Method study for implantation positioning of corn seeds

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Abstract. To meet the needs of precision agriculture for crop location information, to achieve accurate plant position of crops, and to solve the problem of low resource utilization rate and high operation cost caused by repeated identification and positioning of plants in each part of field management, a seed positioning method was proposed by using maize planting as research object. A 4-row precision planter was used, all seed tubes were replaced with opto-electronic sensor (OE-sensor) equipped tubes to monitor seeds dropping. An RTK satellite receiver mounted on seeder frame girder provided global position. Furthermore, time and distance compensation model of seed from OE-sensor to implantation process was established based on EDEM numerical simulation. Seeds implantation location prediction and actual position measurement data acquisition programs were developed. Field test results showed that the mean, range and standard deviations (SD) of the longitudinal deviation between prediction location and actual position in operation direction were greater than vertical deviation which is perpendicular to operation direction. 87.7% of corn seeds dropped within 50mm from prediction location at operating speed of 3.2 km/h. This method can provide theoretical reference for synchronous generation of seed map in seeding process.

1. Introduction
Accurate plant positioning, which is conductive to improve resource utilization rate, saving agricultural costs and increasing farmers’ benefits by helping applying water, fertilizer and pesticides to crops accurately, plays a crucial role in intelligent precision agriculture field management [1-3]. Recognizing crop relative position of operating equipment during operation by techniques as hyperspectral technique, binocular vision and laser radar is a general method for precision field management such as target spraying, variable fertilizing and intra-row weeding [4-9]. The relative position will be cleared immediately after this operating finished. Crop position data cannot be shared with other field management process, and those techniques are subject to natural lighting, image processing algorithm and hardware computing speed. However, with advancement of digital agriculture and acceleration of large-scale planting, agricultural business entities have posed higher demands on cost control and data sharing rate, which means new requirements for acquisition of crop position information. Properties of position data such as real-time, universality, long-term storage and high utilization become the new requirements.

Satellite based seeds position information can be regarded as plant position. It is featured by superior real time, high universality and storage convenience. Seed positioning technology is
originated in the late 20th century. With the development of precision agriculture and booming of individual plant care, acquiring high-precision seed positioning map accurately has become the focus of research. H. W. Griepentrog retrofits a precision seeder with a Real Time Kinematic Global Positioning System (RTK GPS) on seeder, optical seed detectors and a data logging system to map sugar beet seeds they planted\cite{10,11}. Based on above research, M. Nørremark attaches an inclinometer to the antenna pole in order to measure the two-dimensional inclination of pitch and roll. By including the inclination data used to correct positioning accuracy, the mean deviation between true plant and estimated seed position are reduced by approximately 60%. Test shows that 95% of the sugar beet seedlings emerged within 37.3 mm from estimated seed position at the operating speed of 5.3 km/h \cite{12,13}. H.Sun improves seed position technique for tomatoes transplanting, field test results show that the mean error is 2cm between the predicted plant locations and the surveyed location after planting, and 95% of the predicted plant locations are within 5.1cm of their actual locations\cite{14}. Many scholars have also made a lot of attempts on methods in the process of seeding positioning \cite{15,16}. Low position installed seed-meter is the common point of those studies. Seeds or seedlings detection positions were regarded as the actual position.

Some seed-meters are high position installed instead of low position installed in order to minimize the effect of soil and straw on seed-meter during seeding process\cite{17}. A seed tube is installed below the seed-meter, and seeds pass through tube before implantation. OE-sensor fixed in middle section of the tube is used to detect seeds. Seed detection position is far from seedbed and seed irregular movement in the process cannot be ignored \cite{18}. It is not suitable to regard seeds detection positions as the actual position. Therefore, a seed falling process considered positioning system is proposed in this study.

A 4-row precision planter was used, and all seed tubes were replaced with OE-sensor equipped tubes to monitor seeds dropping. An RTK satellite receiver mounted on seeder frame girder providing global position. And a mathematic model based on spatial position of planter and planter monomer was established to realize multi-point positioning with a single satellite antenna. Furthermore, time and distance compensation model of seed from OE-sensor to implantation process was established based on EDEM numerical simulation. Combined with theory of constant velocity interpolation, seed positioning algorithm was established. It provides crop position information for precision field management as well as technical and data support for digital and intelligent precise agricultural.

2. System components and operation principle

2.1 Components of positioning system

The proposed positioning system is illustrated in Fig.1. The seed implantation positioning system hardware consists of a 12V DC power supply, a controller, four OE-sensors, a satellite antenna, a radio antenna, an RTK receiver and a data recorder. Tractor 12V DC power supply was directly used in actual operation; Controller chip was a low-cost stm32f103ZE microcontroller. OE-sensors were fixed in the middle of each seed tube detecting passing seeds. RTK receiver was a R60U receiver produced by Shanghai Lianshi navigation technology co. LTD. RTK receiver sent its signal in national marine electronics association 0183(NEMA 0183). Fixed base station was located within 2 km from test plots. Positioning accuracy of RTK receiver was ±12 mm, and speed measurement accuracy was 0.01 m/s. All components were installed on a planter unit formed by a John Deere tractor (model 1204) and a Debont 4-row precision planter.
2.2 Seed positioning principle

As shown in Fig.2, positioning process is divided into three parts: seeder unit positioning, planter monomer positioning and implantation seed positioning. Projected position of satellite antenna on operating plane reflects the position of the seeder unit. Projected position of OE-sensors on operating plane reflects the position of planter monomer and the actual seed implantation position reflects seed position. RTK receiver collects satellite observation data from satellite antenna and fixed base station data from radio antenna at the frequency of 10 Hz during seeding operation. Differential observation values are composed in system for real-time analytical processing to accurately acquire the position, speed, UTC time, etc. of seeder unit. When seed passes through the tube, seed triggers the OE-sensor, trigger time and row number will be recorded by a signal acquisition circuit, and transmitted to controller. The controller finally determines seed implantation time by integrating satellite UTC time, sensor trigger time, and the time difference of seed from OE-sensors to implantation process; Seeder unit positioning at seed implantation time is determined by constant velocity interpolation. The model based on spatial position of planter and planter monomer is integrated to calculate the positions of each monomer at seed implantation time. Planter monomer position combining with distance difference obtained from EDEM numerical simulation gets the final position of seed implantation.

Fig.2. Seed positioning principle
3. Determination of models

3.1 Determination of spatial position model

Single satellite antenna can simplify the structure and reduce system cost, but one direct locating point on seeder unit only. A mathematic model based on spatial position of planter and planter monomer is necessary. In 2019, Xiantao He from China Agricultural University determined the coordinates of each monomers combining a single position, course information from one satellite antenna fixed above tractor cab and relative position relationship between the antenna and each monomer\[19\].

Relative position of seeder and tractor changes during operation no matter how they are connected. Relative position also changes if the same seeder is hung to different tractors, so the relative position relationship needs to be re-calibrated. In order to avoid problems above, satellite antenna is directly fixed on seeder frame girder in this study.

Projected coordinates of the satellite antenna in the operating plane is $(x, y)$, row spacing of seeder is $m$, distance between satellite antenna and OE-sensor in forward direction is $L$, distance between satellite antenna with right-most OE-sensor in vertical of forward direction is $d$ and the heading angle is $\theta$, as shown in Fig.3.

![Fig.3 Spatial position of planter and planter monomers](image)

Row No. of planter monomer is denoted by $i$ $(i=1,2,3,4)$, Spatial position model of planter and planter monomer is as follows:

$$
\begin{align*}
    x_i &= x - L \cos \theta + [d - (4 - i)m] \sin \theta \\
    y_i &= y - L \sin \theta - [d - (4 - i)m] \cos \theta
\end{align*}
$$

3.2 Determination of spatial position model

As shown in Fig.4, seed tube is on the left when sensor triggered by a seed, then on the right when the seed is implanted. Time difference of this process is $\Delta t$. Distance difference between OE-sensor and seed implantation along forward direction at seed implantation time is $\Delta s$. Motion of seeds from OE-sensor to seedbed is affected by magnitude and direction of seed velocity, vibration of field machineries, etc., seeds collide with tube wall during passing through process, causing trajectory disorder. Therefore, time difference and distance difference cannot be obtained by accurate kinematics and dynamics. An EDEM numerical simulation was carried out to obtain required data indirectly, then time and distance compensation model was established by regression analysis.
3.2.1 Geometric models
EDEM can quickly and easily build seed particle model, and accurately calculate seed motion combining material properties, mechanical properties, contact parameters, etc. It has been widely used in the simulation of precision seeding process in recent years [20-23].

Zhengdan 958 corn seed was selected as the modelling object for simulation particles. The irregular shape seeds were divided into three types: round-flat type, thin-long type and spherical type. Three-dimensional model of corn seed was built in SOLIDWORKS. Seed particle model was constructed by multi-sphere combination filling in EDEM software [24,25]. The number of simulation particles was set based on the ratio of three types of seeds 4:5:1 [26].

Geometric model for simulation was built based on SOLIDWORKS, which mainly included seedbed, seed tube and particle factory, as shown in Fig.5. Particle factory was located at tube inlet to produce three kinds of seeds pro rata. Seed tube and particle factory move along direction of seedbed according to operation speed.

3.2.2 Simulation experiment design
Cells number of seed meter is 27, spacing in the rows (l) is 0.25m, test velocity \( v \) (km/h) and seed arrangement frequency \( p \) (Hz) conform to the relations of Formula (2). Test velocity and seeding frequency were set as shown in Table 1.

\[
p = \frac{v}{3.6l}
\]

Table 1. Parameters of test velocity and seeding frequency

| Item                  | Test group |
|-----------------------|------------|
|                       | 1  | 2  | 3  | 4  | 5  | 6  |
| Test Velocity/km·h\(^{-1}\) | 3  | 4  | 5  | 6  | 7  | 8  |
| Seeding frequency/Hz   | 3.33| 4.44| 5.56| 6.67| 7.78| 8.89 |
Saving time interval during simulation was 0.001s to accurately position the seed implantation moment. $\Delta t$ and $\Delta s$ data of 50 seeds at each speed was recorded, polynomial regression to the data was carried out. As shown in Figure 6, models of $v\Delta t$ and $v\Delta s$ were established. The regression equations for $v \in [3, 8]$ were as follows:

$$
\begin{align*}
\Delta t &= 0.0005v^2 - 0.006v + 0.1634 \\
\Delta s &= 0.6916v^2 - 6.9364v + 116.27
\end{align*}
$$

(3)

3.3 Seed implantation position models

3.3.1 Determination of seed implantation time

Seed implantation time is crucial to positioning. Positioning of seed implantation is based on satellite coordinates and implantation time.

It can be seen from Fig.2 that the positioning involves three time variables, including satellite UTC time, sensor trigger time and time difference($\Delta t$). In order to unify the time reference, a timer was set individually in the system. Timer would be reset when the system receives UTC time ($t_{UTC}$). If a seed triggers sensor in a satellite signal period, sensor trigger time ($t_T$) was recorded, Seed implantation time ($T$) could be computed as:

$$
T = t_{UTC} + t_T + \Delta t
$$

(4)

3.3.2 Positioning of seeder unit at implantation time

Seeder position information received intermittently by satellite antenna is dot information, which is difficult to cover the seeder position at the time of seed implantation. In this study, constant velocity interpolation method was used to make up for the deficiency.

$T_{n-1}$ and $T_{n+1}$ were nearest UTC time received by the system before and after implantation time $T_n$, and corresponding position coordinates of seeder were $(x_{n-1}, y_{n-1})$, $(x_{n+1}, y_{n+1})$. Seeder position coordinates $(x, y)$ at time $T_n$ could be expressed as equation(5):

$$
\begin{align*}
x &= x_{n-1} + \frac{T_n - T_{n-1}}{T_{n+1} - T_{n-1}}(x_{n+1} - x_{n-1}) \\
y &= y_{n-1} + \frac{T_n - T_{n-1}}{T_{n+1} - T_{n-1}}(y_{n+1} - y_{n-1})
\end{align*}
$$

(5)

3.3.3 Determination of seed implantation position

Each monomer coordinate $(x_i, y_i)$ was determined based on spatial position model and seeder position coordinates. Seeds gained a velocity component in opposite direction with tractor before contacting seedbed. Seed implantation position laged behind that of sensor in operation direction, as shown in Fig. 4. Taking $\Delta s$ into account, seed implantation position $(x_2, y_2)$ can be expressed as:

$$
\begin{align*}
x_2 &= x_1 - \Delta s \cos \beta \\
y_2 &= y_1 - \Delta s \sin \beta
\end{align*}
$$

(6)
Connect two points \((x_{n-1}, y_{n-1})\) and \((x_{n+1}, y_{n+1})\) with a straight line, the angle between the straight line and X-axis represented by \(\beta\).

\[
\begin{align*}
\cos \beta &= \frac{x_{n+1} - x_{n-1}}{\sqrt{(x_{n+1} - x_{n-1})^2 + (y_{n+1} - y_{n-1})^2}} \\
\sin \beta &= \frac{y_{n+1} - y_{n-1}}{\sqrt{(x_{n+1} - x_{n-1})^2 + (y_{n+1} - y_{n-1})^2}}
\end{align*}
\]

(7)

4. Field performances

Seed positioning system was built based on a 4-row pneumatic precision seeder to check the performance of the system. Field trials were conducted in the experimental base of Beijing Academy of Agriculture and Forestry Sciences (116.457399E, 40.182066N).

4.1 Seeds implantation location prediction and actual position measurement data acquisition programs

Before the trials, seeds implantation location prediction (SILP) and actual position measurement (APM) data acquisition programs were built. Same hardware was used for those two different programs. SILP collects data during seeding while APM after seeding finished.

The main function of SILP program was to receive and record signals from RTK and sensors, then calculate seed position.

Different from the SILP process, APM process was based on testing methods single seed drills (precision drill) of China. Remove upper soil of seeds to make them fully expose, and place satellite antenna directly above the seeds, keep surrounding space of satellite antenna unobstructed, and record the actual position from RTK receiver. Program flow chart is shown in Fig. 7.
Fig. 7. Flowchart of seeds implantation location prediction and actual position measurement programs

4.2 Field experiment design

The tractor was equipped with an automatic navigation system (straightness error is ± 2.5 cm) independently developed by Beijing Agricultural Intelligent Equipment Technology Research Center. Operating speed was set to 3 km/h. Speed was unstable and changing constantly during the actual operation. A stopwatch was used to measure the actual operating speed. Measured operating speed was 3.2 km/h. The trail area with a length of 100 m was divided into three areas: a start area, a test area, and a parking area with lengths of 10 m, 80 m, and 10 m, respectively. Spacing in the rows was 0.25 m while seeding.

Fig. 8. Field trails

5. Results and discussion

The difference between actual seed position and predicted position was investigated by selecting the data of 252 seeds continuously at random. Calculate the longitudinal deviation (LD) in seeder
operating direction, the vertical deviation (VD) perpendicular to seeder operating direction, and absolute deviation (AD) of linear distance between the actual position and the predicted position.

Table 2. Field performance results of positioning program

|       | VD (mm) | LD (mm) | AD (mm) |
|-------|---------|---------|---------|
| Mean  | 22.39   | 16.58   | 30.45   |
| Range | 68.86   | 42.51   | 70.76   |
| SD    | 15.80   | 10.81   | 15.17   |

The mean, range and standard deviations of VD were less than LD, which implies that the positioning error along longitudinal direction is greater than that of vertical direction in the positioning process.

The above phenomena may be related to the following factors.

1) Seeds were delivered from high position installed seed-meter, then passing through the tube and gaining a high velocity which leads to inevitable collision with seedbed, increasing the deviation between the actual position and the predicted position. Implantation velocity changing with operating speed and seeder vibration increased the dispersion degree of positioning deviation.

2) The automatic navigation system reduced the variation of vertical speed which lowers the difference of vertical speed of seeds, and inhibits the generation of vertical deviation. V-shaped trench furrowed by double-disk ditcher limit the lateral migration range of seeds.

According to the frequency distribution diagram of the absolute deviation of the linear distance between the actual position and the predicted position, 87.7% of seeds were within a distance 50 mm from predicted positioning. Considering RTK receiver error and inevitable collision of seeds, the positioning accuracy was acceptable.

![Fig.9. Frequency distribution diagram of absolute deviation](image)

6. Conclusions

1) A method of seed positioning was proposed. Seeds implantation location prediction and actual position measurement data acquisition programs were developed. Seed implantation location was predicted.

2) Field trails results showed that the longitudinal deviation span and dispersion degree of the actual position and the predicted position in the working direction of the seeder are greater than the vertical transverse deviation of the seeder from the working direction. 87.7% of seeds were within a distance 50 mm from predicted positioning. Centimeter-level seed positioning realized basically. This study can provide theoretical and technical support for real-time seed location mapping.

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