Research on Autonomous Water Surface Garbage Detection and Cleaning Robot Based on YOLO v8 Multi-scale Feature Fusion

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Abstract: With the economic development and the improvement of people's living standards, the number of artificial lakes is increasing year by year, in recent years, due to the floating garbage on the water surface caused by many water odors, eutrophication and other problems, seriously affecting the water ecological environment and human living environment. At present, the recycling of surface garbage is still mainly based on manual salvage and cleaning by large cleaning vessels, which consumes a lot of energy and has low efficiency. In this regard, we propose a design scheme of water surface cleaning robot based on YOLO V8 vision algorithm. The robot has the functions of intelligent recognition and automatic cruise, which greatly improves the automation and intelligence of surface garbage cleaning. The robot uses the YOLO V8 vision algorithm to collect images of water surface garbage and do image processing, and automatically clean up the garbage after identification. And in the absence of manual control, the robot can also automatically scan and clean garbage in a "carpet" manner across the entire water surface, so as to realize the all-weather unattended salvage operation of surface garbage. By optimizing the mechanical structure and power system, using the missile-type buoy as the catamaran structure to reduce the water resistance, and using solar cells to directly supply energy, the working energy consumption can be reduced and its endurance can be improved. The design overcomes the shortcomings of low efficiency of manual salvage method and large size, high cost and limited working area of cleaning boat, and is fully suitable for the cleaning of garbage in small waters, which is in line with the concepts of "green environmental protection", "resource utilization" and "sustainable development", and has good application prospects and promotion value.

Keywords: Surface Garbage; Intelligent Identification; Automatic Cruise; Remote Monitoring

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Introduction

In recent years, water pollution caused by floating garbage in rivers, lakes, and reservoirs has become increasingly severe in China. Over time, this floating garbage first pollutes the aquatic ecological environment and then threatens the quality of life for nearby residents. Currently, water surface garbage cleaning methods mainly include cleaning vessels and manual cleaning. The former is only suitable for large rivers and coastal areas, with drawbacks such as large size, inconvenient mobility, high energy consumption, and high costs, making it unsuitable for small water bodies. The latter suffers from low efficiency, high costs, and safety concerns. Therefore, researching small intelligent garbage cleaning robots to improve the automation and intelligence of garbage salvage holds significant practical importance [1].

1 Demand Analysis for Autonomous Cleaning Robots Based on Deep Learning Algorithms

Autonomous cleaning robots based on deep learning algorithms must meet core requirements in complex aquatic environments. Functionally, they need high-precision, robust multi-target detection capabilities to effectively identify various types of surface garbage, overcoming false detections caused by waves, reflections, and overlapping garbage. They must also adapt to different clarity levels and detection angles while ensuring real-time performance to meet engineering standards. In terms of operation and management, the robots should achieve autonomous navigation based on GPS and visual fusion, support autonomous cruising and path optimization, and integrate with an upper computer remote monitoring system to minimize faults and maximize efficiency. Additionally, the robots should collect and transmit real-time water quality data, enabling intelligent decision-making through the upper computer system's data analysis. This meets the comprehensive needs of accurate recognition, autonomous operation, and intelligent management in surface cleaning tasks.

2 Research on Intelligent Recognition Based on Deep Learning

In intelligent recognition mode, the robot can identify and clean floating garbage while detecting and avoiding non-target obstacles such as lotus leaves and stones. The visual recognition module identifies common garbage like plastic bottles and leaves, compares their positions relative to the robot, and performs further path planning, garbage cleaning, and obstacle avoidance actions.

2.1 Multi-Target Detection Based on YOLO v8 Vision Algorithm

To overcome the limitations of traditional recognition methods, such as low robustness in manual feature extraction and high design difficulty, the YOLO v8 vision algorithm is adopted. During training, the algorithm directly learns features and acquires highly nonlinear semantic information, significantly improving classification accuracy [2]. The detection process is shown in Figure 1.

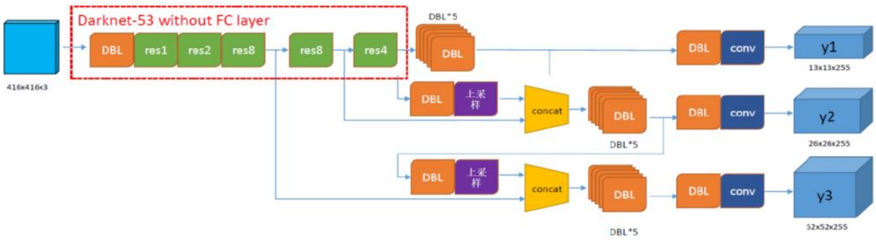

Fig 1 The object detection process of the YOLO V8 vision algorithm

2.2 Path Planning Based on Rolling Window and Artificial Potential Field

The robot relies on local information detected by the camera and uses an interrupt method

for path correction. It performs local path planning within the current rolling window, implements the current strategy, and continuously updates environmental information as the window advances. The artificial potential field algorithm is employed to guide the robot to unexplored areas when no garbage is detected, forming an optimal path while avoiding obstacles[3].

2.3 Remote Monitoring Mode Based on Upper Computer Software

The design includes an upper computer remote monitoring system with real-time monitoring functions for garbage quantity, robot battery level, and speed. It ensures automatic return when the garbage collection is full or the battery is low and displays real-time status. During cruising, if the robot encounters errors, it sends an alert via radio signal to the upper computer, allowing manual intervention. Manual intervention has the highest priority, ensuring the robot safely returns to the docking point, maximizing reliability and safety while minimizing fault probability and providing transient fault protection [4].

3 Autonomous Cruising Mode Based on Deep Learning

Without manual control, the robot performs "carpet-style" scanning and cleaning across the entire water surface. As shown in Figure 3, the robot uses a built-in GPS module and gyroscope to determine the direction, ensuring straight-line movement. An ultrasonic emitter controlled by a servo detects distances to obstacles or shorelines on the front, left, and right sides [5].

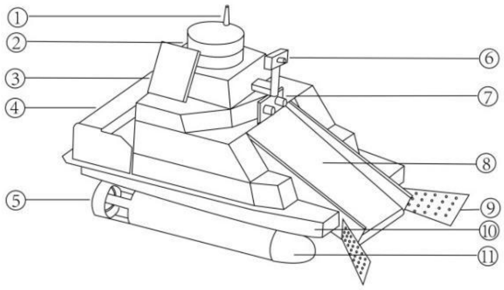

Fig.2. Overall structure of the robot

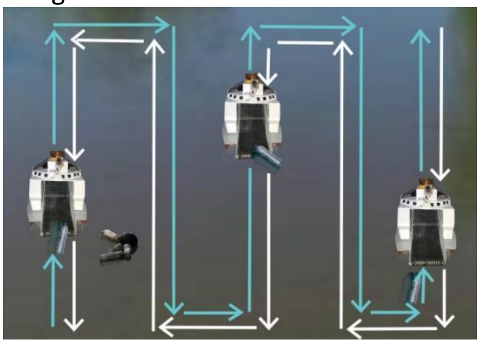

Fig 3 Schematic diagram of automatic cruise control

Antenna; (2) Warning Light; (3) Solar Panel; (4) Collection Bin; (5) Tangle-Resistant Underwater Thruster; (6) PTZ Camera; (7) Ultrasonic Emitter; (8) Conveyor Belt; (9) Collection Baffle; (10) Streamlined Float; (11) Missile-Type Float

In autonomous cruising mode, the robot moves straight initially. If obstacles are encountered, the artificial potential field method calculates a feasible avoidance path. The robot follows this zigzag trajectory to cover the entire lake surface (Figure 4). The machine vision module assists by detecting non-target obstacles like lotus leaves and stones, allowing the robot to avoid them and continue cleaning. After cleaning, the GPS + visual navigation system guides the robot back to the docking point. The visual tracking algorithm identifies AprilTag markers (Figure 5), which provide precise 3D position and orientation data (Figure 6) for accurate docking.

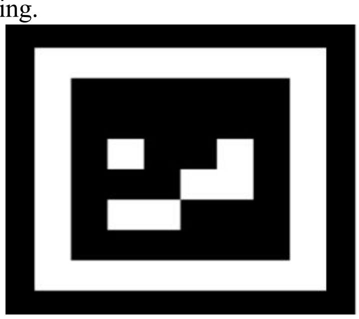

Fig 4 AprilTag logo of the GPS visual navigation system

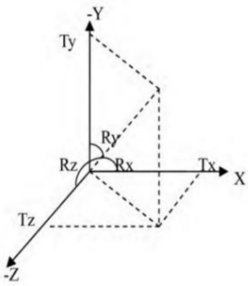

Fig 5 3D values from AprilTag markers

4 Experiments and Analysis

Working Principle of the System:The solar power system first supplies energy to the entire robot system. The sensor system detects environmental information such as floating garbage and obstacles on the lake surface, as well as the robot's own status, in real time through various sensors. All collected data is transmitted to the controller. After reading and processing the information, the controller sends execution commands to the actuators. The actuators control the left and right propellers to enable the robot's movement on the water surface. The collection baffle continuously opens and closes to gather garbage toward the edges of the conveyor belt. The conveyor belt rotates continuously, transporting the garbage into the cabin and then into the collection box at the rear of the robot.

As shown in the figure, the YOLO v8 vision algorithm effectively overcomes false detections caused by waves, reflections, and overlapping garbage. It demonstrates high accuracy and real-time performance across varying clarity levels and testing angles, making it suitable for practical engineering applications.

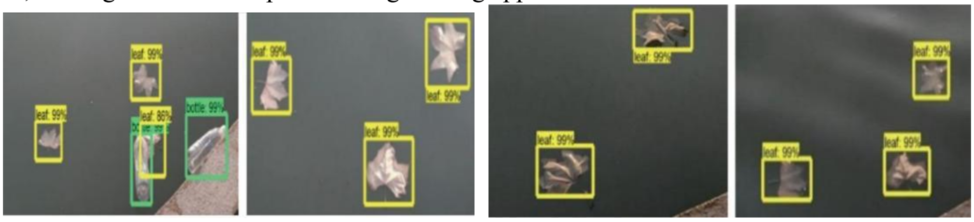

Fig.6 Detection results of floating garbage on the water surface

The accuracy rate (Pr), false alarm rate (Pd), and processing speed were selected as the algorithm's performance metrics. Table 1 presents the average values of these performance indicators, demonstrating that the algorithm meets both the recognition and real-time requirements of the robot.A localization algorithm was used to determine the positions of three instances of floating garbage on the lake surface, and the results were compared with actual measured data (Table 3). The data in Table 2 shows that the algorithm's performance generally fulfills the practical needs of the robot.

Table 1 Algorithm performance metrics

Performance Metric	Accuracy Rate P r/%	FalseAlarmRatePd/%	Processing Speed/fps
Average Value	f90. 27	9. 93	20

Table 2 Garbage location test

Test Case	Actual Coordinates (a /(°) ,r/m)	Measured Coordinates(a1/(°),r1 /m)	Azimuth Error/%	Distance Error/%
1	（33.2，3.6）	（30.4，3.8）	8. 4	5. 6
2	（10.8，4.1）	（11.3，4.3）	4. 6	4. 9
3	（23.5，2.7）	（-22.8，2.4）	3. 0	11. 1

Note: θ represents the angle between the garbage and the robot's forward direction (positive to the right); r represents the linear distance between the garbage and the robot.

At a location 10 meters from the shore, a 1m² square water area was marked on the surface for simulated garbage cleaning tests. As shown in Figure 8, the robot autonomously navigated from the shore to the floating garbage for cleanup. The travel process took 16 seconds, while the entire cleaning operation required 8 minutes.Field test data indicates:Travel speed: 0.63 m/s,Cleaning efficiency: approximately 0.13 m²/min,These results essentially meet the design specifications.

During testing, the need to return to shore for unloading when the garbage collection bin reached capacity reduced overall cleaning efficiency - an issue requiring further optimization [7]. With a fully charged battery, the robot demonstrated a maximum continuous operational duration of 3.5 hours on water, basically satisfying design requirements. The actual test data yielded partial performance metrics of the robot, as detailed in Table 3.

Fig 7. Test of automatic cruise cleaning by robot

Table 3: Some performance indicators of robots

Parameter	Design Specification	Measured Performance

Travel Speed	≥ 0.5m/s	0.63m/s
Cleaning Efficiency	≥ $0.1m^3$/min	$0.13m^2$/min
Single Operation Duration	≥ 3h	3.5h
Maximum Power	≤ 200W	180W
Remote Control Range	>15m (LAN), unlimited (Internet)	20m (LAN), unlimited (Internet)
Mobile Client Capacity	≥ 20 台	25 台
Total Mass	30kg	25kg
Control Latency	≤ 1s	0.6s
Positioning Accuracy	≤ 5m	5m

To meet the fundamental requirements of the YOLO v8 vision algorithm for this project, we first trained the model on a separate large-scale dataset and used the obtained model parameters as initial values for our network. Subsequently, we performed additional training on the target dataset to further fine-tune the original parameter categories. Through iterative refinement, we ultimately developed a network model that better aligns with the expected outcomes [8].During the extensive training process, we monitored the convergence of the loss function in real-time. As shown in Figure 9, the loss value of the entire network gradually decreased, demonstrating continuous improvement in the recognition model's accuracy [9].

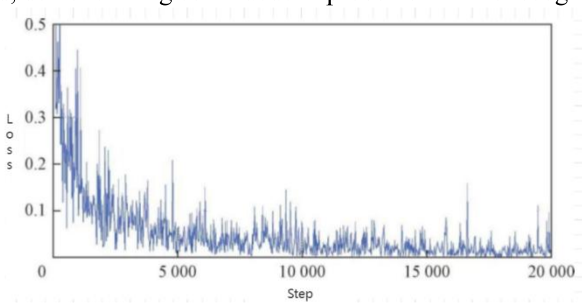

Fig.8 Overall loss function

5 Conclusion

In summary, this research has achieved multiple innovative breakthroughs in the technological implementation and performance optimization of autonomous water-surface cleaning robots:The adoption of the YOLO v8-based multi-target visual detection algorithm effectively overcomes the limitations of traditional recognition methods, such as low robustness in manual feature extraction and high design complexity.Significant reduction in false detection rates under challenging conditions (e.g., wave interference, light reflection, and overlapping garbage).Meets engineering requirements for accuracy and real-time performance across varying clarity levels and testing angles.Combines GPS and vision-based navigation with an upper-computer remote monitoring platform. Enables autonomous cruising and remote management, minimizing failure rates while maximizing operational efficiency.Real-time water quality data collection and transmission to the upper-computer system for analysis. Provides actionable insights for timely environmental monitoring, enhancing overall system intelligence.These technological innovations offer practical and reliable solutions for the engineering application and performance optimization of water-surface cleaning robots.

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