DESIGN AND EXPERIMENTAL STUDY OF PEANUT PLANTER WITH HIGH-SPEED OPERATION AND CONTROLLABLE SOWING DEPTH

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高速作业种肥播深可控的花生播种机的设计与试验研究

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ABSTRACT

Aiming at the traditional peanut planter seed and fertilizer sowing depth inconsistency caused by seed burning and injury, fertilizer waste and low seed emergence rate, the design of a peanut planter with high-speed operation and controllable seed and fertilizer sowing depth was performed. The laser sensor is added to detect the height of the ridge and the furrow opener position feedback, and the speed sensor detects the operating speed of the peanut planter. The mechanical analysis of the four-link rod clarifies the control principle, improves the PID algorithm of the integral term, designs the control strategy based on the operating speed of the planter, controls the electro-hydraulic system, and realizes the sowing and fertilizing depth adjustment of the furrow opener. Through the design of three-factor three-level orthogonal simulation test, it is concluded that the vehicle speed and height deviation value are significant factors affecting the sowing and application depth, and under the verification of the field test, it is obtained that when the sowing depth is 50 mm under the speed of 3 km/h, the dynamic sowing depth qualification rate is 96.26%, and the maximum coefficient of variation of the sowing depth is 2.58%, which improves the effect of the existing control of the sowing depth of the peanut by 6.05%, and reduces the variation of the sowing depth by 2.85%. The research has demonstrated superior performance compared to traditional mechanical adjustment in regulating the planting depth of peanuts, thereby achieving the intended design objective.

摘要

针对传统花生播种机种肥的播施深度不一致造成烧种伤种、肥力浪费以及种子出苗率低的问题，设计一款具备高速作业种肥一致可控的花生播种机。增添激光传感器对垄面高度检测以及开沟器位置反馈、速度传感器检测花生播种机的作业速度。对四连杆进行力学分析明确控制原理，改进积分项的 PID 算法，设计基于播种机作业速度的控制策略，控制电液系统，实现开沟器的播施深度调节。通过设计三因素三水平正交仿真试验，得出车速和高度偏差值是对播施深度影响的显著因素，在田间试验验证下，得到在 3km/h 的速度下播深为 50mm 时，动态播深合格率为 96.26%，最大播深变异系数为 2.58%，比现有的花生播种深度控制效果提升 6.05%，播深变异降低 2.85%。在调节花生播深方面，与传统的机械调节相比，该方法有更优越的性能，实现了预期的设计目标。

INTRODUCTION

Peanut is one of the top ten oilseed crops in China, and it is of great significance to improve peanut production in China *(Zhang et al., 2005)*. The depth of peanut seed fertilizer application will affect the seedling emergence and growth condition, the depth of fertilizer application is too deep and far away from the peanut seeds, resulting in less nutrient absorption by peanuts, which not only wastes the fertilizer, but also affects the seedling growth of peanuts, thus affecting the yield of peanuts; the depth of fertilizer application is too shallow, and is closer to the peanut seeds, which results in seed burning and seed injury, and also affects the yield of peanuts. Similarly for peanut seeds from the ridge surface, too deep or too shallow will also affect the seedling emergence rate, so the development of more precise sowing machinery is the key to improve the yield *(Wan et al., 2020; Wu et al., 2015).*

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At present, there are many types of peanut seeding machines developed both domestically and abroad, and their functions are different, but they all have a commonality in terms of the problem, i.e., there is a low pass rate of peanut seed and fertilizer sowing depth *(Wang et al., 2021; Lü et al., 2012; Lü et al., 2015).* Therefore, in order to enhance the precision of peanut sowing depth, scholars at home and abroad have conducted research in the field of sowing depth control. Sowing depth adjustment is mainly divided into two ways, one is active imitation adjustment, the other is passive imitation adjustment, most of the seeder companies in the market use mechanical passive imitation such as depth limiting wheels, which is a little bit insufficient in terms of the precision of the sowing depth compared to the active imitation *(Yang et al., 2016).* In the late 20th century, foreign agricultural machinery enterprises have begun to conduct research in the field of deep control, and carry out active copying of agricultural machinery with the help of electronic equipment and intelligence. For example, MOLATUDI in the United States and other research in the field of corn sowing depth, to explore the seedling emergence rate and seedling growth *(Molatudi R.L, et al., 2009; Mock J.J., et al., 1977)*. The German company Amazone has carried out research in the field of furrowing depth, where the control of sowing depth is achieved by using an ultrasonic sensor as a detection device and a hydraulic system as a control device *(Zhao et al., 1989)*. At the same time, in 2015, foreign researchers also carried out in-depth research on the field of sowing depth, such as that of furrowing depth based on the ISO communication protocol using angle sensors and ultrasonic range sensors, controlling the hydraulic system pressure to achieve the adjustment of sowing depth *(Pasi S. et al., 2015)*.

In 2012, Kiani S designed a non-contact control device in the field of furrow depth, which used ultrasonic sensors to measure the distance between the soil surface and the furrow, and adjusted the sowing depth by adjusting the hydraulic system. *(Kiani S. et al., 2012)*. With the intelligent development of agricultural machinery, domestic researchers have strengthened the research on active mimicry in the field of sowing depth. In 2009, Li achieved the adjustment of sowing depth in the field of furrowing depth by developing an automatic control system and a furrowing depth adjustment device *(Li et al., 2009; Li et al., 2010)*. In 2012, Hu Jun designed a ground profiling sensing device in the field of furrowing depth to control the furrow opener to achieve the adjustment of furrowing depth *(Hu et al., 2012)*.

In 2016, Li Yuhuan designed a device to adjust the sowing depth using a PLC-controlled electric actuator *(Li et al., 2016).* In 2020, Bai Huijuan designed a sowing device, which realizes the adjustment of sowing depth through control of pressure parameters by PLC *(Bai et al., 2020)*. In 2022, Liu designed an adaptive profiling cutter in the field of cutter height control, which uses profiling ground wheels and inclination sensors, and through a fuzzy Proportional-Integral-Derivative (PID) control system, it accomplished a rapid and accurate positioning in the height of the cutter *(Liu et al., 2022)*. In 2022, Ding explored the relationship between monomers and soil mechanics in the field of rice and wheat sowing depth, designed sowing monomers and developed an intelligent soil mechanics on-line testing system to complete the adjustment of rice and wheat sowing depth *(Ding et al., 2022).* In 2023, in the field of wheat sowing depth control, Xue designed a sowing depth control device for suppressor roller position by using a rope displacement sensor and a biaxial inclination sensor, and proposed a fuzzy PID control method based on sowing depth feedback to complete the adjustment of sowing depth *(Xue et al., 2023)*. Although currently there is quite a lot of research in the field of sowing depth control, the application of sowing depth control technology in peanut is still less, and the actual farmland surface morphology is complex and irregular, while peanut is not the same as other crops.

In view of this, the paper researches the seed and fertilizer sowing depth and sowing depth of peanut under high-speed operation, and designs a peanut sowing machine with the ability to control the sowing depth of peanut and the seed and fertilizer consistency, to provide a new type of idea for the in-depth research on the sowing depth control technology of peanut.

MATERIALS AND METHODS

Structural design of a peanut planter with controllable seed and fertilizer sowing depth for high-speed operation

The structure of a peanut planter with high-speed operation and controllable seed and fertilizer sowing depth is shown in Figure 1. It mainly consists of a fertilizer application device, a seed discharge device, a collection and control device, etc.; where in the fertilizer application device includes a fertilizer box and a fertilizer opener; the seed discharge device includes a seed box and a disc opener, and the collection and control device includes a laser sensor, a speed sensor, a hydraulic system, a parallel four-link rod, a control box, and a ground wheel.

Structural design of a peanut planter with controllable seed and fertilizer sowing depth for high-speed operation

Peanut planter collection control device in the collection unit includes laser sensors, speed sensors, used for peanut ridge height and planter operating speed for real-time collection; data collection success through the transmission and processing module will be sent to the central processing unit PLC data, PLC data computing control hydraulic system adjusts the parallel four linkage to achieve the disc opener and fertilizer opener position adjustment. The laser sensor on the connecting rod of the disc opener collects and feeds back the data of the height to the ground to the central processing unit Programmable Logic Controller (PLC), and completes the feedback to the opener. The PLC will record real-time data and display it on the terminal display. The working principle of the high-speed operation of seed and fertilizer sowing depth control is shown in Figure 2.

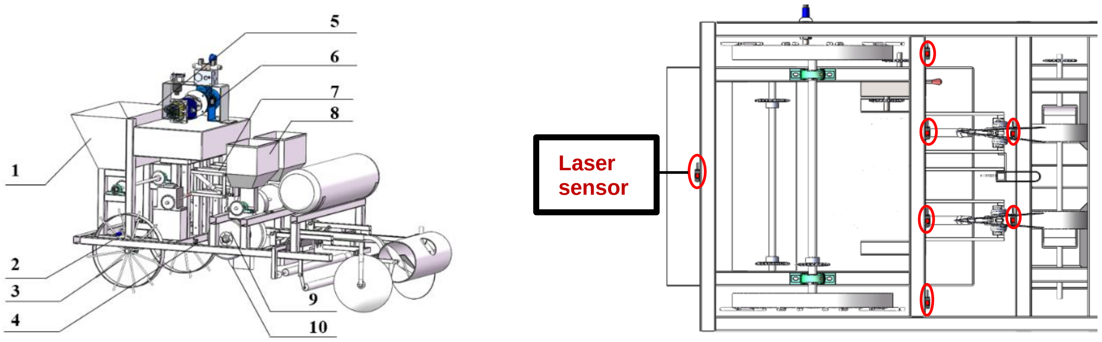


Fig. 1 - Structural design of a peanut planter with controllable seed and fertilizer sowing depth for high-speed operation

1. Fertilizer box; 2. Speed sensor; 3. Ground wheel; 4. Laser sensor; 5. Control box; 6. Hydraulic system; 7. Parallel four-link; 8. Seed box; 9. Disc opener; 10. Fertilizer opener

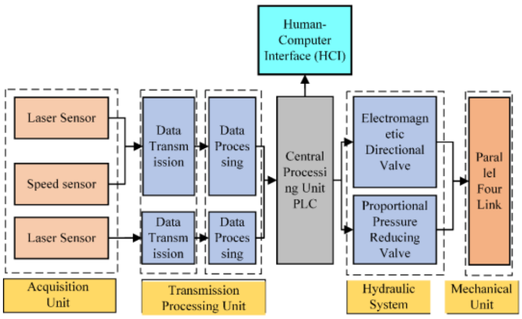


Fig. 2 - Working principle diagram of controllable seed and fertilizer sowing depth for high-speed operation

Theoretical calculation of the operating principle

- Theoretical Calculation of Ranging Principle

This study adopts the direct measurement method of multi-laser sensors to measure the attitude offset of the planter using laser sensors *1, 2, 3*. Each of the three laser sensors transmits the measured distances to the PLC. If the three distances are equal, the planter is not tilted. If the three distances are not equal, it is necessary to calculate the differences between the data measured by laser sensors 4 and 5 from and the data measured by laser sensors 6 and 7. The result will be used next time.
Laser sensor ranging principle is shown in Figure 3.

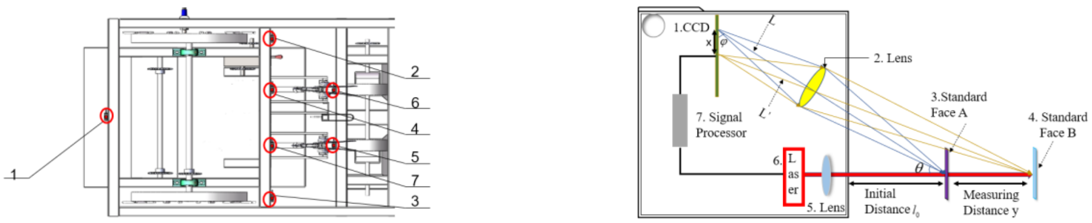


Fig. 3 - Ranging principle diagram of laser triangular reflective displacement sensor

Assuming that the distance moved by the image point on the Charge-Coupled Device (CCD) is x and the distance moved by the surface of the object to be measured is y, Equation (1) is obtained from the similarity triangle:

$$\frac{L'}{x} = \frac{L + y\cos\theta}{y\sin\theta} \tag{1}$$

Equation (1) is collapsed to obtain equation (2):

$$y = \frac{xL}{L'\sin\theta - x\cos\theta} \tag{2}$$

where:

L is the distance from the intersection point of the optical axis of the laser beam to the front principal surface of the receiving lens, (mm);

L' is the distance from the rear principal surface of the receiving lens to the center point of the imaging surface, (mm);

θ is the angle between the optical axis of the laser beam and the optical axis of the receiving lens, (°).

- Control principle calculation

The hydraulic cylinder is mounted on the parallel four-link, when the hydraulic system receives the control command from the central processing unit PLC will complete the expansion and contraction according to the command that is, the parallel four-link will appear in the position of the following Fig. 4, the state I and the state Ⅱ corresponds to the limit state of the upper and lower four-link.

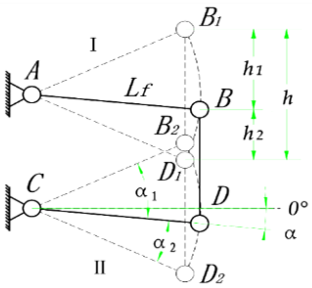


Fig. 4 - Schematic diagram of parallel four-link up and down control volume

Points A and C of the four-link mechanism are fixed with the crossbeam, and points B and D are hinged with the furrow opener connecting rods. AB and CD connecting rods are the upper and lower rods of the profiling mechanism respectively. The BD rod floats up and down along the ground undulation to complete the control when working, and the formula for its control volume is:

$$h = L_f(\sin(\alpha + \alpha_1) + \sin(\alpha_2 - \alpha)) \tag{3}$$

$$h = h_1 + h_2 \tag{4}$$

where:

h is the total control amount, (mm);

h_1 - the upper control amount, (mm);

h_2 - the lower control amount, (mm);

L_f - the length of the connecting rod of the four-bar mechanism, (mm);

α_1 - the upper control angle, (°);

α_2 - the lower control angle, (°);

α - the traction angle, (°).

From equation (3) and equation (4), it can be seen that when the upper and lower control amounts of the four-link are the same, the longer the length of the linkage, the smaller the range of variation of the imitation angle. The change of traction angle depends on the direction of the tractor traction planter frame; in order to ensure that the sowing operation process of the furrow opener works stably, the value of the traction angle should be as small as possible. According to the requirements of peanut agronomic planting, the total control is 50 mm in general.

Selection of detection devices in the seeding depth control system of a peanut planter running at high speeds

The contact detection method has a certain hysteresis and is not applicable to the high-speed working conditions of this study. Therefore, the non-contact method is selected for this study. The BL-400NZ laser sensor selected for this study meets the requirements in terms of sensitivity, accuracy and resolution. The maximum distance of this sensor is 250 mm and the specific parameters are shown in Table 1.

Table 1

Main technical parameters of laser sensors

Technical specifications	Parameters	Technical specifications	Parameters
Model	BL-400NZ	Voltage	24 V
Measuring range	200-600 mm	Signal Output	digital quantity
Accuracy	0.8 mm	Serial Port Type	RS485
Switching frequency	160 hz	Operating Temperature	-20-40℃
Response time	6.25 ms	Protection Class	IP67

The LJA30M-40N1 inductive proximity switch operates at 24 volts and is a reliable sensor with a fast frequency response and adjustable detection distance. It is mounted close to the ground wheel and is used to detect the number of times the axle of the ground wheel passes during operation. Based on the number of contacts in a specified time, the forward speed of the peanut planter can be obtained by calculation. Its specific working parameters are shown in Table 2.

Table 2

Main technical parameters of laser sensors

Technical specifications	Parameters	Technical specifications	Parameters
Model	LJA30M-40N1	Detection distance	0-40 mm adjustable
Working Voltage	DC6~36V	Object detection	Metal
Output form	PNP normally open	Sensing method	Inductive
Output current	300mA	Response time	1 ms

High-speed operation seed fertilizer sowing depth controllable peanut planter software design

This study uses Portal v16 software to compile the control program. After the sowing depth control system is activated, it is necessary to input the set parameters in the terminal display. The PLC saves the set parameters and receives the data transmitted by the sensors in real time. At the same time, the PLC calculates according to the compiled algorithm and outputs PWM signals to the hydraulic system, realizing the adjustment of the sowing depth of peanuts. Laser sensors 6 and 7 transmit the detected data from the fertilizer opener and disc furrow to the PLC in real time, forming a closed-loop control system. The control program flow chart is shown in Figure 5.

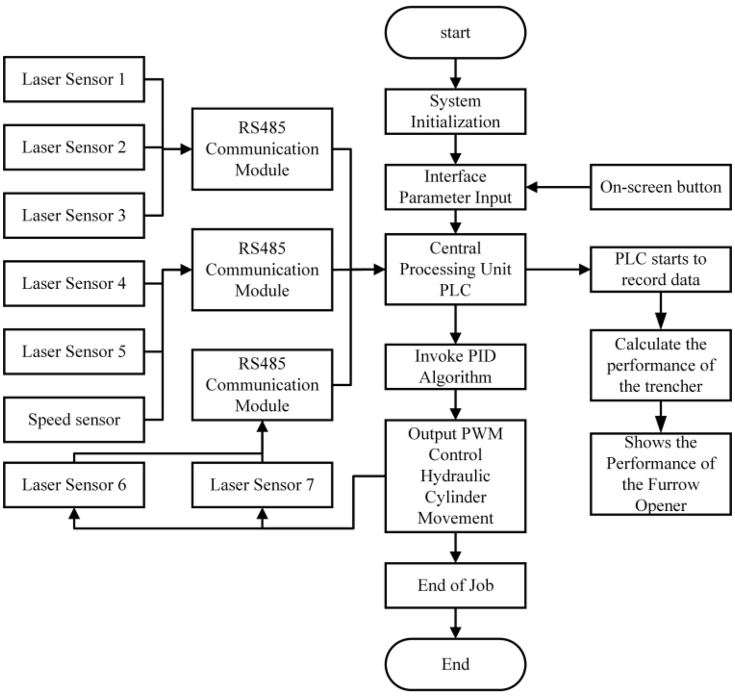


Fig. 5 - High-speed operation seed fertilizer sowing depth controllable peanut planter control program flow chart

Control strategy of peanut planter with controllable seed and fertilizer sowing depth for high-speed operation

- Improved PID control algorithm

For the current most commonly used automatic control feedback technology using PID algorithm to reduce the uncertainty of the system, the control law is shown in equation (5), because the data collected is discrete. Therefore, the PID algorithm is designed discretely in this study and the sampling time is set.

$$e(t) = K_P\left(e(t) + \frac{1}{T_I}\int e(t)dt + T_D\frac{de(t)}{dt}\right) + M \tag{5}$$

From Eq. (5), can be obtained the discretization Eq. (6) and Eq. (7):

$$u(n) = k_p\left\{e(n) + \frac{T}{T_I}\sum_{j=0}^{n} e(j) + \frac{T_D}{T}[e(n) - e(n-1)]\right\} \tag{6}$$

$$u(n) = k_p e(t) + k_i\sum_{j=0}^{n} e(j)T + k_d\frac{[e(n)-e(n-1)]}{T} \tag{7}$$

where: $k_i=k_p/T_I$, $k_d=k_p{*}T_D$; T is the sampling period;

n is the number of samples, $n=1, 2......$, $e(n-1)$ and $e(n)$ are at $(n-1)$ and n times.

When the seeding depth is adjusted, the control system is required to adjust the PWM signal. In this process, the PID algorithm will have the phenomenon of error accumulation, leading to the oversaturation of the integral. To avoid the above situation, the idea of this study is to weaken the influence of the integral term when the system difference is too large; when the difference of the system is small, the integral term should be strengthened, and the cumulative speed of the integral term should be adjusted, so as to synchronize with the difference of the change. Therefore, a coefficient $\int(e(n))$ is added, which is a function of $e(n)$. When the absolute value of $e(n)$ increases, its integral decreases; when the absolute value of $e(n)$ decreases, its integral increases. The expression formula is shown in (8):

$$u_i(n) = n_I\left\{\sum_{i=0}^{n-1} e(i) + \int(e(n))e(n)\right\}T \tag{8}$$

The functional relationship between $\int(e(n))$ and $|e(n)|$ is equation (9):

$$\int(e(n)) = \begin{cases} 1, (|e(n)| \le B) \\ \frac{A-|e(n)|+B}{A}, (B < |e(n)| \le A+B) \\ 0, (|e(n)| > A+B) \end{cases} \tag{9}$$

So that $\int(e(n))$ function value change interval is [0,1], when $|e(n)|$ is greater than the set $A+B$, its function value is 0; when $|e(n)|$ is less than or equal to B, its function value is 1; if it is in the middle of the two, its function value will be accumulated. Therefore, the formula of the letter PID algorithm with improved integral term is:

$$u(n) = k_p e(n) + k_I\left\{\sum_{i=0}^{n-1} e(i) + \int(e(n))e(n)\right\}T + k_D[e(n) - e(n-1)] \tag{10}$$

In figure 6, the unit step response between the improved PID and the traditional PID can be seen. When the deviation between the target value and the actual value is the largest, the integral coefficient of the improved PID is 0, and the integral coefficient changes with $e(n)$, while the integral coefficient of the traditional PID does not change.

- Based on speed detection

In the operation of peanut planter, in order to improve the operation efficiency and improve the operation speed on the basis of ensuring the qualified rate of sowing depth, different sowing speed has different requirements for the response time of this study. Therefore, in order to improve the driving speed in different operations, the high, medium and low speed regions are divided, and different proportion, integral and differential parameters are set for each region. The PID algorithm flow chart of the control strategy based on speed detection is shown in Figure 7.

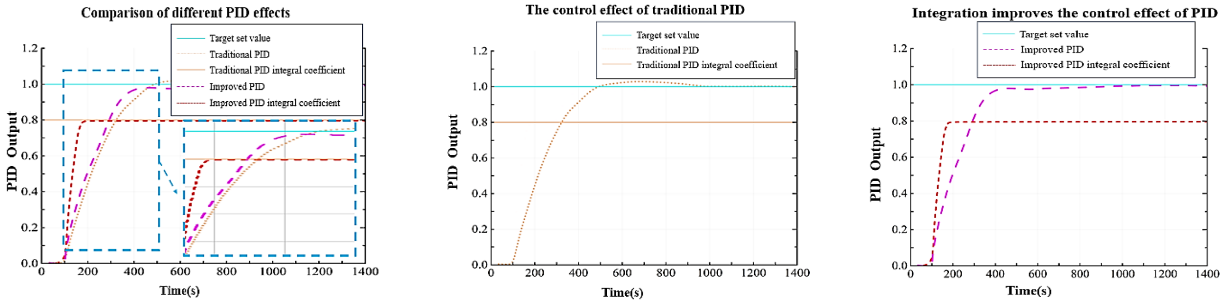


Fig. 6 - Comparison of integral improved PID and traditional PID

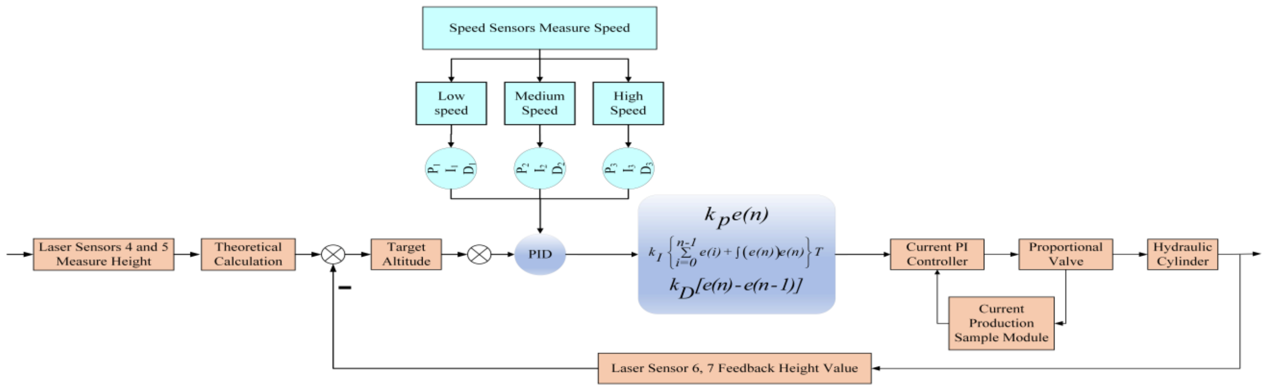


Fig. 7 - Flow chart of control strategy PID algorithm based on speed detection

Orthogonal test of qualified rate of sowing depth

In order to verify that the sowing depth effect of peanut planter is affected by factors such as vehicle speed and height deviation value (height deviation value between the two points in front of the ridge is referred to as height deviation value), the influencing factors of sowing depth effect driven by hydraulic cylinder are further explored, and a three-factor and three-level simulation test is carried out. Taking the sowing depth of peanut seeder as the research object, ignoring the influence of external working conditions, the speed, height deviation value and sowing depth were selected as the test factors, and the qualified rate of sowing depth was taken as the test index, which were expressed by A, B and C respectively. The planter can achieve a working speed of 3 to 7 km/h and a sowing depth of 40 to 60 millimeters. Orthogonal test was used to study the influence of factors on the qualified rate of sowing depth. The factors and level design are shown in Table 3.

Table 3

Sowing depth qualification rate test factor level coding table

Coding	Factor		
	A: Speed v / km·h^{-1}	B: Height deviation h/mm	C: Sowing depth setting h/mm
-1	3.0	0	40
0	5.0	25	50
1	7.0	50	60

In the EDEM simulation test, the response surface model of the qualified rate of sowing depth was constructed with three factors as independent variables and the qualified rate of sowing depth as the evaluation index. The test results are shown in table 4.

Table 4

Sowing depth qualification rate test program and results

Test number	Experimental factors			Response value
	A: Speed km·h^{-1}	B: Height deviation h/mm	C: Sowing depth setting h/mm	P: Qualified rate of sowing depth %
1	3	50	50	93.35
2	3	25	40	95.45
3	3	0	50	98
4	3	25	60	94.06
5	5	25	50	88.25
6	5	50	60	87.95
7	5	25	50	88.3
8	5	0	60	91.35
9	5	50	40	88.2
10	5	25	50	90
11	5	25	50	88.65
12	5	25	50	88.75

Test number	Experimental factors			Response value
	A: Speed $km \cdot h^{-1}$	B: Height deviation h/mm	C: Sowing depth setting h/mm	P: Qualified rate of sowing depth %
13	5	0	40	92.45
14	7	25	40	86.8
15	7	0	50	87.15
16	7	25	60	86.55
17	7	50	50	85.92

Table 5

Analysis of variance of sowing depth qualification rate model

Source	Sum of squares	Degrees of freedom	Mean square	F-value	P-value
Model	189.86	9	21.10	49.54	< 0.0001**
A	148.26	1	148.26	348.16	< 0.0001**
B	22.88	1	22.88	53.73	0.0002**
C	1.12	1	1.12	2.62	0.1493
AB	2.92	1	2.92	6.87	0.0344
AC	0.3249	1	0.3249	0.7630	0.4114
BC	0.1806	1	0.1806	0.4242	0.5357
A^2	9.74	1	9.74	22.88	0.0020**
B^2	2.65	1	2.65	6.23	0.0412
C^2	0.6864	1	0.6864	1.61	0.2448
Residual	2.98	7	0.4258		
Loss of fit Term	0.9639	3	0.3213	0.6372	0.6295
Pure error	2.02	4	0.5043		
Total error	192.84	16			

*Note:**denotes the difference is very significant (P ≤ 0.01).*

The data in the table were fitted by quadratic multiple regression, and the results of variance analysis on the qualified rate of sowing depth were obtained by Design-Expert software, as shown in Table 5.

According to the data samples of the table, the quadratic polynomial regression model of the qualified rate of sowing depth is obtained, that is:

$$P = 88.79 - 4.31A - 1.69B - 0.374C + 0.855AB + 0.285AB + 0.213BC + 1.52A^2 + 0.794B^2 + 0.404C^2 \quad (11)$$

where:

P is the qualified rate of sowing depth;

A is the speed;

B is the height deviation value;

C is the sowing depth.

According to the variance analysis results of the regression model, the P value of the regression model is less than 0.01, indicating that the regression model is extremely significant. The P value of the model's mismatch term is 0.6295, indicating that the regression model has a high degree of fitting. Through the P value of vehicle speed, height deviation value and sowing depth, it can be judged that the influence of three test factors on the qualified rate of sowing depth from large to small is vehicle speed, height deviation value and sowing depth. The adjusted coefficient of determination of the regression model is 0.9647, indicating that the model can explain 96.47 % of the corresponding changes, and only 3.53 % of the data cannot be explained by the model. The determination coefficient of the model is $R^2 = 0.9845$, close to 1, and the coefficient of variation and precision are 0.9037 and 23.9612, respectively, indicating that the test data and the net rate fitting regression model have high reliability.

The response surface method was used to study the influencing factors of the qualified rate of sowing depth. As shown in Fig. 8, the Model Graphs module in Design Expert 13 was used to obtain the corresponding surface of each test factor on the qualified rate of sowing depth.

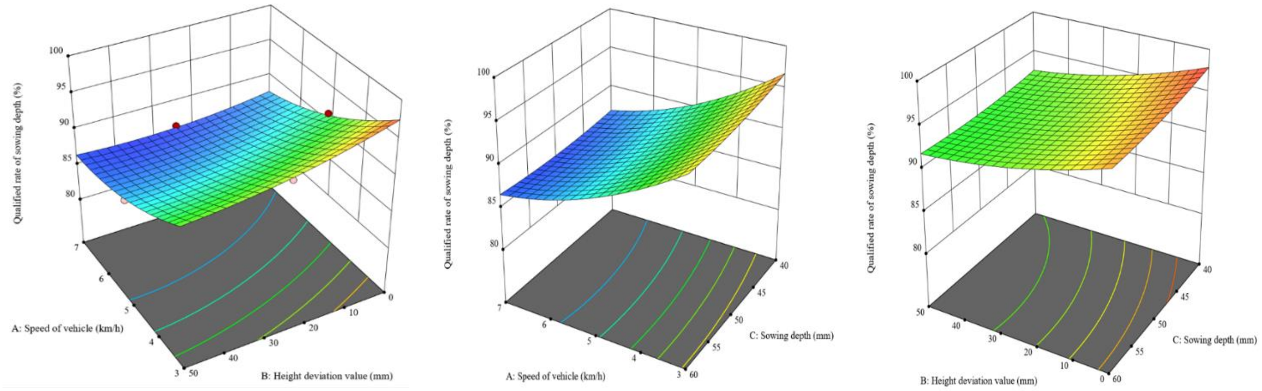


Fig. 8 - The corresponding surface of each test factor on the qualified rate of sowing depth

It can be seen that the qualified rate of sowing depth decreases with the increase of vehicle speed and decreases with the increase of height difference, while the qualified rate of sowing depth is not significantly affected by the setting of sowing depth.

Field experiment

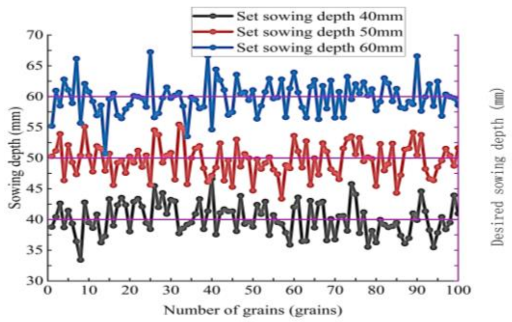
In order to verify the rationality of peanut seeder and control strategy with seed and fertilizer sowing depth control and sowing control, a comparative test was carried out in a real and complex field environment. On October 15, 2023, it was carried out in the test base of Xizhujia Village, Yishui County, Linyi City, Shandong Province. The test machine was a 2MB-1 / 2 peanut planter manufactured by Shandong Yuanyuan Machinery Co., Ltd., and the peanut seed model was Luhua peanut.

- <u>Test method</u>

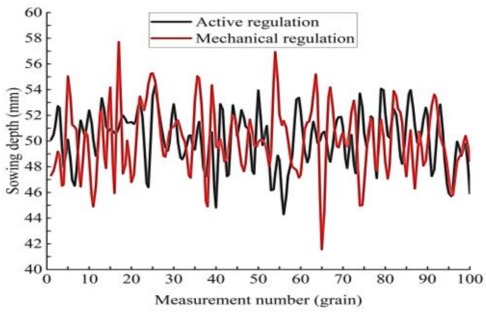
The traditional 2MB-1/2 peanut planter with one ridge and two rows produced by Shandong Yuanyuan Machinery Co. Ltd. was used for comparative test. The test personnel were the employees of the company, and the depth of seed and fertilizer application was positioned at different operating speeds. The test parameters refer to the agronomic standards of peanuts in Shandong Province formulated by Shandong Agricultural and Rural Bureau. The sowing depth of peanuts was set to 40 mm, 50 mm and 60 mm. The fertilization depth was 70 mm below the peanut seeds. The operating speed was set to 3 km/h, 5 km/h and 7 km/h, and the seed spacing of peanuts is set to 25 cm. In order to eliminate the instability of the operation speed of the peanut planter when it started or stopped, a plot with a length of 100 meters and a width of 40 meters was selected, and the middle area of 15 meters from both ends of the ground was selected for random measurement. The field experiment is shown in Fig. 9.

Fig. 9 - Field experiment diagram

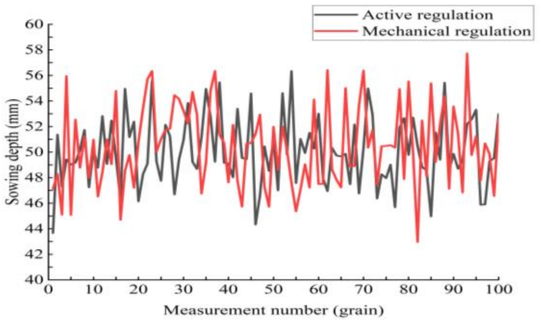
During the measurement, the ridge surface height was first flatly marked, and then the soil above the fertilizer and seed was scraped clean. The height between the leaked fertilizer and seed, the seed and the ridge surface soil layer were measured, and 10 sets of measurements were performed. Each group selected 50 seeds, and some of the data are shown in Figure 10.



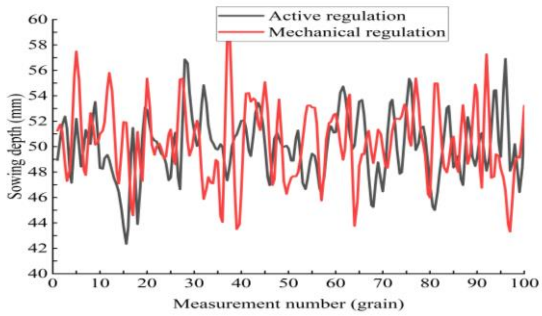
a) When the speed is 3 km/h, the field data of active adjustment methods with different sowing depths are set



b) The field data of two adjustment methods when the sowing depth is set to 50 mm at the speed of 3 km/h



c) The field data of two adjustment methods when the sowing depth is set to 50 mm at the speed of 5 km/h



d) The field data of two adjustment methods when the sowing depth is set to 50 mm at the speed of 7 km/h

Fig. 10 - Part of the field test data

- Test result analysis

According to the calculation formula of each calculation parameter, the experimental data of two different methods are analyzed. The results are shown in Table 6.

$$\bar{h} = \frac{\sum h_i}{N} \tag{12}$$

$$\eta = \frac{n}{N} \times 100\% \tag{13}$$

$$s_h = \sqrt{\frac{\sum (h_i - h)^2}{N}} \tag{14}$$

$$V_h = \frac{S_h}{\bar{h}} \times 100\% \tag{15}$$

where:

H is the qualified rate of sowing depth, %;
n - the qualified number of sowing depth, grain;
n - the total number of measuring points of sowing depth, grain;
h_i - the measured value of sowing depth, mm;
S_h - the standard deviation of sowing depth, mm;
V_h - the coefficient of variation of sowing depth, %.
$\bar{h}$ - the average sowing depth, mm.

Table 6

Comparison of results of each test data

Measuring parameters							**Adjustment mode**
Peanut planter operating speed / km/h	3	5	7	3	3	3	
Peanut seed depth after sowing / mm	50	50	50	40	50	60	
Mean value of peanut seed depth after sowing / mm	50.8	47.54	45.04	41.2	48.68	44.36	Dynamic
	46.12	53.83	40.56	45.62	53.26	44.27	Mechanical

Measuring parameters							Adjustment mode
Pass rate of peanut seed depth after sowing / %	94.26	90.57	85.69	94.03	94.26	92.68	Dynamic
	90.21	83.46	75.25	90.67	90.21	88.52	Mechanical
Standard deviation of peanut seed depth after sowing / mm	2.58	3.34	5.19	2.32	2.02	4.89	Dynamic
	4.03	5.17	6.95	4.95	4.56	5.51	Mechanical
Coefficient of variation of peanut seed depth after sowing / %	4.09	5.26	6.14	5.29	3.95	5.54	Dynamic
	7.24	10.75	13.98	6.96	6.63	12.49	Mechanical

It is known from the test results that the average sowing depth caused by the active adjustment method has little change compared with the traditional mechanical adjustment under different speeds of the seeder, and the maximum error occurs at the speed of 7 km/h, which is 4.96 mm. It is 4.48 mm higher than that of traditional mechanical adjustment. From the qualified rate of sowing depth, it can be seen that the qualified rate is high and the change range is relatively small. The qualified rate of sowing in high-speed operation is not less than 85%, which meets the agronomic requirements of peanut sowing. In terms of the standard deviation of sowing depth and the coefficient of variation of sowing depth, the active adjustment method is also more advantageous than the passive mechanical adjustment. In the low speed 3 km/h operation, the active adjustment method is not much different from the set sowing depth value, and the performance of the sowing depth consistency adjustment is better, and the purpose of the system design is realized.

CONCLUSIONS

(1) A peanut planter is designed, which can control the depth of peanut sowing and keep a constant distance between seed and fertilizer. The laser sensor and speed sensor measuring device were used to detect the working speed of the planter and the position of the fertilizer opener and the disc opener in real time, and the real-time control was completed by the hydraulic system.

(2) According to the actual operation of the peanut planter, the integral coefficient of the traditional PID algorithm is improved and applied to the control strategy of the peanut planter to achieve faster response speed and accuracy.

(3) Under different operating speeds and different sowing depth measurements, the developed peanut planter with controlled peanut sowing depth and with a constant distance kept between seed and fertilizer has more obvious advantages in the average sowing depth, the qualified rate of sowing depth, the standard deviation of sowing depth and the coefficient of variation of sowing depth than the traditional mechanical passive peanut planter in the adjustment of sowing depth consistency.

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