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Research Progress on Electric-Driven Precision Seed-Metering Technology

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Abstract

In recent years, with the continuous development of agricultural intelligence and precision farming, electrically driven seeding technology has gradually be-come an important method for modern crop planting. This paper, based on an extensive review of relevant literature, provides a detailed introduction to the basic principles and core components of electric-driven seeding, with a focus on analyzing the working mechanisms and technical characteristics of such sys-tems. Meanwhile, the study offers an in-depth review of the research status of electric-driven seeding both domestically and internationally, summarizing the progress and achievements of various countries in this field, particularly re-garding seeding accuracy, adaptability, and intelligent control innovations. Fi-nally, in view of the current technological development, the paper identifies the challenges faced by electric-driven seeding technology and proposes future de-velopment recommendations, envisioning its broad application prospects in future agriculture, especially in improving seeding efficiency, operational preci-sion, and intelligent management.

Keywords

Electric-driven Seeding; Seeding Accuracy; Intelligent Control

1. Introduction

Agriculture is a crucial pillar of China’s economy, and its production efficiency and output levels are not only directly related to national food security but also have a profound impact on farmers’ income. Among the various stages of agricultural production, sowing is a critical step, and the accuracy of seed placement directly determines crop emergence rates, uniformity of plant spacing, and ultimately, the final yield.

Traditional seeders primarily rely on mechanical transmission as the driving force for seed metering. This mechanical approach offers advantages such as simple structure and mature technology, but it also has notable limitations. For instance, the seed metering system typically depends on chain and gear drives, which are prone to large transmission backlash and high slippage rates, and adjusting system parameters can be cumbersome. Moreover, in terms of achieving precise seeding and variable-rate seeding, traditional mechanical methods exhibit clear shortcomings, making it difficult to meet the high-efficiency and high-precision requirements of modern precision agriculture.

To address the shortcomings of traditional seeding, both domestic and international scholars and enterprises have conducted in-depth research. Internationally, major agricultural machinery companies such as John Deere, AGCO, and Precision Planting have launched relatively mature electric-driven seeding solutions, which have been widely applied in precision planting of high-value crops such as corn and soybean [1 – 4]. Comparatively, domestic universities, research institutes, and agricultural machinery enterprises are also actively engaged in related research and product development. At present, several experimental models have achieved promising results in field trials, providing valuable experience for the development of electric-driven seeding technology in China.

2. Overview of Electric-Driven Seeding Technology

2.1. Basic Principles

Electric-driven seeding is a novel seeding method powered by electric motors, with its core principle being the replacement of traditional mechanical drives to achieve precise seed placement[5 – 7]. This technology can adjust the motor speed in real time according to key parameters such as plant spacing and the number of holes in the seed plate, as well as varying field conditions, thereby ensuring uniform and consistent seed drop. As a result, it effectively improves emergence rates and the overall quality of the crop population. Compared with mechanical seed metering, electric-driven seeding offers higher precision, greater adjustment flexibility, and lower failure rates. Moreover, it can be integrated with GPS navigation and intelligent control systems to enable variable-rate seeding and precise operations, significantly enhancing agricultural productivity and resource efficiency, aligning well with the development trend of modern precision agriculture.

2.2. Core Components

The electric-driven seeding system mainly consists of three parts: the sensing module, the decision-making module, and the execution module. The sensing module is responsible for real-time collection of field environment and operational condition data and transmits this information to the decision-making module. The decision-making module then analyzes and processes the collected data to generate optimal control commands. Finally, the execution module carries out precise seed placement according to these commands. Through this closed-loop control approach, the system can dynamically adjust and provide feedback throughout the seeding process, significantly improving seeding accuracy and operational reliability.

2.2.1. Sensing Module

In the seeding control system, the sensing module functions like the “tentacles” of the system, with its core task being the collection of key operational parameters to provide reliable data support for the subsequent decision-making module. Among these, the speed sensor is the most critical component, primarily responsible for real-time monitoring of seeding operation speed. Common methods for speed measurement include three approaches: first, installing a rotary encoder on the ground wheel axle to calculate operational speed based on wheel rotation; however, this method is prone to inaccuracy due to wheel slippage. Second, using GPS positioning to obtain vehicle speed, which is simple in principle but can be obstructed in complex environments such as urban areas, forests, or valleys, and its accuracy decreases at low speeds. Third, radar-based speed measurement, which relies on the microwave Doppler effect by emitting microwave signals and comparing the reflected signals to calculate speed; however, this method is susceptible to environmental interference, and its accuracy and stability largely depend on installation conditions.

Overall, each speed measurement method has its own advantages and limitations. The rotary encoder is structurally simple but prone to slippage errors; GPS-based speed measurement is suitable for large-scale, constant-speed operations but performs poorly in complex environments and at low speeds; radar-based measurement offers the benefit of non-contact sensing but is significantly affected by external interference and installation conditions. Therefore, in seeding operation control systems, it is often necessary to combine multiple methods or employ data fusion techniques to compensate for the shortcomings of individual sensors, thereby achieving higher accuracy and more stable speed monitoring, and providing a reliable foundation for precision agricultural operations.

2.2.2. Decision-Making Module

The decision-making module serves as the “brain” of the system. Its primary function is to calculate optimal seed-metering parameters based on data collected by the sensing module, combined with preset parameters such as plant spacing, seed plate hole number, and reduction ratio. It sends motor speed adjustment commands to the execution module while also performing functions such as anomaly alerts, data storage, and communication. The core components of this module include the hardware platform and control algorithms.

Currently, mainstream seeder controllers generally adopt embedded microprocessors as the central control unit. Among them, ARM Cortex-M series chips (e.g., STM32F1/F4) are the most widely used due to their low power consumption, abundant peripheral interfaces, and high cost-effectiveness, which can effectively meet basic control requirements such as seed monitoring and motor driving. For high-end equipment or scenarios requiring complex human – machine interaction, more powerful processors such as the ARM Cortex-A series (e.g., NXP i.MX series) or TI C2000 DSP are often selected, balancing real-time control capabilities with operating system support to enable higher-level functional expansion.

Control algorithms are the core of ensuring seeding accuracy, and their development can be generally divided into three stages. In the early stage, proportional control (P control) was commonly used, adjusting motor speed proportionally based on the deviation between the target and actual plant spacing. This method is simple in structure and easy to implement, but it is prone to overshoot and exhibits relatively slow response. In the subsequent stage, proportional – integral – derivative (PID) control was introduced. The proportional component corrects deviations in real time, the integral component eliminates steady-state errors, and the derivative component predicts deviation trends, thereby effectively enhancing system stability and dynamic response, making it the mainstream control method today[8-9]. In more complex field environments, intelligent control algorithms have gradually been applied, such as fuzzy control, neural networks, and model predictive control (MPC).

2.3. Execution Module

The execution module, as the terminal of the entire control system, is primarily composed of the motor module. Currently, commonly used motors in seeders include brushless DC motors, stepper motors, brushed DC motors, and servo motors, each with its unique advantages and suitable application scenarios.

Among them, brushless DC motors are widely used in electric-driven seeding systems[10 – 11] due to their fast response, low operational noise, long lifespan, high starting torque, and ability to provide stable rated torque. They can achieve high efficiency while maintaining relatively high precision, but they require dedicated drivers (controllers), which increases system complexity. In case of a malfunction, maintenance is challenging and requires professional personnel.

Stepper motors convert electrical pulse signals into precise angular or linear displacement, making them suitable for scenarios requiring accurate seed plate control[12-13]. Their main advantages are high positioning accuracy and simple control logic, without the need for complex feedback adjustment, making them ideal for applications with high precision requirements.

In contrast, brushed DC motors have the simplest structure, can operate directly with a DC power supply without a driver, and have low procurement cost and easy maintenance. However, they have a shorter lifespan, produce more noise, and experience reduced speed accuracy over prolonged use.

Servo motors achieve high-precision, high-response motion control through a closed-loop feedback system, typically equipped with encoders. They can accurately follow control commands for position, speed, and torque, enabling precise motion adjustments[14-15]. However, compared to other motors, servo motors are more expensive, require specialized drivers, have higher system complexity, and are more difficult to maintain. Therefore, when selecting a motor, it is necessary to consider the specific working environment and requirements, and make an appropriate match based on the characteristics of each motor type.

3. Current Research Status at Home and Abroad

3.1. International Research on Electric-Driven Seeding

International research on electric-driven seeding technology began relatively early. Research institutions and companies in countries such as the United States and Japan have gradually established relatively mature technical systems and successfully launched a series of high-performance products. These systems excel in terms of accuracy, efficiency, and adaptability, while also promoting innovation in related fields, providing strong support for the global advancement of intelligent and precision agriculture.

The 4900MHP precision planter developed by Kinze in the United States employs advanced electric pneumatic seed-metering technology, enabling rapid switching between different crops. Seeds of various crops are stored in separate seed hoppers, each connected to the system via an electric pneumatic seeder. Through an intelligent control module, operators can flexibly turn any electric seed meter on or off according to seeding requirements, allowing for fast crop changes. This design not only improves seeding flexibility but also optimizes operational efficiency and seeding accuracy, significantly enhancing the level of intelligent agricultural production[16].

Graham, another U.S. company, designed an innovative electric-driven seeding device controlled via an Android system, which drives the seed meter using a brushless DC motor. The system can precisely execute independent variable-rate seeding according to prescription maps. This ensures consistency and uniformity of plant spacing during seeding, effectively improving seeding accuracy, optimizing the crop growth environment, and enhancing overall yield and quality[16].

French company Monosem launched the ValoTerra series of electric seeders, equipped with a self-developed patented metering box and powered by a 56V system. The design aims to maintain high performance and reliability under various field conditions while significantly reducing maintenance requirements. With the flexibility and stability provided by electric drive, the ValoTerra series not only improves seeding precision and uniformity but also demonstrates unique advantages in durability and operational efficiency, providing strong technological support for modern precision agriculture[17].

Roger Toscan Spagnolo and colleagues conducted systematic comparative experiments on mechanical and electric-driven seeding systems, focusing on seed distribution differences in corn planting. The results showed that electric-driven systems have a clear advantage in achieving uniform seed distribution, with the coefficient of variation of linear distribution significantly lower than that of mechanical systems. This demonstrates that electric-driven technology can effectively improve seeding uniformity and stability, providing strong support for enhancing crop yield and ensuring precision agricultural operations[18].

Turkish scholar Anil Cay and colleagues designed an electric-driven seed-metering control system based on an Arduino microcontroller and CAN communication technology. Using a PID closed-loop control strategy to drive a brushless DC motor, the system achieves precise regulation of the seeding process. This design not only improves the response speed and stability of the seed meter but also ensures uniformity and reliability in seeding operations, providing an important reference for the application of electric-driven seeding technology in complex agricultural environments[19].

In summary, developed countries in Europe and the United States have relatively mature electric-driven seeding technologies, having developed multiple representative products and control systems. Extensive research and practice indicate that electric-driven seeding surpasses traditional mechanical drives in terms of seeding accuracy, uniformity, and operational flexibility. It effectively improves operational quality and efficiency, while providing a solid foundation for the precision and intelligent development of agricultural production.

3.2. Domestic Research on Electric-Driven Seeding

In recent years, China has made significant progress in the field of electric-driven seeding technology, with research mainly focusing on the design of control systems and improvements in control algorithms, laying an important foundation for achieving high-speed precision seeding.

Yao Yingfei and colleagues designed an electric-driven seed-metering control system for high-speed precision corn planters based on the STM32C8T6 microcontroller. The system uses a fuzzy PID algorithm as the core speed control method, an encoder as the feedback element, and a DC motor as the execution device, achieving precise control of the seeding process. Experimental results show that at a high operational speed of 12 km/h, the fuzzy PID control method outperforms conventional PID control in terms of seeding quality index, replanting index, and missing seed index[20].

He Xiantao and colleagues developed a novel electric-driven seed-metering control system centered on the PID control algorithm, innovatively eliminating the traditional "ground wheel + chain" mechanical transmission structure. Tests demonstrate that under high-speed seeding conditions of 12 km/h, the electric-driven system can still maintain high seeding performance, with a single-seed seeding rate reaching 98.4%, and both replanting and missing rates controlled below 1%, significantly improving seeding quality and stability at high speeds[21].

Yang Shuo and colleagues addressed the technical challenge of rapidly adapting seeding control systems to multiple types of seed meters by designing an electric-driven system capable of on-site calibration of corn seed-metering devices. Experiments indicate that under different combinations of vehicle speed and plant spacing, the system maintains high control accuracy, typically above 97%–98%, with short adjustment times and minimal steady-state error, demonstrating good versatility and stability[22].

Zhang Zhaorui developed a new electric-driven seeding control system suitable for strip intercropping of soybean and corn, overcoming the limitations of insufficient ground wheel-driven precision and the difficulty of simultaneously seeding two crops with electric-driven machines. Field tests show that the system significantly improves seeding uniformity, with soybean and corn spacing quality indexes maintained above 91% and 93%, respectively, clearly enhancing overall operational quality and seeding accuracy[23].

Jia Hao developed a motor direct-drive control system for corn planters, employing a dual-channel complementary speed measurement method combining Beidou satellite and ground wheel data to ensure accurate operational speed acquisition. Field trials indicate that the coefficient of variation for seed spacing is 0.24, the seeding depth qualification rate reaches 80%, and the seed spacing qualification rate is 85%, with all indicators meeting design requirements, verifying the system's reliability and practicality[24].

Feng Yugang and colleagues designed a precision electric-driven wheat seeding control system based on satellite speed measurement. The system combines satellite speed measurement with stepper motor drive, enabling automatic adjustment of seeding rate according to vehicle speed. Tests show that under four different forward speeds, the deviation between measured seed and fertilizer application rates and theoretical values did not exceed 5%, demonstrating that the system maintains good seeding uniformity and accuracy across varying operational speeds[25].

In summary, domestic enterprises and research institutions have conducted extensive exploration and development of electric-driven seeding control strategies, proposing multiple technical solutions and significantly improving seeding precision and adaptability, particularly under high-speed operation conditions. However, compared with developed countries in Europe and the United States, domestic research remains primarily at the laboratory and small-scale field trial stage, and a systematic, standardized, and industrially scalable technical framework has yet to be established.

4. Recommendations and Prospects

(1) Improvement of Technical Systems and Adaptability to Working Conditions

Although significant progress has been made in electric-driven seeding technology both domestically and internationally, a unified technical standard and evaluation system are still lacking. In the future, efforts should be made to standardize electric-driven seeding equipment in terms of structural design, performance testing, and interface specifications, thereby enhancing compatibility and interoperability among different manufacturers and systems and improving the overall industrial chain. Meanwhile, with the continuous increase in agricultural machinery operational efficiency, electric-driven seeding systems need to further enhance their stability and reliability under high-speed operations, no-till farming, high straw coverage, and complex soil conditions. To achieve this, long-term field trials and studies under extreme environmental conditions should be strengthened to improve system durability and practicality, ensuring stable and efficient operation under diverse working conditions.

(2) Intelligentization and Multi-Functional Integration

With the development of artificial intelligence and digital technologies, electric-driven seeding control should further integrate intelligent solutions, fully leveraging IoT, big data, satellite navigation, and sensing technologies to achieve real-time monitoring and adaptive regulation of seeding rates, thereby establishing a complete data closed loop and enhancing operational precision and intelligence. In addition, future seeding equipment should focus on multi-functional integration and system collaboration, such as combining electric-driven seeding with fertilization, spraying, and variable-rate operations, creating a versatile intelligent platform to improve agricultural productivity and operational flexibility.

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