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Design Of A Simple Hydraulic Manipulator For Robots

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Abstract:
Since the 21st century, technologies such as 5G and the Internet of Things (IoT) have driven the evolution of robot technology toward "high precision, high flexibility, and low cost". Mobile robots are widely applied in fields like logistics, aerospace, and industry. Although hydraulic robotic arms are suitable for heavy-duty operations due to their high power-to-weight ratio, most existing products feature complex structures, high costs, and large sizes, making them difficult to use in teaching and small-scale industrial scenarios. To address this, this study designs a simple hydraulic robotic arm with a four-bar linkage mechanism as its core: the mechanical and hydraulic systems are simplified, keeping the manufacturing cost within 500 US dollars while ensuring low maintenance costs, basic movement functions, and a certain level of precision; the electronic control system adopts an ESP32 chip with built-in WiFi and Bluetooth, enabling remote control through MicroPython programming; the transmission part innovatively uses a screw mechanism, which eliminates complex components such as hydraulic pumps and drives the expansion and contraction of the hydraulic cylinder via a motor to realize the free movement of the robotic arm.
Keywords: *Hydraulics, Robotic Arm, Screw Mechanism, ESP32*

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I. Introduction

With the in-depth development of industrial automation, robot technology has been widely applied in manufacturing, logistics, aerospace and other fields, becoming a key factor in improving production efficiency. Hydraulic robotic arms, capable of generating large force and torque, perform well in tasks such as heavy-duty handling and heavy equipment assembly. However, traditional hydraulic robotic arms are mostly designed for specific professional scenarios, lacking versatility. They also have high costs and complex maintenance operations, making them difficult to adapt to the needs of educational teaching and small-scale industries. To address this, this study plans to develop a hydraulic robotic arm suitable for educational teaching and simple industrial scenarios. Its core purpose is to fill the market gap between "educational" and "small industrial" lightweight hydraulic robotic arms: it can not only provide universities with disassemblable, programmable and verifiable teaching tools to help students understand the collaborative principles of hydraulic transmission, mechanical structure and automatic control, but also offer cost-effective automation solutions for small enterprises to lower the threshold of their automation transformation. The design will realize three main functions: first, enabling the robotic arm to move freely in space through hydraulic drive; second, equipping it with a mechanical gripper to complete the grasping and placing of objects; third, achieving precise control of motion trajectories with the help of an electronic control system.

II. Mechanical Structure Design

Overall Architecture：

1. Hydraulic manipulator part:

Adopting a modular design, the main body is divided into four parts: base, big arm, small arm and end effector (mechanical claw). The overall dimensions are approximately 540mm * 300mm * 60mm. Three hydraulic cylinders are used to control the rotational movement of the big arm around the small arm, the rotational movement of the small arm around the base, and the opening and closing of the mechanical claw. This structure has the characteristics of simple manufacturing process and low maintenance cost.

2. **Transmission part:**

We innovatively use a screw mechanism as the bridge between the motor and the hydraulic cylinder, that is, converting rotational motion into linear motion. The screw mechanism can well control the speed to achieve more precise positioning of the manipulator. At the same time, considering the requirement of simplicity, only a long screw and nut are used for connection, which can fully achieve the expected function.

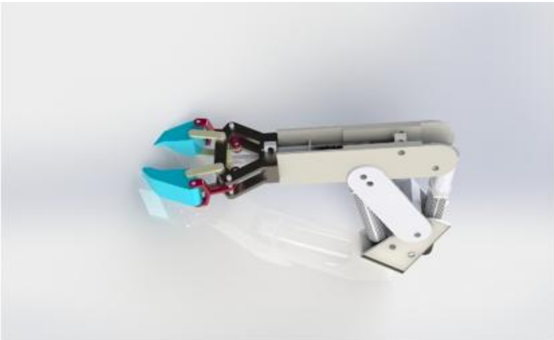

Figure 1 *Hydraulic manipulator part*

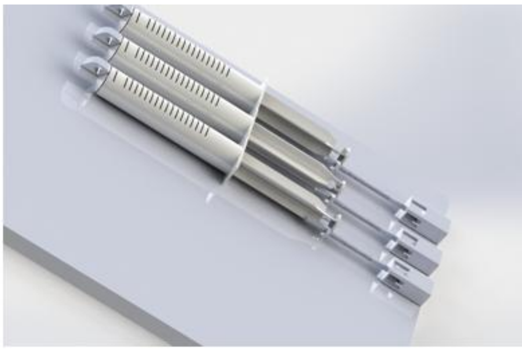

Figure 2 *Transmission part*

3. **Material and Detail Design**

The arm segments of the manipulator are formed by 3D printing with white resin material, which can withstand temperatures of 50-60°C, has a tensile strength of about 30-40MPa, and a bending modulus of about 2GPa, so it can maintain structural stability in conventional environments. Screws, nuts and washers are used to connect each joint, which not only ensures the required strength of the joint connection, but also has a certain simplicity, making disassembly and installation convenient.

Figure 3 real product

III. Electronic Control System Design

1. Hardware Architecture:

The electronic control system consists of four major modules: main control chip, sensor acquisition, power supply, and actuator. The ESP32 is selected as the main control chip, responsible for processing the position feedback data of the hydraulic cylinder and realizing remote control via mobile phone through its built-in WiFi and Bluetooth modules. The sensor module adopts the JY62 six-axis sensor to real-time monitor the acceleration and angular velocity data of each joint of the manipulator, and cooperates with the encoder to achieve precise measurement of joint angles and movement speeds. The power supply system uses a 12V lithium battery to provide stable power for the motor and electronic control components.

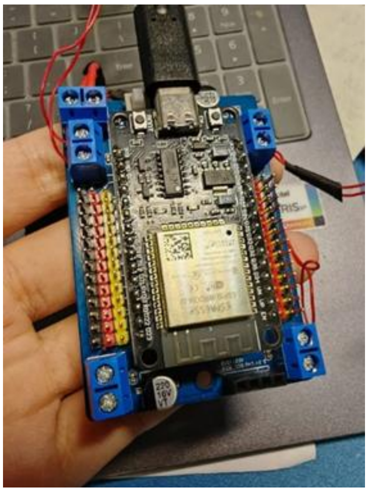

Figure 4 ESP32

2. Software and Control Strategy:

Programs are written into the ESP32 using MicroPython language and Thonny software, including sensor data acquisition, Bluetooth communication, and motion control algorithms. The JY62 module transmits the attitude data of the manipulator in real-time, and the main control chip calculates the expansion and contraction amount of the hydraulic cylinder through the PID algorithm to realize closed-loop control. The communication module adopts Bluetooth serial port, supporting wireless debugging of the manipulator by computer or joystick, and can preset grasping trajectories and execute semi-automatic operations. To ensure safety, the system integrates a pressure reducing valve and an emergency stop button to prevent overload of the hydraulic system.

IV. Experiments And Application Prospects

Test results show that the hydraulic robotic arm can realize the up-down, left-right movement and rotation of the large arm and base, with a maximum load of 5kg and positioning accuracy controlled within ±1mm, which meets the needs of basic material handling. Its total manufacturing cost is approximately 500 US dollars, 60% lower than that of commercial hydraulic manipulators. The cost advantage mainly comes from the selection of simple hydraulic components and simplified mechanical design.

V. Conclusion

The simple hydraulic robotic arm for robots designed in this study combines a four-bar linkage structure, a screw mechanism, a hydraulic system, and a simple electronic control scheme, realizing the movement and grasping functions of the robotic arm at low cost. The mechanical part enables the movement of the robotic arm through the linkage mechanism, the hydraulic system provides power, and the electronic control system ensures the stability of motion control and the convenience of debugging by using the ESP32 main control chip and a six-axis sensor, while the screw mechanism serves as a bridge between the electronic control and the mechanical system. This scheme provides a customizable and lightweight solution for hydraulic robotic arm-related teaching in schools and small-scale industrial applications. In the future, by integrating force sensors, machine vision modules, and other components, it can be further expanded to flexible grasping and fully automated scenarios, offering a cost-effective solution for robot education and small-scale industrial automation. This research was partly supported by 2025 ShanghaiInnovation and Entrepreneurship Training Program for College Students of China. Project Number: cx2501020

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