AN INTEGRATED MODULE FEEDER MONITORING SYSTEM TO MITIGATE PLASTIC CONTAMINATION

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Abstract

Plastic contamination in US lint bales has increased with the adoption of new cotton harvesters that form cylindrical or round modules on the machine. It is of significant interest to the US cotton industry to reduce this contamination to preserve grower profitability and the reputation of the US as a reliable source of clean cotton fiber. The objective of this work is to describe the design and operation of a system for use on cotton gin module feeders that provides monitoring of plastic accumulation on the dispersing cylinders and video data to help document the module wrap condition and unloading/unwrapping procedures that may have caused the potential contamination event on the dispersing cylinders. In 2019, three independent systems were installed on a cotton gin module feeder to provide images of plastic accumulation on the dispersing cylinders, a log of the processing sequence for round modules, and video data of the unloading/unwrapping process for each module. The initial system developed in 2019 provided useful data but improvements were needed to reduce the time and effort associated with analyzing the data. Improvements in 2020 integrated the three independent systems used in 2019 to work on one computer, store the data in a common location, and simplify the process of extracting module specific data for a given potential contamination event. The new integrated module feeder monitoring system was tested at two cotton gins in 2020. Analysis of the data provided useful information for comparing module wrap performance in addition to information useful in training gin employees on module handling procedures to mitigate plastic contamination and improve worker safety.

Introduction

Cotton harvesters that form cylindrical modules onboard the machine (7760, CP690, and CS690, John Deere, Moline, IL) have reduced labor and machinery requirements and increased cotton harvesting productivity. Cylindrical or round modules are wrapped in plastic by the harvester before they are ejected in the field. The plastic material (module wrap) restrains the seed cotton in cylindrical form and protects it from quantity and quality losses caused by environmental effects experienced during storage before ginning.

Plastic contamination in US lint bales has increased with the adoption of round module building cotton pickers and strippers. As a result, in 2018, USDA AMS adopted new extraneous matter classing codes 71 and 72 for plastic contamination levels 1 and 2, respectively. The 2020 USDA CCC loan schedule of premiums and discounts for upland cotton (USDA-CCC, 2020) contained discounts of \$0.1870 and \$0.2080 per pound for bales classed with 71 and 72 extraneous matter designations, respectively. In 2020, spot quotations for lint bales with any plastic contamination designation contained a 40 cent per pound discount (USDA-AMS, 2020). Moreover, merchants and mills often refuse to purchase bales with plastic contamination. Thus, prevention and/or detection/removal of plastic contamination is of keen interest to US cotton growers in efforts to maximize profitability and maintain the reputation of the United States as being a reliable source of clean cotton fiber.

Module handling in the field, during transportation, and at the gin can compromise the wrap material and lead to potential wrap failures and possible plastic contamination in lint bales (Wanjura et al., 2020a). Additionally, the technique used to cut and remove wrap from round modules can lead to increased risk of plastic contamination if pieces of plastic remain with the cotton as it is fed into the gin (John Deere, 2013).

The objective of this work is to describe the design and operation of a system for use on cotton gin module feeders that documents potential plastic contamination events and provides video data for investigation into what events or situations may have caused the potential contamination event. The information collected by this system can be useful in training employees on proper round module handling techniques to minimize contamination and improve worker safety.

Materials and Methods

2019 System Description

In 2019, an experiment was initiated at a gin (Gin A) in the Texas High Plains to evaluate the durability of experimental wrap materials for round cotton modules. The performance of those wrap materials will not be discussed in this paper. Approximately 10 growers that harvest their cotton with John Deere CS690 round module building cotton strippers agreed to participate in the experiment. The experimental wrap materials, differentiated by wrap color (pink, green, and blue), were distributed to the cooperating growers in equal proportions. Additional round modules with pink and yellow wrap that were not part of the experiment were also processed by Gin A in 2019. Gin A processes cotton from both rectangular "conventional" modules and round modules. Before ginning, all modules were loaded from the gin yard onto a chain-bed type module truck and placed on the module feeder. Round modules were stored flat-end to flat-end ("sausage style") and were loaded onto the module truck in the same orientation. The round modules were "flipped" as they came off the module truck so that they stood upright on one flat face as they moved down the module feeder bed. Workers cut the module wrap on both sides of the module as it moved off the truck, leaving about one third of the module length of uncut wrap at the top of the module to help hold the cotton together as it moved along the feeder bed. The wrap was finally cut and completely removed from each round module as the cotton reached the tall side walls of the feeder which begin at approximately half the length of the feeder bed.

The system installed on the module feeder at Gin A in 2019 consisted of thee independent sub-systems that provided data on:

- potential contamination events at the dispersing cylinders (i.e. any instance where plastic was caught by and removed from the dispersing cylinders),
- the condition of the module wrap at the time the module was placed on the feeder,
- the unloading/unwrapping process, and
- a log of the processing sequence for each round module.

The USDA Module Feeder Inspection system (Pelletier et al., 2020) was installed in the dispersing cabinet of the module feeder (figure 1) and collected still images of the dispersing cylinders when the feeder floor was manually paused and sufficient time had elapsed to allow cotton and dust to fall out of view of the internet protocol (IP) cameras. A beta version of the image capture software for the USDA Module Feeder Inspection System was used in 2019. Two cameras were used to monitor the upper and lower dispersing cylinders of the feeder. With a clear camera view of the dispersing cylinders, the ginner pressed a button on the system display (figure 2) located in the gin console room to capture the still images. Live video streams from the two cameras were also displayed on the monitor and allowed the ginner to see plastic accumulation on the cylinders often before still images were captured. Each time plastic was observed on the dispersing cylinders, the gin crew quickly stopped the module feeder, removed the plastic, and placed it in a container labeled with the date and time of removal. A research team member visited the gin several times each week and conducted further analysis of the plastic to identify from what part of the wrap portion the material originated, how much material was collected, and identification number of the module from the RFID tag(s) if present.

At the end of the module feeder where modules are placed on the feeder bed, an RFID scanning bridge was installed along with a network video recording (NVR) system (figures 3 and 4). The RFID Feeder Bridge system developed by Wanjura et al. (2020b) was used to scan the RFID tags on each round module as it was unloaded onto the module feeder bed and create a processing log for all round modules ginned. The serial number, wrap color, and other module specific data for each module wrap portion used in the experiment was loaded into the RFID scanning system database before the ginning season. This data was recorded with the date and time that the module was scanned on the feeder in the processing log. The NVR system (RLK16-410B8-5MP, Reolink, Wan Chai, Hong Kong) utilized four IP cameras to capture video of the module wrap condition and unloading/unwrapping process for each module as it was placed on the feeder bed. The NVR was configured to record the video data from each camera continuously at 7 frames per second. The video files from each camera position were time stamped and stored on a disk drive located in the NVR enclosure. Over the course of the 2019 ginning season, the NVR consumed four 4 TB disk drives.

At the end of the season, data from the three sub-systems were compiled and analyzed by potential contamination event. A potential contamination event was defined as any instance where plastic material was removed from the dispersing cylinders. In some cases, the plastic material was removed from the cylinders before still images of the plastic on the dispersing cylinders were captured. In many cases, the plastic removed from the dispersing cylinders contained at least one RFID tag that identified the originating module. Using the RFID tag recovered from the plastic, the module serial number was searched in the module processing log from the RFID Feeder Bridge system to see when the module was placed on the feeder. Using the scan date/time from the processing log, the video data from the NVR system was extracted and viewed to determine what may have caused the potential contamination event on the dispersing cylinders. In cases where the module serial number could not be retrieved from the plastic removed from the dispersing cylinders, the color of the plastic was used to search the processing log prior to the time the material was removed from the cylinders and review the NVR video data for modules with matching color.

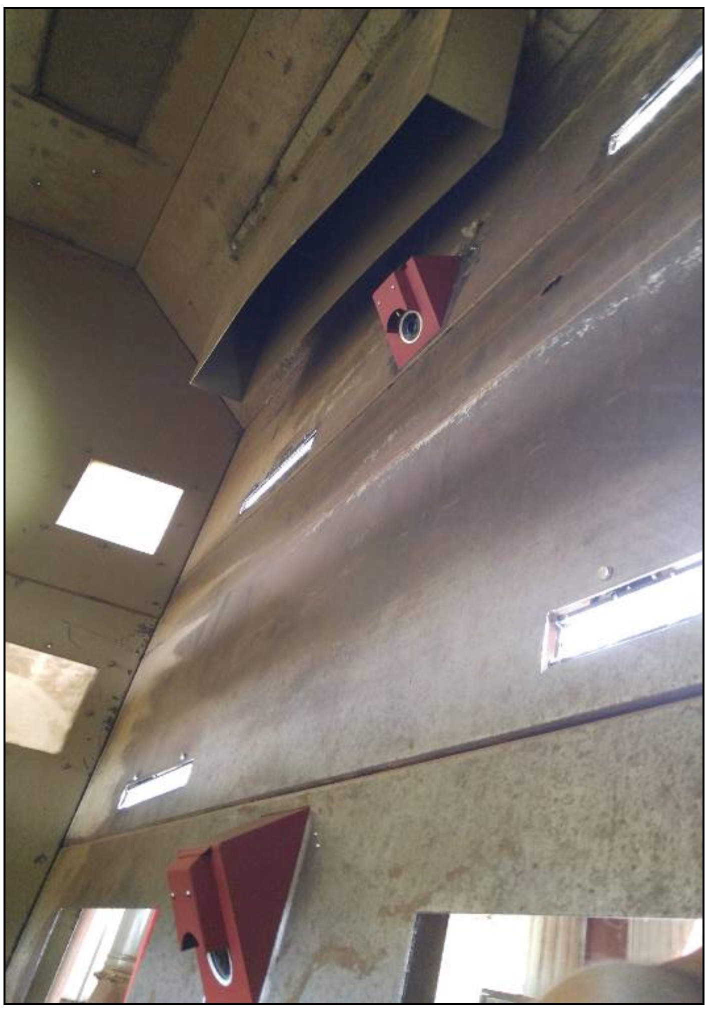

Figure 1. Photo of USDA ARS Module Feeder Inspection System IP cameras installed in back wall of module feeder dispersing cabinet at Gin A.

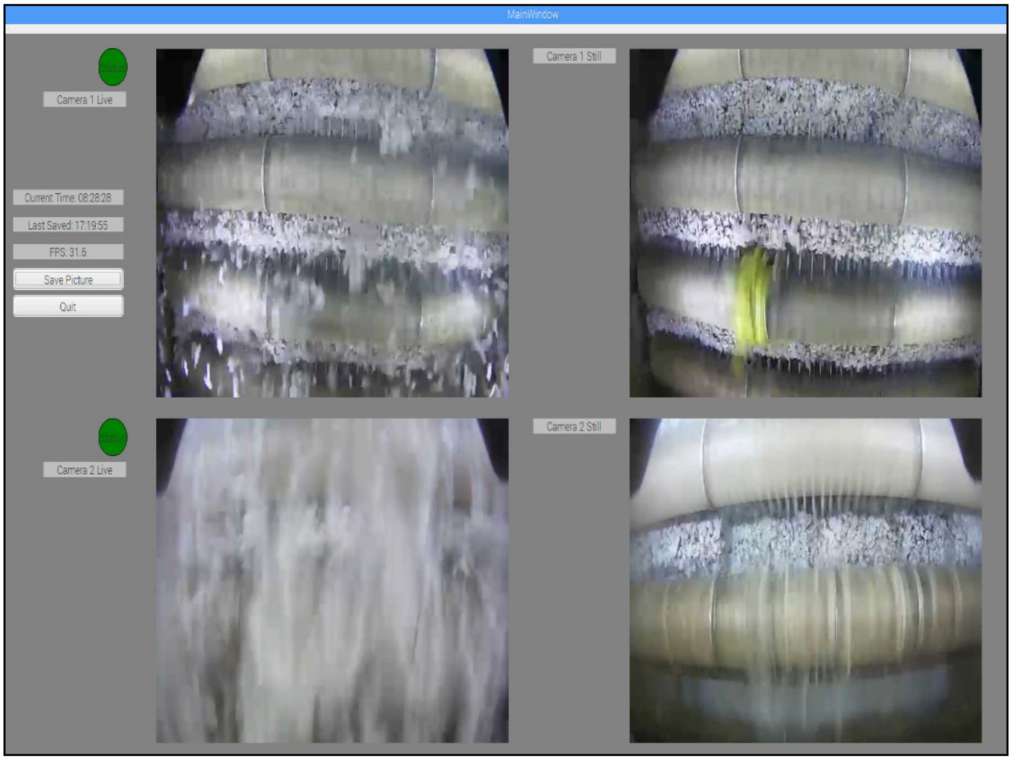

Figure 2. USDA ARS Module Feeder Inspection System display showing live video feeds from top and bottom cameras (top and bottom left side images) installed in the dispersing cabinet along with the latest still images (top and bottom right side images) captured of the dispersing cylinders.

Figure 3. Photo of the RFID Feeder Bridge antennae and NVR IP cameras mounted on top of the yellow poles on both sides of the module feeder bed.

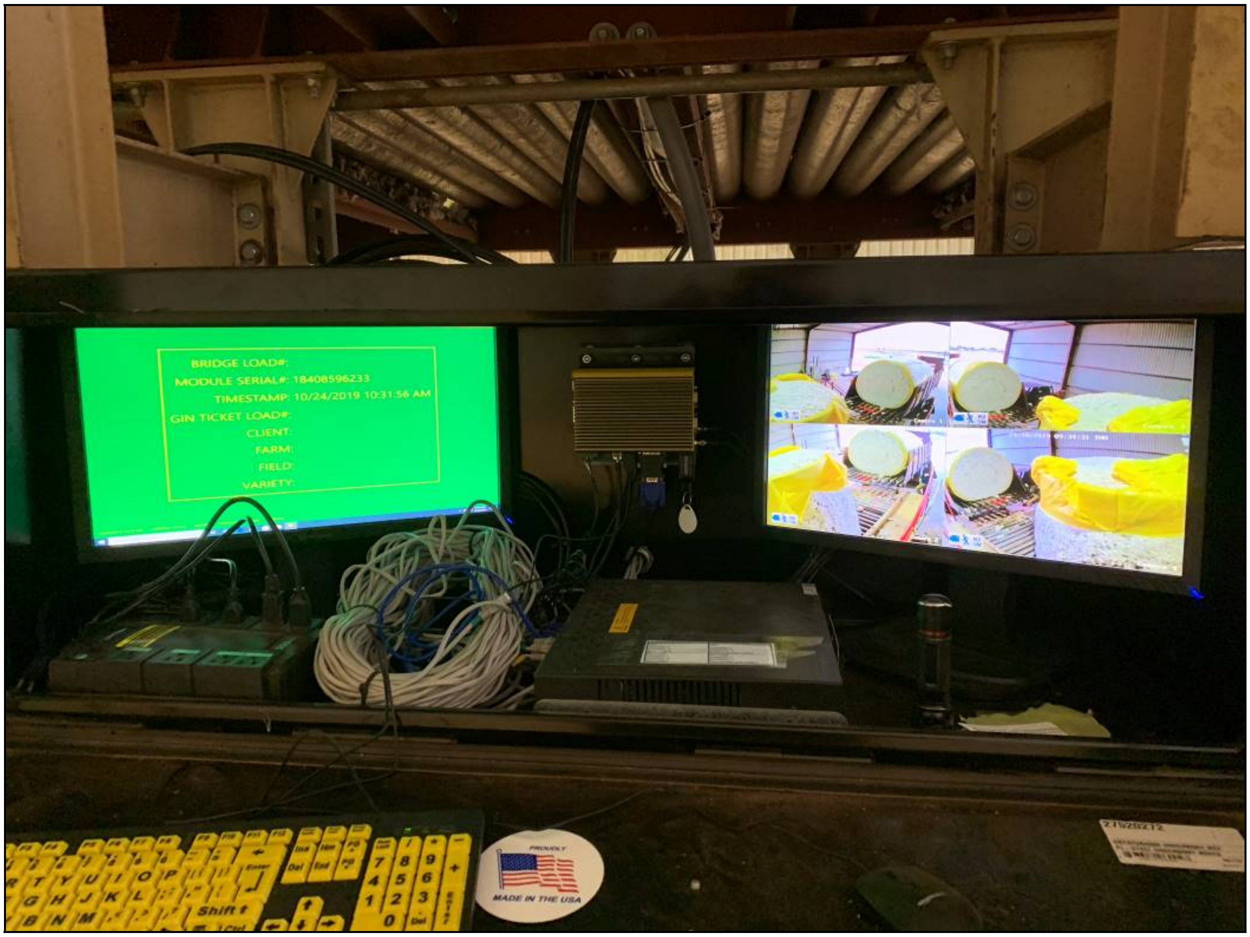

Figure 4. Photo of the enclosure box mounted below the module feeder bed at Gin A that housed the electronics and displays for the RFID Feeder Bridge (left display) and NVR (right display) systems.

2020 System Description

The module feeder monitoring system used in 2019 was modified in 2020 and installed at Gin A and at a second ginning facility in the Texas High Plains, Gin B. The new module feeder monitoring system was designed such that the three independent data collection systems originally installed on the module feeder at Gin A were integrated to operate on one PC and store the data in a common location on a 2 TB portable solid-state drive. The USDA ARS Module Feeder Inspection software was recompiled to run on Windows 10 and was modified to allow still image captures based on the module feeder run signal status. A timing routine was written into the PLC software controlling the module feeder bed at both gins to automatically pause the feeder bed for a ginner specified time period and frequency. The bed pause duration was approximately 11 s at both gins and occurred once every 30 min. A dry-contact relay was actuated by the PLC during the bed pause event, signaling the USDA Module Feeder Inspection software to capture still images from the IP cameras mounted in the dispersing cabinet (figure 5) at the end of the bed pause event. The USDA ARS Module Feeder Inspection software created a data file that contained the bed pause event number, timestamp, and the file pathnames for the still images from both IP cameras. New ball-faced mounts were designed and installed for use with the USDA Module Feeder Inspector system cameras at both gins in 2020. The new camera housing allows for +/- 30 degrees of camera elevation adjustment allowing the cameras to be positioned as needed on the dispersing cabinet back wall regardless of dispersing cabinet design (figure 5). Additional software changes were incorporated that allowed for automatic detection of plastic on the dispersing cylinders via machine vision analysis of the camera images. Additional work is ongoing to improve the performance of the automatic detection feature of the software because operation of the system revealed that sufficient and uniform lighting of the dispersing cylinders is critically important for optimal automatic classification of plastic on the dispersing cylinders.

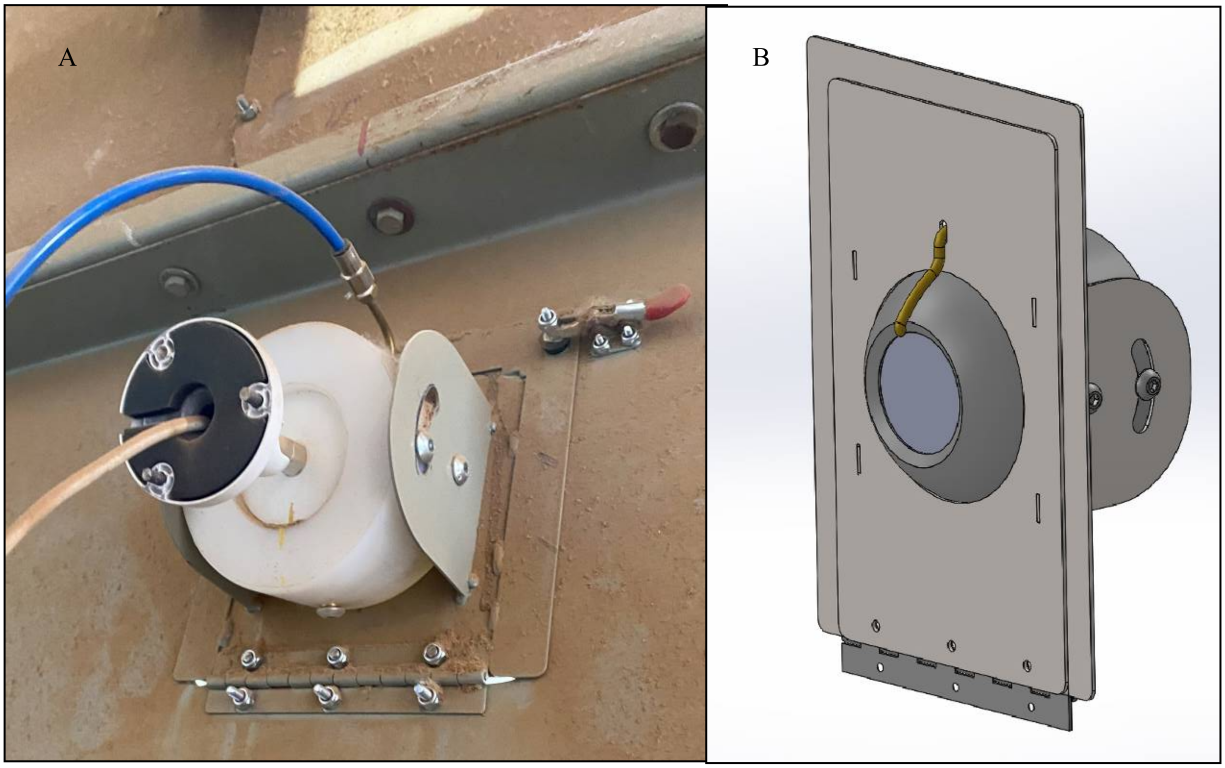

Figure 5. Ball face camera mount installed at Gin B (A) and design model (B).

The RFID Feeder Bridge software was modified to allow the collection of video data from six IP cameras. The six camera positions used at Gin B are shown in figure 6 and the cameras were positioned similarly on the module feeder at Gin A in 2020. Each camera was connected to a power over ethernet (POE) network switch that provided power and data transmission for each camera. The IP cameras were configured to stream real-time data back to the PC at 7 frames per second and the video streams were stored in a temporary data buffer. When the RFID tags on a module being placed on the feeder were scanned by the system, the software recorded the timestamp of the scan event and later extracted video data from each camera for a specified period before and after the RFID scan event. The video data segment was stored on the portable SDD on the local PC with the filename including the module serial number (from the RFID tags), date/time stamp, and camera number.

Figure 6. Photo showing numbered camera positions used on the module feeder at Gin B in 2020. RFID antennae are located between camera positions 1 and 2.

New software was written to help combine the data collected by the USDA ARS Module Feeder Inspection system and the RFID Feeder Bridge software. The software, named "Inspection Report Builder," created a comma separated value (CSV) file that contained the information from the data file created by the USDA Module Feeder Inspection system along with the module serial numbers and associated unloading/unwrapping video file path names for each round module scanned by the RFID Feeder Bridge since the previous bed pause event. The report generated by this software contained active hyperlinks to the still images and video files for each module, making extraction and inspection of those files much simpler and less time consuming than the process used in 2019. The same data analysis process used in 2019 was again used in 2020 whereby the module condition and/or module unloading/unwrapping processes that lead to the potential contamination event were documented. However, the system improvements made in 2020 helped to reduce the analysis time significantly from 2019.

Module Handling Procedures

Round modules were transported, handled, stored, and placed on the module feeder differently at Gin B compared to Gin A. Flat bed semi-trucks hauled all round modules from the field to the gin yard and were loaded and unloaded via wheel loader. Round modules were stored on the gin yard and loaded on to the module feeder in wagon-wheel orientation with flat sides of adjacent modules coplanar. A unique unwrapping system specifically designed to handle round modules in wagon-wheel orientation was used at Gin B but will not be discussed in this manuscript to protect potential intellectual property rights of the inventors.

In 2020, Gin A modified the approach ramp that the module truck backs onto as it positions to place modules on the feeder bed. The new ramp improved the trajectory of modules as they come off the truck bed so that they tended to stay upright after flipping onto the feeder rather than falling forward or backward. Gin A also changed their technique for unloading small diameter modules from the way they were handled in 2019. In 2019, small diameter modules were flipped off the truck onto the feeder bed just as large diameter modules but they often fell forward or backward after landing on the feeder bed because they lack the flat end surface area to support the module in upright position. Once the module was laying on its side, the gin crew was often unable to recover any trapped plastic because the module could only be rolled a short distance before it was stopped by the feeder side wall. In 2020, small diameter modules were effectively rolled onto the feeder bed in wagon-wheel orientation so that workers could more easily reposition the modules to recover any plastic trapped between the cotton and module feeder bed rollers.

Results and Discussion

2019 Results

A total of 77 potential contamination incidents were documented at the module feeder at gin A in 2019. The gin processed a total of 41,236 bales and had 18 plastic calls. Images analyzed for one potential contamination event that occurred on 10 November 2019 are shown in figures 7, 8, and 9. In this instance, pink module wrap was caught by the bottom dispersing cylinder as seen in the lower camera image (figure 7). Upon removal from the cylinder, the plastic did not contain an RFID tag or any other means of identifying the specific module from which the plastic originated (figure 8). Additional green plastic was removed from the dispersing cylinders and stored in the same container as the pink wrap. The pink module wrap color was used to review the RFID scanning log and determine when modules with pink wrap were placed on the feeder. Using the RFID scan event date and time, the video of the unloading and unwrapping events for the most recent pink modules placed on the feeder were reviewed and revealed an unloading mishap for the module shown in figure 9. The module fell backward toward the truck when it was unloaded, trapping a portion of the wrap material between the cotton and the feeder bed rollers. The gin crew was unable to completely remove the trapped module wrap (figure 10) and the remaining portion was caught by the dispersing cylinders.

Figure 7. Lower dispersing cabinet camera still image of pink plastic caught on bottom dispersing cylinder.

Figure 8. Pink plastic removed from lower dispersing cylinder by gin crew after detection via dispersing cabinet camera image. Pink plastic stored with green plastic removed at the same time from other dispersing cylinders.

Figure 9. Image taken from the unloading video captured for the pink module in view (camera 2). The video showed that the module fell backward onto the truck and module feeder bed trapping a portion of the wrap material underneath the cotton.

Figure 10. Image taken from the module unloading video (camera 4) showing plastic remaining under the cotton after attempts to remove the trapped material.

2020 Results

In 2020 the new integrated module feeder monitoring system captured data for 19 potential contamination events at Gin A. The regional crop was considerably smaller in 2020 compared to 2019 due to lack of rainfall. Gin A processed 18,133 bales in 2020 and had 7 bales called with plastic contamination. An example of one potential contamination event captured by the integrated module feeder monitoring system at Gin A in 2020 is shown in figures 11 – 13. In this event, yellow module wrap plastic was caught by the lowest dispersing cylinder as seen in the image from the bottom module feeder cabinet camera (figure 11). Upon removal of the plastic from the dispersing cylinder, the module was identified by serial number 19410229688 from the RFID tag found on the plastic. Because of the presence of the RFID tag, the material was identified as part of the inside opaque leading portion of the wrap material that does not contain tacky layer adhesive. Using the module serial number, the unloading/unwrapping video for the module was directly extracted and viewed. The video showed that the module was unloaded properly with no issues and the plastic was cut and pulled to the top of the module as is standard practice at Gin A. However, when the wrap was finally cut and removed from the module as it reached the midpoint of the module feeder, a piece of the yellow material fell between module 19410229688 and the previously unloaded module. The workers were unable to see the plastic in the cotton between the modules as a portion of the cotton from 19410229688 fell burying the plastic.

Figure 11. Image of yellow plastic on lowest dispersing cylinder at Gin A in 2020.

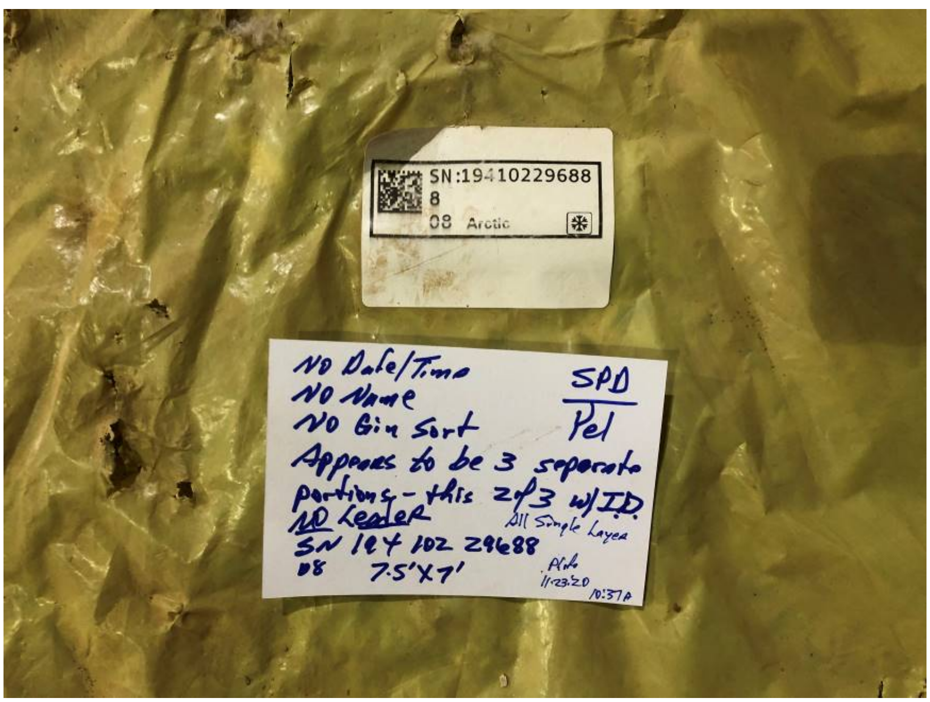

Figure 12. Image of yellow plastic removed from lowest dispersing roller (figure 10) showing RFID tag with serial number 19410229688 that was used to identify the module from which the plastic originated.

Figure 13. Still image from the unloading video captured for module SN 19410229688 showing piece of yellow plastic remaining in cotton between modules after wrap was removed from the top of the module.

In 2020, the integrated module feeder monitoring system captured data for 37 potential contamination events at Gin B. Gin B processed 61,782 bales in 2020 and had 14 bales called with plastic contamination. An example of one potential contamination event captured by the integrated module feeder monitoring system at Gin B is shown in figures 14-16. In this event, yellow module wrap plastic was caught by the lowest dispersing cylinder as seen in the image from the bottom module feeder cabinet camera (figure 14). The second cylinder from the bottom in figure 14 shows white twine accumulation on the cylinder. This twine is used to restrain conventional module tarps in the field and is often not removed from the dispersing cylinders frequently because it poses little contamination risk as it doesn't wear off with processing time. Upon removal of the yellow plastic from the dispersing cylinder, the module was identified by serial number 19403248068 from the RFID tag found on the plastic (figure 15). Using the module serial number, the unloading/unwrapping video for the module was directly extracted and viewed. The video showed that the worker cut the module wrap just ahead of the module truck tail shaft as is common practice at Gin B. In this case, the cut was positioned about 20 in below the white separation tag on the outside of the module. When the module was rolled off the truck onto the feeder bed, the module wrap fell out of the unwrapping system and was trapped under the cotton when the module rolled backward slightly (figure 16). The video showed that the workers removed most all of the trapped module wrap plastic, but an 8.3 ft x 5.7 ft piece remained in the cotton (which contained the identifying RFID tag) and was caught on the lowest dispersing cylinder.

Figure 14. Image of yellow module wrap plastic caught on lower dispersing cylinder at Gin B. White twine on middle cylinders originates from rectangular modules. The white twine is used to restrain tarps on rectangular modules and is often not completely removed from the module prior to processing. However, accumulation of this material on the cylinders tends to remain on the cylinders without wearing off to cause contamination.

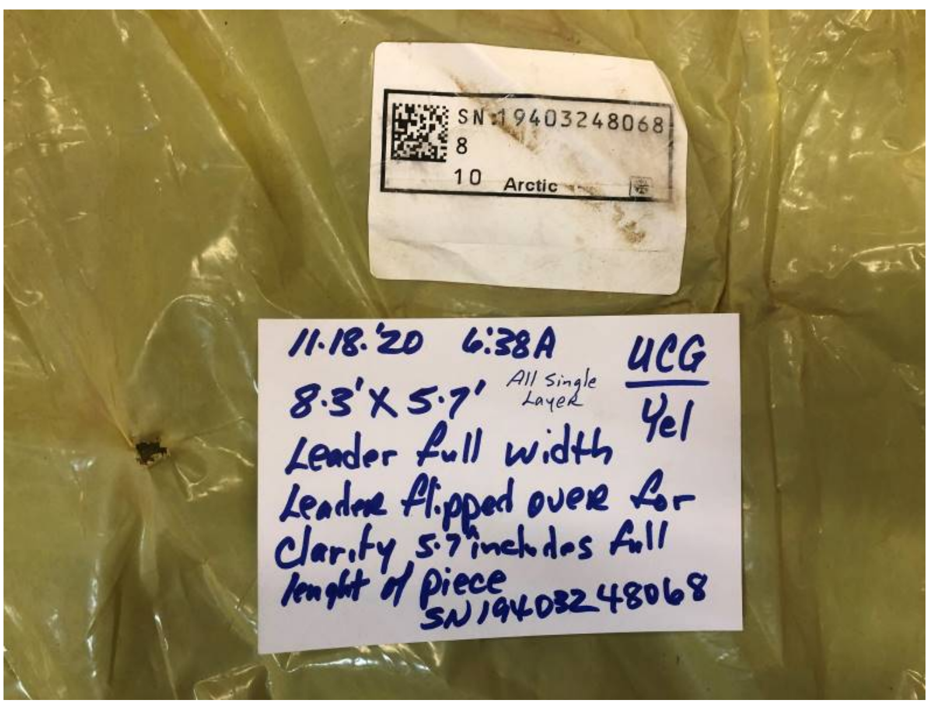

Figure 14. RFID tag and plastic size information collected after the plastic was removed from the dispersing cylinder at Gin B.

Figure 16. Image collected from the unloading video for module serial number 19403248068 showing module wrap trapped under cotton after the module was unloaded from the truck at Gin B.

Summary

The module feeder monitoring system developed in 2019 helped prove the concept that potential contamination events could be traced back to module wrap condition before placement on the module feeder for ginning and module handling techniques used in the unloading/unwrapping process. However, the process used to compile and analyze the data was quite time consuming and labor intensive. Improvements to the module feeder monitoring system in 2020 significantly reduced the time and effort involved with analyzing data from the various systems while maintaining the ability to provide useful data for evaluating module wrap performance. The video and still image data collected provide useful information for ginners to use in efforts to train employees on proper handling procedures to mitigate contamination and improve worker safety.

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