DESIGN OF A PLASTIC REMOVAL SYSTEM FOR A COTTON GIN MODULE FEEDER

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Abstract

U.S. cotton has a reputation for being contamination-free and has commanded premium prices in the international market over the years. The introduction of the onboard round module builders on harvesters has led to potential plastic contamination threat from plastic module wrap. These module covers, despite their benefits, are sometimes damaged during transportation and handling and pose a new contamination threat not seen before in ginning lines. A system was developed by USDA-ARS to automatically detect and manually remove plastic at the gin stand apron; however, additional removal points in the gin are necessary to achieve the goal of zero plastic contamination. Plastics collect on the dispersing cylinders of the module feeder; an automated system to remove these plastics would prevent plastic from entering the gin and reduce gin labor requirements for manual removal. In this work, we designed and constructed an automated plastic removal mechanism for a small-scale cotton module feeder that uses the USDA-ARS plastic detection algorithm as the trigger for its activation. Our follow-up to this work will be an extensive testing and thorough analysis of the designed system's performance. In conclusion, the designed system offers a good prospect for automatic plastic removal in gins.

Introduction

The U.S. is the leading exporter of cotton, accounting for one-third of the total world export trade. Cotton annually creates more than $21 billion in total monetary value for the U.S. economy and accounts for over 125,000 jobs (USDA, 2019). Apart from the large volume of cotton originating from the United States, the quality of US cotton has consistently been excellent and rated as one of the most contamination-free (National Cotton Council, 2009; International Textile Manufacturer Federation, 2014), resulting in premium prices on the international commodity market. However, the introduction of the disposable plastic wrap for round modules has threatened the contamination-free reputation of US cotton. While the round module system has been rapidly adopted due to its high level of automation and protection of seed cotton from adverse weather conditions, this has introduced a potential contamination source into the gin (Pelletier et al., 2020; Hardin and Byler, 2016; Mitchell and Ward, 2020). This has likely resulted in a decrease in the relative price of US cotton bales in the international market in recent years.

While the plastic module wrap has been engineered and manufactured to be durable and protect the seed cotton, improper handling can result in material handling equipment or cotton stalks damaging the wraps. Other plastic disposed of around the cotton fields, especially common on field strips adjoining highways or residential neighborhoods, may also get picked up by the harvester and contaminate the seed cotton. Some of these plastic pieces enter the cotton gin and can cause problems such as fire, machine downtime, and, most importantly, contamination (Hardin and Byler, 2016). Gin machines often break down plastic pieces into smaller fragments, which are more difficult to remove with conventional gin cleaning machines. These fragments contaminate the resulting lint and reduce the value this lint commands in the commodity market.

To combat plastic contamination, several efforts to address this problem have been made by researchers. For instance, in 2019, researchers at the USDA designed an automated plastic detection system that relies on real-time images in the gin for classifying the plastic contamination state of a module feeder head using machine learning and computer vision algorithms and notifying the gin operators to inspect and remove plastic from the system (Pelletier et al., 2020). The designed system offered positive prospects for detecting plastics before they may be broken into smaller fragments, although the systems still failed in some cases during testing, with false alarms of plastic detection. This issue can be resolved by extensive training of the machine learning model as more data become available for more accurate plastic detection in gins, especially in module feeders.
The module feeder naturally appears to be a desirable location for removal, as it serves as the first point of contact of the seed cotton with the ginning operations. The work presented in Pelletier et al. (2020) only ensures that ginners get

notified of the potential presence of plastic in their module feeders and it becomes the responsibility of the operators to manually remove the plastic when present. However, this work aims at offering a means of automatically removing entrapped plastics in the module feeders with minimal or no human intervention.

To achieve this, a prototype was designed to test the concept of automatically removing plastics from the module feeder dispersing cylinders after they are detected using an inspection system, like the one designed by Pelletier et al. (2020). The prototype was first modeled in SolidWorks (Figures 1(a) and (b)), and then modified, fabricated, and installed at the gin laboratory of Biological and Agricultural Engineering Department (BAEN) of Texas A & M University (TAMU).

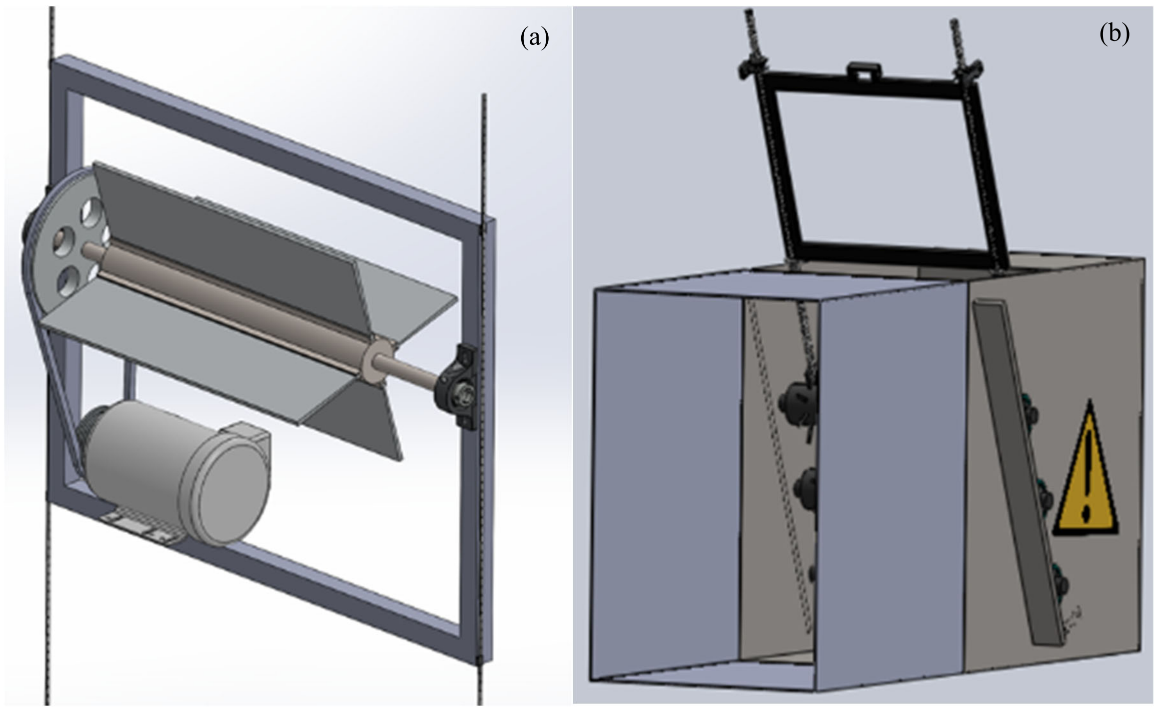

Figure 1. Preliminary 3D models of the designed plastic removal mechanism (a) the cleaning brush assembly (b) mounting the brush assembly on a module feeder with lead screws.

The objectives of this research project are to: (1) design and fabricate a functional plastic removal system that is retrofittable to most existing module feeders in industrial gins with minimal modifications, and (2) install the fabricated automated plastic removal system on a small-scale feeder (similar in design to a commercial module feeder but only downsized).

Materials and Methods

Choosing a Plastic Removal Method

Plastics first get wrapped around the dispersing (spiked) cylinders of the feeder in a gin (Figure 2). Conventional feeders have 5 to 7 spiked cylinders arranged on top of one another at an inclined angle to the direction of seed cotton feed as shown in Figure 3. These plastics then break up into fragments over time if left unattended. Thereafter, the fragments may end up in cotton bales because standard cylinder cleaners do not effectively remove the thicker plastics from module covers (Hardin and Byler, 2016).


Figure 2. Wrapped module cover plastic on a commercial module feeder.

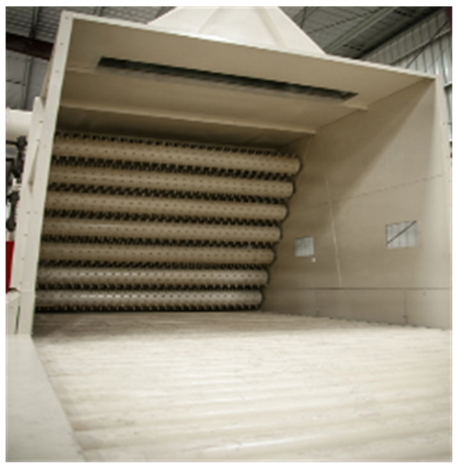
Figure 3. A typical module feeder in a commercial gin.

The geometry and configuration of the spiked cylinders dictates that an effective mechanism design is one that can traverse the entire span of the spiked cylinders without colliding with any structural member. The chosen plastic removal mechanism must also be one that supports a suitable actuation method permitted by the space limitation in a feeder.

After rigorous design considerations, a brush assembly design actuated by a motorized leadscrew was selected as the plastic removal mechanism of choice. The brush assembly comprises 38.1 mm steel tubes and stainless-steel brushes (to avoid sparks that would result from using carbon steel) that rub against the spikes on the dispersing cylinders and the plastic trapped on them. The stainless-steel brush wire is 0.036 mm gauge and about 127 mm in length, so that it extends to the curved surface of the dispersing cylinders. The wire brushes are attached to a circular shaft supported on both ends by ball bearings mounted on the tubular steel frame. The shaft is indirectly driven by a 1.1 kW (1.5 hp) electric motor through a belt drive. Furthermore, for moving the brush assembly from one spiked cylinder to the other, a lead actuation method was chosen because of its simplicity, ease of control, good positioning accuracy and holding torque capabilities, as well as having a good fit for the space in the module feeder compartment, which has little extra room. The leadscrew is driven by a NEMA 34 stepper motor with maximum rated torque of 12 Nm.

The mini-module feeder at the BAEN gin laboratory of TAMU has just three dispersing cylinders, but it is a scaled replica of commercial feeders, usually with seven cylinders, from the same manufacturer (Lummus Corporation, Savannah, Ga.). The brush assembly frame was dimensioned to be able to span the length of a cylinder at a time. Thus, the brush assembly must be able to translate through the entire span of 3 dispersing cylinders, with possible intermediate stoppages using the controlling stepper motor for removing plastics on any of the dispersing cylinders. This knowledge was used to determine the required length of the linear actuation system, the lead screw. The module feeder used in this research required approximately a minimum 2000-mm long lead screw to span the entire cylinder range and provide 780 mm-long storage room for the brush frame on top of the feeder in idle position.

Mounting the Fabricated Mechanism on a Module Feeder

The module feeder had a transparent side panel made of plastic that allowed gin operators to observe the dispersing cylinder from outside the module feeder. However, this material is not structurally capable of supporting the bearings of the lead screw actuation system and was replaced with sheet metal to provide a rigid base for mounting the leadscrew's lower bearing, located inside the module feeder. The upper bearings of the two lead screws were supported by fabricated steel C-channels with sufficient height so that the brush just cleared the spiked cylinders' driving electric motor located on top of the module feeder. In addition, the top of the feeder was entirely covered with sheet metal by the manufacturer, we needed to remove and cut the cover appropriately in order for the plastic removal system—the brush assembly and its actuation system—to be geometrically mounted as depicted in Figures 1(b) and 4.

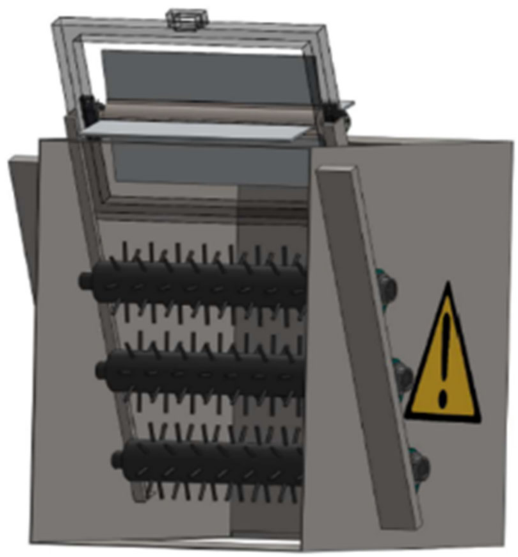

Figure. 4. Fabricated plastic removal mechanism mounted on the module feeder.

System Calibration and Functionality

The designed plastic removal mechanism is meant to move from an initial state designated as the idle position, which corresponds to when the brush assembly is in the storage space above the module feeder chamber. Position 1 corresponds to when the brush is centered on the midline of the first dispersing cylinder. Likewise, position 2 is designated as the state in which the brush shaft is centered on the midline of the second dispersing cylinder. This designation will go on until the last cylinder is reached, depending on the number of cylinders on the feeder, which may be up to 7 in a full-scale commercial gin.

To calibrate the positioning of the brush for plastic removal operations, the axial distance L between the wire brush and the top circumference of the uppermost dispersing cylinder measured along the slope line of the cylinders was determined; likewise, the center-to-center distance l between each cylinder was measured and the radius of each cylinder is defined as r (see Figure 5). The leadscrew was a single-start screw with a lead and pitch of 4 mm. Thus, for every revolution of the screw, the attached nuts translate 4 mm along the leadscrew in a direction determined by the rotation of the driving stepper motor. The leadscrew being right-hand threaded, implies that the nut moves downslope while moving the attached brush assembly with it along the leadscrew when the motor (and thus, the screw) rotates clockwise. Conversely, when the stepper motor rotates counterclockwise the nut together with the brush assembly translate upwards along the sloping leadscrew. The logic for controlling the stepper motor/leadscrew to position the brush is shown in Figure 7.

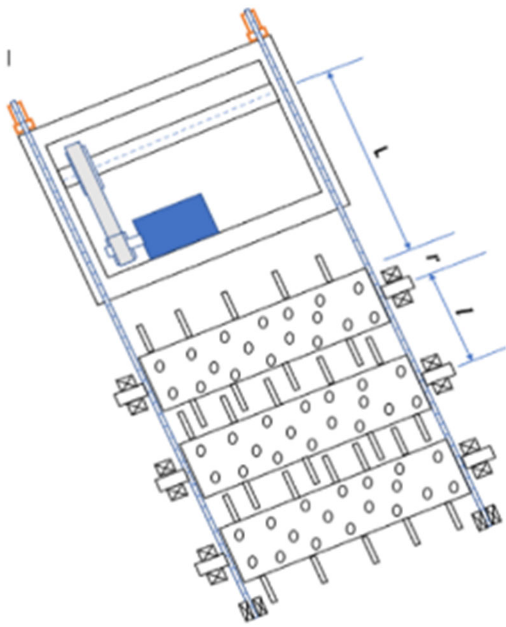

Figure. 5. A schematic view of the plastic removal mechanism mounted on the module feeder.

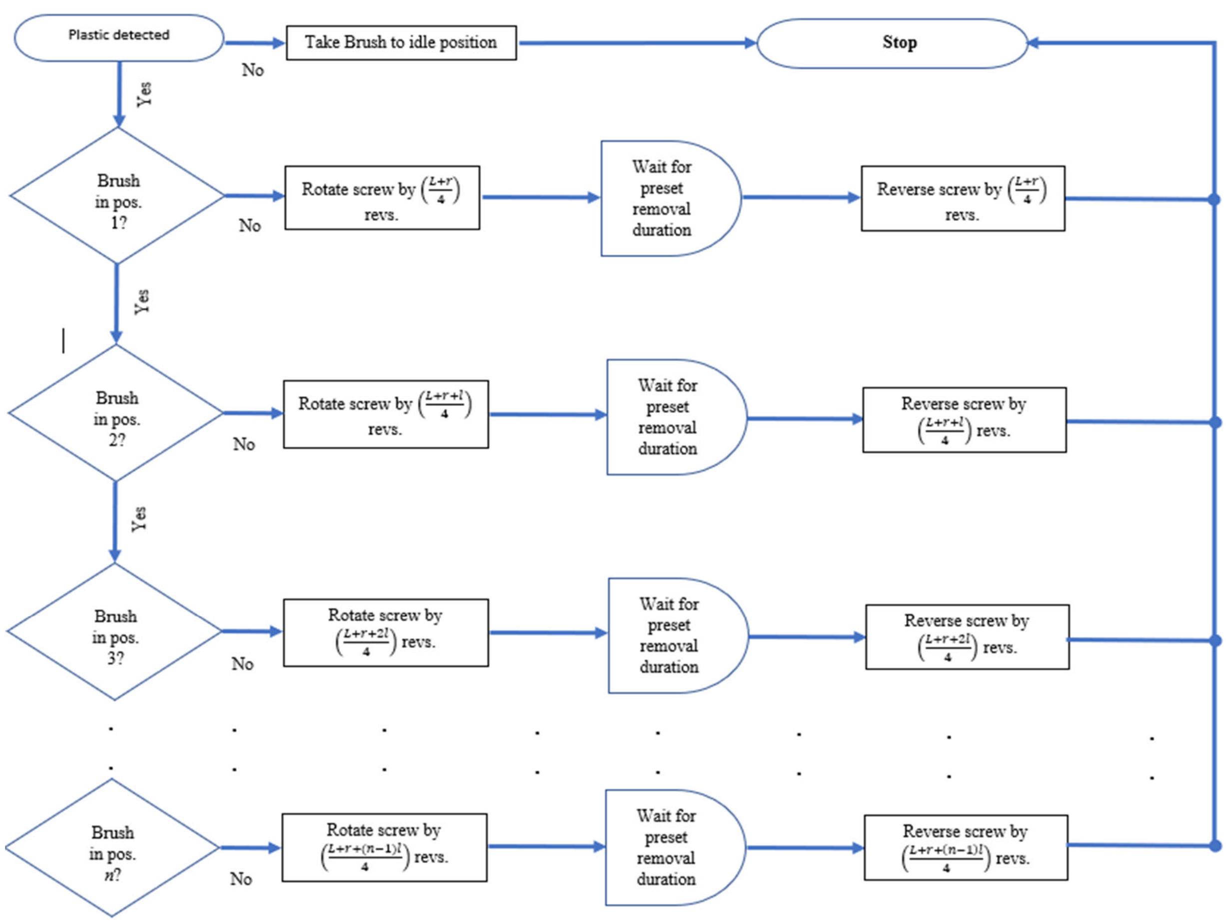

Figure. 6. Flowchart describing the logic for positioning brush for plastic removal.

The flowchart shows that our plastic removal mechanism drives the brush assembly to the idle state when no plastic is found in the feeder. When plastic is detected in the module feeder, our plastic removal mechanism drives the brush assembly to a desired cylinder by making N revolutions, where N is obtained through equation 1, and runs the brush motor, so that the brush runs against the dispersing cylinder and dislodges the entrapped plastic in the process. The brush runs for a preset optimal duration identified for plastic removal. Afterwards, the stepper motor reverses direction covering N revolutions to return the brush assembly to the idle (storage) state.

$$N = \frac{L + r + (n-1)l}{screw\ lead} \tag{1}$$

Where n is the number of dispersing cylinders on the module feeder (3 in this research), and L, r, and l are as described above and depicted in Figure 5. The leadscrew used in this design has equal lead and pitch of 4 mm as mentioned earlier. Full-scale models will likely use larger lead screws, the values can be updated accordingly. The overall control was implemented using a Raspberry Pi 4 model B which drives the stepper motor through a 'microstep driver' connection.

Results

The outcome of this research should be a cost-effective, functional system capable of being installed on a module feeder. After the design procedure was completed as described in the methodology section above, different components were selected and purchased or fabricated. This section presents the final design solution and the fabricated mechanism as well as some of the challenges encountered in the process of physically realizing the design.

Final Mechanism Design

After the selected components were bought and necessary fabrications and assembling were done (for example, figure 7 shows the brush frame and lead screw assembly), the mechanism was mounted on the module feeder. The lead screw was firmly fastened to the redesigned sidewalls (Figure 8) of the module feeder and supported by the C-channels on the module feeder roof. The final structure of the mechanism after being mounted on the module feeder is shown in Figure 9.

Figure. 7. Brush frame and lead screw assembly.

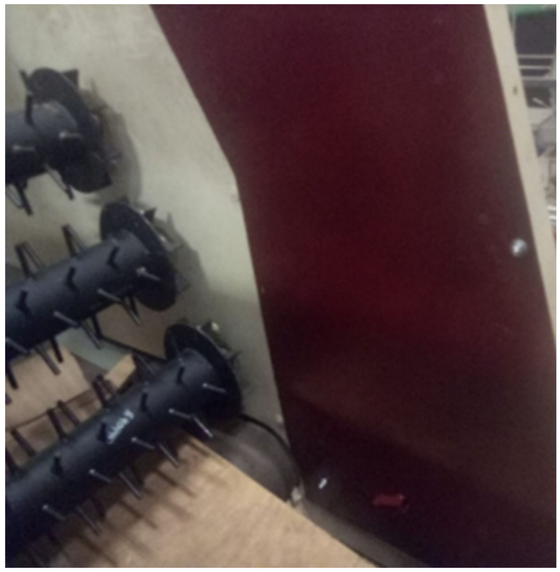

Figure. 8. One of the redesigned sidewalls of the module feeder (the part painted in red).

Fig. 9. Final structure of the mechanism after being mounted on the module feeder.

Challenges

Initially, the lead screw nuts were jamming on the screw because of alignment issues and it took quite some time to carefully set up the brush frame so that it may be actuated by the stepper motor through the indirect drive method. This challenge is expected to be a recurring phenomenon whenever this system is to be installed on module feeders and will require a high level of expertise on the part of the technician to accomplish. In addition, because the work involved some retrofitting, getting accurate measurement and precise dimensioning of parts posed a challenge, especially for dimensions in very narrow positions, for example, between the cylinder face and the feeder sidewalls. Knowledge gained in this project should be useful in subsequent installations.

Future Work

The next step is to complete installation of the brush assembly. Optimization of operating parameters will be completed to maximize plastic removal and minimize time needed for removal. An extensive evaluation of plastic removal efficiency of the designed system will be completed for comparison with manual methods currently used by gins. Evaluation of the performance of this automated plastic removal system will be based on both the number of plastics detected and effectively removed as well as the average time taken to complete the removal task. In addition, the plastic removal mechanism will be equipped with a bin for collecting the removed plastics. Finally, the designed system will be implemented and tested out on full-scale commercial gins to demonstrate commercial applicability of this proposed plastic removal method.

Summary

This work involved the design, fabrication, installation, and control of an automated plastic removal system for a mini-module feeder at a research laboratory, although the system was designed for compatibility with typical full-scale module feeders in commercial gins. Preliminary analysis of the designed system showed a promising automated solution for removing wrapped plastics on module feeders. The final design and preliminary testing conducted in this work has suggested that the removal of plastics wrapped on module feeder cylinders could be wholly automated with little or no human intervention, thereby minimizing the plastic contamination risk to cotton bales at gins. Our future efforts on the project will be geared towards further development of this proposed system and extensive testing to demonstrate its effectiveness and enhance commercial acceptability of the technology in the cotton ginning industry. Furthermore, the initial study and analysis of the fabricated and installed system indicated that the system is not only able to detect the presence of plastic elements in the module feeder compartment but able to remove the plastic in faster time duration than the manual removal operation. The reduced downtime and injury risk to workers manually removing plastic from module feeders makes this proposed automated cleaning system a promising development for industry.

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