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Design and Experimental Study of an Electrically-Driven Seed Metering Control System for Intelligent Agriculture

Xiang Wang[1,2]. Guiyou Ye[3]. Gaowei Li[3]. Gongru Gao[3]. Zunmin Liu[1,2]. Xingyu Fang[3]. Baogang Li[1,3,*]. Wenqi Li[1] and Jingchun Tang[1]

[1]School of Mechanical & Automotive Engineering, Qingdao University of Technology, Qingdao 266520, China
[2]Guangxi Key Laboratory of Automobile Components and Vehicle Technology, Guangxi University of Science and Technology, Liu-zhou 545006, China
[3]Shandong Changlin Machinery Group Co., Ltd., Linyi 276715, China
[*]Corresponding Author: Baogang Li

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Abstract

In order to overcome the limitations of traditional seeders, including inadequate operational accuracy, unsatisfactory seeding performance, and low levels of automation, an intelligent control system for a pneumatic precision seeder was developed. The system is centered on a self-designed main controller, which acquires real-time operating speed through a speed measurement module and dynamically adjusts the seed metering device`s rotational speed according to the preset seeding parameters, thereby achieving high-precision precision seeding. This not only effectively reduces seed wastage and production costs during the operation, but also significantly enhances the level of operational intelligence. Experimental results show that the seeding qualification rate of the control system exceeds 95%, with a missed seeding rate below 3%. The system can stably realize turning compensation, thereby further ensuring the uniformity and reliability of the operation.

Keywords

Precision Seeding; Electrically-Driven Seed Metering; Intelligent Control System

1. Introduction

As agricultural modernization progresses, precision seeding technology has emerged as a crucial means for enhancing crop productivity, improving resource utilization, and fostering sustainable green agriculture[1-3]. However, traditional seeding equipment still suffers from various limitations in terms of operational accuracy, level of intelligence, and environmental adaptability. In particular, issues such as inconsistency in seed metering, missed or repeated seeding, and inadequate energy efficiency make it difficult to meet the demands of modern agriculture for high-efficiency and high-quality seeding operations.

In order to overcome the above-mentioned challenges in seeding operations, researchers and enterprises worldwide have conducted extensive studies and developed a range of technological innovations. For instance, Kuang Lihong[4] and colleagues designed an electric seeding and fertilization control system for a pneumatic maize planter. The system comprises an embedded industrial computer, multiple sensors, a seed-metering motor controller, and a fertilization controller. By correlating seeding parameters with the actual operating speed, the industrial computer dynamically regulates the rotational speeds of the seed-metering and fertilization motors, along with the seeding rate and fertilizer dosage, thus enhancing the precision and uniformity of seeding and fertilization operations. Shen Zhuoqun[5] et al. developed a pneumatic, electrically-driven seed-metering and fertilization no-till planter to meet the requirements of conservation tillage technology, and conducted relevant experimental studies. The results showed that under a no-till seeding mode with high stubble retention and full straw mulching, the planter was able to achieve qualification rates that satisfied agronomic requirements for seeding spacing, seeding depth, and seed-fertilizer spacing. Hao Xiangze[6] et al. designed a seed-metering performance monitoring system for a single-grain precision seeder based on photoelectric technology. The system acquires real-time seed-falling signals through an infrared detection device, which are then processed by a microcontroller to accurately calculate the missed seeding rate, repeated seeding rate, and seeding quantity. Experimental validation demonstrated that the monitoring accuracy of the control system reached 98%, thereby effectively improving the precision and reliability of the seeding process. At the international level, the French company MONOSEM[7] has developed and manufactured the NG Plus series pneumatic precision planters. By employing a rear-mounted transmission device to regulate row spacing and seeding rate, these planters are particularly well-suited for sowing dryland crops, offering significant improvements in both seeding accuracy and operational efficiency. In addition, Japan has also introduced innovations for pneumatic precision planters by developing a novel electromagnetic seed-metering device. This device regulates the seeding rate in real time by controlling the action of an electromagnetic valve according to the seed-falling intervals. Experimental verification has demonstrated that this system achieves high seed-metering accuracy and significantly improves seeding efficiency. These technological innovations provide effective solutions for enhancing seeding precision, optimizing operational efficiency, and meeting the requirements of modern agriculture for efficient and accurate seeding.

The above review indicates that current electrically-driven seed-metering control systems and intelligent monitoring technologies have, to a certain degree, alleviated the limitations of traditional seeders in terms of precision and operational efficiency. However, the information among different modules has not been effectively interconnected, and the data have not been fully utilized, resulting in a certain degree of resource wastage. To address this problem, this paper proposes an integrated control system that combines electrically-driven seed metering with intelligent monitoring functions. The system not only enables precision seeding but also incorporates turning compensation, thereby further enhancing the level of intelligence and automation in seeding operations, maximizing seeding accuracy and efficiency, and reducing resource wastage.

2. Overall Structure and Working Principle

The intelligent seeding control system mainly consists of a power supply module, a speed measurement module, a monitoring module, a display module, and a pneumatic seed-metering device, as shown in **Figure 1**. In contrast to the conventional ground-wheel-driven seed-metering mechanism, this study adopts a distributed layout in which each pneumatic seed-metering device is equipped with an independent motor. This design not only effectively reduces the use of mechanical components such as gears and chains, thereby minimizing mechanical losses, but also enables precise control of the seed-metering motor, resulting in accurate seeding and improved adaptability during the seeding process. In addition, the system incorporates functions such as turning compensation, which further enhances seeding accuracy and reliability under complex terrain conditions.

The working principle is based on a speed-adaptive control mechanism. During operation, the system first collects real-time operating speed and other key data through the speed measurement module. Then, according to preset seeding parameters such as plant spacing, number of seed holes, and reduction ratio, the target seed-metering speed is calculated. Subsequently, the main controller transmits control commands to the electric drive motor via CAN communication and dynamically adjusts the motor speed according to the actual state of the seed-metering wheel, thereby ensuring the consistency of plant spacing. In addition, the system is equipped with intelligent detection functions, capable of monitoring abnormalities such as missed seeding, reseeding, or seed blockage in real time. When such issues occur, the system triggers an alarm to notify the operator for timely adjustment, thus ensuring both seeding quality and maximum operational efficiency.

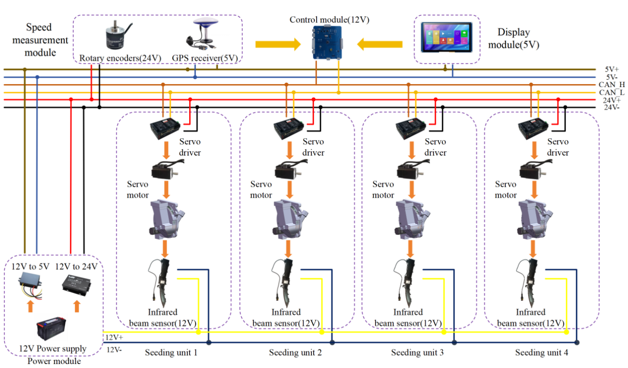

Figure 1. Intelligent seeding control system

3. Control System Hardware Design

The hardware development of the intelligent seeding control system constitutes a critical step toward realizing efficient and precise seeding operations. This process encompasses not only the meticulous selection of hardware components but also the design and implementation of control modules, thereby guaranteeing the stability and reliability of the overall system.

3.1. Control Module Design

As the brain of the entire control system, the control module is responsible for core tasks such as data acquisition and processing, as well as signal processing and control[8-10]. In this study, the STM32F103CT86 microcontroller was selected as the main control chip. This chip provides excellent peripheral configurations, including dual 12-bit ADCs with 1μs conversion time, a USART operating at 4 Mbps, an SPI interface at 18 Mbps, multiple timers, and various communication modules. With its high cost-effectiveness, the chip meets the requirements of high-performance and low-power design. To ensure efficient communication among the different modules, careful optimization was carried out in circuit and PCB design. After board fabrication and soldering, a self-developed main controller was successfully built, as shown in **Figure 2** .

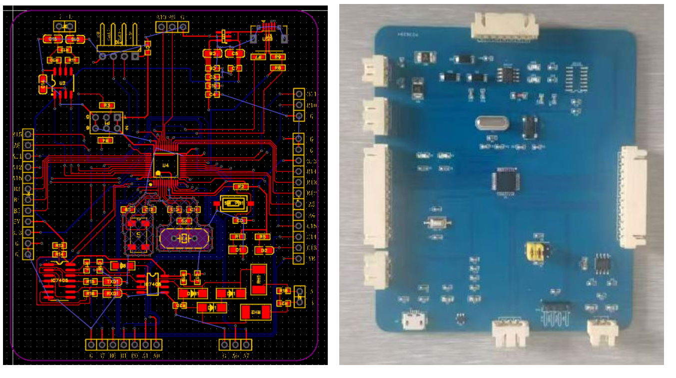

Figure 2. Self-developed main controller

3.2. Speed Measurement Module Design

Speed acquisition is mainly achieved through the speed measurement module, which primarily utilizes a combination of GPS and rotary encoders. When the vehicle speed is low, or when the GPS signal is weak and unstable, the measurement error increases, making it difficult to ensure seeding uniformity. In such cases, a rotary encoder is mounted on the ground wheel shaft to measure the wheel's rotational speed, serving as the basis for precision seeding. The combined use of GPS and rotary encoders not only improves the accuracy and robustness of the positioning system but also extends its applicability to more complex and variable environments.

3.3. Seeding Unit Module Design

As the core component of the seeding process, the seeding unit serves as the executive mechanism for seed placement. It mainly consists of the electrically driven seed-metering device and the pneumatic precision seed-metering device.

In terms of the pneumatic precision seed-metering device, the system adopts a unit developed by the project team. This device features an innovative combination of airflow and mechanical seed agitation, which enhances seed flowability and reduces resistance during the seed-filling process, thereby substantially improving filling performance. Furthermore, the seed-metering device is equipped with a flexible, adjustable rubber wheel that employs soft contact to improve the seed-cleaning effect while minimizing seed damage during the cleaning process.

In the aspect of electrically driven seed metering, this study builds upon previous research on multi-objective electrically driven intelligent variable precision seed-metering systems[11]. A servo motor was selected as the power source to drive the rotation of the seed-metering disk. The associated servo driver integrates a high-precision encoder, enabling closed-loop control of the disk's rotational speed and thereby ensuring both stability and accuracy of the seed-metering process. This design enhances system responsiveness and control precision, while also establishing a robust hardware basis for achieving intelligent variable precision seeding.

3.4. Display Module Design

As the core unit of human-machine interaction, the display module is responsible for real-time presentation of operating parameters and the input of control commands, thereby enabling efficient information exchange between the operator and the control system. In this study, the serial resistive touch screen TJC1060X5A1_011R_Y (**Table 1**) was selected as the display module, which communicates with the main controller via a TTL/RS232 interface. The touch screen features excellent sensitivity and stability, ensuring both accuracy and smoothness of user operation. Furthermore, its size, resolution, and brightness parameters meet the requirements of practical applications, providing a clear and bright visual display.

Table 1. Serial port configuration resistive touch screen parameters

Physical image	Specification item	Parameter
	Overall dimensions	276.60 (L) × 179.00 (W) × 22.15 (H) (mm)
	Display size	235.00 (L) × 143.00 (W) (mm)
	Active display area	222.72 (L) × 125.28 (W) (mm)
	Resolution	1024*600
	Brightness	300 nit

	Serial baud rate	2400～921600
	Serial communication mode	8 data bits, 1 stop bit, no parity
	Serial voltage level	TTL level
	TTL/RS232 switching	Supported

In terms of interface design, as shown in **Figure 3**, the system interface was optimized according to the functional requirements of the control system. The layout is intuitive and the interaction logic is clear, incorporating essential functions such as motor start/stop, as well as the setting and adjustment of key parameters including the number of seed holes, plant spacing, and reduction ratio, thereby enhancing operational convenience and ensuring reliable system performance.

Figure 3. Interface design of the display module

3.5. Intelligent Monitoring System Design

The intelligent monitoring module enables real-time monitoring and feedback throughout the seeding process, thereby ensuring operational quality and uniformity. Its core principle is based on the use of an infrared through-beam sensor to detect the instantaneous state of seeds passing through the seed tube. The transmitter and receiver of the sensor are installed on opposite sides of the seed tube, and when a seed passes through, it blocks the infrared beam, causing a change in the signal received. The main controller acquires and analyzes this signal in real time to determine whether the seeds are falling normally, as well as the timing and quantity of seed drops. The seeding status data are then transmitted immediately to the display module. In addition, the main controller can dynamically adjust the working parameters of the seeder according to the monitoring results, such as modifying the rotational speed of the seed-metering device or optimizing the seeding rate, thereby achieving precise and efficient seeding operations.

4. Control System Software Design

According to the overall system design, the software program for the electronic control system of the pneumatic precision seeder was developed on the Keil Vision5 platform. As shown in **Figure 4**, the development process first involved modular programming of the display module, electrically driven seed metering, and intelligent monitoring functions, followed by verification of each module program. Subsequently, the overall program framework was established to coordinate and integrate the different modules. During system operation, the actual seeding speed is obtained through the speed measurement module and uploaded to the control module. After being processed by the motor speed regulation mathematical model, the required target rotational speed of the seed-metering motor is calculated. This target speed command is then transmitted to the driver via the CAN bus, thereby enabling precise motor operation for seed metering. At the same time, the infrared through-beam sensor is used to monitor and provide real-time feedback on seeding quality. Finally, system-wide integration and joint debugging were carried out on the hardware platform to ensure stable and efficient operation of all functional modules.

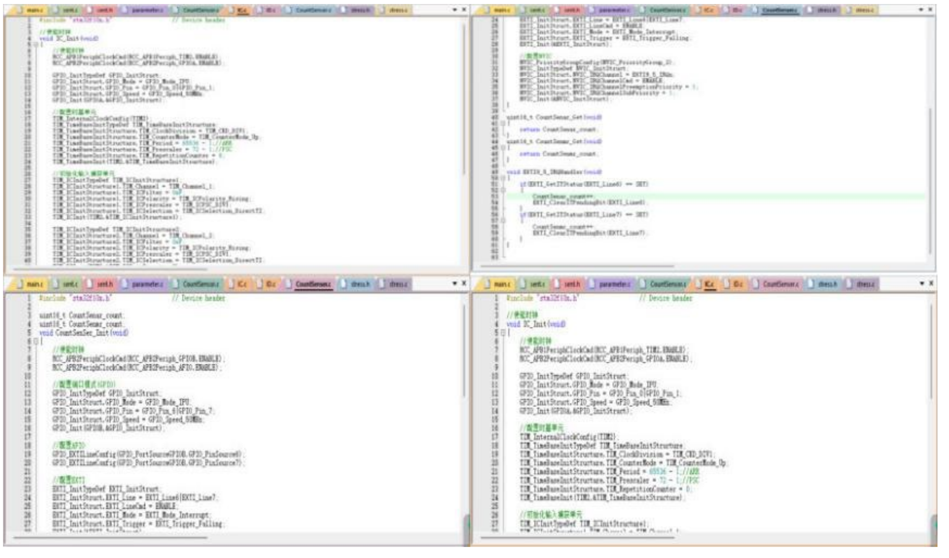

Figure 4. Programming of the intelligent seeding control system

5. Experimental Test and Verification

5.1. Experimental Method

To investigate the seeding performance under different operating speeds, relevant experimental tests were conducted in this study. Operating speed was selected as the test factor, while the performance evaluation indices included the reseeding rate, missed seeding rate, and qualification rate. The experiments were carried out in accordance with GB/T 6973—2005 Test Methods for Single Seed (Precision) Drills. The seeding parameters were set as follows: plant spacing of 25 cm, 35 seed holes per disk, and an air pressure of 4.5 kPa. The test range of operating speeds was 4 – 12 km/h, within which the seeding performance indicators at different speeds were measured. For each test group, the seeding performance of 300 maize seeds was continuously recorded, and each test was repeated three times. The average values were taken as the final experimental results.

Table 2. Experimental Results

	2	4	6	8	10	12
Qualification rate	99.27	98.76	98.38	98.17	97.27	99.27
Missed Seeding rate	0.59	1.13	1.05	1.32	2.46	0.59
Reseeding rate	0.14	0.11	0.57	0.51	0.27	0.14

As shown in **Table 2**, within the operating speed range of 2 – 12 km/h, the seeding qualification rate consistently remained above 97%, while the missed seeding rate was controlled below 3%. Operating speed exhibited a significant effect on qualification rate, missed seeding rate, and reseeding rate. With increasing speed, the qualification rate showed a clear downward trend, whereas the missed seeding rate increased correspondingly. However, due to the effect of the seed-cleaning wheel, the reseeding rate remained relatively stable. The results indicate that under high-speed operating conditions, the decline in qualification rate is mainly attributed to the intensification of missed seeding. At the same time, the seed-cleaning wheel design effectively suppressed fluctuations in reseeding rate to a certain extent. Therefore, when optimizing the balance between operating speed and seeding quality, special attention should be given to the issue of missed seeding in order to ensure the stability and reliability of overall seeding performance.

6. Conclusion

This work presents the design and implementation of an intelligent seed-metering control system utilizing electric drive technology. By adopting an integrated approach that combines the speed measurement module, display module, and seeding unit module, the system achieves enhanced inter-module coordination while reducing overall costs. The developed system enables precise control of the seed-metering process, thereby substantially improving the accuracy and completeness of seeding operations. Moreover, with its strong adaptability, the system incorporates turning compensation functionality, significantly advancing the intelligence and flexibility of seeding tasks.

During the experimental evaluation, seeding quality was verified across different operating speeds. Results indicated that in the range of 2 – 12 km/h, the seeding qualification rate consistently exceeded 97%, while the missed seeding rate remained below 3%, reflecting substantial improvements in seeding quality and uniformity. Across diverse operating conditions, the system exhibited strong stability, effectively overcoming common drawbacks of traditional seeders such as seed wastage and uneven distribution. In comparison with conventional mechanical control systems, the intelligent seed-metering control system not only enhanced operational efficiency but also markedly reduced energy consumption and labor costs.

Future research will focus on further improving the adaptability and flexibility of the system, including optimizing the control accuracy of the electric drive system, incorporating more advanced intelligent algorithms to enhance the robustness of the control system, and strengthening its environmental adaptability. In addition, efforts will be directed toward the deep integration of the system with Internet of Things, big data, and artificial intelligence technologies, thereby expanding its application scenarios in precision agriculture, such as automated farmland monitoring, environmental change prediction, and intelligent decision-making. These advancements aim to provide more efficient, intelligent, and sustainable solutions for agricultural production.

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