



# Design of Control System and Human-Robot-Interaction System of Teleoperation Underwater Robot

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**Abstract.** In order to meet the urgent need of underwater safety inspection and operating and solve the key problem of difficult control of teleoperation underwater robot, this paper proposes a Human-Robot-Interaction scheme for the independently developed teleoperation underwater robot, and successfully develops this underwater robot and Human-Robot-Interaction system. This paper introduces the general composition, key parameters, control system structure and control algorithm of the robot. And expounds the Human-Robot-Interaction system of the robot which includes three parts: visual interaction, data interaction and manipulator interaction. The visual interaction consists of an onshore monitor and an underwater camera. The data interaction is the premise of the normal operation of the robot. The manipulator interaction is designed to realizing underwater grapping and cutting. The system debugging is normal, and the underwater tests carried out in the pool and Qiandao Lake proved that the entire set of stability, reliability, real-time performance of control system and Human-Robot-Interaction system can achieve the design effect to meet the requirements of teleoperation underwater safety inspection and operating.

**Keywords:** Control system · Human-Robot-Interaction · Teleoperation · ROV · Underwater · Manipulator

## 1 Introduction

With the continuous development of marine undertakings, the exploration and maintenance of deep-sea resources and structural safety have become more and more indispensable. However, due to the poor underwater environment, the limited depth of human diving, underwater robots are needed to be submerged for underwater safety inspection and operating.

Underwater robots are divided into three categories: Human Occupied Vehicle (HOV), Autonomous Underwater Vehicle (AUV), Remotely Operated Vehicle

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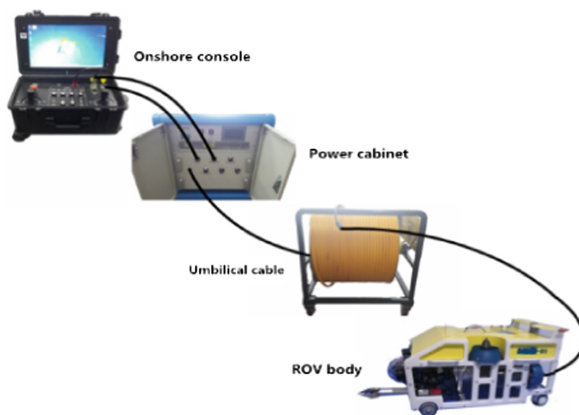
(ROV) [1]. With the advantages of deep working depth, sufficient power and adaptability to the harsh underwater environment [2], the remotely operated vehicle are widely used in different industries such as the inspection of marine pipelines, the maintenance of offshore platforms, the inspection of underwater dams, and aquaculture [3]. The umbilical cord serves as a safety guard against robot loss while providing power and data communication, which greatly improves its safety performance, but the fly in the ointment is that the umbilical cord limited ROV's range of motion [4]. Many domestic scholars have done plenty of researches on robot development. Literature [5] introduced the system composition of a ROV and its characteristics, and discussed the application and development trend of ROV, illustrating the great role of underwater robots; Literature [6] introduced a "conch type" ROV's control system structure and directional control technology, this robot can dive to a depth of 100 m without a manipulator for underwater operating; An ROV relying on manipulator operating was developed in [7], which is mainly through the abdominal operating mechanism to complete the docking and recovery.

Since the birth of "Hailong" ROV and "Haima" ROV, domestic companies have paid more and more attention to the ROV industry, and gradually some civilian-grade ROV appeared, such as "Trident" ROV launched by OpenROV company [8].

In this paper, an independent development teleoperation underwater robot, "METI-01", which is equipped with independently developed Human-Robot-Interaction system is presented.

## 2 General Design of "METI-01"

The independently developed ROV, "METI-01", is mainly composed of four parts: onshore console, power cabinet, umbilical cable and ROV body. The ROV system is shown in Fig. 1.



**Fig. 1.** ROV system

ROV body consists of nine parts as shown in Fig. 2: 1. Floating body; 2. Open frame; 3. Thruster; 4. PTZ camera; 5. Manipulator; 6. Underwater lights; 7. Wheelset module; 8. Electronic pressure tank; 9. Hydrofoil balancing module.

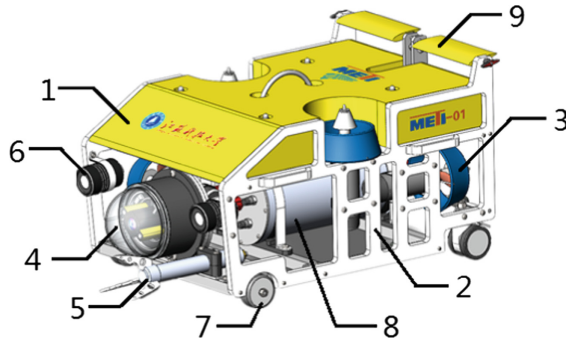


Fig. 2. ROV body

The onshore console sends control command to control ROV body. Data traffic between onshore console and ROV body are transmitted through a twisted pair in the umbilical cable. On the one hand, the power cabinet supplies power to the onshore console; on the other hand, it converts alternating current into high-voltage direct current to supply power to the underwater robot body. High-voltage direct current is conducive to reducing the cable diameter and power loss on the transmission line. The umbilical cord contains two pairs of twisted-pair cables and a pair of power cords for power transmission, a pair of twisted-pair cables for data communication, and another pair for video signal transmission. This ROV body can dive to a depth of 300 m, the specific technical parameters are shown in Table 1. This ROV is equipped with an underwater camera to take underwater images and videos to realize the function of inspecting underwater structures. When the ROV carried out the underwater operating,

Table 1. Key parameters of ROV

Object	Index
Structure type	Open frame
Size	600 × 500 × 400 (mm)
Working depth	300 m
Speed	1.5 m/s
Weight in the air	50 kg
Power supply	400VDC
Propeller	Vertical-2; Lateral-2; Longitudinal-2
Operating equipment	Console
Assisting equipment	Manipulator
Sensor	Depth; Inertial navigation; Water leak inspection
Visual lighting	CCD camera; PTZ; Underwater lights

ROV's motion and manipulator movements are realized through the joystick and the control buttons on the onshore console, and the underwater information, including the video image information and each ROV's sensor information, is monitored in real time displayed on the screen.

### 3 Control System

#### 3.1 ROV's Control System Structure

The control system of this ROV is divided into two sub-control systems, onshore console control system and underwater ROV body control system. The two control system is connected by umbilical cable to transmit signals and power. The control system structure is shown in Fig. 3, the onshore console which includes joystick, control buttons, monitor, and IPC (Industrial Personal Computer), etc., realizes the display of communication data and the issue of control instructions. The data on the control panel is collected by the console control system, packaged and sent to the underwater ROV body control system. ROV body receives control instruction from onshore console control system and adopts embedded microcontroller to control the propellers, underlights, manipulator, camera and other parts, and to collect data from the sensors so as to sending these data to the onshore monitor for operators to watch.

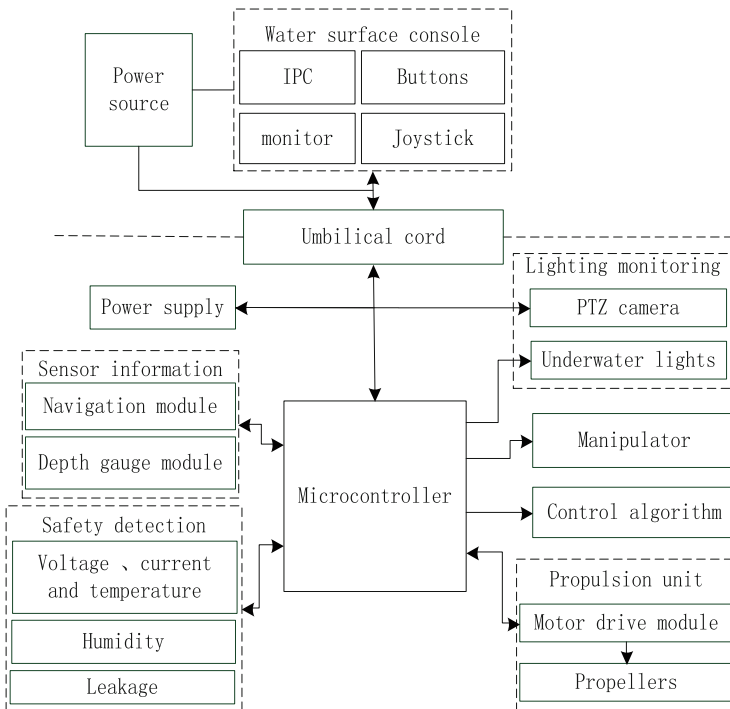


Fig. 3. ROV control system structure

### 3.2 ROV's Control Algorithm

For the ROV to achieve its basic operational capability, it must have the functions of fixed navigation determination, and need to have more accurate control ability of the underwater propeller, and the closed-loop control of the propeller must be realized. PID (proportional, integral, differential) control is a control algorithm based on classical control theory to estimate past, present and future information. PID control strategy has simple structure, good stability, high reliability and easy implementation. The block diagram of PID control algorithm with double closed-loop [9] for fixed navigation is shown Fig. 4.

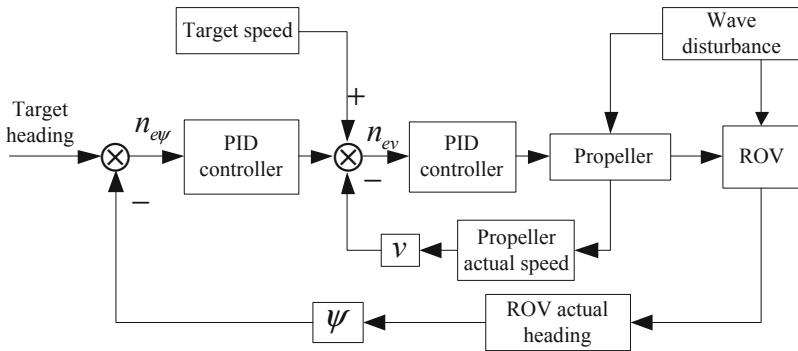


Fig. 4. Fixed navigation double closed loop PID control algorithm

## 4 Human Robot Interaction System

### 4.1 Visual Interaction

The visual interaction system consists of two parts: the onshore monitor and the high-definition underwater camera (see Fig. 5). The monitor is mounted on an onshore console, and the engineers can see the images and video taken by the underwater camera through the monitor.



Fig. 5. Monitors on the console and underwater camera

The ROV onshore console sends the control command directly to the microcontroller on camera cradle via network communication to control the camera rotation, which enables the ROV to observe all directions in real time without moving. The microcontroller can control the camera movement to achieve the focus function. The camera housing is made of transparent acrylic ball with a thickness of 5 mm. Its compressive strength is up to 300 m. A light is mounted below the camera to illuminate the subject. Flange is left at the back of the camera for easy installation.

### 4.2 Data Interaction

In order to realize the teleoperation, the data interaction between the onshore console and the underwater robot body is necessary. The control command is sent by the onshore console to the robot body to control the robot’s action. The robot feeds the state information, video, pictures and other data to the console to realize the communication between console and underwater robot body. A user operating interface is independently developed to realize data interaction. The user operating interface on the console can display data from the onshore console and the ROV body.

The structure of data interaction is shown in Fig. 6.

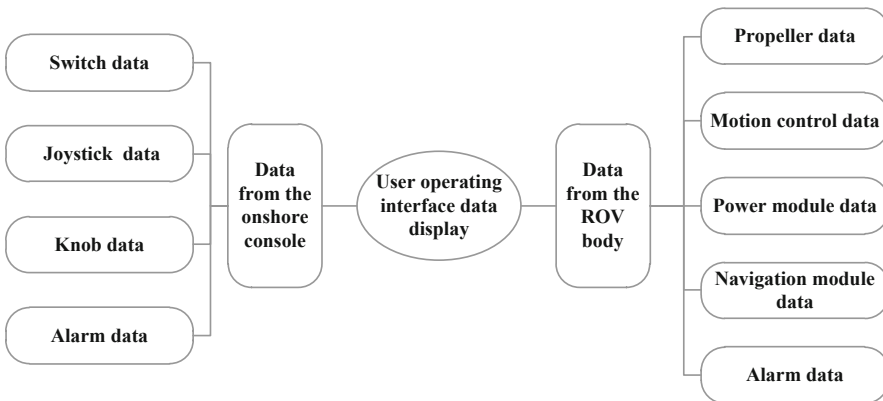


Fig. 6. Data interaction structure

### 4.3 Manipulator Interaction

The manipulator is an important part of the underwater operation of the robot. Although the manipulator used on the ROV has only one degree of freedom, it is equipped with two kinds of manipulator (see Fig. 7). The manipulator can perform underwater grasping and cutting operations, such as grasping attachments on underwater structures and cutting ropes wrapped around propellers.

The engineer controls the action of the manipulator through the buttons (see Fig. 8) on the onshore console to realize the grab or cutting operation.

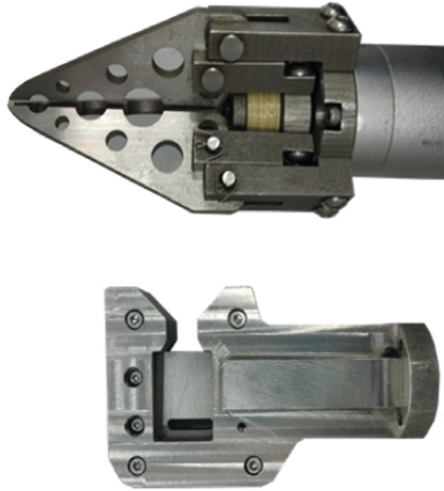


Fig. 7. Two kinds of manipulator



Fig. 8. The onshore console

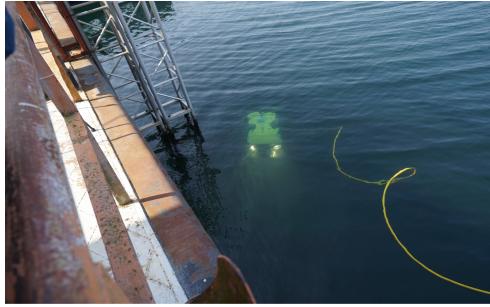
## 5 ROV Underwater Tests

The ROV underwater tests were conducted on a pool and the Qiandao Lake respectively. These tests show that underwater robots can meet the requirements of Human-Robot-Interaction system and teleoperation underwater operating.

### 5.1 Visual Interaction Test

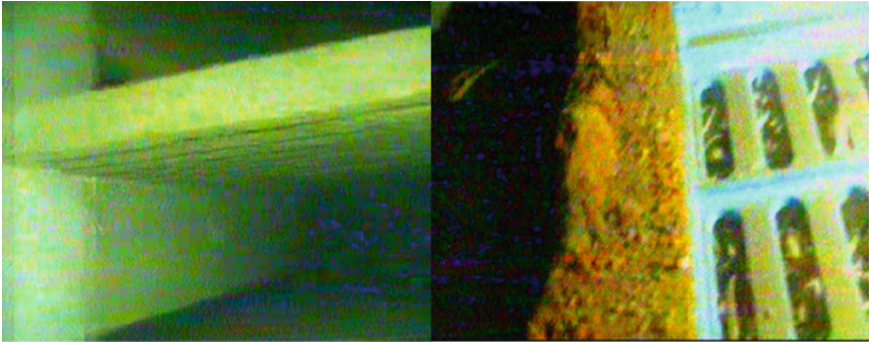
When the robot dived to water in the Qiandao Lake test shown in Fig. 9, the sensor data was normal, and the sharpness of underwater images has improved compared to previous ones after improving the camera's pixels. The stability and reliability of the robot



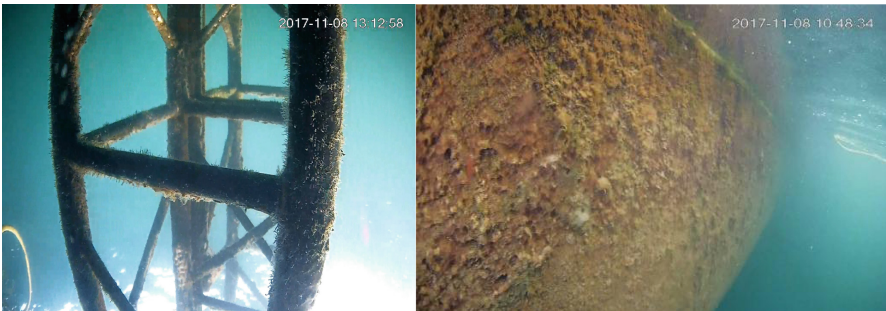


**Fig. 9.** ROV test in the lake

are preliminarily verified and the robot can successfully complete the direct navigation, turning bow, rolling and other motion postures in the lake (Figs. 10 and 11).



**Fig. 10.** Previous underwater images



**Fig. 11.** Improved underwater images





Fig. 12. User operation interface



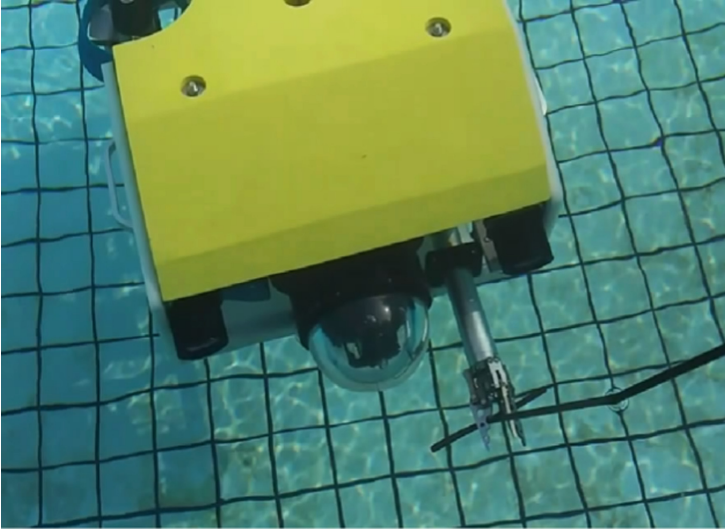
Fig. 13. Background data

## 5.2 Data Interaction Test

In order to display images obtained by underwater cameras and various data of the ROV in real time, a user operating interface based on Qt was independently developed. Due to the large amount of data to be displayed, it is impossible to display images and all data in one interface at the same time. Therefore, all data are displayed in the background, and users can get these data with one click. In this test, the images and data displayed on the interface are all normal.

### 5.3 Manipulator Interaction

The test of the manipulator is carried out in the pool. The engineer controls the action of the manipulator through the buttons on the onshore console to realize the grab operation.



**Fig. 14.** Manipulator clamping test



**Fig. 15.** Setting yaw of ROV

ROV in Qiandao Lake trials conducted on navigation test, as shown in Fig. 12, setting the initial heading angle at  $326^\circ$ , and the experimental data can be seen from Fig. 13. Because of the influence of the flow, the heading angle of underwater robot exists dithering when navigating in directional heading angle, but the robot can quickly adjust to set course, meet the navigation requirements (Figs. 14 and 15).

In the test, the deviation of heading angle is large. Due to the strong nonlinearity of underwater robot and the complex underwater environment, the inertial navigation devices have errors accumulated over time, which disturb the performance of the underwater robot (Fig. 16).

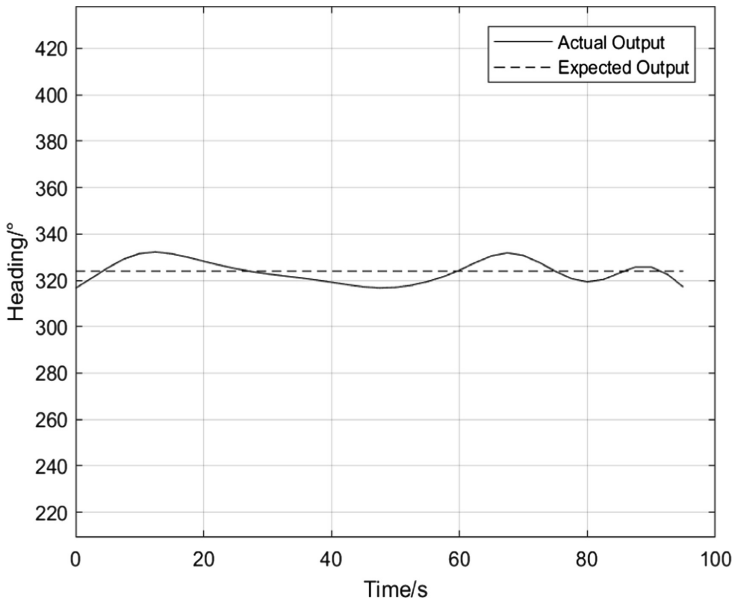


Fig. 16. Data output of heading angle

## 6 Conclusion

This paper introduces the general compositions of teleoperation underwater safety inspection and operational ROV “METI-01”, and introduces the control system structure and control algorithm of the ROV. The Human-Robot-Interaction system of this ROV was designed to realize underwater inspection and operating through visual interaction, data interaction and manipulator interaction. The control system and Human-Robot-Interaction system were verified through the test of ROV conducted in pool and Qiandao Lake. It proves the teleoperated ROV’s underwater inspection and operating capability.

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