

Development and evaluation of a low-cost precision seeding control system for a corn drill

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Abstract: Precision seeding requires that the corn drill drop seeds into the soil by a specific in-row spacing while its travelling speed fluctuates due to unevenness of the field ground. This paper presents a low-cost precision seeding control system for a conventional corn drill with mechanical metering devices of finger-pickup type. A median filtering method was implemented in the control system to process measurements from a rotary encoder in order to acquire stable values of the corn drill travelling speed. The metering unit was driven by an electric motor controlled by the metering ECU according to the actual travelling speed and the desired in-row spacing in real-time. A user interface was programmed to communicate with ECUs for configuring parameters and displaying operating information during working. The newly-developed precision seeding control system was first calibrated in terms of speed measurement and control for two ECUs. Experiments were conducted on a seeding test platform in the laboratory for evaluating its accuracy in dropping seeds by giving different in-row spacing under different travelling speeds of the conveyor sticky belt. Results showed that the average spacing error was less than 2 cm and the maximum RMS error was 0.78 cm for all spacing values including 25 cm, 30 cm and 35 cm under the travelling speed of 1.0-8.0 km/h. These indicated that the low-cost precision seeding control system worked in a both accurate and stable way.

Keywords: precision seeding, corn drill, control system, travelling speed, in-row spacing

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1 Introduction

With the development of precision farming in smart agriculture, variable rate application (VRA) has been becoming increasingly popular, which is intended to make full use of investment of seeds, fertilizers and pesticides according to site-specific management principles within one field. The performance of an active optical sensor for variable N rate fertilization was evaluated to minimize N surplus in areas of lower productivity and to improve the sustainability of N management overall^[1]. An on-the-go visible and near infrared soil sensor was used to optimize the prescription map for VRA of the elemental P^[2]. Environmental benefits of variable rate N fertilizer and cost was demonstrated by presenting experimental results of applying two N rates in each of three management zones^[3]. Due to increasing of N fertilizer price, some experiments conducted to determine seed yield response to N fertilization and to evaluate if NDVI values reliably predicted the N status in Italian ryegrass seed crops in order to achieve rationalized fertilizer applications^[4]. An automatic system was developed for variable rate control of fertilizer application by using a hydraulic motor to drive the dispenser at a desired rotation speed according to prescription maps^[5]. And application errors decreased when the

resolution varies in 1-5 m with a constant width of 3.5 m due to the dynamic response of the dosage system. An electromechanical system was designed to be capable of following-up the tree canopy at a constant distance to reduce the toxicity risk for the worker^[6]. Besides, LiDAR sensors, laser range finders or ultrasonic sensors were utilized to detect the canopy volume and a controller determined a flow rate for adjustment of variable-rate valves^[7-12]. This spraying method reduced the amount of agrochemicals under the background of precision horticulture, compared with conventional pesticide application methods. An existing GPS-based variable-rate fertilizer spreader was modified into a site-specific one by using machine vision to estimate the target volume^[13]. A DC electric variable-rate controller was presented to change the metering shaft speed in real-time by comparing the drill position and moving velocity with reference data in the prescription map^[14]. A fertilizer applicator was evaluated in terms of its accuracy, response time, uniformity in the field within its working speed range^[15]. The position of a soil sensor installed on a variable rate fertilizer application system was optimized by measuring the lag time between acquiring the information on soil phosphorus from the soil sensor and changing the fertilizer rate on the fertilization system^[16]. Methods for VRA in those studies could be generally based on maps or sensors.

A full-factorial field trial was conducted on a farmer's field to test adaptations of tillage (conventional tillage 'CT' vs. no-tillage 'NT'), seeding depth (deep 6.5 cm vs. shallow 4.5 cm) and seeding rate (high 600 grains/m² vs. reduced 450 grains/m²) for potential to increase water use efficiency and grain yield in spring wheat. Results showed that high seeding rates resulted in more reproductive ears whilst reduced seeding rates produced more grains^[17]. The highest yields of 3.19 t/hm² was observed in 2014

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with NT, deep seed placement and high seeding rate, and 3.82 t/hm² in 2015 with NT, deep seed placement and reduced seeding rate, respectively. Row spacing and seeding rate was evaluated with respect to effects on yield and plant stand characteristics of high-biomass sorghum^[18]. And it was concluded that narrower row spacing (19 cm) provides the maximum yield benefit by significantly increasing stem density, and low seeding rates (116 000 seeds/hm²) are preferable because higher seeding rates do not positively affect yield and may cause morphological changes (i.e. taller plants with thinner stems) conducive to lodging. Therefore, the seeding rate is an important factor that affects profits in agricultural production. And this requires that grain drills be equipped with variable rate functions.

The objective of this research was to develop a precision seeding system at a low cost for a corn drill that was commercially available on the market with finger-pickup-type mechanical metering devices. One of the seeding units was modified by using an electric motor to provide driving torque to the metering roller instead of the land wheel. The motor could continuously adjust the rotating speed of the metering unit according to the travelling speed of the corn drill to ensure constant in-row spacing. A metering ECU was developed to control the electric motor in real-time by implementing a digital PID controller according to working parameters including the desired in-row spacing, the travelling speed and the number of metering holes. For evaluation of the newly-developed system, a series of tests were designed and

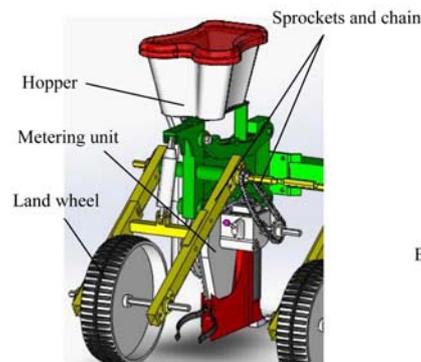
conducted in the laboratory by mounting the seeding unit on a seed drill test platform with a mounting frame, a sticky belt and an electrical operation system.

2 Materials and methods

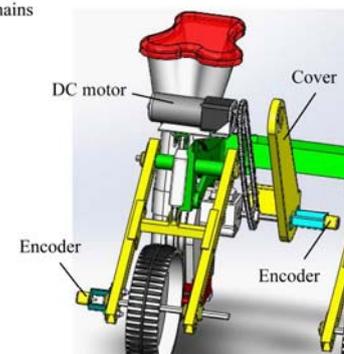
The corn drill platform in this research was a commercially-available product with four separate seeding units as shown in Figure 1a. Four seeding units were driven by land wheels through sprockets and chains as depicted in Figure 1b. The unit on the most left was modified in this research by using an electric motor with a reducer to directly drive its metering unit instead of the land wheel and the other three units remained as contrast ones for field tests in future work. Two rotary encoders of 600 PPR were used to measure the speed of the land wheel and the metering unit, respectively. A speed electronic control unit (ECU) was developed to calculate the traveling speed by reading signals from the encoder connected to the land wheel axis and transferred information in real-time through a CAN-bus communication network. A metering ECU determined appropriate voltage signals for the motor driver to maintain the metering unit at a desired rotating speed in relation to the travelling speed and the desired in-row spacing. A 4.3-inch touch screen with a RS232 port as the user interface provides functions for setting working parameters and displaying states of working components in real-time. Figure 2 illustrates the low-cost precision seeding control system with a reserved node for integrating other devices like an RTK-GPS receiver in future work.



a. Overall appearance



b. Metering unit driven by land wheels



c. Metering unit driven by a DC motor

Figure 1 Corn drill with four seeding units

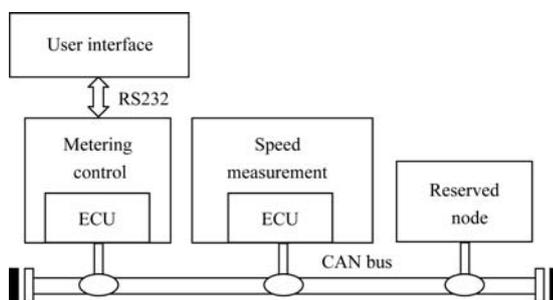


Figure 2 Precision seeding control system

Parameters and variables in this research are listed in Table 1.

2.1 Calculation of travelling speed

For realizing precision seeding, true travelling speed of the corn drill needed to be detected in real-time. Since slip existed between tractor wheels and the ground, the encoder was attached to the land wheel for measuring its rotating speed as shown in Figure 1c. Since the land wheel subjected to no load, we considered that its rotation could exactly represent the travelling speed. The speed ECU read and counted pulses from the rotary encoder connected to the rotating axle of the land wheel by a fixed time

Table 1 Parameters and variables

Variable	Description	Unit
V_i	Travel speed of the corn drill	m·s ⁻¹
D	Diameter of the land wheel	m
C_i	The number of pulses	/
ΔT	Time interval	s
N	Resolution of the encoder	/
K	Window size of the median filter	/
S_d	Desired rotating speed	r·min ⁻¹
V	Travel speed	km·h ⁻¹
D_d	Desired spacing	cm
D_a	Actual spacing	cm
M	The number of metering holes	/
V_i	Speed signal	volt
S_a	Actual rotating speed	r·min ⁻¹
e	Difference between S_a and S_d	r·min ⁻¹
K_P	Coefficient for the proportional term	/
K_I	Coefficient for the integral term	/
K_D	Coefficient for the derivative term	/
S'_a	Rotating speed by the rotary meter	r·min ⁻¹
k_S	Adjustment coefficient	/

interval ΔT , calculated the travel speed V_i by using Equation (1), and distributed the speed information to the metering ECU through the CAN-bus network and the user interface through the RS232 port.

$$V_i = \frac{\pi DC_i}{N \cdot \Delta T} \quad (1)$$

where, D is the land wheel diameter, m; C_i is the number of pulses in ΔT , and N is the encoder resolution in pulse per revolution.

In consideration that speed measurements were noisy due to unevenness of the field ground, a median filtering method was used to pre-process travelling speed measurements by a window size of K as represented by Equation (2). K measurements were firstly sorted numerically and the middle value was considered as the travelling speed value.

$$V = \text{Median}[V_i]_{i=0}^{K-1} \quad (2)$$

2.2 Control of metering unit

The metering unit was driven directly by the DC motor to drop seeds at a desired rotating speed that was calculated by using Equation (3) and controlled in real-time according to the varying travelling speed. Figure 3 shows the metering unit control system.

$$S_d = 1666.67 \times \frac{V}{D_d M} \quad (3)$$

where, M is the number of holes of the metering unit; S_d , V and D_d are in r/min, km/h and centimeters, respectively.

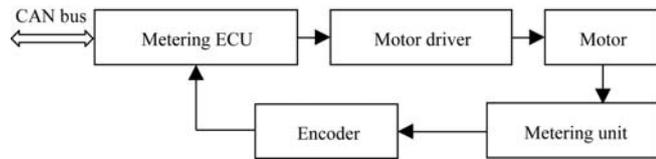
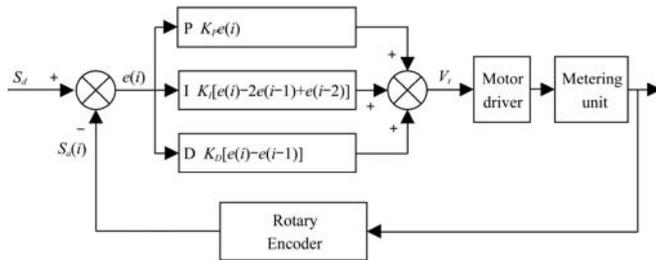


Figure 3 Metering unit control system

The rotating speed of the seed metering unit was fed back to the metering ECU and a digital PID controller was implemented in the metering ECU to determine an appropriate control signal V_i to the motor driver as shown in Figure 4.



Note: S_d – Desired rotating speed, $S_a(i)$ – Actual rotating speed, $e(i)$ – the difference between S_a and S_d , K_p , K_i and K_d are PID parameters.

Figure 4 Digital PID controller for precision seeding

3 Results and discussion

Experiments were designed and conducted on the seeding drill test platform with a sticky belt of 5 m in length in the laboratory as shown in Figure 5. The sticky belt was driven by a frequency-conversion motor at a speed ranging at 0-12 km/h to simulate relative movement between the drill and the ground. Basic parameters including N and M , were set to 600 and 12, respectively, by using the RS232 touch screen according to the encoder and the metering unit used in this research. ΔT was fixed for each ECU and needed to be calibrated by experiments.



Figure 5 Installation of main components for laboratory tests

3.1 Calibration of rotating speed measurement of the metering unit

In order to control its rotation speed at a desired value S_d by using the digital PID controller, the actual rotating speed S_a of the metering unit was sampled at a certain interval, which needed to be calibrated in terms of its true value S'_a because the time spent on the commands execution loop by different ECUs was different and the sampling interval was different.

The metering unit was driven by the DC motor at different speeds as shown in Table 2 according to measurements of a rotary meter. And measurements by the speed ECU were recorded and listed correspondingly. The adjustment coefficient was calculated by Equation (4):

$$S'_a = k_S S_a \quad (4)$$

where, S'_a is the rotating speed measured by the rotary meter; S_a is the rotating speed measured by the developed metering ECU.

From Table 2, it is noticed that values of S_a are a little smaller than those of S'_a . And k_S is set to the average value of k_S for the meter ECU in this research. Similar calibration was conducted for the speed ECU as shown in Table 2 and k_S is set to 1.26 as its average value.

Table 2 Calibration results for the metering ECU

$S'_a/\text{r}\cdot\text{min}^{-1}$	7.98	17.17	26.63	36.29	46.41	56.28	66.64	76.81	87.47	97.40	108.06
$S_a/\text{r}\cdot\text{min}^{-1}$	7.91	16.97	26.45	36.22	46.14	56.03	66.24	76.37	86.96	97.02	107.61
k_S	1.008	1.012	1.007	1.002	1.006	1.004	1.006	1.006	1.006	1.004	1.004

Table 3 Calibration results for the speed ECU

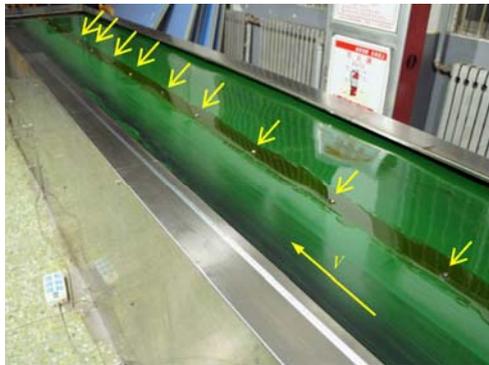
$S'_a/\text{r}\cdot\text{min}^{-1}$	7.97	17.34	27.02	36.99	46.86	57.02	66.90	77.11	87.34	97.38	107.69
$S_a/\text{r}\cdot\text{min}^{-1}$	6.27	13.76	21.42	29.27	37.21	45.30	53.22	61.30	69.41	77.39	85.51
k_S	1.270	1.260	1.262	1.264	1.259	1.259	1.257	1.258	1.258	1.258	1.259

3.2 Evaluation in the laboratory

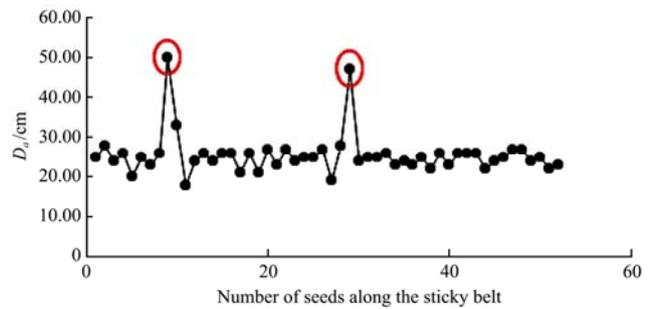
To verify its validation in precision seeding, the newly-developed low-cost precision seeding control system was

tested on the seeding drill test platform in the laboratory as show in Figure 5. The metering unit with 12 holes was fixed on the planting unit placed on the test platform with the drill outlet 50 mm

over the conveyer sticky belt to prevent seeds from bouncing when dropped on the sticky belt. The speed ECU was used to measure the sticky belt moving speed by reading pulses from the rotary encoder connected to the driving shaft of the sticky belt. And the metering ECU controlled the DC motor to rotate the metering unit through a sprocket and chain mechanism at a desired speed so that corn seeds could be dropped at a predetermined spacing. The test computer was used to record and analyze data streamed from the metering ECU through a RS232 serial port.



a. Seeds dropped on the sticky belt



b. Variation of D_a with two large deviations in red circles

Figure 6 Evaluation of precision seeding control

From Figure 6, it can be seen that the actual in-row spacing fluctuates around 25 cm. And there are two large values away from the desired spacing due to seeding absence of the metering unit. Such values would not be considered in evaluation of the system performance. More results in detail are listed in Table 4 with \bar{D}_a , e_{RMS} , e_{max} and \bar{S}_a are the average of D_a , the RMS error of D_a , the maximum value of D_a , and the average of S_d , respectively.

Table 4 Performance evaluation under different moving speed

$V/\text{km}\cdot\text{h}^{-1}$	D_d/cm	\bar{D}_a/cm	e_{RMS}/cm	e_{max}/cm	$S_d/\text{r}\cdot\text{min}^{-1}$	$\bar{S}_a/\text{r}\cdot\text{min}^{-1}$
1.06	25	24.59	0.39	6	5.89	6.10
	30	29.79	0.58	8	4.91	5.15
	35	34.58	0.74	8	4.21	4.18
2.13	25	24.79	0.55	8	11.83	12.26
	30	28.92	0.44	7	9.86	10.11
	35	33.71	0.83	12	8.45	8.83
3.06	25	24.80	0.41	9	17.00	17.56
	30	29.95	0.52	10	14.17	14.57
	35	33.97	0.69	8	12.14	12.49
4.02	25	24.78	0.26	5	22.33	23.30
	30	29.36	0.36	6	18.61	19.20
	35	33.89	0.67	12	15.95	16.53
5.05	25	24.60	0.35	8	28.06	29.02
	30	29.13	0.40	5	23.38	24.15
	35	34.00	0.37	4	20.04	21.53
6.02	25	24.48	0.51	9	33.44	34.24
	30	29.23	0.56	10	27.87	28.69
	35	34.12	0.65	11	23.89	25.66
6.95	25	24.74	0.43	7	38.61	41.04
	30	29.10	0.44	8	32.18	33.48
	35	33.59	0.50	5	27.58	28.65
8.03	25	25.04	0.50	7	44.61	44.50
	30	30.08	0.56	10	37.18	37.12
	35	33.47	0.78	11	31.87	32.24

The travelling speed V of the conveyer sticky belt was configured as different values ranging at 1.0-8.0 km/h and the desired in-row spacing D_d set to 25 cm, 30 cm and 35 cm for each speed value. The actual spacing D_a between two adjacent seeds was measured while the sticky belt stopped. Each parameter setting was repeated to acquire adequate data for evaluating the system performance. Figure 6 shows seeds dropped on the sticky belt and variation of D_a along the sticky belt length with V and D_d set to 5.0 km/h and 25 cm, respectively.

From Table 4, it is noticed that the average of D_a deviates less than 2 cm from the corresponding desired spacing D_d . e_{RMS} becomes larger when D_d is set from 25 cm to 35 cm when the belt speed remains the same because inaccuracy in speed control of the metering unit is amplified much more when the in-row spacing increases. Friction between working parts of the metering unit slightly varies when dropping seeds, which is the reason that the maximum error e_{max} occurs. Correspondingly, the desired rotating speed S_d is given, which covers a wide range from 4.21 r/min to 44.61 r/min. The average of S_a is larger than its corresponding S_d in most tests with a largest deviate of 2.43 r/min. This clearly explains that \bar{D}_a is smaller than D_d .

4 Conclusions

This research explored the possibility of developing a low-cost precision seeding control system that could continuously change the rotating speed of the metering unit by using an electric motor according to the travelling speed. A speed ECU was developed to read pulses from the rotary encoder attached to the land wheel, calculate and distribute the travelling speed through a CAN-bus network. The electric motor was controlled by the metering ECU to drop seeds at a desired in-row spacing while the travelling speed varied. Results in laboratory tests showed that the average of actual spacing D_a deviated less than 2 cm from the desired in-row spacing D_d and its maximum RMS error was 0.78 cm, which indicated that the newly-developed system worked accurately and stably under laboratory environments. In future work, field tests will be conducted to further verify and improve its performance in measurement of travelling speed and variable-rate control of metering devices, which contributes as a research foundation for affordable variable-rate seeding in the field of precision agriculture.

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