Underwater Manipulator Angle Feedback Device System Design

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Abstract. Aiming to address the precision issues related to the angles during the operation of underwater manipulator, research was conducted, and a feedback device for the manipulator angles was designed. This device can accurately detect the working angles of the manipulator, enabling the underwater manipulator to perform gripping, collecting, and other tasks with greater precision. Through angle testing experiments, the rationality of the device design was validated.

Keywords: Underwater Manipulator; Angle Detection; Angle Feedback.

1. Introduction

The underwater manipulator possesses advantages such as flexible movement and strong anti-interference capabilities, making it the preferred operational tool for underwater robots and a current research focus in underwater intelligent equipment [1-3]. Currently, when performing tasks such as gripping and precise collection, underwater manipulators require pre-setting angles followed by multiple simulated learning sessions [4]. After determining the changing patterns of the manipulator's angles, corresponding gripping and collection operations are executed on the target objects. Short simulation learning times and inadequate angle planning can lead to difficulties in achieving successful operations.

In recent years, the structure of robotic arms with feedback devices has been extensively researched. The tactile feedback system studied by Song Chuang et al. [5] can detect tactile signals between the robotic arm and the target object, enabling stable grasping of the target object. The mechanical feedback-based master-slave robotic arm control system researched by Yang Mingming et al. [6] has broad application prospects and can be adapted for various fields. Jianwei Lu [7] proposed an intelligent collision avoidance monitoring system for workshop robotic arms based on pressure feedback control, effectively preventing collisions between robotic arms. Jie Zhang et al. [8] proposed a trajectory planning method based on attitude feedback, which shows significant effects on high-precision tracking of the trajectory for dual-arm spatial robotic arms. The research and implementation of force feedback in master-slave robotic arms by Zhengyu Sun [9] provide valuable experience for subsequent researchers. Zana Roland R. et al. [10] demonstrated through experiments that using a linear feedback controller in conjunction with cable winches and fan-driven actuators can achieve motion control for a spatial double-pendulum robot.

This text outlines the focus and purpose of a study on the precision issue of underwater manipulator angles during operation. It describes the research intention to design and manufacture an underwater manipulator angle feedback device. The goal is to accurately detect the working angles of the manipulator, enabling it to perform gripping, collecting, and other tasks with greater precision. Additionally, it aims to serve as a reference for future researchers working on closed-loop control of manipulator functions such as gripping and collecting.

2. Design of Angle Feedback Device

The design of an angle feedback device includes two main components: structural design and feedback circuit design. The structural design of the angle feedback device ensures its tight and precise installation on the robotic arm, facilitating accurate transmission of rotational angles and the collection of angle feedback data. The design of the feedback circuit is crucial for ensuring the reliable transmission of feedback data. It protects the real-time and stable transmission of data during the feedback process.

2.1 Structural Design

In the process of designing the angle feedback device, considerations must be given to the dimensions and shape of the device itself. The design should ensure that the rotational motion at the joints is not compromised. Additionally, accuracy in measuring the rotation angles at various joints of the robotic arm and the maintainability for future replacement of the angle feedback device should be taken into account. Considering factors such as installation position and measurement methods, the angle feedback device is designed with two different structures.

A structure is suspended between the two arm plates of the robotic arm, directly detecting the angle changes of the arm plates through a pivot axis to collect feedback data. The core detection device utilizes a servo-type potentiometer, thus this structure is referred to as a suspended potentiometer. The main body of the suspended potentiometer is a cylindrical shape with a diameter of 30mm, length of 50mm, and a wall thickness of 2mm, featuring ears for hanging, as illustrated in the design model shown in Figure 1.

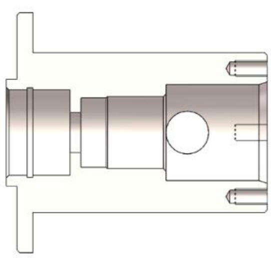
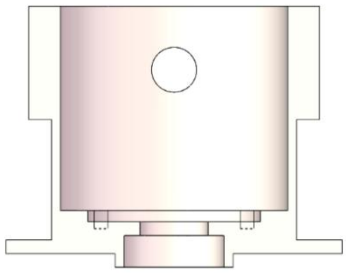
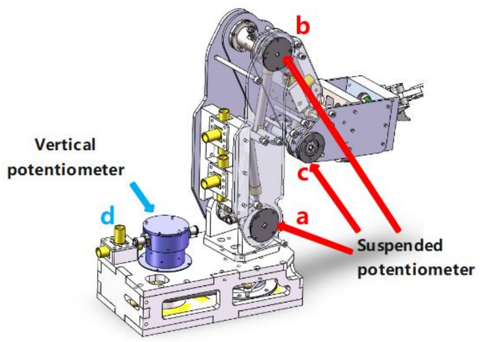



Fig. 1 Design Model of Suspended Potentiometer (Left)
Fig. 2 Design Model of Upright Potentiometer (Right)

The other structure is securely attached to the base of the robotic arm using a bolt structure. It indirectly detects the rotational angle through linear transmission. The core detection device is a high-precision potentiometer with a resistance tolerance of 0.1%. Therefore, this structure is referred to as an upright potentiometer. The main body of the upright potentiometer is a cylindrical shape with a diameter of 65mm, height of 55mm, and a wall thickness of 2mm, featuring a base. The specific design model is illustrated in Figure 2.

The robotic arm equipped with the angle feedback device is a six-degree-of-freedom five-joint manipulator. Angle feedback devices need to be installed on the base rotation joint, upper arm, forearm, and extension arm joints. The specific installation locations are illustrated in Figure 3.



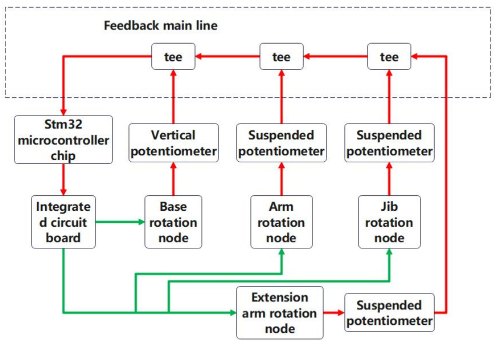


Fig. 3 Sealing Design Diagram for Upright Potentiometer (Left)
Fig. 4 Sealing Design Diagram for Suspended Potentiometer (Right)

2.2 Feedback Circuit Design

The feedback circuit design includes the main data acquisition end, data transmission end, data receiving end, and data processing end. The specific feedback circuit design is shown in Figure 4. The red lines in the diagram represent the main control circuit of the robotic arm, while the green lines represent the data feedback circuit of the angle feedback device. The integrated circuit board controls the hydraulic cylinder to change the rotation angles of various joints. The four angle feedback devices act as the data acquisition end of the feedback circuit, collecting the angle changes of each joint and converting them into electrical signals. The data transmission cables transmit the converted electrical signals to the data receiving end, which is the STM32 microcontroller chip for storage. Once collected, the data is transmitted back to the integrated circuit board and processed into signals recognizable by the computer.

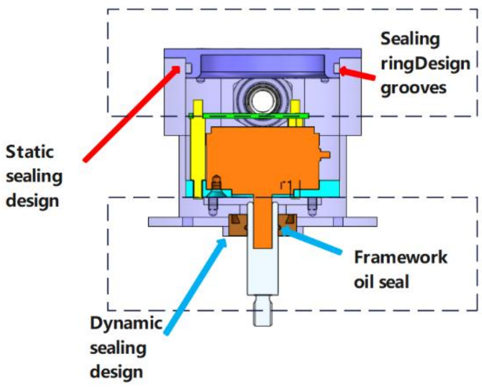
3. Material Selection and Sealing Design of Angle Feedback Device

3.1 Material Selection

The angle feedback device is used for angle detection on an underwater robotic arm, operating in a marine environment. Therefore, consideration should be given to the corrosion resistance of the materials used. As seen from the installation positions of the potentiometers in Figure 1.3, the weight of the robotic arm plates exerts a downward force on the angle feedback devices at the rotational joint connections (a, b, c). Additionally, the structural strength of the material itself needs to be taken into account. Considering factors such as material cost, mechanical properties, corrosion resistance, etc., 316L stainless steel has been selected as the material for constructing the angle feedback device.

3.2 Sealing Design

The angle feedback device adopts a combination of dynamic and static sealing in its sealing design. The sealing of the angle feedback device's housing and end cap falls under static sealing. For this, convenient disassembly and reliable sealing are achieved using O-ring seals as the sealing components. The connection between the pivot for collecting angle change signals and the housing involves dynamic sealing, ensuring the sealing effectiveness during movement through the use of a lip seal. Figure 5 and Figure 6 below respectively depict the sealing design for the upright potentiometer and the suspended potentiometer.



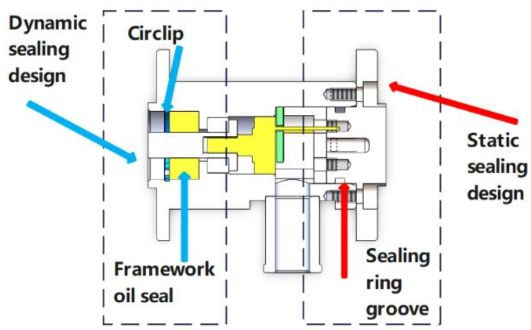


Fig. 5 Sealing Design Diagram for Upright Potentiometer (Left)
Fig. 6 Sealing Design Diagram for Suspended Potentiometer (Right)

4. Angle Feedback Device Angle Detection Experiment

4.1 Construction of Angle Feedback Device

316L stainless steel material has a density of 8027 kg/m³, an elastic modulus of 2.0E+11 Pa, a Poisson's ratio of 0.265, and an allowable stress of 170 MPa. After verification, it is confirmed that the angle feedback devices at locations a, b, c, and d all meet the strength requirements.

The physical construction of the angle feedback device includes the production of vertical and suspended potentiometers, as well as the production of feedback circuits. Complete two angle feedback devices in accordance with the installation rules for mechanical cooperation and the operating specifications for sealing installation.

Fig. 7 The assembly of the angle feedback device is complete

Following the feedback circuit design process outlined in the previous section Figure 4, the feedback loop of the angle feedback device has been assembled. The angle feedback device, feedback loop, and the six-degree-of-freedom five-joint robotic arm are integrated to provide a prototype for the entire experiment, as illustrated in Figure 7.

4.2 The setup of the experimental environment

The construction of the experimental environment provides a platform for angle detection experiments. Prepare a rectangular plastic tank. In addition, you will need a student power supply, a transformer, two waterproof data transmission cables, a network amplification module, and a CAN data transmission box.

The student power supply is connected to 220V AC power and transformed to 24V to power the integrated circuit board inside the hydraulic chamber. The transformer is connected to a 220V power source and outputs a 15V drive power supply to power the mechanical arm's actuation system. The network amplification module is directly connected to the 220V power supply, providing network signal amplification for the integrated circuit board. One end of the CAN data transmission box is connected to the port of the hydraulic chamber, and the other end is connected to a laptop, outputting angle detection feedback data to the CAN data collection software. The final setup of the experimental environment is shown in Figure 8.

4.3 The Angle Detection Experiment

The joint angle design for the six-degree-of-freedom five-joint robotic arm is as shown in Table 1. By rotating the robotic arm to its extreme positions, the angle detection device is used to measure the angle changes in each joint, validating the reliability of the device.

Table 1. The designed angles for each joint of the robotic arm

Joint Names	Base Rotation Joint	Upper Arm Joint	Lower Arm Joint	Extension Arm Joint
Angle Range	-10° ~110°	0° ~90°	0° ~60°	0° ~40°

Connect the USB port of the CAN data transmission box to the laptop. Open the computer's CAN data processing software and robotic arm control software.

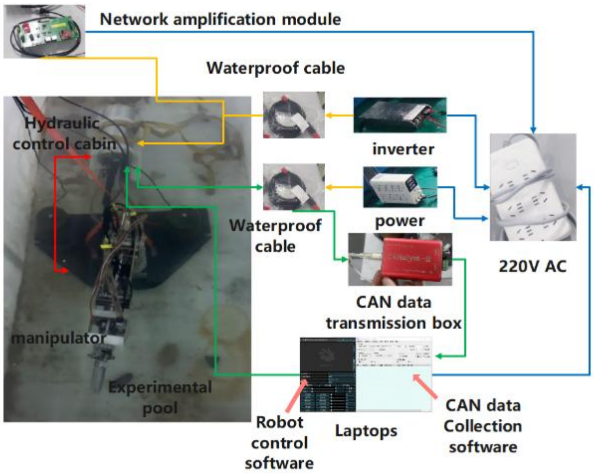
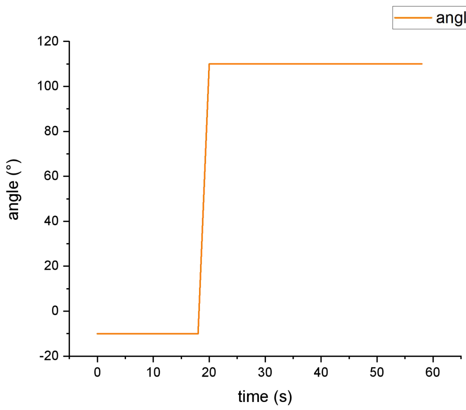
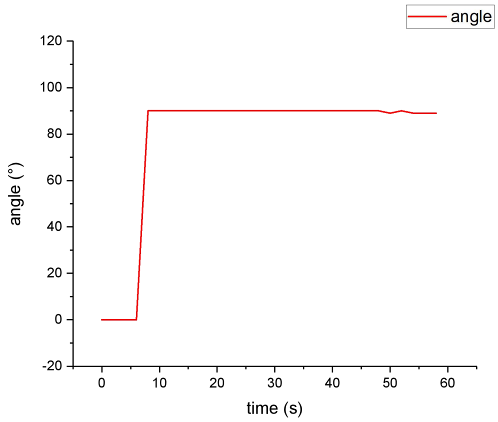
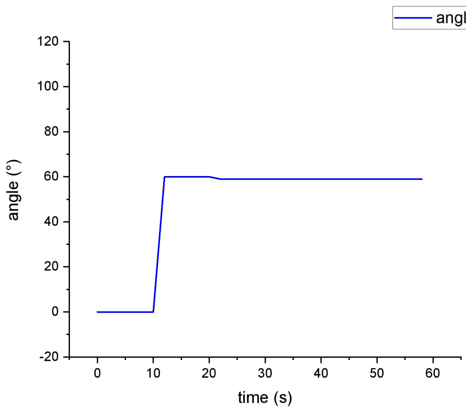


Fig. 8 Assembly Schematic of Angle Feedback Device

Change the rotation angles of each joint of the robotic arm through the robotic arm control software. Then, use the CAN data collection software to collect the signal data transmitted by the angle feedback device and save the collected data in Excel. Utilize the Origin data processing software to organize the data changes for each joint as shown in the curves in Figures 9,10,11and12.







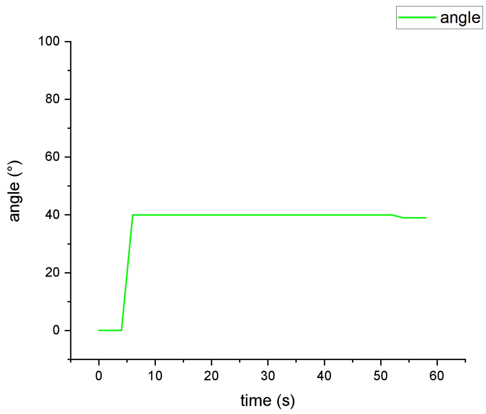


Fig. 9 Measurement data of base rotation joint angle (Top left corner)
Fig. 10 Measurement data of arm joint angle (Upper right corner)
Fig. 11 Measurement data of forearm joint angle (Left lower corner)
Fig. 12 Extended arm joint angle measurement data (Lower right corner)

5. Summary

1. Experimental results indicate that the angle feedback device can accurately measure the rotational angles of each joint of the robotic arm, validating the design's rationality.

2. The design of the angle feedback device can play a crucial role in the control of the robotic arm's angles and posture adjustment, providing valuable insights for subsequent researchers in the field of angle closed-loop control.

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