Design and experimental study of the control system for precision seed-metering device

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Abstract: The precision seeding technique has been developed at full speed along with the continuous development of new agricultural technologies, especially those concerning cultivated patterns. The seed-metering device is the key component of a precision seeder. A ground wheel is used to drive the seed-metering device of the conventional direct seeder. However, the wheel bears high resistance and easily slips. Moreover, the adjustment of the precision seeder's seeding rate is more difficult. In order to solve these problems, a control system which could keep the rotational speed of the seed-metering device consistent with the seeder's working speed for the precision seed-metering device was designed. The control system includes a Hall sensor, a single chip microcomputer system, a motor control module, a stepper motor and a display. The control system used a Hall sensor to measure the seeder's working speed and employed a single chip microcomputer system to predict the rotational speed of seed-metering device. It would then determine the relationship between the seeder's working speed and the rotational speed of the seed metering-device according to the seeder's working state, distance between seeds and the requirement of sowing rate. The system could effectively reduce the influence of inhomogeneous sowing caused by the ground wheel's slipping. The system was found to be reliable by the experiment. The seeding control system could also make the speed of the seed-metering device and seeder's uniform, improving the uniformity of the amount of seeding, and achieving the goal of design. This new design provides a platform to solve problems of the seed-metering device and the seeder.

Keywords: agricultural machinery, precision seeder, seed-metering device, sensor, control system, stepper motor

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1 Introduction

In recent years, with the development of precision seeding technique, precision seeding has become the main feature and developing direction of modern seeding technologies[1-3]. Precision seeding can save seeds and effectively control the sowing depth, sowing densities and the sowing distance[4-6]. According to statistics, the output of precision seeding increases by 10%-30% compared with that of the conventional drill[7,8]. But it is difficult to detect the reseeding and the leakage sowing while using precision seeding. There is practical significance to apply microprocessor and monitoring technology in the precision seeding.

The microprocessor technology is used on precision seeding in many aspects. High-speed camera was used by Karayel to observe the trajectory of seeds while throwing seeds. He predicted the seeds spacing from the trajectory by microprocessor technology[9,10]. Kocher used optoelectronics technology to detect the uniformity of row spacing[11]. An automatic monitoring system of direct seeding was designed by Zhang Xiaohui. When technical trouble occurred, the monitoring program written by assemble language could not only give an alarm by voice and light, but also start the small stepper

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motor to drive the reseeding mechanism to continue work until stop to be examined and repaired[12]. A dust-proof annunciator system was developed for no-tillage planter by Feng Quan. The dustproof annunciator system indicates normal sowing, and the background direct current, then amplifies them respectively with different amplification coefficients, finally they are merged into one signal for later analyses[13].

The seed-metering device is the key component of the precision seeder, properties of which directly influence service behavior and sowing quality of the seeder[14]. The conventional seeder uses a ground wheel to drive the seed-metering device. However, the wheel bears high resistance and slips easily, heavily affecting the drilling quantity[15-17]. Therefore, a seeding control system was designed based on single chip microcomputer control to regulate the amount of seeding. This design used the control of single chip microcomputer and sensing detection technology in automatic regulation and control, applying a stepper motor to drive the seeding plate.

2 Materials and methods

2.1 Materials

The control system used a Hall sensor to measure the seeder's working speed. Based on single chip microcomputer, the control system could measure the speed of the seeder, and then determine the relationship between the seeder's working speed and the rotational speed of the seed- metering device, distance of seeds and the requirement of sowing rate. Instead of using a ground wheel, the system used a stepper motor to drive the seed-metering device, which could reduce the influence of non-uniformity caused by ground wheel's slippage.

The control system consisted of five major components: rotational speed sensor, single chip microcomputer system, motor control module, stepper motor and display (Figure 1).

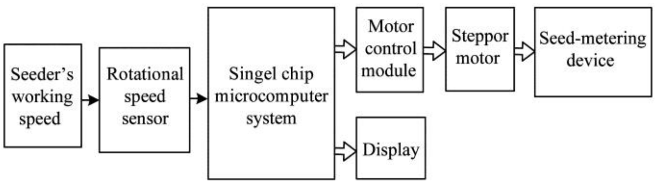


Figure 1 Structure of the control system's hardware

2.1.1 Rotating speed sensor

Generally speaking, there are three kinds of speed sensors, and each of which uses variable-reluctance, Hall effect, and wiegand effect, respectively[18]. The Hall effect sensor with simple structure and small size has high precision, quick response and long service life[19]. The control system finally used M18-48 circular and proximity Hall switch made by Jiazhun Electronic Technology Company, Guangdong, China.

2.1.2 Single chip microcomputer system

89S51 single chip microcomputer circumscribed program store and data memory constituted a single chip microcomputer system[20,21]. To 51 single chip microcomputer, the microcomputer system included single chip microcomputer, clock circuit, reset circuit, input and output equipment. Figure 2 showed the structure of the system. The system used AT89S51 made by ATMEL Corporation as the core of the system.

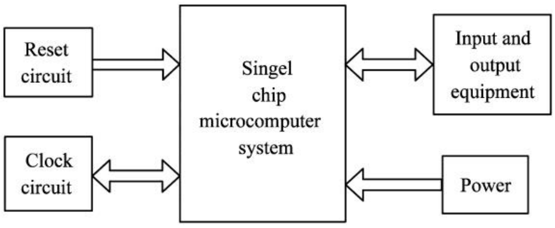


Figure 2 Structure of the control system

2.1.3 Motor control module

The stepper motor's input was pulse signal. When a pulse was inputted, the output shaft of the motor would turn a fixed angle[22,23]. If the frequency of the input pulse was changed, the speed of the stepper motor would also be changed. The 8253 counter had three exactly the same 27-bit subtraction counters which were independent from each other. The 8253 counter could be counted by binary and decimal. As a result, the 8253 counter was used to send pulse that could drive stepping motor.

2.1.4 Stepper motor

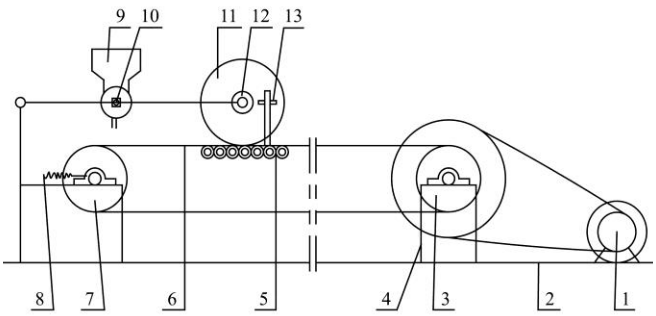
There are three types of common stepper motors which are reaction, permanent magnet and hybrid stepper motor[24]. Because hybrid stepper motor has a small stepping angle, a high starting frequency and a swift response, which costs less power, this control system used 57H76-03 stepper motor made by Golden Tenacious Electrical Company, Shenzhen, China.

2.2 Methods

2.2.1 Experimental setting

The control system used a 2BJD-4 planter unit made by Xinjiang Machinery Company as a vector. A 20-hole soybean planter disc with a diameter of 200 mm and width of 40 mm was used in the experiment. Every hole had a diameter of 10 mm. Internal gear was used to transmit power between the planter plate and the axle of the stepper motor.

Figure 3 showed the schematic diagram of seed-metering device experiment platform according to testing requirement. The seed-metering device experiment platform mainly consisted of an adjustable speed motor, a base, a principal drum, a stand, driving rollers, conveyor belt, a passive drum, a tension silk-pole, feeding mechanism, a stepping motor, a tachometric wheel, a land wheel, and a sensor.



1. Adjustable speed motor 2. Base 3. Principal drum 4. Stand 5. Driving rollers 6. Conveyor belt 7. Passive drum 8. Tension silk-pole 9. Feeding mechanism 10. Stepping motor 11. Tachometric wheel 12. Land wheel 13.Speed sensor.

Figure 3 Schematic diagram of seed-metering experiment platform

Firstly, the stepper motor, the control circuit board and the rotating speed sensor were fixed on the seed-metering device experiment platform. Secondly, the governor was adjusted to make the motor rotate with proper speed. The experiment was started lastly.

2.2.2 Methods of data analysis

These experimental results were analyzed according to customary evaluation method of drilling performance. The index was calculated compared with all samples in the procession of seed spacing statistical treatment[25,26]. The process of the method was as follows:

1) Spacing of 120 seeds was selected as a sample. The spacing of adjacent seeds was calculated by the time interval between the time points when the sensor passed by each of them.

2) The average seeds spacing. The average of all the seeds spacing was calculated and regarded as a standard for judging whether a spacing was qualified or not. The following was the calculation formulas of the average seeds spacing.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (1)$$

"N" was the total number of seeds spacing and "x_i" was the n^th seeds spacing.

3) The number of reseeding, qualified spacing and leakage seeding.

"n_2" was the number of reseeding:

$$n_2 = \sum n_i \quad \{x_i \in (0.0 \sim 0.5\bar{x})\} \qquad (2)$$

"n_i" was the number of qualified spacing:

$$n_1 = \sum n_i \quad \{x_i \in (0.5\bar{x} \sim 1.5\bar{x}) \qquad (3)$$

"n_0" was the number of leakage seeding:

$$n_0 = \sum n_i \quad \{x_i \in (1.5\bar{x} \quad +\infty) \qquad (4)$$

4) Their indexes can be obtained as follows:

Reseeding rate:

$$D_1 = \frac{n_2}{N} \times 100\% \qquad (5)$$

Qualified rate:

$$A_1 = \frac{n_1}{N} \times 100\% \qquad (6)$$

Leakage seeding rate:

$$M_1 = \frac{n_0}{N} \times 100\% \qquad (7)$$

Standard deviation:

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (8)$$

Variable coefficient:

$$V = \frac{S}{\bar{x}} \times 100\% \qquad (9)$$

All of the performance indexes above were measured on a certain dropping frequency. The calculation formulas of dropping frequency were as follows:

$$f = \frac{n}{60} Z \qquad (10)$$

"n" was the rotational speed of the seeding device. "Z" was the number of seeding device's cells.

3 Results and discussion

Two experiments were carried out. The seed-metering device was driven by a ground wheel in the first experiment. In the second experiment the seed-metering device was driven by the control system with two different situations. Finally we obtained three sets of data from the experiments. Therefore, there were three aspects of this problem to be addressed. The first question involved the results of the seed-metering device driven by a ground wheel at three working speeds of 1.0, 1.5 and 2.0 m/s. The second problem related to experimental results of the seed-metering device driven by the control system at three working speeds of 1.0, 1.5 and 2.0 m/s. The third aspect dealt with the results of the seed-metering device driven by the control system while the working speed increased from 0 m/s to 1 m/s gradually. The working speed mentioned was the conveyor belts' speed.

3.1 Results of the seed-metering device driven by a ground wheel

Figure 4 showed the distribution of seeds spacing. Table 1 showed the analysis results of the data driven by a ground wheel under three different speeds.

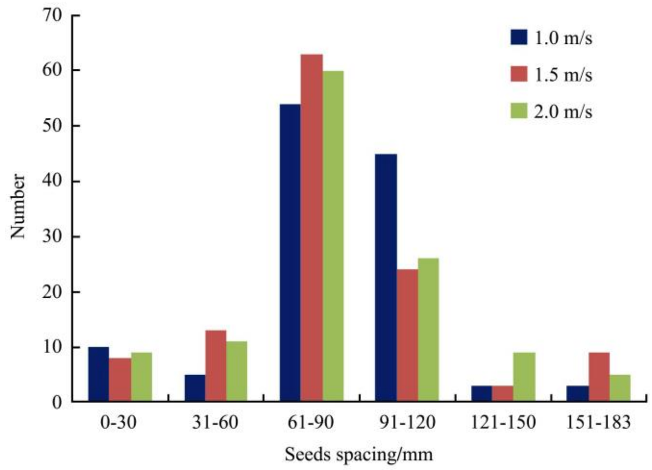


Figure 4 Distribution of seeds spacing driven by a ground wheel

Table 1 Data analysis of results driven by a ground wheel

Working speed/m s^{-1}	Average seeds spacing /mm	Qualified rate/%	Leakage seeding rate/%	Reseeding rate/%	Standard deviation	Variable coefficient/%
1.0	84.79	85.83	5	9.17	0.16	18
1.5	83.99	82.50	9.17	8.33	0.19	19
2.0	81.85	80.83	10.83	8.34	0.22	22

Figure 4 and Table 1 suggested that as the working speed increased, the qualified rate of the seed-metering device dropped gradually; the reseeding rate had a rising trend; the qualified rate decreased significantly; and the leakage seeding rate increased gradually. The variation of standard deviation indicated that the degree of seeds spacing deviated from the average seeds spacing became greater with the increasing working speed. The variable coefficient of the seed-metering device was greater than the standard variable coefficient mentioned [27].

The result was caused by three factors. The first was the slipping of the ground wheel. While the ground wheel slipped, the seed-metering device still rotated and sowed seeds. The second was the shape of the seeding tube that could influence the trajectory of seeds. The third one was the ground with a rough surface. While the roughness of ground changed, the speed of the ground wheel would change.

3.2 Results of the seed-metering device driven by the control system

The distribution of seeds spacing driven by the control system with three different working speeds was as follows (Figure 5). Table 2 showed the analysis results of seed-metering device driven by the control system at three working speeds.

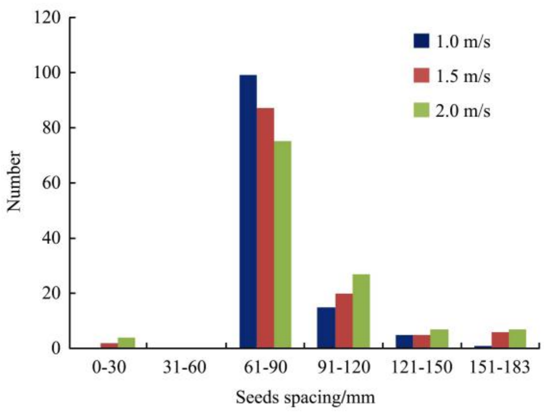


Figure 5 Distribution of seeds spacing driven by the control system

Table 2 Analysis results driven by the control system

Working speed/m s^{-1}	Average seeds spacing /mm	Qualified rate/%	leakage seeding rate/%	Reseeding rate/%	Standard deviation	Variable coefficient/%
1.0	87.75	95	5	0	0.09	9
1.5	92.34	90.83	7.5	1.67	0.12	12
2.0	94.59	85.83	10.83	3.34	0.15	15

However, the sower's working speed has been changing while sowing in the field. Therefore, another experiment in which the seed-metering device was driven by the control system with variable speed was added. The working speed increases from 0 m/s to 1 m/s gradually. Table 3 showed the analysis results of seed-metering device driven by the control system with variable speed. From Table 3 we found that the seed-metering device had a better working performance. The qualified rate was higher when the leakage seeding rate, reseeding rate, standard deviation and variable coefficient all maintained at a low level. Compared with Table 2, the working performance showed in Table 3 was even better than that of the seed-metering device driven by the control system at 1 m/s. Results imply that the control system can adjust the rotational speed of the seed-metering device well.

Table 3 Analysis results driven by the control system with variable speed

Working speed/m s^{-1}	Qualified rate/%	leakage seeding rate/%	Reseeding rate /%	Standard deviation	Variable coefficient/%
0-1	95.83	3.33	0.83	0.086	8.6

The single chip microcomputer was used to collect signals and detect seeding. The seeding quantity was showed on the display[28]. Wang Zhenhua further employed the monitoring system to monitor the pneumatic sower's walking speed, rotational speed of the seed-metering device, and planting area[29]. In contrast, the single chip microcomputer in this study could adjust the speed of seed axis automatically according to the working speed of the sower, showing the working speed and rotational speed on the display. It should be noted that this study was only on adjusting the rotational speed of the seed-metering device. It would be better that the control system could use the servo motor to adjust the speed of seed axis according to tractor travel speed and the seed distances automatically according to moisture and fertility of soil, together with planting agronomy. Not withstanding its limitation, this study does suggest the control system could adjust the seed-metering device's rotational speed well according to the working speed of experimental equipment.

4 Conclusions

Inspired from self-regulation function of biology, a seeding control system was designed. The control system used a Hall sensor to measure the seeder's working speed. It determined the relationship between the seeder's working speed and the rotational speed of the seed-metering device. The control system could make the seed-metering device keep synchronization with the working speed of the seeder so as to reduce the effect of seeding nonuniform caused by ground wheel's slipping. Ultimately, the design target was achieved. The experiment results proved that the control system was reliable. The experiment also showed that uniformity could be maintained between the speed of the seed metering- device and the seeder concerning the amount of seeding. The qualified rates of the designed seeding control system were above 88%, which were obviously higher than those driven by a ground wheel.

The design used the control system based on single chip microcomputer to control the seed-metering device's rotational speed on a real time basis. The control system could compensate the sowing rate effectively and raise the seeding uniformity of the seeding machine. The system would greatly improve the sowing quality, reduce the leakage seeding rate and increase production. The new design in this study provides a platform to solve the problems of the seed-metering device and the seeder.

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