DESIGN AND EXPERIMENT OF A CONTROL SYSTEM FOR THE OBLIQUE SEEDLING PICKING-AND-RELEASE DEVICE OF VEGETABLE TRANSPLANTERS
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蔬菜移栽机斜置式取投苗装置控制系统设计与试验

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ABSTRACT
At present, the oblique seedling picking-and-release device of vegetable transplanters has low positioning accuracy and poor stability, which easily leads to issues such as failing to pick, damaging seedlings, and breaking seedling grippers during operation. Conventional PID control is difficult to meet the positioning control requirements. A step positioning control system based on fuzzy PID was designed, the transfer function of the control system was determined, and a fuzzy PID controller was established. Simulation analysis shows that with the displacement of the seedling picking-and-release frame as the system input, under optimal parameters, the times to reach steady state taken for conventional PID control and for fuzzy PID control are 1.2 s and 0.5 s, respectively. Field test results show that under fuzzy PID control, the maximum displacement error is reduced to 2.6 mm, with a relative error of 1.24%, which is less than the maximum relative error allowed for the displacement of the seedling picking-and-release frame. Fuzzy PID control has a shorter adjustment time, enabling rapid and precise positioning of grippers, and improving the success rate of seedling picking. The research results can provide reference and basis for the development of the control system for seedling picking-and-release device.

摘要
目前，蔬菜移栽机斜置式取投苗装置定位精度差、稳定性低，容易出现漏苗、伤苗、取苗爪损伤等问题。常规 PID 控制难以满足定位控制要求。本文设计了一种基于模糊 PID 的步进定位控制系统，确定了系统的传递函数，建立了模糊控制器。仿真分析表明，以取投苗臂位移为系统输入量，在最优参数条件下，常规 PID 控制和模糊 PID 控制系统到达稳态的时间分别为 1.2s 和 2.5s。田间试验结果表明，采用模糊 PID 控制，取投苗臂最大位移误差为 2.6mm，最大相对位移误差为 1.24%，小于取投苗臂允许的最大相对位移误差。模糊 PID 控制缩短了调节时间，实现了取苗爪的快速精准定位，提高了取苗成功率。研究结果可为蔬菜移栽机取投苗装置控制系统的开发提供参考和依据。

INTRODUCTION
Transplanting is a critical stage in vegetable production, and its level of mechanization directly influences the overall progress of mechanized vegetable cultivation (*Frasconi et al., 2019*). In China, however, manual operation remains the dominant method for transplanting many vegetables, leading to high labor intensity and low operational efficiency (*Cheng et al., 2024*). The large-scale adoption of automatic transplanters presents a viable solution to significantly reduce labor costs and enhance operational productivity (*Khadatkar et al., 2024*). The seedling picking-and-release device is a key component of automatic transplanters and remains currently in the prototype development stage (*Paradkar et al., 2021, Zhu et al., 2023*). A gantry-type seedling picking-and-release device was developed, based on the grippers' motion path during the process of seedling picking-and-release (*Qiu et al., 2024, Tian et al., 2023*). This mechanism facilitates the reciprocating movement of the picking-and-release arm through independently driven horizontal and vertical transmissions. Despite its ability to replace manual labor and improve transplanting efficiency, the long travel path of the grippers inherently limits the overall operating speed. To address the issue of low transplanting efficiency, an oblique automatic seedling picking-and-release device was designed (*Xie et al., 2020, Bai et al., 2025*). Both the seedling tray and the picking-and-release arm are oriented at a 45° angle to the horizontal.

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The grippers move in a straight line between the picking-and-release positions, thereby reducing the travel distance. However, this device requires frequent starts, stops, and high-speed direction changes during operation. Consequently, minor positioning errors can rapidly accumulate over numerous cycles, leading to higher rates of missed planting and seedling damage, thereby significantly compromising the transplanting quality.

At present, most research on automatic transplanters is focused on implementing the basic automation of transplanting operation. There has been little research on the precise positioning control of seedling picking-and-release. A Programmable Logic Controller (PLC) is employed as the control unit to manage the automatic execution of seedling picking and transplanting actions (*Liu et al., 2020*). The automatic transplanter developed by Jiangsu University employs a pneumatic control system, equipped with detection components such as tray sensors and limit switches (*Hu et al., 2020*). However, the positioning accuracy of the seedling picking and transplanting still faces challenges in practical operation. In order to realize the accurate and rapid positioning of the whole row seedling picking manipulator, a fuzzy PID control algorithm is adopted to improve the positioning accuracy of the manipulator in horizontal and vertical directions (*Ren et al., 2020*). The proposed method improved the stability of the control system and provided a reference for the research and development of the control system of automatic transplanters.

To address the positioning errors in the oblique automatic seedling picking-and-release device during high-speed operation, this study employs a fuzzy PID control algorithm for real-time adjustment of control parameters. The objectives are to achieve accurate positioning and rapid response of the seedling picking and transplanting device, thereby improving the working efficiency and meeting the transplanting requirements.

MATERIALS AND METHODS

Structure and working principle of the oblique seedling picking-and-release device

The oblique seedling picking-and-release device is mainly composed of a picking-and-release frame, two stepper motors, two lead screw modules, two guide rails, two linear motors, a linear encoder, and four grippers, as illustrated in Figure 1. The picking-and-release frame is mounted on the nuts of the lead screw modules via connecting plate and can move along the lead screws. The linear motors, guide rails, and grippers are installed to the picking-and-release frame. The control system primarily manages the timing of the stepper motors and linear motors during operation to achieve coordinated functioning of the seedling picking-and-release device. The linear encoder above the picking-and-release frame detects the frame's displacement changes in real time. The position information is fed back to the control unit.

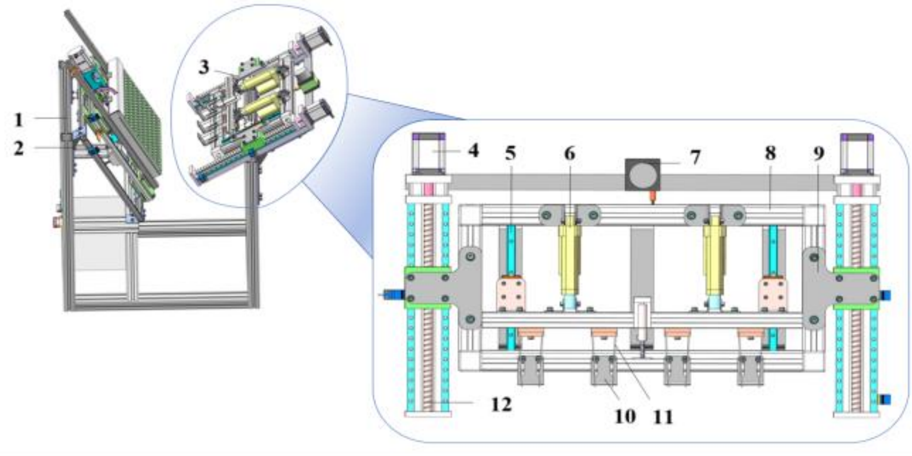


Fig. 1 - Schematic of the oblique seedling picking-and-release device

1-support frame; 2-tray feeding device; 3-seedling picking-and-release device; 4-stepper motor;5-guide rail; 6-linear motor; 7- linear encoder; 8-picking-and-release frame; 9-connecting plate; 10-guide plate; 11-gripper; 12- lead screw module

The tray is at a 30° angle to the horizontal direction, and the seedling picking-and-release device is at a 60° angle to the horizontal direction, as shown in Figure 2. Therefore, the movement direction of the grippers is perpendicular to the tray. The trajectory of gripper movement from the picking point to the release point is an inclined reciprocating straight line. The stepper motors drive the frame to move along an inclined path via the lead screw modules until it reaches the seedling picking point. Then, the pushrods of the linear motors extend, and the grippers insert into the seedling pots to grasp the seedlings. Subsequently, the frame moves to the seedling release point.

The pushrods of the linear motors retract, and the seedlings separate from the grippers and fall into the seedling cups of the transplanter. The tray feeding device completes precise stepping within the time interval between two seedling pickups. The above process is repeated in sequence until all the seedlings in the tray are picked up.

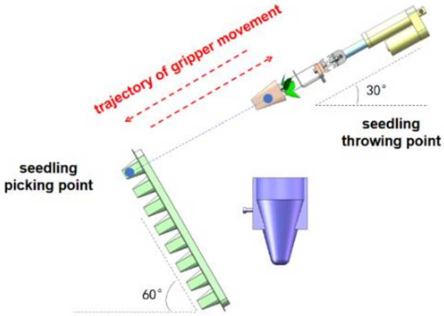


Fig. 2 - Trajectory of gripper movement

Design of the control system

The control system consists of two stepper motors and their drivers, a linear encoder, a control unit, a power supply, and other components. The electrical schematic diagram of the control system is shown in Figure 3. The control unit adopts the Xinje XD560T4C PLC (36 input terminals, 24 output terminals), with NPN transistor output type and 24V power supply. The ladder diagram is programmed using the dedicated software for this model of PLC to achieve the logical control of seedling picking-and-release, allocation of input and output ports, and control of stepper motors and linear motors.

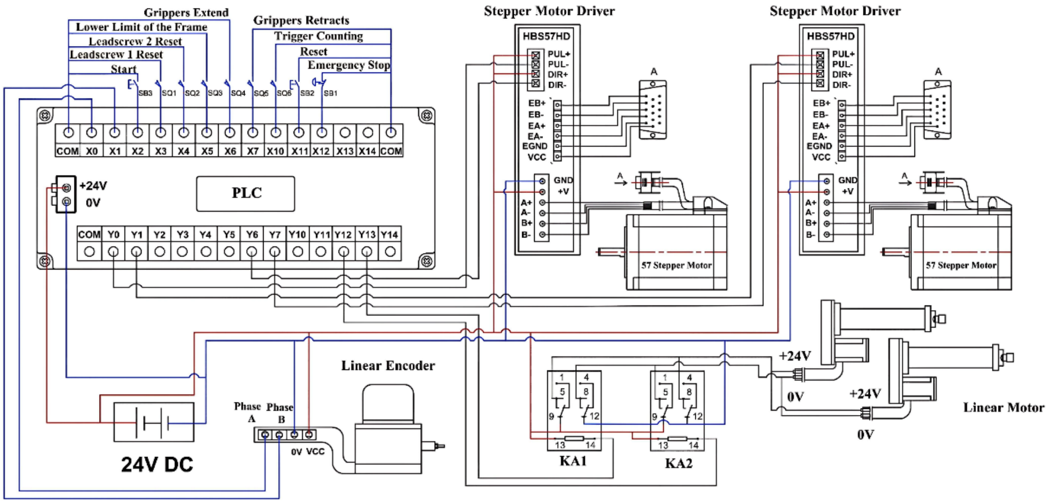


Fig. 3 - Electrical schematic diagram of the control system

Motion control requirements of the seedling picking-and-release device

The positioning accuracy of the device is determined by the control accuracy and the transmission accuracy of the mechanism (*Ma, 2020*). The two stepper motors control the seedling picking-and-release frame to move up and down along an inclined direction. Therefore, the motion accuracy of the stepper motors determines whether the seedling grippers can accurately and smoothly reach the seedling picking point and the seedling release point. When picking seedlings, the frame displacement determines the depth at which the gripper clamps the seedling plug. Excessive displacement may cause the gripper needles to penetrate the tray bottom and damage the needles, while insufficient displacement may result in the gripper needles to grasp the plug too shallowly, making it difficult to remove the seedling from the tray. When seedlings are released, if the frame displacement is too large or too small, the seedling grippers will fail to align with the seedling cups of the transplanter. This causes the seedlings to fall outside the cups, resulting in missed plantings.

This study uses a 72-cell tray with a cell depth of 40 mm. The stroke of the linear motor is 50 mm. To achieve optimal seedling picking results, extensive experiments were conducted, taking into account the positional inaccuracies arising from the installation of the seedling gripper. The experimental results indicate that the best performance is achieved when the distance between the tip of the gripper needle and the upper surface of the seedling pot is maintained within the range of 12-14 mm.

Considering a position fluctuation margin of 3 mm at the end of the gripper, so the allowable position is 9-17 mm from the tip of the gripper needle to the upper surface of the seedling pot. Therefore, the maximum displacement error allowed by the device is (17-9)/2=4 mm.

The lead screw module is driven by a 57BYG250C stepper motor, with parameters as shown in Table 1. The displacement of the seedling gripper is transmitted to the PLC via a linear encoder. Since the displacement of the gripper from the seedling release position to the seedling picking position is 210 mm, a KS20 linear encoder with a measuring range of 500 mm and a measurement accuracy of ±0.1% was selected.

Table 1

Parameters of the 57BYG250C stepper motor

Rated voltage	Rated current	Resistance	Inductance	Step angle	Number of rotor teeth	Viscous damping coefficient	Rotary inertia
[V]	[A]	[Ω]	[H]	[°]			[kg·m²]
24	3.0	1.0	3.5×10^{-3}	1.8	40	0.06	4.6×10^{-5}

The required number of step angles for the stepper motor can be expressed as:

$$n=\frac{360^{\circ}}{\theta/i}\cdot\frac{l}{p} \tag{1}$$

where n is the required number of step angles; θ is the step angle, (°); i is the gearbox reduction ratio; l is the displacement of the gripper from the seedling release position to the seedling picking position, (m); p is the pitch of the lead screw module, (m).

The rotational accuracy of the stepper motor is generally 3% to 5% of the step angle. In this study, the maximum value was adopted. Thus, the maximum rotation angle error of the stepper motor can be expressed as:

$$\triangle\theta=(\triangle n+5\%\ n)\ \theta \tag{2}$$

where $\triangle\theta$ is the maximum rotation angle error, (°); $\triangle n$ is the rounding error associated with the calculated number of step angles (°)

The maximum error rate of closed-loop control system can be expressed as:

$$\delta_0=\triangle\theta/\theta_m\times100\% \tag{3}$$

where δ_0 is the maximum error rate; θ_m is the rotation angle of stepper motor, (°).

In this study, θ was taken as 1.8°, i was taken as 6, l was taken as 0.21 m, and p was taken as 0.01 m. From Equation 1, the calculated number of step angles is n =25200. The rounding error $\triangle n$ is 0. The rotation angle of stepper motor θ_m is 45360°. By substituting the values of $\triangle n$, n, θ, and θ_m into Equations 2 and 3, the maximum error rate is obtained as δ_0 =5%.

The maximum displacement error rate of the seedling picking-and-release device can be expressed as:

$$\delta_1=\triangle l/l\times100\% \tag{4}$$

where δ_1 is the maximum displacement error rate, $\triangle l$ is the maximum allowable displacement error of the device, (m). In this study, $\triangle l$ was taken as 0.004 m. Based on Equation 4, the calculated displacement error rate is δ_1=1.905%.

Since $\delta_0 > \delta_1$, it indicates that the displacement accuracy of a simple closed-loop control system for a stepper motor theoretically can't meet the positioning requirements for seedling picking-and-release. Moreover, the complex and variable working environment makes the signal transmission between the control system and the stepper motor drive system susceptible to interference, potentially leading to signal loss and errors during signal conversion. Meanwhile, the stepper motor drive system itself exhibits nonlinear and time-varying characteristics (*Gaan et al., 2018, Gang et al., 2005*). Therefore, in order to effectively resist external environmental interference during operation, overcome complex nonlinear effects, and ensure the efficiency and precision of seedling picking-and-release operation, it is necessary to improve the displacement accuracy of the step control system.

Transfer function of the seedling picking-and-release device

The precise positioning control of the seedling picking-and-release device essentially involves precise control of the stepper motor of the device. To achieve precise and stable positioning for seedling grippers every time, an accurate mathematical model for the device needs to be established. The transfer function of the seedling picking-and-release device can be expressed as:

$$G_s = \frac{G_a(s)G_b(s)G_c(s)G_d(s)G_e(s)}{1+G_a(s)G_b(s)G_c(s)G_d(s)G_e(s)G_f(s)} \tag{5}$$

where: G_s represents the transfer function of the device, $G_a(s)$ represents the transfer function of the PLC, $G_b(s)$ represents the transfer function of the stepper motor driver, $G_c(s)$ represents the transfer function of the stepper motor, $G_d(s)$ represents the transfer function of the gearbox, $G_e(s)$ represents the transfer function of the lead screw module, and $G_f(s)$ represents the transfer function of the linear encoder.

The stepper motor is controlled by step pulse voltage. Upon receiving a pulse signal, it rotates by a preset angle which oscillates around a new stable equilibrium position. Let the motor step angle be θ, and the actual angle rotated by the motor be θ_m. Based on the linearization of the small oscillation theory and Laplace transform (*Wang, 2024*), the transfer function of the stepper motor can be derived as:

$$G_c(s) = \frac{\theta_m(s)}{\theta(s)} = \frac{Z^2Li^2/2J}{s^2+\frac{B}{J}s+\frac{Z^2Li^2}{2J}} \tag{6}$$

where θ_m(s) represents the Laplace transform of θ_m; θ(s) represents the Laplace transform of θ; Z represents the number of rotor teeth; L represents the winding inductance, (H); i represents the rated current, (A); J represents the rotary inertia of rotor, (kg·m^{2}); B represents the viscous damping coefficient of motor.

By substituting the motor parameter values from Table 1 into Equation (6), the following is obtained:

$$G_c(s) = \frac{54.782}{s^2+0.130s+54.782} \tag{7}$$

The stepper motor driver can be regarded as a proportional element, and the transfer function can be represented as $G_b(s)$=8 based on experience. The reducer can also be treated as a proportional element, and its transfer function is $G_d(s)$=1/i=0.167. The lead screw module converts the angular displacement of the stepper motor into the linear displacement of the picking-and-release frame. It can be regarded as a proportional element with a proportional gain m. Therefore, its transfer function is $G_e(s)=m=p/360$=0.028. The linear encoder transforms position signals into digital signals, and can be regarded as a proportional module. Its transfer function is $G_f(s)$=1. The PLC converts the difference between the preset pulse number and the pulse number fed back by the linear encoder into the actual pulse number for controlling the motor. It can be regarded as a proportional element, and its transfer function is $G_a(s)=1/m(\theta/i)$ =119.05 (*Wang et al., 2013*).

Design of fuzzy PID step positioning control system

As the stepper motor exhibits pronounced nonlinear behavior, the fuzzy control algorithm has been integrated into the traditional PID framework to achieve accurate, real-time, online tuning of the PID parameters (*Mahmoud et al., 2025*). The formulas for adaptive adjustment of parameters are

$$K_p = K'_p + \Delta K_p \tag{8}$$

$$K_i = K'_i + \Delta K_i \tag{9}$$

$$K_d = K'_d + \Delta K_d \tag{10}$$

where K_p, K_i, and K_d represent the proportional, derivative, and integral parameters of the controller, respectively; K'_p, K'_i, and K'_d represent the parameter values tuned in the previous cycle; ΔK_p, ΔK_i, and ΔK_d represent the output increments of the fuzzy controller used to adjust PID parameters.

Fig.4 shows the block diagram of the fuzzy PID control system for the seedling picking-and-release device.

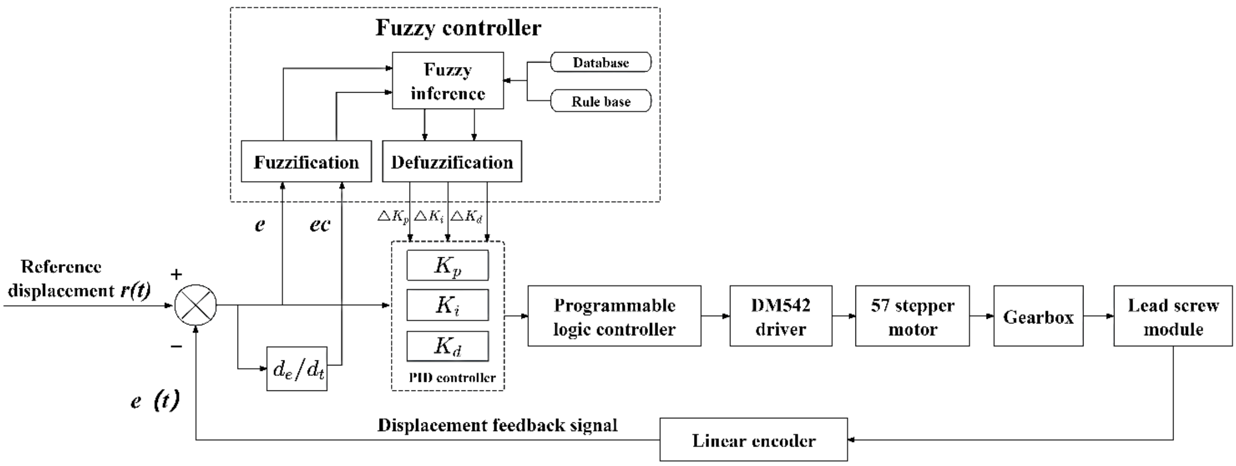


Fig. 4 - Block diagram of the fuzzy PID control system

The fuzzy controller adopts a two-input three-output form. The displacement deviation of the gripper e and the change rate of displacement deviation ec are the inputs of the fuzzy controller, with e and ec corresponding to the input language variables E and EC, respectively. The outputs are $\triangle K_p$, $\triangle K_i$, and $\triangle K_d$, and the corresponding three output language variables are DKP, DKI and DKD. Based on the actual control requirements for the displacement of the seedling gripper, combined with factors such as mechanical structure constraints, the basic domain of the input variables is determined.

After fuzzification mapping to appropriate fuzzy subset domains, the domains of the input linguistic variables are obtained as E= [-3mm, 3mm], EC= [-2mm/s, 2mm/s], and the domains of the output linguistic variables are obtained as DKP = [-3, 3], DKP = [-0.9, 0.9], and DKP = [-1.2, 1.2]. The values of the linguistic variables are all set to seven levels: {NB, NM, NS, ZO, PS, PM, PB}, representing {Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big}. The input variables are quantified to a fuzzy domain, which consists of 13 elements: {-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6}. The corresponding quantization factors are K_e=1 and K_{ec}=1.5. Similarly, the output variables are quantified to a fuzzy domain, which consists of 13 elements: {-3, -2.5, -2, -1.5, -1, -0.5, 0, 0.5, 1, 1.5, 2, 2.5, 3}. The corresponding quantization factors are K_1=1, K_2=0.3 and K_3=0.4 (*Han et al., 2022*).

Considering the frequent start-stop operations of the seedling picking-and-release device and complex field conditions, combined with the practical experience of experts and the advantages and disadvantages of different membership functions, a membership function combining Gaussian and trigonometric functions was selected (*Zhang, 2025*).

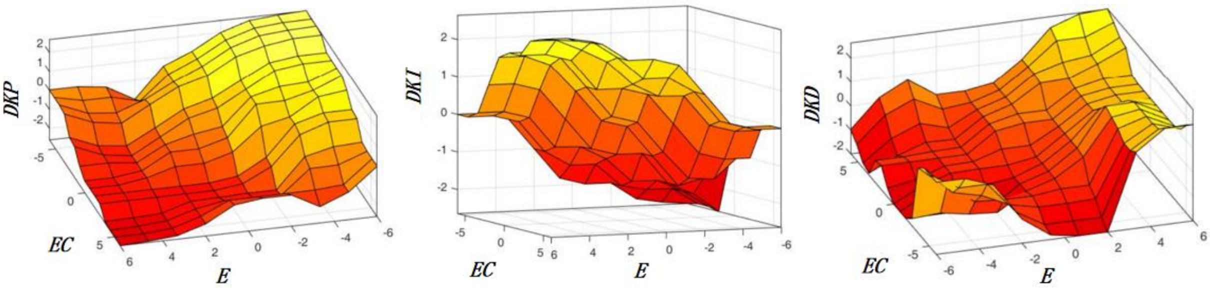
Fuzzy control rules are the most crucial component in fuzzy control. Different control rules lead to significantly different final results in the reasoning process of a fuzzy controller. According to the influence of PID control parameters on system output, combined with expert experience, and after repeated experimental comparisons, a control rule table for DKP, DKI, and DKD under different values of E and EC is obtained, as shown in Table 2 (*Phu et al., 2020*).

Table 2

Fuzzy control rules for *DKP*, *DKI*, and *DKD*

		EC						
		NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
	NB	PB/NB/PS	PB/NB/PS	PM/NB/NM	PM/NS/NM	PS/NS/NS	ZO/ZO/NM	ZO/ZO/NS
	NM	PB/NB/PS	PB/NM/NS	PM/NM/NM	PS/NM/NS	PS/NS/NS	ZO/ZO/NS	NM/ZO/PS
	NS	PM/NM/NS	PM/NM/NS	PS/NS/NM	PS/NS/NS	NS/ZO/NS	NM/PS/NS	NS/PS/ZO
E	ZO	PS/NM/NM	PS/NS/NS	ZO/NS/NS	NS/ZO/NS	NM/PS/ZO	NM/PS/ZO	NS/PM/ZO
	PS	NS/NS/NM	ZO/NS/NS	NS/ZO/ZO	NS/PS/ZO	NM/PS/ZO	NM/PM/PS	NM/PM/PS
	PM	ZO/ZO/PM	NS/ZO/PM	NM/PS/PM	NM/PM/PS	NM/PM/PS	NB/PB/PS	NB/PB/PB
	PB	ZO/ZO/PM	ZO/ZO/PS	NS/PS/PS	NM/PM/PS	NM/PM/PS	NB/PB/PM	NB/PB/PB

Using MATLAB software, input the fuzzy control rules into the Fuzzy Rule Editor, and import the input and output variables and membership functions into the Fuzzy Logic Designer. This will generate the fuzzy control rule surface plots for DKP, DKI, and DKD as well as the fuzzy inference process diagram, as shown in Figure 5.



(a)*DKP* (b)*DKI* (c)*DKD*

Fig. 5 - Fuzzy control rule surface plots

Simulation of the step positioning control system

By utilizing the simulation modules in MATLAB Simulink Toolbox, the simulation models of PID and fuzzy PID were established (*Liu et al., 2017*), as shown in Figure 6 and Figure 7, respectively.

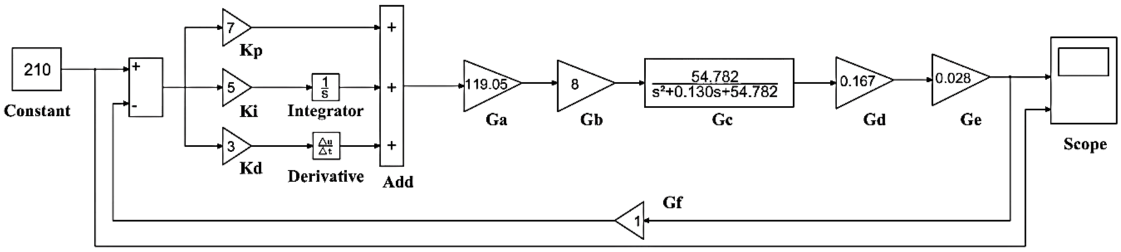


Fig. 6 - Simulation model of PID step positioning control system

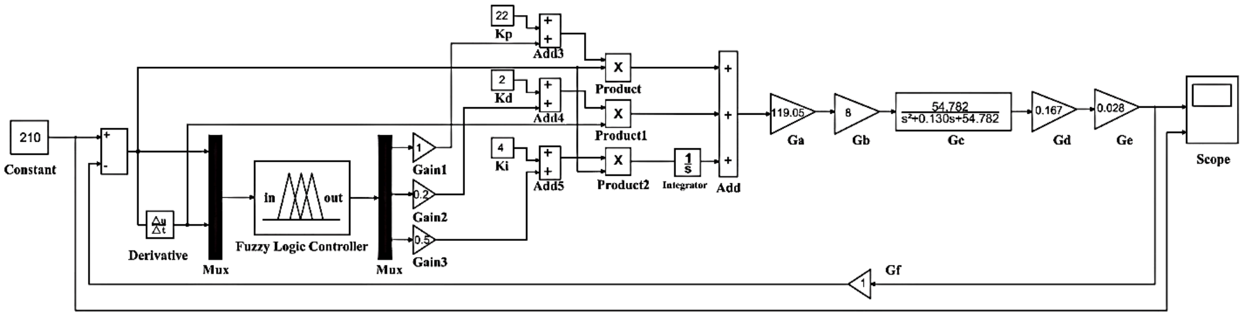


Fig. 7 - Simulation model of fuzzy PID step positioning control system

The simulation parameters were set as following. Input magnitude: 210, Stop Time: 10, Solver type: variable-step, Solver: ode 23, Initial step size: auto, Maximum step size: auto, Minimum step size: auto, Relative tolerance: 1e-3, Absolute Tolerance: auto, Number of consecutive min steps: 1.

Positioning control experiments

The experiments were conducted in March 2025 at the experimental field of Huorong Agricultural Technology Development Co., Ltd. in Qingzhou City, Shandong Province, China. The prototype of oblique automatic seedling picking-and-release device is shown in Figure 8. Cabbage plug seedlings cultivated by Shandong Deruikang Vegetable Seedling Co., Ltd. were used in the experiments. To avoid the influence of factors such as moisture content of seedling pot and seedling age on the success rate of seedling picking, two trays of seedlings with the same batch and cultivation specification were selected, as shown in Figure 9. The emergence rate of the seedlings was 100%.

Fig. 8 – Experimental prototype

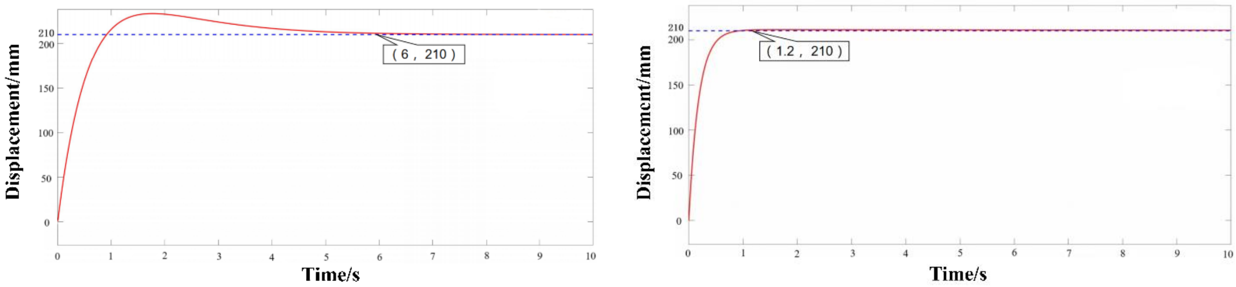
Fig. 9 - Seedlings for experimentation

According to the actual agronomic requirements, the planting speed is set at 60 plants/min. The programs for both the conventional PID controller and the fuzzy PID controller were separately written into the PLC. The PLC sends control signals and drives the seedling picking-and-release frame to complete 18 rounds of reciprocating actions based on different control algorithms. By calculating the absolute error between the actual displacement and the required displacement of the frame under two control algorithms, the performance difference between the two control strategies was compared. The smaller the error value, the higher the positioning accuracy. The required displacement of the frame from the initial position to the seedling picking position is 210 mm.

RESULTS

Simulation analysis of the control system

When the PID controller parameters K_p, K_i, and K_d were set to 7, 5, and 3 based on experience and experimentation, the simulation result was shown in Figure 10(a), with a response time of 6 s and an overshoot of 8.2%. Through the empirical trial and error method, adjust K_p, K_i, and K_d to 22, 2, and 4, respectively. The simulation result was shown in Figure 10(b), with a response time of 1.2 s and no overshoot. The seedling picking-and-release device operates in harsh field environment where the control system is prone to signal interference and load fluctuation. Since the PID controller runs in an offline adjustment mode, if it cannot quickly adjust to a steady-state value in the presence of interference, errors will occur, affecting the precision and stability of seedling picking-and-release.



(a) K_p=7, K_i=5, K_d=3 (b) K_p=22, K_i=2, K_d=4

Fig. 10 - Simulation results of the conventional PID control

Based on the Simulink simulation environment, the proportional factors corresponding to $\triangle K_p$, $\triangle K_i$, and $\triangle K_d$, as well as the optimal reference values of K_p, K_i, and K_d, were input into the model. The simulation result of the fuzzy PID controller is shown in Figure 11. The system response time is 0.5 s, and no oscillation occurs. Compared with conventional PID control system, the fuzzy PID control system has faster response speed and stronger stability, which is conducive to more precise and stable seedling picking-and-release.

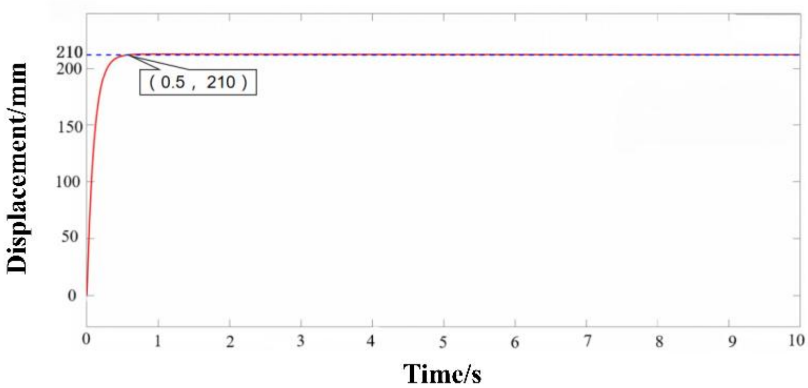


Fig. 11 - Simulation results of the fuzzy PID control

Analysis of field tests results

The actual displacement, displacement error, and number of successful pickings under the conventional PID and fuzzy PID are shown in Figure 12, Figure 13, and Figure 14, respectively. As shown in Figure 12 and Figure 13, the fluctuation of the actual displacement and the displacement error of the seedling picking-and-release frame under conventional PID control are both greater than those under fuzzy PID control. The actual displacement under the conventional PID control changes between 205.4 mm and 213.6 mm, with an average displacement error of 1.97 mm. The maximum displacement error is 4.6 mm, with a maximum relative error of 2.19%, which fails to meet the control requirements for seedling picking. The actual displacement under the fuzzy PID control fluctuates between 207.4 mm and 211.2 mm, with an average displacement error of 0.84 mm. The maximum displacement error is 2.6 mm, with a maximum relative error of 1.24%, which is less than the maximum relative error allowed for the movement of the frame.

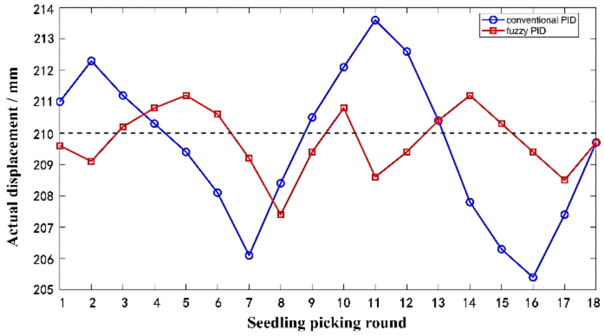


Fig. 12 - Actual displacement of the seedling picking-and-release device

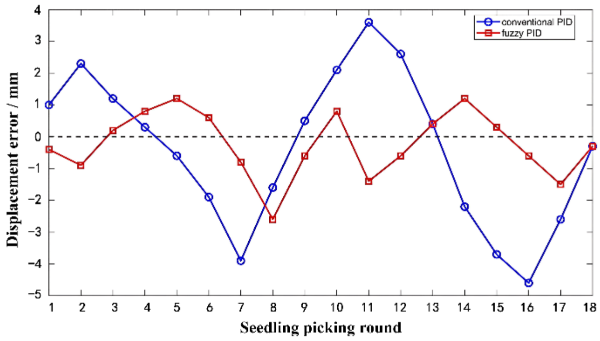


Fig. 13 - Displacement error of the seedling picking-and-release device

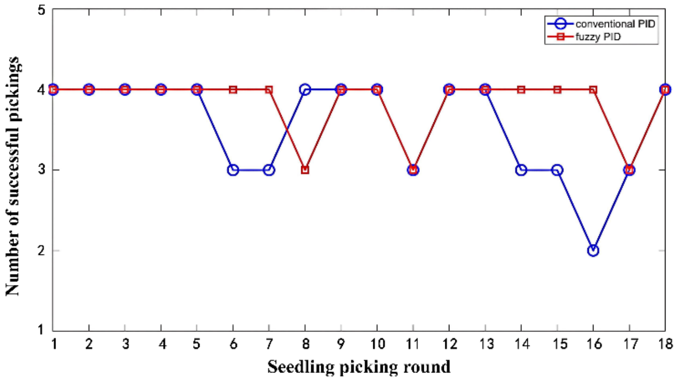


Fig. 14 - Number of successful pickings of the seedling picking-and-release device

As can be seen from Figure 14, under conventional PID control, there are a total of 7 instances of seedling missing, involving 8 plants. However, under fuzzy PID control, there are only 3 instances of seedling missing, involving 3 plants. The fuzzy PID control demonstrates stronger adaptability and robustness during the experiment, with significantly better performance than the conventional PID control.

CONCLUSIONS

For the oblique seedling picking-and-release device, a step positioning control system with a PLC as the control unit was designed to achieve precise positioning of the seedling grippers. The simulation models for both conventional PID control and fuzzy PID control were established. Using the displacement of the seedling picking-and-release frame as the system input, the simulation results show that the fuzzy PID control has a shorter adjustment time and stronger anti-interference ability. Field experiments were conducted using cabbage seedlings. The results show the accuracy of fuzzy PID control is superior to that of conventional PID control, achieving rapid and accurate positioning of the seedling gripper, improving the success rate of seedling picking, and better meeting the requirements of field operations.

For the fuzzy PID algorithm, the initial values of control parameters still need to be selected based on experience, and have a significant impact on the system's performance. In future research, it is necessary to use particle swarm optimization or genetic algorithm to optimize the initial values. Additionally, to enhance the system's operational speed, STM32 microcontrollers or Raspberry Pi can be employed to replace PLC as the control unit.

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