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Implementation of Unmanned Aerial Vehicle Swarm Control Alogorithm in Search and Rescue Operations

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***Abstract*— The typhoons and floods in Vietnam have brought severe consequences, posing not only property damage but also endangering the safety of millions of citizens. In such emergencies, using UAV (Unmanned Aerial Vehicle) technology becomes an extremely crucial option in search and rescue operations. UAVs offer flexibility and speed in accessing hard-to-reach areas affected by natural disasters. This becomes especially vital when it comes to gathering information from terrains that are difficult for humans to reach. Moreover, UAVs help shorten the critical time in pinpointing the location and rescuing those in distress, saving numerous lives and minimizing casualties. This paper focuses on implementing control algorithms for a fleet of unmanned aerial vehicles in search and rescue missions. Integrating Deep Learning artificial intelligence and UAV swarm control algorithms enhances effectiveness in urgent situations. We conducted real-world experiments to validate the feasibility and efficacy of this system in real-life scenarios. The results demonstrate that this research presents a highly potential solution, capable of supporting rapid response teams in swiftly locating and rescuing individuals in a large area, with speed, precision, and efficiency, thereby minimizing human casualties when disasters occur.**

Keywords*— UAV, Drone, UAV-Swarm, intelligent autonomous systems, disaster response.

I. INTRODUCTION

In recent decades, the application of unmanned aerial vehicles (UAVs) has led to significant advancements in the field of search and rescue operations[1, 2]. Numerous studies have demonstrated the feasibility and effectiveness of utilizing individual UAVs in emergency situations [3], providing on-site information and supporting rapid decision-making for rescue operations in a short amount of time. However, the effectiveness of employing single UAVs in disaster scenarios may be limited due to constraints in capabilities, search speed, and search range [4, 5].

Faced with this challenge, deploying a fleet of unmanned aerial vehicles (UAVs) [6] becomes a viable solution. Combining multiple UAVs in search and rescue operations offers a range of significant benefits. Firstly, it provides the capability to enhance control and management over a larger area [7]. Secondly, through the collaboration of UAVs, they can optimize the search process while ensuring synchronization in responding to emergency situations [8].

While there have been numerous studies on the application of individual UAVs in search and rescue operations [9], there has yet to be a comprehensive study on the integration of multiple UAVs working together in disaster response scenarios. Therefore, the aim of this research is to combine and deploy an advanced control algorithm to optimize search and rescue capabilities using a fleet of unmanned aerial vehicles.

The main contributions of the paper are summarized as follows:

We integrate hardware control solutions and the architecture for monitoring a fleet of unmanned aerial vehicles to effectively carry out a specific mission of search and rescue in a large space. Instead of relying on individual UAVs for the search, detection, and rescue of individuals in distress, which comes with limitations, we successfully tested and implemented a combined UAV control algorithm in search and rescue operations, initially with a maximum of six UAVs. These UAVs are continuously controlled and monitored through the supervisory control interface that we developed using QT Creator.

Provide an assessment and discussion of the swarm control algorithm and propose an intelligent search and rescue algorithm model.

This study not only contributes to the search and rescue field but also opens up new potentials for the application of UAVs in other areas such as mapping, traffic control, and more.

This paper is organized as follows: Section 2 will analyze and evaluate related studies, Section 3 will describe the system model and control algorithm, section 4 will present the experimental results and evaluation, and finally, section 5 will give out conclusions and propose future research directions.

II. RELATED RESEARCH

The process of researching and developing solutions using UAVs in Search and Rescue (SAR) operations has garnered widespread attention and implementation worldwide over the past decades [10, 11]. In this field, research efforts are focused not only on hardware but also on software, aiming to achieve the best efficiency in performing SAR missions [12].

In SAR, constructing and controlling a single UAV with the capability to manage and collect image data to a central processing station is not overly complex. Furthermore, UAVs can be equipped with the Jetson Nano TX1 embedded computer to autonomously execute the task of detecting humans during search and rescue missions [10]. This is a solution that addresses the issue of object detection and transmits image data of the affected individuals back to the center or commands the UAV to take immediate action.

However, UAVs have limitations in terms of energy [13], so equipping them with embedded computers adds extra weight to the UAV, and the processing required for human detection also consumes a significant amount of power. Therefore, search time, exploration capabilities, and the ability to transport relief packages are all restricted. In general, the payload capacity and flight time of UAVs are both limited, and direct processing information on UAVs still faces some constraints.

Therefore, in the process of developing SAR solutions using UAVs, it is necessary to continue researching and exploring more scientifically sound methods to optimize performance and enhance the operational capabilities of UAVs. This may include researching more efficient information processing algorithms, optimizing power consumption and payload capacity, as well as developing effective data communication methods from UAVs to processing centers [14].

Furthermore, one of the crucial considerations in the control of UAV swarms is signal synchronization for the central station [15]. These signals are divided into two types. The first is control data signals for UAVs to perform tasks such as takeoff, landing, mission-based flight, or executing relief package drops. The second type is video signals collected from the field to the central processing station through various frequencies like 5.8 GHz, 2.4 GHz, 1.2 GHz, or even 900 MHz [16]. Some studies on communication architecture between UAV-UAV-central stations have been mentioned, such as Ground Control Station (GCS), Flying Ad-Hoc Network (FANET), or Machine to Machine (M2M) [17, 18]. These studies have proposed effective communication solutions for controlling unmanned aerial vehicle swarms. However, this research has only stopped at analyzing and evaluating synchronized control architectures without implementing any real-world applications.

In the field of Search and Rescue (SAR), numerous research efforts have been made to develop and test network techniques and routing protocols aimed at enhancing system performance. Ensuring the stability and reliability of UAVs, in particular, has garnered significant attention from the research community and has achieved notable advancements in task allocation and promoting collaboration among UAVs.

One of the unique ideas is to build an airborne electronic cloud system based on a UAV swarm, which integrates airborne electronic systems through the interaction and coordination among UAVs. This opens up significant potential for the development of intelligent and versatile aerospace applications, ranging from space communications to emergency relief and environmental monitoring [19].

However, during operations, a UAV swarm requires the ability to access and connect simultaneously through multiple channels, especially when encountering interference. To facilitate communication, omnidirectional antennas are often used to minimize signal attenuation and enhance the effectiveness of signal transmission between UAVs [20].

Furthermore, the use of wide-spectrum sensors and cognitive radio technology has opened up the possibility of applying more advanced reinforcement learning algorithms to optimize the decisions and behaviors of UAVs. In particular, research has developed real-time reinforcement learning systems based on Q-Learning combined with wide-spectrum sensors and optimization methods to enhance real-time interaction within UAV swarms [21].

These studies not only focus on researching algorithms and methods, but also address practical applications and their potential for expansion. The diversity and richness of research works in this field can be observed in Figure 1 - providing important information and directions for future research in the UAV domain.

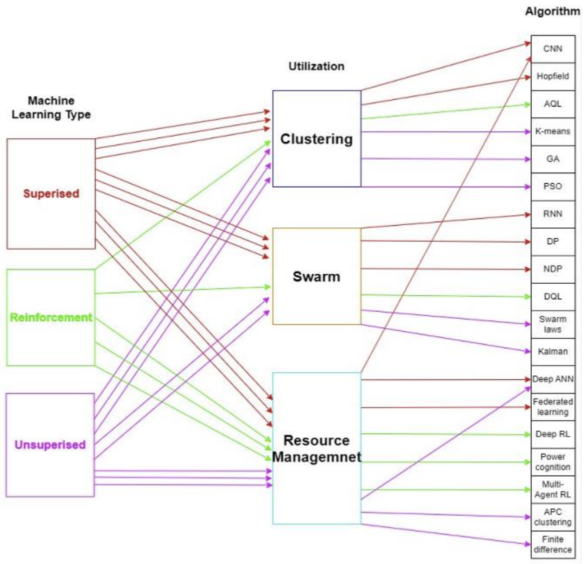


Fig. 1. Diagram of machine learning paradigms, applications, and implementation algorithms

III. DESCRIPTION OF THE SYSTEM MODEL AND IMPLEMENTATION OF THE CONTROL ALGORITHM

In this section, we introduce the overall architecture of the unmanned aerial vehicle swarm system and implement the appropriate control algorithm for the proposed system.

A. *Describe the system architecture*

Figure 2 illustrates an overview of the unmanned aerial vehicle swarm system carrying out exploration, search, and rescue missions. The UAVs will be partitioned to operate in specific areas of the actual disaster terrain for the purpose of locating human survivors. The UAVs will continuously collect data at the scene and transmit it to the Ground Control System (GCS) for automatic processing without human intervention. The GCS is responsible for segmenting the search areas for the UAVs and processing image data from them. When the GCS identifies a human target within the UAV operation area, it immediately extracts the current operational parameters, including basic information such as operating mode, aircraft ID, altitude, voltage, remaining battery percentage, RSSI, and most importantly, GPS coordinates and the current quantity of relief packages. At this point, the GCS will automatically analyze and make control decisions for the nearest UAV with the best conditions to execute the rescue mission.

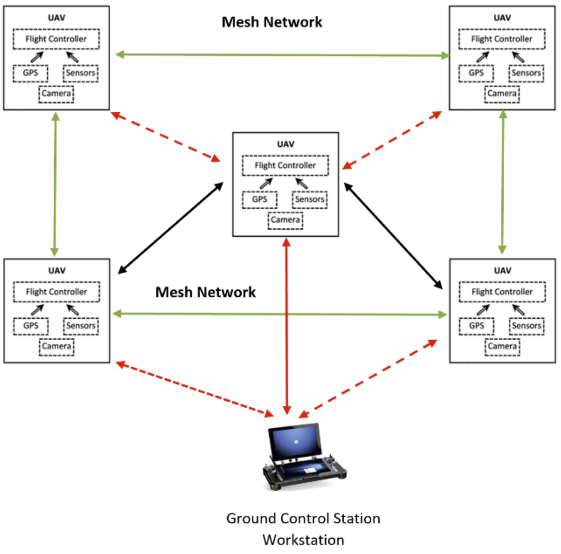


Fig. 2. Overall architecture of the drone robot complex system

In addition, the Ground Control System (GCS) can also save search results such as video information and UAV parameters in integrated memory of up to 2TB for long-term retention. All of this information is highly valuable for disaster relief teams to swiftly assess the situation and minimize human casualties.

B. *Communication between UAV- UAV- GCS*

We have analyzed and determined that areas affected by natural disasters such as storms, floods, or landslides often experience localized power outages. During these times, utilizing the existing network infrastructure for communication is not feasible. Therefore, we propose the use of RF transceiver modules. This system employs two types of transceiver modules: Module 1 is responsible for transmitting control data between UAVs, UAVs, and the Ground Control System (GCS) (detailed parameters are shown in Table I). Module 2 can handle mixed communication streams from UAV to GCS, including video streams, Datalink, Sbus, and Gimbal, making it easier for operators to interact with the system in case of emergencies (detailed parameters are shown in Table II).

TABLE I. PARAMETERS OF THE RF TRANSCEIVER MODULE 1

Information	Value
Transmission speed (Kbs)	4, 8, 16, 19, 24, 32, 48, 64, 96, 128, 192 and 250
The distance has obstacles and interference	100-300 m
The distance is free of obstacles and interference	10 km or more depending on antennas
Transmit Power	0 to 30 dBm in 1 dBm steps
Receiver sensitivity	> 121 dBm at low data rates,
Frequency Band	902-928 MHz
Serial Interface Data Rate	2400, 4800, 9600, 19200, 38400, 57600, 115200 baud
Supply Voltage	+5V nominal (+4V min, +5.5V max),
Transmit Current	~1 A peak at max power

TABLE II. PARAMETERS OF THE RF TRANSCEIVER MODULE 2

Information	Value
Max Transmission Range	15 km
Control signal	16 Sbus, 5 PWm
DATALink data communication	Yes (Wifi, Bluetooth, UART)
Stream video communication	Yes (Wifi, Bluetooth, HDMI)
Working temperature	$-10^o c - 50^o c$
Video format	H265
Control data format	UART
System configuration	Android 9.0, Ram 4 Gb, Rom 64 Gb
Antenna	5 dBi omnidirectional antenna
Waterproof ability	IP 4x

For the UAV to communicate with the GCS, we use the MAVlink protocol whose structure is illustrated in Figure 3. This is an open-source code designed and widely applied in the UAV research community. Using this protocol will help the system increase compatibility and interoperability between devices in the system. Specifically, a packet contains basic information as described in section III-A.

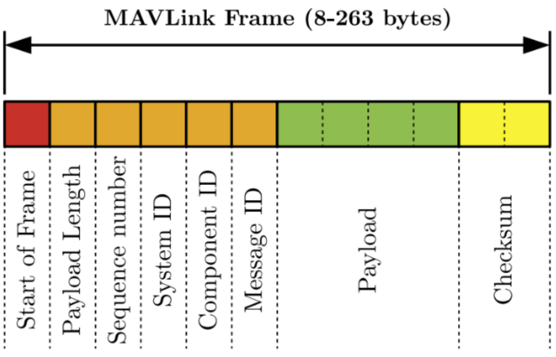


Fig. 3. MAVLink frame, according to [ProtocolOverview]

C. Implementation of control algorithm

The Ground Control Station (GCS) plays a crucial role in orchestrating operations and search and rescue missions. Its task is to deploy a combination of artificial intelligence and unmanned aerial vehicle swarm right at the disaster site. Building on previous research [22-24], the application of this combined approach with the architectural model we propose in section 3.1 shows promising potential. Specifically, we have key adjustments summarized as follows:

- This article employs the YOLO method for human detection and utilizes ToA, RSSI for estimating the distance from the UAV to the distressed target. The scope of this article is to deploy algorithms aimed at optimizing the system's performance during disasters. Specifically, we develop a new process tailored to operate the proposed system as presented in Figure 4 - Deployment Algorithm Diagram for search and rescue operations.
- The image processing algorithm is implemented in the Ground Control Station (GCS) to enhance the system's effectiveness in human detection.
- Communication techniques are enhanced to meet the requirements in challenging environments.

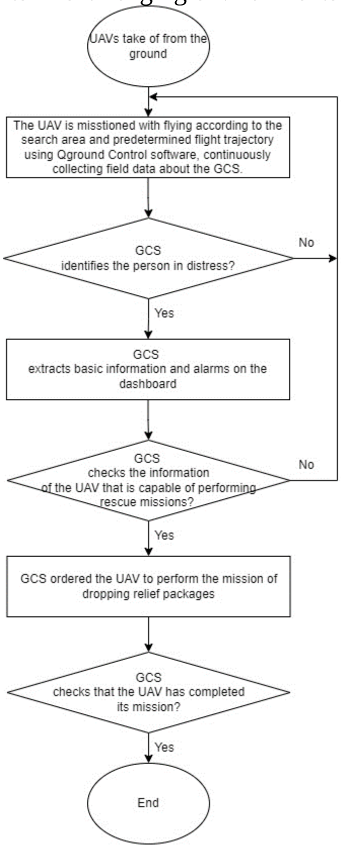


Fig. 4. Algorithm diagram for implementing search and rescue for the system

The algorithm diagram in Figure 4 illustrates the overall operation process of the proposed system. The UAVs are prepared and connected to the ground control system with optimal conditions. They are assigned specific search areas and continuously transmit basic flight information and streaming video to the ground control station. Until a human is detected in the disaster area, the GCS extracts basic information from the UAVs, analyzes it, and makes the decision to control a UAV to carry out the rescue mission. The UAV with the best capability will be selected to execute the rescue task. The UAVs are configured to automatically return to the ground station when the battery level is low or after completing the mission.

IV. SIMULATION AND EXPERIMENTAL RESULTS

A. System simulation

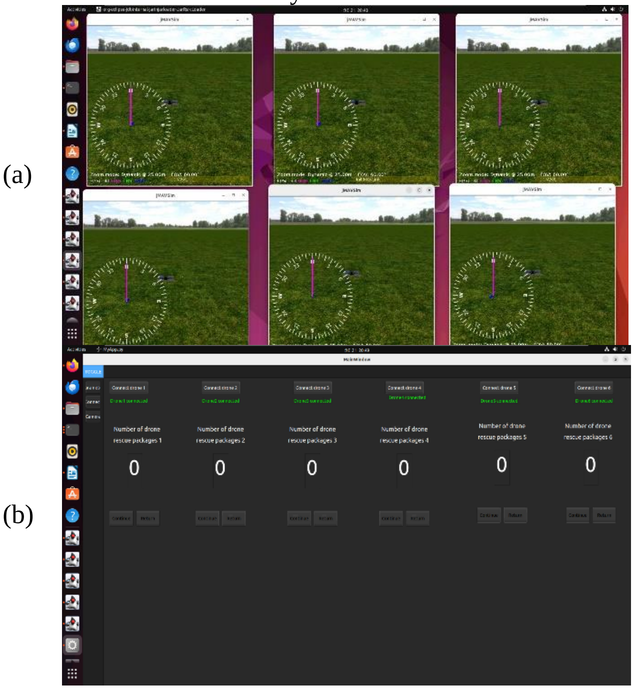
We used JMAVsim software to conduct the simulation of the combined control system operation. While there are several other options available such as Gazebo, Ros, and Microsoft AirSim, JMAVsim consumes fewer resources, starts up quickly, and is lightweight. This software allows for the creation of virtual UAVs using a flight controller with PX4 firmware and various hardware configurations like quadcopters, hexacopters, and more. It enables testing UAV functionalities without the need to invest heavily in building expensive UAVs. Furthermore, it aids software developers and researchers in testing and debugging UAV systems before conducting real-world tests on actual UAVs.

Figure 5a - Illustrates 6 simulated UAVs connected to the system instead of real UAVs.

Figure 5b – Interface for configuring the connection of UAVs to the system and setting the information on the number of equipped rescue packages on UAVs. This is an important initialization step to provide initial information for the system to operate.

Figure 5c – Monitoring and control interface of the system during task execution, displaying essential parameters of UAVs and video streams collected from the field to the ground control station. Furthermore, the interface supports emergency command operations to allow the operator to intervene when necessary.

Figure 5d – This is the interface for partitioning the search and exploration area for each UAV on the widely used QGround Control software in the unmanned aerial vehicle research community.



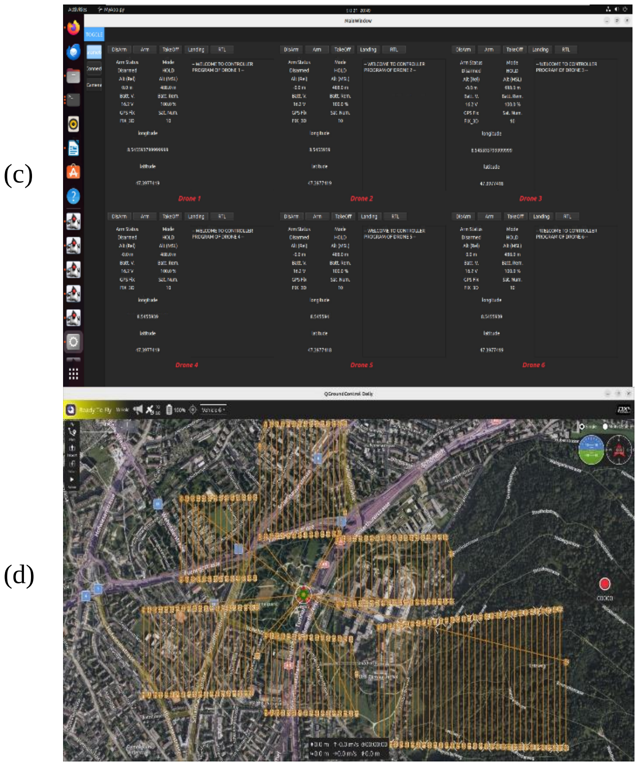


Fig. 5. (a) Simulating 6 UAVs using JMAVsim software, (b) UAV-GCS connection interface, (c) System monitoring control interface, (d) Interface dividing the operating area of the UAVs

B. Test and evaluate the system

After conducting the simulation process outlined in section 4.1, we have established the fundamental basis to affirm that this system can be deployed in a real-world scenario. In this experimental phase, we tested with two actual UAVs fully equipped with control accessories, communication systems, and cameras, while the remaining four UAVs were simulated. Our team conducted the testing on a large piece of land located in the Ngoai Giao Doan urban area (N03) in Xuan Dinh commune, Tu Liem district, Hanoi.

We have 02 test scenarios:

Scenario one involves connecting and controlling each UAV for takeoff and landing to verify the theoretical foundation that real UAVs can indeed interface with the constructed system. Figures 6(a) and 6(b) respectively demonstrate the successful connection and takeoff control with the actual UAVs.

Scenario two encompasses flight planning for the actual UAVs and introducing human signals to validate the combined algorithmic model with system control. Upon detecting the human signal, the UAV immediately executes the rescue mission and returns to its initial position after takeoff. Figure 6(c) illustrates the experimental results of scenario two.

Evaluation: The experimental results align with the designed scenarios. Specifically, scenario one has confirmed aspects such as system feedback, and connection quality, and has achieved the objective of connecting and controlling each UAV. Scenario two has successfully integrated the human recognition algorithm with the combined control of the system.

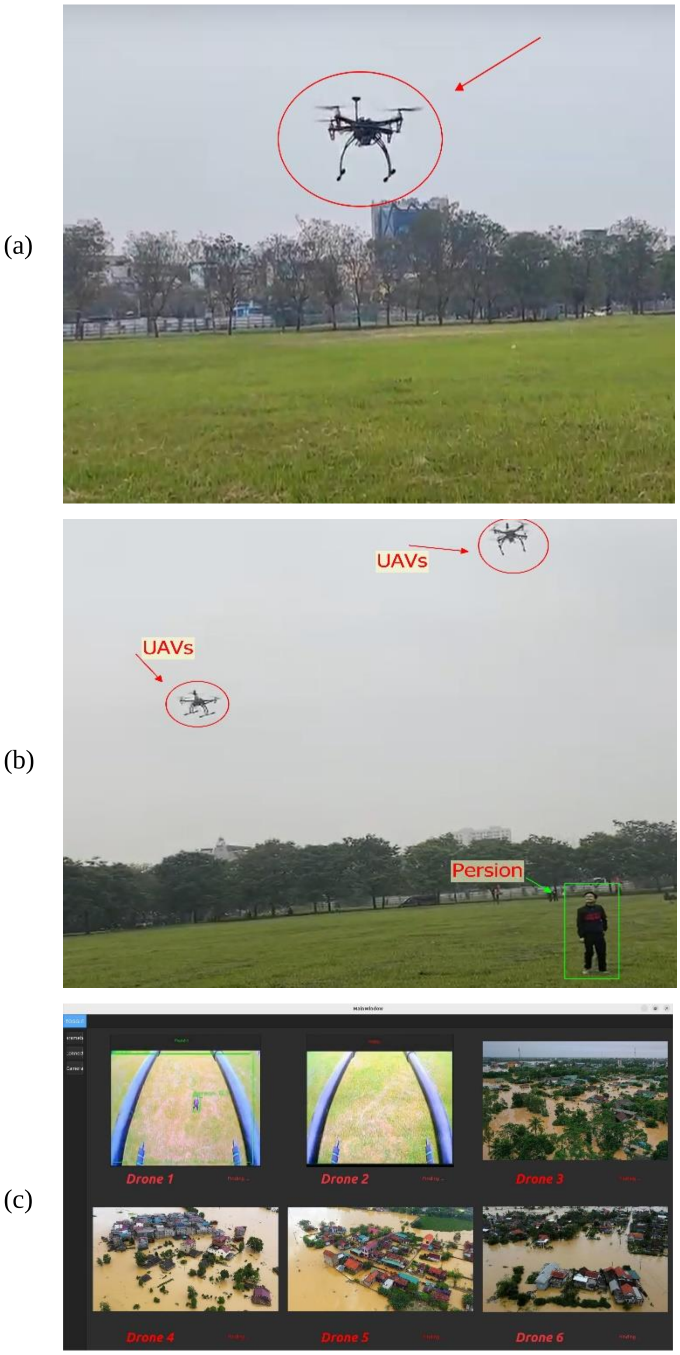


Fig. 6. (a) Results of connecting and controling 1 UAV, (b) Results of connecting and controling 2 UAV , (c) System interface test results

V. CONCLUSION AND PROPOSED DIRECTIONS FOR RESEARCH DEVELOPMENT

This paper proposes a communication architecture between UAVs and the Ground Control Station (GCS) and develops a new operational procedure tailored to this architecture. We introduce a combined unmanned aerial vehicle system to carry out exploration, search, and rescue missions in disaster-stricken areas. The system comprises UAVs partitioned for operation, and connected to the Ground Control Station (GCS) for image data collection and processing. Upon detecting a human presence in the disaster area, the GCS will automatically control the most suitable UAV to perform the rescue mission.

The system employs the MAVlink protocol for communication between UAVs and the GCS. To ensure stability in harsh wireless environments, we utilize RF transceiver modules operating in the 902-928 MHz frequency range (ISM – designated for industrial, scientific, and medical use). Furthermore, the application of human detection algorithms (Yolo) and the estimation of distance from the UAV to the distressed subject (ToA, RSSI) has enhanced the system's operational efficiency.

While the research has achieved positive results, there are still several limitations. Below are some suggestions for further development and improvement of the system:

Enhance the performance and accuracy of the human detection algorithm to increase the capability of detecting and locating subjects in need of rescue.

Explore the potential application of the system in other domains such as mapping, traffic control, etc.

Optimize the performance of UAVs to enhance their reliability and operational duration, thereby contributing to the overall effectiveness of the system during search and rescue missions.

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