Development of An Aquatic Wall-Clinging Robot Utilizing Bernouli's Principle for Enhanced Adsorption

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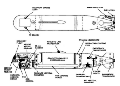
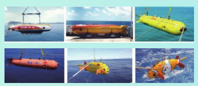
Background

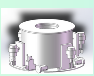
With approximately 71 per cent of the Earth's surface covered by water, there is a growing interest in the exploitation of underwater resources, with the potential for research into deep-water detection and treatment technologies, the core technologies of which include underwater detection equipment, diving technology and underwater operation technology.

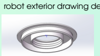



Project Goal

The goal of this project is to design an aquatic mobile robot to address challenges in underwater pipeline maintenance and resource development.
1. The robot should be able to move on the wall of underwater pipelines, with an angle range of 60 to 300 degrees. By controlling the propeller, the robot can achieve angular rotation.
2. The robot should be able to cling on the wall surface.
3. The robot requires remote control and manual control handles.

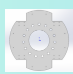
1st Generation


robot exterior drawing design

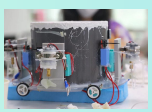

robot cover

The robot cylinder is formed by two PVC plastic tubes with different diameters in the inner and outer layers, and the cylindrical space in the middle is used to place the ROV thrusters.

Bottom base
- A laser-cut acrylic plate.
- When the ROV thruster moves, it will form a high-speed flow area within this space.
- Due to the pressure difference, the acrylic plate will be tightly pressed on the wall.


Acrylic board cutting

Robot cover
- The two grooves on the outer ring are set more spread out, while the grooves on the inner ring are more compact.
- Provides dual protection
  - reduces the probability of water leakage
  - ensures that the robot can effectively maintain internal dryness in underwater environments



Testing

Adsorption testing
Test whether the robot can successfully cling on different types of walls.

PWM signal value	Land	Wall surface 1 (smooth)	Wall surface 2 (rough)	Success rate
1100 (reverse)	succeed	succeed	succeed	100%
1300 (reverse)	succeed	succeed	succeed	100%
1500	succeed	succeed	succeed	100%
1700	succeed	succeed	succeed	100%
1900	succeed	succeed	succeed	100%
2000	succeed	succeed	succeed	100%

Mobile testing
Test whether the robot can successfully move on different types of walls.

Orientations	Land	Wall surface 1 (smooth)	Wall surface 2 (rough)	Success rate
Left	succeed	succeed	succeed	100%
Right	succeed	succeed	succeed	100%
Before turning	succeed	succeed	succeed	100%
After turning	succeed	fail	succeed	66.67%
Forward	succeed	fail	succeed	66.67%
Backward	succeed	succeed	succeed	100%

Angle	1	2	3	Accuracy
30°	40°	35°	30°	66.67%
60°	50°	55°	70°	75.00%
90°	90°	80°	85°	94.44%
180°	200°	180°	150°	83.33%
270°	300°	280°	260°	88.89%
360°	360°	340°	360°	94.44%

The total accuracy is 83.79%.

Rotation and accuracy testing
Test whether the robot can rotate on different wall surfaces.

Orientations	1	2	3	Success rate
Turn left	succeed	succeed	succeed	100%
Turn right	succeed	succeed	succeed	100%
Flipping forward	fail	succeed	succeed	66.67%
Backward flip	succeed	succeed	succeed	100%

Problems & Solutions

1. **Waterproof issue**
- **Installation is very difficult.**
- **Frequent opening and closing can have an impact on the rubber ring.**
- There are **many positions that need waterproofing**.

2. **Power charging issue**
- The cover of the robot is fixed with **waterproof glue and hot melt glue**, it needs to be removed when the battery runs out, which consumes a lot of time and is difficult to disassemble.

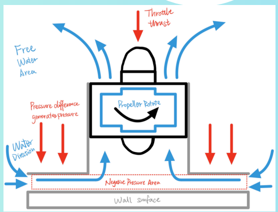
3. **Stability issue**
- The **rubber wheels are too small and the friction with the wall is limited, the robot will shake when moving.**

Design

Bernoulli's principle

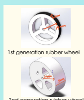
Bernoulli's principle states that as fluid velocity increases, pressure decreases.

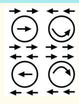
$$P + \frac{1}{2}\rho v^2 = \text{constant}$$



- A gap between the negative pressure effect plate and the wall due to the rubber wheel.
- When the propeller rotates, it will suck in the fluid around the gap and discharge it from the top, forming a high-speed fluid.
- The pressure difference generated will form a pressure perpendicular to the wall on the negative pressure effect plate..

Adsorption module
- negative pressure adsorption
- combined with ROV thrusters
- Bernoulli principle


1st generation rubber wheel
2nd generation rubber wheel



Mobile design
Rubber wheels
- The rubber wheel surface has a concave transverse pattern, which increases the coefficient of friction.
- The material of rubber wheels has a certain degree of elasticity, possessing a certain seismic resistance function.

Propeller
Designing the propeller is the core of making the robot rotate
- four propellers are installed on the robot to maintain balance
- each of which is composed of three spiral blades that can be regarded as inclined fan blades that generate propulsion when rotating.

Hardware design

Arduino Mega2560 Control Panel
The Arduino Mega2560, as the main hardware for controlling robots, can achieve control over ROV thrusters, rubber wheels, and propellers.

PS2 rocker
- The self-made remote control handle is equipped with 2 PS2 rockers.
- Control the start of the ROV thruster while controlling the direction of the rubber wheel.

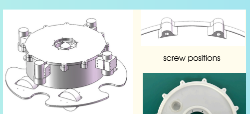
HC12 bluetooth module
The serial communication between the HC12 Bluetooth module, realizes the control of ROV thrusters and rubber wheels.

Waterproof motor
To Control the rotation speed and direction of the rubber wheel.

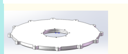
Program design

- Arduino Mega-2560 control board
- HC-12
- ROV thruster
- 4 waterproof motors
- 4 propellers
- 4 rubber wheels.

2nd Generation



screw positions

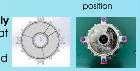


Design for Waterproof
- Embedded rubber rings for waterproofing, and the inner walls of both circles are higher than the outer walls.
- The rubber ring in the groove at the top of the inner wall and outer wall.

There are many places to screw around the cover.
- The screws will exert a downward pressure on the rubber rings.


waterproof position

There are **only two holes** that need to be waterproofed



The interior of the robot has two compartments that can store important wires, components, and batteries in this space with a dual waterproof function.

Rubber Wheel
- **Increases the size of the rubber wheel** so that the robot has better stability when moving on the wall
- When the radius of the rubber wheel is 20mm, the **minimum diameter of the robot is 765.84mm**.

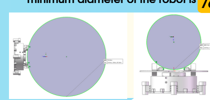
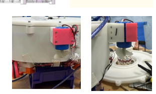
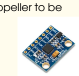


Diagram of pipes with different diameters corresponding to different sizes of rubber wheels

Propeller
- Fixed by a 3D print.
- Does not affect the bottom during operation
- No risk of falling.

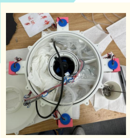


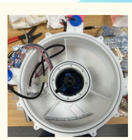
MPU6050 gyroscope
- Placed parallel inside the robot.
- MPU6050 can detect and rotate the propeller to be balanced.



Trolley pump
- Help the robot to sink or float.
- A container for collecting sewage (check the quality of sewage discharge)

Testing


tissues


waterproof sticker

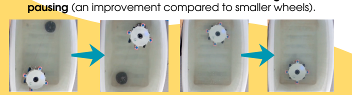
Waterproof testing
- Test whether the robot can be waterproof in water.
- The tissues are not wet, and the stickers do not show significant discoloration.

Balance Testing
- To test whether the robot can maintain balance in water.
- **MPU6050 can help the robot maintain balance in water by controlling the rotation of the propeller.**

Rotation testing
- The total accuracy is **84.72%**
- There is some improvement compared to the success rate of 83.79% in the first generation, which shows that fixing the propeller can make the robot reverse more effectively.

Angle	1	2	3	Accuracy
30°	40°	35°	30°	66.67%
60°	50°	55°	70°	75.00%
90°	90°	80°	85°	94.44%
180°	190°	180°	150°	88.89%
270°	300°	280°	260°	88.89%
360°	360°	340°	360°	94.44%

New mobile testing
- To test whether the robot can successfully move on different types of walls.
- Robots can **move in all directions without shaking or pausing** (an improvement compared to smaller wheels).


Movement on the pipeline   Plane movement

Tension testing
- To test the maximum pressure that the robot can withstand when clung on the wall.

Experimental steps:
1. Fix a rope on the robot.
2. Ensure that the ROV thruster is successfully started.
3. Put the robot into water and make it adhere to the wall.
4. Attach the robot to the plane and sides in two directions, and test the tension using a rope and a tension gauge.

Pre-experimental analysis: The direction of different surfaces can more accurately find out the suction and pulling force of the robot on the wall during adsorption.

Result:
Plane: 12.0N
Side: 11.0N

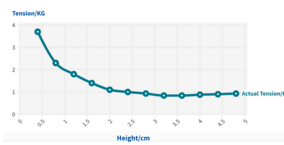

Clung on the bottom of the water   Clung on the wall

Conclusion

An experiment was also carried on the tension and the height of the robot from the wall to find out the relationship between the tension and the height.

Relationship between tension and robot height from wall

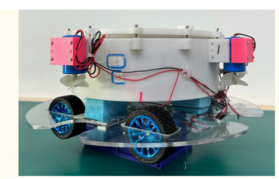
This image can demonstrate the Bernoulli principle, where the distance between the robot and the wall is greater and the tension is smaller.



Height/cm	Actual Tension/KG	Tension after subtracting the counterweight block/KG
0	5.6	5.6
0.4	3.7	3.675
0.8	2.3	2.25
1.2	1.8	1.725
1.6	1.4	1.3
2	1.1	0.975
2.4	1	0.85
2.8	0.93	0.755
3.2	0.84	0.64
3.6	0.84	0.615
4	0.88	0.63
4.4	0.9	0.625
4.8	0.93	0.63

Through the design and optimization of the second-generation aquatic robot, the problems encountered in the first generation experiment have been solved. The rotation accuracy of the robot reached **84.72%**, and the success rate of movement reached **100%** providing more reliable and advanced technical support for the application of aquatic robots in marine scientific research, resource exploration tasks, and other fields.

The aquatic robot is capable of stably clinging on the outside and walls of underwater pipelines to perform tasks. In order to achieve this goal, the robot adopts a **negative pressure adsorption mechanism**, combined with the control of **ROV thrusters, rubber wheels, and propellers**, to achieve omnidirectional movement and directional operation. In addition, it is equipped with various sensors and tools to meet the needs of different tasks.



Future Work

Although the design and implementation of this aquatic robot have been discussed, there is still much room for improvement and expansion. Here are some possible prospects:

- Integration of **Artificial Intelligence (AI)** and **Machine Learning (ML)** :
  - AI-driven capabilities allows the robot to make **real-time decisions** and have better operational efficiency in a situation such as low battery.
  - Machine learning algorithms can be utilized for pattern recognition, object detection, and predictive modeling, etc. The robot can **identify and respond to changing underwater conditions, including variations in water currents, temperature, salinity, and marine life behavior.**
  - By adding AI-driven techniques, aquatic robots can **adapt their behaviors in response to environmental stimuli**, and improve their performance over time.
- It is possible to consider adding **more types of sensors**, such as cameras, to enable robots to perform tasks underwater and adjust their angles autonomously.
- Robots can be equipped with some **robotic arms** to meet more task requirements, such as ocean research and underwater maintenance.

References

(1) Chinese Academy of Sciences. Research, development and engineering application of industrial robots. 2000
(2) Hundun Wuxing. Analysis of the motion characteristics of Mecanum wheel. Zhihu. 2021- 06-24.
(3) Xiaokcehui. Chinese Autonomous Underwater Vehicle (AUV) - Qianlong. Zhihu 2022-10-13.
(4) Song Baowei, Pan Guang, Zhang Lichuan, etc. The development trends and key technologies of autonomous underwater vehicles (J). Chinese Journal of Ship Research, 2022, 17 (5): 27-44 doi: 10.19693/j.issn.1673-3185.02939.
(5) The experimental application work of Qianlong 1 in the ocean has been successfully completed China Ocean Mineral Resources R&D Association 2014-09-23.
(6) MD Ageev Autonomous underwater vehicle of the institution of marine technology problems, ussr academy of sciences In Fourth Pacific Congress on Marine Science and Technology, 1990.
(7) Gokhan ATALI Prototyping of a novel thrust for underwater rocks International Journal of Applied Mathematics Electronics and Computers, 10 (1): 11 {14, 2022.
(8) Harry Bohm and Vickie Jensen Introduction to Underwater Technology&Vehicle Design Marine Advanced Technology Education Center, 2001.
(9) Tadeusz Chusciel, Ewelina Ciba, and Julita Docke Cfd and FEM model of an underwater vehicle projector Polish Maritime Research, 21 (3): 40 {45, 2014.
(10) Luis B Gutierrez, Carlos A Zuluaga, Juan A Ramirez, Rafael E Vasquez, Diego A Florez, Elkin A Taborda, and Raul A Valencia Development of an underwater remotely operated vehicle (rov) for surveillance and inspection of port facilities In ASME International Mechanical Engineering Conference and Exposition, volume 44489, pages 631 {640, 2010.
(11) Li Hui. New robotic vessel extensions deep ocean exploration, 1997.
(12) Zeng Jiangcheng. The development trend of robots In Advancements in Social Science, Education and Humanities Research, volume 631, pages 1261 {1265 Atlantis Press, 2014.
(13) Robert E Johannes. The renewal of community based marine resource management in ocean Annual review of Ecology and Systematics, 33 (1): 317 {340, 2002.
(14) Simon Jollands How a programmer works Boat Maintenance, Preparation, Yacht Ownership 2023.
(15) Guilherme F Marques, Jay R Lund, and Richard E Howitt Modeling irrigated agricultural production and water use decisions under water supply uncertainty. Water resources research, 41 (8), 2005.
(16) AP Nyrkov, AA Zhilenkov, VV Korotkov, SS Sokolov, and SG Chernyi. Development of aquatic robotics In Journal of (17) Physics: Conference Series, volume 803, page 012108 IOP Publishing, 2017.
(18) John Pike Advanced unmanned search system (auss). Federation of American Sciences 1999.
(19) Ruqing Qin and Chunyi Duan The principle and applications of Bernoulli equation In Journal of Physics: Conference Series, volume 916, page 012038. IOP Publishing, 2017.
(20) Robert L Wernli Trends in UV development within the us navy In Oceans' 97 MTS/IEEE Conference Proceedings, volume 2, pages 841 {848 IEEE, 1997..
(21) Yan Xiang, JinBao Sheng, Lei Wang, YueBo Cai, Ying Meng, and Wei Cai Research progress on equipment technologies used in safety inspection, repair, and reinforcement for deepwater dams Science China Technical Sciences, 65 (5): 1059-1071, 2022.