Autonomous Emergency Rescue Robot in Water based on Cloud Edge Collaboration

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Abstract

With the increase of global marine activities, overboard accidents are frequent, especially in the fields of tourism, fishery and shipping. Existing unmanned lifeboats have significant shortcomings in terms of stability and applicability, especially performing poorly in complex marine environments with waves up to 1.5 meters and above. To this end, this project designs a cloud-side collaboration-based autonomous emergency rescue robot for waters, based on the Small Waterline Surface Catamaran (SWATH), combining its advantages of good wave resistance and fast speed, aiming to improve rescue efficiency and stability. The U-shaped floater design enhances wave resistance and stability, which aligns with findings from previous studies on SWATH vessels. In addition, the robot is equipped with a forward drag-reducing obstacle-avoidance structure, which effectively avoids entanglement of water plants and other obstacles through streamlined design. The rear round-up lifesaving mechanism can quickly rescue unconscious or non-swimming drowning people, expanding the rescue range and shortening the rescue time. The design is not only applicable to lakes and rivers, but also can operate efficiently in the sea with frequent waves and under adverse weather conditions, providing more protection for the safety of human life at sea. Combined with the Cloud Edge Collaboration technology, the robot realizes intelligent and automated rescue, significantly improves rescue efficiency and safety, and provides innovative solutions for the development of future water rescue equipment.

Keywords

Water Rescue Robot; Cloud Edge Synergy; Small Waterfront Surface Catamaran; U-shaped Upper Floats.

1. Introduction

With the rise in global marine activities, overboard accidents have increased, particularly in tourism, fishing, and shipping[1]. The International Maritime Organization (IMO) reports around 1,000 annual fatalities from such incidents. Current unmanned lifeboats face stability and applicability issues, especially in waves over 1.5 meters, limiting rescue efficiency and highlighting the need for improved equipment[2].

The unmanned lifeboat market is projected to reach USD 3 billion by 2025, growing at a 15% CAGR. Despite cost reductions from mass production, existing models struggle with stability, wave resistance, and control precision. In harsh conditions, traditional lifeboats have a 30% capsizing rate, and their control systems often fail when submerged. Additionally, they are typically limited to calm waters with waves under 0.5 meters, making them unsuitable for sea rescues[3].

To address these issues, we propose an autonomous emergency rescue robot using cloud-edge collaboration technology. Based on the Small Waterline Surface Catamaran (SWATH), the robot combines wave resistance and speed with an innovative U-shaped floater for enhanced stability and reduced drag. (Fig. 1: Fuselage side view [left], top view [center], and front view [right]).It features a streamlined obstacle avoidance design and a rear lifesaving mechanism for quick rescues, even in challenging conditions.

This design is effective in both calm and rough seas, offering greater safety for maritime rescues. Integrated with cloud-edge collaboration, the robot enables intelligent, automated rescues, using AI and big data to optimize paths and maintain control in complex environments.

This paper details the design and technical advantages of the robot, comparing it to traditional lifeboats to showcase its improvements in stability, wave resistance, control precision, and rescue efficiency, offering a innovative solution for future water rescue equipment.

Fig. 1 Fuselage side view (left), top view (center) Fuselage front view (right)

2. Technical Implementation and System Design

2.1 System Architecture Design

2.1.1 General Idea

(1) Water remote control rescue

In response to more complex water conditions, the need for frequent changes in the robot sailing state, the rescuer can be controlled by remote control, in order to achieve rapid and accurate rescue. In long-distance rescue or poor weather conditions, the operator can use the camera device to provide real-time images. The water rescue robot can automatically return according to the original route after receiving a person in the water and enabling a key to return. On the way to rescue, if it encounters obstacles such as reefs or runs aground on the beach, it can enable the reverse gear function to go backward, avoid obstacles or return to the water, and continue to carry out the rescue mission.

(2)Water Intelligent Rescue

The robot can be equipped with intelligent identification, automatic cruise and other modules, which can be applied to offshore, lakes and other waters of the water surface cruise work and rapid unmanned rescue on the water. In specific use, the robot will be initialized and thrown to the water surface to be rescued, the robot quickly search for the designated water surface, when the robot found the person who fell into the water, immediately issued an alarm to remind the person who fell into the water and the shore rescuer, close to the person who fell into the water, and the person who fell into the water and brought back to the ring.

(3)Underwater search and localization

Select multi-beam sonar technology for underwater human search and localization work[4], robot equipped with multi-beam sonar and other devices, can be widely used in the search for drowned people. In specific use, the robot will be initialized and thrown to the waters to be implemented search, the robot quickly to the designated waters using multibeam sonar search work, when the robot found the drowning person, immediately issued an alarm to remind the shore salvage personnel, and real-time monitoring and tracking of the underwater movement of the drowning person, to master the real-time coordinates of the drowning person.

2.1.2 Feasibility Analysis

(1) Three-dimensional model simplification

For this device, the resistance it is subjected to is calculated by computational fluid dynamics, which has been widely used in marine engineering for performance optimization [5]and it is compared with the U-shaped power lifesaving device(Table 1).

Table 1. Comparison model main scales

USS Main Parameters		U-Powered Life-Saving Device	
Physical Parameters	Size/ cm	Physical Parameters	Size/ cm
Overall length	95	Overall length	95
Overall Width	85	Overall Width	85
Internal Width	50	Internal Width	50
Float diameter	15	Float diameter	15
Height	40	Height	20

Three-dimensional modeling software is used to simplify the model of the traditional motorized lifesaving device and the rescue catamaran, and it is imported into STAR-CCM+ software as the object of simulation and calculation, and the simplified effect of the two models is shown in Fig 2.

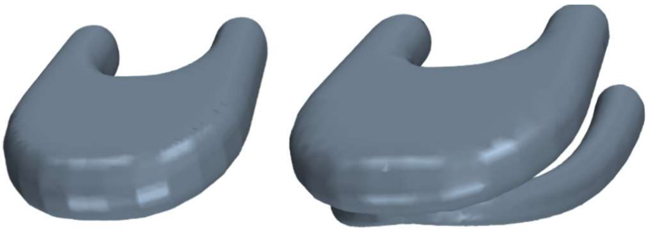


Fig. 2 Comparison of simplified models

(2) Calculation domain settings

Flat wave wave environment, set up the simulation to compare the resistance between the two, the calculation domain settings and specific dimensions are shown in in Fig 3:

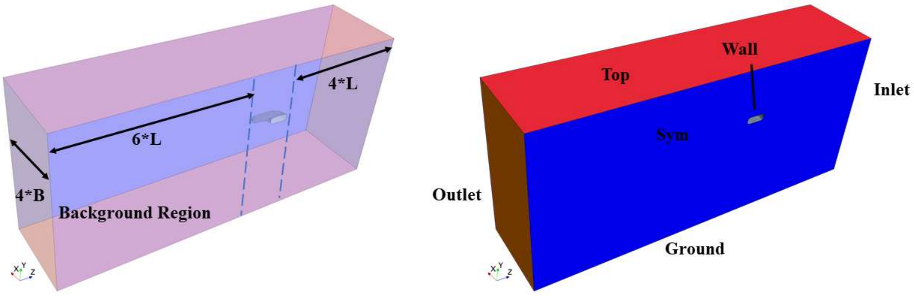


Fig. 3 Computational domain settings

The velocity inlet is set at the front side of the navigator, with a length of 4L for wave creation; the pressure outlet is set at the back side, with a length of 6L for full wave development, and a 2L dissipation area is set to avoid the fluid reaching the back wall and thus generating reflections, which leads to an impact on the flow field.

In the width direction, when the speed of the vehicle is low, the rear flow field is wider in the width direction, so the width of the computational domain is set to be 4 times the width of the vehicle, and the two sides are set to be symmetric walls. Since the main body of the navigator is symmetric about the plane mirror image in the width direction, only half of the navigator and the computational domain are taken for simulation in this paper, so as to save the computational time and improve the computational efficiency.

The top wall velocity inlet, the volume fraction is set to [0,1] respectively, and the velocity size is 0 m/s. The bottom surface is set as a wall. The navigator is 3m from the ground and 1.5m from the top surface.

(3) Meshing

The 3D model was imported into STAR-CCM+, and the built-in mesh repair tool was used to optimize the computational grid. The effectiveness of the mesh repair process is demonstrated in Fig 4.

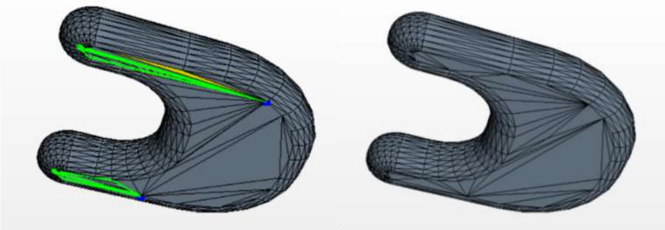


Fig. 4 Grid repair

Mesh encryption is performed for the free surface to capture the free-surface fluid flow more precisely, for the forward and aft sides of the navigator, and for the aft ship traveling wave region. The computational domain meshing results are presented in Figs 5-7:

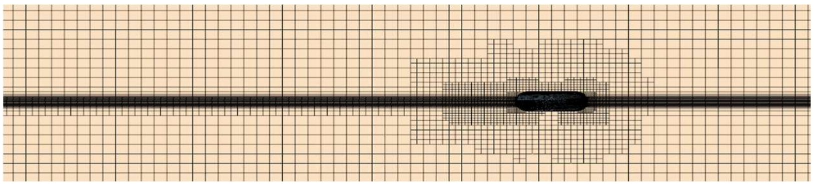


Fig. 5 Gridding – lateral

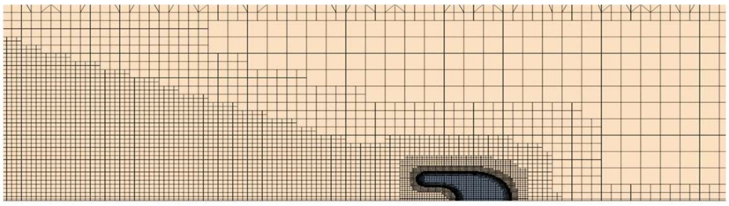


Fig. 6 Mesh division - top surface

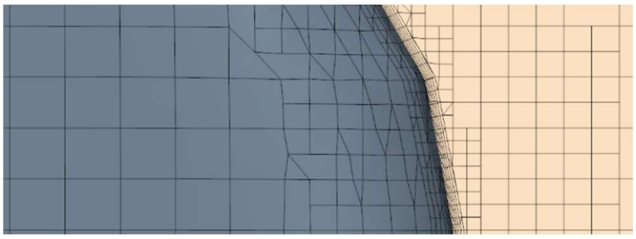


Fig. 7 Boundary layer meshing

(4)Numerical simulation

Numerical simulations were performed for both simplified models under identical operating conditions to ensure comparative validity. The simulation parameters for each test case are detailed in Table 2.

Table 2. Simulation working conditions

Mode	Working condition	Sailing speed
Model 1	Case 1	2m/s
	Case 2	6m/s
Model 2	Case 1	2m/s
	Case 2	6m/s

The calculated resistance values for both devices are presented in Fig 8.

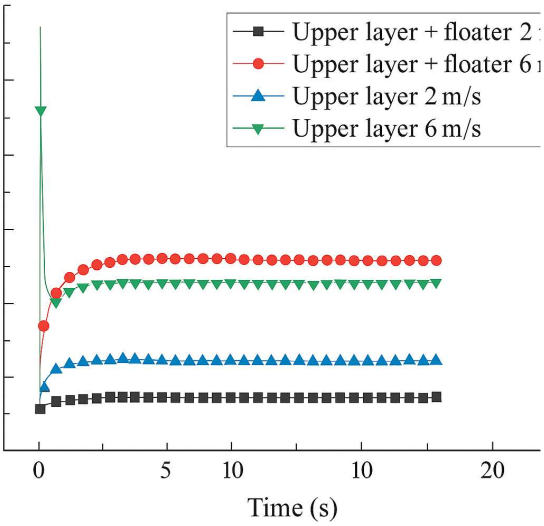
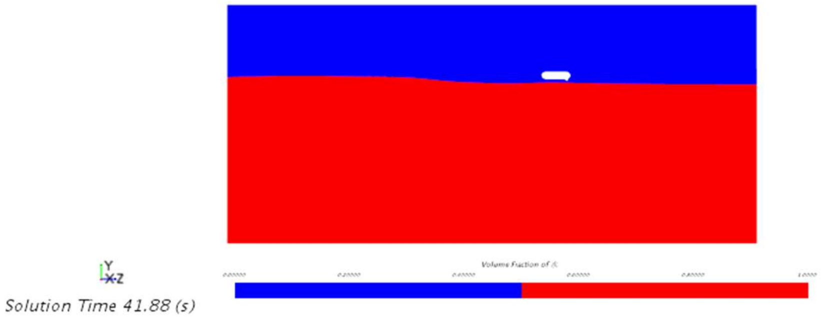


Fig.8 Resistance calculation

From the above figure, we can see that in the low-speed driving condition, the resistance of this device is smaller than that of the traditional life-saving device; in the high-speed driving condition, the resistance of this device is larger than that of the traditional life-saving device.

We get that the resistance of this device is not much different from that of the traditional U-shaped life-saving power unit. Because of the shallow draft, the device can provide more reserve buoyancy, provide a larger load, and in the case of a load, its speed is higher.



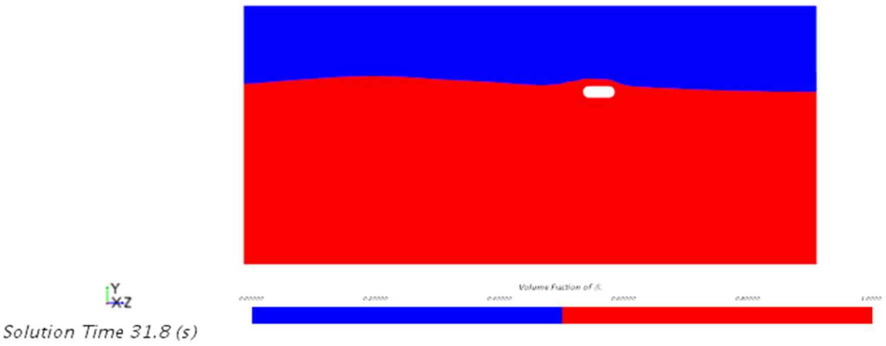


Fig.9 Waves on two different devices

As we can see from the Fig 9, the small waterline surface dual body rescue device has a smaller upper wave and less impact on the human body compared to a separate mechanical rescue device.

(5)Propulsion performance test

In order to ensure that the rescue robot can reach the person in the water in a short period of time, the model was tested for propulsion speed and whether the turning was stable.

Fig. 10 Propulsion performance test

Propulsion performance tests conducted in a 100m experimental pool under wave interference (0.1m wave height, 6s period) and 2kg load conditions demonstrated the rescue robot's stable turning capability and operational reliability (Fig. 10), confirming its ability to quickly reach victims in water rescue scenarios. Observe its speed change, repeat the measurements for three times, the data are shown in the Table 3:

Table 3. Propulsion Performance Table

No.	Pool environment	Round trip time	Propulsion speed
1	Calm water	101.3s	0.987m/s
2	Wavy environment	135.5s	0.738m/s
3	Load 2kg	132.7s	0.754m/s
4	Wave environment load 2kg	156.6s	0.639m/s

3. Rescue Type Design

(1) Water remote control rescue

To adapt to complex water conditions and enable frequent changes in the robot's sailing state, rescuers use remote control for precise and rapid rescue operations. The process is as follows: when a person in the water is detected, the rescue robot is deployed, and the operator remotely controls its movement-forward, backward, and steering. The robot follows these instructions to quickly reach the victim, using its buoyancy and propeller power to bring them to safety.

The robot is equipped with a temperature sensor, GPS, display, wireless transmission, alarm, and lighting modules, enabling functions like positioning, temperature measurement, and distance tracking. Data is transmitted to the user terminal, allowing rescuers to monitor the victim's location and surrounding conditions.

For long-distance rescues or adverse weather, a camera provides real-time images. The robot can automatically return via its original route after rescuing the victim. If obstacles like reefs or beaches are encountered, the reverse gear function helps avoid or navigate around them, ensuring the rescue mission continues.

(2) Water Intelligent Rescue

The robot is equipped with intelligent recognition and an automatic cruise module, enabling it to perform surface patrols in near-shore and lake waters, as well as rapid unmanned rescues. During operation, the robot is deployed onto the water, quickly searches the designated area, and upon detecting a person in the water, it alerts both the victim and rescuers, approaches the victim, and safely brings them back.

① Control System

The control system consists of two main parts: the lower computer and the upper computer. The lower computer, centered on an STM32 microcontroller, includes devices like a gyroscope for direction sensing and heading correction, and an ultrasonic module for obstacle avoidance.

② Intelligent Recognition System

For water surface recognition, the YOLOv5 and GoogLeNet models were enhanced to improve performance in aquatic environments. Key improvements to YOLOv5 include:

1) AF-FPN Structure: Added to enhance feature extraction through an adaptive feature pyramid network, improving recognition accuracy for targets at different scales[6].

2) CIoU Loss Function: Replaced the original GIoU to optimize bounding box regression by considering centroid distance and aspect ratio.

These enhancements enable YOLOv5 to achieve 96.25% accuracy in recognizing water fallers(Fig 11), as validated by a custom dataset of 2,120 images. Training results show decreasing loss trends, indicating stable model performance without overfitting or dataset anomalies.

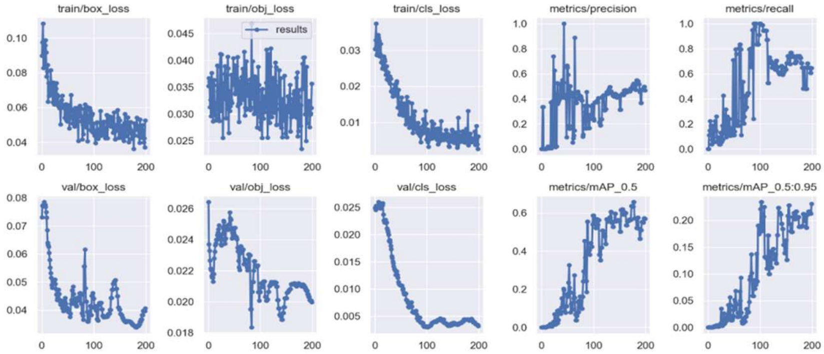


Fig.11 Schematic diagram of image recognition model training metrics

4. Application Prospect Analysis

1) Can be widely deployed in the city waterfront swimming pools, landscape rivers, waterfront platforms and other visitors dense, regulatory demand intensity of urban tourism waters, as well as rivers, sea and other areas, but also applies to the ocean, reservoirs, rivers, lakes and other water rescue application scenarios as a government emergency response, civil rescue organizations of various types of water rescue standard rescue equipment is demonstrated in Fig 12.

2) The use of unmanned surface vehicles for maritime supervision and rescue has been proven effective in reducing operational costs and improving efficiency, particularly in tasks such as channel mapping, automatic patrol, and navigation monitoring[7]. Night marine safety management of ships increases the difficulty of the night for violation of the natural conditions provided by the night. If the sea patrol boat night scene stationed, will consume a lot of manpower, financial resources, energy, long-term implementation of the difficulties, the use of this product can effectively solve the above problems.

3) Can be used for emergency rescue of marine accidents, will be equipped with a large ship, in the ocean voyage, when the occurrence of people overboard, the crew can be put on the sea in time for rescue activities. The device is equipped with temperature sensing system, ultrasonic ranging system, positioning system, can accurately detect the water conditions and location information, the data will be transmitted back to the information terminal, it is convenient for the rescuer to grasp the information on the scene, and it is suitable for rescuing under all kinds of weather conditions.

Fig.12 Application Effect

5. Conclusion

This paper presented an autonomous emergency rescue robot based on Cloud Edge Collaboration and Small Waterline Surface Catamaran (SWATH) technology, addressing the limitations of traditional unmanned lifeboats in stability, wave resistance, and rescue efficiency. Key contributions include:

1) Enhanced Design: The U-shaped floater and streamlined obstacle-avoidance structure significantly improved stability in waves up to 1.5 meters, while the rear lifesaving mechanism enabled rapid victim retrieval.

2) Technological Integration: Cloud-edge collaboration facilitated intelligent path planning and real-time control, validated by propulsion tests showing reliable performance in wavy (0.738 m/s) and loaded (0.754 m/s) conditions.

3) Rescue Versatility: The system supports remote control, intelligent recognition (96.25% accuracy via improved YOLOv5), and underwater sonar-based search, expanding applicability to lakes, rivers, and open seas.

Limitations and Future Work:

Further optimization of high-speed resistance (currently higher than traditional devices at 6 m/s) is needed. Field tests in extreme weather (e.g., storms) will be conducted to validate robustness. Integration with drone-assisted search systems could broaden operational scope.

This research provides a foundation for next-generation water rescue robots, combining innovative design with smart technologies to save lives in diverse aquatic environments.

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