Cloud Infrastructure to Perform Distributed Multi-user Platform for Self-organizing Uav Swarms

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***Abstract* — Unmanned aerial vehicle (UAV) swarms offer a resource-effective and time-efficient method of collecting and analyzing data for a range of applications. The paper presents a cutting-edge collective artificial intelligence-powered self-organizing UAV swarm mission planning and preparing platform designed to enhance task performance with a fleet of UAVs and facilitate terrain monitoring. Users can create requests easily from the QT interface due to the cloud-based multi-user platform's interactive capabilities, which enable smooth user collaboration and real-time video viewing for group study of dynamic landscape imagery. Optimizing the behavior and performance of UAV swarm navigation maps, the UAV map configurator makes it easier to create and modify them. Additionally, the QT service layer guarantees safe data transfer to cloud servers, and the parameter gossip system encourages coordination and communication among swarm members. This integrated data sets significant parameters such as the number of swarm participants, starting relative coordinates, and statuses (imager and/or strike), and drives the establishment of critical swarm and target jobs. The server uses complex algorithms, such as the research road graph, which is based on the rotor-router model, and the complete information exchange graph, which uses the gossip/broadcast model, to carry out these tasks. These algorithms complement each other in the server environment, allowing the UAV swarm to plan and coordinate tasks more effectively. In addition, the platform provides the smooth transfer of the created goal tasks to each member of the swarms' memory, benefiting decision-making skills and swarm performance as an entire. The QT-based user interface also provides the capability to modify the specific member task type of UAVs. This implies that UAVs can be used for specific area consideration, information gathering, transport, or, in the case of a military use, as an enemy position attacker. A server environment and QT-based interface can be used as a data sharing transponder to accomplish all of these functional changes. The task categories within the mentioned swarm shift when alterations occur in the initial transfer graph of UAVs, necessitating the inclusion of new locations for completing the modified tasks. Additionally, ensuring a unified primary administrative domain and coordinated data transmission among users across multiple platforms are crucial aspects of the suggested method. This domain ensures secure connections and offers additional security features.**

***Keywords* — swarm of UAVs, gossip/broadcast models, rotor-router walk, mathematical models.**

I. INTRODUCTION

In recent years, UAVs (Unmanned Aerial Vehicles) have increasingly taken on diverse industrial and civilian roles, executing tasks that surpass human capabilities across extensive areas. These drones provide high performance, flexibility, stability, and efficiency, while preserving traditional resources. UAV swarms, configured in either ad-hoc or other formations, are essential for achieving high-demand, mission-specific objectives. Each UAV is tailored to its specific mission, offering resilience against individual drone failures, ease of device integration or removal, rapid mission execution due to parallel operations, and self-organizing capabilities.

A comparative analysis of UAVs, highlighting key features and applications of well-known drones, is presented in [1]. This study also examines UAV swarm management and control mechanisms. Protocols for UAV swarm management, including mission coordination and secure drone-to-drone communication, are discussed in [2]. Efficient swarm control methods are explored in [3] and [4]. Security aspects of UAV swarms, such as collision avoidance, self-organization, and swarm intelligence modeling, are detailed in [5] and [6]. The field extensively employs multi-agent system design, collective decision-making, and targeting algorithm development [7-9].

A UAV swarm operates as a mathematical multi-agent system, with each drone functioning independently. A set of simple, logically designed drones, configured as a cellular automaton on a connected graph, establishes a reliable framework for group decision-making. A key feature of swarm intelligence is its ability to exceed the capabilities of individual UAVs. Within a swarm, local uncertainties, errors, or malfunctions are mitigated by transferring responsibilities from compromised drones to neighboring swarm members. UAV swarm modeling, a relatively new and evolving field, investigates the collective behavior in decentralized self-organizing systems. UAV swarms are increasingly employed in topological and video surveillance, agriculture, climate monitoring, disaster management, civil security, and other emergency operations, thereby minimizing the human factor.

UAV swarm missions are divided into task and motion planning problems in robotics, employing strategies to build individual UAV trajectories. This involves collecting data on the surveyed area and identifying points of interest for flights, ranging from simple geometric paths to complex network solutions. The frequency characteristics and spatial location of the UAV swarm can be determined with high accuracy, forming a comprehensive, continuous image of the surveyed area. UAVs can operate independently while targeting and exchanging information with neighboring drones through logical links.

The development of a cloud platform for self-organizing UAV swarms, incorporating multi-agent systems (optimal gossip broadcast schemes, sandpile, and rotor-router models) and algorithms, represents a novel advancement in the field of logically linked, decentralized intelligent networks. Designing a software toolkit for self-organizing UAV swarms is complex and expensive. Therefore, integrating cloud technologies, virtual environments, and computing resources into a single platform offers realistic opportunities to overcome on-field challenges. The platform aims to reduce the time and cost of UAV swarm missions and support autonomous missions across diverse tasks and environments.

This study aims to design and analyze a secure cloud-based mathematical model for self-organizing UAV swarms. The proposed platform is intended to facilitate the deployment of adaptable, self-organizing UAV swarms in real-time, even in dynamic environments. Developing decentralized and self-organizing UAV swarms involves designing optimal and fault-tolerant schemes (gossip/broadcast models) for dynamic snapshotting and comprehensive image exchange of surveilled areas during the swarm's quasi-random walk (rotor-router model). The construction includes essential definitions, concepts, and mathematical models [10].

The premises for designing and implementing the cloud platform, in line with modern requirements, are based on our proposed and validated solutions for building high-performance computing infrastructures [11-12], AI-based big data gathering, classification, and processing [13-14], optimizing cloud computing environments [15], reducing energy consumption in electronic infrastructures [16], efficiently using HPC resources in linear arithmetic calculations [17], and providing cloud services [18].

II. PREPARATION ENVIRONMENT

This section discusses the simulation environment provided by the platform, including dynamic scenarios and environmental variables (see fig. 2).

2.1. Generate requests from QT environment

The Applications set is being created using C++/QT library with using Flask API's. So, everything is using QT environment to manage the toolset. The procedure for creating requests from the QT environment to power the platform's functionality is described in this section (see fig 1.).

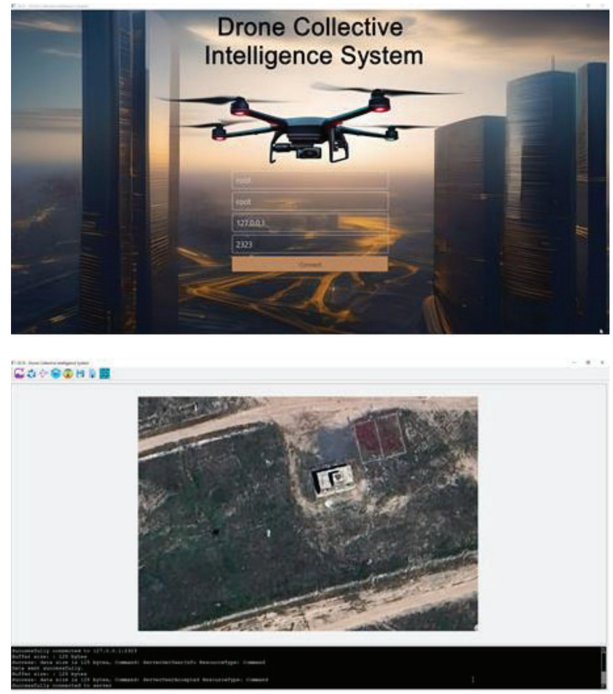

Fig. 1. User interface for desktop application.

The preparation platform must be started by an active server, and programs must automatically establish connections. Users submit location photographs to the server, which opens an input window with a map based on the coordinates of the image [18-19]. When users enter the necessary coordinates, the system determines the real-world coordinates for each pixel, guaranteeing accuracy when setting up the simulation environment. The QT service layer employs strong encryption to protect against assaults while transferring data to virtual servers in the cloud architecture over secure Internet TCP protocol communication channels. Users can design and manage maps for UAV swarm navigation and tasks with the help of the UAV map graph module. The JSON format of all requests guarantees effective and transparent communication between the platform and the QT environment. Using the computed absolute coordinates of the terrain image's pixels, users create a flight operation network for the UAV swarm. Precise planning for UAV operations is made easier by the classification of vertices into Corner, Side Border, and Inner types. After that, users enter the IP port of the drone to initiate communication and choose particular side vertices for UAV installation. The system creates coordinates and navigation data, which are put into the UAV ground station when the return router algorithm clears any network cycles. With the correct coordinates, the UAVs can navigate the network on their own without assistance from a human. Target locations for UAV strikes can be marked by users on the terrain image, with internal geographic coordinates. Users can change the provided default network topology as needed. All changes are recorded in a thorough log, which instantly notifies the cloud server and keeps all users' graphical interfaces in sync.

2.2. Cloud infrastructure

In the domain of logically interconnected and decentralized intelligent networks, the development of a cloud-based platform for mission preparation for self-organizing UAV swarms utilizing multi-agent systems-such as sandpile models, rotor-router models, and optimal gossip broadcast schemes-represents a significant innovation (see fig 2.).

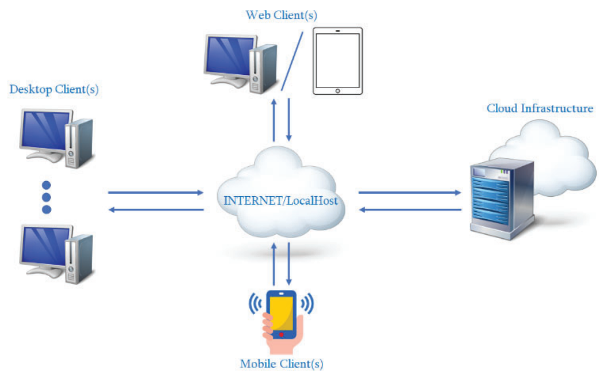

Fig. 2. Cloud infrastructure.

The creation of software toolsets for managing self-organizing UAV swarms is notably challenging and costly. Therefore, integrating virtual environments, cloud technologies, and computational resources into a unified platform presents practical opportunities to address these challenges. The proposed platform aims to enable autonomous mission execution across a diverse array of activities and scenarios, simultaneously reducing the time and cost associated with UAV swarm missions [18-19]. Our proposed and validated solutions for constructing high-performance computing infrastructures form the basis for the design and implementation of this cloud platform, adhering to contemporary standards [11], AI-powered collection, categorization, and processing of massive data [15], improving electronic infrastructure energy usage and cloud computing settings [16], utilizing HPC resources for linear algebra computations in an efficient manner [15] and cloud service disposal. Utilizing scalable computational resources and substantial storage capacity, cloud computing has significantly enhanced the efficiency of UAV image-processing operations [10]. Our approach employs a serverless cloud platform for high-performance computing (HPC), meticulously designed to manage the HPC workloads of the UAV swarm effectively, thereby ensuring the timely execution of swarm operations [16]. This platform leverages Kubernetes and container technologies, such as Docker and Singularity, to deploy and manage containerized applications. This approach facilitates the rapid and efficient completion of resource-intensive operations, eliminating the need for traditional, complex HPC infrastructure installation. By optimizing resource management and minimizing the potential for constraint violations, this method enhances the operational capabilities of the UAV swarm. Within the cloud infrastructure, a server execution environment is established, with a dedicated server allocated for executing swarm or single UAV flight operations. The IP address of this server is recorded in a working log file, which is accessible to users through a graphical user interface. Specific tasks are assigned to each server, initiating data processing and ensuring that results are visualized and synchronized. This configuration enhances the distributed and efficient execution of UAV flight operations and data processing.

III. MISSION PREPARETION HIERARCHICAL SYSTEM

The system is structured with a four-tier security hierarchy, wherein each tier grants specific access permissions and operational functionalities.

Tier 4: Observation-Only Access

User Group: General Clients Permissions: Limited to observing the graph editing workspace. Device Compatibility: Accessible via smartphones, tablets, and computer browsers. Functionality: Users can only view the workspace without altering the graph, ensuring data integrity and preventing unauthorized changes.

Tier 3: Basic Modification Access

User Group: Intermediate Clients Permissions: Authorized to make basic modifications to the graph workspace. Capabilities: Users can add or remove nodes and edges within the graph. Purpose: Facilitates structural adjustments to the graph while maintaining control over modifications.

Tier 2: Advanced Modification Access

User Group: Privileged Clients Permissions: Granted advanced editing capabilities, including strategic modifications. Capabilities: Users can introduce attacking drones and specify their targets, with actions at this level concealed from lower-tier users to uphold strategic confidentiality. Functionality: Supports complex operations and strategic maneuvers within the system, ensuring heightened control and operational security.

Tier 1: Administrative Access

User Group: System Administrators Permissions: Unrestricted root-level access. Capabilities: Administrators can approve all graph changes, upload maps indicating drone placement, and initiate missions. Responsibility: Ensures comprehensive oversight and control over the system, upholding operational integrity and security.

This structured hierarchy delineates distinct roles and responsibilities, bolstering security and operational efficacy. By segregating access levels, the system ensures that sensitive operations and data remain accessible solely to authorized personnel, safeguarding against unauthorized interventions. Each tier builds upon the permissions of the preceding one, establishing a logical progression of access and control. This hierarchical model offers a robust framework for managing user permissions, aligning each level of access with the user's role and responsibilities.

The tiered access system optimizes both security and functionality, preserving the system's integrity while accommodating necessary operational flexibility. This scientific approach to access management ensures precise delineation of capabilities for each user level, fostering a secure and efficient operational environment.

IV. CONCLUSION

Utilizing UAV swarms offers a cost-effective and efficient method for data collection and analysis across various industries. This study introduces a new self-organizing UAV swarm mission preparation platform. Through collaborative data exchange, crucial tasks like determining swarm size and coordinates are efficiently managed. This platform, powered by advanced algorithms, ensures seamless planning and coordination within the UAV swarm.

Similarly, implementing a hierarchical security system with four levels provides a structured approach to access management and operational integrity. From basic observation to advanced administrative control, clear roles and permissions are defined, safeguarding sensitive operations and data. Each level builds upon the previous one, enhancing security and operational efficiency. This approach optimizes security while allowing necessary operational flexibility, promoting a secure and efficient environment for UAV swarm missions.

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