Ocean Guardian

Team 012 - Killer Whale

Beijing No. 35 High School & Guangdong Experimental High School, China

Abstract

This project is committed to designing and manufacturing a low-cost, open-source Remote Operated Vehicle (ROV) with a focus on marine environmental protection and restoration. This ROV is equipped with four core functions: real-time collection of underwater images and water quality parameters; provision of a robotic arm to assist in cleaning up small pollutants; establishment of a regional marine pollution database; and serving as a science education tool to enhance public awareness of marine protection.

The project adopts a modular design that encompasses mechanical structure, power system, control circuit, and sensor modules, ensuring system stability and ease of expansion. The ROV framework utilizes PVC pipes and 3D-printed connectors, combined with the Arduino open-source platform, to reduce technical complexity and make it suitable for practical application by high school student teams. With a total budget under 800 yuan, low-cost components are used to facilitate replication and promotion, providing a case study for STEAM education.

The project outcomes are expected to attract attention at campus science festivals and community science popularization events, inspiring teenagers' enthusiasm for scientific and technological innovation and cultivating citizens' scientific literacy.

Background & Motivation

In the current context of increasingly severe global climate change and marine pollution, the protection of marine ecosystems has become a common challenge faced by humanity. According to statistics from the United Nations Environment Programme, more than 8 million tons of plastic waste enter the oceans annually, causing marine life to ingest, suffocate, and have their habitats destroyed. Additionally, overfishing, oil spills, and coral bleaching are accelerating the collapse of marine ecological balance.

The design of a wired Remote Operated Vehicle (ROV) project stems from the urgent need for marine environmental protection. Traditional manual diving operations are costly, risky, and difficult to cover deep-sea areas; while commercial ROV technology is mature, its high price and closed technical system limit its popularity. By independently designing a low-cost, open-source ROV, I hope to provide a scalable solution for marine environmental monitoring and restoration. For example, the ROV can carry high-definition cameras and water quality sensors to efficiently identify areas with accumulated plastic waste on the seabed and even assist in cleaning up small pollutants through a robotic arm, providing technical support for marine cleanup operations.

Methodology

1.Design Stage

1.1 3D Modeling and Structural Optimization: Utilize SolidWorks software for precise 3D modeling of the Remote Operated Vehicle (ROV). Analyze the pressure distribution and resistance of water flow on the frame structure and conduct multiple optimizations of the frame structure to reduce water flow resistance and enhance motion efficiency.

1.2 Motor Drive Circuit Design: Conduct in-depth research on motor drive principles to design an efficient and stable motor drive circuit.

2.Prototype Fabrication

2.1 Mechanical Structure Processing: Utilize 3D printing technology to manufacture joint components. Select appropriate ABS materials according to design requirements to ensure the strength and precision of the joint components. Assemble PVC pipes and 3D-printed joints using stainless steel screws to form the basic framework of the ROV.

2.2 Circuit Welding and Program Debugging: Manually weld various modules such as the control circuit and drive circuit. Download the programmed code into the Arduino Nano controller and debug the ROV's various functions, including motor rotation and sensor data acquisition, promptly identifying and resolving issues in the program.

3.Testing Stage

3.1 Motion Performance Testing: Establish a testing environment in a 1.5-meter-deep pool to conduct comprehensive testing of the ROV's motion performance. Testing covers straight-line navigation speed, steering flexibility, and depth-keeping ability. By recording data of the ROV under different motion states, analyze whether its motion performance meets design requirements, providing a basis for subsequent optimizations.

3.2 Functional Verification Testing: In addition to motion performance testing, verify the ROV's various functions, such as the image acquisition function of the high-definition camera, the data acquisition function of the water quality sensor, and the grasping function of the robotic arm. Ensure that the ROV can accurately and stably complete various tasks in practical applications.

Category	Material Name	Specification/Description
Mechanical Structure	PVC Pipes	Diameter: 50mm
	3D-Printed ABS Joints	Made of ABS material through 3D printing, with high strength and precision
	Stainless Steel Screws	-
Power System	775 DC Motors	12V/200RPM, 4 units
	L298N Drive Module	-
	Propellers	Diameter: 60mm
Control Circuit	Arduino Nano	-
	Motor Drive Module	-
	Communication Module	-
Sensing Module	USB Camera	-
	DS18B20 Temperature Sensor	-
Auxiliary Materials	Epoxy Resin Adhesive	-
	Silicone Gaskets	-

Results & Discussion

Core Findings

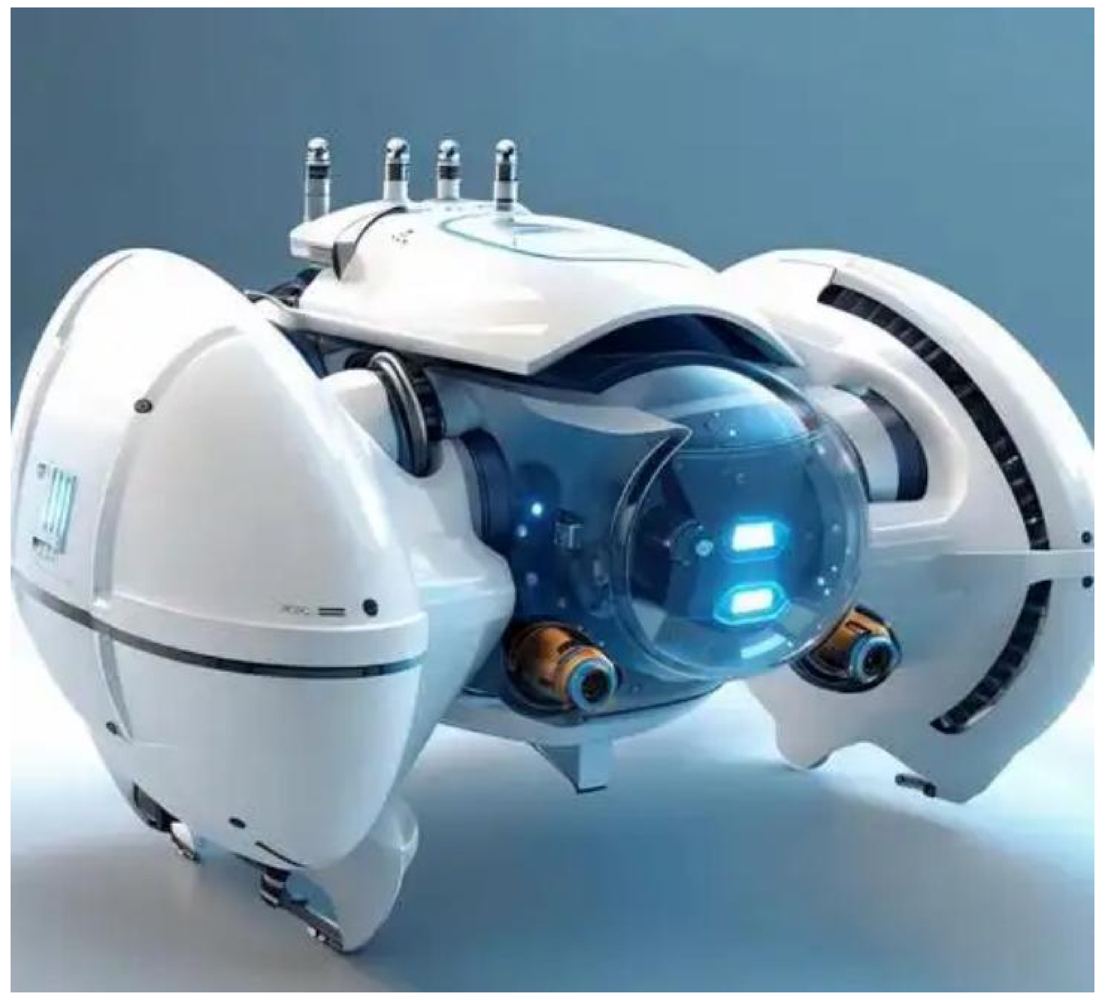
- **Motion Performance:** The ROV achieves a maximum speed of 0.5 m/s, a turning radius of less than 0.3 m, and depth-keeping accuracy within ±0.1 m.
- **Sensing System:** The camera has a transmission delay of less than 150 ms, and the water temperature measurement accuracy is within ±0.3°C.
- **Endurance:** Equipped with a 12V/2000mAh lithium battery pack, the ROV can operate continuously for 35 minutes.
- **Failure Rate:** After 20 pool tests, only one instance of motor overheat protection triggering occurred.

Unexpected Gains

- **Verification of Fluid Mechanics:** Experimental data on the relationship between propeller speed and thrust validated the thrust formula in fluid mechanics.
- **Optimization of Control Algorithm:** The implementation of the PID algorithm improved heading control accuracy by 60%.
- **Material Characteristics:** It was discovered that the strength of PVC pipes decreases after prolonged immersion, leading to consideration of using an aluminum alloy frame in the future.

Lessons Learned

- **Design Iteration:** The mechanical structure underwent three rounds of improvements, and the electronic circuit went through four rounds of debugging, highlighting the importance of prototype design.
- **Testing Standards:** The establishment of standardized testing procedures enhanced data reliability.
- **Team Collaboration:** The use of Git for code version management and Trello for task allocation improved collaboration efficiency.



ROV conceptual model generated using ChatGPT

Conclusion

- **Enhanced Awareness of Marine Pollution:** Centered around the core concept of "Ocean Guardian," this project has successfully developed a prototype of an underwater robot (ROV) with environmental monitoring and remediation capabilities. Through the intuitive presentation of sensor data and underwater imagery, the project team has gained a profound understanding of the severity and urgency of marine pollution.

- **Campus Impact and Interdisciplinary Collaboration:** The project has become a star exhibit at science festivals and academic display events. During the three-day campus science festival, the ROV provided visitors with an "immersive" experience of the current state of marine pollution through real-time transmission of underwater footage. The interactive "pollutant salvage simulation game" designed for the event attracted a large number of student participants.

Next Steps

Future work will focus on the intelligence enhancement and functional expansion of the ROV, specifically including:

- **Sensing Upgrade:** Integration of sonar sensors to achieve obstacle avoidance functionality with a detection distance of ≥1m;

- **Tool Modules:** Design of interchangeable mechanical grippers (with a gripping force of ≥5kg) and water quality samplers;

- **Communication Upgrade:** Development of an underwater wireless communication module to overcome the limitations of wired transmission distances;

- **Motion Control:** Research on reinforcement learning-based adaptive control algorithms to enhance motion stability in complex environments;

- **Human-Machine Interaction:** Development of a VR control interface for a more intuitive operational experience.

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