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# Development of an electric-driven control system for a precision planter based on a closed-loop PID algorithm

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ABSTRACT

This study presented the design of an electric-driven control system for the seed meter of a precision planter to avoid the issues of poor planting quality and low travel speed limitations associated with conventional ground wheel and chain driven planters. A closed-loop proportional-integral-derivative (PID) algorithm was deployed to control the seed plate rotation speed. The performance of three PID tuning methods (Ziegler-Nichols step response method (ZNM), Cohen-Coon method (CCM), and Chien–Hrones–Reswick method (CHRM)) was compared by Matlab-Simulink simulation, and results testified that the CCM had a better performance with smallest rise time of 0.018 s, settling time of 0.082 s and maximum overshoot of 26.1%. Field experiments indicated that a four-row planter equipped with the developed electric-driven control system had significantly better quality of feed index (QFI), miss index (MI), and precision index (PREC) values compared with those of a ground wheel and chain driven planter under equivalent working conditions. For a travel speed of 8.6 km/h, the average values of the four rows for the QFI, MI, and the PREC were 98.62%, 1.29%, and 14.51%, respectively. For a high travel speed of 13.0 km/h, the average QFI still achieved a value of 97.09%. Most of the components employed in the system were made in China, and the overall system cost was much less than similar systems obtained from abroad. As such, the proposed system is accessible to precision planters in developing countries.



## 1. Introduction

The planting quality obtained from a planter is affected by the seed metering performance, which is itself impacted greatly by the system employed to drive the seed meter. Conventional planters employ one of the planter's ground wheels and a chain driven system for seed metering, and slippage between the wheel and ground, and chain instability result in poor planting quality (Saadat et al., 2013). Moreover, the planting quality deteriorates with increasing planter travel speed, making mechanical ground-wheel driven systems unsuitable for high speed planting, and limiting their productivity (Yang et al., 2016). Some researchers have proposed using electric driven systems to solve these issues.

Research into electric driven systems began in the 1980s. Saadat et al. (2013) designed a mechatronic transmission system for a row crop planter, and the results of field evaluation showed that the system increased the QFI and decreased both the MI and the PREC. Chaney et al. (1986) developed an automatic control system for a sugarcane planter. Singh and Mane (2011) developed an electronically controlled metering mechanism for okra seed. Nowadays, most manufacturers of advanced planters worldwide provide electric driven systems with an associated control system. Kinze Manufacturing (USA) employed an electric motor to drive the seed meter with external gear engagement. John Deere (USA), Horsch (Germany), and Väderstad (Sweden) employed a DC motor to drive the seed meter shaft. Precision Planting LLC (USA) and Ag Leader (USA) developed electric driven systems for original equipment manufacturers (OEM) or for after-market sales. These systems provide high control accuracy and adaptability, and can accommodate travel speeds as high as 15 km/h. However, these systems are very expensive and are not suitable for large scale application in developing countries.

Researchers in China began to develop electric-driven seed meters for planters only in recent years with limited success. Yang et al. (2015) employed a stepper motor to drive a corn meter along its circumference, developed the associated control system, and the results of field test demonstrated that planters equipped with the mechatronic driven system were suitable for high speed planting. Li (2006) employed an optoelectronic wheel speed sensor

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to measure travel speed, and a seed meter was driven by a stepper motor to dynamically adjust the meter rotation speed. Tang (2009) employed a Hall-effect sensor to measure planter travel speed, upon which the meter control was based. He (2013) developed a wheat planter control system using a stepper motor, and conducted some experimental research. Studies of electric-driven seed meters in China have predominantly employed a stepper motor with open loop control. However, the torque required by a seed meter often varies considerably in actual practice, and may cause the stepper motor to lose steps. Also a stepper motor has limited driving torque at high rotational speeds, which impacts the precision of planting, and limits further improvement in the planting speed.

The present study was conducted to solve the high cost of imported control system and the low performance of domestic control system by (1) developing a practical and cost-effective control system for an electric-driven seed meter; (2) developing a pro portional-integral-derivative (PID) control algorithm with appropriately tuned parameters to improve the response time of motor rotation and control accuracy, resulting in enhanced planting quality under high speed conditions; (3) conducting experiments to validate the performance of the proposed control system under actual field conditions.

## 2. Materials and methods

### 2.1. Modification of the seed meter for electric drive

The seed meter used in this study is an air-pressure precision seed meter (Shi et al., 2014, 2015) developed by the corn mechanization lab of China Agricultural University. A study by Shi (2015) demonstrated that this meter is suitable for high speed planting because it can achieve over 98% singulation under travel speed from 4 to 14 km/h with a seed spacing of 25 cm in laboratory bench testing. Additionally, the moving component of this meter has small rotational inertia due to the light weight of its seed plate, and thus the seed meter is easily to be driven by a motor.

The meter was modified for this study, as shown in Fig. 1, by adding a ring gear at the back of the seed plate. A small gear driven by a drive motor was mounted along the perimeter of the seed meter to engage the ring gear. The ratio of the small gear to the ring gear is 1:5. Driving the seed meter from a point near its circumference reduces the motor toque, and improves the stability of seed plate acceleration and deceleration, which, in turn, achieves better planting quality by avoiding excessive seed plate vibration.

### 2.2. Components of the electric-driven control system

The system designed for a four row planter consists of a control box, MT4414T touch screen display (Kinco Automation Inc, China), TRD-2T500BF incremental encoder (Koyo Electric Inc, Japan) to measure travel speed, four drive motors (Times Brilliant Electrical LLC, China), four seed meters, and power supply, as shown in Fig. 2. Most of the components used in the electric-driven control system are locally manufactured in China with a total cost less than $1000, as shown in Table 1, which is considerably less than similar systems from abroad (for example, the cost of the controller alone from Precision Planting LLC is greater than $5000 in the Chinese market).

A twelve volt tractor battery provides power for the entire electric-driven control system. The value of travel speed is measured by an incremental encoder that is mounted on the shaft of a ground wheel. With the rotation of the ground wheel, the encoder outputs corresponding pulses from which the controller can calculate travel speed by measuring the number of pulses received within a given time. The drive motors are brushless DC motors, each with three Hall-effect sensors mounted in the back for measuring the positions of the U, V, and W rotors, which realizes current switching for the rotors. Simultaneously, the three Hall-effect sensors measure the motor speed in real time to achieve closed-loop control. A touch screen display allows the entry of parameters such as seed spacing, wheel slip ratio, diameter of the ground wheel, and number of seed holes per disk, displays travel speed, and seed plate rotation speed, and sounds alarms to warn of system malfunction. The controller is the core of the system. Its main functionality is to output a pulse signal with a given frequency and duty cycle to control seed plate rotation speed based on travel speed to achieve uniform seed spacing.

### 2.3. Working principle of the electric-driven control system

Hardware structure of the electric-driven control system is illustrated in Fig. 3. The main controller incorporates an STM32F103VCT6 processor, and, in addition to communicating directly with the touch screen display via a MAX232 RS232 transceiver, it also receives the pulse signal from the incremental encoder by a PC357 optical coupler (OC), and calculates the current value of travel speed. Based on travel speed and planting parameters pre-entered from the display interface, the main controller calculates the target value of seed plate rotation speed and transmits this value in pulse format to the auxiliary controller via a dedicated

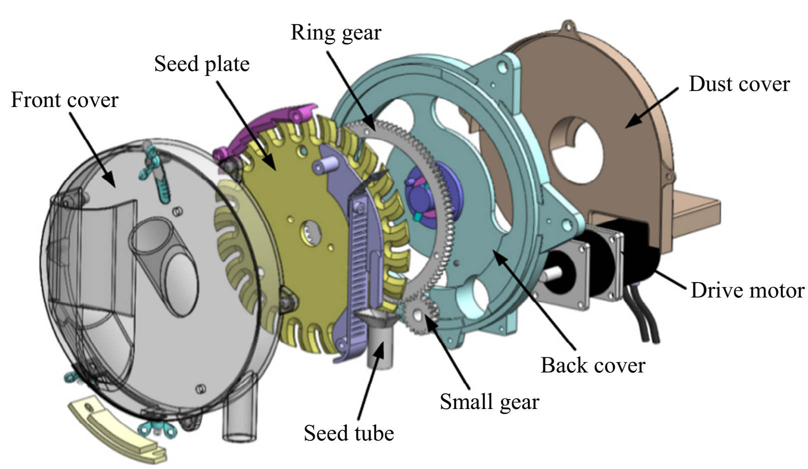


**Fig. 1.** Modification of the air-pressure precision seed meter for electric drive.

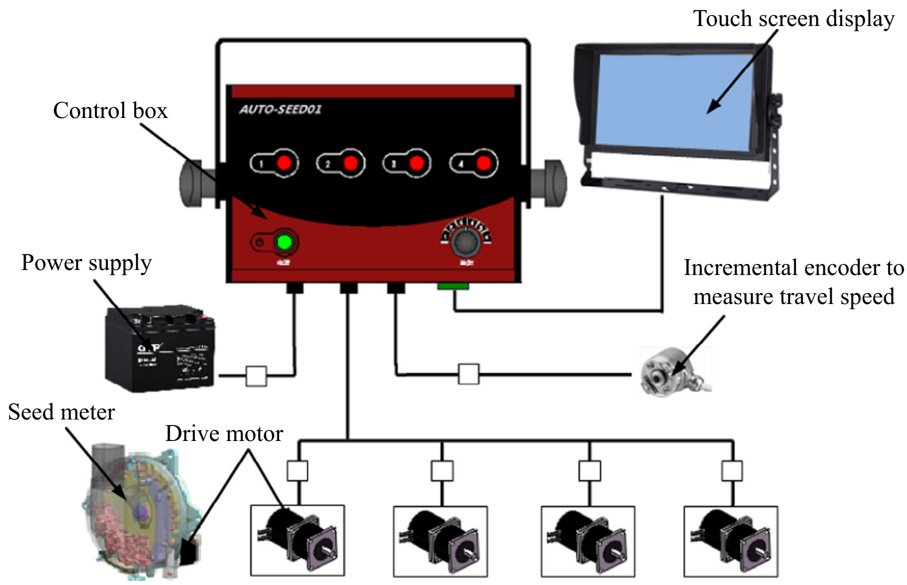


**Fig. 2.** Components of the electric-driven control system.

**Table 1**
The price list of components used in the electric-driven control system.

| | Number | Unit price (USD) | Total price (USD) |
|---|---|---|---|
| Control box | 1 | 286 | 772 |
| Touch screen display | 1 | 177 | |
| Incremental encoder | 1 | 53 | |
| Driver motor | 4 | 64 | |

OC. The auxiliary controller converts the pulse into the target value of seed plate rotation speed, compares the target value with the actual value of seed plate rotation speed measured by the Hall-effect sensors, and executes the PID control algorithm to control the motor speed. The four auxiliary controllers respectively control the four drive motors employed for the four rows of the planter. The software control flow of the system is illustrated in Fig. 4.

### 2.4. Determining the target value of seed plate rotation speed

The method by which the main controller calculates travel speed, and then converts this into the target value of seed plate rotation speed is discussed as following.

$$V = 0.036 \cdot \frac{\pi DNS}{T_p M} \tag{1}$$

where $V$ is travel speed (km/h), $D$ is diameter of the ground wheel (cm), $N$ is number of pulses from the incremental encoder within a period ($T_p$, s), $S$ is wheel slip ratio (%), $M$ is resolution of the encoder (pulses/revolution [rev]). The target value of seed plate rotation speed ($W$, rev/min) is calculated according to seed spacing ($Z$, cm), number of seed holes per disk ($H$), and travel speed ($V$, km/h) as

$$W = \frac{5000}{3} \cdot \frac{V}{HZ} \tag{2}$$

### 2.5. Closed-loop PID control of seed plate rotation speed

A PID controller is a control loop feedback mechanism commonly used in various control systems (Skogestad, 2003; Bucz and Vesely, 2012). A PID controller continuously calculates an error value as the difference between a target set point and a measured process variable, and employs a linear combination of the proportional error, integral error, and differential error as the control input. It is a simple algorithm with high reliability to get faster response time (Chen et al., 2008). This study thus employs a

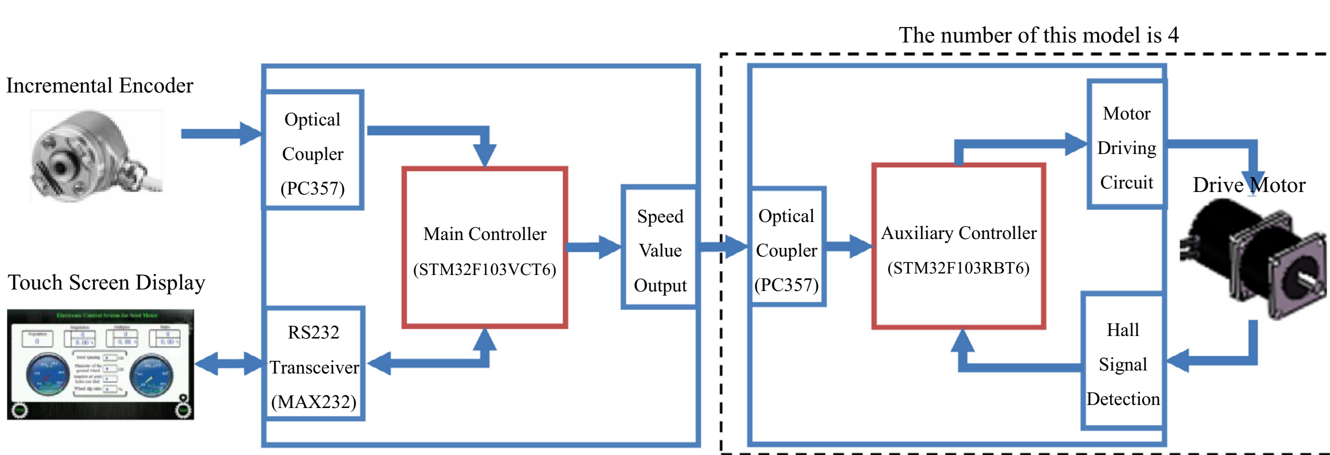


**Fig. 3.** Hardware structure of the electric-driven control system.

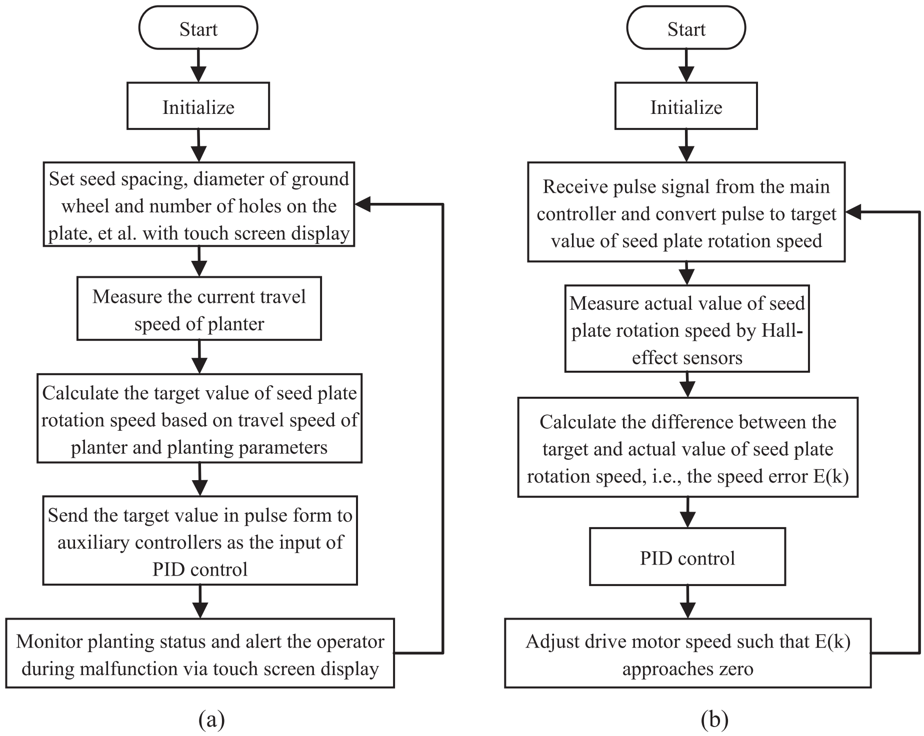


**Fig. 4.** (a) Flow chart of the main controller operation. (b) Flow chart of the auxiliary controller operation.

closed-loop PID to realize seed plate rotation speed control for improving the seed meter's dynamic response and the resulting planting quality.

Fig. 5 presents a schematic diagram illustrating the PID control method employed for controlling seed plate rotation speed in this study. The auxiliary controller receives the target value of seed plate rotation speed from the main controller and the actual value of seed plate rotation speed from the Hall-effect sensor, and calculates the error ($E(t)$, rev/min) between the target and actual values of seed plate rotation speed at a time ($t$). The control system uses a power MOSFET to control the speed of the motor by varying the control signal's duty cycle ($P_w(t)$), resulting in a varying voltage applied to the motor until $E(t)$ approaches zero. The mathematical expression of the control signal is expressed as

$$P_w(t) = K_P e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{3}$$

where $K_p$, $K_i$, and $K_d$ represent the gain constants associated with the proportional error, integral error, and differential error (i.e., the PID parameters), respectively. Eq. (4) is then discretized into sampling points $k$ to provide a discrete duty cycle ($p_w(k)$) according to $T_p$ for software implementation. To reduce the computation cost, the discrete PID is calculated incrementally according to the difference in $p_w(k)$ between successive sampling points $k$, $k-1$, and $k-2$ (i.e., $\Delta p_w(k)$) as follows.

$$\begin{aligned}\Delta p_w(k) &= p_w(k) - p_w(k-1) \\ &= K_P[e(k) - e(k-1)] + K_i e(k) + K_d[e(k) - 2e(k-1) + e(k-2)]\end{aligned} \tag{4}$$

Here, $e(k)$ is the discrete error (rev/min).

### 2.6. Building simulation model of the closed-loop PID control

With PID algorithm, the function block diagram of closed-loop PID control of seed plate rotation speed is built as Fig. 6.

$G_m(s)$ is core of closed-loop PID control of seed plate rotation speed and can be solved by following steps.

Base on Kirchhoff's law of voltages for the rotor network, the equation is

$$L\frac{di}{dt} + iR + E_d = U \tag{5}$$

where $L$, $R$, $i$ are armature inductance (H), resistance (Ω) and armature current (A), respectively, the $E_d$ is back emf (V) which is proportional to angular velocity of the motor ($W_1$, rad/s).

$$E_d = K_d W_1 \tag{6}$$

Here, $K_d$ is the back emf constant (Vs/rad).

The shaft torque ($M$, Nm) is used for driving load against the inertial and load torque ($M_L$, Nm), on the basis of theorem of motion of mass center,

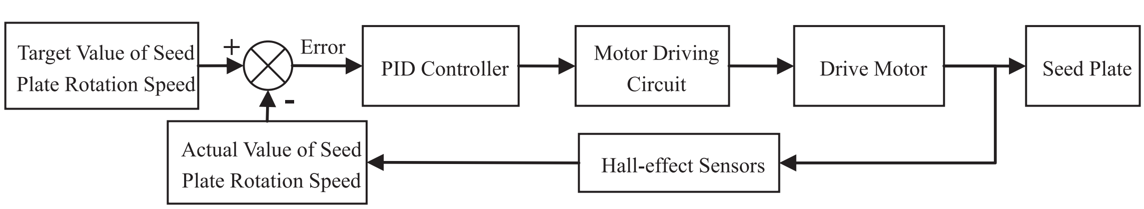


**Fig. 5.** Schematic illustrating the PID control method for controlling the seed plate rotation speed.

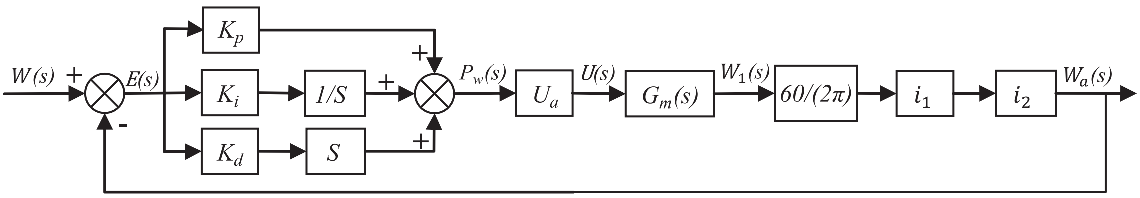


**Fig. 6.** The function block diagram of closed-loop PID control of seed plate rotation speed. Where $W(s)$, $W_a(s)$ are transfer function of target and actual value of seed plate rotation speed, respectively, $U_a$ is power supply voltage ($U_a = 12$ V), $U(s)$, $W_1(s)$ are transfer function of inputted armature voltage and outputting angular velocity of the motor, respectively, $G_m(s)$ is transfer function of the drive motor, $60/(2\pi)$ is used to convert unit of rad/s to unit of rev/min, $i_1$, $i_2$ are reducing ratio of motor reducer ($i_1 = 1/10$) and ratio of the small gear to the ring gear ($i_2 = 1/5$), respectively.

$$M = J\frac{dw_1}{dt} + M_L = K_m i \quad (7)$$

where $J$ is the total moment of inertia of the motor spindle (kg m$^2$), $K_m$ is torque constant (Nm/A).

Take (5), (6), and (7) into Laplace transform, respectively, the equations can be described as Fig. 7, which is also $G_m(s)$ 's function block diagram. Combining Figs. 6 and 7, the simulation model of the closed-loop PID control was built. The parameters of the drive motor are shown in Table 2.

### 2.7. Simulation of PID tuning methods

A simple method to get the parameters of a PID controller developed by Ziegler and Nichols and published in 1942 is known as ZNM (Ziegler and Nichols, 1942). This method is applied to plants with the open loop step responses of the form displayed in Fig. 8. The response is characterized by two parameters, the delay time ($L$, s) and the time constant ($T$, s), which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady-state level line (Meshram and Kanojiya, 2012). The PID parameters of the ZNM is determined in Table 3.

CCM and CHRM are another two versions of Modified Ziegler-Nichols PID tuning method (Neil, 2002), which are also based on the open loop step responses displayed in Fig. 8 and provide a better way to select a compensator for process control applications. The PID parameters with this two method are designed by the direct use of Table 3 (where $\tau = L/(L + T)$).

In order to evaluate the performance of the three PID tuning methods above and select a proper method applied in the electric-driven control system of seed meter, the three tuning methods were implemented by Matlab-Simulink. With the open-loop step response of open-loop control of seed plate rotation speed (the delay time and the time constant were got as L = 0.021 s, T = 0.118 s) and calculation formulas of PID parameters in Table 3, PID parameters of the three tuning methods were determined ($K_p$ = 6.743, $K_i$ = 160.548, and $K_d$ = 0.071 for ZNM, $K_p$ = 7.828, $K_i$ = 159.755, and $K_d$ = 0.059 for CCM, $K_p$ = 5.338, $K_i$ = 32.352, and $K_d$ = 0.534 for CHRM). The Simulink model of closed-loop PID control of seed plate rotation speed was built in Fig. 9. Fig. 10 and Table 4 showed the simulation result of the step response of closed-loop PID control of seed plate rotation speed.

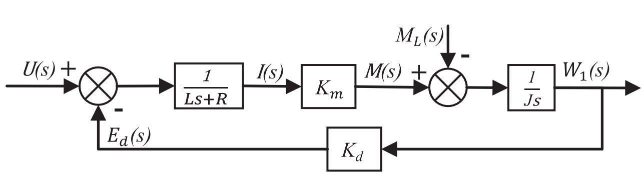


**Fig. 7.** Function block diagram of the drive motor.

**Table 2**
The parameters of the drive motor.

| Parameter | Value |
|---|---|
| L | 0.021 H |
| R | 1.15 Ω |
| $K_m$ | 0.055 Nm/A |
| $M_L$ | 0.064 Nm |
| J | $3.11 \times 10^{-4}$ kg m$^2$ |
| $K_d$ | $5.763 \times 10^{-2}$ Vs/rad |

Comparisons of the maximum overshoot, rise time and settling time for each tuning method are presented in Fig. 10 and Table 4, and it is clear that CCM gives a better performance with smallest rise time of 0.018 s, settling time of 0.082 s and maximum overshoot of 26.1%, so the CCM was adapted by this paper and the final tuned PID parameter values are $K_p$ = 7.828, $K_i$ = 159.755, and $K_d$ = 0.059.

## 3. Field experiments

Field experiments were conducted on September 25th, 2015 in Liu Quan, Guan County, Hebei Province to evaluate the performance of the proposed system.

### 3.1. Testing method

Experiments were conducted using the 2BYDJ-4 model precision corn planter developed by China Agricultural University shown in Fig. 11. The planter was pulled by a John Deere 820 tractor made in Tianjing, China. The proposed system, including the touch screen display, seed meter, and control box was installed. The incremental encoder was mounted on a ground wheel, of which diameter is 70 cm. In all experiments, seed spacing is 25 cm, and wheel slip ratio is 18%. A 200 m length field plot was plowed, which includes 10 m start and stop zones. Prior to testing, the tractor power takeoff (PTO) was engaged, and the PTO shaft was adjusted to ensure a seed meter pressure of 3.0 kPa with a deviation of 0.2 kPa.

Experiments were designed to evaluate the performance of the system under three values of travel speed (8, 10, and 12 km/h). The actual value of travel speed cannot be controlled precisely during testing, so the actual value was based on the average measured value of travel speed obtained using a stop watch with a measurement error of ±1 s. After the completion of testing, three zones were randomly selected from the testing plot to measure 250 seed spacing intervals. Data were processed according to the China National Standard GB/T 6973-2005 (2005). The three zones were processed independently, and were then averaged together in the end. The planting uniformity in the row was analyzed using the methods described by Kachman and Smith (1995). QFI is the percentage of plant spacings that are more than half but no more than 1.5 times the nominal spacing and indicates the percentages of sin-

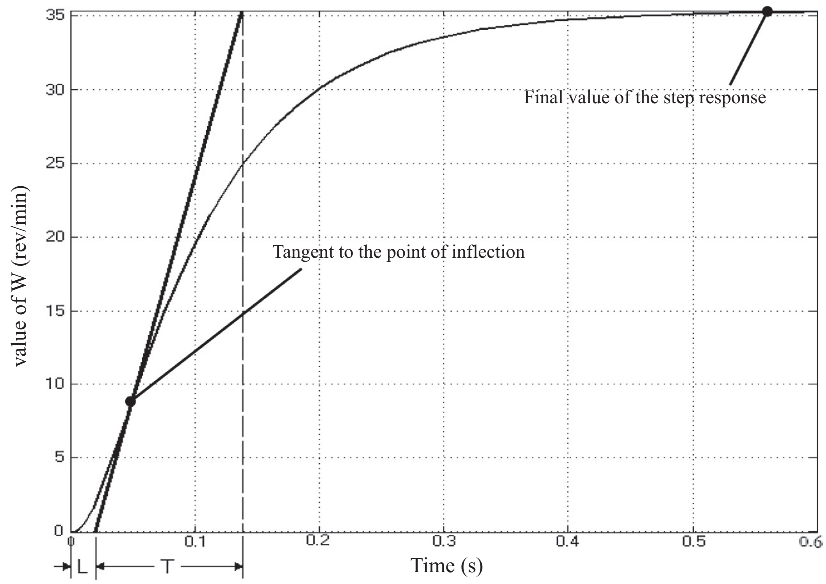


**Fig. 8.** The open loop step response of open-loop control of seed plate rotation speed.

**Table 3**
Calculation formulas of PID parameters.

| Tuning method | *Kp* | *Ti* | *Td* |
|---|---|---|---|
| ZNM | $1.2\frac{T}{L}$ | $2L$ | $\frac{L}{2}$ |
| CCM | $\frac{1.35T}{L}\left(1+\frac{0.18\tau}{1-\tau}\right)$ | $\frac{2.5-2\tau}{1-0.39\tau}L$ | $\frac{0.37-0.37\tau}{1-0.81\tau}L$ |
| CHRM | $0.95\frac{T}{L}$ | $1.4T$ | $0.47L$ |

gle seed drops. MI is the percentage of seed spacings that are greater than 1.5 times the nominal seed spacing and indicates the percentage of missed seed locations or skips. PREC is the coefficient of variation of the spacings (length) between the nearest seeds in a row that are classified as singles after omitting the outliers consisting of misses and multiples. The calculation formulas for QFI, MI and PREC are as follows.

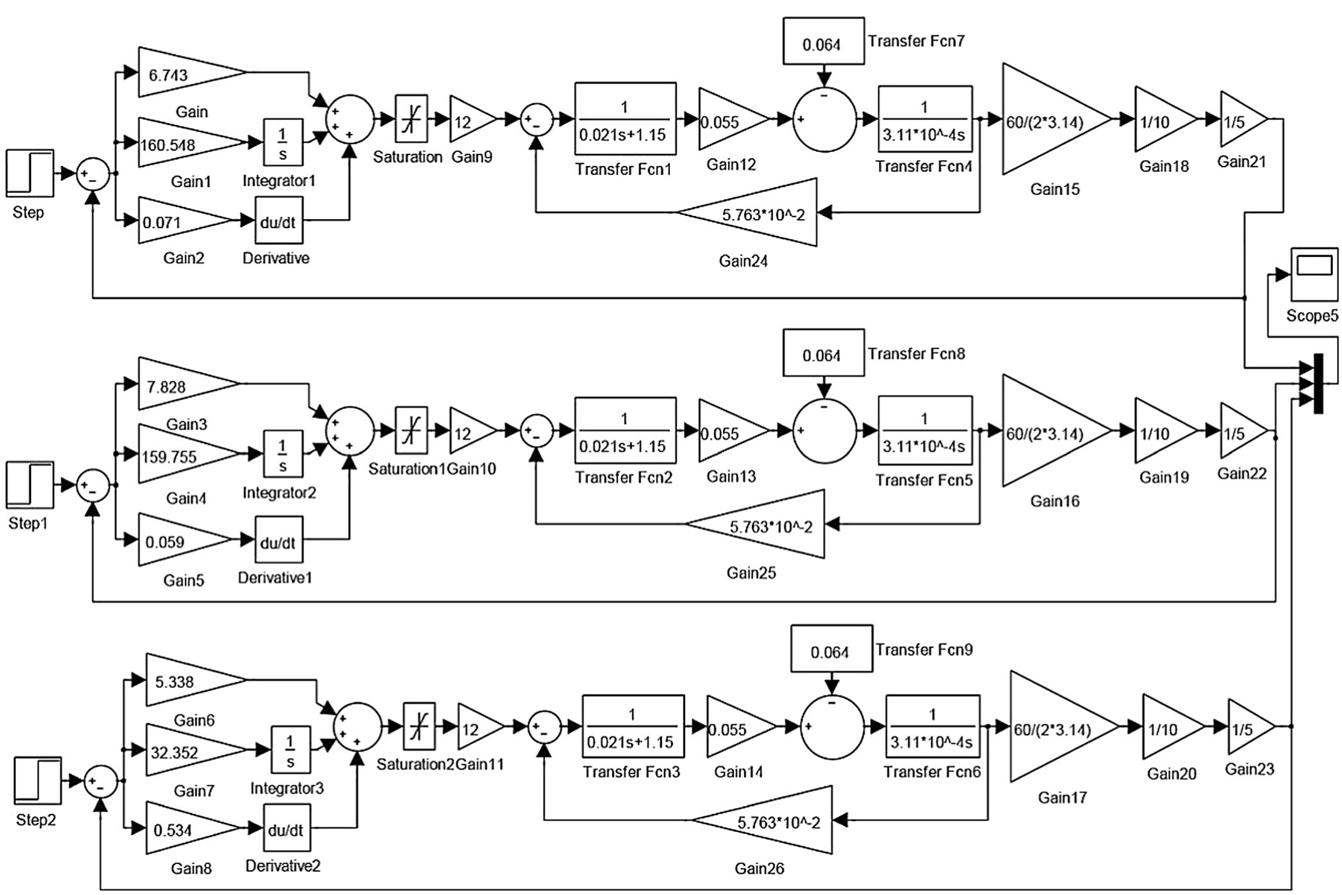


**Fig. 9.** The Simulink model of closed-loop PID control of seed plate rotation speed.

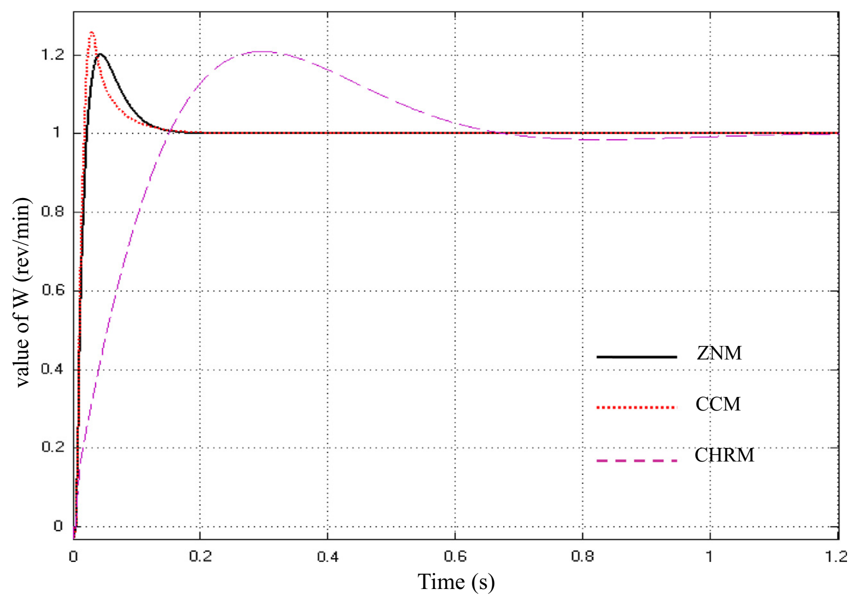


**Fig. 10.** The curve of the step response of closed-loop PID control of seed plate rotation speed.

**Table 4**
The results of simulation.

| Tuning method | Maximum overshoot (%) | Rise time (s) | Settling time (s) |
|---|---|---|---|
| ZNM | 20.3 | 0.023 | 0.1 |
| CCM | 26.1 | 0.018 | 0.082 |
| CHRM | 20.9 | 0.151 | 0.556 |

*Note:* Settling time was set within a range of 5% of the final value.

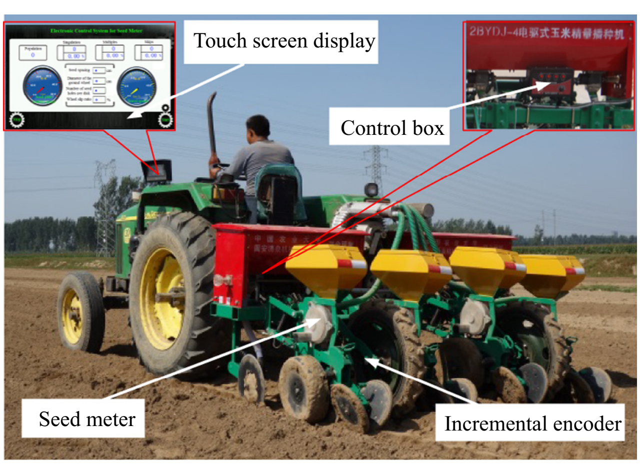


**Fig. 11.** Field experiment conditions.

$$QFI = \frac{n_1}{N} \times 100\% \tag{8}$$

$$MI = \frac{n_0}{N} \times 100\% \tag{9}$$

$$PREC = \frac{S}{\bar{x}} \times 100\% \tag{10}$$

where, $N$ is the total number of seed spacing and $x_i$ is the nth seed spacing (cm). $n_1$ is the number of qualified spacing: $n_1 = \sum n_i$, $\{x_i \in (0.5\bar{x} \sim 1.5\bar{x})\}$. $n_0$ is the number of miss seeding: $n_0 = \sum n_i$, $\{x_i \in (1.5\bar{x} \sim +\infty)\}$. $S$ is the standard deviation of seed spacing: $S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$. $\bar{x}$ is the average seeds spacing (cm): $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$.

### 3.2. Results and discussion

The experimental results are summarized in Table 5. As shown in the table, with increasing travel speed, the QFI for all four planting rows decreased, while the MI and PREC both increased, which are results that are strongly supported by the work of Liu et al. (2004). Further analysis shown in Fig. 12 indicates that, when travel speed increased from 8.6 km/h to 10.3 km/h, the QFI, MI, and PREC values of all four planting rows changed only moderately. However when travel speed changed from 10.3 km/h to 13.0 km/h, the QFI, MI, and PREC values changed appreciably, particularly for the 1st and 3rd rows. This change was possibly caused by the use of conventional seed tubes during testing, which allows the seed to bounce and roll inside the tube and in the trench during high speed planting. Some studies (Chen and Zhong, 2012; Zhou et al., 2014) have shown that seeds increasingly bounce and roll in the trench as planting speeds increase when employing a conventional seed tube, which alters the seed spacing especially at high speed. As a result, John Deere and Precision Planting LLC developed belt delivery systems that eliminate bounce and roll by conveying seeds from the seed meter to the trench by a belt, and ensure the uniformity of seed spacing under high speed conditions. Fig. 12 also shows that the QFI, MI, and PREC values are consistent among all four rows at a given travel speed. This implies that the electric driven system enhances the uniformity of all planting rows.

The presented analysis indicates that the planter has good uniformity for all planting rows at a given travel speed, and good uniformity across different values of travel speed. For a speed of 8.6 km/h, the average QFI, MI, and PREC values are 98.62%, 1.29%, and 14.51%, respectively, which are much better than the minimum standards set by China Machinery Industry Standard JB/T 10293-2013 (2013). These values are also better than the values obtained with a conventional ground wheel and chain driven planter employing equivalent seed meters under equivalent working

**Table 5**
The results of field experiments.

| Average travel speed (km/h) | 8.6 | | | | 10.3 | | | | 13.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Row number | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| QFI (%) | 98.43 | 98.81 | 98.81 | 98.41 | 98.04 | 98.43 | 98.02 | 98.04 | 96.9 | 97.28 | 96.9 | 97.28 |
| MI (%) | 1.57 | 1.19 | 1.19 | 1.19 | 1.96 | 1.57 | 1.58 | 1.96 | 3.1 | 2.72 | 3.1 | 2.72 |
| PREC (%) | 14.38 | 14.71 | 14.41 | 14.55 | 14.94 | 14.99 | 14.83 | 15.05 | 15.95 | 15.69 | 16.04 | 15.69 |

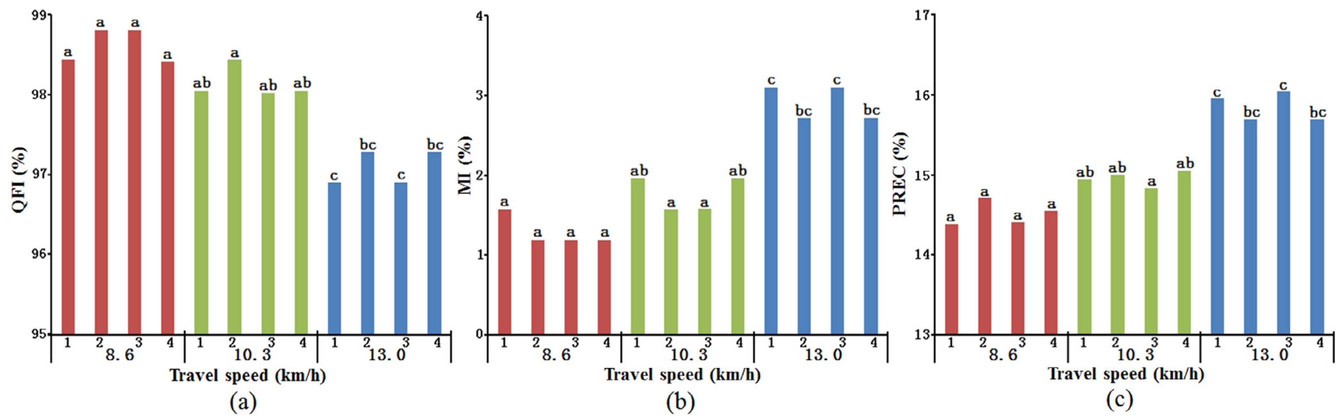


**Fig. 12.** (a) QFI of the four planting rows under three different travel speeds. (b) MI of the four planting rows under three different travel speeds. (c) PREC of the four planting rows under three different travel speeds. Columns labeled with equivalent letters are not significantly different ($p < 0.05$).

conditions, which achieves QFI, MI and PREC values of 97.87%, 1.69%, and 17.79%, respectively, at a maximum travel speed of only 7.89 km/h (Shi et al., 2014)). Even at a high speed of 13.0 km/h, the average QFI, MI, and PREC values still are 97.07%, 2.9%, and 15.8%, respectively, which is hard to reach for conventional ground and chain driven planter as it's planting quality declines quickly at high speed. What's more, the components of the electric-driven control system are easier to be installed or maintained during use for its a few number of components and eliminating complicated chain driven mechanism. Thanks to application of computers and electronics technology, the planter with the electric-driven control system is also more intelligent and easy-to-use.

## 4. Conclusions

This study developed an electric-driven planter control system to replace ground wheel and chain driven systems for improving planting quality, and conducted field experiments using a 2BYDJ-4 precision corn planter. The conclusions of the research can be drawn as follows.

(1) Comparing performance of three PID tuning methods (ZNM, CCM, and CHRM) by Matlab-Simulink, and results testified CCM gives a much better performance with smallest rise time of 0.018 s, settling time of 0.082 s and maximum overshoot of 26.1%, then the final tuned PID parameter values are determined as Kp = 7.828, Ki = 159.755, and Kd = 0.059.

(2) The results of field experiments indicate that the four-row planter equipped with the proposed electric-driven control system demonstrated good seeding uniformity among all four planting rows and consistent precision under various travel speeds. For the four rows under a travel speed of 8.6 km/h, the average values of the QFI, MI, and PREC in seed spacing were 98.62%, 1.29%, 14.51%, respectively. Under a high travel speed of 13.0 km/h, the average QFI still achieved a value of 97.09%. Compared with a ground wheel and chain driven planter under equivalent working conditions, the QFI, MI, and PREC all demonstrated an apparent improvement.

(3) Most of the components employed in the proposed system are locally manufactured in China, and the overall system cost is much less than similar systems obtained from abroad, making the system accessible to precision planters in developing countries.

## Conflict of interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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