DEVELOPMENT OF AN INTELLIGENT YIELD MONITOR FOR GRAIN COMBINE HARVESTER

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Abstract: An intelligent yield monitor for grain combine harvester was developed. The harvested crop was wheat, and the harvesting combine used to equip the monitor was JL1065, a typical machine with 4-meter swath width in northern China. The monitor can collect four analog signals, grain flow, grain moisture content, grain temperature, and header up/down signal, and two digital signals, ground speed and elevator speed. Two digital signals were sensed by Hall effect elements. The monitor can also synchronously receive DGPS signal. A liquid crystal display and a touch screen were integrated as an I/O interface. Field tests showed a linear relationship between actual yield and the output of the yield monitor. The error between measurement and prediction was less than 3%. It is concluded that the developed intelligent yield monitor is practical.

Key words: artificial intelligence, yield monitor, yield mapping, precision agriculture

1. INTRODUCTION

Yield monitor is an important component of precision agriculture ^(1, 2). Yield maps provide feedback for determining the effects of management inputs such as fertilizer and lime, seed and pesticides, and cultural practices such as tillage, irrigation and drainage ^(3, 4). Some commercial yield monitors are available, such as Greenstar®, Fieldstar®, Ag Leader® and AFS® ^(5, 6). However, all these systems were designed for large combine harvester used by American or European farmers. It is difficult to apply this type of monitors to typical small Chinese machine. In addition, their high price is

another obstacle for their application in developing countries like China. Thus it is necessary to develop an intelligent yield monitor for grain combine harvester in China ⁽⁷⁾.

This paper describes a new impact type of grain yield monitor used for small combine harvester with the swath width less than 4 meters, and reports the results of performance test and field test, and finally gives an evaluation of its practicability.

2. DEVELOPMENT

In order to obtain correct grain yield information and yield map, except for grain weight sensor or grain bulk sensor, some other sensors are necessary. Figure 1 shows the yield monitor system developed. It includes six sensors (grain flow sensor, header height sensor, elevator speed sensor, ground speed sensor, grain moisture and temperature sensor) and some other components, such as a GPS receiver, a liquid crystal display (LCD), a touch screen, and an intelligent controller.

Figure 1. Components of the grain yield monitoring system developed

The yield monitor collected four analog signals (grain flow, header height, grain moisture, and grain temperature), two pulse signals (ground speed and elevator speed), and DGPS data at the same time. After a series of process, the system stored all data on a CompactFlash® (CF) card once per second. The yield monitor also included a liquid crystal display (LCD) and a touch screen as the Man-Machine interface ⁽⁸⁾.

Figure 2 shows the diagram of the yield monitor developed. It used a P80C592 manufactured by Philips Semiconductors as the microcontroller. It had a 10-bit analog-to-digital converter (ADC) with 8 multiplexed analog inputs and 15 interrupt sources with 2 priority levels ⁽⁹⁾.

Figure 2. Diagram of the yield monitor system developed

For each analog signal, the microcontroller used an analog channel to collect it. Then these signals were converted into digital. Two Hall effect sensors were individually mounted in the drive shaft of the front wheel and the shaft of elevator to measure ground speed and elevator speed respectively. Each of them was able to generate a square wave with a frequency in direct proportion to the measured speed. Data storage device was a necessary part of the system. Storage media should be large enough and safe enough to save all the data mentioned above once per second for several days or even a whole harvest season. CompactFlash® card was chosen as the storage media. The user interface consisted of a touch screen and a LCD. The touch screen was used to input some parameters and settings for system configuration. The LCD was used to show the data related to yield. Microcontroller operated these two devices through RS-232 serial port.

3. TESTING AND MODELING

3.1 Lab Test and Modeling

Grain flow sensor is the most important part of yield monitor system. It was performance-tested on a special test-bed in laboratory. The test-bed was made by a elevator of combine harvester, a driving motor and a adjustor to change RPM of the motor, a hopper to input grain to the elevator, and a chamber. The grain flow sensor was fixed in the chamber near the outlet of the elevator so that it can monitor the grain flow and then change the grain impact to an electric signal.

Firstly, the sensitivity of the grain flow sensor was tested. Figure 3 shows an example of the test result. It is obvious that when grain was input to the test-bed the output signal of the sensor jumped remarkably and kept stable in high level. A linear estimation model was proposed to transform the output of the flow sensor to grain weigh (wet):

$$W = kU \tag{1}$$

where, U was the output of flow sensor (V); k was a coefficient obtained from sensitivity test (calibration) as shown in Figure 3; W was the grain weight. The frequency of sampling and transforming was 1 Hz, so that W also meant the grain flow. Table 1 shows the test result.

Table 1. Result of repeatability test for grain flow sensor

Number	Estimated Weight (kg)	Scale Weight (kg)	Error
1	277.1	277	0.04%
2	328	324.3	1.14%
3	311	341.1	8.82%
4	309	318.4	2.95%
5	311	315.7	1.49%
Sum	1536.1	1576.5	2.56%

Figure 3. Result of sensitivity test for grain flow sensor

Five tests were executed and the estimation errors were calculated based on equation (2):

$$\text{Error} = (\text{Estimated Weight} - \text{Scale Weight}) / (\text{Scale Weight}) \times 100\% \quad (2)$$

Except for test 4, all other errors were smaller than 3%. If calculated the sum of grain weight for all five tests, the relative error between estimated weight and scaled weight was 2.56%. All these showed that the repeatability of the flow sensor was practical.

3.2 Field Test

3.2.1 Calibration method

In field test, the flow sensor was calibrated again to correct the coefficient k obtained from equation (1). The calibration steps were listed below:

(1) Harvesting a piece of field, then calculating the grain weight (wet) with equation (1). The coefficient k was initially set as the system default value (0.9) obtained from lab test.

(2) Measuring the actual weight of the harvested grain (wet).

(3) Inputting the actual weight to the system through touch screen.

(4) System automatically calculated the new k according to equation (3):

$$k = k_1 \times W_1 / W_2 \quad (3)$$

where W_1 was the actual weight of the harvested grain; W_2 was the weight calculated by system; k_1 was the value of the coefficient k , which was just used in the harvest. The calibration can be repeated several times to improve sensor accuracy.

3.2.2 Calibration in field

First field test with total six loads was performed on June 11, 2004. The data of the six loads are shown in Table 2. Calibrations were conducted in the first three loads, and then validation was executed in the last three loads. System used the default value of k (0.9) for the first calibration. The huge error of 45.55% showed that the default value obtained from the simulation test was not fit for real harvests. Calibration changed the value of k to 0.618, and the errors in the second and third loads were greatly decreased. After the third calibration, the value of k was modified to 0.613; and then it was not changed in last three loads (validation test). The errors of the last three loads were all less than 3%. Therefore, the flow sensor performed well in linearity and stability.

Table 2 Data and result of the field test on June 11, 2004

Load number	Value of k	Actual grain weight (wet) (kg)	Grain weight (wet) measured by system (kg)	Error
1	0.900	366.2	533	45.55%
2	0.618	277.1	277	-0.04%
3	0.618	383.1	380	-0.81%
4	0.613	421.7	426	1.02%
5	0.613	406.6	416	2.31%
6	0.613	375.4	381	1.49%

Second field test was taken on June 13, 2004. The data are shown in Table 3. The k value of 0.613 from the last test was used for calibration in the first load. After the calibration, the errors of the second and third loads decreased significantly. However, the error in the first load of the test was much bigger than the errors in the second and third loads of the previous test. The possible reason was thought to be environmental temperature. The environmental temperature increased greatly between the two days, and the grain moisture decreased greatly. So the ground speed and grain flow would both increase in the second test. The several changed conditions contributed to the increase in error.

The difference between the two tests shows that the system calibration method should be improved, so that the system can work with a high accuracy for a relatively long period of time.

Table 3 Data and result of the field test on June 13, 2004

Load number	Value of k	Actual grain weight (wet) (kg)	Grain weight (wet) measured by developed system (kg)	Error
1	0.613	418.4	367	-12.28%
2	0.705	324.3	328	1.14%
3	0.705	362.5	367	1.24%

4. SUMMARY

An intelligent yield monitor for grain harvester based on an 8-bit microcontroller was developed. A long time of laboratory and field tests showed that the monitor was in high accuracy and practicability.

Modeling of the grain flow sensor in both laboratory and field tests showed that the sensor had a high linearity and worked steadily. Field test showed that the system had the capability to predict accumulated grain mass with an error less than 3% under the given harvest conditions. More filed tests are needed to improve the calibration method and to reduce the effect of the harvest conditions on measurement accuracy of the monitor system.

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