DESIGN AND TESTING OF SEEDING QUALITY MONITORING SYSTEM FOR COTTON HILL-DROP PLANTER

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棉花精量穴播器播种质量检测系统设计与试验

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ABSTRACT

To address the limitations of seeding quality monitoring methods under the seeding operation mode of cotton hill-drop planter without grain, this paper designed a seeding quality monitoring system that can eschew the traditional reliance on seed conductor. The system realizes real-time monitoring based on the differences in the cotton seeds' absorption of light of different wavelengths, and achieves accurate evaluation of seeding quality by obtaining the seeding quality parameters with multiple types of sensors. Bench tests showed the lowest accuracy of seeding rate monitoring was 97% and the highest accuracy of missed seeding monitoring was 95% while the field tests showed that the highest drop in the accuracy of seeding rate monitoring was 2.03 percentage, but the lowest accuracy of missed seeding monitoring is still above 91%. The system does not require the transformation of the equipment carrier, but has a high degree of equipment adaptability, which can meet the requirements on monitoring of cotton seeding. The monitoring method is effective and feasible, with high accuracy and stability.

摘要

针对棉花精量穴播器无导种管播种作业模式下的播种质量检测方式的局限性，本文摒弃依赖导种管的监测方式，提出播种质量监测系统。该系统基于棉种对不同波长光吸收特性的差异性实现实时监测，并采用多种形式传感器获取播种质量计算参数，完成播种质量精准评估。台架试验表明，播量检测准确率最低为97%，漏播量检测准确率达 95%；田间试验表明，播量检测准确率最高下降幅度为 2.03 个百分点，漏播判定准确率最低仍维持在91%以上水平。系统无需对机具载体进行改造，具有高度机具普适性，并满足棉花播种状态监测要求，监测手段有效可行，准确率和稳定性较高。

INTRODUCTION

Cotton is the main cash crop in China, which is widely used in the production of cotton textiles, being an important strategic material that bears on the national economy and people's livelihood. With agricultural modernization, cotton planting in Xinjiang has been refined according to local conditions, where the mulch-covered precision hill-drop seeding effectively improves the seeding quality and efficiency and reduces the cost (*Shen et al., 2022*). In order to realize the refined management of seeding, a seeding quality monitoring system has been developed to assist the monitoring of the planter's seed discharge and the early warning of failures. The problems such as missed seeding, repeated seeding and blockage can be timely identified and solved in a targeted manner, which is important to speeding up accurate and efficient mechanization and integrated development in cotton production (*Majcher et al., 2023; Liao et al., 2017*).

In precision seeding, the research and development of special high-precision sensors and intelligent measurement and control terminals for agriculture are of great significance to promoting rapid development of smart agriculture and improving the precision of seeding device (*Wen et al., 2022*). Online accurate seeding monitoring methods can be divided into photoelectric detection (*He et al., 2021*), piezoelectric detection (*Zhao et al., 2020*), capacitance detection (*Zhang et al., 2022; Xu et al., 2022*), machine vision detection (*Dong et al., 2023*), etc. according to the different detection principles of sensors.

Among them, machine vision detection is accurate, but is mostly used in laboratory evaluation other than fields with complex operating environments. Piezoelectric detection and capacitive detection have high requirements for device stability, and are weak in detecting subtle changes of seeds, which makes them not suitable for detection of small-particle seeds (*Mapoka et al., 2019*). Photoelectric detection is widely used in the monitoring of seeding due to its high accuracy and good stability, and has broad application prospects.

Scholars have conducted considerable research on the seeding monitoring system, and achieved real-time monitoring by installing photoelectric sensors at seed conductor to capture the seed discharge signals. The SeedStar TM series precision agriculture operating system by U.S. John Deere is mature in the development of seeding monitoring products. Its user-friendly interface visually displays the information of seeding monitoring and operatable parameters, which guides farmers' seeding operation by providing detailed seeding decision based on the status of field plots.

Besharatia (*2019*) developed an infrared sensing system composed of infrared light-emitting diodes and photodiodes based on the physical characteristics of different types of seeds (chickpeas, wheat, alfalfa), but failed to achieve high monitoring accuracy on small-particle seeds due to diameter limitations of optical components. Previous studies (*Ding et al., 2020; Ding et al., 2021; Wang et al., 2023*) demonstrated real-time monitoring of small-particle seed flow and the perception of high-throughput seed flow signals could be achieved by enhancing the resolution of the detection sensitive system with piezoelectric thin films and thin-surface laser-silicon photocell modules. Regarding the monitoring of double overlapping seeds, *Xie et al.* (*2021*) proposed the use of a laser sensor as the signal capture source, and used a triode to improve the drive force and anti-interference ability.

Yin (*2018*) proposed adoption of a distributed information structure to reduce the average response time of the system. In summary, there is rapid progress of current research on the monitoring system of small-particle seeds, but it is difficult to realize the commercialization of the seeding monitoring system or fully cover all types of seeders on the market. Especially, there is weak research on the monitoring of seeding by mechanical planter without a seeding conductor. Therefore, it is urgent to address the problems with real-time monitoring in single operation without a seed conductor.

The primary objective of this study was to develop a real-time seeding quality monitoring system for mechanical precision hill-drop planter by leveraging the light absorption characteristics of cotton seeds, thus eliminating the traditional reliance on seed conductor. A secondary objective was to enable the visualization and remote access of monitoring information on both vehicle terminal and cloud storage platform. Tests will be conducted to demonstrate that the monitoring accuracy meets the criteria for cotton seeding state monitoring. Ultimately, this research will contribute to addressing the challenges of seeding monitoring in planters without seed tubes and enhance the precision and efficiency of seeding operations.

MATERIALS AND METHODS

Overall system design

As the hill-drop planter is dragged by an auxiliary tractor at a working speed, some duckbill devices dig holes in the ground, while the seed tray inside the planter rotates and capture cotton seeds from the pile below. Due to gravity, the cotton seeds fall out of the pits and further slide out of the duckbills along the spacer sleeve before finally dropping into the hills. The system consists of four parts, namely, seeding rate monitoring module, basic parameter monitoring module, vehicle terminal (including touch screen, data acquisition module and STM32 master control unit), cloud storage platform, as shown in figure 1.

The seeding rate monitoring module is the core of the monitoring system to realize the monitoring of the seeding status of the hill-drop planter; on the basis of the machine's operating parameters collected by the basic parameter monitoring module, the information of the seeding quality and the planter positioning in the field is obtained. The display control terminal system is composed of the STM32 master control unit and its peripheral circuitry, and can achieve the visualization of seeding quality, BDS message analysis, integration, packaging and remote transmission of the information of seeding quality and positioning, users can access the operation information of the planter through the agricultural machinery operation platform.

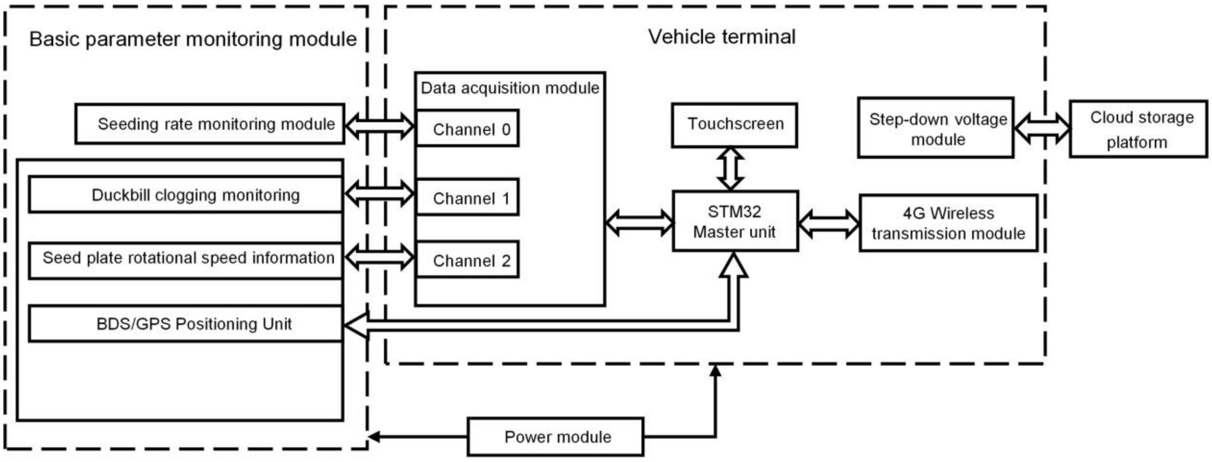


Fig. 1 - Monitoring system structure diagram

System hardware design

- **Hill-Drop seeding rate monitoring module design**

The hill-drop seeding rate monitoring module is composed of a color marker sensor and its peripheral circuitry, which operates based on the principle that different colored objects have varying reflectance to light (*Lu et al., 2021*). Three primary color light-emitting diodes are selected to provide the light source. The color marker sensor is of a Y-shaped optical fiber probe structure to adapt to the small space, transmits the light of specific color, and identifies the color according to the difference in the absorption of light of different wavelengths by the surface of the detection area (*Petzi et al., 2023*). The sensor's receiving element is embedded with a filter to suppress interference of ambient light, and effectively receives diffuse reflected light signals from the detection area; the sensor's color recognition system filters and amplifies the signal after photoelectric conversion, and the A/D converter converts the analog signal into a digital signal and outputs the RGB value for comparison with the standard color to identify cotton seeds. The structure of the color mark sensor is shown in figure 2.

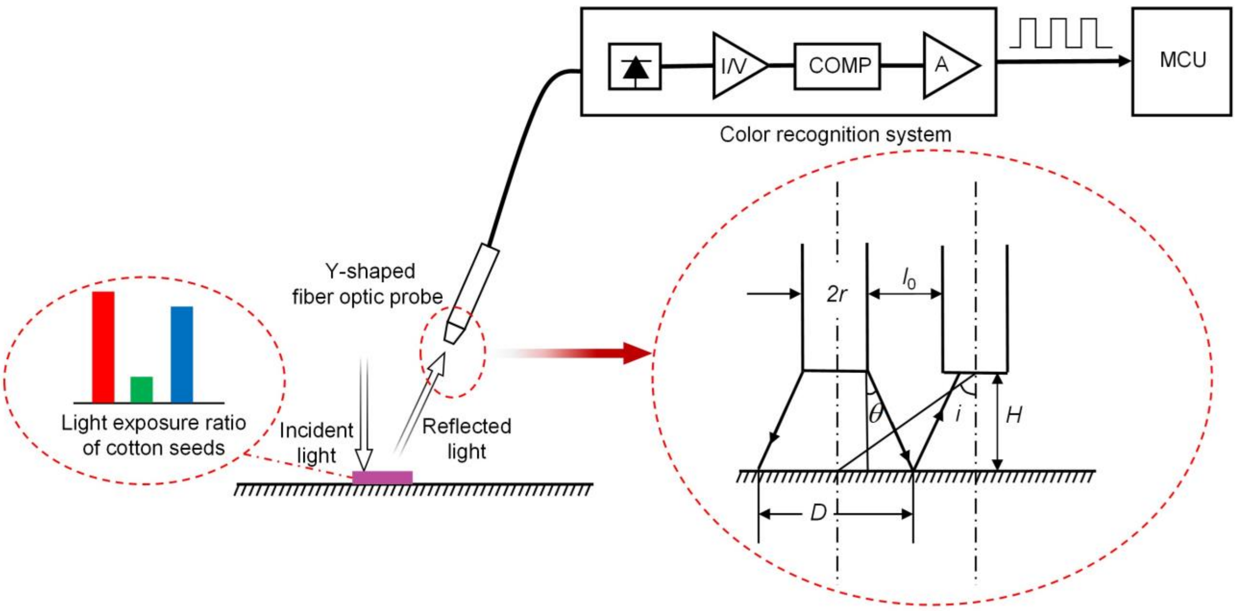


Fig. 2 - Structural composition of color sensor system

The distance of the sensor (optical fiber probe) from the pit in the detection area is the same as the working distance of the optical fiber probe of the color marker sensor. The operating area of the hill-drop planter's seed tray is a closed dark space, and lit only by the light-emitting diode, where the interference of ambient light on the spectral response of the sensor and the reflection characteristics of the object surface can be ignored.

The seed tray is made of reinforced nylon, and can be simplified to a Lambertian scatterer, that is, the incident energy is evenly reflected in all directions and the surface radiation intensity satisfies Lamber's cosine law (*Vazquez et al., 2020; Oguntosin et al., 2019*).

The detection height of the Y-shaped optical fiber probe is H, and a three-color light source lights the reflective surface of the detection area. When the diffuse reflectance of the surface of the detection area is ρ, there is:

$$B = \rho E_0 \tag{1}$$

where B is the surface brightness of the detection area; E_0 is the illuminance of the light source.

The diameter of optical fiber core of Y-shaped optical fiber probe is $2r$, the aperture angle is θ_r, and the distance between the two sets of optical fibers in the probe is l_0.The reflected luminous flux F in the detection area received by the color marker sensor in any reflection direction i is obtained:

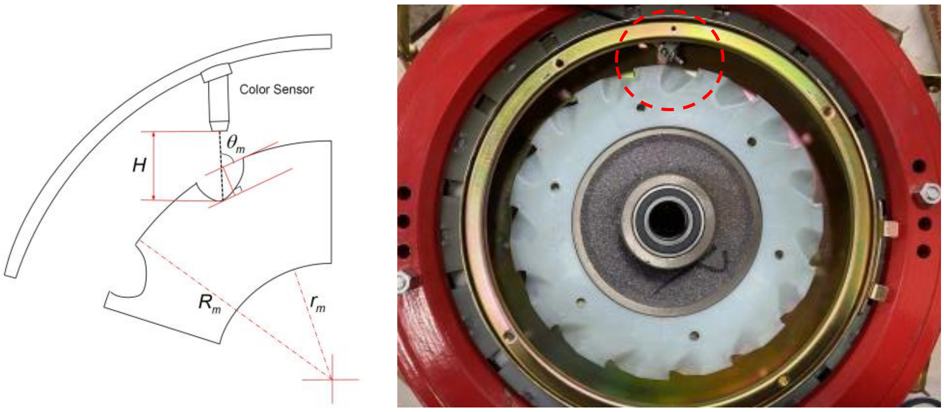
$$B = \frac{\rho E_0 \cos^2 i}{\pi H^2} \tag{2}$$

To ensure that the information of diffuse reflection of the detection surface obtained by the color mark sensor is not distorted, the installation height H of the color sensor from the detection center should satisfy $H >> (l_0 + 2r)$. At this time, i tends to 0, and there is:

$$F = \frac{\rho E_0}{\pi H^2} \tag{3}$$

When the reflectance ρ is fixed, the luminous flux F received by the sensor's light probe is related to the installation height H, where $F \propto H^2$. In practical applications, the luminous flux reflected to the sensor should be increased as much as possible. For curved detection areas, the installation height should be adjusted within the working range of the sensor to avoid blocking and shading, and the operating of the seed tray should not be affected, as shown in figure 3, where R_m is the radius of the outer ring of the seed tray; r_m is the distance from the concave point of the pit of the seed tray to the center of the seed tray; θ_m is the angle of the tangent line at the intersection of the concave extension cord and the outer ring.

The installation height of the sensor is determined: $H = \min\{(R_m - r_m)\sin^{-1}\theta_m, H_0\}$ (H_0=50mm). This is to obtain the maximum luminous flux to achieve the best detection effect. By reference to the design data of the hill-drop planter (*Zhang et al., 2021; Jiang et al., 2021*), the values of R_m=110 mm, r_m=67.5 mm, and θ_m = 30° were substituted into the formula, and H=21.25 mm.



(a) Installation diagram *(b) Real installation*

Fig. 3 - Installation of the color sensor

$$H \geq R_m - r_m \sin^{-1}\theta_m \tag{4}$$

The photoelectric conversion element of the color marker sensor are TCS34725 series whose peripheral circuit is as shown in figure 4.

The color marker sensor communicates with the STM32 master control unit through a 7-bit I[2]C bus, where the communication clock is 100 kbit/s. A read command is issued to the internal RGBC channel data register (0x14~0x1B) to access and obtain RGB values.

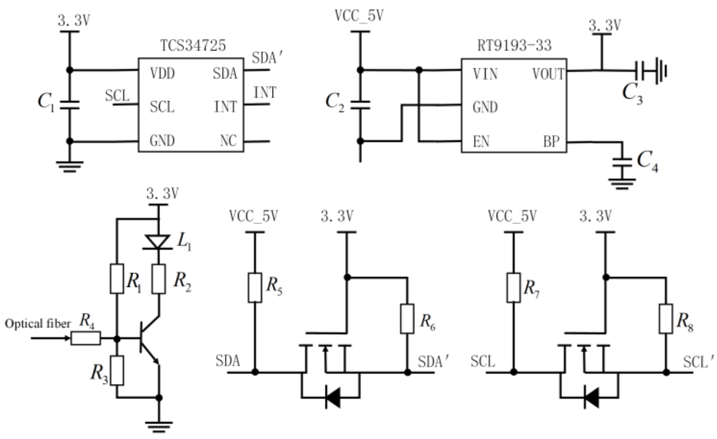


Fig. 4 - Peripheral circuitry of the color sensor

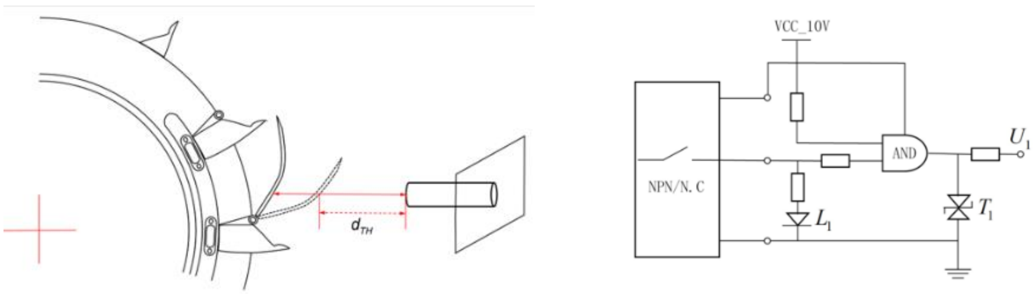
The sensor sequentially gates the filters to obtain the frequency pulse signals of the three primary colors R, G, and B, calculate their light intensity ratio and compare it with the RGB range interval of cotton seeds. If the detected values fall within the reference range, the sensor micro-processing unit directly outputs the TTL high level through the GPIO. The RGB component range (dimensionless) of fuchsia-coated cotton seeds was determined to be 120~200, 30~100 and 120~200 by the comparison with standard colorimetric cards, and the light receiving ratio was close to 4:1:4.

- **Basic parameter monitoring module**

The basic parameters include the duckbill clogging state, the speed of seed discharge tray (that is, the forward speed of the machine), other parameters for calculation of seeding quality, and the field positioning information of the planter. The infrared diffuse reflection photoelectric sensor transmits and receives continuous infrared light, and uses the intensity of the reflected light to perceive the opening and closing of the duckbill, thereby identifying the blockage. The speed measuring encoder captures the speed information of the seed discharge plate. Inside the encoder, there is usually a grating code plate engraved with an equidistant opaque grating, and the light-emitting diode illuminates the moving grating code plate to produce Moir stripes, where two columns of speed information fed back by pulse are generated alternately. BDS/GPS positioning unit receives and solves the field positioning of the planter through the antenna.

(1) Infrared diffuse reflection photoelectric

Through the infrared diffuse reflection photoelectric sensor M18 series (NPN-NC detection distance is 30-300 mm), the infrared signals are transmitted to the surface of the duckbill, and received and compared with the light intensity threshold, whereby whether there are seeds in the channel interfering the closing of the duckbill can be judged from the sensed opening and closing state. As shown in figure 5, when the duckbill is set to open, the detection distance d reaches the threshold distance d_{TH}. At this time, the reflected light intensity I_{TH} is the light intensity threshold, and an infrared signal is triggered. After judgment based on the gate logic circuit, high voltage is output. After being stabilized by the voltage regulator T_1, a 5V pulse is detected at U_1. At the same time, the diode D_1 is turned on and the clogging alarm light is on, if there is no seed in the channel and the early warning trigger condition is not reached, the output at U_1 is 0V.



a) b)

Fig. 5 - Blockage detection monitoring module

(a) Blockage state monitoring model *(b) Blockage sensor circuit*

(2) Incremental rotary encoder

The speed parameters of the seed discharge plate of the hill-drop planter are collected through the incremental rotary encoder E6B2-CWZ6C type (hereinafter referred to as the encoder). The encoder is fixed to the edge of the moving disc through a spring bracket. The silicone wheel on the encoder is directly in contact with the moving disc of the hill-drop planter, without slide between the surfaces. The moving disc drives the rotation of silicone wheel and further causes the rotation of encoder shaft, whereby the A and B sets of periodic pulse sequences with a phase difference of 90° are output. The data acquisition module captures the output pulse of encoder at a sampling rate of 20 kHz, and uploads it to the display control terminal through RS485 two-wire communication for discrimination of seeding status.

The counter counts the number on the rising and falling edges, which improves the resolution by 4 times. Since the encoder is installed by the side of the moving disc, the formula for calculating the speed of the hill-drop planter is obtained:

$$V_n = \frac{v_n r_n}{R_y} = \frac{T_n r_n}{4T_y R_y} \times 60 \tag{5}$$

where:

v_n is the encoder speed, r/min; T_n is the number of output pulses of the encoder; T_y is the number of pulses generated by the encoder in a complete rotation; r_n is the radius of the encoder's synchronous wheel; R_y is the radius of the moving disc of the hill-drop planter.

(3) Vehicle terminal

The on-board terminal is mainly composed of FZ4050 series data acquisition module, STM32 master control unit, 4G wireless transmission module and Guangzhou Dachai serial port touch screen, and can achieve data processing and cloud storage of the information of the planter's seeding quality and positioning information, and realizes the visualization of monitoring information and touch screen human-computer interaction. The system is powered by an external 12V power supply, and the step-down chip TPS5430DDAR provides a 3.3V/5V regulated power supply for each sensor and the master control unit chip.

The master-slave communication between data acquisition module and the STM32 master control unit are based on the RS485 Modbus protocol (RTU transmission mode) (*Yan et al., 2023*). The data acquisition module plays the role of a slave station in the communication with the STM32 master control unit. The Modbus protocol specifies that the slave station provides services in the form of a function code based on the request/response communication mode, and its message frame structure is shown in table 1. "0000~0002" was assigned as the input address range of CH0~CH2 channel in the Modbus register. The device address of the FZ4050 data acquisition module as a slave was 0x01. During transmission, it responded to the request of the STM32 master control unit through the 03 function code and read the channel data.

Table 1

Modbus RTU message structure

Address code	Function code	Data zone	Checksum
8-bit	8-bit	N×8-bit	16-bit

System software design

The on-board terminal software is designed to realize the monitoring and management of the seeding, which covers system hardware driver, terminal human-computer interaction design, acquisition and process of seeding quality and positioning information, and database cloud management, etc. The software process is shown in figure 6. After the system is turned on, the hardware peripherals are initialized. The working status of sensor is checked circularly; the GPIO general input and output are defined, and the cloud platform connection is initialized. Cloud_Int () is called to establish a cloud platform connection, and the IP address (j.caams.org.cn) and port information (9926) are passed. The TCP/IP protocol stack is initialized. The cloud platform automatically assigns dynamic ports to the display control terminal according to the current equipment scheduling. Then, C/C++ is used to write a data transmission and reception script, and an AT command is sent to configure the 4G wireless transmission module for entry into the working mode. The information of seeding quality and the planter positioning is fused and written remotely to the cloud platform.

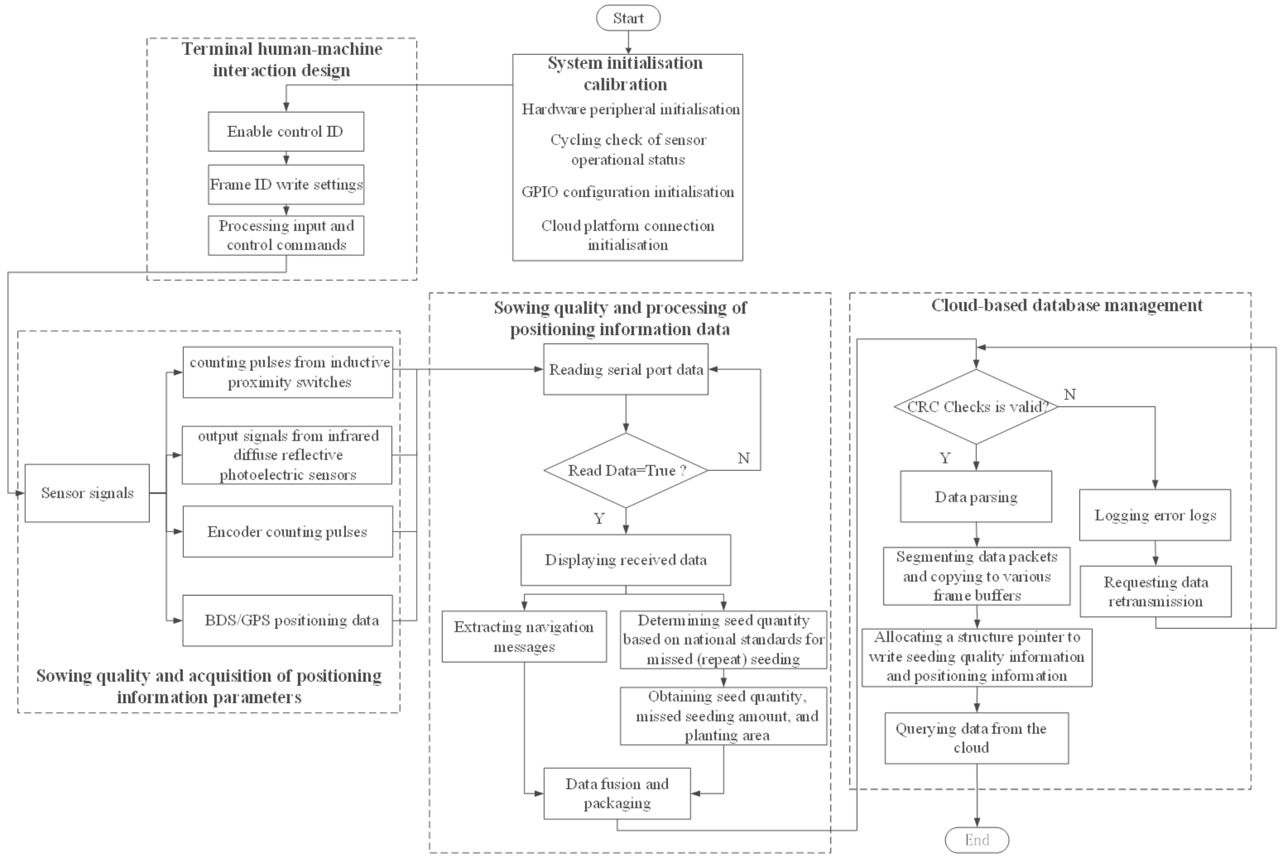


Fig. 6 - System software design process

- **Acquisition of seeding quality information**

The timer TIM2 is configured to external counting mode, and a double-edge trigger mode is adopted to monitor 6 channels of signal quality information. The system clock source is specified as the PLL output, with a clock frequency of 168 MHz. The AHB bus clock divider is set to 1, the PCLK1 divider to 4, and the PCLK2 divider to 2. The seeding quality discrimination result is written to the touch screen in real time.

After the forward speed v_1 of the machine is obtained, the actual seeding distance S_d of the two adjacent seeds is calculated:

$$S_d = \frac{v_1 \Delta t_1}{1000} \tag{6}$$

The seeding area A_1 is calculated:

$$A_1 = P_0 S_0 L_0 \tag{7}$$

where:

P_0 is the theoretical seeding rate; L_0 is the working width of the planter. By reference to GB/T 6973-2005 Single Grain (Precision) Planter Test Method, theoretical seeding distance S_0 is taken, and the actual seeding distance is S_d.

The judgment criteria is:

$$\begin{cases} 0.5S_0 < S_d \le 1.5S_0 \, (\text{Normal}) \\ S_d \le 0.5S_0 \, (\text{Repeated seeding}) \\ S_d > 1.5S_0 \, (\text{Missed seeding}) \end{cases}$$

The touch screen human-computer interaction interface visualizes the operation results, as shown in figure 7.

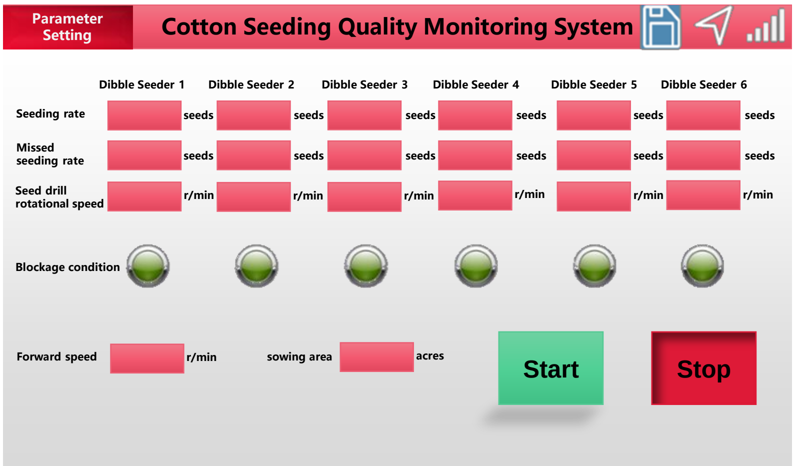


Fig. 7 - Cotton seeding quality monitoring software

- **Acquisition and remote transmission of positioning**

The serial port UART3 interruptedly collects the planter's field positioning information on the GNSS positioning module. The data format of the planter's positioning information is NMEA-0183. On the basis of 4G wireless transmission module, the serial port UART2 is defined to send the integrated data packets to the remote server regularly. The database schema design is shown in Table 2.

Table 2

Database schema design

Field name	Data type	Field definition
AllotPort	Int	Terminal identifier
Itime	Verchar	Timestamp
Latitude	Double	Seeder latitude information
Longitude	Double	Seeder longitude information
Seeded_area	Double	Sowing area
Seeded_P1	Int	Sowing rate of the first row
Seeded_Q1	Int	Missed sowing rate for the first row
Seeded_P6	Int	Sowing rate for the sixth row
Seeded_Q6	Int	Missed sowing rate for the sixth row

RESULTS AND ANALYSIS

Bench tests

Xinluzao No. 78 cotton seeds (with a mass of 84.40 g per thousand grains and a moisture content of 4.45%, approximate ellipsoidal shape with a major axis of 1.2 cm and a minor axis of 0.5 cm) were used in the test. A test bench was built to simulate the forward movement of field machines, so as to test the system's monitoring performance. The equipment includes a test bench for double-chamber cotton hill-drop planter with turntable vertical disc, a stepper motor controller, and a cotton seeding quality monitoring system.

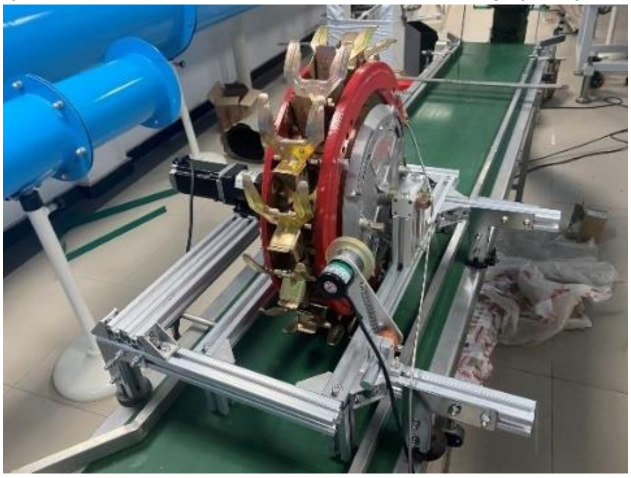


Fig. 8 - The seeding monitoring system test bench

By reference to NY/T 987-2006 Operation Quality of Film-laying Hill-drop Planter, the hill-drop planter is set to operating at 20, 25 and 30 r/min within the normal seed discharge interval in 6 repeated tests. The manual counts of the seeds were the real value, and the measured value was displayed on the industrial computer interface. The computer system determined the accuracy and measurement error.

(1) Test of the accuracy of seeding rate monitoring

In the test of the accuracy of seeding rate monitoring, the monitoring system started counting after the device was in stable operation for 10 minutes. The seed tray of the hill-drop planter has 15 pits, and the seeding rate was counted for every 20 laps of rotation.

After the monitoring is completed, cotton seeds in the bag are counted as the actual seeding rate, thereby the accuracy of the system's seeding rate monitoring is calculated:

$$\eta_1 = \left(1 - \frac{|P_0 - P_1|}{P_0}\right) \times 100\% \tag{8}$$

where η_1 is the accuracy of seeding rate monitoring; P_0 is the theoretical (actual) seeding rate; P_1 is the system's monitored seeding rate. The monitoring results of the system at different speeds were obtained, as shown in Table 3.

Table 3

Seed driller seeding rate monitoring results at different speeds

Rotation speed ($r \cdot min^{-1}$)	No.	Actual seeding rate	Monitored seeding rate	Monitoring accuracy of seeding rate (%)	Mean (%)	Standard Deviation (10^{-3})
20	1	302	298	98.67	99.33	4.724
	2	304	303	99.67		
	3	298	295	98.99		
	4	296	296	100		
	5	299	297	99.33		
	6	306	304	99.35		
25	1	300	302	97.39	98.08	4.750
	2	302	295	97.68		
	3	307	302	98.37		
	4	305	299	98.03		
	5	300	296	98.67		
	6	297	303	98.32		
30	1	296	291	98.31	97.79	5.123
	2	295	300	98.33		
	3	309	317	97.41		
	4	300	306	98.00		
	5	306	297	97.05		
	6	294	287	97.67		

With the increase of the rotation speed, both accuracy and precision of seeding monitoring decreased slightly. The reason is that the higher speed will cause some smaller cotton seeds fail to completely enter the pit, as a result of which they are not detected by the sensor. The overall accuracy of seeding rate monitoring maintained at over 97%, and the standard deviation of the monitoring results at different speeds was low, which indicates that the system's seeding rate monitoring accuracy is high.

(2) Test of accuracy of missed seeding rate monitoring

In order to further evaluate the seeding quality and evaluate the stability and reliability of the system's detection of missed seeding, the monitoring accuracy of missed seeding rate is subject to quantitative analysis according to formula (8). At each operating speed, the cotton seeds on the seed tray were reduced manually to increase missed seeding rate. Then, actual missed seeding on the planting bed was manually counted, and compared to the monitored value of the system to determine the error range. The monitoring results of missed seeding rate at different speeds are shown in Table 4.

Table 4

Missed seeding monitoring results of seed driller at different speeds

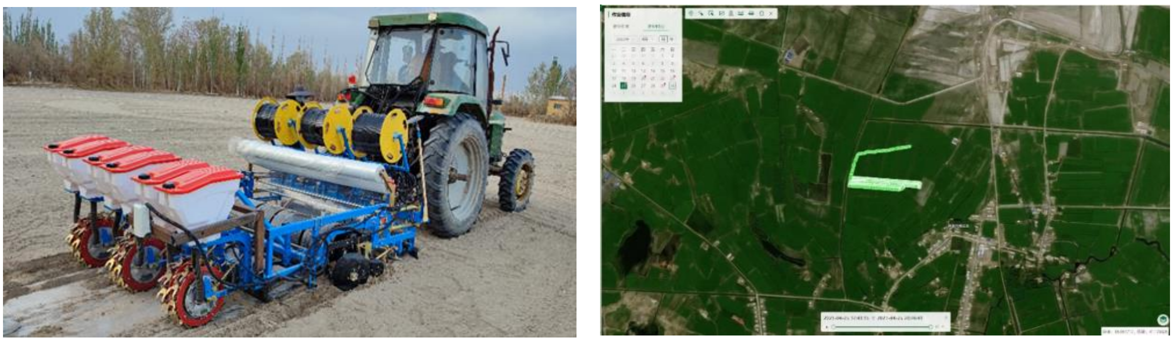
Rotation speed (r·min^{-1})	No.	Actual missed seeding rate	Monitored missed seeding rate	Monitoring accuracy of missed seeding rate (%)	Mean (%)	Standard deviation (10^{-3})
20	1	303	295	97.36	97.55	2.912
	2	292	285	97.60		
	3	307	300	97.72		
	4	295	302	97.84		
	5	297	306	97.06		
	6	302	309	97.73		
25	1	305	295	96.72	96.76	3.869
	2	303	294	97.03		
	3	299	310	96.45		
	4	301	291	96.68		
	5	297	308	96.30		
	6	303	295	97.36		
30	1	315	302	95.87	95.82	2.915
	2	299	287	95.99		
	3	293	306	95.75		
	4	303	315	96.19		
	5	299	285	95.32		
	6	308	295	95.78		

With the increase of the rotation speed, the accuracy of monitoring of missed seeding rate exhibited a slight downward trend. The comparison found that the accuracy of missed seeding rate monitoring was slightly lower than that of seeding rate monitoring, but it was still above 95%. The reason is that the higher speed of the seed discharge plate caused multiple collisions between the seed flow and the seed tray, which caused a small amount of broken seeds (shell of cotton seeds) that led to misdetection by the sensor. The manual operation to increase the missed seeding rate inevitably interfered with the seeding process of the hill-drop planter and affected the original trajectory of the seed flow. However, judging from the standard deviation of the monitoring results, the system's monitoring accuracy of the missed seeding rate still maintained at a high level, that is, the monitoring results are reliable.

Field tests

The test plot was 100 m long and 20 m wide, with soil suitable for cotton planting. The tested equipment was cotton precision planter (one membrane and 6 rows) pulled by John Deere 804 tractor. The seeding quality monitoring system was installed on the planter to obtain the seeding parameters in real time. By reference to the national machinery industry standard JB/T 7732-2006 Membrane Planter and the national agricultural industry standard NY/T 987-2006 Membrane Planter Operation Quality, the system was powered on before the start of the test, and the data was cleared after the system was initialized and calibrated. Finally, the machine was started for the tests.

During the test, the basic speed of John Deere 804 tractor was fast first gear speed (about 2 km/h, and the diameter of the hill-drop planter was 420 mm). By adjusting the throttle to control the speed, the speed of the seed discharge plate was set to 20, 30, and 40 r/min, respectively, the tractor moved 100 m (15 hills per lap, 75.8 laps, 1137 hills per ridge). The cotton seeds in soil were counted manually and seeding rate was monitored, thereby calculating the monitoring accuracy of the seeding rate; 100 hills were selected randomly on each ridge as the observation points (600 observation points in total at each rotation speed), and the current missed seeding monitoring result of the system was recorded for comparison, thereby finally counting the times of correct judgment at each rotation speed and calculating the accuracy of the system's judgment. At the same time, the location of the planter in the field, the operation area of the agricultural machinery, the operation path, and seeding status etc. were fed back to the agricultural machinery operation cloud platform, which provides users with remote monitoring channels, as shown in figure 9.



(a) Prototype field test (b) Cloud platform remote monitoring

Fig. 9 - Field Seeding Monitoring Test Site

The monitoring results of each ridge at different speeds are shown in table 5.

Table 5

Field Monitoring Results of the System

Rotation speed (r·min-1)	No.	Actual seeding rate	Monitored seeding rate	Monitoring accuracy of seeding rate (%)	Mean (%)	Standard deviation (10-3)	Judgment accuracy of missed seeding (%)
20	1	1137	1105	97.19	97.48	5.419	95.00
	2	1130	1160	97.35			
	3	1137	1155	98.42			
	4	1139	1103	96.84			
	5	1140	1170	97.37			
	6	1145	1171	97.73			
25	1	1138	1077	94.64	95.33	5.569	91.67
	2	1130	1087	96.19			
	3	1137	1193	95.07			
	4	1142	1173	95.53			
	5	1133	1083	95.59			
	6	1143	1085	94.93			
30	1	1134	1201	94.09	93.79	6.814	91.67
	2	1145	1072	93.62			
	3	1131	1068	94.43			
	4	1137	1199	94.55			
	5	1130	1208	93.10			
	6	1132	1052	92.93			

The field test results showed that the accuracy of seeding rate monitoring at different speed is reduced to different extent compared to the bench test results. At low speed (20 r/min), the monitoring results were almost consistent, with a decrease of 0.07 percentage; at high speed (30 r/min), the accuracy decreased more significantly by 2.03 percentage points, and the data variability (standard deviation) also increased. This is because the increase in the amplitude of machine jittering in the field tests and the inconstant moving speed of the machine caused the reduced sensor monitoring accuracy. Nonetheless, the accuracy of seeding rate monitoring in the field tests was still slightly above 93%, and the judgment accuracy of missed seeding at high operating speed also be maintained above 91%, which indicates that the monitoring system exhibits satisfactory accuracy, reliability and performance in the fields.

CONLUSIONS

In this paper, a seeding monitoring system suitable for mechanical precision cotton hill-drop planter was designed, and a test bench for double-chamber cotton hill-drop planter with turntable vertical disc was established for the performance test regarding the system's accuracy in monitoring the seeding rate and missed seeding rate. Meanwhile, the reliability and stability of the system's monitoring performance is further verified through field tests.

(1) This paper proposed the establishment of a seeding rate monitoring module with color marker sensor as the core, thereby realizing the identification and counting of cotton seeds based on the differences in their absorption of light of different wavelength. Accounting the counting test, the counting accuracy could reach 95%. Compared with the traditional laser beam detection method, the one-sided installation layout is more suitable for the small and compact space inside the hill-drop planter and requires no adjustment to the mechanical structure, which achieves satisfactory adaptability.

(2) The BDS/GPS positioning module was used to collect the field positioning information of planter; a rotary encoder was adopted to monitor the speed of seed discharge plate; an infrared diffuse reflection photoelectric sensor was provided to identity the clogging of the equipment; and a peripheral unit monitoring module was established to obtain their operation parameters in real time for seeding status discrimination. The judgment accuracy of missed seeding at high speed was above 91%. The information can be uploaded remotely to the terminal through the 4G wireless communication module, which provides the information traceability support to refined management of seeding operations.

(3) The reliability and accuracy of the monitoring system were verified through bench tests and field tests, separately. In the bench tests, the system's lowest seeding rate monitoring accuracy was 97%, and the missed seeding rate monitoring accuracy rate was 95%; in the field tests, seeding rate monitoring accuracy was above 93%, and the judgment accuracy of missed seeding was above 91%. In general, at different operating speed, the accuracy of field monitoring was reduced to different extent compared to the indoor tests: the accuracy of seeding rate monitoring at high speed (30 r/min) in field was reduced by 2.03 percentage compared to the bench test results, and that at the low speed (20 r/min) was reduced by 0.07 percentage without significant difference. The system exhibits satisfactory and stable monitoring performance.

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