DESIGN AND TEST OF INTELLIGENT YIELD MONITORING SYSTEM FOR PLOT COMBINE HARVESTER
/
小区联合收割机智能测产系统的设计与试验

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ABSTRACT
Traditional yield monitoring in breeding plots is manually conducted, which is labour-intensive and inefficient. To address this issue, a harvester-borne yield monitoring system that collects yield information during the harvesting in plots was designed. The system consists of a host computer and a slave computer. The slave computer used weight and moisture sensors to collect yield information of crops. The host computer used LabVIEW software to design a data management platform that displays and saves yield information and draws yield distribution maps for data visualization. The host and slave computers communicate data through 4G networks. By designing anti-interference measures, the dynamic experimental results showed that the maximum relative errors between the measured weight and moisture content by the system were 1.330% and 2.800%, which met the accuracy requirements of yield testing in plot breeding. The results indicated that the structure of the system is reasonable and can provide reliable yield monitoring tools for researchers in breeding plots.

摘要
传统的小区育种产量测试通过人工抽检完成，该方法劳动强度大、工作效率低。针对此问题，本文设计了一种在小区收获过程中采集产量信息的机载测产系统，该系统分为上位机和下位机两部分。下位机使用称重传感器与水分传感器采集小区作物的产量信息；上位机使用 LabVIEW 软件设计数据管理平台，对产量信息进行显示与保存，并绘制产量分布图，实现数据可视化；上下位机通过 4G 网络进行数据通信。通过对收割机进行抗干扰设计，动态实验结果显示测产系统重量与含水率测试的最大相对误差为1.330%和2.800%，均满足育种试验产量测试的精度要求。结果表明该系统结构设计合理，可以为小区育种科研工作者提供可靠的测产工具。

INTRODUCTION
Plot breeding is an important method for selecting superior varieties in agricultural research. In breeding experiments, the fundamental method for evaluating crop varieties is to use the actual yield of the variety in the same production environment, which requires breeders to monitor the yield every year. Compared with field operations, the advantages of plot breeding are many experimental varieties, small planting areas, and the harvesting and species examination of all plot crops can be completed in a shorter period, in which the influence of irrelevant factors on the experimental results is effectively reduced. At present, most breeding units rely on manual sampling for yield measurement, and the usual method is to use electronic scales and portable moisture loggers to measure the harvested grain in each plot and record the data manually (*Shuqi et al., 2021; Shuai et al., 2021*). This method leads to high labour intensity and low efficiency, and it is very likely to cause data confusion and affect the analysis of the results of breeding experiments.

Many types of yield monitoring systems for plot breeding experiments have been devised in some developed countries. For example, H2 Classic, H2 Stationary, and H2 High-Capacity yield monitoring systems produced by HM (HarvestMaster) in USA, and W1 and W1 plus weighing systems developed by Wintersteiger in Austria.

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All of them can accurately complete the one-time measurement of moisture, weight, and volumetric weight of the plot grain by cooperating with the harvester or thresher and analyse the data directly through software (*Campbell et al., 1996; Yan et al., 2011*). However, these yield monitoring devices are very expensive and must be used with supporting data analysis software, which discourages most breeding research units without enough budgets.

Yield monitoring, a crucial step in grain harvesting, has been studied extensively and advanced rapidly in the past decades. Currently, the mainstream yield monitoring methods primarily involve impact force measurement *(Fulton et al., 2018; Risius, 2014; Vlăduț et al., 2022)*. However, this method is not suitable for measuring yields in small areas. Another method involves the use of radiation, but the radiation sensors are restricted in many countries and regions *(Chosa et al., 2006*). The final approach is the design of weighing components to measure crops in blocks *(Bayano-Tejero et al., 2023; Mailander et al., 2010; Rosa et al., 2023)*. However, this method is susceptible to external influences during the monitoring process, leading to significant errors. Therefore, it is typically necessary to enhance measurement accuracy through improvements in both hardware and software. Most of the research on plot breeding yield monitoring equipment in China is only at the experimental stage, and no commercialized equipment has been developed. Zhao Liqing et al. of Qingdao Agricultural University designed a yield monitoring system for peanut based on plot breeding, which can achieve the monitoring of yield, water content and volumetric density of peanut (*Liqing, 2018; Liqing et al., 2015*). Zhang Hongmei et al. of Henan Agricultural University developed a plot yield monitoring system, which can measure yield at the plot experiments and realize the function of data recording and printing (*Hongmei et al., 2021; Yanzhong, 2019*). The above developed devices are only suitable for static measurements and are not suitable for using on plot harvesters, and do not enable simultaneous data collection.

To address the above problems, a yield monitoring system was designed for breeding experiments in plots. The system consists of a host computer data management platform and a slave computer data acquisition system. The slave computer collected yield information through sensors and transmitted the data to the host computer. A yield distribution map using this collected data was produced by the host computer. The system is relatively inexpensive and can significantly improve the efficiency of breeders in measuring crop yields, making it suitable for promotion during field harvest operations.

MATERIALS AND METHODS

Design of yield monitoring system for plot breeding

To avoid interference between different varieties during experimentation and facilitate field management, interval tracks is set up in the breeding area (as shown in Figure 1). The combine harvester will stop for about 10-20 seconds in the interval tracks to perform seed cleaning work to ensure that all crops harvested in the previous plot are loaded into the grain tank to prevent mixing. When the harvester stops at the edge of the interval track, the engine is in idle state. At this time, the yield date is collected and saved by the yield monitoring system. After the crop yield monitoring system finishes its work, workers will bag the harvested crops.

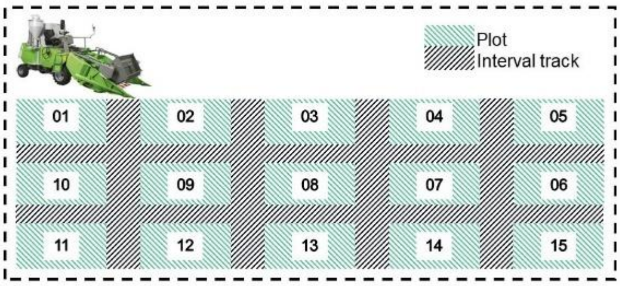

Fig. 1 - Plot operation

The intelligent yield monitoring system was designed according to the planting characteristics and harvest requirements of the breeding area. The system consists of two parts: the slave computer and the host computer (as shown in Figure 2). The slave computer was installed on the combine harvester and collected the production information of harvested crops; 4G-DTU transmission module was used to send production data to the host computer; the host computer was a computer installed with LabVIEW software which was used to design the data management platform to display and store production data, so that the date can be analysed more conveniently by researchers.

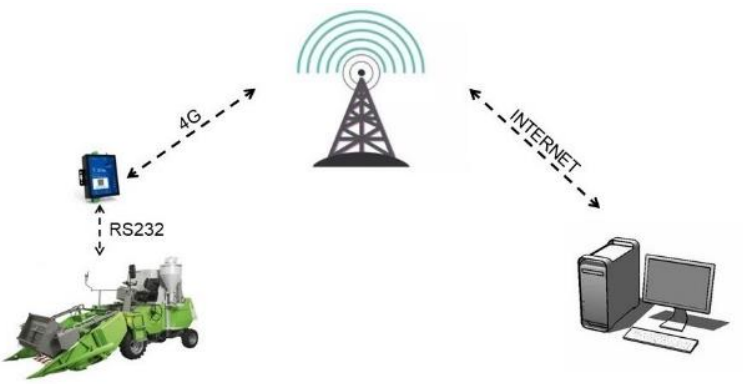

Fig. 2 - Overall flow chart for the yield monitoring system

Design of the slave computer

The slave computer was installed on the plot combine harvester and mainly used to collect yield information on crops in the plot. A main control module, weighing module, moisture content measurement module, data transmission module, and power supply module are included in the slave computer, whose composition diagram is shown in figure 3.

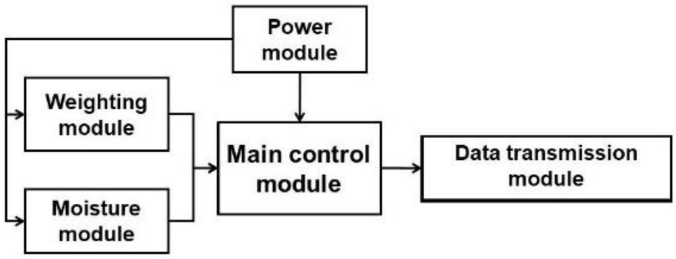

Fig. 3 - The slave computer composition system diagram

Main control module

The data collection and processing of various sensors was completed by the main control module, then the date was sent to the host computer through the data transmission module. The main control module of the yield monitoring system was designed using the STM32F103ZET6 chip produced by STMicroelectronics. This chip featured an ARM Cortex-M3 core (*Shuying et al., 2010*), which provided high data processing capability and running speed while consuming low power, making it suitable for the requirements of the yield monitoring system. The main performance parameters of the chip are shown in Table 1.

Table 1

Performance Parameters of Microcontroller

Project	Parameter
Controller size	100 × 100mm
Scale of printed circuit board	double-deck
Central processing unit	STM32F103ZET6
Maximum calculation speed	168 MHz
Memory size	64 KB
Disc size	1 megabyte
Input voltage	DC 9-28 V
Communication mode	RS-232，RS-485
Serial port	5
Working stability range	–40°C ~85°C

Yield monitoring module

Collecting information of plot crop yield is the most important part of the yield monitoring system, which includes the weight and moisture content of crops. To measure yield information in the plot experimental field, dynamic weighing method was chosen to obtain grain weight for the individual plot size (*Chung et al., 2016*), low yield, and the harvesting process cannot be continuous. In the method, weighing sensors were used to weigh grain tanks or grain conveying components in motion. A yield monitoring platform designed is shown in Figure 4. The grain was poured into the grain tank by the plot combine harvester through the feeding inlet, then the weight sensor and moisture sensor started measuring the weight and moisture content of the grain. When the measurement was completed, the grain was taken out through the collection box, and then the harvester would begin to work on the next plot.

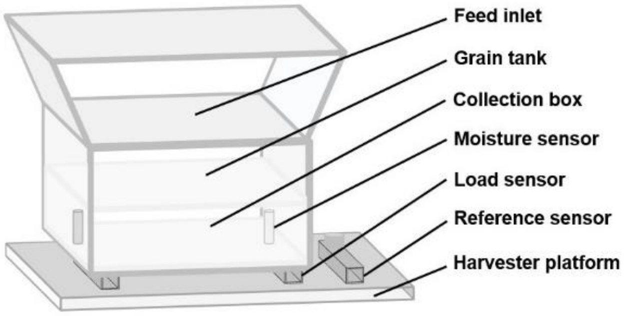

Fig. 4 - Weighing platform schematic

A strain gauge parallel beam weighing sensor (with a type of LC3151, range of 0~15kg and accuracy of 0.03%) was selected and installed at the bottom of the grain box. This sensor outputted weak differential voltage signals, amplified them and outputted voltage signals with an A\D conversion circuit. The main control module converted the voltage signal into the weight of the plot crops using a formula. The equivalent circuit of the weight sensor is shown in figure 5.

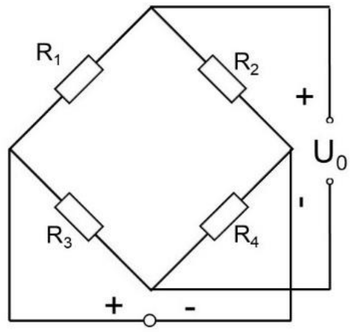

Fig. 5 - Equivalent circuit diagram for weighing sensor

The output voltage was calculated from the equivalent circuit diagram:

$$U_0 = \frac{R_1R_3 - R_2R_4}{(R_1+R_2)(R_3+R_4)}U \quad [\text{v}] \tag{1}$$

where R_1, R_2, R_3, R_4 is the resistance values of strain gauges, U_i is the DC power supply, U_O is the output voltage.

When the sensor was subjected to external pressure, the strain gauge underwent deformation, causing a change in resistance. The change in resistance for R_1 and R_3 due to tensile stress is ΔR_1 and ΔR_3. The change in resistance for R_2 and R_4 due to compressive stress is ΔR_2 and ΔR_4. The physical and electrical properties of the four strain gauges are identical, so $\Delta R_1=\Delta R_2=\Delta R_3=\Delta R_4=\Delta R$.

The output voltage of the sensor is:

$$U_0 = U_i\frac{\Delta R}{R} \quad [\text{v}] \tag{2}$$

where R is the resistance value of the four equivalent strain gauges, ΔR is the change in resistance value for all four strain gauges.

The output voltage of the formula (2) was converted into the weight of the measured grain after passing through the signal conditioning circuit (as shown in Figure 6). By utilizing SGM8424 and HX711 chips, a signal conditioning circuit for weighing sensors was designed. The SGM8424 chip's anti-aliasing circuit achieved hardware filtering, while the HX711 chip's amplification and A/D conversion circuits achieved high-precision signal conversion. Analog and digital wiring were separated and optocouplers were used for isolation to effectively avoid mutual interference caused by common impedance of ground wires between components. The sensor signal line was shielded and twisted together to reduce the influence of external electromagnetic fields on the circuit and effectively prevented the circuit from radiating electromagnetic energy outward.

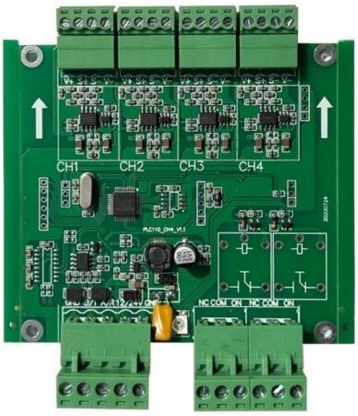

Fig. 6 - Signal conditioning

To improve the data acquisition accuracy and anti-interference ability of the yield monitoring system, a weight compensation device was designed, and software filtering algorithm was developed. An identical reference sensor was installed next to the weighing sensor, and a certain amount of iron block was fixed on the reference sensor as a counterweight. The reference sensor was only affected by the vibration of the harvester. The reference sensor and the weighing sensor were fixed in the same position, so the variation pattern of the vibration frequency and amplitude they received was synchronous. By using hardware differential circuit and microcontroller to process the weighing signal based on the reference signal, the interference of vibration can be reduced to some extent. The hardware circuit structure of a weighing sensor is shown in figure 7.

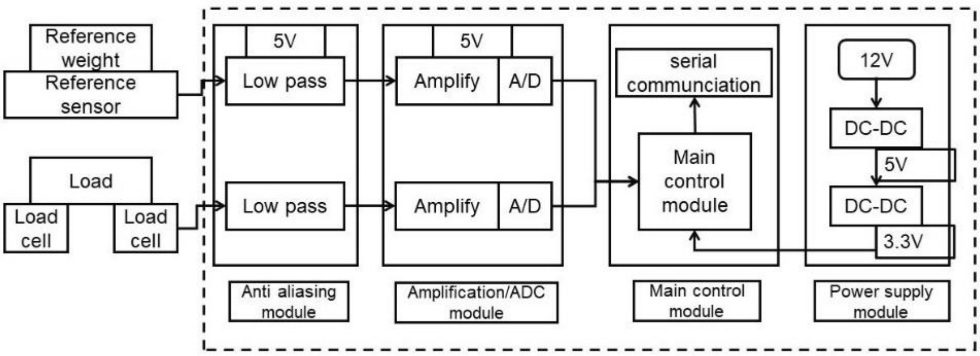

Fig. 7 - Hardware schematic for weighing module

Software filtering algorithms can also improve the anti-interference ability of measuring and producing systems. The voltage signal sampling values of weight sensor outputted, taken as a time sequence, were processed using a software algorithm that combined clipping filtering and recursive averaging filtering (*Qian et al., 2021; Pietrzak et al., 2014; Richiedei et al., 2018*), and errors caused by chance factors can be overcome, and periodic interference can be suppressed, significantly improving the repeatability and accuracy of the system's data acquisition.

The mathematical expression of the limit filtering algorithm is formula (3); and the mathematical expression of the recursive averaging filtering algorithm is formula (4).

$$Y_i = X_i \qquad | X_i - x_{i-1} | \le A$$
$$Y_i = X_{i-1} \qquad | X_i - x_{i-1} | \le A \tag{3}$$

$$Z_n = \frac{1}{N} \sum_{i=1}^{N-1} Z_{n-1} \tag{4}$$

In equation (3), X_i is the current sampling value, X_{i-1} is the previous sampling value, Y_i is the actual returned value, A is the maximum allowable error value. In equation (4), Z_n is the output after filtering the n(th) sampling value, Z_{n-1} is the unfiltered n-i(th) sampling value, n is the number of recursive averaging terms, that is, the arithmetic mean of the n(th) sampling's n, n-1, ..., n-N+1 sampling values.

The moisture sensor used for yield monitoring module was HM1500lf (accuracy ±3% RH, supply voltage 3.3 V). The sensor is small, has a built-in solid polymer, and can still work in harsh environments. Two sensors were installed at the bottom of the grain tank to calculate the moisture content of the crop in each plot by averaging the voltage. When comparing the yields of different varieties in experiments, it is necessary to convert them to the weight at the same moisture content using formula (5) (*Nelson et al., 1991; Rodrigues et al., 2020*).

$$M_i = M_k \frac{1 - W_a}{1 - W_b} \tag{5}$$

Where, M_i is the actual weight of crop in the (i)th plot, M_k is the weight of crop measured by the yield monitoring system, W_a is the moisture content of the crop measured by the yield monitoring system, W_b is the national standard moisture content of the crop.

Date transfer module

After the slave computer collected the information on the yield of the plots, it is necessary to transmit this data to the host computer. Due to the complexity of the field environment and problems such as long distances and difficult wiring in data transmission, wireless data communication was chosen for data transmission. 4G DTU (Data Terminal Unit) is a highly integrated data transmission unit that can conveniently convert serial port output data into IP information and send it to the server (*Su et al., 2021*). This method had fast transmission speed, long distance, stable communication during transmission, and low data loss.

The 4G DTU used the USR-781 designed by Jinan Youren Technology Co., Ltd. In the actual working process, the microcontroller converted the yield and location information into serial port data, which was sent through the RS232 circuit to the DTU module that communicated with the remote terminal. The received information was converted into IP information by DTU and sent through the base station. Finally, the server received the raw data, parsed it into yield information recognizable by the computer, saved it to the database for further processing, and the entire process achieved wireless data transmission. When transmitting data between the 4G DTU and the server, it is necessary to write a communication protocol. The collected data was packaged by the microcontroller and analysed by the remote terminal according to the communication protocol, which can ensure the smooth communication of the yield monitoring system. The communication protocol format is shown in Table 2.

Table 2

Coding Method

Data domain	Bytes
Header	1
Length	2
Mode	1
Identifying	2
Data	N（variable）
Checksum	1
End of frame	1

The communication protocol specified that each data frame consisted of seven parts: frame header, length, mode, identification, data, checksum, and frame footer. The frame header and footer were used to identify a data frame; length indicated the length of all data information from the frame header to the frame footer. There were two modes, one was 0x01, indicating that the host computer sent instructions to the slave computer, including communication request, positioning request, and information acquisition, the other was 0x02, indicating that the slave computer sent data to the host computer, including weight and moisture content. The identification is used to identify data types. There were 0x8001, 0x8002 and 0x8003 to represent grain quality, grain moisture content, and instructions respectively. The checksum was the XOR checksum of a frame of data, used to verify if the received data was correct.

Power supply module

The slave computer module of the yield monitoring system needed to be powered when working in the field, using the self-contained battery of the harvester. The supply voltage of the STM32 main controller in the system was 3.3 V, and the supply voltage of the weight sensor and moisture sensor was 5 V. The voltage of the battery power supply was 12 V. Therefore, LM2596 chip and LM1117 chip were used to design a power-down circuit to reduce the 12 V voltage of the battery to a stable 5 V and 3.3 V for the main control module and various sensors. The designed power module is shown in figure 8.

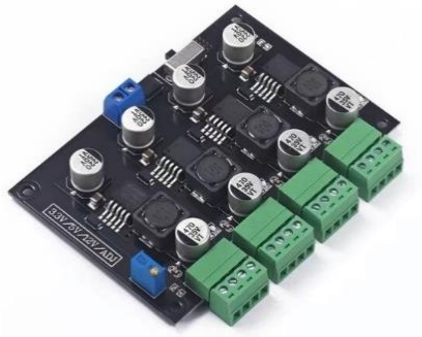

Fig. 8 - Power module

Host computer design

Based on the Windows 10 operating system, the host computer data management platform was designed using LabVIEW software. LabVIEW is a virtual instrument design software that uses graphical programming. It supports TCP data transmission and graphic drawing, and has obvious advantages in intelligent programming, processing capability, and cost-effectiveness *(Castillo-Ruiz et al., 2015; Purti et al., 2021; Voicea et al., 2011; Vlăduț et al., 2023)*. Using the built-in TCP serial port in LabVIEW can establish data communication with 4G DTU. The data sent by the slave computer was parsed according to the protocol and saved in the database created by Access, and then data management was performed by calling the database. The functions that the host computer needed to achieve include data display, storage, and drawing of yield information charts to help plot researchers further analyse data.

The designed data management platform is shown in the figure 9, including three interfaces for data acquisition, yield chart drawing, and data saving and querying. The data acquisition interface implemented functions such as network connection and data calibration. In the drawing interface, when comparing the yield of various plot crops, it is necessary to convert to weights at the same moisture content. In the data storage interface, the received data was parsed by protocol and stored in an established Access database in chronological order. The data display and table generation were achieved by writing a program which called the contents of the database, and can be queried historically.

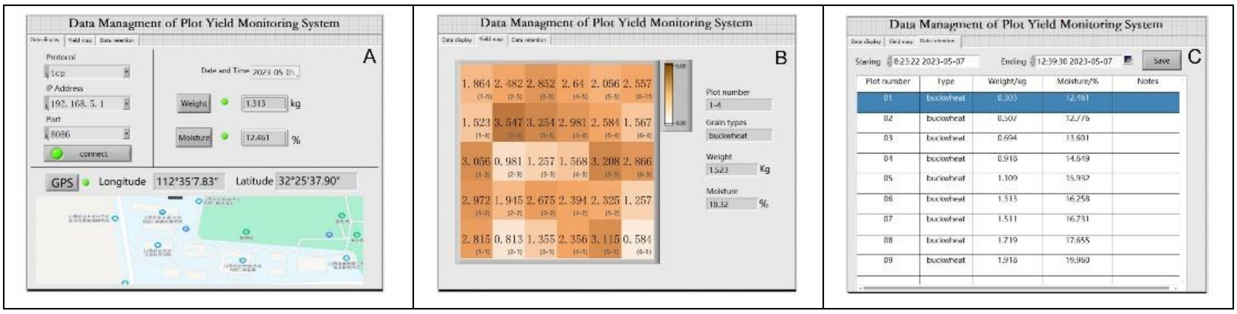

Fig. 9 – The yield monitoring system date management platform

a) Data acquisition interface; b) Yield chart drawing interface; c) Data storage and query

RESULTS AND DISCUSSION

Test of intelligent yield monitoring system

In order to verify the accuracy and stability of the intelligent yield monitoring system, the performance of the system for buckwheat was tested using a 4LZX-1.5 type plot combine harvester in the laboratory (as shown in figure 10).

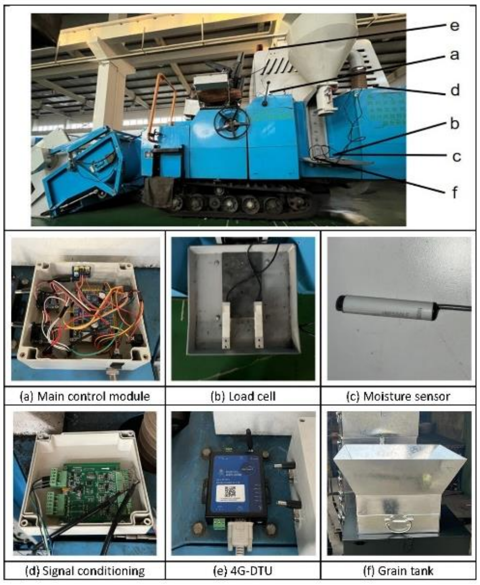

Fig. 10 – Components diagram of the yield monitoring system

Before the test, the weighing sensor and moisture sensor were first calibrated. A standard weight was used to calibrate the weighing sensor and reference sensor respectively. After the calibration, ten samples of buckwheat (weight limit within 0-10 kg) using an electronic balance (range 0~20 kg, precision 0.01 g) were randomly taken, then they were put into the weighing tank in batches and the output voltage of the weighing sensor was recorded. The measurement was repeated three times, and the average value was taken each time. The experimental result is shown in figure 11, which indicated that there was a strong linear relationship between the output voltage of the weighing sensor and the weight of the buckwheat sample between 0-10 kg, and the y-axis intercept was 0.332 V, which was due to the weight of the sensor box, indicating that the output voltage of the sensor under no load was 0.332 V. Due to the influence of the volume of the tank and the range of the sensor, the maximum weight that could be measured each time didn’t exceed 15 kg when the system was running. In actual field work, the yield of each small area will not exceed this value.

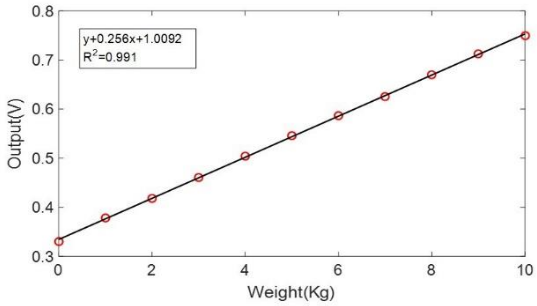

Fig. 11 – Weight calibration experimental results

The calibration of the moisture sensor was conducted in the laboratory. An electronic analytical balance (with an accuracy of 0.01g) was used to weigh a certain mass of buckwheat samples and they were placed in a sealed bag. Moisture content measurement samples were prepared ranging from 5% to 35% by adding distilled water. First, the moisture contents of the samples were measured by the drying method and taken as the actual values. Then, at different temperatures, the HM1500lf moisture sensor was inserted into the sealed bag for measurement. Five gradient temperatures were chosen: 14°C, 18°C, 22°C, 26°C, and 30°C for the measurements, repeated each experiment three times, and the average value was taken. The experimental result is shown in the table 3.

Table 3

Output voltage values of moisture sensors under different factors

Moisture contents /%	Temperatures /℃				
	14	18	22	26	30
6.01	0.937	0.950	1.011	1.135	1.209
10.93	1.424	1.474	1.554	1.678	1.750
15.14	1.699	1.756	1.845	2.041	2.101
21.28	2.180	2.341	2.392	2.464	2.526
27.83	2.589	2.701	2.747	2.777	2.882

The results showed that the output voltage of the moisture sensor had a clear pattern with the changes in moisture content and temperature. By performing regression analysis on the data, the optimal mathematical model is obtained as follows:

$$Y = 8.991 - 24.5002X_U^{\ 2} - 0.1666X_T^{\ 2} + 2.5004X_U + 0.5793X_T + 4.5071X_U X_T \tag{6}$$

where: Y is the moisture content of buckwheat samples, X_U is the voltage value of the humidity sensor, X_T is the sample temperature.

The mathematical model obtained through calculations was written in the C language and incorporated into the software equation of the system, and then the model was validated. 10 buckwheat samples with moisture content ranging from 5% to 35% were randomly prepared and the yield monitoring system was used to obtain measurement values, the results were finally compared with the actual values by drying method. The results are shown in figure 12.

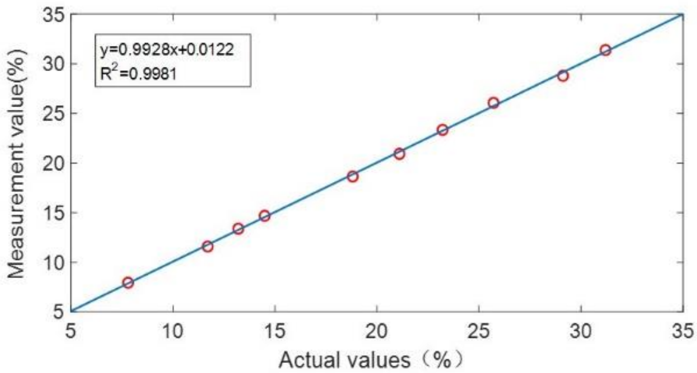

Fig. 12 – Model validation results

The calibrated results were written into the software program of the monitoring system, and the designed weighing platform was installed on a 4LZX-1.5 combine harvester. A data connection was established with the host computer to simulate field working conditions, where the engine of the harvester was idling (810 r/min). Different weight and moisture content buckwheat seeds were put into a weighing box, and the data collected by the intelligent yield monitoring system was recorded and analysed. The observation was made to see if the host computer could display the data and draw the yield diagram.

RESULTS

During operation, the yield monitoring system was affected by vibrations from the combine harvester. A test was conducted by pouring 2.5 kg of buckwheat seeds into a weighing tank and comparing the unprocessed data with compensated and filtered data. The table 4 showed that after compensation and software filtering, the maximum error decreased from 5.140% to 1.330%, and the average error decreased from 0.624% to 0.146%. This indicated that the designed compensation device and filtering algorithm effectively reduced data errors.

Table 4

The weight experiment result before processing and after compensation and filtering

Number	Without compensation device and filtering		After compensation device and filtering	
	Measurement value / kg	Relative error / %	Measurement value / kg	Relative error / %
1	2.606	4.256	2.526	1.050
2	2.372	-5.140	2.467	-1.330
3	2.581	3.230	2.522	0.875
4	2.597	3.882	2.526	1.037
5	2.446	-2.144	2.484	-0.625
6	2.526	1.040	2.512	0.465
7	2.479	-0.821	2.490	-0.415
8	2.622	4.885	2.528	1.118
9	2.406	-3.766	2.477	-0.925
10	2.521	0.822	2.505	0.214
Mean	2.516	0.624	2.504	0.146
Standard deviation	0.088	3.515	0.023	0.909
Range	0.251	10.025	0.061	2.448

During the moisture content testing experiment, ten samples with different moisture contents were prepared and poured into a grain tank in sequence. The moisture content test results from the computer were recorded and compared with the results obtained using the drying method. The results in table 5 showed that the maximum relative error between the actual and measured values in the moisture content test was 2.800%, the minimum relative error was 0.552%, and the average error was within the allowable range, meeting the requirements for monitoring crop yield.

Table 5

The Moisture content testing results

Sample number	Actual value/%	Measurement value/%	Relative error /%
1	12.230	12.461	1.889
2	12.570	12.418	-1.209
3	13.480	13.201	-2.070
4	14.250	14.649	2.800
5	15.620	15.332	-1.844
6	15.950	16.258	1.931
7	16.560	16.331	-1.383
8	17.080	17.550	2.752
9	17.570	17.407	-0.928
10	19.560	19.452	-0.552
Mean	15.487	15.506	0.139
Standard deviation	2.346	2.345	1.864
Range	7.330	7.03	4.870

Analysis of error sources in performance experiments may include the following aspects: inability to completely eliminate vibrations during weight measurement, failure to consider road excitation, and failure to consider changes in temperature and differences in particle gaps after grains fall into the grain tank during moisture content testing. To address these issues, corresponding measures had been taken to reduce their impact. Reducing the impact on harvesting machine vibrations and road excitation, algorithms with better filtering effects were developed and some limit devices were installed at the physical level. To address the error caused by the temperature difference and the grain gaps, a temperature measurement device was designed, and temperature factors were incorporated into the process of measuring grain moisture content. To address the issue of uneven gaps between particles, the method of taking multiple measurements was employed and they were averaged.

Compared with other commercial monitoring systems (as shown in table 6), it was found that the designed system has a certain gap in date acquisition accuracy. The cost of our design is lower and the performance can basically meet the needs of plant breeding research, which has a high cost-performance ratio. Therefore, further research will be conducted to improve the collection accuracy based on the experimental results analysis, making it a potential alternative for commercial small-scale production measurement equipment.

Table 6

Performance index of yield monitoring system

Technical date	Wintersteiger W1	HM H2 Classic	INTELLIGENT YIELD MONITORING SYSTEM
Test Weight	±0.1 lbs (± 45g)	+/- 0.8 lb/bu (+/- 1 kg/hl)	0.909%(0 ~ 20kg)
Moisture	Accurate to ±1 %	+/- 0.5% for 0% to 27% moisture; +/-1.0% for 27% to 40% moisture	1.846% (for 10% to 30% moisture)

CONCLUSIONS

In this paper, a plot breeding yield monitoring system was described, which consists of a host computer and a slaver computer, achieving yield monitoring and wireless data transmission. It is proposed to improve the accuracy of data acquisition by combining a weighing compensation device with a software filtering algorithm to solve the problem of large measurement error of the yield monitoring system under dynamic conditions. The performance test results of the system showed that the maximum error between the measured value and the actual value in the weight test was 1.330%, and the standard deviation error was 0.909%. The maximum error between the measured value and the actual value in the moisture content test was 2.800%, and the standard deviation error was 1.864%. The host and slave computers can establish a stable data connection, resulting in high system stability which meets the requirements of yield monitoring in plot breeding experiments.

The system achieved synchronous yield monitoring during plot breeding experiments, improved efficiency, avoided data confusion, and was low-cost with good performance, providing breeders with cost-effective monitoring tools. Next, further research will be made to improve data collection accuracy.

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