Status and Vision of the Application of Unmanned Equipment in Maritime Rescue

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***Abstract*—This paper comprehensively reviews the current status of the application of unmanned equipment in maritime rescue and looks forward to its future development direction. First, it analyzes the current status of the application of unmanned devices in responding to emergencies at sea (e.g., crude oil leakage, drowning personnel location and material delivery); then it discusses the potential of unmanned devices in military rescue at sea; then it summarizes the specific application of unmanned devices in rescue at sea through a literature review and an analysis of actual cases and analyzes their suitability and technical difficulties faced in the existing rescue system. The results show that unmanned devices exhibit significant advantages in maritime rescue, including rapid response, remote operation and efficient coverage, but they also face difficulties such as technical adaptability and operational complexity. With the technical difficulties overcome and adaptability improved, unmanned equipment will work intelligently and jointly in future maritime casualty search and rescue, forming a powerful rescue force and significantly improving rescue efficiency and effectiveness.**

***Keywords*—unmanned equipment, joint unmanned equipment systems, maritime search and rescue, military rescue, casualty evacuation, emergency response**

I. Research Background

According to data released by the China Maritime Search and Rescue Center, from January 2023 to April 2024, a total of 1,899 search and rescue operations were carried out, 11,310 search and rescue ships and 310 search and rescue aircraft were dispatched, 1,240 ships in distress were rescued, 12,529 people in distress were rescued, and 12,125 people were rescued [1]. At present, there are many demands for maritime rescue, and the new changes in the maritime situation have put forward higher requirements for my country's maritime rescue forces. The traditional method of maritime search and rescue is mainly for search and rescue personnel to drive search and rescue ships or helicopters close to the people who fell into the water, deliver life-saving equipment or go into the water for rescue, but this method has problems such as difficulty in locating search and rescue personnel, restricted search and rescue conditions, and relatively low search and rescue efficiency. At the same time, the treatment of shipwrecked personnel is also affected by the environment such as wind and waves, heavy rain, heavy fog and even rapids, causing the physical condition of the wounded to deteriorate rapidly, and even drowning on the spot. In view of this, for the search and rescue of shipwrecked personnel, short-term and high efficiency are the prerequisites, and quickly grasping the location of the wounded is the key point. Timely and accurate implementation of treatment is an important guarantee for improving the survival rate of the wounded. Unmanned equipment has the functions of rapid response, joint action, remote survey, fishing search and rescue, and precise positioning. It can realize rapid search of a larger area, thereby speeding up the search and rescue process and improving the efficiency and effectiveness of rescue operations, which just provides new ideas and new means for this need [2].

In recent years, unmanned search and rescue equipment at sea has made significant progress in Europe, the United States, Japan, South Korea, Russia and other countries and regions, and has gradually become an indispensable and important equipment in the field of medical rescue. This reflects the versatility of unmanned equipment technology and provides more extensive support for rescue operations. At the same time, the intelligent command and decision-making system is gradually shifting from "man-machine co-ring" and "man in the ring" to the new stage of "man outside the ring". Due to the development level of information system technology and the increasingly close human-machine collaboration, unmanned equipment can effectively expand the scope of execution of tasks and form a mutually coordinated search and rescue system with unmanned equipment as the main unit and manned ships or helicopters as the auxiliary. This is the main development direction of future naval battles or search and rescue of shipwrecked wounded. This article mainly analyzes the newly developed unmanned maritime rescue equipment in various countries in recent years, and discusses the application prospects of future maritime search and rescue or evacuation of the wounded and sick in military operations.

II. Classification and Development Status of Unmanned Marine Equipment

A. Drones

Unmanned aircraft is a fully autonomous or semi-autonomous unmanned aircraft that is controlled by a remote control or ground station through self-programming [3]. UAV has huge advantages over manned aircraft. UAV is small in size, low in cost, can be remotely controlled, has strong battlefield survivability, obtains information quickly and directly, and will not cause casualties to our side after being shot down. These characteristics make UAV's commercial and military value unlimited. At present, the research and development of UAV in various countries in the world, especially military powers, has become mature. At present, the leading UAV manufacturers are the United States, Israel, China, Iran and Russia. In addition, India is also developing the Rustom series of UAVs. The functional classification of UAVs is becoming more and more clear. According to their uses, they are divided into reconnaissance UAVs, electronic countermeasures UAVs, firefighting UAVs, transport UAVs, interference UAVs and meteorological survey UAVs. my country has been developing UAVs for more than 40 years, and the use of products in various aspects has become more mature, and their application in the field of rescue has gradually been valued. The 2020 study proposed an autonomous drone system that can initiate a search and rescue mission after receiving a signal that a person has fallen into the water, and use the corresponding detection algorithm to locate the person in the water. This is the first time that a ship-borne search system that can be planned and executed in real time has been proposed, showing the potential to improve the success rate of finding people in the water and shorten the total search time [4]. In response to the actual need for the possible search and rescue of casualties at sea, our military has now designed a drone-based search and rescue decision system, and designed a drone-based platform for quickly discovering and grasping the situation of casualties at sea. Search and rescue is accompanied by the rapid development of remote operation, remote transmission, and sensors. Maritime search and rescue drones equipped with corresponding functions can quickly carry out maritime rescue work. The payload weight carrying capacity of drones varies greatly from their space (volume, environment), mission profile (altitude, range, duration), and command, control, and data collection capabilities. As shown in Table 1, a summary of the capabilities and characteristics of some mainstream drones is provided.

Table 1. Selected UAS capabilities and characteristics

Drone Name	Weight (kg)	Validity time (hours)	Payload (kg)	Range (km)	Wingspan(m)
Desert Hawk	3	1	0.45	15	1.32
AV Dragon eye	2.2	0.75–1	0.5	10	1.14
AV Pointer	4.3	1	0.9	5	2.7
Luna	40	6–8	5	80	4.17
Raven	1.9	1–1.5	2	10	2.4
Dragon drone	4	1–1.5	2	10	2.4
Neptune	36	4	10	75	2.8
Finder	26	10	6	100	3
Pioneer	175	5	34	185	5.2
Shadow	170	6	27.2	125	3.9
Shadow 600	272	14	45	200	6.1

B. Unmanned Surface Vehicle

An unmanned surface vessel is a surface vessel that is remotely controlled by a control center. It completes the functions of the vessel as required, and cooperates with different configuration modules such as radar, electronic jamming, search and rescue, and positioning to realize different functions such as the arrangement and recovery of instruments and equipment, automatic information collection and processing, data exchange, and rapid offshore support. The United States has always been in a leading position in this regard. The U.S. Navy has been studying this project since the 1990s. From the release of the "Navy Unmanned Surface Vessel Master Plan" in 2007 to the revision of the surface unmanned vessel plan in 2019, and then to the release of the Navy Unmanned Combat Framework in 2021, it has basically formed an unmanned vessel system structure from ten tons to hundreds of tons and then to thousands of tons; Israel's research and development of USV is relatively mature. Rafael Advanced Defense Systems has developed the "Protector" USV, which is equipped with armed firepower such as radar, global positioning system, machine guns and naval guns, and also includes communication workstations for communication with other unmanned platforms or manned platforms, so that USV can meet basic tactical needs.

C. Unmanned Undersea Vehicle

Unmanned underwater vehicles started early in the civilian field. The United States, Russia, France and other countries have already made a lot of applications in the research of this project. Like UAV and USV, this type of equipment can use its own various sensors and modules to perform remote anti-submarine warning, battlefield survey, underwater reconnaissance and search and rescue functions through the control center. According to the energy supply, it is divided into two categories: Remote-controlled underwater vehicles that need to be connected to optical cables and autonomous underwater vehicles that carry power. At present, China has developed various types of UUVs with a full sea depth of 100~11000 m. For example, the "Qianlong No. 1" autonomous underwater vehicle that has been developed has a maximum working depth of 6000 m, a cruising speed of 2kn, a maximum endurance of 24 h, a weight of 1500 kg in the air, and can complete the application test mission of the 29th ocean voyage. Unmanned underwater submersibles have significant application potential in detecting the bottom of the deep sea to find potential casualties, especially in emergency search and rescue operations. They can act as underwater relays to transmit information and share intelligence through local area networks, expanding the combat range and three-dimensionality of operations.

III. Application of Unmanned Equipment in Maritime Rescue Operations

A. Crude Oil Spill Emergency Response

Scientists in Louisiana have launched a surface unmanned vehicle (as shown in Fig. 1) on a platform. Solar panels are installed on the hull and wings, which are driven by wind and solar energy to provide power for command, control, communication and sensor operations. Researchers used surface unmanned vehicles to study the oil seepage of natural oil on the surface of the Gulf of Mexico [5]. The purpose of this study is to quickly detect crude oil leaks and make decisions. Compared with other methods, this action is cheaper and has higher data quality. Surface vehicles are light in weight, compact in structure, easy to operate, and can be deployed in shallow waters where ships cannot operate effectively. In addition, a domestic team has designed an overall solution for a laser fluorescence sensor oil pollution detection system based on an unmanned boat. The system consists of a shore-based terminal and a laser fluorescence sensor installed on the unmanned boat. The laser fluorescence sensor system sends the collected data to the shore-based terminal through wireless communication. At present, laser fluorescence sensors have been used in rivers for testing to measure different targets such as river water and oil. This system will have great development space after being adapted to current unmanned equipment, providing a solution for future offshore crude oil leaks [6].

Fig. 1. Unmanned aerial vehicle.

B. Locating Drowning Persons

The British Royal Navy has been involved in a series of tests using the T-80 and T-150 Minerva drones (pictured in Fig. 2) for several months to see if it can be a reliable solution for helping sailors who have fallen into the water. The drones are used to locate victims who have fallen into the water and deliver life-saving equipment, with the remote control system hovering over the location until the rescue team arrives to indicate the correct location. The Royal Navy successfully tested the drone on Hosea Island, where the aircraft successfully found a dummy in the water and dropped a package containing a life raft. It then hovered above the dummy waiting for rescuers. These exercises have proven that drones can quickly find sailors when they fall into the water, thus shortening rescue time and delivering the necessary equipment to save them from drowning. The remote control system can be equipped with a thermal imaging camera to simplify the work.

Fig. 2. Heavy-duty Minerva drone used for water exercises.

C. Material Delivery

According to the World Health Organization, between April 2020 and June 2021, drones delivered 440 suspected COVID-19 samples from 10 regions, totaling 2,537 samples [7]. Fixed-wing drones have been used in the United States for long-distance Red Blood Cell (RBC) solution transportation. During the experimental COVID-19 pandemic, the use of drone sample transportation greatly reduced the distance that samples had to be transported by road to the testing site. The Mpanya Zipline drone delivery station has multiple drones for the transportation of suspected COVID-19 samples. Before the outbreak, Ghana’s drone delivery service was launched on April 24, 2019, with the aim of delivering medical supplies such as blood, plasma, protective equipment, medicines and vaccines to designated areas.

Out-of-Hospital Cardiac Arrest (OHCA) is widely considered to be the most time-sensitive medical emergency. From 2019 to 2022, there are an estimated 350,000 OHCA cases in the United States each year, with a survival rate of less than 10%, which has remained largely unchanged over the past three decades. A Swedish study showed that compared with traditional emergency medical services (AED devices are usually carried by first responders or public defibrillators), delivering automated external defibrillators via drones (Fig. 3) within the time required for patient resuscitation can improve patient survival rates.

Fig. 3. Drones with defibrillators.

IV. Prospects for the Application of Unmanned Equipment in Military Rescue Operations

A. Working Mode Assumption

In the future, the main working mode of UAV, USV and UUA for naval combat injury rescue missions is joint formation operation, which will be released simultaneously in the designated sea area to form a sea-air, sea surface and seabed trinity search and rescue unit. UAV flies over the sea surface, with high maneuverability and wide field of view, equipped with lighting, video transmission and other modules, which can realize rapid and large-scale search. Unmanned equipment on the surface and underwater can also be combined with sonar for environmental exploration and environmental monitoring, plan routes for rescue personnel in advance, avoid secondary injuries, and realize data fusion and remote information transmission. Since each unmanned equipment individual can be used as a repeater, the entire unmanned formation establishes a communication network through 5G modules, so that the unmanned formation can maintain real-time communication with manned ships or shore-based personnel, establish multi-dimensional information feedback, so that the rear rescue personnel can understand the location and vital signs of the wounded according to the returned data, determine the wounded's injuries, and quickly implement rescue [8]. Rescue system simulation is shown in Fig. 4.

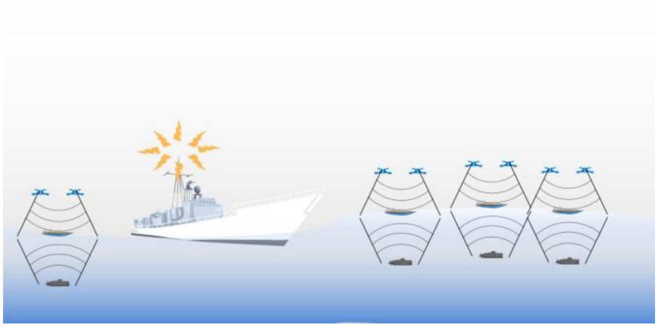

Fig. 4. Rescue system simulation.

B. Specific Search and Rescue Design

According to the superior's orders and task arrangements, unmanned equipment is mobilized to salvage the injured who fell into the water. The unmanned equipment first conducts a large-scale mobile search. After determining the location of the person who fell into the water, the UAV drops rescue equipment such as life jackets and single-person inflation valves. The USA deploys a salvage conveyor belt for the person who fell into the water and takes the person to the ship for temperature restoration and emergency rescue work. If the person who fell into the water is underwater, the UUA sneaks under the person and floats up to receive the injured, thus completing the salvage and rescue mission for the person who fell into the water.

For the wounded salvaged by unmanned equipment, the ship's own equipment can be used to complete emergency treatment such as abdominal impact, drug injection and body rewarming. Medical staff in the rear hospital can use the vital signs detection devices and video and audio communication equipment in the cabin to complete the condition assessment and injury classification of the people who fell into the water.

In the future naval battle rescue process, unmanned equipment needs to cooperate with ships at sea. It is unlikely to achieve full unmanned operation on the front line in the short term, and the cooperation between unmanned equipment and personnel is the most likely to become the mainstream. Unmanned equipment, especially UAV, can complete the remote delivery of materials with its extremely high mobility, providing strong material support for rescue personnel to provide first aid on the spot or for the wounded to rescue themselves and each other, thus improving the rescue rate.

V. Difficulties That Unmanned Equipment Should Solve

A. Battery Life Issues

The endurance of drones is affected by many factors, including power systems, battery technology, and aerodynamic design. At present, the endurance of smart terminal devices is mainly limited by the slow development of lithium-ion battery material technology. The effective endurance of unmanned equipment is generally not ideal. This duration cannot fully meet the needs of video shooting in civil aircraft, and the battery needs to be replaced after landing. Once the unmanned equipment cannot return to the starting point or cannot obtain effective energy replenishment, it is easy to cause accidents such as crashes, forced landings, and engine failures, which not only make the unmanned equipment unrecoverable, waste resources, but also limit the search range. If traditional energy methods such as fuel are used, the size of the unmanned equipment will also increase accordingly, and it will be useless in some environments where small unmanned equipment is required. Therefore, vigorously developing new energy sources for unmanned equipment and solving the endurance problem are the basis for improving the upper limit of unmanned equipment. Through software and hardware optimization, power consumption management and other means, the endurance can be effectively improved.

B. Insufficient Stability of Information Transmission

Unmanned equipment needs to be remotely controlled, so the remote control station is very important for the information transmission, information identification, and stable communication and anti-interference of unmanned equipment [9]. However, when UAV enters a high electromagnetic environment or encounters high-salt and high-humidity sea conditions, it will not only cause corrosion to its mechanical structure, thereby damaging core parts, but may even transmit confusing information, and even the channel may be used by enemy forces, causing information misleading or interference and even stronger threats. In this case, the information and location information of the injured sent during search and rescue is likely to be biased, which will have a huge impact on the efficiency of rescue. Therefore, strengthening and protecting the information transmission of unmanned equipment is an important part of improving the development of unmanned equipment.

VI. Conclusion

Accelerate the "clustering" and "connection" of unmanned equipment and systems, and use PDA+unmanned equipment to collaborate to complete the rapid search, rescue and triage of sick and wounded at sea. In future research, the collaborative development of unmanned equipment and medical services needs to form an efficient path. Specifically, through the Internet of Things, every person and every object can become an effective carrier for information transmission, thus forming an "embedded system" [10]. The wounded use the health detection equipment they carry with them to inform the rear or unmanned equipment performing search and rescue work of their location and vital signs at any time. The unmanned equipment forms a formation to provide basic life support for the wounded on the way back, transmitting vital sign information in real time, and the computer completes the triage work until the wounded can be directly transported to the corresponding team room in front of the pier ambulance station, saving time. In addition, the injury and injury information of the wounded is still transmitted backwards, and after statistical processing, first-hand medical information is provided to the rear command headquarters, thus saving manpower.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

Xiaorong Liu reviewed and revised the manuscript for intellectual content and accuracy; both authors read and approved the final version of the manuscript.

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