Development of an Amphibious Surface Garbage Collection Robot and Its Applications

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Abstract

This paper presents an amphibious water - surface garbage - collecting robot. It incorporates innovative technologies such as efficient garbage collection, accurate identification and classification, stable amphibious operation, and sustainable energy utilization. The double - four - bar linkage and "three - pipe" collection device ensure effective collection and classification. The amphibious crawler provides buoyancy and land - moving ability. Visual recognition technology has high accuracy. GPS automatic cruise and solar charging system are also included.

Keywords: amphibious, water - surface,GPS, remote control, monitoring

1. Introduction

With the acceleration of urbanization and the continuous expansion of human activities, it is more difficult to collect garbage in small and medium-sized waters. Algae reproduction, cigarette butts, plastic products discarded at will. In the long run, the ecological balance of small and medium-sized waters will be completely broken, and the biodiversity will continue to decline[1].

The investigation of the existing water surface garbage collection ships shows that large collection vessels occupy the majority and can quickly solve the situation of a large amount of garbage and water grass in the river. But it will take a lot of manpower and resources to clean up. In addition, large collection vessels are too large to enter small basins and closed basins, and require manual operation, and automation is not comprehensive enough. For small and medium-sized collection machines, most of the control accuracy is low, the garbage collection accuracy is not high, the efficiency is low, and the energy consumption is large.

Based on the above discussion, the focus of this design is the overall structure of small and medium-sized water surface garbage collection robot and the motion simulation of high-precision collection and low-energy design when the machine runs on the water surface under the GPS cruise state. The purpose of this design is to create a machine with amphibious, automatic garbage identification, sorting and positioning functions, so that small and medium-sized water garbage collection problems can be improved.

The rest of this paper is organized as follows. The second section introduces the structure of each part of the model, the third part introduces the design of visual recognition module, and the fourth part introduces the simulation of water surface operation to verify the effectiveness of the design. The fifth part summarizes the main content of this paper.

2. The mechanical structure

The water surface garbage collection robot is mainly responsible for garbage collection, sorting and automatic landing. Therefore, we use amphibious wheels, two sets of collection devices, one set of pull-back mechanism.

Amphibious wheel, using a specific foam material and crawler composite design. Foaming material can provide buoyancy and auxiliary power in water, and does not affect the land walking, has a strong amphibious mobility performance. The design of the amphibious wheel is shown in Fig.1.

Fig.1 The design of the amphibious wheel

2.1. Execution module

The execution module is mainly a push and pull double four-link mechanism, referring to the design of the packaging machine bag mechanism. Through visual identification, double four rod mechanism mainly carries out the collection of plastic products for recycling. When action, the motor drives the original parts to rotate. When the original driver rotates clockwise, the FEI rod moves to the right, the CBI rod moves to the left and the mechanism opens; when the original member rotates counterclockwise, the FEI rod moves to the left and the

CBI rod moves to the right to close.The mechanism schematic diagram is shown in the Fig.2.

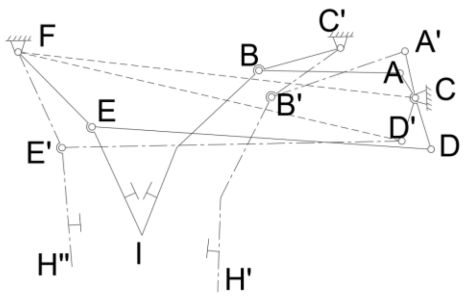

Fig. 2. Brief diagram of the double four-bar mechanism

2.2. Gathering unit

The design adopts dual-mode switching and three-tube collection. For plastic products, supplemented by visual identification, double four-bar mechanism, into the middle pipe, sent to the tail of the machine collection net; For floating debris, algae, etc., the suction method is used to enter the two side tubes and enter the collection bin inside the machine.The collection device is shown in Fig.3.

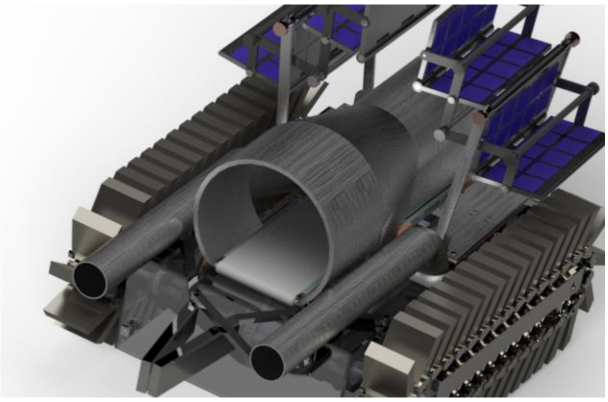

Fig.3. Collection device

3. Visual Recognition Module

In the design of the visual recognition module, we collected pictures of various types of trash and labeled them one by one, which were then imported into the model training as a dataset. The model was trained on the YOLOv5s and then compared with the validation set for model recognition. The visual recognition module is shown in Fig.4.

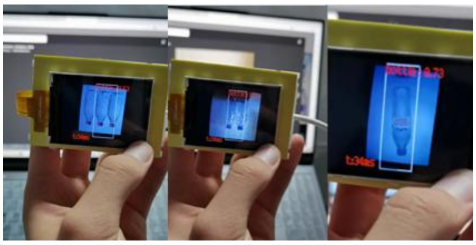

Fig.4. Visual recognition module

Sample identification data sheet is shown in Table 1.

Table 1. Sample identification data sheet

Sample name	Sample set	Successful number	success rate
Plastic	1000	963	96.3%
Cigarette butts	1000	951	95.1%
algae	1000	950	95.0%
leaves	1000	977	97.7%

4. Surface Operation Simulation

The model building process involves setting various parameters and dynamically adjusting the range of variables, referring to the setting and adjustment of the multi-agent system simulation platform to simulate the system performance under different working conditions [2]. At the same time, considering the CFD model of amphibious vehicles [3], the simplification of body shape follows certain principles (such as ignoring small scale structure, etc.) to adapt to the numerical simulation, in order to realize effective model construction and analysis in complex practical situations.

Model building and simulation are performed by using MATELAB software.

4.1. Mechanical simulation model

There are two main factors affecting mechanics. The first is buoyancy and weight on the surface of the water: the more objects collected, the greater the weight, the greater the buoyancy, and the mass of different objects is different. The second water resistance: related to buoyancy, the greater the buoyancy, the greater the resistance.

In some studies, the turbulent free surface flow of viscous liquid [5] or the influence of ship speed change on ship speed loss during deceleration were considered in the calculation of drag [6]. By comparing various optimization models, this paper approximately simplifies the resistance relation to a linear relation and sets the linear coefficient as K_x.At the same time,let the buoyancy F_1 the resistance F_2, the water uncertainty resistance F_x, the weight of the robot itself is G_0, and the inconsistent weight of each object is set to G_x.The formula can be obtained as follows.

$$\begin{cases} F_1 = K_1 \times (G_0 + n \times G_x) \\ F_2 = K_2 \times F_1 + F_x \end{cases} \quad (1)$$

- Buoyant simulation model: buoyancy F_1 is closely related to the weight of the robot itself G_0, the number of collected objects n and the weight of a single object G_x.The relationship is as follows.

$$F_1 = K_1 \times (G_0 + n \times G_x) \tag{2}$$

In the simulation, let $K_1 = 1$, $G_0 = 10$, and n values range from 0 to 50. In order to more fit to the actual working condition, with the increase of n the G_x value range is dynamically adjusted.

$$\begin{cases} \min\{G_x\} = 0.2 + 0.02 \times n \\ \max\{G_x\} = 1 + 0.1 \times n \end{cases} \tag{3}$$

For each calculation, G_x randomly takes values in this interval. At the same time, the robot submerged threshold was set to 100, and when $(G_0 + n \times G_x) > 100$, F_1 kept the former value unchanged. The F_1 value of each n was calculated to construct the buoyancy change curve with the number of collected objects.

- Resistance simulation model: resistance F_2 is affected by the buoyancy F_1 and the uncertain resistance F_x, the relation $F_2 = K_2 \times F_1 + F_x$, take $K_2 = 0.5$. When calculating F_2, G_x is determined within the range of n, and a random number of F_x (mean of 0, standard deviation of 5) is randomly generated, which obtains the corresponding F_2 value of each n and draws the change curve of resistance with the number of collected objects.

Simulation model of speed and energy relationship: speed v is closely related to energy E and resistance F_2, the expression is $v = K_4 \times (K_5 \times E - K_6 F_2)$, setting $K_4 = 0.1$, $K_5 = 2$, $K_6 = 0.2$. The grid n and E takes n to 50, E 0 to 100, F_1, F_2 and v values are calculated point by point, drawing the relationship surface between speed v and energy E and the number of collected objects n.

The simulation results of F_1, F_2 and n are shown in Fig.5.

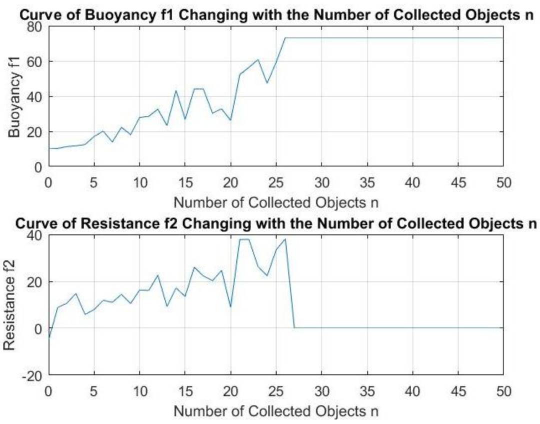

Fig.5. Simulation result diagram

Buoyancy characteristics: In the initial stage, n increases F_1 almost linearly, due to the increase of objects, and the buoyancy increases accordingly. When n exceeds a certain value and the total weight is close to the submerged threshold, the growth rate of F_1 slows down or even constant. This phenomenon indicates that the carrying capacity of the robot is limited and close to the critical state.

Resistance characteristics: The resistance F_2 curve shows that it increases with n rising and fluctuates significantly. This is attributed to $F_2 = K_2 \times F_1 + F_x$ increases the resistance base term with n growth, while the random fluctuation F_x increases the curve fluctuation, highlighting the complexity of the water surface environment on the robot motion resistance, indicating the direction for optimizing the robot shape and propulsion system design, to reduce the uncertainty resistance interference. The results are similar to the effect of various factors on resistance analysis of high-speed amphibious vehicle (HSAV) [4]. The resistance of HSAV includes friction resistance, viscous pressure resistance and wave resistance, and is affected by many factors such as vehicle shape and navigation speed. In this study, the resistance of water surface robot is affected by buoyancy and uncertain water surface resistance. The analysis of resistance characteristics can provide a basis for the optimal design.

4.2. GPS simulation model

The machine uses GPS module for positioning, and the positioning accuracy of GPS module affects the collection efficiency. Set the target point coordinates of the machine as (X, Y), the actual coordinate points of the machine at present as (X_1, Y_1), the GPS module output positioning coordinate points as, the expected turning Angle as (X_2, Y_2), the output heading Angle as θ_1, and the deviation Angle as θ_2,the formula can be obtained.

$$\begin{cases} \cos\theta_1 = \dfrac{X \cdot Y + X_1 \cdot Y_1}{\sqrt{X^2 + Y^2} \cdot \sqrt{X_1^2 + Y_1^2}} \\ \cos\theta_2 = \dfrac{X \cdot Y + X_2 \cdot Y_2}{\sqrt{X^2 + Y^2} \cdot \sqrt{X_2^2 + Y_2^2}} \\ \theta = |\theta_1 - \theta_2| \end{cases} \tag{4}$$

It can be seen from the formula that the smaller the absolute value of the deviation Angle, the higher the GPS positioning accuracy. The machine collection accuracy mainly depends on the GPS positioning accuracy. The positioning accuracy of GPS is not only related to its own control, but also positively related to its speed [7]. But at the same time, we should consider the system error, the fluctuation of water and the physical inertia impact of the double four-bar mechanism. Reducing the system error requires reducing the speed. Therefore, the relationship between accuracy and velocity obtained by curve fitting is shown in Fig.6.

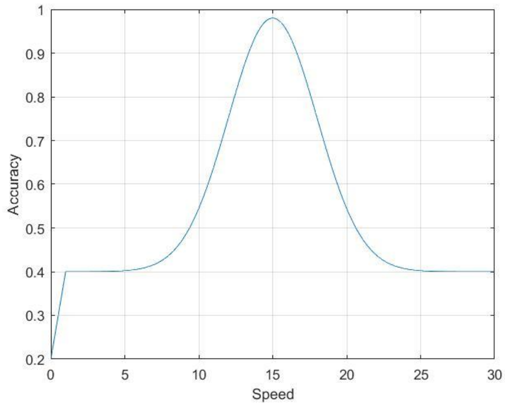

Fig.6. GPS fitted curve

4.3. Energy consumption simulation model

Energy consumption is related to speed, and the higher the resistance, the lower the speed. In addition, the speed is not constant, and the efficiency of collecting objects needs to be improved by accelerating or decelerating under certain conditions.

Simulation model of speed and energy relationship: speed v is closely related to energy E and resistance F_2, the expression is

$$v = K_4 \times (K_5 \times E - K_6 F_2) \tag{5}$$

Let $K_4 = 0.1$, $K_5 = 0.1$, $K_6 = 0.2$. The grid n and E takes n to 50, E 0 to 100, F_1, F_2 and v values are calculated point by point, drawing the relationship surface between speed v and energy E and the number of collected objects n.

The simulation results are are shown in Fig.7.

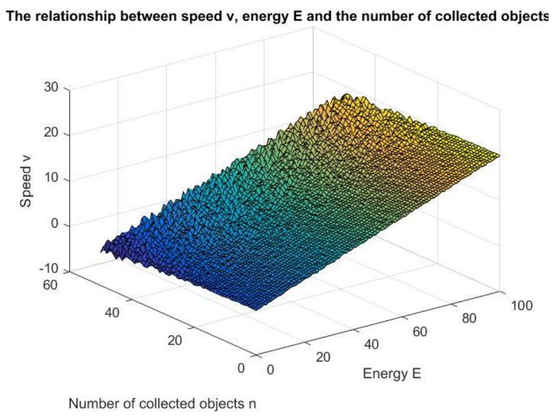

Fig.7. Simulation result diagram

Velocity-energy-object number relationship: the three-dimensional surface of velocity v intuitively presents its complex relationship with E and n. When n is fixed, E increases v increases, indicating that the energy supply can improve the speed and ensure the operation efficiency; E is constant, n increases v decreases, increasing the load of the robot, which is in line with the actual operation expectation.

4.4. Analysis and integration

In order to improve the accuracy of garbage collection and reduce the energy consumption under long working hours. The accuracy and energy consumption were simulated by MATELAB. Because the machine garbage collection is at full load, the inertia is maximum and the energy consumption is highest. In order to ensure more accurate simulation, it is considered to fit the machine under full load conditions.

When the speed is particularly large, considering the inertia and water fluctuation and other factors, the collection error will increase and the collection accuracy will be reduced. When the speed is particularly small, due to the very low speed, the gps accuracy will be lost , and the collection error will increase, so the entire collection accuracy can be approximately regarded as a normal distribution in the speed interval [7]. The gps accuracy curve can be divided into two sections, that is, it is a proportional function before the precise positioning speed threshold, and it is a constant beyond the speed threshold. After simulation by MATLAB, obtain Fig.8.

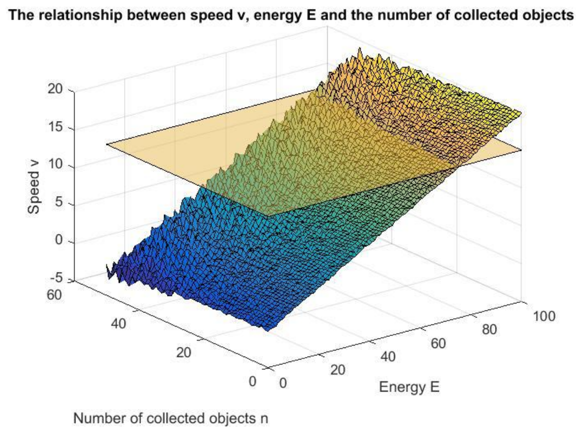

Fig.8.Speed threshold curve

5. Conclusion

Through the simulation of resistance buoyancy, GPS accuracy and energy consumption, it is found that in order to achieve high-precision collection and low-energy design of the machine, it is necessary to ensure that the value of the speed must be in a certain range, and the maximum threshold of the speed can be obtained under the full load state. Therefore, the speed is controlled within the interval, which can achieve high-precision collection while saving energy.

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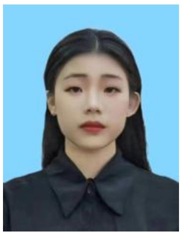

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