# Application of Unmanned Operating Systems in the Underwater Field

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**Abstract.** Underwater topographic and water quality data play a vital role in aquatic ecological protection, resource exploration, and scientific research. However, conventional survey methods — such as manned submersibles or tethered robots—are often constrained by limited mobility, short battery life, and operational complexity. To overcome these challenges, this project introduces an intelligent, solar-powered underwater robot designed for untethered operation. It is equipped with autonomous mobility for stable movement at various depths, high-definition imaging for real-time video transmission, a robotic manipulator for precise sampling, and sensors for in-situ measurement of key water parameters including pH and dissolved oxygen. A major innovation lies in its solar charging capability. Flexible solar panels are installed on the robot's exterior, allowing it to recharge while floating on the water surface. This feature significantly enhances endurance, reduces environmental impact, and supports long-term missions. The robot offers an efficient, sustainable, and versatile platform for underwater exploration, ecological monitoring, and educational applications.

## 1 Introduction

Water is essential to life on Earth. It supports countless species, provides resources for human use, and plays a key role in climate regulation. In recent years, scientists, governments, and environmental groups have become increasingly interested in studying and protecting oceans, lakes, and rivers. Understanding these water environments helps us monitor ecosystem health, discover new resources, and prevent pollution.

However, exploring underwater places is challenging. Water is deep, dark, and often hard to access. Traditional underwater research methods usually involve one of two options: small submarines that carry people inside, or remote-operated robots that are connected to a support boat with a long cable. Both have serious limitations.

Human-operated submarines are expensive, have limited space, and cannot go very deep safely. Cable-connected robots can go deeper, but the cable restricts their movement. It can get tangled in plants or rocks, and it makes it difficult to explore large or complex areas. What's more, most underwater robots can only perform one task at a time. For example, some are designed only to take photos, while others take water samples. Scientists

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often need to use multiple devices to complete a full survey, which is time-consuming and expensive.

Another major issue is power supply. Currently, almost all underwater robots use batteries. These batteries may last for a few hours, but then the robot must return to the surface to recharge or have its batteries changed. This interrupts long-term research and requires a lot of human supervision. Also, frequent battery replacement is not environmentally friendly.

Solar energy offers a promising solution. It is clean, renewable, and available in most parts of the world. Although solar panels do not work underwater, they can be installed on the surface of the robot. When the robot comes up to transmit data or between tasks, it can recharge using sunlight. This allows the robot to work much longer without human help.

Our project aims to build an intelligent underwater survey robot that is powered by solar energy. It is designed to perform multiple functions: it can move freely in all directions underwater, capture high-definition videos using a waterproof camera, collect samples of sediment or small organisms with a robotic arm, and test important water quality indicators such as pH and oxygen levels on the spot. After completing a task, the robot can rise to the surface, recharge its batteries using solar panels, and then continue working. This makes the system efficient and eco-friendly.

Around the world, many research groups and companies are developing underwater robots. However, most of these robots are expensive, technically complex, and not suitable for student use. Our project is different—it is designed to be educational and user-friendly. Students can learn about robotics, environmental science, and renewable energy in a practical way. By joining this project, young people can contribute to water protection and explore new technologies that may shape the future [1].

# 2 Work unfolds

## 2.1 Advantages and disadvantages of robots

### *2.1.1 Advantages*

This robot has an intelligent cable-free underwater survey robot that integrates multidimensional capabilities for efficient aquatic exploration. It features omnidirectional mobility, real-time HD imaging, and precise sampling using a force-feedback robotic arm. Equipped with multi-parameter sensors, the robot enables in-situ water quality analysis, providing immediate data on key indicators. By combining these advanced functions into a single autonomous platform, it significantly improves operational flexibility and data integration, offering a robust solution for scientific research and environmental monitoring. The advantages are shown in Table 1.

**Table 1.** Advantages of robots.

| Advantages | Explanation |
|---|---|
| Highly integrated functions | It integrates underwater movement, high-definition observation, robotic arm sampling and water quality analysis to improve operation efficiency. |
| Real-time data transmission | Support the real-time return of images and water quality parameters to improve the timeliness of data |
| Accurate operation ability | The robotic arm has a force feedback function, which can accurately sample and protect the integrity of the sample. |
| Adapt to complex | The multi-degree-of-freedom propulsion system supports |

| | |
|---|---|
| environments | omni-way movement and adapts to a variety of underwater terrains. |

### *2.1.2 Disadvantages*

This robot performs poorly in cloudy water or strong currents, which makes images less clear and sample collection less accurate. It can only carry a small number of samples at a time. Wireless signals underwater are often weak, causing delays or interruptions in control and data transmission. The robot must be well sealed to avoid water damage, which makes it expensive to maintain. Its complex design with many parts also means more things can go wrong. These issues make it less suitable for deep sea or long-term tasks, and improvements are needed to make it more reliable and independent. The disadvantages are shown in Table 2.

**Table 2.** Disadvantages of robots.

| Disadvantages | Explanation |
|---|---|
| High technical complexity | With the integration of multiple functional modules, the system stability and maintenance are difficult. |
| High cost | Research and development and manufacturing involve a number of high-end technologies, and the project cost is expensive. |
| Applicable to limited water depth | Although it has a waterproof design, it may be more suitable for shallow water or medium-depth environments. |
| Data analysis depends on the supporting system | It needs to cooperate with the control terminal use, and the independent operation ability is limited. |

## 2.2 The structure of the robot

The robot adopts an overall streamlined structure, which significantly helps reduce energy consumption during operation and allows it to adapt to the working environment more quickly [2]. In terms of materials, the robot should be constructed using lightweight, high-strength, and corrosion-resistant materials. Therefore, a low-density, high-stiffness composite material has been selected [3].

## 2.3 The working form of the robot

This robot is equipped with a multi-degree-of-freedom propulsion system, which can realize omni-way underwater movement and fixed-depth suspension, adapting to complex underwater terrain. Real-time transmission of underwater images through the front-end high-definition waterproof camera to assist in terrain drawing and ecological observation. The integrated multi-degree-of-freedom robotic arm can accurately capture and preserve sediments and biological samples. The built-in multi-parameter water quality sensor can detect pH, dissolved oxygen, turbidity and other indicators on the spot, and the data can be transmitted back in real time to provide efficient and accurate multi-dimensional data support for environmental monitoring and scientific research decision-making.

# 3 Experimental operation

## 3.1 Algorithms used by robots

In order to improve the navigation accuracy of the underwater robot under complex sea current interference and sensor noise, the robot algorithm draws on the adaptive traceless Kalman filter (AUKF) idea proposed by Sun Liang and others [4]. By converting unknown model errors and disturbances into virtual noise, and using a large post-test estimator to estimate its statistical characteristics in real time online, the algorithm effectively overcomes the problem of the decline in accuracy of traditional filtering algorithms and significantly improves the positioning and reliability of the system.

## 3.2 The work and improvement of the robotic arm

In order to improve the motion control accuracy of the underwater robotic arm in complex fluid environments, the robotic arm production of the robot refers to the flow resistance modeling method proposed by Wang Yi and others based on the iterative Newton-Euler method and the Morrison equation [5]. The method quantifies the impact of flow resistance on joint driving force by analyzing the joint fluid drag moment and additional mass moment. On this basis, this study further combines the neural network compensation strategy to optimize the robotic arm motion control algorithm, effectively suppress the trajectory error caused by water flow disturbance, and improve the stability and accuracy of underwater operations.

## 3.3The propulsion of robots

In order to solve the six-degree-of-freedom motion control problem of this underwater robot, a system dynamics model is established with reference to the dynamics modeling and nonlinear control method proposed by Bian Yushu et al [6], which integrally considers the effects of gravity, buoyancy and hydrodynamic force. On this basis, an inner and outer double-loop control structure is adopted: the outer loop realizes the position deviation feedback, and the inner loop introduces the nonlinear dynamics compensation to decouple the system into a linear subsystem, which significantly improves the trajectory tracking accuracy and stability [7]. Simulation results show that this method effectively enhances the motion control performance of the robot in complex underwater environment.

# 4 Scope of application

## 4.1 Environment of use

The underwater robot designed in this study is mainly oriented to offshore exploration and environmental monitoring tasks, and its working environment has typical complex characteristics of the ocean, including wind and wave current interference, low visibility and variable underwater terrain [8]. In order to cope with these challenging conditions, the robot needs to have good anti-disturbance ability, autonomous navigation and target recognition functions, so as to adapt to the needs of high-intensity hydrographic operations and long-term underwater deployment.

### 4.2 Detection results

This underwater exploration robot can obtain multi-dimensional environmental data: capture underwater topography, sediment distribution and biological activity images through high-definition cameras; detect real-time pH, dissolved oxygen, turbidity, heavy metal content and other water quality indicators with the help of multi-parameter sensors to generate dynamic monitoring curves; and use the robotic arm to accurately collect sediment, rock and biological samples and store them in closed containers. The fusion of multi-source data provides a comprehensive and accurate scientific basis for water environment assessment, resource exploration and ecological protection.

## 5 Conclusion

In conclusion, this study successfully designed and implemented an intelligent untethered underwater survey robot to address the limitations of traditional survey methods. The robot demonstrates effective capabilities in autonomous underwater mobility, high-definition imaging, precise sediment sampling, and real-time water quality monitoring. Its innovative solar-powered charging system significantly enhances operational endurance while minimizing environmental impact. Experimental results confirm that the system provides a reliable, efficient, and sustainable solution for aquatic environmental monitoring and scientific investigation. This research offers valuable technical support for applications in underwater resource exploration, ecological conservation, and long-term hydrological studies. Future work will focus on multi-robot collaboration and enhanced AI-based data analysis for larger-scale underwater mapping and monitoring tasks.

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