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Research on glass intelligent storage control system

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Abstract: *In insulating glass processing enterprises, the storage system plays an important role, which can affect the efficiency of the entire insulating glass production line. At present, China's insulating glass storage system localization rate is low, foreign equipment is expensive, relying on imports will increase a lot of costs. The insulating glass storage system is studied in this paper, and a set of insulating glass storage system based on PLC and servo control is proposed. With S7-1500 PLC as the control core, three-phase AC motor and servo motor as the main actuators, HMI carried out visual human-computer interaction, and designed the cutting manipulator and conveying equipment to realize the storage and retrieval automation in the deep processing of insulating glass. The system is simple in structure and relatively low in cost. In order to improve the positioning accuracy of the manipulator, a fuzzy PID algorithm based on PLC is designed to suppress the positioning error caused by motor inertia. The research results show that the system can automatically complete the process of glass processing, stable and reliable, high positioning accuracy, greatly improve the production efficiency.*

Keywords: *PLC; Servo control; Automatic control; Fuzzy control; Fuzzy PID*

1. Introduction

With the development of the world economy and science and the progress of The Times, glass has become an indispensable product in modern life. Glass is not only widely used in traditional fields such as architecture, decoration, and automobiles, but also increasingly used in new fields such as spacecraft, energy conservation and emission reduction, and new energy. Therefore, glass plays a very important role in people's production and life, and its market demand continues to rise every year [1].

Flat glass mainly includes laminated glass, tempered glass and insulating glass. Among them, insulating glass sound insulation and noise reduction can improve the indoor environment and has many advantages. With the improvement of people's living standards, the market of insulating glass is expanding, widely used in residential, office buildings, hospitals and other places. In the deep processing process of insulating glass, the original sheet is cut, edged, cleaned and dried [2], and then entered into the storage system for storage using L-shaped glass shelves. When necessary, the L-shaped glass shelves are sent out of the warehouse together with the L-shaped glass shelves, and transported to the entrance of the sealing sheet production line for automatic loading. Insulating glass storage system is mainly used in the middle stage of insulating glass production line, which plays the function of production buffer storage, and is one of the core equipment in the glass processing industry. Insulating glass storage system mainly solves two problems. On the one hand, it is to improve the safety of the storage process, including the safety of the glass and the safety of the operator. The glass is fragile, manual handling or the use of mechanical handling position control accuracy is low, easy to damage, when there is an accident may even threaten the safety of human life. The second is to improve the production efficiency of enterprises, manual handling efficiency is low, the use of machinery for handling will improve some efficiency, but still can not meet the production needs of enterprises.

In China, many mature insulating glass storage systems are imported from abroad, and there is less literature on insulating glass storage systems. Su Xiangrui et al. [3] designed an intelligent storage system for insulating glass based on servo control, using ERP system, IPC module, warehouse handling car and grid frame to realize the storage, exit and entry of glass. This paper presents a new insulating glass storage system with simpler mechanical structure and control system.

1.1 Warehousing system layout

The insulated glass storage system includes three parts: the unloading robot platform, the mobile ground rail workbench module, and the storage position workbench module (including the unloading position workbench). The structure of the storage workstation and the unloading workstation are the same, with the same working principle but different functions. The storage workstation is responsible for storage, while the unloading workstation is responsible for unloading. The layout of the system is shown in Figure 1.

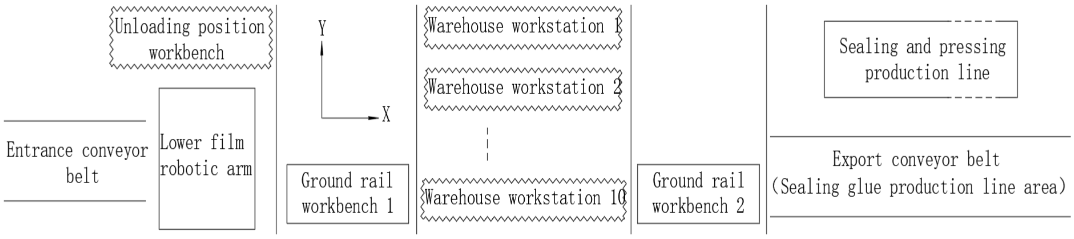

Figure 1: System layout

1.2 Electrical control system

The electrical control system includes PLC controllers, touch screens, servo drive systems, three-phase AC motors, sensors, etc. [4]. The block diagram of the control system is shown in Figure 2.

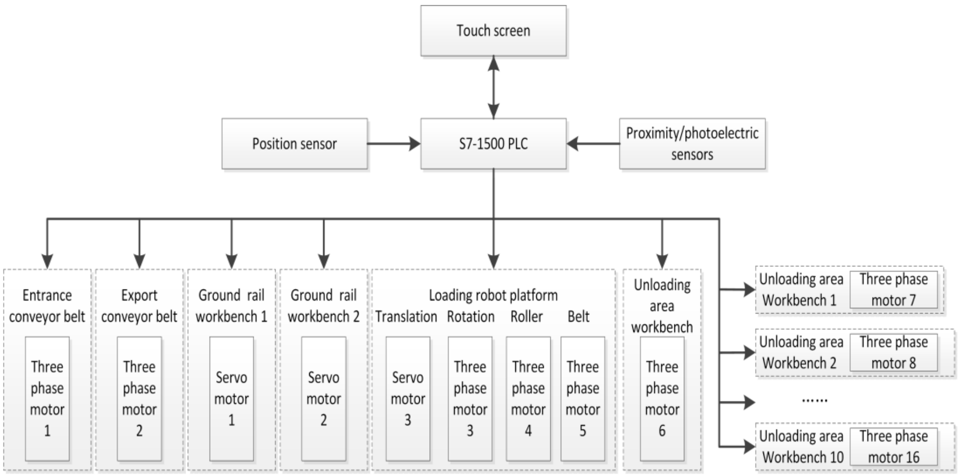

Figure 2: Block diagram of electrical control system

1.3 Loading robot platform

In the hollow glass storage system, the unloading robot platform is the core equipment, and the unloading speed directly affects the operational efficiency of the entire storage system. It is responsible for transporting the glass on the conveyor belt to the L-shaped frame on the unloading position workbench, as shown in Figure 3. The end effector of the robotic arm platform has a horizontal span of 1 meter and a vertical span of 0.8 meters. It is equipped with 3 large suction cups and 5 small suction cups, and can handle glass sizes up to 1.6 m x 1.2 m. The storage workstation (including the unloading workstation) and the surface of the mobile ground rail are both equipped with nylon conveyor belts, which can complete the X-axis transmission of the L-shaped glass frame.

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Figure 3: Next chip manipulator platform

2. Methodology

2.1 Servo control requirements

The translational motion of the unloading robot arm and the ground rail worktable in the Y-axis direction is driven by servo, which requires high motion accuracy, especially the translational motion of the unloading robot arm in the positive Y-axis direction. The position relationship between the unloading position workbench and the robotic arm is relatively fixed. Before the system runs, the thickness parameter W of the glass needs to be input into the system, including the angle of glass stacking α Fixed, the placement of glass by the robotic arm reduces the translation distance by one L each time. The geometric relationship of glass stacking is shown in Figure 4. If the translational motion accuracy of the unloading robot arm is not sufficient, even if the spring on the suction cup has a certain compression margin, it may still cause damage to the glass due to collision. Therefore, the Y-axis translational motion control of the robotic arm for unloading has become the most demanding aspect of the system control.

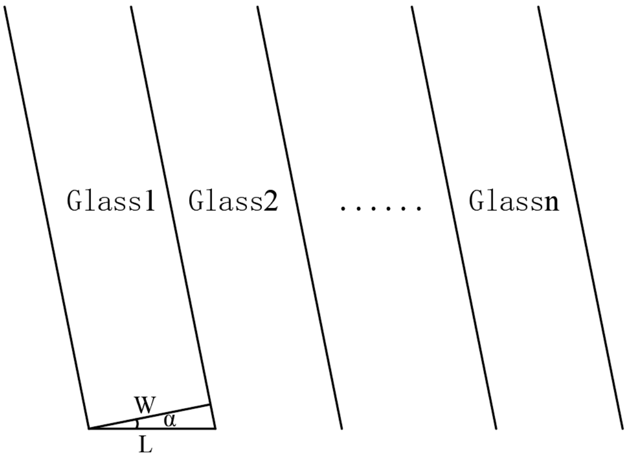

Figure 4: A geometric diagram of a glass stack

2.2 Fuzzy PID control strategy

In the servo drive stroke of the robotic arm and the ground rail worktable, speed adjustment is needed to increase the stability of motion control. When traditional PID algorithm is used for position control, the front stroke may give a large speed due to the large deviation, which can easily cause glass damage.

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This article designs a fuzzy PID control algorithm to reduce the output of the controller by reducing the PID parameter coefficients when the deviation is large. This is of great significance for improving the unloading speed and reducing the glass damage rate [5-8].

Traditional PID relies on idealized control models, which cannot adjust the proportion, integral, and differential coefficients in real-time and cannot meet high-precision control requirements. Therefore, in this study, the fuzzy PID speed control algorithm was adopted. The fuzzy PID control algorithm is mainly based on expert experience, and optimizes the proportional, integral, and differential coefficients through fuzzy logic according to certain fuzzy rules. The fuzzy self-tuning PID structure diagram is shown in Figure 5.

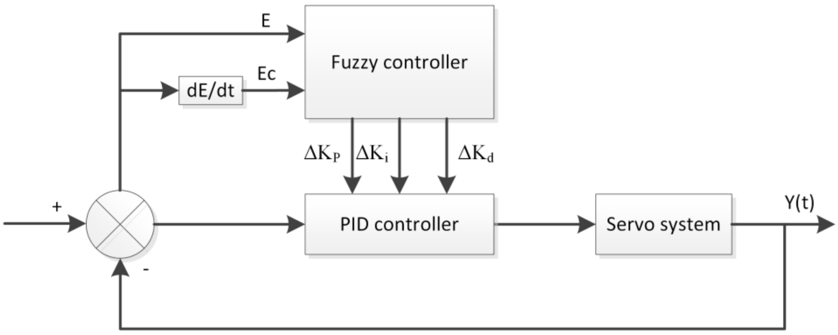

Figure 5: Fuzzy self-tuning PID structure diagram

The input variables of the system are the deviation e of the translation stroke and the deviation change rate ec. After fuzzification, fuzzy reasoning, and clarification processes, the proportional, integral, and differential adjustment variables of the PID are output ΔK_P,ΔK_I ,ΔK_D. The initial values KP0, KI0, and KD0 of the PID controller, along with the tuning variable, are used as output values to act on the controlled object. The final correction formula for K_P, K_I and K_D is shown in equation (1).

$$\begin{cases} K_P = K_{PO} + \Delta K_P \\ K_I = K_{IO} + \Delta K_I \\ K_D = K_{DO} + \Delta K_D \end{cases} \tag{1}$$

(1) Fuzzification

In fuzzy algorithms, the input variables are the deviation e of translation displacement and the rate of deviation change ec, and the output variables are K_P, K_I and K_D, with two inputs and three outputs. The variation intervals of e and ec are [-6, 6], corresponding to the domains of {-6, -4, -2, 0, 2, 4, 6}, K_P, K_I , and K_D are [1, 13], corresponding to the basic domains of {1, 3, 5, 7, 9, 11, 13}, fuzzy subsets are {NB, NM, NS, ZO, PS, PM, PB}, using triangular membership functions [7-8]. When fuzzy processing, it is necessary to convert the actual deviation and the rate of change of the actual deviation into corresponding fuzzy domains.

(2) Fuzzy inference

During the translation process of the unloading robot arm, when the distance from the target displacement is large, the servo speed should be increased to improve the unloading speed. When the distance from the target displacement is small, the speed should be slowed down to reduce positioning errors. Based on expert experience, determine the tuning principles for K_P, K_I and K_D.

1) When the current robotic arm starts translation, the deviation value e is relatively large. In order to quickly improve the response ability, K_P should be taken as a larger value; To prevent excessive differential effect caused by excessive deviation rate ec during startup, K_D should be taken as a smaller value. To avoid significant overshoot, K_I is taken as a smaller value [9].

2) When the deviation value e and deviation rate ec are moderate, to avoid excessive overshoot, K_P should be taken as a smaller value, and K_I and K_D should be taken as moderate values [10-13].

3) When the current robotic arm is close to the target stroke, the deviation e is small. To improve the stability performance of the servo, the values of K_P and K_I should be increased; To avoid exacerbating oscillations, the K_D value should be moderate.

Based on the above tuning principles, a fuzzy rule table is obtained, as shown in Tables 1, 2, and 3.

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Table 1: KP fuzzy rule table

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2: KI fuzzy rule table

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3: KD fuzzy rule table

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

(3) Defuzzification

The output result of a fuzzy controller is a fuzzy set, and it is necessary to first convert the fuzzy set into an exact value of the domain. However, the precise value of the domain does not directly control the output of the servo. It needs to be multiplied by the transformation scaling factor ku to convert it into an accurate value that can actually control the servo speed. There are more than one methods to convert the fuzzy set output by a fuzzy controller into precise values in the domain, and the most commonly used centroid method is used for conversion.

Similar to the calculation method of center of gravity, the weighted average of $\mu_c(z)$ is the clarity value of z.

$$z_o = \frac{\int_a^b z\mu_c(z)dz}{\int_a^b \mu_c(z)dz} \tag{2}$$

3. Results and discussion

3.1 Experimental process of the robotic arm for unloading

To verify the feasibility of the servo fuzzy PID control method, physical experiments were conducted on a robotic arm platform to compare the control effects of fuzzy PID and traditional PID. Considering the detection accuracy, the data acquisition sensor uses a grating ruler with an accuracy level of 5 microns. The translation stroke of the robotic arm for unloading is basically between 1100mm and 1300mm, with 5 target strokes set, namely 1100mm, 1150mm, 1200mm, 1250mm, and 1300mm. During each target

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stroke testing process, fuzzy PID and traditional PID were tested 20 times each to obtain the average positioning error, as shown in Table 4. The total number of experiments was 200, and statistics were conducted on the glass damage rate and cutting speed. The statistical results are shown in Table 5.

Table 4: Experimental parameters of servo positioning accuracy

Parameter	Journey1	Journey 2	Journey 3	Journey 4	Journey 5
Target itinerary	1100mm	1150mm	1200mm	1250mm	1300mm
Actual Itinerary (Fuzzy PID)	1100.19mm	1150.23mm	1200.21mm	1250.26mm	1300.24mm
Actual Itinerary (Traditional PID)	1100.87mm	1150.94mm	1200.95mm	1250.89mm	1300.93mm
position Error (Fuzzy PID)	0.19mm	0.23mm	0.21mm	0.26mm	0.24mm
position error (Traditional PID)	0.87mm	0.94mm	0.95mm	0.89mm	0.93mm
Error difference between fuzzy and traditional PID	0.68mm	0.71mm	0.74mm	0.63mm	0.69mm

Table 5: Statistical results of damage rate and unloading speed

Using Algorithms	Glass damage rate(%)	Dropping speed (flat/min)
Traditional PID	1.5%	6.3
Fuzzy PID	0.5%	6.1

3.2 Analysis of experimental results of the robotic arm for unloading

During the experiment, with 5 target strokes, as shown in Table 4, the positioning error of the fuzzy PID servo speed control method is between 0.19~0.26mm, while the positioning error of the traditional PID servo speed control method is between 0.87~0.95mm. The reduction in comparison error is between 0.63~0.74mm. The servo control method based on fuzzy PID has more advantages and can effectively improve the reliability of the system. According to Table 5, in terms of glass damage rate, the fuzzy PID algorithm has better control effect than the traditional PID algorithm, reducing the damage rate by 1%, ensuring the safety of the glass handling process. In terms of unloading speed, the effect of fuzzy PID is reduced by 0.2 pieces/min compared to traditional PID, and the reduction is not significant, with little impact.

3.3 Analysis of experimental results of the robotic arm for unloading

As a hot research technology, moving target tracking technology has been widely used in various fields. With the help of low cost, low power consumption, self-organization and high error tolerance of wireless sensor networks, moving target tracking based on wireless sensor networks also has broad application prospects.

4. Conclusion

A hollow glass storage system based on PLC and servo control was designed with the process of hollow glass storage as the research object. This article introduces the composition of the storage system, elaborates on the functions and roles of each part, not only realizing the automation of storage in the glass deep processing process, but also enhancing the safety of glass handling.

As a key equipment of the insulated glass storage system, the unloading robot arm affects the safety of the entire glass conveying process in the system. In the servo control algorithm of the robotic arm, a fuzzy PID control strategy is used to adjust the Kp, Ki, and Kd parameters in real-time based on fuzzy inference rules. Through experimental verification, it has been found that in terms of servo position control, fuzzy PID has higher accuracy than traditional PID control. In the ground track servo position control, good control effects have also been achieved. However, the fuzzy PID algorithm heavily relies on expert experience, and once the fuzzy rules are set, they no longer change, resulting in control accuracy being limited by expert experience. The Kp, Ki, and Kd parameters output by the fuzzy PID may not necessarily be the optimal solution. In subsequent research, it can be considered to use machine learning and deep learning to adjust PID parameters in real-time, or to link advanced algorithms such as machine learning and deep learning with fuzzy control, using advanced algorithms to obtain better rule tables, so that fuzzy control is no longer limited by limited expert experience, in order to obtain the optimal solution.

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