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Design of Cargo Handling Robot System Based on Fuzzy PID Control

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Abstract— **In order to solve the problem of large fluctuation and low control accuracy of the traditional cargo handling robot system, a cargo handling robot system based on fuzzy PID control is designed. Next, the system uses hydraulic as the transmission system; it adopts SIEMENS PLC as the control core and adopts the multi-sensor fusion technology; and it uses fuzzy PID control technology to control the cargo handling robot's control system. More specifically, the principle diagram of the hydraulic system is designed, and the working principle of the system is analyzed, the PLC selection, I/O port allocation, hardware wiring, and software programming of the control system are analyzed and designed. Finally, the system adopts fuzzy PID control method, and the fuzzy PID controller is simulated, the simulation results show that the control system has small overshoot, fast response, small oscillation, high control precision, which meet the work needs of the cargo handling robot.**

Index Terms— **cargo handling robot, fuzzy PID control, hydraulic, PLC**

I. INTRODUCTION

The cargo handling robot is a kind of industrial robot, which is used instead of human labor to complete the transportation[1]. It is widely used in the packaging and transportation of products in industrial production. The traditional cargo handling robot can not meet the industrial demand, because it has the problems of unstable working load, low control accuracy, low efficiency, and noise. Therefore, it is particularly important to adopt advanced control techniques to continuously improve the efficiency of the cargo handling robot. Most of the cargo handling robot's work process is non-linear, and its characteristics change with time, when the workload or the environment changes of system need to adjust the controller to ensure the quality of control, using the conventional PID control method is simple algorithm, good reliability and strong robustness, but it is difficult to adjustment of PID parameters in real time[4,5]. Therefore, this paper uses fuzzy PID control method, which make the control target can be controlled in real time through the on-line adjustment of PID parameters, thus, enhance the stability and efficiency of the cargo handling robot.

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II. HYDRAULIC SYSTEM DESIGN

A. The composition of the hydraulic system

The hydraulic system consists of the fuel tank, filter, double hydraulic pump, electric motor, check valve, overflow valve, flow control valve, three-position five-path electromagnetic directional valve, one-way speed regulating valve, walking hydraulic cylinder, telescopic hydraulic cylinder, lifting hydraulic cylinder, globe valve, pressure gauge, pressure sensor and displacement sensor, the principle diagram of the hydraulic system is shown in figure 1.

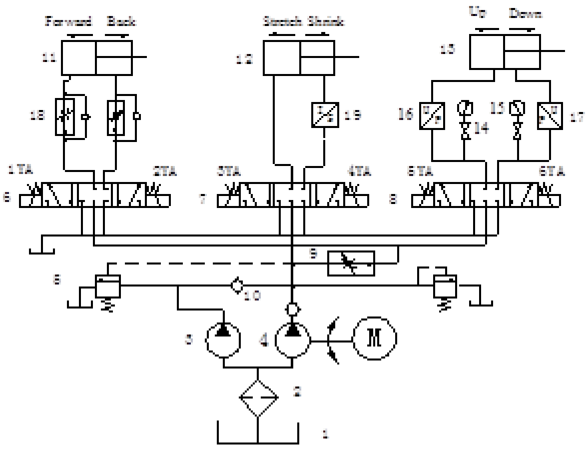

Fig.1 The principle diagram of the hydraulic system

1 fuel tank 2 filter 3 hydraulic pump HP1 4 hydraulic pump HP2 5 overflow valve 6 three-position five-path electromagnetic directional valve YV1 7 three-position five-way electromagnetic directional valveYV2 8 three-position five-path electromagnetic directional valve YV3 9 flow control valve 10 check valve 11 walking hydraulic cylinder 12 telescopic hydraulic cylinder 13 lifting hydraulic cylinder 14 globe valve 15 pressure gauge 16 pressure sensor SL1 17 pressure sensor SL2 18 one-way speed regulating valve 19 displacement sensor

B. Analysis the working principle of hydraulic system

The cargo handling robot system based on fuzzy PID control mainly realizes the transportation of goods. The working principle of hydraulic system is analyzed as follows:

(1) The walking hydraulic cylinder move to the left rapidly. Press the start button, then the hydraulic pump and motor starting, next the solenoid valve 2YA gets electricity, the right-hand position of three-position five-path electromagnetic directional valve YV1 starts working, which drive the walking hydraulic cylinder move to the left rapidly, it stops when it touches the travel switch SQ1;

(2) The lifting hydraulic cylinder begin to down. When walking hydraulic cylinder touches the travel switch SQ1, then the solenoid valve 5YA gets electricity, the left-hand

position of three-position five-path electromagnetic directional valve YV3 starts working, which drive the lifting hydraulic cylinder begin to down, it stops when it touches the travel switch SQ2;

(3) The telescopic hydraulic cylinder extends out. When the lifting hydraulic cylinder touches the travel switch SQ2, then the solenoid valve 4YA gets electricity, the right-hand position of three-position five-path electromagnetic directional valve YV2 starts working, which drive the telescopic hydraulic cylinder extending out, it stops when it touches the travel switch SQ3;

(4) The telescopic hydraulic cylinder retracts. When the telescopic hydraulic cylinder touches the travel switch SQ3, then the solenoid valve 3YA gets electricity, the left-hand position of three-position five-path electromagnetic directional valve YV2 starts working, which drive the telescopic hydraulic cylinder retracts, it stops when it touches the travel switch SQ4;

(5) The walking hydraulic cylinder move to the right slowly. When the telescopic hydraulic cylinder touches the travel switch SQ4, then the solenoid valve 1YA gets electricity, the left-hand position of three-position five-path electromagnetic directional valve YV1 starts working, which drive the walking hydraulic cylinder move to the right slowly, it stops when it touches the travel switch SQ5;

(6) The telescopic hydraulic cylinder extends out. When the walking hydraulic cylinder touches the travel switch SQ5, then the solenoid valve 4YA gets electricity, the right-hand position of three-position five-path electromagnetic directional valve YV2 starts working, which drive the telescopic hydraulic cylinder extending out, it stops when it touches the travel switch SQ3;

(7) Repeat step (4). Then the end of a work process, and the system goes into the next working process.

III. CONTROL SYSTEM DESIGN

The control system is an important part of cargo handling robot system, if it wants to complete the transportation of goods, the system must have the functions of walking, lifting and telescopic, and its system should have good stability and accurate positioning , so the design of control system is very important.

A. The composition of control system

The control system is mainly composed of PLC, buttons, travel switches, sensors, hydraulic pumps, motors, solenoid valves, man-machine interface and so on, as shown in figure 2.

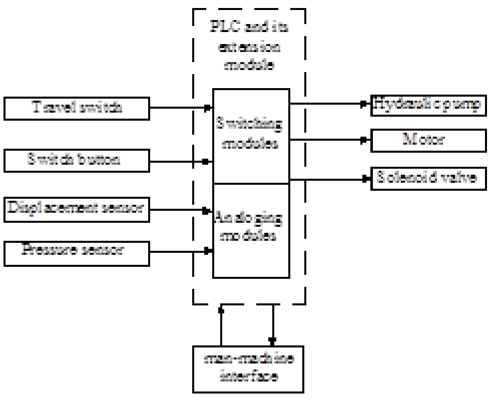

Fig.2 The composition of control system

B. PLC selection and I/ O address assignment

The control system selects S7-200 PLC, according to the requirements of the control system, which has 10 binary input channels, 8 binary output channels, and 3 analog input channels. It is important to note that there may appear input channels or output channels is insufficient in the specific use, so there should be set aside 15% margin[2]. As a result, the control system selects CPU224, which has 14 binary input channels and 10 binary output channels, in addition, it also selects an analog input extension module EM231, which has 4 input channels, these two modules can meet the requirements of the system. The address assignment of I/O is performed according to the functional requirements of the system, as shown in table 1.

Input Name	Address	Output Name	Address
Start Button SA1	I0.0	Motor Start KM1	Q0.0
Travel Switch SQ1	I0.1	Hydraulic Pump Start KM2	Q0.1
Travel Switch SQ2	I0.2	Electromagnet 2YA	Q0.2
Travel Switch SQ3	I0.3	Electromagnet 5YA	Q0.3
Travel Switch SQ4	I0.4	Electromagnet 4YA	Q0.4
Travel Switch SQ5	I0.5	Electromagnet 3YA	Q0.5
Emergency Stop Button SB1	I0.6	Electromagnet 1YA	Q0.6
Stop Button SB2	I0.7	Electromagnet 6YA	Q0.7
Motor Stop Button SB3	I1.0		
Motor Start Button SA2	I1.1		
Pressure Sensor SL1	AIW0		
Pressure Sensor SL2	AIW2		
Displacement Sensor SL3	AIW4		

Table 1 The assignment table of I/O address

C. The connection diagram of PLC hardware

According to the characteristics of the input and output signals and the control requirements of the system, the connection diagram between the input terminals and output terminals and the PLC of the cargo handling robot control system based on the fuzzy PID control are plotted, as shown in figure 3.

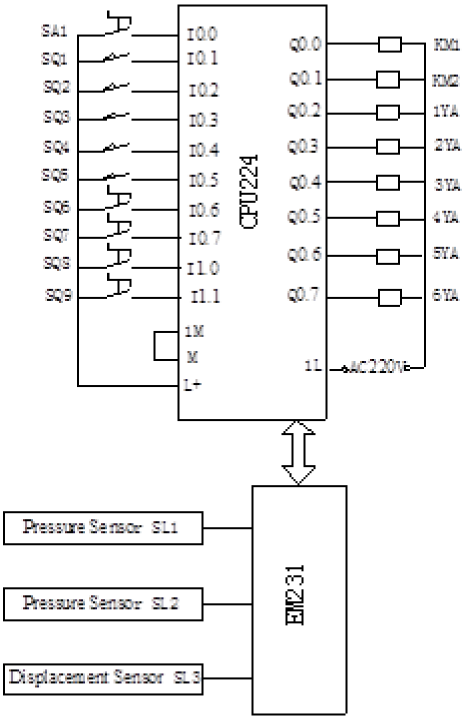

Fig.3 *The connection diagram of PLC hardware*

D. Plotting the sequential function diagram of PLC

According to the connection diagram of PLC hardware and the working principle of the hydraulic system, the software program is programmed by the sequential function diagram of PLC, as shown in figure 4.

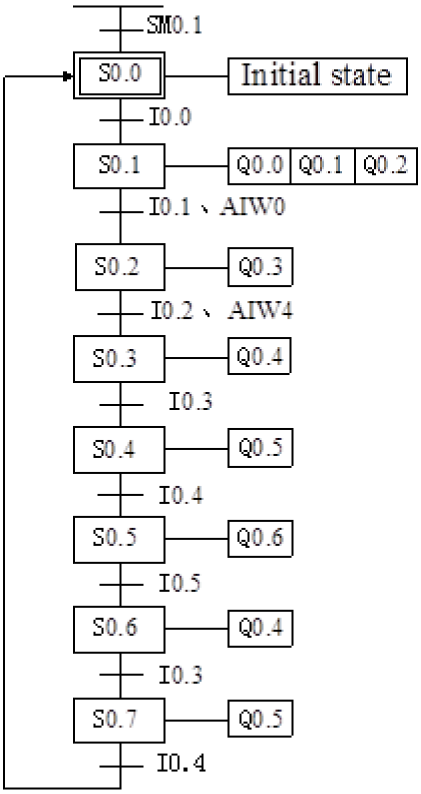

Fig.4 The sequential function diagram of PLC

E. Plotting the ladder diagram of PLC

When the sequential function diagram of PLC is programmed with a ladder diagram, since the sequential control instruction does not support double coil output, first, the SCR section uses the intermediate relay to represent the output of its segment when the program is written in ladder diagram, and then merges and outputs it at the end of the program[3], as shown in figure 5.

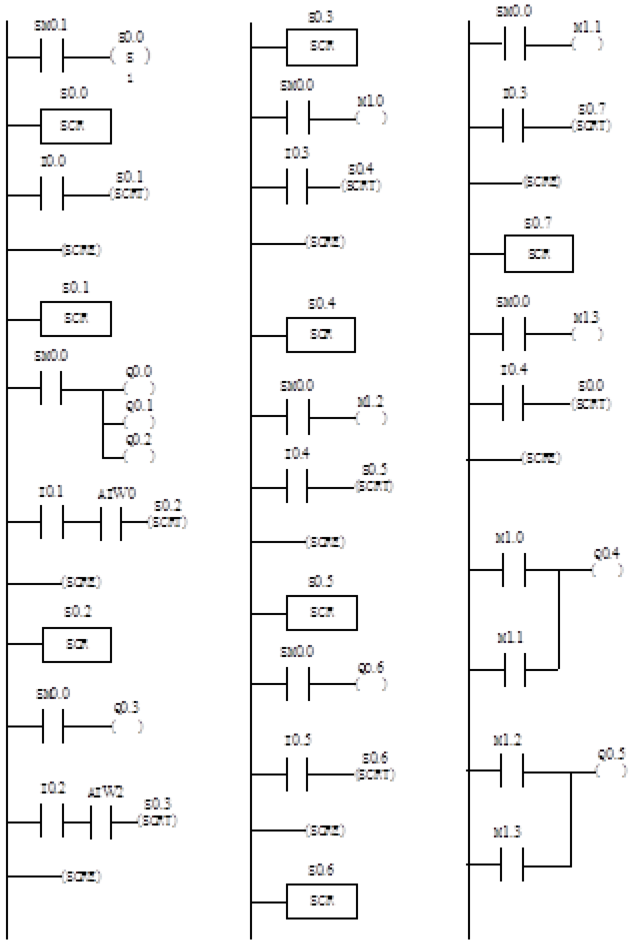

Fig.5 The ladder diagram of PLC

IV. FUZZY PID CONTROL METHOD

A. The principle of fuzzy PID control

Fuzzy PID control method combines fuzzy control with traditional PID control. Based on the real-time state of the control system, the precise control of the system is realized by dynamically adjusting the three parameters K_P , K_I ,and K_D of the PID. Specifically, the fuzzy controller takes the system deviation e and the system deviation change rate ec as the input, and establishes the fuzzy relationship between them and the three parameters K_P , K_I , and K_D , then fuzzy controller detects the e and the ec continuously in the system operation, and dynamically adjusts the above three parameters according to the fuzzy control principle, the purpose is to meet the different stages of the e and the ec with different control parameters, so that the controlled object can better adapt to changes in environment and load of the cargo handling robot, and avoid the system interference, which make the cargo handling robot working under the steady load, and it meets the control requirements of system. The diagram of the fuzzy PID control principle is shown in figure 6.

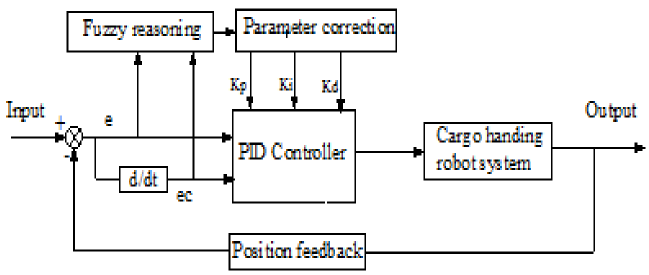

Fig.6 The diagram of the fuzzy PID control principle

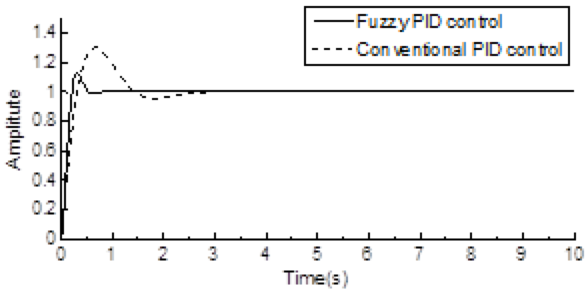

Fig.7 Simulation curves of fuzzy PID control

The values of parameters K_P , K_I , and K_D affect the stability, response speed, overshoot, and control accuracy of the system. The value of KP can speed up the response and improve the adjustment accuracy of system, but it produces overshoot and oscillation, which can lead to instability of the system; The value of KI is mainly used to eliminate steady state error of the system, the greater the integral action of the system is, the faster the error is eliminated, but the oscillation is prone to occur, on the contrary, the smaller the integral action of the system is, the slower the error is eliminated; the greater the value of the KD, the stronger the inhibition of the e change, instead, the smaller the value of the KD, the weaker the inhibition of the e changes.

The fuzzy regulation rule of PID parameters[7]: when the value of system deviation |e| is large, in order to improve the response speed of the system, the value of KP should be larger; in order to avoid differential supersaturating, the value of KD should be smaller, at the same time, in order to avoid a large overshoot of the system, usually take KD = 0 to eliminate the integral effect; when the value of system deviation |e| and the system deviation change rate |ec| are medium, in order to make the system have smaller overshoot, the value of KP should be smaller, the value of KD has a great influence on the system, and the value of KI should be appropriate; both the values of KP and KI should be larger when the value of system deviation |e| is smaller. In order to avoid the oscillation of the system at the set value, and consider the anti-interference performance of the system, when the value of system deviation rate |ec| is large, the value of KD can be smaller, when the value of system deviation rate |ec| is small, the value of KD can be larger.

B. The simulation of Fuzzy PID control

The fuzzy PID control model is established in MATLAB /Simulink, in order to better display the effect of fuzzy PID control, the simulation model is put fuzzy PID control and the conventional PID control together. When inputting unit step signal to the system, the simulation image is obtained, as shown in Figure 7. The simulation results shows that the fuzzy PID control method has small overshoot, fast response, small oscillation and high control accuracy. The fuzzy PID controller meets the control requirements of the cargo handling robot system.

V. CONCLUSIONS

(1) The system adopts double hydraulic pump. As the system has many work steps, the double hydraulic pump can save energy and reduce heat. When the system requires small flow, the hydraulic pump HP1 supplies oil; when the system requires large flow, the two hydraulic pumps supply oil simultaneously.

(2) The system uses multi-sensor fusion technology. It uses pressure sensors and displacement sensors to obtain pressure information and displacement information at all times, which ensure the control accuracy of the system.

(3) The system uses PLC as the control core. It uses PLC to control the operation of the whole system, which not only saves manpower costs, but also makes cargo handling robot system more stable, accurate, and highly automated.

(4) The system adopts fuzzy PID control technology. The fuzzy PID control is applied to the control system of cargo handling robot, which not only takes full advantage of the high precision of the conventional PID controller, but also realizes the online adjustment of the parameters.

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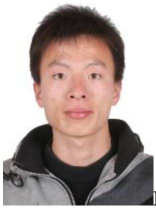
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