Enhancing Maritime Search and Rescue (SAR) Operations Using UAV - Based Flight Control Systems: Opportunities, and Challenges

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ABSTRACT

The number of maritime accidents has been generally in decline in recent years, but maritime incidents still pose an important threat to human life, with optimization of search strategies and efficient use of resources hence being a high priority. In this regard, this study employed a mixed-methods approach by carrying out a Python-based simulation in the modeling of UAV-supported SAR missions and semi-structured interviews with professionals in the areas of maritime SAR and experts in drone technology.

This study aims to explore how UAVs may enhance the effectiveness of maritime SAR by employing both quantitative simulations and qualitative insights from expert viewpoints. The research investigates the potential of UAVs in optimizing search patterns, detecting persons in water (PIW), and delivering life-saving equipment under various conditions.

Besides the quantitative analysis through a Python-based simulation modeled UAV-supported SAR missions, semi-structured interviews provided practical insights into operational challenges. Many practitioners recognized the potential of UAVs for faster observations and interventions, but they expressed concerns about their vulnerability to bad weather conditions, regulatory restrictions, and also limited payload capacities.

The interviewees mentioned the greater strength and weather resistance given to drones, improved sensorial advances like thermal imaging, Lidar, and further action in terms of algorithms within autonomous navigation. Again, participants stressed that availability is related to specialized training for this type of SAR team with high-performance UAV systems. These results have proved that UAVs indeed provide a quantifiable advantage under maritime SAR situations, precisely in terms of speed and area covered, real-time situational awareness. The significant hurdles will be overstepped before UAVs can be fully integrated into normal SAR operations. Better long-enduring drones, up-to-date sensors for further detection, refined flight stabilizing controls, and easier regulatory frameworks-when that matures with the technology, UAVs will find their rightful place as invaluable tools bound to go a long distance in increasing the chances of survival during maritime disasters.

Keywords: Maritime Search and Rescue (SAR) - Drones - Unmanned Aerial Vehicles - Python Simulation - Payload Delivery

1. INTRODUCTION

Maritime SAR operations are important in the protection of life from the dangers inherent at sea, which is very complex and unpredictable (Baig, Lagdami, and Mejia 2024). International trade relies on maritime transportation, and much of the global economy depends on this industry. Also, offshore activities have grown tremendously, including human exploration at sea. This, on the other hand, has generated more maritime accidents due to the increase in activities, usually exacerbated by natural disasters like storms, tsunamis, and high waves (Liu et al. 2024). This incident may lead to a severe threat to human life with drowning and casualty incidents. Therefore, improving the effectiveness and efficiency of SAR missions has become one of the most important research topics, aiming to optimize search strategies in order to increase the chances of survival for Persons-in-Water (PIW) (Dong et al. 2024). The dynamic nature of maritime SAR, involving great resources, calls for innovative solutions to mitigate challenges like resource scarcity and adverse weather conditions (Somaiyeh et al. 2024).

The SAR operations in waters are intrinsically difficult to implement effectively, as these works rely on the effective harmonization of all elements of SAR. The enormity of the ocean, limitations of resources, and limited timeframe make the detection of bodies or life rafts/boats really problematic to conduct (Sirry and Patra 2024). Delayed response also diminishes survival chances with the passing of time; precise action must be taken promptly for a successful SAR operation. Most of these operations require the involvement of multiple agencies and organizations. Most of the time, equipment that is highly costly and specialized needs to be involved in most cases. Optimizing the searching strategies so that to reduce as much area and also locate targets much quicker, was thus another critical element for the SAR: with lives usually highly dependent upon speed of detection, it becomes urgent to search an area much sooner and increase the visibility (Li et al. 2023). By addressing these challenges, SAR can greatly enhance the outcomes that would ensure the preservation of life in dangerous maritime situations (Wu et al. 2024).

The phase of searching is important and forms the basis for rescue operations that might follow (Cucinelli, Goerlandt, and Pelot 2023). However, two main problems can restrict the SAR process: the scarcity of resources available to search and the mostly adverse, unpredictable weather conditions at sea. These two facts draw a background to implementing strategic methods of organizing the search-and-rescue operation on water, where the job of a search planner is to minimize the size of a searched area with the greatest probability of detecting the target. This is where search optimization becomes a very crucial process that will help derive higher success rates and effective utilization of time and resources, both of which are often highly constrained in maritime emergencies. (Zhou 2022; Sun et al. 2022)

The unique vulnerability of PIWs in maritime environments dictates a real need for timely and precise location efforts in their SAR missions. Basically, there are three tasks to be addressed in the successful searching for PIWs. It includes the first condition of correctly and quickly predicting the drift trajectory of PIWs, with consideration of sea currents and wind patterns, as well as other dynamic factors (Ai et al. 2021). This includes optimally defining the search area such that it is fully covered, encompassing the probable distribution range of the PIWs while minimizing the chance of missing some areas. Finally, there is a need to efficiently plan the search paths for SAR units with the aim of maximizing the cumulative probability of success in the whole search operation (Baig, Lagdami, and Mejia Jr. 2024).

Each of these activities calls for highly sophisticated modeling, real-time data analysis, and decision-making tools that advance operational precision and effectiveness. These aspects are fundamental in helping maritime SAR overcome the logistic and environmental challenges and timeliness in interventions that may improve overall survival outcomes of people in distress at sea. With drones finding their application in almost every other industry, the international maritime industry was amongst the latest that saw some considerable development with the use of Unmanned Aerial Vehicles (UAVs) commonly referred to as drones-propelled by developments such as the Internet of Things, digital systems, autonomous driving, and Artificial Intelligence (Sánchez-García et al. 2018). With advanced systems in aviation, cloud computing, network communication, and flight control, technology has made the drone indispensable in maritime operations. Drones are being used for a wide application base that comprises ship and structure inspections, monitoring sea life, observation of environmental impacts, and even critical missions related to saving lives (Sánchez-García et al. 2018). It transforms decision-making in the maritime sector, with their real-time capability to gather data on ocean currents, weather conditions, and water quality by ensuring better navigational safety, optimizing shipping routes, and minimizing environmental impacts (Aslam, Michaelides, and Herodotou 2020). Probably adaptability and efficiency are two of the most transformational assets in drones. They can tackle operational problems in any industry conventionally faced while pushing the bar in terms of safety and sustainability standards.

In recent years, drones have also gained recognition for their potential in disaster response, especially in SAR operations. Their versatility allows them to support a host of different applications, from gathering real-time information on ground conditions and creating detailed 3D maps, to improving situational awareness, logistics assistance, damage assessment, and temporary communication relays. The performance of drones in these SAR operations has been found particularly useful for delivering lifesaving equipment to distressed people, like life vests, and initiating two-way communication with onboard speakers once survivors have been found. These add to the operational scope of the SAR teams for quicker, effective responses in critical emergencies (Xiong, van Gelder, and Yang 2020).

However, despite all their possibilities, drones have not become so far the main tool for a systematic casualty detection and completely independent missions within SAR (Lyu et al. 2023). While such systems have already been created that independently detect and find people in distress using drones, practical usage is still limited regarding main sources within SAR operations. It is also owing to many challenges related to technology: first, limitations in on-board detection systems are generally RGB-based; second, when visibility is poor or glare and/or vegetation are high, often performance will be very much compromised (Guimarães et al. 2020).

In addition, other operational challenges that have continued to retard its broad applicability in the operation of SAR include regulatory restrictions, need for special training, and lack of advanced drone system supplies (Emimi, Khaleel, and Alkrash 2023). Overcoming these challenges will require further development of drone technology. Integration of multi-sensor systems, such as thermal imaging and Light Detection and Ranging LIDAR, better autonomous navigation algorithms, and enhanced detection capabilities would make the drones much more reliable and functional in the performance of SAR missions. In addition, the development of methods to make these technologies more accessible and practical for the teams of SAR around the world will be important to maximize their potential. With the development of technology, drones are foreseen to play a more vital role in SAR operations, offering cost-effective, efficient, and safer alternatives to traditional methods.

2. Methodology

The research applies a mixed-methods approach: quantitatively, simulations in Python will yield optimization for SAR strategies; qualitatively, semi structured interviews with professionals within the maritime SAR domain and experts within the drone domain. Based on this, the possible analysis of UAV potential with regard to optimizing search patterns, more accurate detection, and overall efficiency in rescue operations in maritime SAR operations would be done through a two-way approach:

2.1. Python-Based Simulation for SAR Optimization:

The first step in the methodology is to develop and employ a Python-based simulation to model a SAR mission with UAVs. The code in Python will simulate some key aspects of the operations concerning SAR missions, like launching drones, running search patterns, and locating PIW. The approach will allow the testing of search methods, optimization of operational parameters, and evaluation of the possible use of drones in general SAR operations. The simulation includes a number of key functions and components related to SAR:

- UAV Deployment and Takeoff: (The arm_and_takeoff) function ensures that the drone initializes and takes off to the target altitude. This stage emulates the first part of a SAR operation, where the UAV has to reach a safe operating altitude before commencing search patterns.

- Search Pattern Simulation: (The function search_and_rescue) manages different parts of the simulation: the takeoff of the UAV, flying in a search pattern, and the detection of people in distress. In a real-world SAR operation, this would be a search that includes GPS waypoints or predefined patterns such as grid or spiral search patterns to have maximum coverage of the area in which the search is being carried out. Though the above simulation uses a simplified version with video frame analysis, this Python code lays the basic framework for higher-end implementations that could involve dynamic navigation and real-time data integration.
- Person Detection in Water: This simulation will mainly focus on the detection of persons in the water by the on-board camera of the drone. In the main functionality of this simulation, the function detect_person() processes video frames captured by the UAV's camera to detect objects in the water. A simple thresholding method is applied to convert the video feed into a binary image, followed by contour detection to identify possible objects that may represent a person. If an important object, that is a person, has been detected above some area threshold, then its behavior will change into hovering on a target to simulate the detection of a PIW.
- Payload Release to Rescue a Person: This implements the dropping of a life buoy on a person who is in distress through the function (release_payload). It is one of the most important SAR mission activities, it involves dropping life-saving equipment like life vests or buoys. This function emulates payload release via a servo mechanism. Various conditions shall be simulated based on different search patterns, environmental factors, including wind and current simulation, and drone capabilities, such as payload capacity, camera quality, and detection range. The Python code will allow for the comparison of different search strategies by changing parameters such as the size of the search area, altitude, and detection thresholds.

2.2. Semi-structured Interviews:

The qualitative part of the interviews is complementary to the quantitative results to be obtained in the Python simulation; hence, this research will lean on semi structured interviews with experts from institution related to maritime SAR operations. Such interviews will grant deep, qualitative insight into practical challenges and real-world considerations in using UAVs during a SAR mission. The semi-structured format allows flexibility in the discussion of experiences and opinions by participants yet maintains focus on key themes relating to UAV integration into SAR operations. Target interviewees would include firstly, professionals in Maritime SAR: This includes rescue coordinators, and emergency response personnel who have first-hand experience with SAR missions. Secondly, Drone Technology Experts: Specialists in UAV technology who can give insight into the potential and limitations of drones in SAR operations, especially in the maritime context.

Interview Topics

1. Current Use of UAVs in SAR: How drones are currently used in the SAR operation; to understand real-world applications, challenges, and operational benefits. This will help to assess the gap between theoretical optimization-from the Python simulations and practical deployment.
2. Challenges in SAR Operations: Establishing the operational, technological, and environmental challenges of the SAR teams, including weather conditions, resource constraints, and the limitations of current UAV systems in maritime environments.
3. Effectiveness of UAVs in Maritime SAR: The perceived impact of UAVs on the efficiency of SAR operations will be discussed in terms of response times, detection capability, and speed of rescue. The interviewees will be asked to describe the possible advantages of the use of UAVs compared to traditional SAR methods, such as manned helicopters or ships.
4. Technological Barriers and Training Needs: A discussion on technological limitations of the current UAV systems, such as detection range, battery life, payload capacity, and the ability

to operate in challenging weather conditions. Also, interviewees will comment on the training needed by SAR personnel in order to effectively use UAVs during maritime SAR missions.

5. Future Directions for UAVs in SAR: Gaining insights into the future potential of UAV technology in SAR, including desired improvements in autonomous navigation, multi-sensor systems, and AI-based detection algorithms. Participants will also discuss ways in which UAVs could be integrated with other SAR technologies in order to enhance overall mission effectiveness.

2.3. Data Collection and Analysis

The interviews have been conducted with 20 professionals, and were recorded for further analysis with their consent. Thematic analysis will then be used to identify common themes and patterns across interviews; these will then be compared with the findings from the Python-based simulations. Key insights from the interviews will be used to interpret the results of the simulations, focusing on practical considerations and barriers to the wider adoption of UAVs in maritime SAR.

Data Integration and Triangulation

The quantitative findings from the Python simulations and the qualitative data from the semi-structured interviews will be integrated in order to comprehensively understand the potential and limitations of UAVs in SAR operations. A python-based simulation would then be used for SAR strategy optimization and estimation of performance using UAVs in ideal setups. Interviews would provide some much-required contextual knowledge regarding the employment done currently, the challenges they pose during actual operations of the respective technologies. By comparing and contrasting the results from both methods, this study will be able to verify the validity of UAVs in enhancing the efficiency of maritime SAR but also considering practical problems related to detection reliability, regulatory obstacles, and preparedness.

Ethical Considerations

All participants in the semi-structured interviews will be informed of the purpose of the research and informed consent will be obtained from them in writing before participation. Any information from participants will be guaranteed in terms of anonymity and confidentiality. Interview data will be anonymized, and storage will be done securely. Ethical criteria for data usage and participant rights will be maintained throughout the study.

3. The Proposed System Components

This research aimed to assess the potential of UAVs to improve maritime SAR operations. Coupling the knowledge gained from the Python-coded, simulation-based analyses and the knowledge obtained from semi-structured interviews with professionals involved in maritime SAR, this study provides proof of the benefits, challenges, and avenues for the future when it comes to integrating UAVs for the performance of SAR missions. Sections below discuss in detail major findings derived from both the simulation experiments and qualitative interviews.
The research flow signifies that there are three main stages in-volved in these procedures. The first stage focuses on the capability of the drone to carry devices such as camera and Global Navigation Satellite System / GSM Tracker Device without affecting the drone's mechanical function. Stage 2 allowed the drone operator to control the drone from a base station using First Person View "FPV" while searching for victims. Last stage, the tracker device will transmit location of victim to the rescuer through GSM net-work.

Figure (1), shows the key components and working of a flight control system in an unmanned aerial vehicle applicable to maritime SAR missions. The Flight Controller Board is the central unit that integrates data from several sensors: the IMU sensor, including a gyroscope and accelerometer, a magnetometer, a barometer, and a temperature sensor. These sensors provide critical input for stabilizing and navigating the UAV. The Main Processor uses this information to regulate the flight of the UAV, providing it with decision-making.

The system interfaces with various modules, which include camera module off-boards used for identification, telemetry communications, optical flow sensors enabling very accurate positioning, and GPS for tracking location. The Comm Unit gives communication between the UAV and Ground systems like the GCS, RC Transceiver and AV Receiver, among its kinds. In general, such modules ensure functionality with enablement for remote operability, transmitting data while receiving feedback for monitoring and otherwise.

The Drive Unit: ESC is the electronic controller employed to regulate the motors and propellers of the UAV; this transforms the instructions from the processor into changes in propulsion. With this integration, the UAV would be able to accomplish search patterns with great efficiency, go through turbulent environments, and drop payloads in SAR missions.

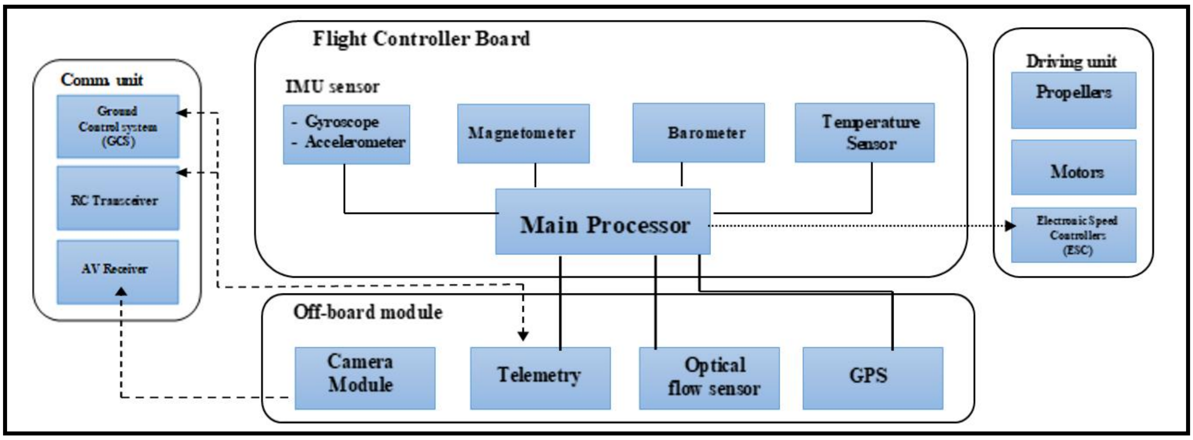

Figure 1 Proposed UAV system components

Optimization of Search Patterns in Maritime SAR

Among the main objectives of this research was to investigate the effectiveness of UAVs in optimizing searching patterns for Persons in Water. The Python simulation focused on various searching patterns, such as grid and spiral, under different environmental conditions. Outcomes in such scenarios have proven that UAVs can significantly reduce time when considering covering a large area relative to most the other traditional SAR methods. In particular, the gridded search patterns demonstrated superiority in structured and predictable environments. This while spiral patterns were useful in locations where ocean currents were either difficult to predict or when a general uncertainty existed as to where the PIW was located (Dong et al., 2024). A few studies have indicated that optimization of search patterns increases the probability of detection of PIWs. Our simulation results support this by suggesting that drones with autonomous navigation algorithms can execute optimized search patterns, balancing area coverage with detection probability. The findings indicate that this supports the argument by Xiong et al. (2020) improving efficiency and speed in the operations of SAR since the areas covered would be huge while the time taken is just a fraction of what other means like ships or helicopters could take. However, the simulation has also emphasized the shortcomings of current UAV technology during extreme weather conditions. The drone, under high winds, heavy rain, and poor visibility, could not maintain stable flights that could complete the search efficiently. This again reiterates the work of Guimarães et al. (2020), which showed that adverse environmental factors remain one of the major challenges to the performance of UAVs in maritime SAR operations. One of the senior SAR coordinators interviewed during this research noted that "while UAVs can surely help expedite the search missions, their efficiency is still at the mercy of the weather conditions. In tranquil seas, they can cover quite an area in minimum time, while in bad weather, they become almost useless." We still rely on boats and helicopters for the heavy lifting in these conditions." This reflects a common understanding among all persons involved in the field of SAR that UAVs are simply not yet the key solution to all types of maritime search challenges. Among those interviewed was this drone operator too who works in the same professional area of SAR; they furthered, "In good conditions, UAVs can locate survivors more quickly than we could. But when winds are high, or seas are rough, they tend to get grounded."

As stated by, searching technique is very important since drone have limited duration of flight time and sensor limitation. SAR team cannot deploy the drone without a proper plan. First of all, task force needs to determine the optimal area where the drone effort should be deployed, which is an area where the victim is most likely to be found. Next, they have to divide searching area into appropriate sub-areas for assignment to individual search patterns as shown in Figure 2.

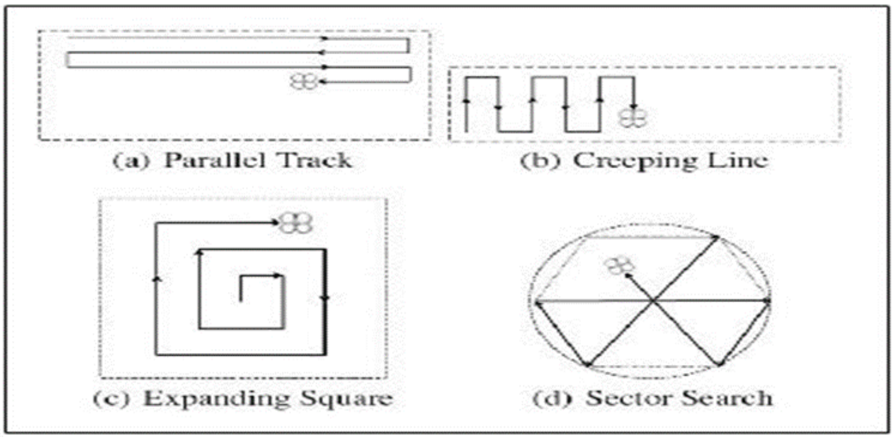

Figure 2 Maritime Search and Rescue Paterns

4. Analysis Results

4.1. Mocking Process

The original code attached in appendix 1 for a search and rescue drone was designed to operate with real hardware, Drone Hardware and Communication: Using a MAVLink-compatible drone simulator or actual vehicle. Real-time Camera Feed: Capturing frames via cv2.VideoCapture.

To validate the functionality in a controlled environment, a mock simulation was implemented. This simulation mimicked the behavior of the drone and the payload release system while avoiding the dependency on actual hardware.

4.2. Mocking the Drone Interface:

The MockVehicle class was created to emulate the behavior of the vehicle object in the original code. Essential methods such as simple_takeoff, simple_goto, and close were mocked to simulate the drone's actions.

Mocking Camera Feed: A synthetic video frame (numpy array of zeros) was generated to simulate input from a camera. The person detection logic (mock_detect_person) used randomization to simulate detecting a person with a 70% likelihood.

Mocked Payload Release: The servo override was simulated by directly modifying the channels["overrides"] dictionary in the mock vehicle.

Simulation Sequence: Initialization: The mission begins with vehicle arming and takeoff to 20 meters.

Search Pattern: Simulated by iterating through mock search steps, capturing synthetic frames.

Detection and Payload Release: The payload release is triggered upon detecting a "person" in the water.

Return to Launch: The drone is commanded to return to its starting point, concluding the mission.

4.3. Python Results

The mock simulation executed the mission successfully, validating the logic of the original code in a controlled environment. Below are the observed results:

Arming and Takeoff:The drone was successfully "armed" and reached the target altitude of 20 meters.

Search and Detection:During the first search step, the mocked person detection logic identified a "person" in the water.

Payload Release:The servo override for channel 7 was successfully simulated, releasing the payload.

Return to Launch (RTL): The drone simulated a return-to-launch maneuver, completing the mission.

Final Shutdown:The vehicle connection was cleanly closed.

5. Findings and discussions

Effectiveness of UAVs in the Identification of a Person

Another essential aspect of the research was the assessment and review of how effectively UAVs can identify PIWs using on-board real-time image processing algorithms. The Python code implemented basic image processing with OpenCV, detecting color contrast and contours to identify persons in the water. Very promising results were returned-in-water objects of larger dimensions were correctly identified, like life rafts and persons wearing bright-colored life vests. It had poor detection performance against small-sized objects or personnel without striking visual contrast amidst poor visibility, glare, and rough sea states. A related result confirming that a low capability for UAVs, equipped with an RGB-based system, exists for detecting targets within highly complex marine environments is the fact that under conditions in which a target cannot be well distinguished from water, there will be very weak contrast for detection. On the other hand, Sánchez-García et al. (2018) and Aslam et al. (2020) demonstrated that the combination of multi-sensor systems including thermal cameras or LIDAR significantly increases the accuracy of detection even at low visibility. The results presented here confirm that more sophisticated image systems are needed-capable of working effectively under all kinds of conditions at sea. Insights from Interviews: One drone specialist active in both SAR and commercial drone operations related, "Most of the drones that have image detection ability right now have a very preliminary system. We can spot large objects in the water, but with bad weather conditions, it struggles to spot small objects. The difference could be made by thermal sensors, but they are too expensive, and most SAR teams can't afford them." This observation agrees with the result of this study that current detection technologies on UAVs face challenges, especially when it comes to the detection of small or low-contrast objects in the water. One interviewee, previously involved in disaster response efforts, stated the following, "The real-time data UAVs gather, even in light of the limitations of modern sensors, allows the SAR to gain situational awareness of the area they have not had so far. If we can reach a surviving person sooner, that pays off.". This is something that will only get better as time and technology advance. However, UAVs already represent a quantum leap in terms of speed: "Detection accuracy will improve with time and technology, but UAVs already offer a huge advantage in terms of speed."

Payload Delivery in SAR Operations

The payload delivery-a specific release, for example, of lifesaving apparatus like life buoys-was also put to test and was part of the drone's capability in SAR. The simulation showed that UAVs could provide releases with reasonable accuracy, provided the drone can maintain a stable flight above the detected target. However, for low accuracy of release, problems were encountered in hovering the drone under unsteady conditions of winds or rough seas. This agrees with the results of other works, such as Sánchez-García et al. 2018, that UAVs are not very effective in delivering payloads under adverse environmental conditions. Successful deployment of lifesaving equipment, such as life buoys, was dependent on the ability of the drone to hover precisely over the target. This finding stresses the need for further refinement in the stability control systems of UAVs, especially in dynamic maritime environments. Considering most of the SAR missions involve high-risk situations with a very short window of opportunity, this potential for quick and correct release of payloads might just be what increases the survival rate in distress significantly. Insights from Interviews: A leader of a maritime SAR team said, "Theoretically, the payload release is useful, but we find that drones have difficulty with precise delivery.". When the water is rough, the wind nudges the drone off course, and it's a tough thing to drop exactly where the life raft needs it. It's a fantastic idea, but we need more robust technology before it goes mainstream." This agrees with the technical limitations found in the simulations, suggesting that while payload delivery may prove a useful tool, it still faces significant operational challenges.

Environmental Factors Affecting UAV Performance

As determined from the previous section, environmental factors were one of the major factors that dictated performance of a UAV in the ANY SAR missions. The simulations performed in this study demonstrated that drones could be effective in light to moderate weather conditions. However, in adverse conditions such as high wind, heavy rain, and fog, the UAVs could not fly steadily, therefore affecting the success of the SAR missions. These observations are in agreement with results from previous studies by Li et al. (2023) and Wu et al. (2024), where it was observed that harsh sea conditions can affect performance and lead to mission failure or require manual handling of UAVs. In practical SAR operations, environmental conditions can be unpredictable and may change markedly throughout a single mission. Given that in some conditions, UAVs are useful, this paper tends to believe that technological improvements must be made to enhance robustness against bad environmental conditions. The study of weather-resistant UAVs and advanced flight stability algorithms will be important in the development of the capabilities of UAVs under harsh maritime conditions. Insights from Interviews: "In maritime environments, when working with UAVs, you just cannot afford to ignore the wind and waves. I've experienced flying off course or even making them crash when the going gets tough. Until these machines can handle more extreme weather, they're just supplementary tools and not replacements for boats or helicopters." This echoes the significant number of operational concerns raised throughout the interviews on the vulnerability of UAVs to environmental elements.

Operational Challenges and Barriers to UAV Adoption

The semi-structured interviews conducted with SAR professionals provided valuable insights into the operational challenges and barriers to the widespread adoption of UAVs in maritime SAR. The major challenges identified included regulatory restrictions, specialized training needs, and few advanced drone systems. These challenges are reflected in the findings of Emimi et al. (2023), who said that mostly regulatory barriers restrict the possibility of deploying UAVs into SAR missions, especially in busy or restricted-visibility airspace. Besides that, SAR representatives pointed out a limited ability to access high-performance UAVs equipped with adequate payload and detection capabilities. The interviews showed the need for specialist training in order for SAR teams to deploy UAVs and integrate them with other SAR structures. This is corroborated by Cucinelli et al. (2023), who noted that training and operational integration remain critical factors in effectively employing UAVs in SAR missions. Insights from Interviews: In the words of a senior drone technician, "We lack proper infrastructure and trained people in most of the places to deploy UAVs in the SAR mission.". Many of the SAR teams I have spoken to don't have the resources to train everyone on drone operations. Until there's a big sea change in how SAR is integrated with UAV technology, these tools will continue to be peripheral. This view underlines the relevance of both operational readiness and regulatory barriers as two major concerns to ensure successful integration of UAVs into the SAR missions.

6. Future Directions for UAVs in SAR Operations

Operations Based on the simulation results as well as interview findings, UAVs hold great potential to enhance maritime SAR operations by improving search efficiency and enabling real-time data collection. However, key areas for improvement were also elucidated in this study. Particularly eye-catching is the integration of multi-sensor systems, such as thermal imaging and LIDAR, could improve detection accuracy in challenging conditions. Additionally, advancements in drone stability control systems and the development of weather-resistant drones could make UAVs more reliable in adverse maritime environments. A drone operator remarked, "The future of UAVs in SAR is promising, but we need more research on how to make them more autonomous and reliable in extreme weather. We're not there yet, but with AI and better sensors, UAVs could be a game changer in SAR." This aligns with the study's conclusion that UAVs' future effectiveness depends largely on advances in autonomy, sensor technology, and environmental resilience.

7. Conclusion

This study has demonstrated that UAVs can play a vital role in enhancing the efficiency and effectiveness of maritime SAR operations. While UAVs offer significant advantages in optimizing search patterns, detecting targets, and delivering payloads, there are still several operational and technological challenges to overcome. The findings suggest that, with continued advancements in UAV technology, regulatory adjustments, and improved training for SAR teams, UAVs will become an integral part of maritime SAR operations, contributing to faster, more accurate, and cost-effective rescue missions.

8. Limitations of the Study

While this study highlights the potential benefits and applications of UAV-based SAR operations, it does not address the cost-effectiveness of implementing UAV-based SAR solutions compared to traditional methods. The financial implications, including procurement, maintenance, training, and operational costs, remain unexplored. This limitation suggests the need for future research to evaluate the economic feasibility and compare it with conventional SAR methods to provide a more comprehensive assessment of UAV adoption.

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10. Appendix (1) Python code

```
# Connect to the vehicle (drone)
vehicle = connect('127.0.0.1:14550', wait_ready=True)  # Change IP/port for actual connection

# Define the servo channel for payload release
PAYLOAD_SERVO_CHANNEL = 7  # Example channel for payload release

# Function to arm and takeoff
def arm_and_takeoff(target_altitude):
```

```
    print("Arming motors")
    while not vehicle.is_armable:
        print("Waiting for vehicle to initialize...")
        time.sleep(1)

    vehicle.mode = VehicleMode("GUIDED")
    vehicle.armed = True

    while not vehicle.armed:
        print("Waiting for arming...")
        time.sleep(1)

    print("Taking off!")
    vehicle.simple_takeoff(target_altitude)

    while True:
        print("Altitude: ", vehicle.location.global_relative_frame.alt)
        if vehicle.location.global_relative_frame.alt >= target_altitude * 0.95:
            print("Reached target altitude")
            break
        time.sleep(1)

# Function to release the payload (life buoy)
def release_payload():
    print("Releasing life buoy...")
    vehicle.channels.overrides[PAYLOAD_SERVO_CHANNEL] = 1900  # Max servo position
    time.sleep(1)
    vehicle.channels.overrides[PAYLOAD_SERVO_CHANNEL] = None  # Clear override

# Function to process camera feed and detect a person in the water (simplified)
def detect_person(frame):
    # Convert to grayscale for easier processing
    gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)

    # Simple thresholding to detect objects (assumes person is a different color/contrast in water)
    _, thresh = cv2.threshold(gray, 127, 255, cv2.THRESH_BINARY)

    # Find contours (areas that may represent a person)
    contours, _ = cv2.findContours(thresh, cv2.RETR_TREE, cv2.CHAIN_APPROX_SIMPLE)
    for contour in contours:
        area = cv2.contourArea(contour)
        if area > 500:  # Arbitrary threshold for detecting a significant object
            print("Person detected in the water!")
            return True
    return False

# Main search and rescue loop
def search_and_rescue():
    print("Starting search and rescue mission")
    arm_and_takeoff(20)  # Take off to 20 meters

    # Simulate search pattern (in practice, you would use GPS waypoints)
    print("Executing search pattern")
```

```
    # ... Add GPS waypoints or pattern logic here ...

    cap = cv2.VideoCapture(0)  # Assuming camera feed from onboard camera (index 0)
    while True:
        ret, frame = cap.read()
        if not ret:
            print("Failed to grab frame")
            break

        if detect_person(frame):
            # Hover above the detected person
            print("Hovering above the target")
            vehicle.mode = VehicleMode("LOITER")
            release_payload()  # Release the life buoy
            break

        # Add logic here for moving the drone around (search pattern)
        # For example: vehicle.simple_goto(LocationGlobalRelative(lat, lon, alt))

    cap.release()
    cv2.destroyAllWindows()

    # Return to home
    print("Returning to launch")
    vehicle.mode = VehicleMode("RTL")

# Execute the mission
try:
    search_and_rescue()
finally:
    print("Closing vehicle connection")
    vehicle.close()
```