REAL-TIME CALIBRATED COTTON YIELD MONITOR

J. He
J. A. Thomasson
X. Han
Texas A&M University
College Station, TX
R. Sui
USDA Agricultural Research Service
Stoneville, MS
J. D. Wanjura
M. G. Pelletier
USDA Agricultural Research Service
Lubbock, TX

Abstract

Cotton yield monitors are important in identifying the variability of cotton yield to generate yield maps and in determining revenue and profit across farm fields. Multiple yield monitors have been developed and commercialized over roughly the past two decades, but their reported lack of accuracy and repeatability means the data requires time-consuming post-correction in GIS software. Therefore, a highly accurate yield-data calibration system has been coupled with a yield monitor that has proven effective at the research level. The new system comprises four major components: a pair of mass flow sensors, a single data processing system, an onboard weight-based calibration system, and a GPS receiver. The system processes data with a Raspberry Pi 3, a highly capable and versatile unit which works as the "brain" of the system to (a) receive data from mass flow sensors, the GPS receiver, and the calibration system, (b) process and store data, and (c) control the display of the results and communication between all the other components of the system. The system was field tested on a cotton stripper in the Dec 2018 harvest in Lubbock, Texas. Results indicated that the mean absolute percentage error was 11.7%.

Introduction

Precision agriculture is based on observing and measuring conditions, attempting to make optimal input decisions, and taking actions based on inter- and intra-field variability to maximize yield and profit as well as minimize environmental impact. Yield is the basic data requirement in cotton production to map spatial variability in fields, so yield sensors can play a critical role in optimizing intra-field management. Cotton yield monitors are used to collect cotton yield data. They consist of one or more sensors mounted on cotton harvesters to sense the amount of material being harvested at precise locations in the field. Coupled with GPS data, yield data can be mapped to provide a basis for precision-agriculture decision making.

Multiple yield monitor systems have been developed and marketed over more than two decades. The first optical-attenuation-based sensor was developed in 1994 by Wilkerson et al. and later improved. Thomasson et al. (1999) tested two optical-attenuation-based devices to measure the flow of cotton in a gin. Since 1997, cotton yield monitors have been evaluated in fields and commercialized by AgLeader (Ames, IA), FarmScan (Perth, Western Australia), Micro-Trak (Eagle Lake, MN), AGRIplan (Stow, MA), and John Deere (Moline, IL). Thomasson and Sui (2003) developed and successfully tested optical-reflectance based sensors which measure cotton flow as it passes the cotton harvester's duct to the basket.

The mass flow sensors are optical-reflectance-based sensors that were designed by Thomasson and Sui (2003) and have proven effective for yield monitoring in cotton and peanuts. The light sources and detectors of these sensors are mounted in one housing unit and thusly automatically aligned, unlike previous sensor designs. The configuration of the housing unit is simple to install on a harvester because each sensor only requires one port to be cut into the wall of a cotton picker or stripper duct. After this system was tested in the 2000 cotton harvest season, the sensor design was improved by limiting the influence of stray light and temperature and by comparing monitor output with the actual weight of the load (Thomasson and Sui, 2001). Results of the 2001 season were quite promising with an average absolute error of 3.7% for one field and 4.9% for a second field.

Most available commercial cotton yield monitors are based on optical sensing techniques that measure the flow of cotton in the harvester ducts. These yield monitors have collected useful information, especially on the variability of yield in a given field, but remain limited by their accuracy and repeatability weaknesses. Manufacturers generally recommend that yield monitor systems be calibrated whenever field conditions change, but it is difficult for users to do this in practice; calibration is tedious and takes time from an already busy harvesting process.

An on-board weight-based calibration system was developed to calibrate cotton yield monitors' data in semi-real time as crop conditions or varieties change throughout a field (Wanjura et al., 2015). On-board seed cotton weight in the harvester's basket was measured as a function of hydraulic cylinder pressure lifting the basket at a single consistent position. The absolute value of seed cotton weight for each basket was measured on a static scale on the side of the field. Compared to the absolute values measured, the on-board weight-based calibration system had a mean absolute error of 2.75%.

The objectives of this study are to combine the weight-based calibration system (Wanjura et al., 2015) with cotton mass flow sensors developed by Thomasson and Sui (2003) by a high performance data processing system in order to upgrade conventional cotton yield monitors' accuracy and repeatability with real-time in-field calibration. The desired end state is an integrated system of these components in terms of sensing, data acquisition, and communication, so that accurate yield information can be recorded and displayed in real time with no need of post-harvest data manipulation, and used to generate yield maps for site-specific management.

Materials and Methods

The new combined system comprises 4 major components: the mass flow sensors (Thomasson and Sui, 2003), a single Raspberry Pi 3-based data processing system, the onboard weight-based calibration system (Wanjura et al., 2015), and one Ublox GPS receiver. The data processing system is the key component in the combined system, and works as the "brain" of the system to receive data from mass flow sensors, the GPS receiver, and the calibration system, to process and store data, and to control the display of results and communication between all the components. A Raspberry Pi 3 Model B+ development board with an A/D converter was used because it provides a robust hardware platform with 1.4 GHz 64-bit quad-core processor and 40-pin GPIO for flexibility and expansibility. A Python GUI (Graphic User Interface) was designed to display sensor data, GPS data, and get calibration data from the onboard weight-based calibration system in real time.

Lab Tests

Lab tests preceded field tests to verify the functionality of the new data processing system. An approximate model of a cotton stripper pre-cleaning duct was made of plywood with 91cm height, 127cm width and 18cm depth. Two sensors were mounted on it with 42cm away from the each edge and 30.5cm away from top as shown in Figure 1. One load of seed cotton was defined by a container with dimensions 28cm length by 14cm width by 12.5cm height and was dropped by hand down the duct. Each load weighed about 360 g. Two lab sessions were conducted to record performance of the combined system. The mounted sensors and GPS on the model duct continually collected data and sent them to the Raspberry Pi. A Lenovo laptop sent simulated weight data to the Raspberry Pi in place of the onboard weight-based calibration system. Both sets of data were displayed on the GUI. Improvements in the data processing system software were made in-between sessions. The first session ran 6 loads and the second one ran 11 loads.

Figure 1. Sensors installation on the mimic duct for lab tests.

Field Tests

In the 2018 harvesting season, the real time calibrated cotton yield monitor was mounted on a JD 7460 four-row cotton stripper in Lubbock, Texas for field evaluation of the system's accuracy, long-term utility, and reliability. The sensors were mounted behind the cab on the collection duct of the cotton stripper, which conveys seed cotton from the field to a cotton cleaner within the duct and then to the basket (Figure 2). One 7.6 cm hole was cut for each sensor with 30.5 cm away from top and 30 cm away from the inner edge. The antenna of the GPS receiver was mounted on top of the cab. The data processing system and display were affixed to the wall in the harvester cab by the armrest (Figure 3) so that communication is available between it and the on-board weight-based calibration system (already in place). Both the sensors and GPS output were connected to the data processing system via cables.

Figure 2. Sensors location on the cotton stripper 7460.

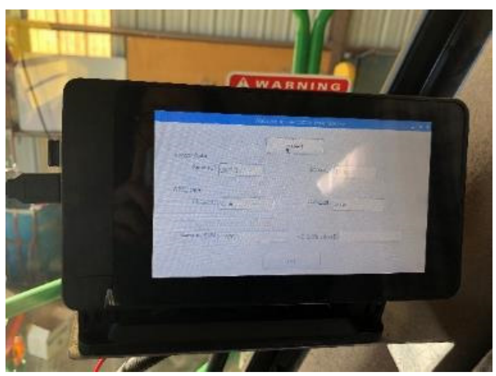

Figure 3. Data processing system location in the cab.

Data collected by the mounted sensors and GPS receiver were continually saved and displayed on the data processing system. The calibration system took samples by measuring the weight of seed cotton when the harvester basket was full and transferred that measurement to the cotton yield monitor. Each weight measurement was synchronized with all previous weight data from the weight-based calibration system and remotely saved on the data processing system. To synchronize a new piece of weight data, the data processing system would track the timestamp of the previous save of the whole weight data file. If the timestamp was changed, the latest line of the weight data file would be read and extracted to correct the sensors' accumulated value in real time and get the yield data in-situ.

About 1.5 acres of cotton were harvested, but due to weather limitations this season, only 12 samples were collected. During the harvesting, the data processing system worked for 4 hours with no stopping.

Results and Discussion

Figure 4 illustrates a strong linear relationship ($R^2 = 0.912$) between the cotton mass flow sensors' output and weight data from the on-board weighting system. The seed cotton weight ranged from 0 kg to 600 kg and the cotton mass flow sensor output varied from 10V to 50V. The results of this field test indicated that data points had a mean absolute percentage error (MAPE) of 11.70% against the linear regression (Figure 4).

There were some problems during testing. Firstly, there were some unexplained problems that happened with the optical sensors. Secondly, the GPS readings were not always accurate. Thirdly, other factors influencing the results included weed level in the field and environment temperature. Some future improvements to the system should include 1) troubleshooting the optical sensors, 2) improving the data processing system's sampling rate to demonstrate the progression of the seed cotton weight measurements, 3) increasing the stability of the firmware, and 4) further field testing.

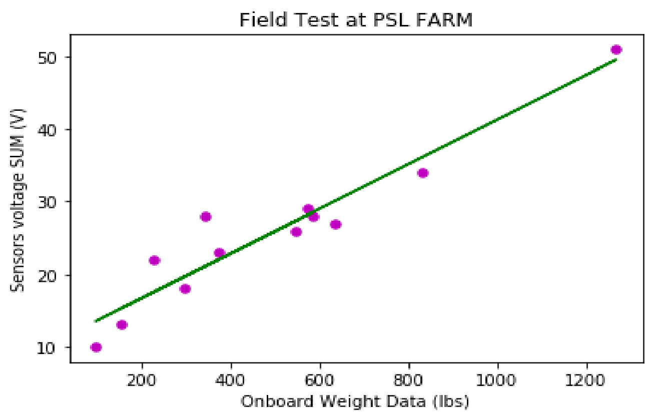

Figure 4. Onboard weight data vs. sum of sensors output signal.

Summary

The results showed a strong correlation (R^2=0.912) between onboard weight data and accumulated sensors' output data with a low error (11.7%). This indicates that the cotton yield monitor works without calibration and with a high accuracy. Because cotton yield monitor calibration has been necessary in the past, much time and money can be saved by this novel combined system in the future.

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