APPLICATION OF UAV SWARM SEMI-AUTONOMOUS SYSTEM FOR THE LINEAR PHOTOGRAMMETRIC SURVEY

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ABSTRACT:

Unmanned Aerial Vehicles (UAVs) are used as stand-alone systems for a variety of purposes from agriculture, and environmental monitoring through architecture, and construction to humanitarian missions. The advantage of UAV is high spatial and temporal resolution but on the other hand, the disadvantage is the small area of cover and time demanding data collection. As a result of technological advancements, the complexity of systems to unprecedented levels these disadvantages can be solved by UAV Swarm systems. A UAV Swarm system is defined as the utilization of more than one UAV that are cooperating together in a semi-autonomous or autonomous manner to achieve a common goal. There are numerous factors in play while designing a system as advanced as a UAV Swarm. In our experiment, we focused on the semi-autonomous concept of creating and deploying a UAV Swarm with three Small UAVs in master-slave architecture for high-resolution fine-scale mapping. We demonstrate the implementation of collective behaviour of UAV swarm for river bed mapping that considers all on-board systems, including high resolution georeferenced aerial photography and navigation using high accuracy GPS. The testing field for this study was a 13.3 ha linear area of Solani River in the Haridwar district of the state of Uttarakhand, India. Images were captured by all three UAVs (one leader and two followers) and 5 ground control points (GCP) were used for geo-referencing. Aerial Triangulation and Bundle Block adjustment were processed by photogrammetric software Pix4DMapper. This UAV swarm mapping concept generates standard accurate geospatial results of 1.24 cm GSD and RMS Error 0.023 meter. Assessing the proposed system's efficiency and accuracy after such processes are taken into account reduces the time and cost manifolds of the UAV surveying.

KEYWORDS: UAV, UAV swarm, Swarm Mapping, UAV Photogrammetry.

1. INTRODUCTION

Current advances in remote sensing technology, particularly the use of small and efficient unmanned aerial vehicles (UAVs), are transforming aerial mapping, generating vast amounts of data that can be used to optimize processes in practically every aspect of topographic map generation. Before recent times, high-resolution satellite photos were regarded as the primary source of information, but this is changing owing to the widespread use of unmanned aerial vehicles (UAVs), which reduce issues such as high level of ground details and restricted availability of satellite imagery. Fixed-wing UAVs become impractical since they can't hover and must fly at too high an altitude. Therefore, rotary-wing UAVs like quadcopters have become the preferred option for the majority of studies (Fascista, 2022; Tang and Shao, 2015; Yao et al., 2019). Given the current state of the art, they are restricted in flight time, necessitating time and energy-efficient solutions (Sampedro et al., 2016). Aerial mapping also necessitates a higher level of autonomy for UAVs than their existing role as passive sensors with predetermined mission plans. The intelligent, real-time updating of the UAVs sampling strategies to reflect the information being acquired allows for greater concentration on important regions while avoiding wasting resources on less important locations. The principle of precision farming, "more production with less input" becomes attainable in this method. UAVs can cover a large area by a single flight of a swarm to observe crops, which minimizes human involvement in obtaining information on crop health status. Due to this timely detection of vulnerable health areas can save losses by adopting proper action (Velusamy et al., 2021). Similar techniques may be used on a UAV with more intelligent autonomy, but they are less versatile and efficient in terms of time and energy consumption. It's also worth noting that, despite falling hardware prices as the drone industry grows, top-end mapping systems with onboard autonomy and high accuracy sensors would still be prohibitively expensive.

As a result, an autonomous UAV is a liability that does not scale expenses with farm size and does not provide resilience against defects during operation execution. The foregoing discussion motivates the current research, which aims to use a swarm robotics approach involving groups of miniaturized low-cost UAVs that can provide collectively similar precision to high-end solutions, can be scaled to various farm sizes without sacrificing speed, and has intrinsic resilience against individual flaws (Rizk et al., 2020). That is why we have decided to create an experiment focusing on a multi-UAV-based swarm system for mapping the river bed.

2. STATEMENT OF THE PROBLEM AND MOTIVATION

High-level missions, such as automated target recognition and inspection or autonomous area exploration with a UAV may be

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difficult tasks. A strong and adaptable architecture is required to efficiently accomplish such high-level missions with a high level of autonomy A localization module for estimating the UAV's position in the world geodetic system, a mission planner for assigning and monitoring the mission's tasks, a projected path planner for assigning routes with obstacle avoidance, a trajectory control system for relocating the UAV along the desired routes given by the trajectory planner, and several modules for error checking, environment parameters monitoring, communication, and supervision are all required components of this architecture. The requirement for such architectures is stressed for complicated tasks that must be carried out in an industrial setting. Missions requiring the use of a complex and coordinated system, such as power line inspection, bridge inspection, and so on, necessitate the use of a coordinated system to optimize resources while fulfilling the objective. Due to the limited durability of the real batteries, doing these duties with only one UAV would need multiple inspection efforts in most circumstances. In these types of settings, the benefits of utilizing a swarm of UAVs can lead to more effective resource management and, as a result, cost savings for businesses. Furthermore, in a variety of missions where time is a vital limitation, a swarm of UAVs can be a very efficient way to complete the desired task (Jahan et al., 2020).

On the other hand, a UAV swarm is a complex system in which numerous units must work together efficiently. To do this, a modular and adaptive architecture capable of managing all of the elements of such a complicated system must be created. Our traditional generation has all of the essential capabilities for this management, but it lacked a coordinator capable of steering a multi-robot swarm of UAVs through the execution of a mission that could be dynamically re-adapted at any time if an issue occurred. This effort is a step in the right direction in that regard. As a result, new modules have been developed based on all of the functionalities of our current semi-autonomous architecture: the swarm system in Mission Planner (MP), which is in charge of dynamically and efficiently distributing missions across all of the agents in the swarm while monitoring swarm behaviour, and a local coordinator using the radio mesh network, who is in charge of executing these tasks with multipoint communication with the MP.

3. MATERIALS AND METHOD

The present paper intended to provide a real-time framework for UAV photogrammetric applications for topographic surveys using a UAV swarm system.

3.1 Study Area

The study area selected for testing the proposed system is located in the northern part of India. Roorkee is a city and municipal corporation in Uttarakhand, India, located in the Haridwar district. It is located on a level plateau under the Himalayan Shivalik Hills. The experimental site is located at an altitude of 268 meters and part of the district Haridwar, just 30 kilometers distant. It is positioned between the rivers Ganga and Yamuna on the banks of the upper Ganga canal. The test field selected for this experiment was the Solani riverbed, and the total area covered was 0.133 km^{2,} as shown in Figure 1.

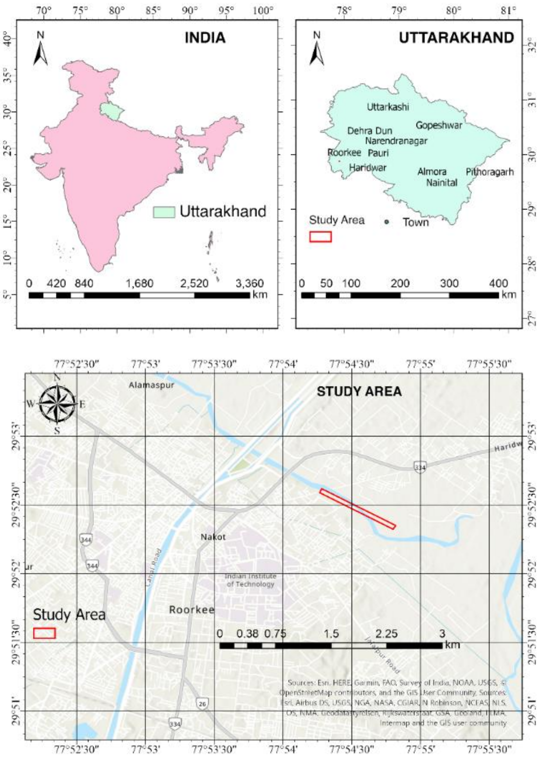

Figure 1. Study area map and UAV swarm testing field.

3.2 UAV Swarm System

Yaw, pitch, roll, and thrust and six degrees of freedom for movement and maneuvering are regulated by an underactuated autonomous and adaptive quadcopter and propellers in the UAV swarm system (Erdelj et al., 2017). There are different kinds of sensor and control devices required for every quadcopter to ensure a stable and controllable flight are ESC and IMU. The ESC operates the brushless motor while converting the Pulse Width Modulation (PWM) data from radio receivers or flight controllers by delivering a proper amount of electric power. ("https://ardupilot.org/planner/docs/swarming.html," n.d.).A little change in the speeds of the four motors while simultaneously providing a constant input signal to the four individual ESCs causes quadcopter position drift in the x-y plane. This drift is usually avoided by using flexible feedback control techniques.

Figure 2. Three UAVs connected with Mission planner for flight together.

An IMU is an electromechanical device that combines an accelerometer and a gyroscope into one unit. It aids in determining the quadcopter's angular location and altitude. The accelerometer is responsible for detecting acceleration forces such as gravity (applied to each axis) about the Earth, while the gyroscope is responsible for measuring the rate of angular rotation for each axis. Additional modules like a barometer, magnetometer, and altitude sensors may be utilized to provide very precise real-time information on height and direction of movement, making high-precision control of a drone much easier. Quadcopters frequently use the Global Positioning System (GPS). The primary goal of a navigation module like this is to enable path planning, tracking, and drone localization (Tahir et al., 2019).

APM Planner, which is also built on a multiple-vehicle architecture, offers more complex swarming/multiple-UAV control. However, Mission Planner does this in a restricted fashion by concurrently creating several serial port MAVLink connections and transferring GPS location data from one leader, flying in any mode, from manual to auto, to the other followers, flying in Guided mode. The leader's GPS position is updated by a predetermined offset before being communicated to the followers as a sequence of dynamic waypoints. The followers will follow the leader at predetermined X, Y, and Z offset distances (Khan Beigi and Reza Soleymani, 2021). Getting the beginning location in a UAV swarm might be difficult. The SYSID_THISMAV number and COM port are used to identify them in the grid. It's a good idea to fix the SYSID_THISMAV number to the physical vehicles so you can match the on-screen numbers and grid positions to the physical arrangement of the vehicles on the ground. Multiple networks with the same setup can be launched at the same time to accommodate additional nodes.

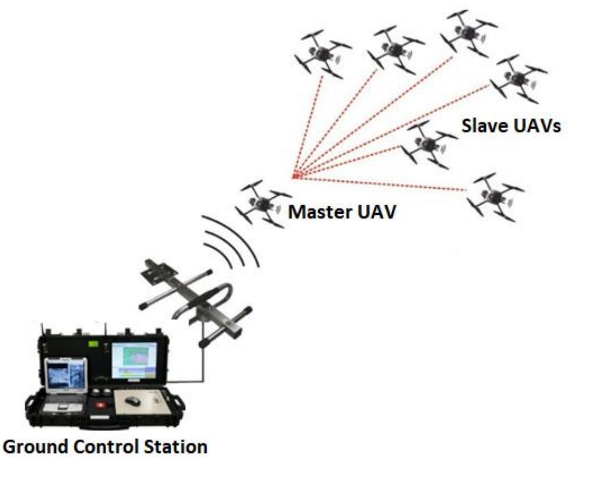

Figure 3. Proposed semi-autonomous architecture for UAV swarm.

3.3 Swarm Communication Architecture

The RFD900X telemetry radio establishes a mesh network by linking multiple drones to a single ground station without the need for additional radio on the central ground control station side. The role of fast-acting network monitoring and configuration software also needs to be included. The centralized communications architecture evolved from the development of single-UAV systems and was later applied to the creation of UAV swarm technology. As shown in Figure 3, it primarily consists of a central point to which all UAVs in the UAV swarm are effectively connected and responsible for exchanging information (Zhao et al., 2018). Under the system of decentralized communication architecture, the UAV operates and performs the interactive communication system in real-time in an ad-hoc manner as per the requirement of the mission, eliminating the dependency of the central control station and all restrictions on the communication system (Skorobogatov et al., 2020).

To solve the routing problem in multi-radio infrastructure mesh networks, in which each mesh node has multiple radio interfaces, and a subset of nodes acts as communication gateways. We introduce a new interference-aware routing mesh network that improves the discovery of pathways with lower interflow and intra-flow interference. This statistic and new capabilities for multi-radio networks are incorporated into the multipoint routing protocol to provide an improved mesh topology routing protocol (Campion et al., 2019).

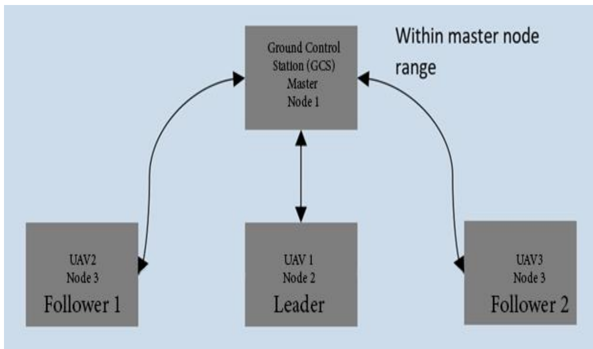

Figure 4. Multipoint mesh network using RFD900x modules.

Figure 5. UAV swarm flight in leader and follower mode.

We evaluate the performance of our new routing measure in our wireless testbed, which consists of four mesh nodes. There will still only be one master node, and all nodes will need to be in the range of the master for synchronization. Node 1 on NetworkIDs other than 0 will act as normal nodes and need no master node setting configurations. Nodes will only see other nodes on the same network (Davoli et al., 2021).

3.4 Flight Plan And Data Collection

The Solani River flowing along the Roorkee City was chosen to select a straight line and safe from human reach for testing the UAV swarm. The survey process was carried out by keeping the front overlap 75 % and the side overlap 75 % out of a total area of 0.133 km2.

Table 1. Flight parameters for UAV swarm system.

Parameter	Specification
Area of interest	0.133 km^2
Flying height	60 meters
Front overlap	75 %
Side overlap	75 %
Master UAV Flying Speed	5 m/s

UAV swarm has been deployed in every field of engineering mostly in the defense sector, but one field that remains untouched is aerial mapping. As far as UAV photographing is concerned, the UAV completes the mission by flying back and forth on its path during the mission. Since the task of photogrammetric mapping by the UAV swarm is to cover the area of interest in a single flight, each member of the UAV swarm must be at such a constant distance from the master UAV during the flight that the required side overlap for the photogrammetric calculation can be fully satisfied.

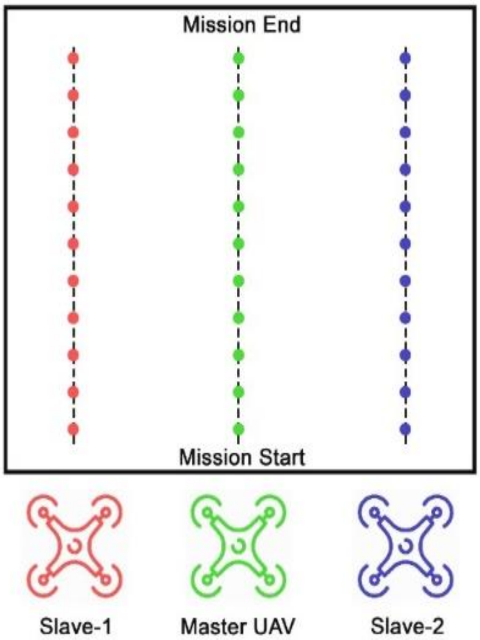

Figure 6.UAV swarm system for aerial mapping.

3.5 Methodology

It is conceivable for the UAV to scan a region of interest that is too large for a single flight. Because UAVs rely on batteries, their lifetime dictates how long they can remain in the air and, in turn, how much ground they can cover before they run out of power. In such instances, numerous flights employing two or three UAVs in an overlapping way may cover the whole research region. This allowed each mission region to be surveyed entirely in a single trip. In such instances, mission planning for the mission area is required (Nesbit et al., 2022). We must first establish and configure specific settings in your mission planner program before you begin shooting photographs. Figure 7 shows an example of a mission planner interface that you may use to schedule your flights. Take-off and landing site identification and specifications, flying height, direction, speed, number of flight lines, overlap, and other criteria are among them. These variables affect the final photographs as well as the entire flying campaign. As a result, it is critical to understand what goes into each of these characteristics and what to look out for when choosing them. We will need to figure out how high you want your UAV to fly, which will be determined by the spatial resolution of the final photographs and the focal length of the camera (Liu et al., 2022). The link between spatial resolution and flying height is inverse. The spatial resolution decreases as the flying height increases. Images are captured with an overlap to ensure the generation of a height model. Front overlap refers to the overlap between two consecutive photographs obtained on the same flight path, while side overlap refers to the overlap between two photos acquired on adjacent UAV flight tracks.

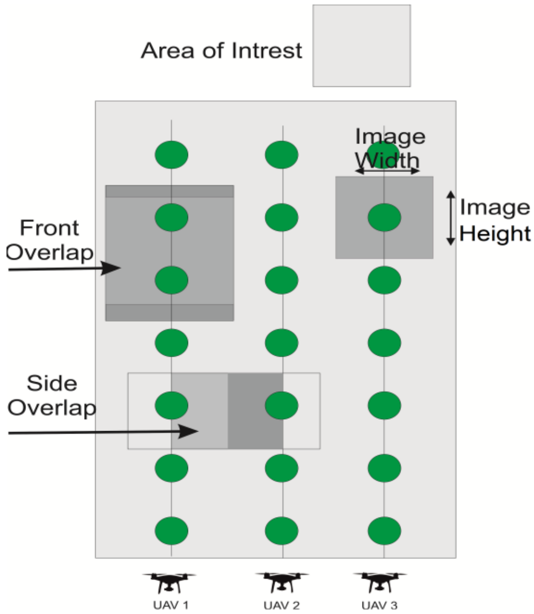

Figure 7. Flight parameters for UAV swarm flight.

A flight line is a route that the drone takes while gathering images, as the name implies. A shared region is seen on two sequential or adjacent pictures thanks to longitudinal and lateral overlaps. This allows for the creation of stereo pictures, which may then be used to create a height model. The percentage of forward and side overlap provided affects the number of flight paths and the number of photographs per flight path. Higher overlaps result in more flight lines and images per flight line, whereas smaller overlaps result in fewer paths and fewer aerial photographs per flight line. Overlaps of 75 to 75% were utilized inside the UAV swarm system. If precise height models are to be constructed, these overlaps are required (Rossi et al., 2017).

Aerial triangulation is a technique for obtaining the coordinates of all objects in a picture using geographical coordinates. The images must include 3D coordinates and aerial triangulation to determine the correctness of the mapping. The criteria for assessing aerial geometry in photogrammetry are now the same as in classic photogrammetry (Mugnai et al., 2022).

To a substantial fraction, the outcome of a UAV operation is driven by pre-flight planning. Mission planner programs are often included with UAVs, making this step quite simple. This step enables you to plan the whole flight mission by choosing and defining critical criteria for success. However, in the case of a UAV swarm flight, each UAV flight path separation is determined by the distance between the master UAV in the center and two adjacent slave UAVs. Therefore, make the best selections if you have a deeper grasp of these characteristics. As a result, this part will go through some of the key pre-flight preparations needed for a successful UAV operation (Šiljeg et al., 2022).

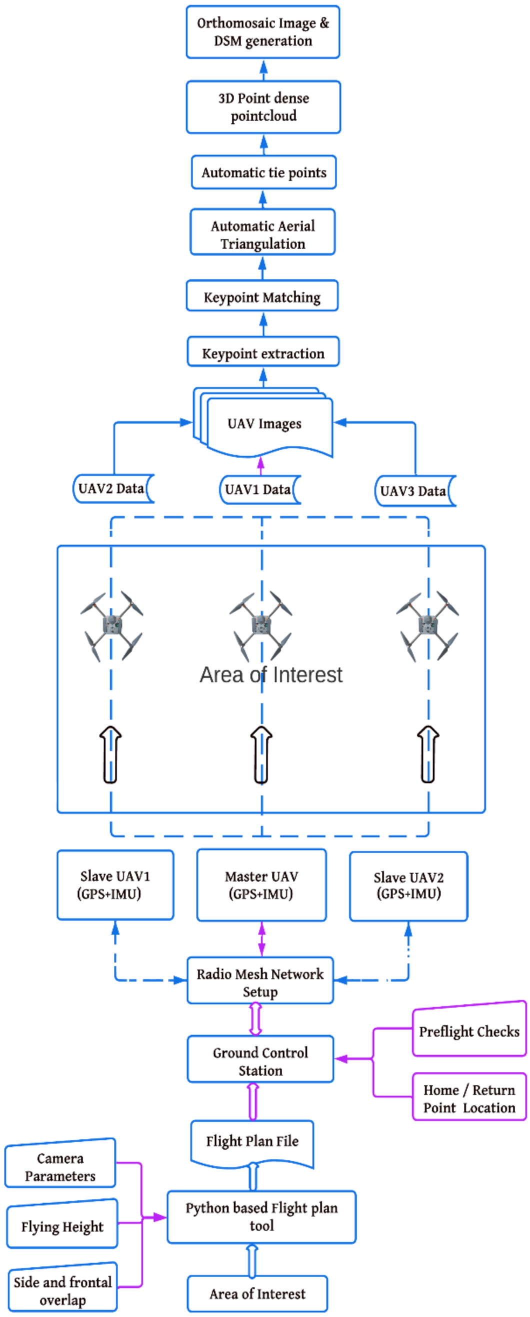

Figure 8.Complete methodology for UAV swarm system for aerial mapping.

4. RESULTS

Data acquired from the swarm system was processed in Pix4D Mapper pro photogrammetric software. Standard 3D mapping workflow was followed in the propriety software to generate DSM (Digital surface model) and Ortho-photo as shown below.

Figure 9. Data processing in Pix4DMapper photogrammetric software.

The accuracy of DSM (Figure 10) generation requires well-established feature points extracted from the image with accurate exterior orientation parameters. For this drone-based IMU and GPS data are utilized and this information is recorded in EXIF tags for each acquired image. The initialization of the photogrammetric process uses this information for calibration and further re-optimization of the solution. The triangulation algorithm based on Delauney triangulation is used. This method is recommended for flat areas (agriculture fields) and stockpiles.

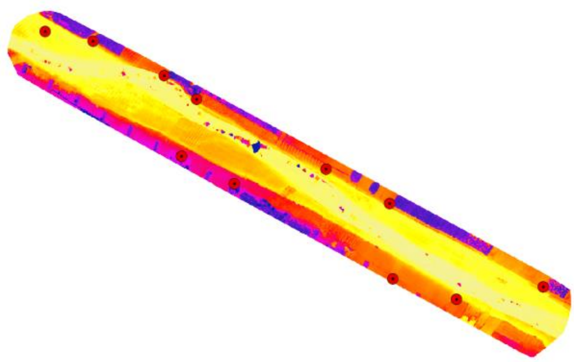

Figure 10.DSM generated by Pix4DMapper.

The resolution of ortho-photo is related to the resolution of DSM used, as a rule of thumb a DSM is generated from a set of images that varies in resolution >= 4 times the input image resolution. The point cloud, DSM, and, consequently, the ortho-photo accuracy are also affected by the quality of the initial images and their visual content. Generated ortho-photo here provides an orthographic overview of the study area consisting of a river bed with surrounding agricultural land parcels.

Figure 11.Orthomosaic of the area of interest.

For validation purposes, well-distributed 11 Ground control Points (GCP) were taken in the study area. GCPs were taken using Spectra Precision (SP60) GPS receiver in RTK mode. For accuracy assessment, these GCPs were compared with the derived DSM from the above-mentioned processing using Swarm-based image data. The notable vertical deviations as compared with the reference GPS points show very promising results as shown in the chart below.

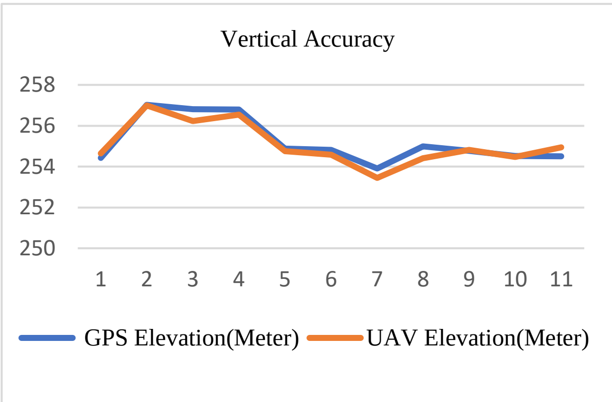

Figure 11. Comparison between GCPs and derived corresponding elevation values

5. CONCLUSION AND FUTURE WORK

It's very challenging and hard to integrate mission planning with unmanned aerial vehicles (UAVs) based Swarm system. To achieve the goal of designing adaptable and diversified mission planning architecture that can operate in real-time while maintaining the desired scalability, research and development efforts should focus on designing adaptable and dynamic architectures for a wide range of missions and integrated with other architecture modules. The present research is a step in that direction, with an emphasis on building a multi-UAV swarm mission planning architecture that can offer a solid and fully operational framework for completely autonomously performing different high-level tasks like Locate Targets or Exploring and aerial mapping.

To address the challenge of UAV swarm coordination, this study provides basic mission planning architecture for application scenarios based on a Mission Planner (MP). The MP can perform a low-level local mission (Find ground object) into multiple low-level missions and tasks and distribute them among the various UAV nodes that make up the swarm, thanks to its ability to plan and supervise in real-time the tasks that must be accomplished by each member in the swarm. A single multi-UAV flight was done for Solani Riverbed mapping were done in this study, with a swarm of three UAVs undertaking a high-level aerial mapping task. To determine the proposed architecture's scalability and adaptability. The suggested mission planning architecture's scalability and adaptability for a variable number of UAVs and various types of situations for broad area coverage are shown by results gained during flights. The immediate emphasis of future development is on the inclusion of numerous functions related to the mission management of the swarm's behaviour in the event of failures, such as the disconnection of each member of the swarm from the ground control station, and in the case of sensor controller failures. Another focus of the research is on examining various optimization techniques from various perspectives, such as optimizing the flight paths that the swarm group member must follow, boosting the swarm behaviour patterns using the time required to complete the mission, and ideal conditions based on the high level of flight autonomy of each UAV of the swarm group. The above-mentioned advancement results in a more efficient and resilient architecture for future research.

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