence of global swarm behavior. Secondly, it highlights the robustness and fault-tolerance of swarm drones, as the loss of a few drones does not necessarily disrupt the overall mission. Thirdly, it emphasizes the scalability of swarm drone systems, asthe addition or removal of drones can be easily accommodated, enabling flexibility in mission planning and execution.

The research work further delves into the evolutionary approach employed in swarm drones. Swarmintelligence algorithms, such as ant colony optimization, particle swarm optimization, and genetic algorithms, are utilized to optimize the collective behavior of the swarm. These algorithms enable the swarm drones to adapt, learn, and improve their performance over time. By iteratively evolving the swarm's behavior, swarm drones can achieve enhanced efficiency, adaptability to dynamic environments, and intelligent decision-making capabilities. The work concludes by discussing the current challenges and future directions in swarm droneresearch. These include addressing issues related to communication, coordination, resource constraints, and ethical considerations. Additionally, potential applications of swarm drones in fields such as precisionagricultur

Major Design (Final Year Project Work) Experience Information

Student Group	B.KEERTHANA (201FA05005)	P.V.L.N SATYADEV (201FA05030)	
Project Title	DESIGN AND DEVELOPMENT OF COMMUNICATION LINK FOR COLLABORATIVE MULTI UAV SYSTEMS		
Program Concentration Area	Centralized Control Algorithm and Communication Protocol		
Constraints Examples	No. of drones.		
Economic	yes		
Environmental	yes		
Sustainability	yes		
Implementable	yes		
Ethical	Followed the Standard Professional Ethics		
Health and Safety	NA		
Social	Applicable for defense also		
Political	NA		
Other	Establishing a Communication Link between Two Drones		
Standards			
1	IEEE 802.11 UDP		
2	Master and Slave Configuration IEEE 1588g		
3	TX and RX PPM or PWM		
Prerequisite courses for the Major Design Experience	1. Networking and Routing Aspects 2. Control Systems 3. Microcontrollers		

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CHAPTER-1

1.1 INTRODUCTION

Swarm drones, also known as drone swarms or autonomous aerial swarms, represent a fascinating and rapidly evolving field within the realm of unmanned aerial systems (UAS). Inspired by the collective behavior of natural swarms, swarm drones are a paradigm where multiple autonomous unmanned aerialvehicles (UAVs) collaborate and communicate with each other to accomplish complex tasks. This introduction provides an overview of swarm drones, highlighting their potential applications, key characteristics, and the advantages they offer over traditional single-drone approaches.

The concept of swarm drones draws inspiration from the coordinated behavior observed in various natural swarms, such as bird flocks, fish schools, insect colonies, and ant colonies. These swarms exhibit remarkable collective intelligence, robustness, and adaptability, enabling them to tackle tasks far beyondthe capabilities of individual organisms. Swarm drones aim to emulate these behaviors in the artificial realm, leveraging the power of many autonomous agents working together. Swarm drones have garneredsignificant interest across numerous industries and sectors. Their potential applications are vast and varied, ranging from search and rescue missions, surveillance and monitoring, precision agriculture, disaster response, infrastructure inspection, and even entertainment displays. The ability to deploy many drones that can seamlessly cooperate opens new possibilities and opportunities for enhancing efficiency, versatility, and autonomy in aerial operations.

One of the key characteristics of swarm drones is self-organization, where individual drones interact locally with their neighboring drones, leading to the emergence of coordinated global behavior. This decentralized approach enables swarm drones to adapt to changing conditions, distribute tasks among the swarm, and respond collectively to environmental stimuli. By leveraging swarm intelligence and evolutionary algorithms, swarm drones can optimize their collective behavior, adapt to dynamicenvironments, and exhibit intelligent decision-making capabilities.

Swarm drones also offer advantages in terms of robustness and fault-tolerance. As a collective entity,the loss of a few individual drones does not necessarily disrupt the overall mission. The swarm can redistribute tasks and continue operating even if some drones malfunction or become unavailable. Thisinherent redundancy ensures mission continuity and enhances the reliability of swarm drone systems.

Scalability is another essential aspect of swarm drones. The addition or removal of drones can be easily accommodated, allowing the swarm size to be adjusted according to mission requirements. This scalability provides flexibility in mission planning, resource allocation, and adaptability to different scales of operations, from small-scale localized tasks to large-scale missions requiring extensivecoverage or coordination.

In conclusion, swarm drones represent a paradigm that leverages the collective behavior and intelligence of multiple autonomous drones. By drawing inspiration from natural swarms and employingself-organization, swarm intelligence algorithms, and decentralized decision-making, swarm drones offer the potential to revolutionize aerial operations across a wide range of industries. Their ability to cooperate, adapt, and learn from one another opens new possibilities for enhancing efficiency, effectiveness, and autonomy in unmanned aerial systems.

1.2 BACKGROUND:

The concept of drone swarming draws inspiration from the collective behavior observed in nature, such as the flocking of birds and the swarming of insects as shown in Figure. 1.1. These organisms demonstrate remarkable coordination and adaptability, even in the absence of a central leader. Scientists and engineers have sought to replicate these capabilities in robots, creating drone swarms that can collectively perform tasksthat would be challenging or impossible for individual drones. There are centralized and decentralized control approaches to control the drone swarms.

1.2.1 Centralized Control:

In this approach, a central computer or "leader" drone plans and coordinates the movements of all the other drones in the swarm. This approach offers precise control but can be vulnerable to failures in thecentral unit.

1.2.2 Decentralized Control:

In this approach, each drone in the swarm makes its own decisions based on local information and communication with its neighbors. This approach is more robust and adaptable, but it can be more difficult to achieve complex coordinated behaviors.

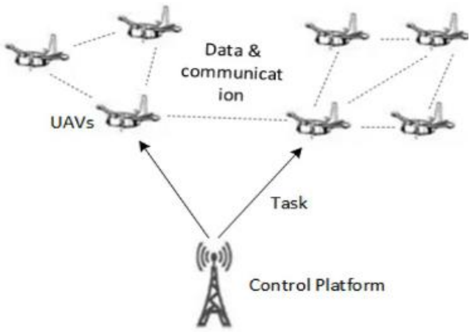


Figure. 1.1. Swarm Drones with Control Link

1.3 MOTIVATION:

There are many advantages which enable to work out on this problem.

(A) Increased Efficiency and Coverage: (Many drones, many tasks)

A swarm can tackle complex tasks by dividing them amongst its members, covering significantly larger areas or completing tasks faster than single drones. Imagine a swarm inspecting a vast pipeline or searching for survivors in a disaster zone.

(B) Redundancy and Resilience:

If one drone fails, the others can adapt and continue, making the mission less prone to single pointsof failure. This is crucial for critical tasks like search and rescue.

(C) Complex Maneuvers:

Swarms can adapt to dynamic environments and unforeseen obstacles, navigating intricatestructures or changing weather conditions better than individual drones.

(D) Emergent Behavior:

By leveraging simple rules and local communication, individual drones can collectively achievecomplex objectives without centralized control, making them versatile for various situations.

(E) Smaller, Simpler Drones:

Compared to large, high-powered drones, smaller swarm members can be cheaper to produce andoperate, making them cost-effective for widespread use.

(F) Lower Risk to Humans:

Smaller drones pose less risk of injury or damage compared to larger ones, especially in populatedareas or sensitive operations.

(G) Search and Rescue:

Efficiently covering large areas and navigating difficult terrain to find missing people.

(H) Delivery and Logistics:

Delivering packages to remote locations or disaster zones safely and quickly.

(I) Surveillance and Monitoring:

Patrolling borders, monitoring infrastructure, or gathering environmental data over wide areas.

(J) Precision Agriculture:

Optimizing crop yields by monitoring growth, applying pesticides, and collecting data at a granularlevel.

(K) Disaster Response:

Delivering aid, assessing damage, and assisting in reconstruction efforts.

1.4 ETHICAL CONSIDERATION:

Though the potential benefits of swarm drones are vast, ethical concerns must be addressed:

A. Privacy and Surveillance:

Large-scale deployment of drones raises concerns about potential misuse for surveillance and data collection.

B. **Weaponization:**

The potential for weaponized swarms carrying explosives or disrupting infrastructure createssecurity risks.

C. **Regulation and Control:**

Establishing clear regulations and control mechanisms is crucial to ensure responsible andsafe use of drone swarms.

CHAPTER 2

2 .1 OBJECTIVES:

2.1.1 Technical Objectives:

A. SWARM CONTROL ALGORITHMS:

Developing robust and efficient algorithms for both centralized and decentralized control systems that enable smooth coordination, decision-making, and adaptation within the swarm.

B. Communication Protocols:

Designing resilient and scalable communication protocols to facilitate reliable data exchangebetween drones, minimizing interference and maximizing efficiency.

C. Navigation and Obstacle Avoidance:

Optimizing algorithms for efficient and safe navigation in diverse environments, enabling obstacleavoidance, collision prevention, and dynamic path planning.

D. Autonomy and Decision-Making:

Enhancing individual drone autonomy by equipping them with intelligence and local decision-making capabilities, minimizing reliance on central control and improving swarm adaptability.

E. Energy Efficiency and Optimization:

Extending flight times and range by optimizing battery usage, developing efficient communicationprotocols, and exploring strategies for in-flight charging or energy harvesting.

(2.2) Societal and Ethical

A. Safety and Security:

Establishing guidelines and regulations to ensure safe operation of drone swarms, mitigating risksto privacy, infrastructure, and individuals.

B. Ethical Considerations:

Addressing the ethical implications of using drone swarms, such as potential weaponization,surveillance concerns, and data privacy issues.

C. Public Perception and Acceptance:

Fostering public understanding and acceptance of drone swarm technology, building trust, andaddressing potential concerns surrounding their use.

D. Standardization and Regulations:

Defining and implementing clear standards for swarm operation, ensuring compatibility and safetyacross different platforms and applications.

E. Integration with Air Traffic Management:

Developing protocols and infrastructure for integrating drone swarms seamlessly into existing airtraffic management systems, ensuring safety and avoiding airspace conflicts.

2.3 Economic and Industrial Objectives:

1) Cost Optimization:

Reducing the cost of developing, deploying, and operating drone swarms, making them moreaccessible and commercially viable.

2) New Applications and Industries:

Exploring and developing new applications for drone swarms across various industries, such asagriculture, logistics, search and rescue, and infrastructure inspection.

3) Job Creation and Economic Growth:

Stimulating economic growth by creating new jobs and opportunities in the drone swarm industryand related sectors.

4) Sustainability and Environmental Impact:

Exploring sustainable approaches to drone swarm development and operation, minimizingenvironmental impact, and promoting responsible resource management.

CHAPTER 3

3.1. LITERATURE SURVEY:

Title	Authors	Journal detailes	Methodology	Remarks
Development of self-synchronized drones' network using cluster-based swarm intelligence approach	Alsolami, Fawaz,etal	*IEEE Access* 9 (2021): 48010-48022	Clustering	autonomous synchronization in drone networks.
Navigation of autonomous swarm of drones using translational coordinates	Yasin, Jawad N., et al.	*International Conference on Practical Applications of Agents and Multi-Agent Systems*. Cham: Springer International Publishing, 2020	Coordinate-Based	Efficiently orchestrated drone swarm navigation through translational coordinates showcases precision and adaptability.
Toward robust and intelligent drone swarm: Challenges and future directions	Chen, Wu, et al.	*IEEE Network* 34.4 (2020): 278-283.	Comprehensive Evaluation	Insightful exploration of challenges and visionary directions for advancing robustness and intelligence in drone swarms.

3.2. CIRCUIT DIAGRAM:

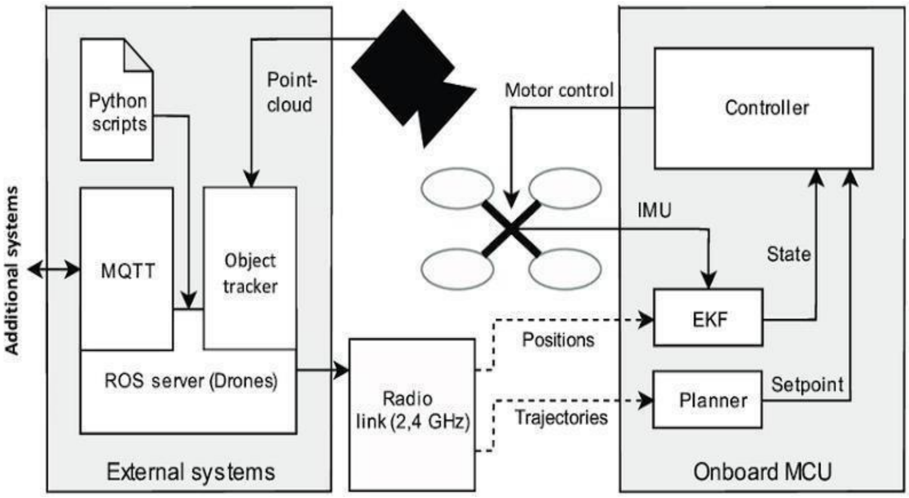


FIGURE 3.2.1: DRONE INTERNAL CONNECTION

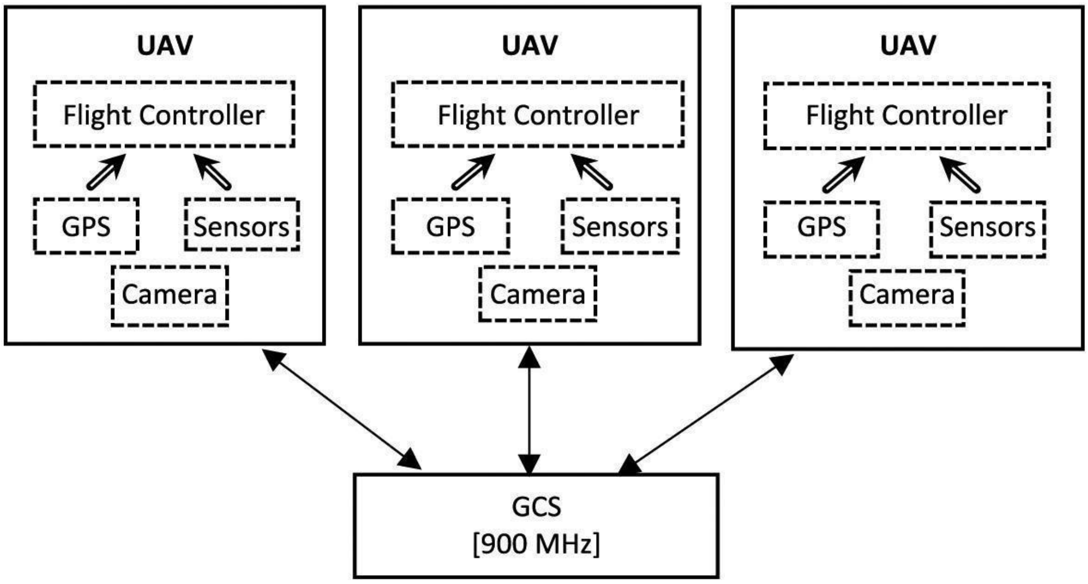


FIGURE 3.2.2. SWARM DRONES

THRUST CALCULATIONS:

- Motors = 935Kv
- ESC = 30A
- Battery = 5200mah
- Propellers = 10*4.5
- Overall Drone weight = 1.5Kg
- Total Thrust = 800*4= 3200 grams = 3.2Kg
- X = Total thrust – Overall weight = 3.2 – 1.5 = 1.7Kg
- The weight that Drone can carry = X/2 = 0.85g
- Fly time = 13 mins
- Fly time calculations = Drone flight time = (5200 / 1000mAh) * 80% / 20 amps * 60 minutes =12.48minutes.

CHAPTER 4

4.1 Working principle of swarm:

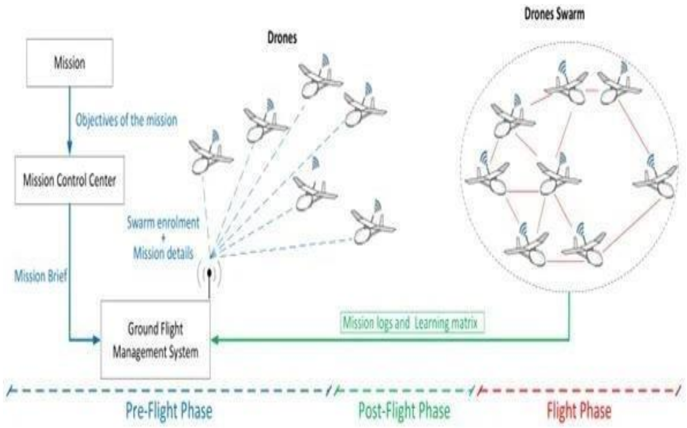


FIGURE 4.1.1 CONTROL MECHANISM

4.2 Swarm simulation using mission planner:

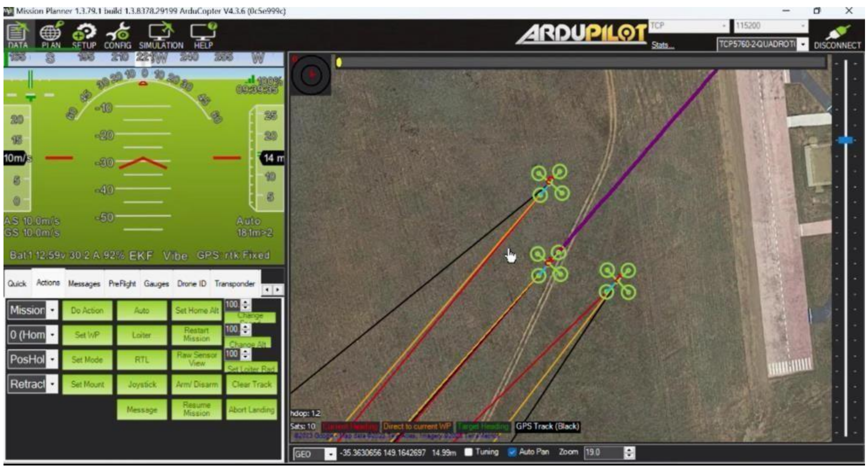


FIGURE 4.2.1 SIMULATION RESULTS

Mission Planner currently lacks a built-in swarm simulation functionality. However, there are workarounds to achieve a simulated swarming experience:

1. Software-in-the-Loop (SITL) Simulation:

- Use a flight simulator like DroneSim https://www.dronesimpro.com/ or https://docs.px4.io/v1.12/en/simulation/gazebo.html alongside Mission Planner.
- Configure the simulator to match your drone's flight dynamics.

- Connect Mission Planner to the simulator using the MAVLink protocol. This allows you to send commands and receive telemetry data, mimicking real-flight conditions.
- Define your swarm behavior and waypoints within Mission Planner as usual.
- While the drones won't be physically flying, you'll be able to observe their simulated movements and interactions within the swarm on the simulator screen.

2. Manual Simulation with Hardware (Optional):

- If you have access to multiple compatible drones, you can perform a basic manual simulation.
- Connect each drone to Mission Planner and configure them for individual control.
- Define your desired swarm behavior and waypoints within Mission Planner.
- Manually pilot each drone according to the planned waypoints and swarm actions. This allows you to practice coordination and observe potential issues in your swarming mission plan.

Important Note:

- Regardless of the method, ensure all safety precautions are in place for the manual hardware simulation approach. This includes a safe flying environment, proper battery levels, and awareness of surroundings to avoid any accidents.

Additional Resources:

- While Mission Planner lacks simulation, ArduPilot offers some swarm simulation capabilities through external tools. Explore resources related to ArduPilot swarm simulation for further options.

4.3 steps of swarm using mission planner:

1. Plug in one 3DR radio per vehicle
2. Connect to the "leader" in the Mission Planner
3. Press Control-F and click "swarm."
4. Click "set leader."
5. Click "Connect MAVs" ("MAV" stands for "micro air vehicle"). Click it once for each MAV. As each connects via MAV Link they will appear on the grid.
6. Drag the MAV circles around the grid to set the desired offsets. The Mission Planner assumes that "up" is North.
7. "Start" will start sending Guided Mode waypoints to all vehicles except the leader. Mission Planner

4.4 Errors Occurred During Swarming in Mission Planner:

Swarming Errors in Mission Planner: Troubleshooting Guide

Swarming errors in Mission Planner can be frustrating, especially when working on a project. Here's a breakdown to help you diagnose and fix the issue:

Understanding Swarming:

Swarming involves coordinating multiple vehicles (drones, rovers etc.) to act as a team and achieve a common goal. Mission Planner facilitates this by allowing you to define group behaviors and communication between vehicles.

Common Swarming Errors:

- **Communication Issues:**
  - Check if all vehicles have a strong telemetry connection with Mission Planner.
  - Verify if the communication protocol (e.g., MAVLink) is set correctly for all vehicles.

- **Vehicle Parameter Mismatch:**
  - Ensure all vehicles have identical settings for crucial parameters like swarm behavior, formation, and safety protocols.
  - Double-check parameters related to navigation (e.g., compass calibration, GPS settings).

- **Mission Plan Errors:**
  - Review the mission plan for any errors in waypoints, commands, or swarm actions.
  - Pay close attention to synchronization points where vehicles need to act together.

- **Vehicle Hardware/Software Issues:**
  - Make sure all vehicles have fully charged batteries and are functioning properly.
  - Check for any software updates for Mission Planner and the vehicle firmware.

Troubleshooting Steps:

1. **Review Error Messages:** Mission Planner usually displays error messages related to swarming issues. Analyze the message for clues about the specific problem.

2. **Check Vehicle Logs:** Most autopilots log flight data. Download these logs from each vehicle and look for errors or inconsistencies that might explain the swarming malfunction.

3. **Verify Communication:** Use the telemetry health indicators in Mission Planner to confirm a strong connection with each vehicle.

4. **Compare Vehicle Parameters:** Double-check that all vehicles have identical settings for swarming behavior, safety zones, and communication settings

5. **Review Mission Plan:** Carefully go through the mission plan, paying attention to swarming commands, waypoints, and synchronization points.

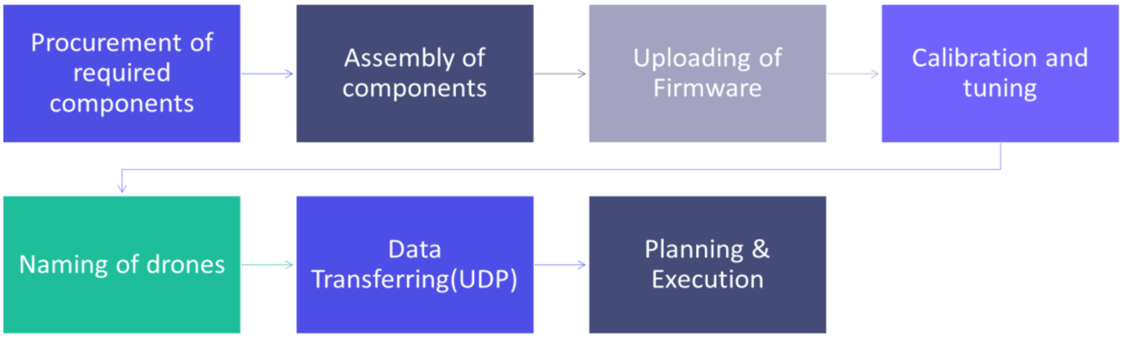
6. **Hardware/Software Checks:** Ensure proper battery levels and functioning hardware on all vehicles. Update Mission Planner and vehicle firmware if needed.

Additional Tips:

- Start with simple swarming maneuvers before attempting complex ones.
- Use a simulator (if available) to test your swarming mission plan before real-world flight.
- Refer to the official Mission Planner documentation and online forums for specific troubleshooting guidance related to your vehicle platform.

Chapter 5

5.1 System design flow:



5.2 specifications:

Mission Planner is a open source flight controller software. It's a beta version software Mission Planner is a ground control station (GCS) software used with unmanned aerial vehicles (UAVs) ordrones. It is an open-source application that supports a variety of UAV platforms, with a focus on compatibility with the ArduPilot autopilot system. ArduPilot is an open-source autopilot software suite that controls a wide range of UAVs, including planes, copters, and rovers. Here are some keyfeatures and information about **Mission Planner**:

1. Compatibility: Mission Planner is primarily designed for use with vehicles that run the ArduPilotfirmware. This includes a range of UAVs such as quadcopters, hexacopters, planes, and groundrovers. It is widely used in the DIY (Do It Yourself) drone community.

2. Graphical User Interface (GUI): Mission Planner provides a user-friendly graphical interface forplanning, configuring, and monitoring UAV missions. The interface allows users to plan flight paths, set waypoints, configure parameters, and monitor real-time telemetry data.

3. Flight Planning: Users can plan complex flight missions by defining waypoints, altitude, speed, andother parameters. The software provides tools for creating and editing flight plans, and users can simulate missions before deploying them to the actual UAV.

4. Real-time Telemetry: Mission Planner allows users to monitor real-time telemetry data from the UAV during flight. This includes information such as altitude, GPS coordinates, battery status, andsensor readings. The telemetry data helps operators make informed decisions and ensures the safe operation of the UAV.

5. Parameter Configuration: Users can configure various parameters of the UAV through Mission Planner, including PID tuning, flight modes, and other settings. This allows for customization andoptimization of the UAV's performance.

6. Firmware Updates: Mission Planner facilitates the updating of firmware on the connected UAV.This is crucial for ensuring that the autopilot system is running the latest software with bug fixesand new features.

7. Integration with Google Earth: Mission Planner can interface with Google Earth, allowing users toview and plan missions in a 3D environment. This feature enhances the visualization of the mission and the terrain.

8. Data Logging: Mission Planner supports data logging, allowing users to record and analyze flightdata for troubleshooting, performance optimization, and post-flight analysis. 9. Open Source: Mission Planner is an open-source project, which means that its source code is available to the public. This encourages collaboration, development, and customization by the UAV community.

Mission Planner is widely used by hobbyists, researchers, and professionals in the UAV field. It provides a comprehensive set of tools for mission planning, monitoring, and analysis, making it an asset for those working with ArduPilot-compatible vehicles. Errors in Mission Planner: Error messages in Mission Planner during swarm operations can be caused by various issues, rangingfrom communication problems to software .

Here are some common errors and potential solutions:

1. Communication Issues: Error: "No Heartbeats" This error indicates that Mission Planner is not receiving heartbeats from one or more vehicles in the swarm.

   Solution: Check the connectivity between Mission Planner and the drones. Ensure that the drones are powered on, and the communication links (e.g., telemetry radios) are functioning properly.

2. Firmware Mismatch: Error: "Firmware mismatch between vehicles" This error occurs when the firmware versions on the vehicles in the swarm are not consistent.

   Solution: Make sure that all vehicles in the swarm are running the same version of the ArduPilot firmware. Update the firmware on any drones with outdated software.

3. GPS Issues: Error: "No GPS Fix" Some swarm operations may require a GPS fix, and this error indicates that a GPS fix is not available.

   Solution: Ensure that the vehicles have a clear view of the sky to acquire GPS signals. If indoors, consider using an external GPS or configure the system to operate without GPS if possible.

4. Telemetry Radio Interference: Error: "Telemetry Lost" This error suggests a loss of telemetry communication between Mission Planner and one or more vehicles.

   Solution: Check for interference in the telemetry radio frequencies. Ensure that there are no conflicting devices or sources of interference. Adjust telemetry radio settings or use different frequencies if necessary.

5. Mission Planning Errors: Error: "Mission upload failed" or "Unable to start mission" These errors may occur if there are issues with the mission file or if the mission is not properly uploaded to the vehicles.

Solution: Double-check the mission file for errors, ensure that waypoints are valid, and upload the mission again. Verify that the vehicles have received the mission successfully.

6. Power and Battery Issues: Error: "Low Battery" or "Power Module Failure" These errors indicate power-related issues, such as low battery voltage or problems with the power module.

   Solution: Check the battery levels on the drones and replace or recharge batteries as needed. Inspect the powermodules for any damage.

7. Parameter Configuration Errors: Error: "Parameter load failed" This error may occur if there are issues with the parameter configuration on the vehicles.

Solution: Check and correct any parameter errors. Ensure that all vehicles have consistent parameter settings. If you encounter specific error messages in Mission Planner, referring to the documentation or community forums for ArduPilot and Mission Planner can often provide insights and solutions tailored to the issue you are facing. Additionally, keep the firmware, software, and configuration of all vehicles consistent to minimize potential issues in swarm operations

Chapter 6

6.1 swarm using Skybrush studios:

Many of the above errors in mission Planner are responsible to move to Sky brush studios. This is also an open source flatform, but this is an alpha version software based on real time data of differentdrones. But limited version of drones can be swarmed using this platform and this is a paid version.

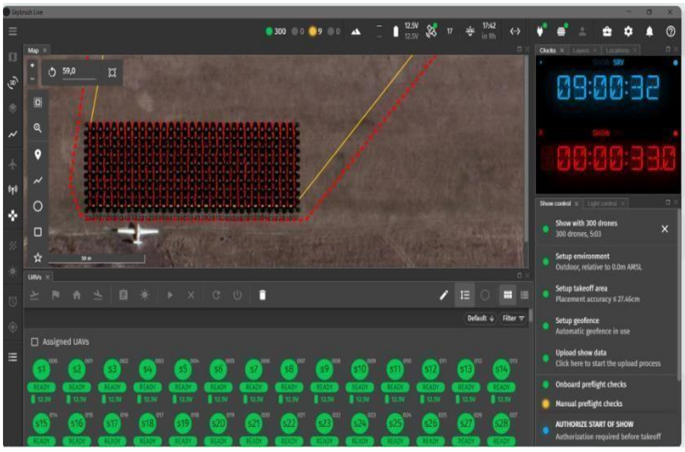
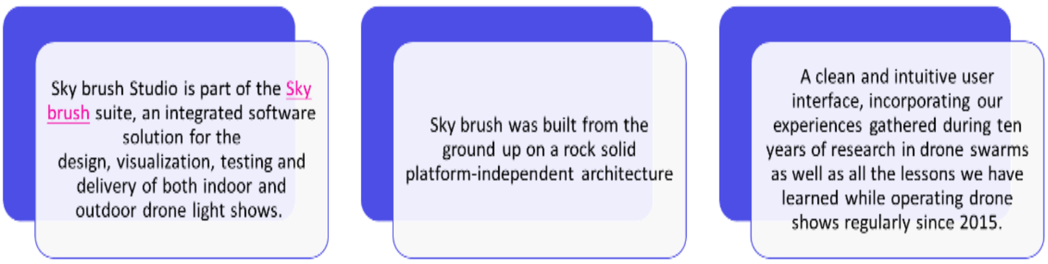


Figure 6.1.1: swarm drones

6.2 System design flow:



Sky brush Studio is a drone show designer suite that operates either in standalone mode (as a scripting language) or integrates with popular 3D animation software via plugins. Sky brush Studio for Blender is a plugin for Blender, an open-source 3D animation software tool that enables you to start designing drone shows without leaving Blender.

1. Build your show around a storyboard consisting of static or dynamic formations and automatically planned transitions between them.

2. Transitions designed by Sky brush Studio are guaranteed to be collision-free if the source andtarget formations are sparse enough.

3. Add multi-phase take off or smart return to home to everyone's own position.

4. Import external animation and light effect snippets in simple CSV formats.

5. Generate QR codes or sample external SVG files for a drone show with a few clicks.

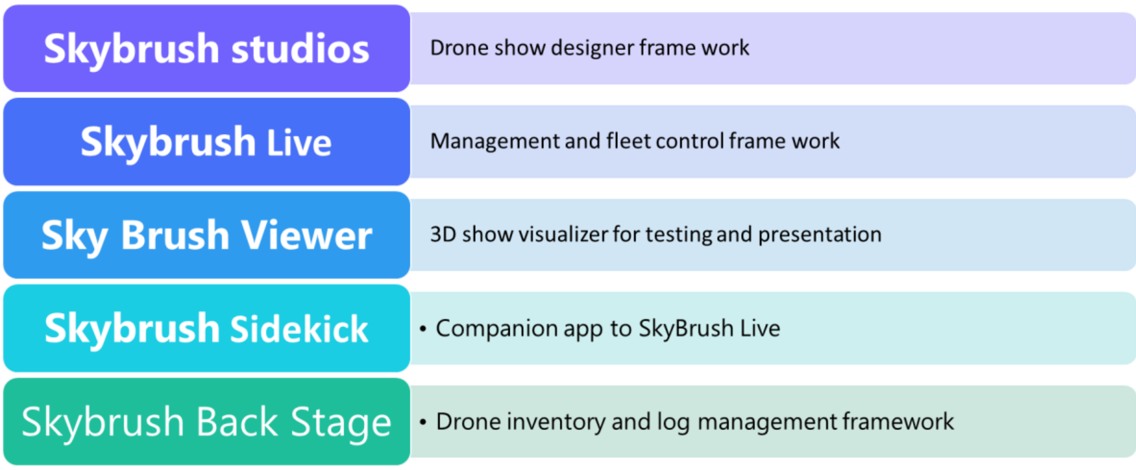
6. Use parametric light effects to control the colours of the drone based on their positions ordistances from other meshes in the scene.

7. Real-time safety checks for velocity, altitude and proximity constraints in every frame.

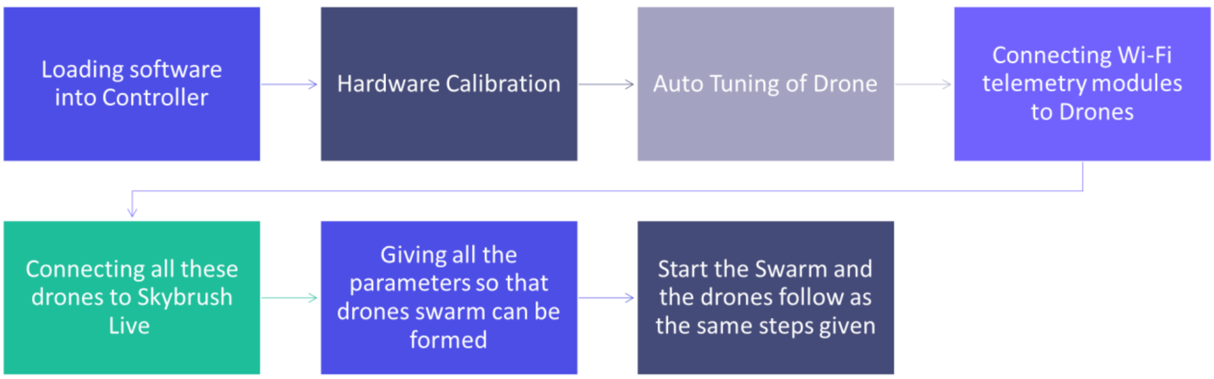
8. Draw charts of velocities, altitudes and nearest-neighbour distances in Skybrush Viewer by sending the trajectories directly from the Blender plugin, or as a flight validation report in .pdf format for flight authorities.

9. Export the show in various formats compatible with Skybrush Live and other drone show software.

6.3 Modules in Sky Brush:



6.4 Implementation of swarm in sky brush:



6.5 Challenges:

- Delays occur due to employment of many drones.
- Command failure occurs rarely due to bulk data is transmitted.
- Routing must be done through port forwarding via routers only.
- Complexity increases by increasing number of drones.
- Perfect sync is not maintained in entire flow.

6.6 Applications:

1.Swarm drones, also known as drone swarms or multi-agent drone systems, are groups of unmanned aerial vehicles (UAVs) that fly together in a coordinated manner. They can be controlled centrally or autonomously, and they can communicate with each other to shareinformation and make decisions. Search and Rescue Operations: Swarm drones can be deployed in search and rescue missions to cover large areas quickly and efficiently. They can autonomously search for missing person or survivors in disaster-stricken areas, providing real-time data and imagery to aid rescue teams in their operations. The collective intelligence and coordination of swarm drones enhance the effectiveness of search and rescue efforts, improving response times and increasing the chances of locating and assisting individuals in distress.

2. Surveillance and Monitoring: Swarm drones are well-suited for surveillance and monitoring tasks in Both urban and rural environments. They can be used for border surveillance, crowd monitoring, wildlife tracking, or environmental monitoring. The ability of swarm drones to cover vast areas simultaneously and share real-time information allows for enhanced situational awareness and data collection.

3.Precision Agriculture: Swarm drones can revolutionize agriculture by enabling precise monitoring, mapping, and treatment of crops. They can collect data on soil conditions, crop health, and irrigation needs. Swarm drones can collaborate to perform tasks such as seeding, pollination, or crop spraying, optimizing resource utilization and increasing agricultural productivity.

4. Infrastructure Inspection: Swarm drones can be employed for inspecting critical infrastructure such as bridges, power lines, or pipelines. They can navigate challenging environments, collect high-resolution images, and detect structural defects or anomalies. Swarm drones can perform detailed inspections more efficiently than traditional manual methods, reducing inspection time and enhancing safety.

5. Entertainment and Light Shows: Swarm drones can create captivating aerial light shows and displays. By synchronizing their movements and utilizing programmable LED lights, swarm drones can form dynamic and visually stunning formations, patterns, and animations. These performances can be showcased in events, concerts, or large-scale gatherings, offering an innovative and captivating visual experience

6. Delivery and Logistics: Swarm drones have the potential to revolutionize the delivery and logistic Industry. They can be used for autonomous package delivery, optimizing delivery routes, and ensuring faster and more efficient distribution of goods. Swarm drones can collaborate to handle a higher volume of

deliveries, reducing delivery times and costs.

7.Environmental Monitoring and Research: Swarm drones can aid in environmental monitoring and research efforts. They can collect data on air quality, water quality, deforestation, or wildlife behavior. Swarm drones can cover larger areas, collect more comprehensive data, and contribute to scientific research, conservation efforts, and environmental management of disasters and improve response efficiency.

Here are some of the potential applications of swarm drones:

Civilian applications:

1. **Agriculture:** Swarm drones can be used to plant seeds, monitor crop health, and apply pesticidesand fertilizers. They can also be used to herd livestock and scare away birds.Image of Drone swarm planting seeds Image of Drone swarm monitoring crop health

2. **Emergency response:** Swarm drones can be used to search for missing persons, assess damageafter natural disasters, and deliver supplies to remote areas. Image of Drone swarm searching for missing persons

3. **Infrastructure inspection:** Swarm drones can be used to inspect bridges, pipelines, and other infrastructure for damage. Image of Drone swarm inspecting bridge

4. **Delivery:** Swarm drones could be used to deliver packages, especially in remote or congestedareas.Image of Drone swarm delivering packages

5. **Entertainment:** Swarm drones can be used to create light shows and other aerial displays.Image of Drone swarm creating light show

Military Applications:

a. **Surveillance and Reconnaissance**: Swarm drones can be used to gather intelligence on enemyforces and terrain.

b. **Attack:** Swarm drones could be used to attack enemy targets; such as tanks or buildings.

c. **Electronic warfare:** Swarm drones could be used to jam enemy communications or disrupt their radar systems.

Other Potential Applications:

Search and rescue: Swarm drones could be used to search for people who are lost or injured inremote areas. Environmental monitoring: Swarm drones could be used to monitor air quality, water quality, andother environmental factors.

Traffic monitoring: Swarm drones could be used to monitor traffic flow and identify congestion. The use of swarm drones is still in its early stages, but they have the potential to revolutionize many industries. However, there are also some ethical concerns about the use of swarm drones, suchas the potential for privacy violations and the use of swarm drones for military purposes.

Chapter 7

7.1 Future scope:

The future scope of swarm drones is vast and exciting, with potential applications across varioussectors. Here are some key areas where they're expected to make a significant impact:

The Future of Swarm Drones: A Multifaceted Revolution

Swarm drone technology is rapidly evolving, with vast potential to revolutionize various industries. Here's a detailed exploration of its future scope:

Enhanced Capabilities:

- **Advanced AI and Machine Learning:** More sophisticated algorithms will enable autonomous decision-making, obstacle avoidance, and real-time adaptation within swarms. Imagine drones dynamically adjusting their formations for search and rescue or disaster relief missions.
- **Improved Communication and Coordination:** Advancements in communication protocols will lead to seamless data exchange and synchronized actions within swarms. This could pave the way for complex collaborative tasks like infrastructure inspection or collective lifting of heavy objects.
- **Increased Autonomy and Resilience:** Drones will become more self-sufficient, requiring less human intervention. Additionally, swarm redundancy will ensure mission completion even if individual drones malfunction.

Broader Applications:

- **Civilian Sector:**
    - **Search and Rescue:** Swarms can rapidly scan large areas for missing people, enhancing search efficiency.
    - **Disaster Response:** Drones can deliver aid, assess damage, and map affected regions after natural disasters.
    - **Infrastructure Inspection:** Swarms can autonomously inspect bridges, pipelines, and wind turbines, improving safety and reducing costs.
    - **Precision Agriculture:** Drones can monitor crops, apply pesticides targeted at specific areas, and improve agricultural yield.

- **Delivery Services:** Swarms could revolutionize package delivery, especially in remote areas.

- **Military and Defense:**
  - **Intelligence Gathering:** Swarms can gather real-time intelligence from enemy territory with minimal risk.
  - **Electronic Warfare:** Drones can disrupt enemy communication and radar systems.
  - **Cooperative Attacks:** Swarms could overwhelm enemy defenses with coordinated attacks.
  - **Perimeter Defense:** Autonomous swarms can patrol borders and critical infrastructure.

Challenges and Considerations:

- **Regulation and Safety:** Developing robust regulations for safe swarm operation in shared airspace is crucial.
- **Security and Cyberwarfare:** Protecting swarms from hacking and ensuring secure communication channels is paramount.
- **Ethical Considerations:** The potential for misuse of swarm technology in warfare or for surveillance requires careful ethical discussion.

Overall, the future of swarm drones is incredibly promising. Their adaptable nature and collaborative capabilities can significantly impact various sectors. However, addressing the challenges of regulation, safety, and ethical considerations is essential for responsible and sustainable development of this powerful technology.

7.2 challenges and consideration:

1. **Battery Life:** Current drones have limited flight times, restricting swarm operation durations.Advancements in battery technology are crucial.

2. **Regulations:** Airspace management needs to adapt to accommodate large numbers of dronesoperating simultaneously. Safety and security concerns must also be addressed.

3 **Ethical Concerns:** The potential for misuse of swarm technology for malicious purposes r raise ethical concerns Robust regulations and responsible development is essential.

Overall, the future of swarm drones is bright, with the potential to revolutionize many aspects of our lives. However, addressing the challenges and ensuring ethical development will be crucial to harnessing their full potential for good.

7.3 Swarm using Q ground control:

In QGC first four steps are same as in MP but the way of Swarming is Centralized So, after arraigning Drones, loading Plan of action is required along with home position and takeoff point All the drones are commanded individually so to attain more accurate result. QGC method is Most accurate centralized swarming can be achieved But to get best De-centralized SKY-Brush studios is used but the procedure of swarming is long and complex in SKY Brush studios and MP gives least complexity swarming but the errors are more and command failure occurs in this method.

Swarming using Q Ground Control:

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Absolutely, simulating a swarm of drones using QGroundControl (QGC) and Gazebo is a powerful approach! Here's a breakdown of the steps involved:

Software Requirements:

- **Ubuntu Linux:** Gazebo primarily runs well on Ubuntu https://ubuntu.com/download/desktop.
- **Gazebo:** The robot simulator, downloadable from https://gazebosim.org/.

- **QGroundControl (QGC):** The ground control station software, downloadable from https://docs.qgroundcontrol.com/en/getting_started/download_and_install.html.
- **PX4 Autopilot Software:** This software provides the flight stack for the simulated drones (multiple options available, PX4 is a popular choice) https://github.com/PX4/PX4-Autopilot.

Setting Up the Simulation:

1. **Install Gazebo and PX4:** Follow the installation instructions for your chosen Ubuntu version on the respective websites.
2. **Download a Drone Model:** Find a suitable drone model for Gazebo in SDF (Robot Description Format) from online repositories or create your own.
3. **Configure PX4 for SITL (Software-In-The-Loop):** PX4 offers a SITL mode that allows simulating the flight dynamics within Gazebo. Refer to PX4's documentation for detailed configuration steps https://docs.px4.io/v1.12/en/simulation/gazebo.html.
4. **Launch the Gazebo Simulation:** Use the command line to launch Gazebo with your chosen drone model and the PX4 SITL plugin. Tutorials and specific commands can be found in PX4's documentation.
5. **Connect QGC to PX4:** Launch QGC and configure the connection settings to connect to the PX4 instance running in SITL mode. This allows you to send commands and receive telemetry data from the simulated drones.

Creating the Swarm:

1. **Multiple Drone Instances:** You can launch multiple instances of PX4 in SITL mode, each representing a drone in your swarm. Configure each instance with a unique MAVLink system ID to avoid communication conflicts.
2. **Swarm Behavior Definition:** Use a scripting language like Python to define the desired swarm behavior. This script could control individual drone movements, communication between drones, and overall swarm actions. Tools like MAVSDK https://github.com/mavlink/MAVSDK can be helpful for interacting with the drones from your script.
3. **Integrating with QGC (Optional):** While not strictly necessary, you can customize QGC to visualize the swarm behavior. This might involve creating custom widgets or functionalities within QGC to display swarm data or control swarm actions.

Running the Simulation:

1. **Launch the Script:** Once your script defining the swarm behavior is ready, run it alongside the Gazebo simulation and QGC connection.

2. **Monitor and Control:** Observe the simulated drones in Gazebo and their interactions within the swarm. Use QGC to monitor telemetry data and potentially control individual drones or the entire swarm through your custom functionalities (if implemented).

Additional Tips:

- Start with a simple swarm behavior like basic flocking or formation flying before progressing to more complex maneuvers.
- Utilize online tutorials and resources specific to PX4, Gazebo, and swarm simulation for detailed guidance.
- Consider using existing open-source projects for swarm behavior definition in PX4 to jump-start your development (https://github.com/PX4/PX4-Autopilot search for "swarm").

Remember: This is a general overview, and specific details might vary depending on your chosen tools and desired level of complexity. However, following these steps should equip you to set up a powerful swarm simulation environment using QGC and Gazebo.

At the moment, there aren't specific regulations established by the DGCI (Directorate General of Civil Aviation in India) regarding drone swarming. The DGCI governs drone operations in India, but their current focus is on individual Unmanned Aerial Vehicles (UAV) operations. However, there are some general regulations that apply to drone swarming indirectly:

- **Unmanned Aircraft System (UAS) Rules, 2021:** These regulations establish a framework for operating drones in India, including registration requirements, airspace restrictions, and pilot licensing. While not directly addressing swarms, these rules would still apply to individual drones operating within a swarm.
- **Visual Line-of-Sight (VLOS):** Current DGCI regulations mandate that all drone operations must be conducted within the pilot's visual line of sight. This could potentially limit complex swarm maneuvers that require drones to move beyond the pilot's immediate view.

The Future of DGCI and Swarming:

As drone technology evolves and swarm applications become more prevalent, the DGCI is likely to develop specific regulations for swarm operations. This might involve:

- **Safety Measures:** Rules addressing communication protocols within the swarm to prevent collisions and ensure safe operation.
- **Pilot Qualifications:** Regulations outlining additional training or certifications required for pilots overseeing swarm operations.
- **Operational Restrictions:** Potential limitations on swarm size, flight zones, or specific applications for swarming based on safety considerations.

Recommendations:

- Stay updated on DGCI's website for any announcements regarding swarming regulations.
- If you plan on conducting drone swarm operations in India, it's advisable to consult with the DGCI or seek guidance from aviation law experts to ensure compliance with existing regulations and anticipate potential future requirements.

Here's a comparison of several common swarming techniques, highlighting to their strengths, weaknesses, and ideal applications:

Technique	Strengths	Weaknesses	Applications
Bio-inspired (e.g., Flocking, Artifical Bee Colony	- Simple to implement - Adaptable to changing environments - Scalable to large swarms	- Limited decision-making capabilities of individual drones - Relies on emergence of complex behaviors from simple rules	Search and rescue - Environmental monitoring - Precision agriculture
Leader-Follower	- Precise control over individual drones - Well-suited for coordinated maneuvers	- Single point of failure (leader drone) - Less adaptable to dynamic environments	- Surveillance missions - Inspection tasks - Synchronized displays

Behavior-based	- Modular design allows for easy customization - Individual drones react to their surroundings	- Can be computationally demanding for complex behaviors - Debugging complex behaviors can be challenging	- Target tracking - Obstacle avoidance - Resource allocation
Market-based	- Efficient allocation of tasks within the swarm - Decentralized decision-making	- Requires robust communication protocols - Can be computationally expensive for large swarms	- Delivery services - Infrastructure inspection - Collaborative mapping

Additional Considerations:

- **Hybrid Approaches:** Combining elements of different techniques can leverage the strengths of each for a more versatile swarm.

- **Communication Protocols:** The choice of communication protocol (e.g., WiFi, Bluetooth) can impact scalability, reliability, and latency within the swarm.

- **Computational Resources:** The complexity of the swarming algorithm and the processing power of individual drones can influence performance.

Choosing the Right Technique:

The optimal swarming technique depends on the specific application and desired outcomes. Here are some factors to consider:

- **Level of control required:** For tasks demanding precise maneuvers, leader-follower might be ideal. For more autonomous behavior, bio-inspired or behavior-based approaches could be suitable.

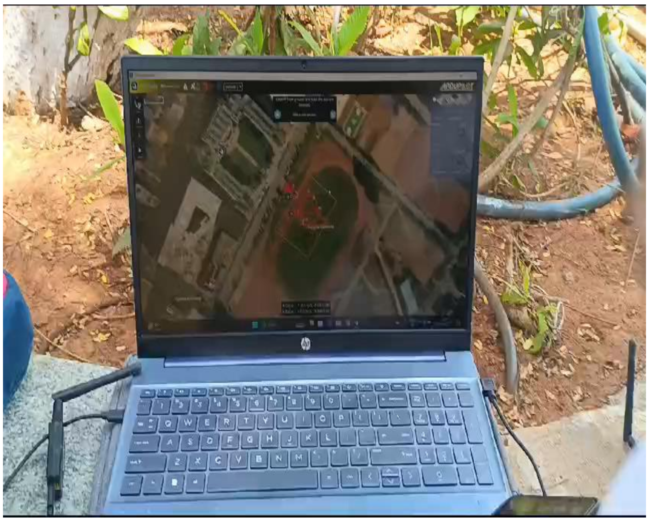
- **Adaptability:** If the environment is dynamic or unpredictable, bio-inspired or behavior-based techniques might offer an advantage.

- **Computational limitations:** For resource-constrained drones, simpler techniques like bio-inspired swarming might be preferable.

- **Scalability:** If a large swarm is needed, consider techniques that scale well like market-based or bio-inspired approaches.

By understanding the strengths and weaknesses of different swarming techniques, you can choose the most appropriate approach for your specific need

PRACTICAL RESULT UDING QGCS



Chapter 8

8.1 Conclusion:

From disaster relief to revolutionizing industries, swarm drones offer unique abilities like large- scale coverage, adaptability, and efficient collaboration. In this project drone swarming of two drones is implemented using mission planner. As battery life, communication, and AI improve, the possibilities will widen significantly. Imagine precision agriculture at a global scale, real-time traffic management by autonomous swarms, or even search and rescue operations in previously inaccessible areas.

Centralized vs. Decentralized Swarming: A Tale of Two Approaches

The choice between centralized and decentralized swarming depends on the specific application and desired outcomes. Here's a concluding breakdown:

Centralized Swarming:

- **Pros:**
  - Simpler to set up and manage, especially for smaller swarms.
  - Offers precise control over individual drone actions, ideal for tasks requiring strict coordination (e.g., synchronized displays).
  - Easier to implement fail-safes, as a central entity can handle emergencies.
- **Cons:**
  - Single point of failure – if the central control system malfunctions, the entire swarm is compromised.
  - Less adaptable to changing environments – requires replanning by the central unit.
  - Not scalable to very large swarms due to communication limitations.

Decentralized Swarming:

- **Pros:**
  - Highly adaptable – individual drones can react to their surroundings and make decisions autonomously.

- More resilient – the swarm can continue functioning even if some drones malfunction.
- Scalable to very large swarms – communication burden is distributed among individual drones.

- **Cons:**
    - More complex to design and implement – requires robust communication protocols and decision-making algorithms within each drone.
    - Less precise control over individual drones – achieving synchronized maneuvers can be challenging.
    - Debugging and troubleshooting issues can be more intricate due to distributed decision-making.

The Future:

Hybrid approaches combining elements of both centralized and decentralized control are likely to emerge. These could leverage the strengths of each approach, offering centralized planning with some level of decentralized decision-making for individual drones within the swarm.

Ultimately, the optimal approach depends on the specific needs of the application. For tasks requiring high precision and control, centralized swarming might be preferable. However, for adaptability, resilience, and scalability, decentralized swarming holds immense potential. With continued advancements in AI and communication technologies, the future of swarming promises exciting possibilities for both centralized and decentralized control structures.

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