ROUND MODULES: HANDLING LOGISTICS AND COVER DAMAGE, 2ND YEAR

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Abstract

Round cotton modules covered with engineered plastic film are becoming increasingly popular because the system is largely automated. Cotton growers still face challenges in managing information about each module, which is required to produce good quality fiber during ginning. To address these challenges, a single-board computer-based system was developed and installed on a loader used to handle modules to store the data encoded in the RFID tag and capture module images automatically during handling. The system consisted of a GNSS module, an RFID module, a moisture probe, a temperature probe, and three cameras, controlled by a Raspberry Pi4. Using the system, the module's GPS location, moisture content, temperature, and images from different views were associated with the unique RFID tag number for each module. From the captured images it was possible to detect the nature, amount, and source of the plastic film damage that occurred during the handling process. Further, it is possible to reduce the transportation cost, time, and labor by conducting a path planning study using the GPS positioning data recorded by the system. Using the module data collected by the developed system, improved handling and ginning processes can be developed to produce contamination-free high-quality cotton and uphold the reputation of US cotton in the international market.

Introduction

As the third-largest cotton (*Gossypium hirsutum* L.) grower, the US has a reputation worldwide for producing contamination-free cotton. The price of cotton depends on the quality of the cotton fiber, which is related to genetics and the environment and management practices from planting through post-harvest (Bradow et al., 1997). The harvesting process of cotton has been fully mechanized in the US. To identify the owner of the module before ginning, each module is provided a unique identification number. Historically, any module data associated with an identification number would need to be manually entered. Use of radio frequency identification (RFID) technology for this purpose could be a fruitful alternative to store the information of any module using an automated system to reduce labor requiremenst. Over the last decades, RFID has become one of the most promising technological innovations used in the manufacturing and industrial field (Urso et al., 2020). This technology is providing significant advantages also in smart agriculture by reducing the possibility of human error in data storage with comparatively low cost and labor (Ruiz-Garcia and Lunadei, 2011).

Considering the low labor and time requirements, ease of transportation, and preservation of fiber quality, round cotton modules are increasing in popularity (van der Sluijs et al., 2015). However, small plastic pieces from the round module cover can enter the gin. Moreover, this plastic contamination can result in a discount of \$0.88/kg (\$0.40/lb) to affected bales. The plastic contaminants in the cotton are highly unacceptable to textile manufacturers because it may ruin a large batch of produced yarn and/or textiles. Total losses to the US cotton industry are estimated at \$750 million annually (Pelletier et al., 2020). For these reasons, the removal of plastic contaminants has become a prime concern for the cotton industry. The cotton fiber is commonly contaminated by the plastic during the ginning process when a small amount of plastic remains in the cotton after removing the cover. This phenomenon mostly happens when the plastic cover is damaged before the ginning operation started; during loading, unloading, or transportation. The location and causes of the damage during the transportation process of modules from field to gin yard need to be identified, so appropriate prevention or mitigation steps can be taken. Therefore, a system is needed for monitoring the type and origin of plastic film damage during the handling process. For monitoring system development, the use of cameras has become a popular option in various applications in agriculture because of low cost, reliability, and measurement speed (Pelletier et al., 2020; Condotta et al., 2020). The use of multiple cameras for monitoring the module during the handling process would be an effective and economic method of identifying cover damage.

Moisture content has a significant effect on both the fiber and seed quality of a cotton module. At above 14% moisture content (w.b.) in traditional cotton modules yellowing of the fiber occurs and moisture content above 16% completely arrests germination of the seeds (Searcy et al., 2010). Also, the high moisture content of seed cotton requires more drying fuel and reduces the ginning rate, which increases ginning costs. Cotton seeds with high moisture content are more likely to break during ginning, which produce seed coat fragments in the fiber. For efficient ginning and best quality, the moisture content of seed cotton should be below 12% entering the gin (van der Sluijs and Long, 2016). Temperature is another indicator of seed and fiber quality in the cotton module. Temperatures inside a conventional cotton module more than 20 °F above ambient indicate high moisture content and deterioration of seed and fiber quality. Therefore, measuring the moisture content and temperature of the cotton module during handling would be useful in producing high-quality fiber.

Another issue with cotton module handling are high transportation costs. To reduce transportation costs, semi-tractor trailers (STT) are often used to transport round modules, instead of module trucks. However, no specific data is available regarding the time and cost of loading and unloading STT. Using a Global Navigation Satellite System (GNSS, includes GPS) for path planning for agricultural field operations of cooperating machines can significantly reduce both transportation cost and time (Jensen et al., 2012). Use of a GNSS could be a potential solution for path planning during cotton module loading and unloading.

To address these challenges in handling cotton modules, the development of a smart monitoring system is necessary. The objective of this research was to design and develop a portable monitoring system compatible with any transportation machine for the cotton module. The specific objectives were:

- Design a sensor assembly to determine the moisture and temperature of the module during handling.
- Install cameras to capture the module images from different direction to determine the origin and nature of plastic cover damage.
- Integrate a GNSS receiver to determine the path of the machine during the handling process.
- Employ an RFID reader to identify the modules through the unique RF tag attached to the cover and associate all data and images with the RFID tag number.

Materials and Methods

Overall Structure and Working Principle

The original version of the smart monitoring system for measuring real-time data and associating with the RFID tag number for cotton modules was designed and developed by Wang et al. (2020). In this work, moisture and temperature sensing capability was added, the processor and cameras were upgraded, and improvements to the software were implemented. The upgraded system consisted of six basic units, which were the central processing unit (CPU) (Raspberry Pi4, Raspberry Pi Ltd., Cambridge, UK), RFID reader (ThingMagic Micro-LTE, Jadak Technologies Inc., NY, USA), USB cameras (ELP-USB4K02AF-KL100, Ailipu Technology Co., Ltd., Shenzhen, China), GNSS module (u-blox M8, U-blox Inc., Thalwil, Switzerland), moisture sensor (830-T/C, Delmhorst Instrument Co., Towaco, New Jersey, USA), and temperature sensor (M12MJSS-1/4-U-24, Omega Engineering Inc., Norwalk, Connecticut, USA). All the components were connected with the CPU, and data from each component was stored in the memory of the CPU (Figure 1). The RFID reader and the cameras were connected to the CPU using the USB serial port. The GNSS module was connected through the general-purpose input/output (GPIO) pins of the CPU. The moisture and temperature sensor provided signal output in mA and mV, respectively, but the GPIO pins of the CPU can only receive digital signals. Therefore, the moisture sensor was connected to the GPIO pins of the CPU through a 10-bit A-to-D converter (MCP3008, Adafruit Industries, New York, USA) to convert the output of the sensors into a digital signal. Similarly, the temperature sensor was connected to the GPIO pins of the CPU through an A-to-D converter embedded with a MCP6900 voltage amplifier. To minimize error during measurement, the sensors were calibrated before connecting to the system. The electronic components were mounted in a metallic enclosure. A display attached to the enclosure was used to detect the working status of the system and to provide needed commands to the system during the initial set up and testing.
The system was installed on a John Deere 544K-II loader equipped with a spear for the round cotton modules (Figure 2). The moisture and temperature sensors were attached in the middle of the spears to collect the data from the center

of the cotton modules handled by the loader. The RFID antennas were installed on both sides of the loader mast to detect the RFID tags attached to the cotton module cover accurately. Two cameras were installed on each side of the mast to collect the images of the module from the two sides; also, a camera was installed under the chassis to collect images of the bottom of the module. A 28dB gain waterproof antenna was connected to the GNSS module and placed on the top of the cabin of the loader to receive the GPS signal without interference. The enclosure with system electronics was installed in the cabin of the loader, and the system was powered using the 12V battery of the loader.

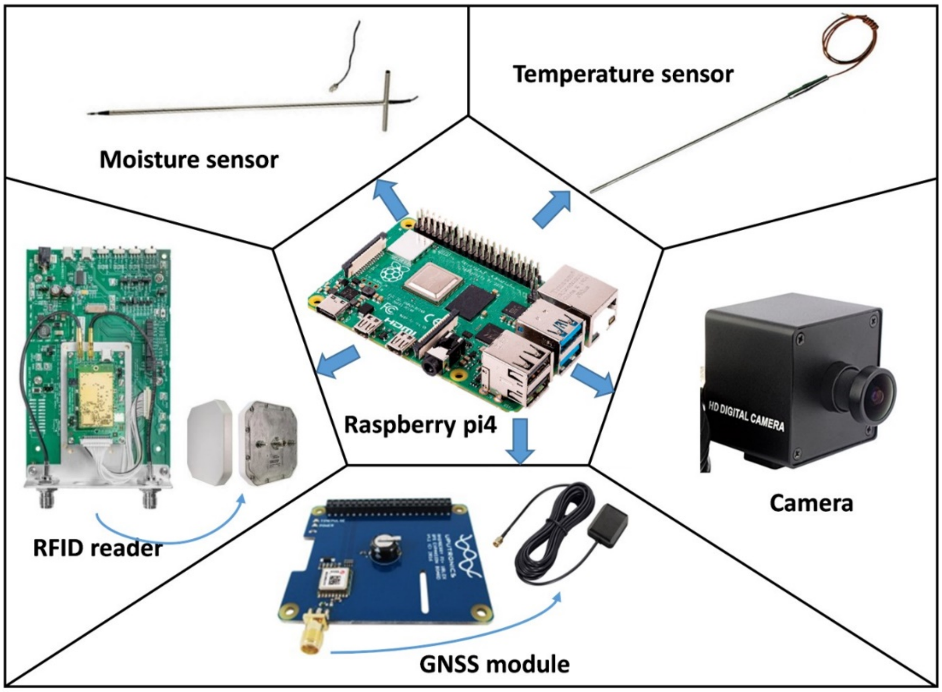


Figure 1. Components used for developing the smart monitoring system.

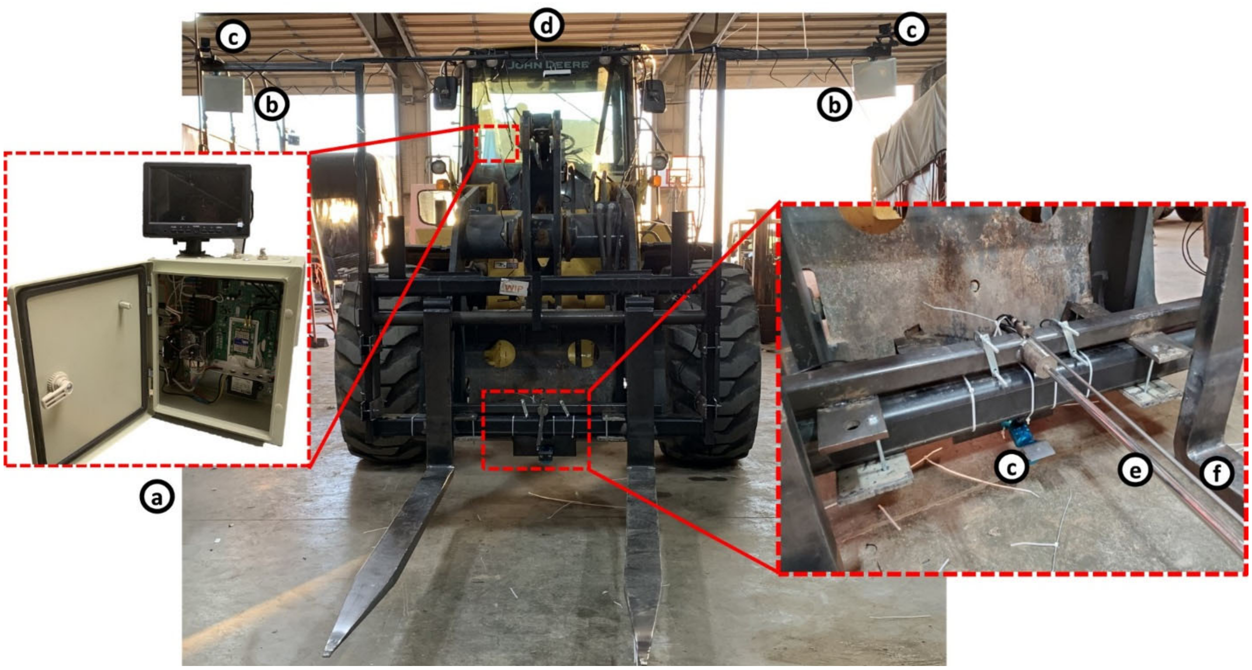
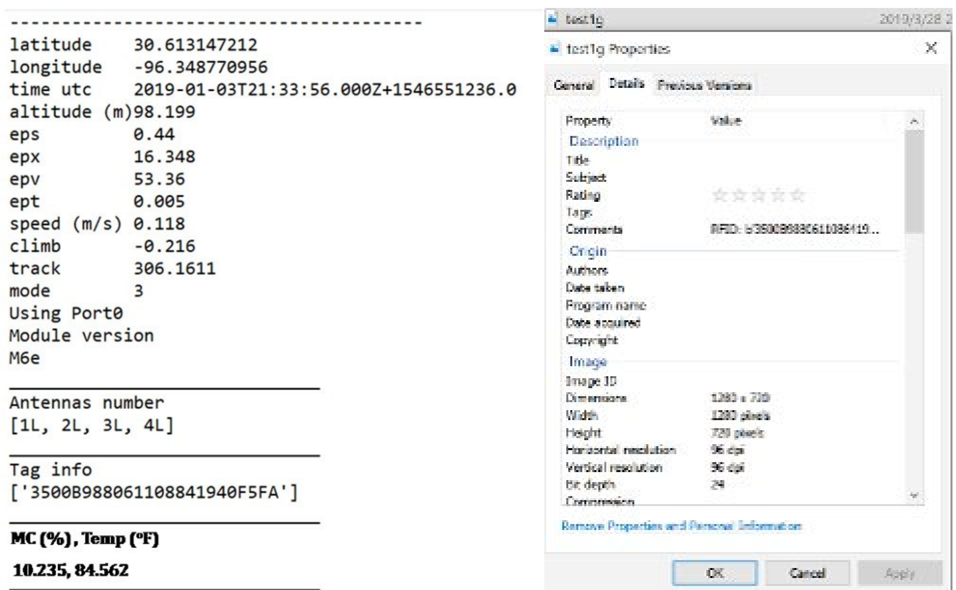


Figure 2. John Deere 544K-II equipped with round cotton module handler with installed smart monitoring system: (a) controlling box, (b) RFID reader antenna, (c) camera, (d) GNSS antenna, (e) moisture sensor, and (f) temperature sensor.

The system was designed to identify the cotton modules based on their RFID tag and turn the cameras and moisture and temperature sensors on only when handling modules. During loading of a module, all cameras turned on, and pictures (1280 × 720 pixels) of the module from different angles were collected and stored at a frequency of 1 Hz. The images were stored in an assigned folder and followed the following naming convention, RFID tag number_camera number_latitude_longitude_time for easy identification during data processing. At the same time, the location data of the loader from the GNSS module and cotton moisture and temperature data of the module from the related sensors were logged into a CSV file with respect to both local CPU and GNSS time at a frequency of 1 Hz. After the cotton module was collected by the loader, it started moving to the destination to unload the module. During movement, the cameras turned off automatically to reduce storage and processing requirements because damage to the cover was considered more likely to occur during loading and unloading. When the loader reached the destination for unloading the module, the cameras again captured images. After unloading, images were not captured until beginning loading of the next module. For operating each component according to the design specifications, system code was developed in Python.

Data Processing

The real-time data from the components were stored in a CSV file at a frequency of 1 Hz. The files contained the generated information of RFID tag number, GNSS information, moisture data, and temperature data (Figure 3a). The RFID tag number and GNSS information was added to image metadata (Figure 3b).



(a) (b)

Figure 3. The collected RFID tag and GNSS information (a) and appended to the image metadata (b).

Initial data collection indicated the moisture sensor and the temperature sensor data contained unwanted noise. To remove noise, a processing method was designed based on the fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT). The noise was filtered in the frequency domain, the noise was eliminated, and waveforms of the signal spectrum were inversely transformed into the time domain (Liqiang et al., 2014). This analysis was done by using a software package (MATLAB R2016a ver. 9.0; The MathWorks, Natick, Massachusetts, USA).

The data from the GNSS module were extracted and maps of the loader routes were created by using a commercial mapping software package (ArcGIS ver. 10.1; ESRI, Redlands, California, USA). The images were analyzed to determined the amount and nature of the plastic film damage. For each cotton module, comments were provided based on the plastic damage and stored against the specific RFID tag to help ginners to take necessary steps for different modules for removing the plastic contaminants completely.

Experimental and Analytical Procedures

Data was not collected in 2020 with the new version of the system. The extensive redesign and limitations due to COVID-19, coupled with a short ginning season in the Texas High Plains resulted in a limited window for field testing.

The system was installed on a loader but data was not successfully collected. Sensing components worked satisfactorily, but problems occurred with data transmission over USB.

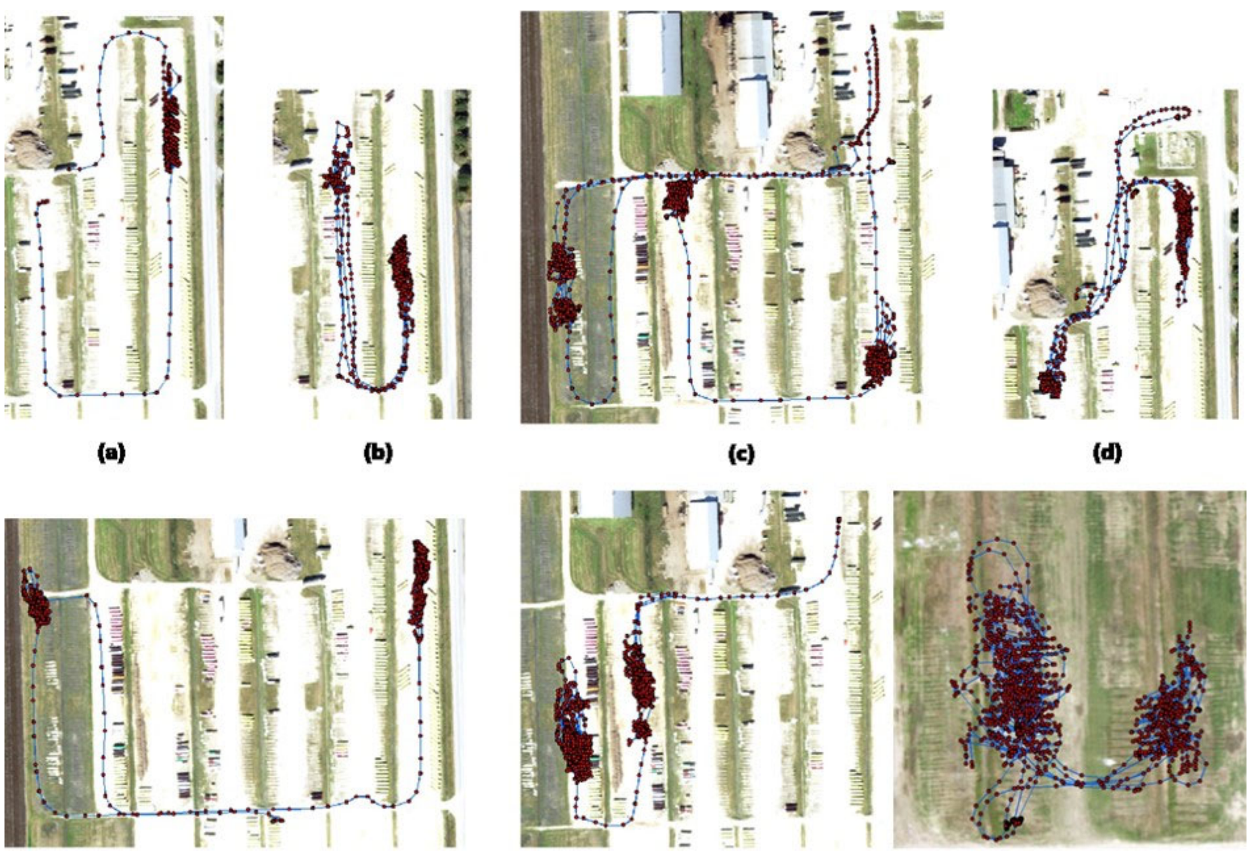
In this paper, we present additional analysis of data collected using the previous version of the system (Wang et al., 2020). This system did not have moisture or temperature sensors, a different camera model was used, and images were collected less frequently. Other principles of operation remained the same.

Results and Discussion

Handling Routes

The system was evaluated by examining seven time periods which included three different operations (i.e., organizing, loading, and unloading). A total of 240 cotton modules were handled with the loader, which traveled 40.4 km. From the GPS data, real-time position information of each cotton module was determined during handling, and their movement route was created (Figure 4). During the first case study, the total working time was 3,328 s and the loader traveled 3.2 km (Figure 4a). A total of 23 cotton modules were organized on the yard, requiring an average of 144.7 s per module. The loader was only actively transporting cotton modules for 569 s, an average of 24.7 s per module. The rest of the time the loader was returning to the pickup location empty or was stationary.

During five separate study periods, the loader was unloading modules from a flatbed trailer on to the gin yard. During the second study period, 40 cotton modules were handled in 4,349 s, and the total driving route for the loader was estimated to be 4.85 km (Figure 4b). This resulted an average time per module of 108.47 s, of which the loader was actively transporting cotton modules for an average of 31.85 s. The handling time of the cotton modules during the second study period was higher than the first study period because of the longer transportation distance.



(a) (b) (c) (d) (e) (f) (g)

Figure 4. Routes of the loader during module handling: (a) first time period, (b) second time period, (c) third time period, (d) fourth time period, (e) fifth time period, (f) sixth time period, and (g) seventh time period.

Similarly, from the third (Figure 4d) through the sixth (Figure 4f) study period, the average handling time and total travel path for the loader were foundd to be 169.81 s and 7.97 km, 176 s and 5.38 km, 182.56 s and 5.37 km, and 210.3 s and 7.247 km, respectively. The seventh case study (Figure 4g) consisted of loading 60 cotton modules on a trailer. Total time for loading all of the modules was 9,511 s, and the loader traveled 6.38 km. The average time taken per module was 158.51 s. During this study period, the average active engagement of the loader and the cotton module was estimated to be 40.05 s.

Assuming the empty return trip requires similar time as the time spent with a module on the loader, the loader was idle between 41.3% to 76.9% of the handling time, depending on the study period. Not surprisingly, shorter handling routes resulted in faster operation. Applying path planning methods to handling operations could minimize time and labor requirements, reducing the costs of module handling operations.

Plastic Cover Damage Detection

Images of the cotton modules were taken from three different views during loading and unloading to identify the nature and location of the plastic cover damage. However, images from the cameras mounted on the loaded mast were generally unusable due to lack of shielding from sunlight. A total of 5,414 images were collected while handling 240 cotton modules during the experiments and cover damage was identified in the captured images manually (Figure 5). From the captured images, it was determined that 10 modules' plastic covers were damaged; thus the damage rate during the handling process was determined to be 4%. While data is limited, the damage rate (13.04%) was higher for the modules that were re-staged on the yard (Table 1). The additional handling step may have resulted in more damage to the covers.

Figure 5. Plastic cover damage of the cotton modules during the experiments.

Table 1. Summary of the analysed data collected by the developed system in different experiment.

Period #	Operation	Number of modules handled	Average time taken (s)	Active time (%)	Number of covers damaged	Damage rate (%)
1	organizing	23	144.70	17.10	3	13.04
2	unloading	40	108.47	29.37	0	0
3	unloading	49	169.81	14.23	2	4.08
4	unloading	26	176.00	15.38	2	7.69
5	unloading	18	182.56	12.66	1	5.56
6	unloading	24	210.29	11.56	1	4.17
7	loading	60	158.51	25.27	1	1.67

Summary

A smart monitoring system for round cotton modules was developed and tested to determine the handling route and identify plastic cover damage. A time and motion study of the loader used to handle modules on the gin yard indicated that only between 23.1% and 58.7% of the loader operating time was actually used for moving modules or returning to the loading point. Plastic cover damage was manually identified from the captured images. An improved system was developed that incorporates an upgraded CPU, better cameras, and moisture and temperature sensors. Data will be collected with this system in 2021. Image processing algorithms for identifying and classifying cover damage will also be developed.

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