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Research on Structural Design and Strength Performance Analysis of Unmanned Lifeboats

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Abstract

With the increasing frequency of water activities, traditional rescue methods have obvious deficiencies in efficiency and safety. This paper conducts research on the technical bottlenecks of unmanned lifeboats in structural design, strength analysis, and function realization, and proposes a new type of structural design that adopts symmetrical double buoys and hidden catamaran propellers, significantly improving navigation stability and maneuverability. At the same time, solar photovoltaic panels and wind generators are integrated to build a renewable energy system and extend battery life. The finite element analysis of the frame, buoy, and bottom plate through SOLIDWORKS verifies the rationality of the structure and materials. In terms of functions, automatic path planning is realized, and a three-dimensional search and rescue system is built by combining unmanned aerial vehicles (UAVs), searchlights, and cameras. It is also equipped with emergency medical equipment and rope-connected lifebuoys to form an integrated "search-rescue-first aid" mechanism. In the future, the application of lightweight materials and optimization of intelligent algorithms will be explored to promote the standardization and practical application of unmanned lifeboats.

CCS Concepts

• **Applied computing** → Physical sciences and engineering; Engineering.

Keywords

Unmanned lifeboat, Structural design, Strength analysis, Finite element analysis

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1 Introduction

Due to the increasing number of water activities leading to frequent accidents, traditional water search and rescue methods have many drawbacks. With the development of science and technology, unmanned boat rescue can break through the limitations of traditional manual rescue in efficiency, safety, and environmental adaptability through intelligent and unmanned operations, providing key technical support and improving practical capabilities for the "Belt and Road" marine safety guarantee and the construction of the "Smart Ocean" system [1]. At present, although research on unmanned rescue boats at home and abroad has made progress, there are still many bottlenecks. In terms of structural design, the existing unmanned rescue boats are relatively traditional in design, and some studies only focus on the optimization of a single structure, ignoring the coordination between various structures. Wang Weiping and others proposed that the single-hull unmanned rescue

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boat has poor stability when encountering strong winds and waves, and is prone to violent shaking or even capsizing [2]; Tang Zhenyu and others mentioned that although the stability of the multi-hull ship has been improved, the design of the structural connection parts is defective, and long-term impact by sea waves is easy to loosen and break, affecting reliability and service life. There are few domestic studies on single marine rescue and maritime search and rescue of rescue boats. For example, Wuhan Shilong Technology Co., Ltd., Zhuhai Yunzhou Intelligent Technology Co., Ltd., Wuhan University of Technology, Tsinghua University, Huazhong University of Science and Technology, and Lantai Sheng Technology have all been involved [3]-[4]. Foreign research and application of high-speed rescue boats started earlier and have a wide range of applications. For example, the Coast Guard is equipped with more than 1,000 small rescue boats, among which only the "CUSV" high-speed rescue boat produced by Textron has hundreds of boats, and the number continues to increase at a rate of more than 20 boats per year. The Japan Coast Guard is also equipped with hundreds of small fast patrol boats, all of which have a speed of more than 30 knots and are the main ship types for rescue and search and rescue missions. For example, research on structural strength mostly focuses on the analysis of conventional working conditions, and part strength tests are often carried out in a simulated environment of calm sea conditions and normal loads, which is difficult to cope with extreme sea conditions. Additionally, underwater vehicles, sonar systems, and unmanned aerial vehicles (UAVs) are all considered feasible options in coordination with lifeboat rescue services. Over 40% of the callouts by the Royal National Lifeboat Institution (RNLI) do not require manned rescue support, which highlights the significant importance of unmanned rescue boats[5]. Sajjad [6]investigates the First Boat Rescue (FBR) problem whose objective is to rescue a set of boats at sea in the shortest time possible.

In response to the above problems, this paper focuses on the structure of the unmanned rescue boat, the finite element structural strength analysis of the unmanned rescue boat, and the realization of the functions of the unmanned rescue boat. A new structure is proposed to reduce weight while ensuring strength, improve navigation performance and rescue efficiency; SOLIDWORKS numerical simulation method is used to carry out finite element analysis on the main stressed components, providing theoretical and technical support for the design, manufacture, and application of unmanned rescue boats, and contributing to the marine safety guarantee under the "Belt and Road" initiative.

2 Overall Structural Design of Unmanned Lifeboat

2.1 Overall Structural Design

A new type of unmanned lifeboat with a new structure designed in this paper is mainly composed as shown in Figure 1. The boat is 6.3m long, 4m wide, and 3.5m high. Its structure includes the main hull, wind generator, rope-connected lifebuoys, propulsion system, searchlight, solar photovoltaic panels, UAV, main hull, communication module, camera, emergency medical equipment, and catamaran buoys. The combination of solar photovoltaic panels and wind generators aims to improve energy utilization efficiency and ensure the endurance of the unmanned lifeboat at sea. The series-connected lifebuoys mounted on the back can provide rescue after the lifeboat reaches the person overboard. At the same time, the emergency medical facilities on the boat can provide emergency rescue for the injured person overboard, striving for valuable time for subsequent formal treatment.

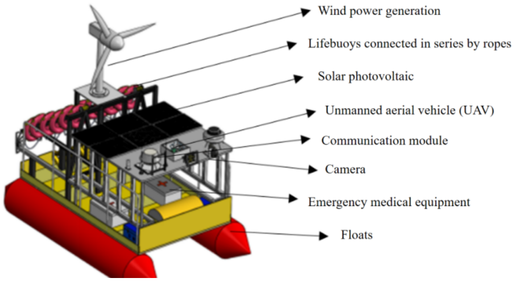

Figure 1: Main components of the unmanned lifeboat

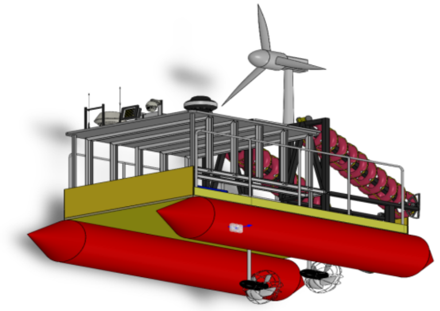

Figure 2: Oblique view of the unmanned lifeboat

2.2 Main Hull and Propulsion System

This unmanned boat features a hidden catamaran propeller design as shown in Figure 2. It achieves forward and backward movement through commands from the control system. The symmetrical dual propellers enhance the flexibility of heading control and ensure uniform force distribution on the hull, while the hidden design prevents harm to rescuers.There are protective covers on both sides of the propellers, which can prevent debris from entangling the motor and protect the impellers in shallow waters.In addition, the unmanned boat adopts a symmetrical dual floating body design with a hollow interior, boasting the characteristics of pressure resistance, wear resistance, and high buoyancy. It outperforms traditional monohull boats in terms of stability, speed, and space utilization: the wide hull spacing enhances lateral stability, reduces rolling, and solves the problem of easy capsizing; the hull design reduces water resistance, and the innovation in the propulsion system makes up for the lack of flexibility of traditional catamarans, making it an excellent choice for unmanned rescue boats.

2.3 Solar Panels and Wind Power Generation

In recent years, the control equipment and mission components of unmanned boats have improved significantly, but there has been

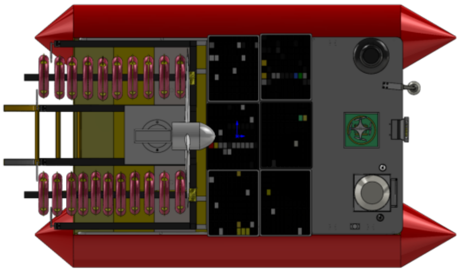

Figure 3: Top view of the unmanned lifeboat

little progress in their power facilities. Maritime search and rescue operations take a long time, and the endurance of unmanned boats greatly affects the efficiency and success rate of the search and rescue. Therefore, we propose adding wind turbines as a solution as shown in Figure 3.

3 Structural Strength Analysis of Unmanned Rescue Boat

Unmanned rescue boats perform tasks in complex marine environments, and their structures need to bear a variety of complex loads. Structural strength is the key to ensuring the safe and reliable operation of rescue boats.

The loads on the unmanned rescue boat mainly include gravity, buoyancy, wave force, and inertial force. Gravity is determined by the mass of the hull structure, equipment, and carried materials, which can be calculated by Formula 1:

$$\mathrm{G = mg} \tag{1}$$

Where m is the total mass and g gravitational acceleration . The gravity is determined by the total mass of the hull structure, the carried depth sounder and other equipment, and fuel and other materials. Buoyancy is determined according to Archimedes' principle, which can be determined by Formula 2:

$$F_b = \rho g V \tag{2}$$

ρ is the seawater density and V is the displacement volume.For unmanned rescue boats with different designs, such as catamaran search and rescue unmanned boats, their unique double buoy structure design will affect the displacement volume, thereby changing the buoyancy.

Wave force is a complex load that has a significant impact on the structural strength of unmanned rescue boats. Irregular waves are usually described by spectral analysis methods, such as the Pierson-Moskowitz spectrum, to describe the distribution of wave energy. Given the complex working environment of offshore platforms and the significant impact of wave force [7], for cylindrical structural components of unmanned rescue boats, the wave force per unit length can be calculated by the Morison equation:

As shown in Formula 3:

$$F = \frac{1}{2}\rho C_F D v|v| + \rho\frac{\pi D^2}{4}C_K\dot{v} \tag{3}$$

Where C_F is the drag coefficient, C_K is the inertia coefficient,D is the structural diameter , v is the water particle velocity, and $\dot{v}$is the water particle acceleration. Cylindrical structures such as buoys on unmanned rescue boats will be subjected to such wave forces under the action of sea waves. For unmanned rescue boats of different types and sizes, the diameter$D$, and in different sea conditions, the water particle velocity u and acceleration $\dot{u}$ will also change, resulting in different wave forces.

4 Finite Element Analysis of Key Components

The reliability of the rescue boat refers to the degree to which it can bear the maximum force during operation. In this chapter, numerical simulation methods will be further used to conduct finite element analysis on the main stressed components of the rescue boat using SOLIDWORKS to ensure safety and the ability to bear the maximum load in actual operation [8].

4.1 Finite Element Analysis of the Overall Frame of the Fast Rescue Boat

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4.1.1 Selection of frame material properties. In finite element analysis, the selection of frame material properties is a key link to ensure the accuracy and reliability of the analysis. The accuracy of material selection directly affects the subsequent analysis results. If different materials are used, their key parameters such as yield strength will change. The properties affecting material characteristics mainly include crystal structure, working temperature, material density, and tensile strength. Based on this, the frame structure of the fast rescue boat in this paper is made of alloy steel. The material parameters are shown in Table 1

- Applying constraints: Fixed hinge constraints are applied to each base connection of the frame.
- Adding loads: The calculated pressure is applied around the frame.
- Performing calculations: The calculation results are shown in Figures 4 and 5

Through SOLIDWORKS finite element analysis, as shown in Figures 4 and 5, the yield stress of alloy steel is (6.204 e+08 N/m^2), while the maximum stress borne by the part is only (4.247 e+06 N/m^2), which is much lower than the yield strength of the material. The analysis results show that the structural design and material selection of the rescue boat frame are reasonable and can meet the strength requirements in actual work.

4.2 Finite Element Analysis of the Buoy of the Fast Rescue Boat

For the finite element analysis of the rescue boat's buoy, rubber is used as the stress analysis material. To fit the real working scenario, fixed hinge constraints are applied to both ends and edges of the buoy, and corresponding loads are applied around the buoy considering the impact of sea waves. After simulation calculation,

Table 1: Main parameters of alloy steel

Elastic modulus	2.1e+11 N/m2
Poisson's ratio	0.28
Yield strength	620422000 N/m2
Mass density	7700 kg/m3

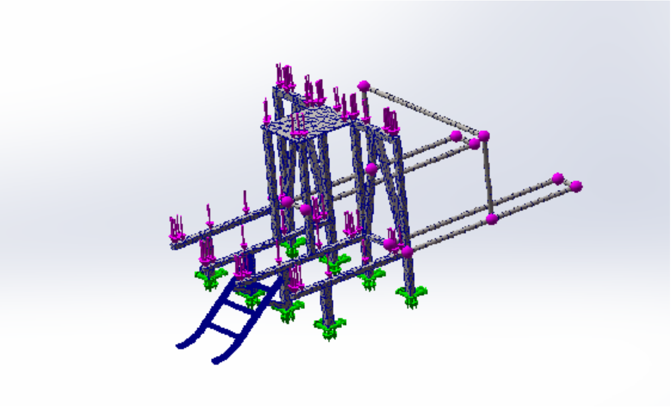

Figure 4: Finite element analysis mesh diagram of the frame

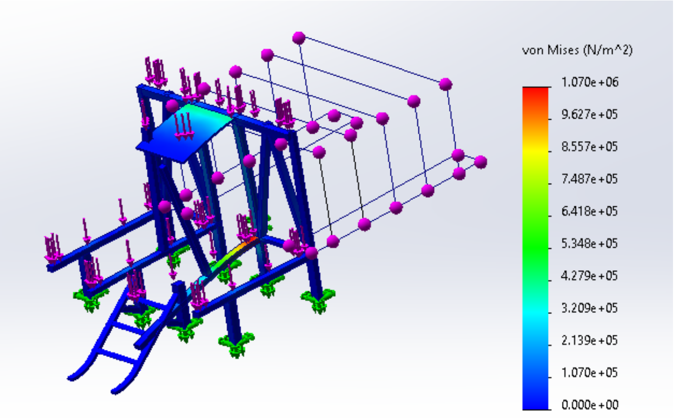

Figure 5: Finite element analysis stress diagram of the frame

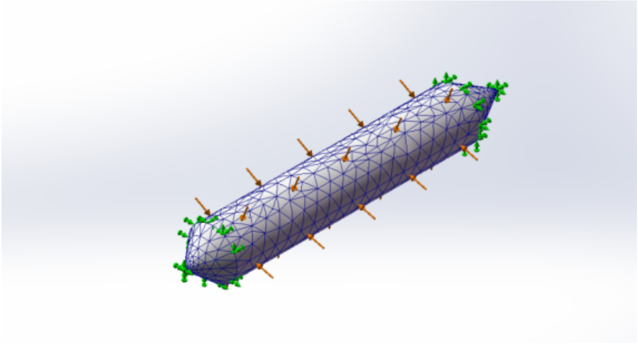

Figure 6: Finite element analysis mesh diagram of the buoy

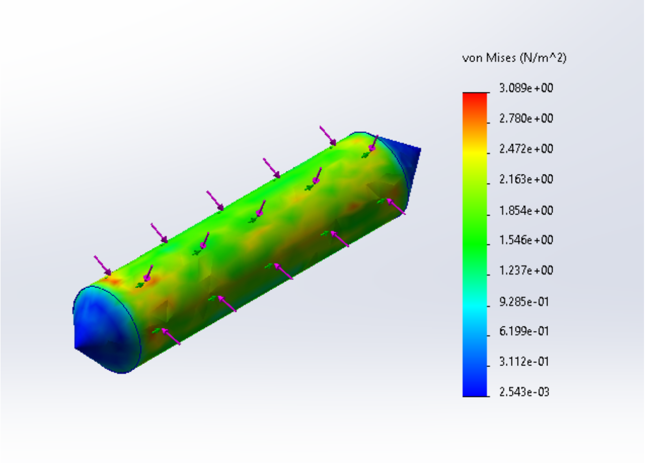

Figure 7: Finite element analysis stress diagram of the buoy

the results shown in Figures 6 and 7 are obtained, laying a data foundation for evaluating the strength performance of the buoy structure in complex sea conditions and optimizing the design.

Through SOLIDWORKS finite element analysis as shown in Figure 7, the maximum strain of the component is (3.112e-02 N/m^2), which is small. Therefore, the structure and material design of the rescue boat's buoy are reasonable.

4.3 Finite Element Analysis of the Bottom Plate of the Fast Rescue Boat

In the finite element analysis of the rescue boat's bottom plate, alloy steel is used as the stress analysis material. Based on the actual working conditions, fixed hinge constraints are applied to both ends and edges of the bottom plate to simulate the real installation state, and corresponding loads are added according to the surrounding force conditions. Through simulation calculation, the analysis results shown in Figures 8 and 9 are obtained, providing data support for evaluating the structural strength of the bottom plate and optimizing the design.

Through SOLIDWORKS finite element analysis as shown in Figures 8 and 9, the yield stress of alloy steel is (6.204 e+08 N/m^2). Moreover, the maximum strain of the component is (1.026e-06 N/m^2), and the strain is small. Therefore, the structure and material design of the rescue boat's frame are reasonable.

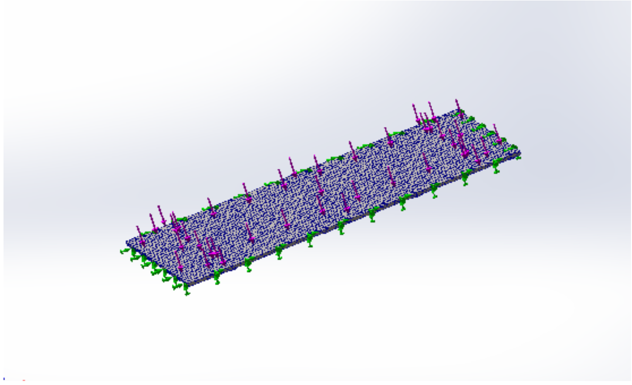

Figure 8: Finite element analysis mesh diagram of the bottom plate

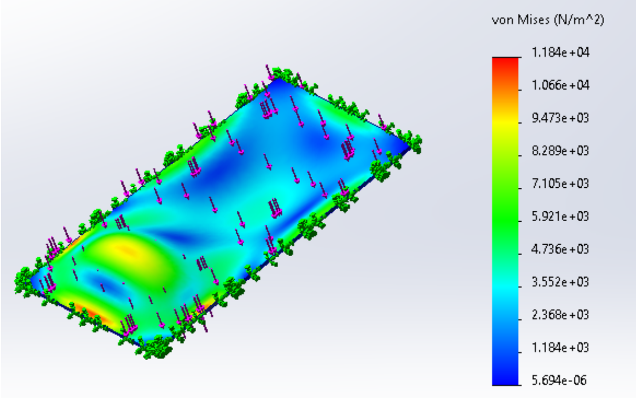

Figure 9: Finite element analysis stress diagram of the bottom plate

5 Conclusion

This paper addresses key technical issues of unmanned rescue boats in structural design, strength analysis and function realization by proposing a new structure with symmetrical double buoys and hidden catamaran propellers: hollow buoys enhance lateral stability; propeller protective covers solve traditional problems like easy capsizing, damage and entanglement. It integrates solar and wind energy to build a renewable energy system, significantly improving endurance.Finite element analysis via SOLIDWORKS verifies the strength and controllable deformation of alloy steel frames and rubber buoys under extreme sea conditions. Functionally, it realizes automatic path planning, builds a 3D search and rescue system with UAVs, searchlights and cameras, and is equipped with medical equipment and lifebuoys to form an integrated "search-rescue-first aid" mechanism, effectively improving rescue efficiency and success rate. In the future, the focus will be on promoting the practical application of lifeboats through algorithms.

Acknowledgments

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