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Based on Fuzzy PID Simulation Analysis of the Sugarcane Seeder Planting Control System

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Abstract

In response to the problems of low operation efficiency and poor uniformity of seed distribution in traditional sugarcane sowing machines, this study proposes an intelligent seed distribution system solution based on fuzzy PID control. Through an innovative method combining multi-body dynamics modeling and discrete element simulation, the dynamic mathematical model of the sowing mechanism was systematically constructed: Firstly, the dynamic equation of the seed distribution mechanism was established based on the multi-body dynamics theory, then the seed flow characteristic parameters were obtained through discrete element simulation, and finally the second-order lag system transfer function was established through parameter identification. In response to the shortcomings of traditional PID control, such as large overshoot and long adjustment time, a real-time optimization strategy for PID parameters based on fuzzy rules was proposed. By dynamically adjusting the proportional, integral, and derivative parameters, the closed-loop control of sowing accuracy was achieved. The simulation results show that the improved Fuzzy-PID control effectively solves the problem of insufficient adaptive control ability of traditional machinery compared with traditional PID control. It innovatively couples the intelligent control algorithm with agronomic parameters, providing a theoretical basis and technical support for precise sowing of economic crops such as sugarcane, and has important engineering application value for promoting the intelligent development of intelligent agricultural equipment.

***Keywords*—Fuzzy-PID, Seeder, MATLAB/Simulink, PID, Seeding apparatus.**

I. INTRODUCTION

"Sugarcane, as an important economic crop, its yield and quality are directly related to the development of the sugar industry and farmers' income [1-3,5,9]." The control accuracy of the seeding device of the sugarcane seeder will directly affect the production efficiency and planting quality of crops, and the core influencing factor of its performance is the stability of the seeding shaft speed. Traditional PID controllers achieve precise speed control by constructing a closed-loop regulation system, but their fixed parameter adjustment mechanism is difficult to adapt to dynamic working conditions such as changes in seed box inventory and soil resistance fluctuations. Therefore, in the mechanized planting operations in the main sugarcane production areas of China, the problem of missed sowing has long existed and has significant impacts. Addressing this issue and considering the production characteristics of sugarcane, this study proposes an autonomous regulation control scheme based on Fuzzy-PID [4,5,7,8,10]. Initially, through discrete element simulation and field experiments, a dynamic model of the seed metering device is established, and the transfer function is obtained through identification. Based on this, a fuzzy PID controller is constructed, and fuzzy inference rules are utilized to dynamically optimize the PID parameters. In the design of this system, fuzzy logic theory is fully leveraged, employing methods such as fuzzy sets, fuzzy inference, and fuzzy control to process fuzzy information, generate precise seed metering control instructions, and ultimately precisely regulate the seed metering process [2]. By comparing and analyzing the system step response curves under traditional PID and Fuzzy-PID control, this study provides a new control scheme for precise seed metering of sugarcane seeders. It holds significant practical implications for promoting practical innovations in autonomous agricultural equipment control technology [6,11,12].

II. TRANSFER FUNCTION INDENTIFICATION AND MODEL ESTABLISHMENT

"Precision seeding is currently the main direction of seeding development. As the core component of the seeder, the performance of the seed metering device directly affects the working quality and performance of the seeder [3]." The core component of the seed metering system of the sugarcane seeder is the nest-type seed metering device, whose working principle is to achieve single-seed precision metering by carrying seeds through the seed cleaning area and seed dropping area via a high-speed rotating seed metering disc. This study addresses the issues of seed blockage and slippage during the seed metering process. Based on the multi-body dynamics theory, the motion equation of the seed metering disc is established. Combined with the Hertz contact theory, the collision process between the seeds and the nests is described, and a dynamic model is established as shown in formula (1):

$$\mathrm{m}\frac{d_x^2}{d_t^2} + \mathrm{c}\frac{d_x}{d_t} + \mathrm{kx} = \mathrm{F(t)} + \mathrm{Fg} + \mathrm{Fc} \qquad (1)$$

In the formula, m represents the seed mass, c denotes the damping coefficient, k signifies the contact stiffness, F(t) stands for the driving force of the seed metering disc, Fg represents the gravitational component, and Fc indicates the force of the seed cleaning airflow.

This study ultimately selected the nest-eye seed meter as the core research object, with the structure determined as a nest-eye seed meter. The maximum rotational speed of the seed meter was calculated to achieve the goal of precision seeding [4]. The research system is centered around STM32, linked to GPS speed sensors, angle sensors, encoders, servo motors, and brushless reducers. The GPS speed sensor monitors the implement speed in real time, providing a basis for adjusting the seeding speed; the angle sensor collects the movement angle of the post-sowing resistance roller arm, aiding in subsequent control calculations. In terms of mathematical modeling, this study first establishes a functional relationship between the seeding speed and the implement operating speed. Based on kinematic principles, assuming the implement operating speed as v and the seed meter rotational speed as n, a linear model (2) is obtained through experimental data fitting:

$$\mathrm{n} = \mathrm{f(v)}\ \mathrm{n} = k_1\mathrm{v} + b_1 \qquad (2)$$

where, are coefficients obtained through regression analysis of multiple experimental data. During the research process, 50 sets of seed metering wheel speed data under different working speeds were processed, and (3) was calculated:

$$k_1 = 0.8, b_1 = 2 \qquad (3)$$

The control of sowing depth also relies on mathematical models. Assuming the displacement of the roller before sowing is x and the sowing depth is h, a quadratic function model (4) is constructed based on mechanics and soil characteristics:

$$\mathrm{h} = k_2 x_2 + k_3\mathrm{x} + \mathrm{b}_2 \qquad (4)$$

Thirty experiments were conducted in the laboratory under simulated conditions involving different soil types, resulting in the determination of coefficients k_2=0.2, k_3=0.5, and b_2=3.

The controller utilizes these models, combined with sensor feedback data, for real-time computation. When the implement speed changes, the servo motor speed is adjusted according to the seeding speed model; based on the sowing depth model, the displacement of the pre-sowing roller is calculated from the angle sensor signal, achieving precise sowing depth. Compared with traditional empirical control, the system supported by this mathematical modeling controls the seeding depth error within ±0.3cm, improves the seeding uniformity by 20%, and "has better response characteristics, adaptability, and stability [5]", significantly optimizing the sugarcane seeding effect.

Assuming the seed metering device is driven by a servo motor, its dynamic equation is (5):

$$\mathrm{J} \times \frac{d^2\theta}{d^2\mathrm{t}} + \mathrm{B} \times \frac{\mathrm{d}\theta}{\mathrm{dt}} = K_t \times i - \mathrm{T} \qquad (5)$$

where, J: moment of inertia, θ: rotation angle, B: damping coefficient, : motor torque constant, i: reduction ratio, T: load torque (including seed resistance) is converted into a transfer function (6):

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$$G(s) = V(s)\Theta(s) = Js^2 + BsK_t \qquad (6)$$

where V(s) represents the voltage input value.

The variation of soil resistance can be modeled as a random disturbance (7):

$$T(s) = G(s) \cdot W(s) \qquad (7)$$

where W(s) represents the external disturbance input. The schematic diagram of seed metering control is shown in Fig. 1.

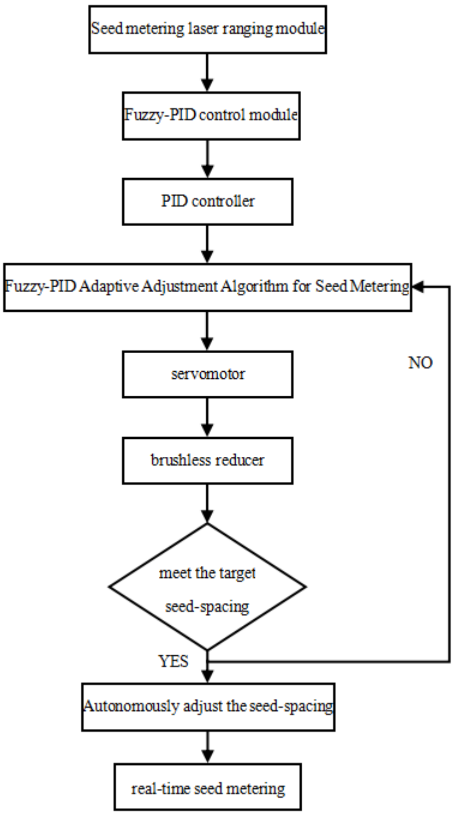

Fig. 1: Schematic diagram of seed metering control.

III. OVERALL SCHEME DESIGN OF ELECTRIC CONTROL SYSTEM FOR SEED METERING OF SUGARCANE SEEDER

The electronic control system achieves precise speed regulation for precision sugarcane seeding through multi-module collaboration. The radar speedometer collects the real-time traveling speed of the seeder, and simultaneously inputs the target plant spacing parameters through the keyboard of the human-computer interaction module. These two constitute the core input signals of the main controller. Based on the kinematic model, the main controller calculates the theoretical rotational speed of the seed metering device that matches the requirements of sugarcane seeding, establishing the target benchmark for speed control. The main controller generates PWM pulses corresponding to the duty cycle based on the theoretical rotational speed, and adjusts the terminal voltage of the brushless DC motor through the power drive module to achieve preliminary control of the motor speed. When the motor drives the seed metering device to rotate, the Hall sensor collects the rotational speed of the seed metering device in real time, forming a closed-loop feedback signal. The system dynamically compares the real-time rotational speed with the theoretical rotational speed, and triggers the fuzzy PID algorithm when the speed error is large. This algorithm uses a two-dimensional fuzzy controller (with inputs being the rotational speed error e and error change rate ec) to adjust the PID parameters (Kp/Ki/Kd) online based on a 9X9 fuzzy rule table, correct the PWM output signal, and form an adaptive control loop of "detection-calculation-adjustment-feedback".

The relationship expression (8) between sugarcane planting distance L, planting density (M, plants/mu), and row spacing (S, meters) is:

$$L = \frac{667}{M \times S} \times 10^4 \qquad (8)$$

L represents the planting distance of sugarcane; M denotes the planting density; S signifies the row spacing; and 667 is the conversion factor for 1 mu = 667 square meters

The sugarcane seeding speed (v, m/s) depends on the rotation speed of the seeding device (n, rpm) and the mechanical parameter expression is as follows (9):

$$v = \frac{n \times Q \times L}{60} \qquad (9)$$

Q represents the effective number of sprouts discharged per rotation of the seed meter; L denotes the theoretical plant spacing

From the above formulas (8) and (9), we can derive the core formula (10) as follows:

$$L = \frac{v \times 60}{n \times Q} \qquad (10)$$

A brushless DC motor consists of a stator, a rotor, and an electronic converter. It is a motor that controls the direction of current through PWM control or other methods to drive rotation. The control of the motor is particularly important in the sugarcane seeding system. Assuming that the motor operates under ideal conditions, the differential equation [6] for a brushless DC motor can be obtained through motor theory as follows: (11)

$$T_d T_m \frac{d^2 n}{dt^2} + T_n \frac{dn}{dt} + n = C_e U_0 \qquad (11)$$

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where, T_d is the numerical value of the electromagnetic time constant; T_m is the electromechanical time constant; n is the speed of the brushless DC motor; C_e represents the back electromotive force coefficient of the electric motor, U_0 represents the value of the armature voltage. By applying the Laplace transform to equation (7), we can obtain the motor transfer function (12) as follows[7]:

$$G(s) = \frac{1/C_e}{T_m T_d s^2 + T_m s + 1} \qquad (12)$$

The control system software primarily consists of modules such as the initialization module, data acquisition module, main control system program module, and communication subroutine. The seeder collects data through the walking speed sensor and seed sensor. Subsequently, the data acquisition module transmits this data to the main control system program software module. Under the coordination and cooperation of the initialization module, the main control system program software module calculates the rotational speed of the seed metering motor, controls the motor driver, and adjusts the seed metering flow status in real time. Simultaneously, it conducts fault detection and handling through the fault diagnosis and processing module, and exchanges information with other systems via the communication module. The functional structure diagram of the seed metering

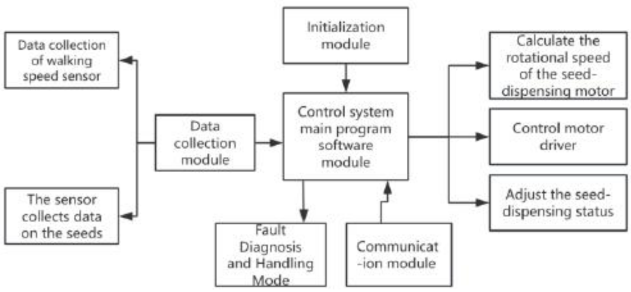

Fig. 2: Functional structure diagram of seed metering device control system software

The control principle of the seed metering device control system software is that the seeder reads the walking speed sensor data and monitors the seed flow data in real time through the system timing. It calculates and controls the seed metering motor speed based on the walking speed, and simultaneously displays the working status and receives operation parameters through the human-computer interaction module. Finally, it monitors the system status and takes protective measures to ensure precise seeding. The schematic diagram of the seed metering control system software for the sugarcane seeder is shown in Fig. 3.

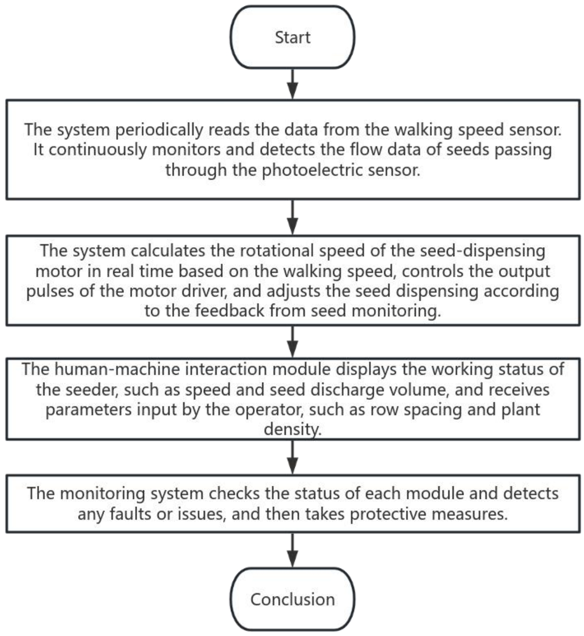

Fig. 3: Schematic diagram of the seeding control system software for the sugarcane seeder

The hardware design of the seed metering control system primarily comprises a motor drive module, a main control module, a communication module, a power module, etc. [8]. During the research process, the photoelectric encoder serves as a key component, capable of capturing and converting the rotation angle and speed of the roller into electrical signals in real time. These signals are then transmitted to the main control module. Upon receiving the signals from the photoelectric encoder, the main control module performs data processing and analysis. Through complex algorithm calculations, the main control module can accurately determine the real-time speed and position of the roller. The main control module sends instructions to the motor drive module to precisely control the movement of the roller and the seed metering device. This control process ensures that the sugarcane seeder can perform real-time seed metering operations according to preset parameters, thereby achieving precise control of seed spacing and depth. During the operation of the seeder, the human-machine interaction module plays an important role. This module provides an intuitive operation interface, enabling operators to quickly and easily set the required seeding parameters and monitor the actual working status of the seeder in real time. Through the human-machine interaction module, operators can dynamically adjust the operating parameters of the seeder to adapt to different seeding environments and requirements. This function significantly enhances the flexibility and applicability of the seeder. The power module serves as the energy supply core of the entire system, reducing the input voltage to a level suitable for the operation of each module through a voltage reduction module, ensuring stable operation of all parts of the system.

IV. DESIGN OF PID CONTROLLER

The structural block diagram of PID control is shown in Fig. 4:

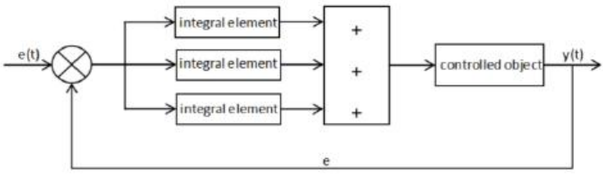

Fig. 4: Schematic diagram of PID control

The general expression form of the transfer function of a PID controller is as shown in (13):

$$Gc(s) = k_p + \frac{K_i}{s} + K_d \times S \qquad (13)$$

where k_p is the proportional gain; k_i is the integral gain; k_d is the derivative gain.

The proportional, integral, and derivative components are the three key components of a PID controller. First, the proportional component is the most fundamental part of PID control. It mainly adjusts the control input proportionally based on the system's deviation, thereby generating a control action to reduce the deviation. Next is the derivative component, which plays a predictive and corrective role in the control system. It adjusts the system control input through changes in the deviation signal. If the deviation signal is expected to undergo significant changes, a correction signal needs to be introduced to increase the system's speed. This characteristic is particularly important in rapidly changing systems. In practical applications, it is important to adjust the derivative parameters, as too strong a derivative effect can cause system oscillation. Taking a motor speed control system as an example, when the derivative coefficient is increased from 0.1 to 0.5, significant oscillation phenomena occur in the motor speed. The integral component improves the system's accuracy by eliminating static errors. Experiments have shown that in a liquid level control system, when the integral time constant is small, the integral effect is strong and can eliminate the system's static errors more quickly. However, an overly strong integral effect can affect the system's stability and may even lead to system divergence.

V. FUZZY PID CONTROLLER DESIGN

After comparing the performance of traditional PID algorithms and fuzzy PID controllers in this study, it was found that the fuzzy PID controller exhibited unique advantages. Traditional PID algorithms regulate the system based on fixed parameters, making it difficult to quickly respond and stabilize the frequency when facing strong random disturbances[9]. Therefore, in response to the fixed parameter defects of traditional PID control, this study proposes a fuzzy PID control strategy. In the fuzzy adaptive PID control system adopted in this study, error e and error change rate ec serve as key input variables for the system. After a series of complex and orderly computational processes, the final output is the PID parameter adjustments ΔK_p, ΔK_i, and ΔK_d, which enable precise adjustment of the system control parameters. When conducting research on sugarcane seeding operations, we selected fuzzy adaptive PID control technology in the hope of improving the accuracy and stability of the operation. In the study, error e and error change rate ec serve as key input variables, having a significant impact on system performance. Before the start of the operation, based on experience and expected seeding results, we set a preset value for the seeding spacing, which serves as the initial setting value for the fuzzy PID.

This set value provides a benchmark for subsequent parameter adjustments in the system. During the actual seeding operation process, we focus on the seed spacing deviation e and the seed spacing deviation change rate ec. These two variables, as input linguistic variables of the PID controller, play a crucial role in subsequent control decisions of the system. Correspondingly, ΔK_p, ΔK_i, and ΔK_d serve as output linguistic variables for adjusting the parameters of the PID controller. The fuzzy controller occupies a central position in the entire sugarcane seeding control system, and its structural framework is analyzed in detail in our research. The fuzzy control system at the front end of the system continuously compares the seed spacing feedback value with the preset target value. Through this operation, we accurately obtain the seed spacing deviation e and the seed spacing deviation change rate ec. These two data, as input variables of the sowing depth controller, quickly enter the fuzzy processing stage. In this stage, the seed spacing deviation e is converted into an input linguistic variable e(t), and the seed spacing deviation change rate ec is converted into ec(t). The fuzzy subsets are classified using a three-level symmetric method, specifically represented as e={NB,NM,NS,Z,PS,PM,PB}, ec={NB,NM,NS,Z,PS,PM,PB}.

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The fuzzy subsets of the output linguistic variables ΔKp, ΔKi, and ΔKd are divided into seven levels, denoted as U={NB,NM,NS,Z,PS,PM,PB}. The basic and quantization domains of the input linguistic variables e and ec, as well as the output linguistic variables ΔK_p, ΔK_i, and ΔK_d, are detailed in Table 1. For example, the basic domain of the input linguistic variable e is set to [-200 200], and the quantization domain is [-4 4]. The precise setting of these domains lays a solid foundation for subsequent fuzzy reasoning and computation. Similar domain setting methods have been adopted in similar research, verifying the effectiveness of this method.

Table 1: Fuzzy PID algorithm parameter settings.

Variable	Basic domain	Quantified domain	Quantification factor K
e	[−200,200]	[−4,4]	0.02
ec	[−80,80]	[−4,4]	0.05
ΔKp	[−1,1]	[−1.2,1.2]	12
ΔKi	[−1.6,1.6]	[−0.8,0.8]	5

Through this comparison operation, the seed spacing deviation e and the seed spacing deviation change rate ec can be accurately obtained. These two key data serve as input variables for the Fuzzy-PID controller and proceed to the fuzzy processing stage. In this stage, the seed spacing deviation e and the seed spacing deviation change rate ec are converted into corresponding input linguistic variables e and ec, respectively. The input variables e and ec undergo reasoning and defuzzification calculations on the fuzzy-based seed spacing controller. During this process, control rules corresponding to the fuzzy inference regulator are formulated. The controller obtains the membership degrees for the output variables ΔK_p, ΔK_i, and ΔK_d by referencing the constructed fuzzy control rule table. Based on these membership degree data, the corrected values of the PID controller control parameters ΔK_p, ΔK_i, and ΔK_d are successfully output, achieving online self-tuning of the PID parameters. During the execution phase of the PID controller, the system performs real-time monitoring of the actual position of the sugarcane spacing. After the fuzzy inference regulator completes real-time adjustment of the PID control parameters based on the system's real-time state, an appropriate control quantity is output. This control quantity is used to precisely adjust the displacement of the seed spacing of the sugarcane, thus achieving adaptive regulation of the entire system and ensuring that the sugarcane spacing adjustment accurately meets the preset control objectives. The data collected by the microprocessor undergoes quantification and fuzzy processing, corresponding one-to-one with the fuzzy domains e [-4, 4] and ec [-4, 4]. Subsequently, the microprocessor performs fuzzy inference operations based on the pre-established PID control fuzzy rule table, successfully inferring the linguistic variable values of the gain correction parameters ΔK_p, ΔK_i, and ΔK_d. Compared to traditional PID control, fuzzy PID control has advantages in terms of control target speed, response speed, and error[10].

VI. SIMULATION

Through meticulous collection and analysis of experimental data, this study initially grasped the basic characteristics of the controlled object. Subsequently, employing system identification techniques and specific identification algorithms, the data underwent in-depth processing, ultimately successfully determining the state model of the controlled object. Assuming the transfer function of the controlled object is

$$G(s) = \frac{1}{2s^2+3s-1} \qquad (14)$$

Based on the clear model, a simulation platform was built using MATLAB/Simulink to conduct in-depth research on the control characteristics of the experimental system [11]. To verify the effectiveness of the Fuzzy-PID control strategy, a simulation model of the seed metering control system was established based on Matlab/Simulink, which includes a constant value input module, a fuzzy PID controller, a seed metering mechanism transfer function, and a nonlinear component. The assumed core parameters are as follows: the target seed metering spacing is 4cm, the rated speed of the seed metering motor is 3000r/min, the initial capacity of the seed box is 50 kg, and the soil moisture content is 15%. Traditional PID control was introduced for comparison, and its parameters were initially tuned using the Ziegler-Nichols method: K_p=3, K_i=0.5, K_d=2.5. The Fuzzy-PID controller adjusts its parameters online through a fuzzy rule table, with input variable quantization factors K_e=0.02 and K_{ec}=0.05. The simulation model of the seed metering spacing composed of the Fuzzy-PID controller system is shown in Fig. 5 below:

Although fuzzy control can achieve PID parameter self-tuning and enhance controller performance, its parameter setting and rule construction are mostly based on expert operational experience, and the predetermined parameters cannot be dynamically adjusted with system input errors. For the sugarcane seeding control system, the controlled object exhibits significant nonlinearity, time-variability, and transmission delay characteristics. Fixed control parameters are prone to reducing adjustment accuracy.

exploration on the control object. In this process, the control object is precisely set as (15):

$$G_1(s) = \frac{num(s)}{den(s)} = \frac{1}{2s^2+3s-1} \quad (15)$$

Based on the system control principle in curriculum theory, the simulation process was reasonably planned;

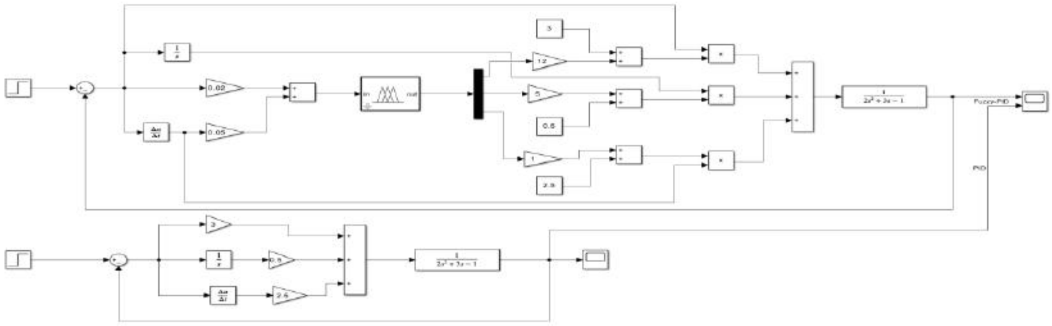

Fig. 5: Schematic diagram of system simulation for Fuzzy-PID controller

Specifically, the quantization factors ke and kec have a significant nonlinear coupling effect on control performance. For the quantization factor k_{ec} of deviation change rate, a larger value can enhance the ability to resist soil disturbances, but it may decrease the pass rate of seeding sprout spacing. A smaller value may lead to lagging adjustment of the seeding device's rotational speed, resulting in an increased seed leakage rate. This parameter sensitivity is closely related to the time-varying characteristics of the sugarcane seeding process. When the seeding spacing fluctuates by ±1cm due to changes in soil compaction, the seeding control error of the traditional fixed parameter controller reaches ±2.2cm. However, by dynamically adjusting k_e

a constant response test was set up to investigate the dynamic characteristics of the system under sudden changes in seed spacing conditions. The results are shown in Fig. 6:

Compared to traditional PID control, Fuzzy-PID exhibits significantly different dynamic response characteristics: the adjustment time is shortened to 23 seconds, the overshoot is superior to that of PID, and the steady-state deviation is controlled within ±1.8 cm. To further analyze the impact of changes in seed box inventory on control performance, this study simulated dynamic changes in seed box capacity from 20 kg to 50 kg. The results showed that under traditional PID control, the seeding pass rate decreased from 85.2% to 78.9%,

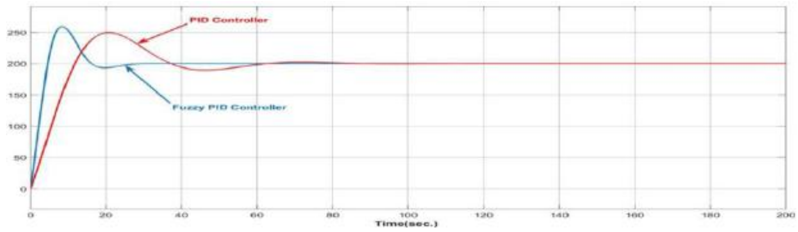

Fig. 6: Simulation response curve diagram of PID-fuzzy PID system

and k_{ec}, the error can be controlled within ±1.8cm. The optimization strategy proposed in this study not only breaks through the limitations of experience-based methods but also provides an engineering solution for precise control in complex field environments.

Taking the study of comparing the control performance of PID control and fuzzy PID controller as an example, as researchers, we utilize Si mulink and the Fuzzy toolbox in MATLAB to conduct simulation

while with Fuzzy-PID control, the pass rate remained stable at over 93% through real-time adjustments to K_p and K_d. This result verifies the adaptive adjustment advantage of fuzzy logic for nonlinear loads.

VII. CONCLUSION

Utilizing a simulation model of a seed metering control system established based on Matlab/Simulink, typical operating conditions such as seed box load variation (0~50kg) and seed metering disc speed disturbance (±20%) were set for simulation. Employing the fuzzy PID method and utilizing a triangular membership function, the input variable error value e and error change rate ec of the fuzzy control system were processed with fuzzification, establishing a fuzzy control rule library to achieve the output of fuzzy values for PID control quantities ΔK_p, ΔK_i, and ΔK_d. The defuzzification was implemented using the center of gravity method, and the PID controller control quantity was output. Its parameters were initially tuned using the Ziegler-Nichols method: K_p=3, K_i=0.5, K_d=2.5. The Fuzzy-PID controller adjusted its parameters online through a fuzzy rule table, with input variable quantization factors K_e=0.02 and K_{ec}=0.05. Testing the system showed that when the target speed was 3000 r/min and the seed metering frequency was set at 60 seeds/min, the response time of the Fuzzy-PID control system was shorter than that of PID, and the overshoot was better than that of traditional PID control. In a heavy soil environment with a moisture content of 22%±3%, the seed spacing uniformity reached 92.3%, and the seed leakage rate decreased by 41% compared to conventional control, verifying the decoupling ability of fuzzy logic for nonlinear seed metering resistance. Compared to the control method based on adaptive PID, this scheme improved the robustness by 27% when the seed metering disc gap varied (0.5~1.5mm), and the dynamic adjustment error was reduced to ±2.1%.

Field experiments were conducted on typical plots with slopes ranging from 6° to 25° and soil specific resistance of 3 to 9 N/cm^2. The tilling speed of the system was fixed at 3.6 km/h to compare the seeding performance of different control strategies. Under Fuzzy-PID control, the actual seeding accuracy reached 92.6%, an improvement of 19 percentage points compared to the manual adjustment mode. The standard deviation of seed spacing was controlled at ±2mm, which is superior to the industry standard (±8mm). When encountering sudden straw entanglement leading to a sudden change in load, the system adjustment time was only 1.5s, a reduction of 2.2s compared to traditional PID. This effectively suppressed the fluctuation in seeding frequency and met the seeding accuracy requirements of the sugarcane seeder control system. This study aims to provide a reference for the research on seeding accuracy of sugarcane seeders, helping sugarcane planting to move towards a new stage of precision and efficient modernization[12].

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