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Static Simulation Analysis of Surface Garbage Cleaning Robot

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Abstract

This paper aims to address the difficulty in cleaning garbage from small water areas by designing a water surface garbage cleaning robot. To tackle the deformation of the robot's hull structure caused by its own weight during manual handling and lifting, a static simulation analysis was conducted using Solidworks/Simulation. The analysis results show that when the hull structure was handing the maximum stress of 58.1 MPa, and the the angle of deformation β is 0.49°, when the hull structure was lifting the maximum stress of 77.1 MPa, and the the angle of deformation β is 0.65°. Regardless of whether it is during manual handling or lifting, the robot's hull module experiences stress and angle deformation that are both less than the design criteria. The structural design of the water surface garbage cleaning robot is reasonable.

Keywords

Garbage cleaning robot; Stress deformation; Static simulation analysis; Solidworks/Simulation.

1. INTRODUCTION

In recent years, China's water garbage pollution has become increasingly severe. The amount of floating garbage in rivers, lakes, and reservoirs has been on the rise. Over time, this floating waste first pollutes the aquatic environment and then poses a threat to the health of nearby residents[1,2].

Various water surface garbage cleaning boats are available on the market, generally driven by fuel, which causes air pollution, noise pollution, and oil pollution. These boats are large, have high operating costs, consume a lot of energy, and are not easily popularized[3-5]. Additionally, garbage cleaning in lakes and urban rivers is mostly performed using manually piloted boats to fish for waste, which is labor-intensive, inefficient, time-consuming, and unsafe. This method usually involves significant human and material resources, yet the results are not evidently effective. To solve these problems, a water surface garbage cleaning robot suitable for small water areas was designed, specifically for the cleaning of surface garbage in lakes, ponds, and urban rivers[6]. This paper analyzes the deformation issues of the designed small water area garbage cleaning robot during manual handling and lifting, using Solidworks/Simulation software for static simulation analysis to verify that its structure meets the usage requirements.

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2. ROBOT STRUCTURE

Analyzing both the catamaran structure of the robot body and the characteristics of floating garbage on the water, and applying the separation principle from the TRIZ theory of innovation, the garbage lifting device was redesigned into a garbage collection device. Taking advantage of the water's buoyancy to counteract gravity, and using the propulsion of the garbage collection device to transport the garbage, it significantly reduced the complexity of the structure and the energy loss. The structure of the robot body with the integrated floating garbage collection device is shown in Figure 1.

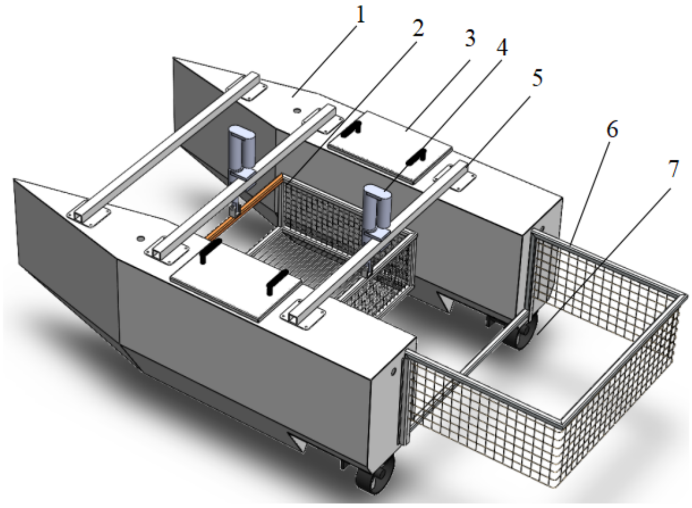

Figure 1. Water surface garbage cleaning robot structure diagram
1-Hull body 2-Heavy floating object collection basket 3-Battery box lid
4-Electric push rod 5-Connector 6-Lightweight object collection basket 7-Propeller

3. STATIC ANALYSIS OF THE ROBOT

After assembling the robot, the stress state in water navigation is largely consistent, so the stability of the junctions of the hull can be overlooked. However, when the robot is dismantiled, during the handling of individual hull modules, the aluminum alloy shell bears all the weight. During the lifting process, the ship's aluminum alloy shell, in addition to bearing the weight of the hull modules, will also be affected by additional forces from acceleration, leading to deformation. The extent of these deformations strongly impacts the structural stability of the hull. The design requirements state that the maximum stress on the hull during handling and lifting must be less than 205 Mpa, and the angle deformation must be less than 1°. The following uses Solidworks/Simulation's static analysis feature to analyze the deformation during handling and accelerated lifting.

3.1. Simulation Analysis during Handling of the Robot Hull Module

(1) Model Simplification

For ease of finite element analysis, the aluminum alloy shell of the hull module was transformed from a welded sheet metal part to a single sheet metal part using Solidworks software. The battery box was designed as the same part as the aluminum alloy shell, eliminating components such as the battery, battery box cover plate, and propeller, which can be represented by concentrated forces. The comparison of structures before and after simplification is shown in Figure 2.

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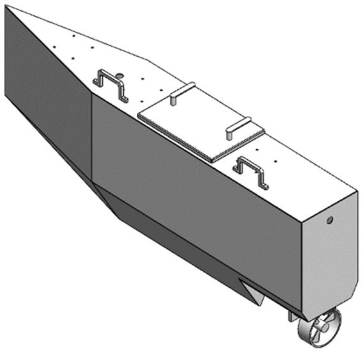
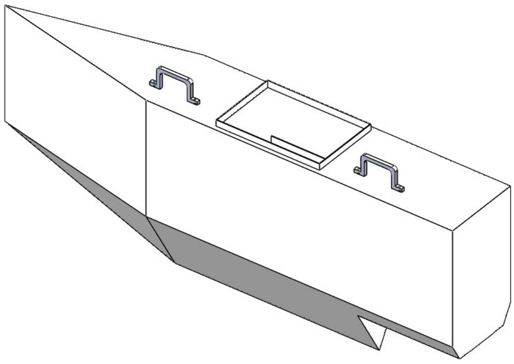


(a) Before simplification



(b) After simplification

Figure 2. Comparison of the hull module model before and after simplification

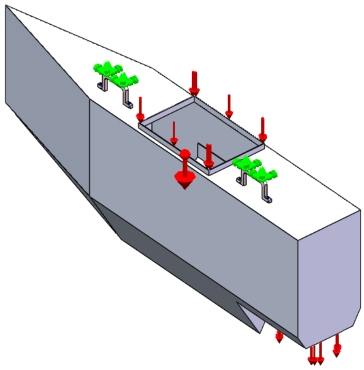
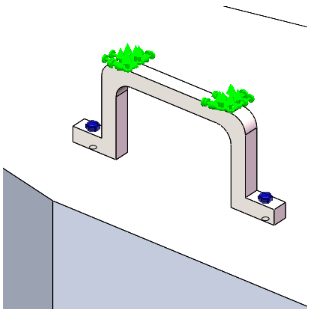
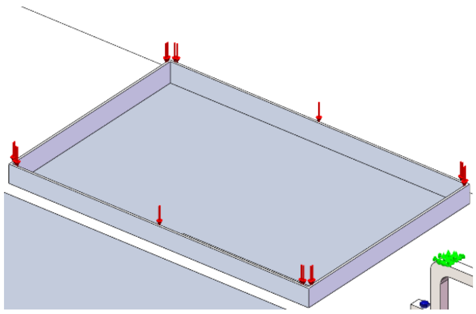


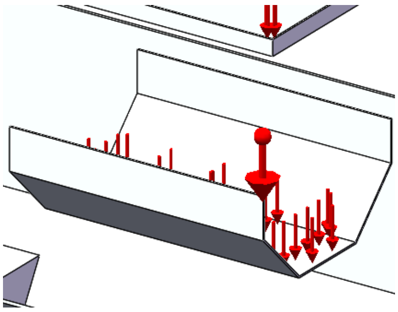
Figure 3. Simulation Model



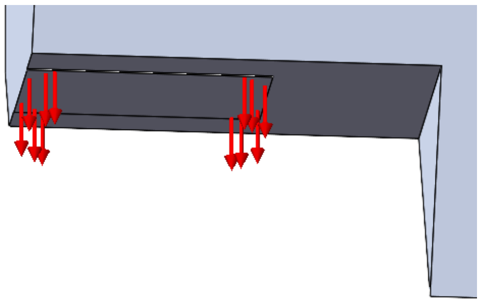
(a) Bolted connection between the handle and the shell



(b) Battery box cover plate simplified to a concentrated force



(c) Lithium battery simplified to a concentrated force



(d) The propeller is simplified to a concentrated force

Figure 4. Details of the Simulation Model

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(2) Creation of the Simulation Model

Using the simplified model in Figure 2(b), the simulation model was created, as shown in Figure 3. The shell material was selected as 6061 aluminum alloy with a tensile strength of 205 MPa; the handle was fixed at the top; the handle was bolted to the shell; the contact surface was set to bonded and impenetrable, as shown in Figure 4(a); The battery box cover plate was simplified to a concentrated force on the shell, as shown in Figure 4(b); The lithium battery was simplified to a concentrated force acting on the bottom of the battery box, as shown in Figure 4(c); The propeller was simplified to a concentrated force acting on the tail of the shell, as shown in Figure 4(d), (the size of the concentrated forces was set as the simplified mass divided by the combined surface). Gravity was set downwards with an acceleration of $g=9.8m/s^2$.

The mesh was set with a size of 10mm, with a Jacobian of 16 points, high mesh quality, a total of 119862 points, and a total of 238873 nodes. The model with the grid divided is shown in Figure 5.

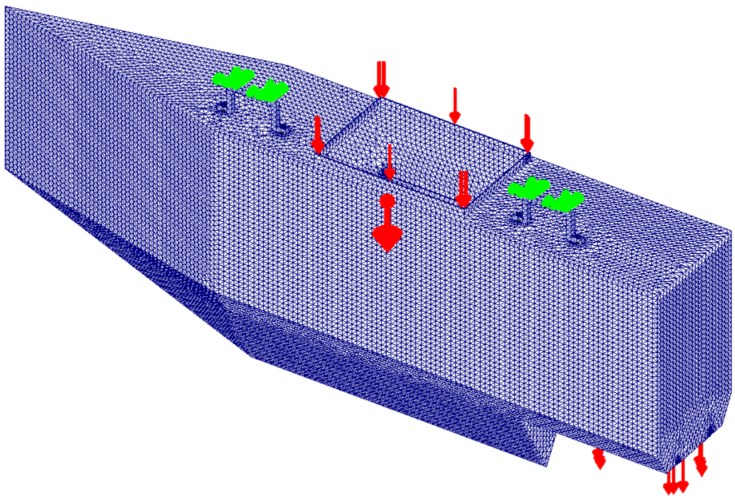

Figure 5. Grid-divided Model

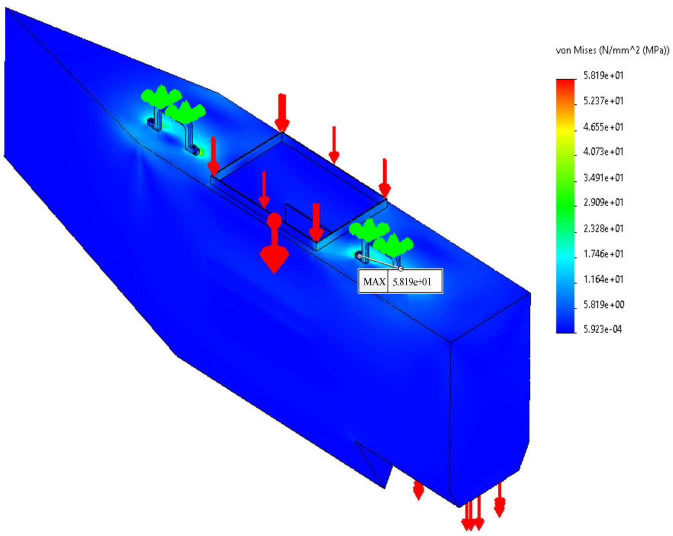

Figure 6. Stress distribution cloud of the hull module during handling

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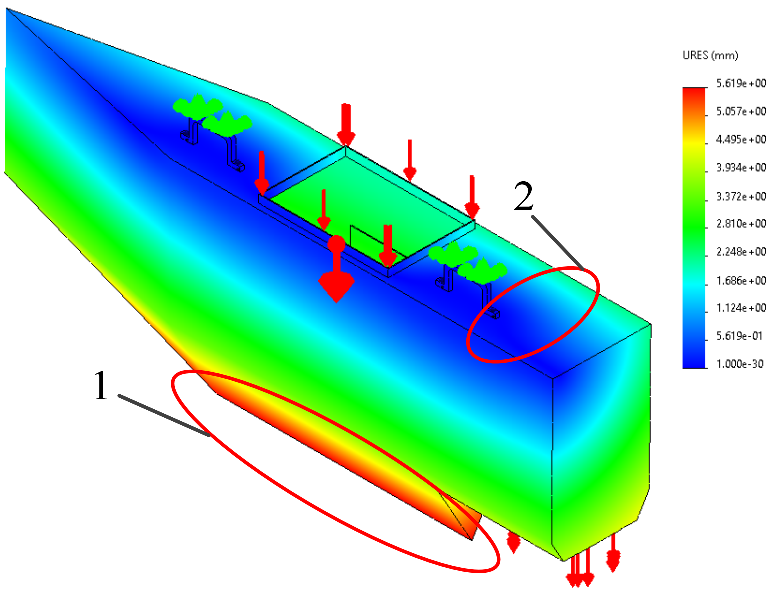

Figure 7. Displacement distribution cloud of the hull module during handling

(3) Analysis of Simulation Results

Running the simulation program, the stress contour map obtained during the handling of the hull module is shown in Figure 6. The maximum stress occurs where the handle connects to the shell, with a maximum stress of 58.1 MPa, lower than the tensile strength of aluminum alloy, 205 Mpa, meets the strength requirements.

As shown in Figure 7, the displacement contour map during the handling of the hull module shows that the maximum displacement occurs at the bottom of the shell (marked with a 1 circle), measuring 5.8mm. By observing the results, it can be seen that the displacement at location 1 is basically consistent, indicating that it will not cause an angular deformation of the hull. Therefore, although the bottom of the shell exhibits significant displacement, this does not impact the stability of the individual hull modules. However, at the location marked 2 on the shell top, there is a large difference between the blue and cyan areas, which could lead to angular deformation. This position needs further discussion to determine if the angle deformation is within 1°.

Using a probe tool, the displacements at the two node positions shown in Figure 8 were extracted. The displacement at the blue part was 0.169mm, and at the cyan part, it was 2.17 mm. Through calculations, it has been determined that the angle of deformation β generated during handling is:

$$\tan\beta = \frac{\Delta h}{b} = \frac{2.17 - 0.169}{230} = 8.7 \times 10^{-3}$$

By trigonometric transformation, we get: $\beta = 0.49^{\circ}$

After calculation, it is known that β<1°, meeting the design requirements.

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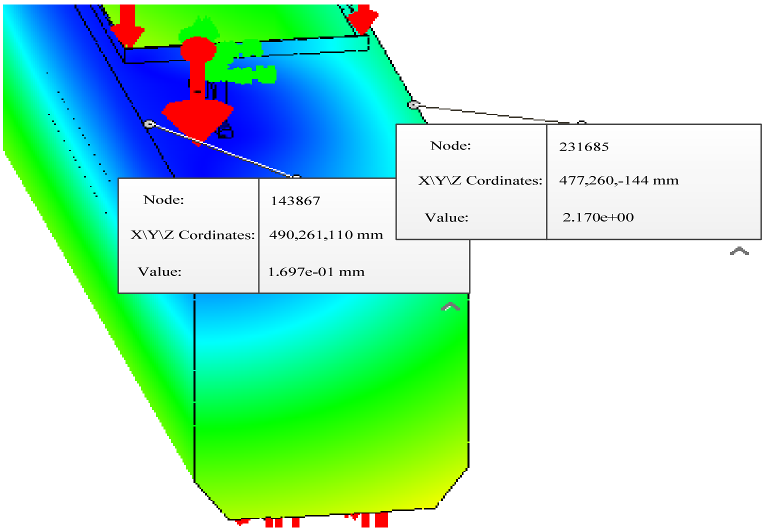

Figure 8. Node Displacement Detection

3.2. Simulation Analysis of Lifting the Robot Hull Module

(1) Adjustment of Simulation Parameters

When lifting the robot hull module, there is an acceleration process, and the gravitational force on the shell changes; other settings remain consistent with the handling phase. Assuming that the hull module is lifted by 0.7 m (the height of a tricycle cargo bed) within 0.5 s. If the entire process is acceleration, the acceleration can be calculated as $a=5.6\ m/s^2$. At this time, the gravity setting in the simulation model should be $a+g=15.4 m/s^2$. Other settings in the simulation model remain unchanged.

(2) Analysis of Simulation Results

Running the simulation program, Figures 9 and 10 show the stress distribution cloud diagram and displacement distribution cloud diagram when lifting the hull module, respectively. As can be seen from Figure 10, the maximum stress still occurs at the handle connection point, with a maximum stress of 77.1 MPa, less than the tensile strength of aluminum alloy, 205 MPa, and thus meeting the strength requirements.

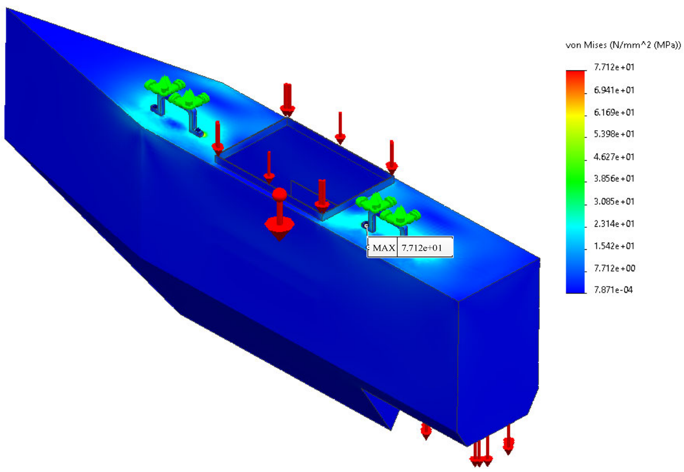

Figure 9. Stress distribution cloud diagram of the hull module when lifting

As shown in Figure 10, the displacement distribution of the hull module when lifting is similar to that during handling. Location 1 has the largest displacement, 7.465 mm, and since the

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displacement changes uniformly, we can disregard angle deformation. At location 2, the displacement is smaller, but there is a significant difference between the blue and cyan positions, so angle deformation must be discussed. Calculations show that the angle deformation at this location is β=0.65°, which meets the design requirements.

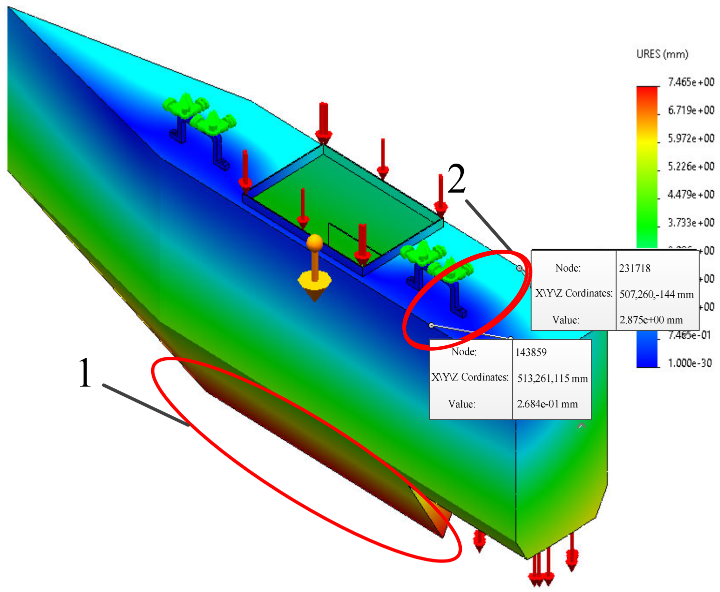

Figure 10. Displacement distribution cloud diagram of the hull module when lifting

Through finite element analysis of the robot's hull module during handling and lifting phases, it can be concluded that the design of the robot body meets usage requirements, demonstrating a reasonable design.

4. CONCLUSION

This paper analyzes deformation issues encountered during the manual handling and lifting of the designed water surface garbage cleaning robot under its own weight, using Solidworks/Simulation software for static simulation analysis. Simulation results indicate that, regardless of whether it is during manual handling or lifting, the robot's hull module experiences stress and angle deformation that are both less than the design criteria. The structural design of the water surface garbage cleaning robot is reasonable.

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