Unmanned aerial systems in search and rescue applications with their path planning: a review

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Abstract. In recent days, the Unmanned Aerial Systems (UAS) is an emerging technology rapidly across many warfare’s and enable new civilian domains which include real-time monitoring, security, border surveillance, wildlife surveys, providing wireless coverage, weather monitoring, smart farming, surveying, search and rescue, products delivery, farming, and civil structure inspection. Initially, there were many challenges in the design and control of UAS as it lacks an onboard pilot for navigation. Now the condition is improved with the implementation of artificial intelligence techniques in path planning and their coordination. Unmanned Aerial vehicles (UAV) in UAS technology open up new potentials in a variety of fields. This paper presents a review of recent literature, starting with the introduction about the UAS and its types, components, developments, potential applications of UAV in search and rescue and the paper completes with a summary of the different path planning methods used in UAS.

1. Introduction

The unmanned aerial vehicle (UAV) is an airborne unit comparable to an airplane; however, it differs from an aircraft in that it does not have an onboard pilot [1]. UAVs can be used to execute surveillance or recognition missions based on their controllability it’s termed remotely operated or autonomous systems. They are mostly utilized in search and rescue, mapping and surveying, monitoring environmental change, disaster response, and other applications[2],[3]. The usage of UAVs in geometrics and photogrammetry has grown significantly, as has the development of mathematical algorithms and sensors to enable more exact navigation and stabilization of UAVs [4],[5]. Generally, UAVs are equipped with various types of sensors for search and rescue operations. UAVs are widely used to supplement the human sensory units in damage assessment and evaluation, area mapping or surveying, and visual inspection because of their increasing availability and outstanding camera guiding capabilities[6]. Despite significant efforts by academics to expand the field of UAV features such as autonomously exploring, aerial grasping, or transportation, their use remains confined to
human-operated surveillance and cinematography[6],[7]. The primary goal of a Search and Rescue (SAR) operation is to detect also retrieve subjects in the lowest amount of time feasible. This is essential since any delay may lower the victim's chances of survival[8]. UAS is appropriate for circumstances that are too risky and unsafe where direct observing of humanly impractical. These winged robots can monitor the condition from the sky using appropriate sensors, and then send the acquired data to human controllers at the ground control station for an extra act if required. The UAS may be used for a variety of reasons, but in this article, the authors focused solely on search and rescue missions.

2. Classification of UAV

There is no universal classification to systematically describe the model's various classifications, but it can be considered based on different authors' criteria. According to the author[5], depending on how they operate, unmanned vehicles may be divided into five main categories These include unmanned ground vehicles, unmanned aerial vehicles, unmanned surface vehicles, unmanned underwater vehicles, AND unmanned spacecraft. Here the authors have primarily concentrated only on the second type, unmanned aerial vehicles. Based on [6],[9],[10],[11],[12],[13],[14],[15],[16],[17]the UAV’s are classified based on their build types as presented in table 1.

| Types of wing | Advantages | Disadvantages |
|---------------|------------|---------------|
| Fixed         | Long-range Endurance | Poor maneuverability compared to Vertical Take-off And Landing(VTOL). Horizontal take-off requiring substantial space. |
| Tilt          | Benefits of both fixed and VTOL. | Complex And Expensive. |
| Unmanned Helicopter | VTOL, high maneuver capability, high payloads. | Expensive and also a comparably high cost for maintenance. |
| Multi-copter  | VTOL, lightweight, reasonable cost, easy to launch. | Restricted payloads. Weak to wind/gust due to low weight. |

Another kind of classification[19] is (i) Lighter than air, (ii) heavier than air as presented in figure 1.

![Figure 1. UAV Classification][18]

Based on authors [8],[5],[10],[11],[13],[14],[15],[19],[20],[21],[22],[23],[24] the UAV systems are also classified based on different constructional and performance data and it's projected below fig. 2.
3. Components of UAS

According to [18], [25],[26],[27],[28] a UAS is an agent with the following components as shown in fig.3., (a) a UAV, (b) human-operated control station, or an autonomous and (c) A command and control system, presented in figure 3.

The elements of the UAV include the sensors to perceive the environment, systems to impart analysis capabilities, communication capabilities, and the use of onboard computers for planning and decision-making, and require vehicle control algorithms. To fly an unmanned aerial vehicle (UAV), we need to use the flight controller, which is a microprocessor that interacts with the transmitter to control the UAV, each RC transmitter includes several channels[24],[29]. As reported by [12], UAVs come in a variety of forms, each with its own (aerodynamic configuration, weight, range, size, etc.). As a general rule, UAV systems may be classified into one of the following four configurations as presented in figure 4. While considering literature [14],[18],[30], [31],[32] the UAV consists of the following parts the UAV airframe structure and its materials[34], the flight computer, the communication modules, the actuators, the sensors, the payloads, the propulsion systems, the power source. These modules coordinate work to get vital control of UAVs and a general view in figure 5. The ground control station is designed for high-quality commercial and military drones. A command and control system provides remote communication between the UAV and the ground station. Transmission of data includes [34],[35],[30],[36],[37] flight data, commands, and sensor data, such as video, images, and measurement values. The wireless data link interacts with the drone’s control module to adjust the

![Figure 2. Classification of UAVs based on important performance characteristics.](image1)

![Figure 3. Block diagram of a typical UAS [18].](image2)
aircraft's throttle, flight control surfaces, rotors, etc. according to the type of drone and the required flight parameters.

4. Application of UAV

Robotic SAR systems have many differences, such as the amount and type of robots involved (USV, UAV, UGV, and UUV) in the environment (urban, marine wilderness), the level of autonomy, and how humans control the robot, etc. Few of the important applications [25],[38],[39],[40],[41],[42],[43] are discussed here,

4.1. Maritime search and rescue

During maritime SAR operations [44],[45],[46],[47], it is imperative that the responders’ safety be protected at all times. Lack of coverage or poor meteorological and/or marine circumstances often compel these groups to modify or even halt their activities. Considering the author[50] there are various applications in the field of maritime but[8] has classified it in two, Offshore Marine Search and Rescue Operations and Nearshore Marine SAR Operations[49] as shown in figure 6. While considering the offshore maritime SAR operations [49] conducted a test on ROAZ-USV with a precise GPS for location and both visible spectrum and infrared cameras to detect human or animal presence in the water as shown in figure 7. However, [52] improved the system by introducing various types of systems to it. And also [51] describes the UAS types and equipment used in maritime scientific missions along with applications in physical and biological resource management. The idea of delivering floats[52] to drowned people to help them stay afloat has created more supports.

Figure 4. UAV configurations [12].

Figure 5. General view of a UAS network [26]

Figure 6. Search and Rescue cases (yellow dots) in the Hawaiian Island region [49].

Figure 7. An aerial image of a blue whale was generated from a photogrammetric survey by a UAV[51].
4.2. Defense application

UAS systems have been there for years, now they are the standard fighting force, with unrivaled endurance and devastating combat capabilities[55]. Unlike drones used in other civil applications, military drones must provide much higher precision and accuracy so it becomes more expensive. And also it requires advanced algorithms and powerful sensors that can sense their surroundings and perform assigned actions. The UAV system provides operational, technical, economic, and environmental benefits[56]. The development of UAV systems has created the possibility for the military to conduct military operations in a more efficient and less risky way than if the aircraft were piloted by people. Furthermore[57], in cases other than counterinsurgency and counter-terrorism, the effectiveness of drones is highly dependent on the operating environment. UAVs can be most useful when performing important tasks that are too dangerous for manned aircraft, such as conducting electronic warfare in enemy territory or real-time detection or identification of ground objects[58]. Even this can be used in border surveillance where the soldiers cannot reach due to many environmental, physical, or any other conditions. While author[57] focuses on two airborne surveillance applications: cooperative search & monitoring of targets, a simple UAV-specific mission on the Warfield is shown in figure 8.

UAV systems now have numerous intelligence, surveillance, and reconnaissance (ISR) capabilities and tactical air support to the armed forces laser illumination of targets designated to be hit, route and zone recognition, combat damage assessment, providing real-time information, and new fire capabilities[58].

Figure 8. UAV-specific missions on the Warfield[58].

4.3. Urban search and rescue

Urban SAR [29],[59],[60],[61],[62],[63],[64],[65],[66] is one of the most visible applications of employing UAVs instead of human missions. The main objective of urban search and rescue (USAR) teams in the case of a natural or man-made disaster are to locate victims as soon as feasible[66]. Even seconds may make a difference in a survivor[69]. Visual data and information on the impact of catastrophes from UAVs may be provided in live time as shown in figure 9. Emergency workers need to have actual information to make better judgments and save time in the event of a disaster or accident occurs[68]. UAVs can significantly reduce the cost and risk of SAR missions by providing rapid situational awareness over a very large area, minimizing the time and number of investigation teams to identify out injured or missing persons. Infrared (IR) thermal imaging cameras are used to spot the heat of the human body to find the missing person[69]. This feature greatly improves the ability to find people and things that may be hidden during daytime work at night. While considering various literature[70] describes a Fog Computing architecture for hybrid human drone cooperation that can manage real-time limitations and synchronisation goals. To enhance reaction times and change search patterns dynamically, the drone fleet may cooperate with ground people using this architecture.

Figure 9. Global description of the system for urban SAR operations.
4.4. Wilderness search and rescue

UAVs have numerous uses in forestry, from forest cover assessment to species categorization to simultaneous monitoring of forest fires[1],[11],[71],[11]. While the authors of [75] have used drones for regular monitoring of animal populations and wildlife health. The unhealthy animals can also be rescued and provided necessary medical aids. Also, drones are being used for wildlife surveys, monitoring forest fires, and rescuing the animals when necessary. While the authors[73] have developed a prototype for forest fire suppression using drones.

5. Path planning of UAV

Autonomous UAV path planning is both one of its most successful and one of the most challenging parts of autonomous UAV engineering[74],[75],[76],[77],[78],[79].

Table 2. Features and challenges of existing works.

| Author [Citation] | Adopted methodology | Features | Challenges |
|-------------------|----------------------|----------|------------|
| Yang and Yoo[98]  | Joint Genetic Algorithm (GA) and Ant Colony Optimization | Dynamic environmental adaptivity, high utility, and maximize network data communication. | Higher energy consumption, Lower convergence. |
| Na and Yoo[100]   | Particle Swarm Optimization (PSO) | Maximize the aggregated sensor data information’s value, better sensing information acquisition. | Higher computational complexity in terms of time. |
| Xu et al.[101]    | Grey Wolf Optimizer | Minimizing the overall flight cost, lower path cost, and faster convergence speed. | Higher fuel consumption |
| Qu et al.[102]    | Modified Symbiotic Organisms Search and the Simplified Grey Wolf Optimizer | Higher convergence speed, Improve exploitation ability, shorter execution time. | Tedious, Higher computational cost. |
| Shao et al.[103]  | improved PSO | Faster convergence speed, Lower computational cost, achieve the highest success rate. | Higher path failures. |
| Shen et al.[104]  | Tabu Table into PSO Parallel Genetic Algorithm and Parallel Particle Swarm Optimization | Has a faster iterative speed. | Higher detection time. |
| Jamshidi et al[105], Jing li et al[106] | | The performance of the path planning is very high. | More computation time, less effect on the network function. |
| Ramirez Atencia et al[107] | Genetic Algorithms | Reduced makespan, Improved fuel consumption. | Lower convergence speed, Higher computational complexity, and computational cost. |
For example, the route planning problem for a UAV may be viewed as an optimization problem in which all the goals must discover a feasible path from the beginning location to the terminal position while following different optimization parameters and mission restrictions, and environmental constraints[80],[81]. Several approaches for UAV path planning have been suggested in recent years. It is possible to design a path using graph-based methods such as the Voronoi Diagram Algorithm or A* Algorithms, Probabilistic Roadmaps. The UAV’s kinematic and dynamic limitations, however, are seldom taken into consideration in these algorithms, therefore they are rarely helpful in actual [82],[83],[84],[85]. Furthermore, these algorithms are related to the production map, which must be generated and processed in advance, rendering the cost map construction period. Another kind of optimal routes planning approach is the potential field-based method. Algorithms such as the artificial potential field and the interfering fluid dynamics[86]. Such algorithms determine the relationship between the attractive and disgusting fields geographically in terms of generating the flyable direction [86],[87],[88],[89],[90],[91]. As a consequence, they become easily stuck in a local minimum. This is because, when the target and barriers are near, no practicable route can be assured. Population-based evolutionary algorithms have made significant strides in recent years with the advancement of swarm intelligence techniques, and they continue to have a good potential to find the best solution in a more effective and scalable manner[92],[93],[94],[95],[96],[97],[98],[99]. When developing a UAV's coverage path, the most important factors to consider are the path length, the weight, the optimality of the path, the range, endurance, completeness, cost-efficiency, time-efficiency, and energy. The various path planning techniques and their features are tabulated in table 2.

6. Conclusion
UAV can be considered a valuable technology in SAR. In this paper, the search and rescue (SAR) operations of the UAS were discussed, which helps to identify the targets in different operations and the ability to reduce casualties so drastically. Several path planning methods have been discussed here to discover optimal or close-optimal collision-free pathways for UAVs. And also investigated the scope of several successfully implemented path planning algorithms in an unmanned aerial vehicle that focuses on increasing range, endurance, payload, and coverage area, flying over low-altitude urban areas. In addition, through the integration of artificial intelligence and drone technology, drones can make their own decisions and independence to human controllers present at ground stations. These will be milestones to transform present-day remote-controlled/semi-autonomous UAS to autonomous smart UAS for the future.

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