ROBOTIC COTTON HARVESTING AND FIELD FIBER SEED SEPARATION APPROACHES AND CHALLENGES

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Abstract

Different aspects of robotic cotton harvesting including field fiber-seed separation, logistics, and end-effector design have been assessed in this study. The ultimate goal of the Cotton-Inc is to make a robot that uses just solar power. Although field fiber-seed separation has advantages, it is a very power demanding process that is not consistent with the project's goals. Accordingly, all parts and actuators of the cotton harvester robot must use as low energy as possible. Therefore, designing an energy-efficient end-effector is underway. Logistics also can affect the efficiency of the cotton harvester robot. In this regard, the feasibility of using drone images is assessed in this study. The objective was to find areas with open cotton bolls and then ask the robot to reach them. However, having multiple harvesting cycles doesn't let to defoliate the field. Hence, plants will be bushy and drone images cannot detect cotton bolls completely. Cotton boll distribution in the field is also important in logistics.

Introduction

Currently, cotton is harvested either by manually driven pickers or strippers in the USA [www.ers.usda.gov]. The John Deere round module cotton picker is most common, weighing 66,000 lbs. and cost about $800,000. Aside from the expense, heavy machinery can cause soil compaction, reducing fertilizer and water use efficiencies among other issues. For this and other reasons, Cotton Incorporated recently introduced a Robotic Cotton Harvesting project. Potential advantages of robots include minimizing soil compaction, the potential to utilize solar power as the power source, and multiple harvesting cycles, which could increase lint quality. Currently, harvesting occurs once at the end of the growing season, meaning that many cotton bolls are exposed to the weather while waiting for the others to mature, resulting in reduced lint quality. If one considers how robotic cotton harvesting efficiency could be improved, it is conceivable that remote sensing with unmanned aerial vehicles (UAVs) could be used to map boll density in the field in order to direct robots to important areas of the field. It is also conceivably possible to separate seed and cotton in the field right after harvesting, potentially improving logistics. The objectives of this study are thus as follows:

- To assess the feasibility of field fiber-seed separation.
- To assess the feasibility of mapping cotton boll density with remote sensing.
- To design an efficient end-effector for robotic cotton harvesting.

Materials and Methods

Field Fiber-Seed Separation

One solution for field fiber-seed separation is incorporating a small ginning machine on a robot. In this regard, a tabletop gin. Its model is TB510A made by Testex located in Dongguan-China. (Figure 1) was procured and tested in the lab. Batches of 100 g of seed cotton were divided into three roughly equal parts. The time interval for feeding each part of seed cotton was about 30 s. After feeding each part, ginning continued until seeds had enough fiber removed such that they began to fly out of the machine, the indication of the stop time. The seed cotton was stirred with a paint stick during ginning.

Figure 1. A tabletop gin which is being used while lab tests.

Cotton Boll Picking Approaches

The suction end effector is a simple solution for seed-cotton picking, but according to our lab tests it requires at least 1 kW to remove seed cotton from an open boll. We conducted some other lab tests to estimate the required power to remove the seed cotton mechanically. The tests proved that mechanical end effector can remove the seed cotton with less than 20 W. However, the mechanism of the mechanical end effector is not as simple as suction, and there are requirements for doffing and transferring the picked seed cotton. Additionally, a good end effector must deal with different cotton boll orientations.

Cotton Boll Detection

An undefoliated cotton plant has many leaves and branches, and cotton bolls are often hidden under them. Images of cotton plants at various angles were collected with an RGB camera (Figure 2) to compare actual cotton boll numbers to numbers of cotton bolls detectable in images. The height of the camera was about 135cm. Angles of 30, 45 and 60 degrees (downward from horizontal) were tested. Since the camera stand was placed between two rows there was a limitation of the camera and plant horizontal distance. In such a condition, 45 degrees was found to be best in terms of accommodating the whole plant inside the image.

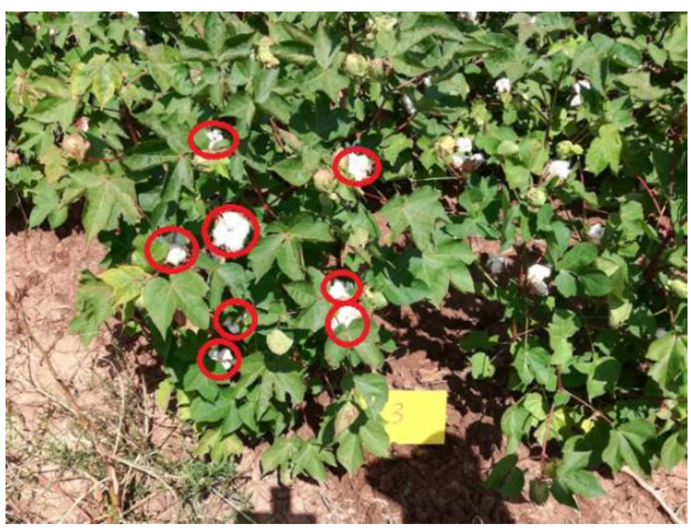

Figure 2. The detectable cotton bolls from the image

Partial detection of cotton bolls can also be a problem. It is possible for the imaging system to detect only a portion of the cotton boll (see marked white areas, Figure 3) and identify point B as the center of the cotton boll when point A is the actual center that the end effector must target.

Figure 3. Partial detection of cotton boll

Navigation and Logistics

There is potential to use remote sensing to map high-density cotton boll areas and then direct the ground robot to concentrate its activities in those areas. Jung et al. (2018) used UAV images of defoliated fields to measure the number of open bolls in order to estimate the cotton yield. However, for multiple harvests like those envisioned in the robotic-harvesting effort, the field must remain undefoliated through most of the harvest season. In 2019 we collected UAV images over an undefoliated field, located small zones (red ovals, Figure 4) within them, and counted actual cotton bolls in each zone.

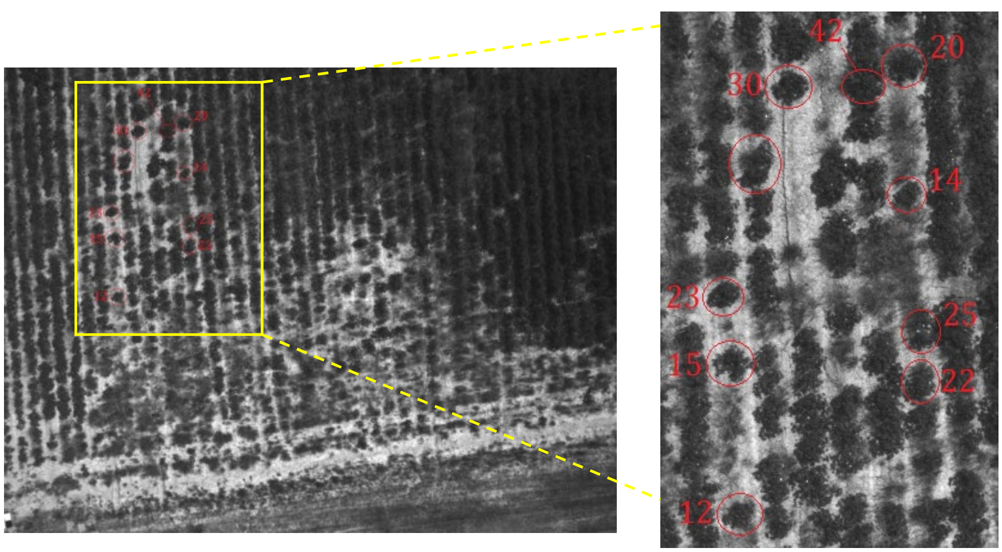

Figure 4. Locating small zones and counting actual cotton bolls

Results and Discussion

Table 1 provides a comparison between the tabletop gin we used and a conventional gin, and it shows two main differences: saw diameter and power consumption. The tabletop gin has saw diameter that is one-third that of the conventional gin, and it consumes seven times more power. The power which is required to gin 4 boll/s by conventional gin is about 1 hp but tabletop gin requires about 7 hp.

Table 1. Summary of conventional and table-top gin comparison

Fiber-seed separation	Saw Diameter (in)	Number of teeth/diameters	Saw Thickness (in)	Saw spacing (in)	Saw tip linear speed (m/min)	Required power for 4 bolls/s (hp)
Conventional	12.0 to 18.0	22.0 to 23.5	0.036 to 0.045	0.787 to 0.518	753 (d =16.0 in)	1
Table-top	4.0	30.0	0.035	0.675	850 (nominal)	7

Considering 25 harvesting cycles and allocating one fiber-seed separator per robotic harvester (Figure 5), each fiber-seed separator would require 1 hp. The calculations are based on conventional gin power requirements and 4 boll/s harvesting speed. Since the ultimate goal of Cotton Inc. is to use solar power, providing that level of power appears to be very challenging at the moment.

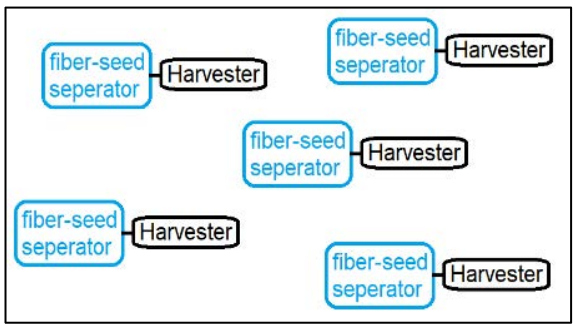

Figure 5. Allocating a fiber-seed separator per cotton harvesting robot

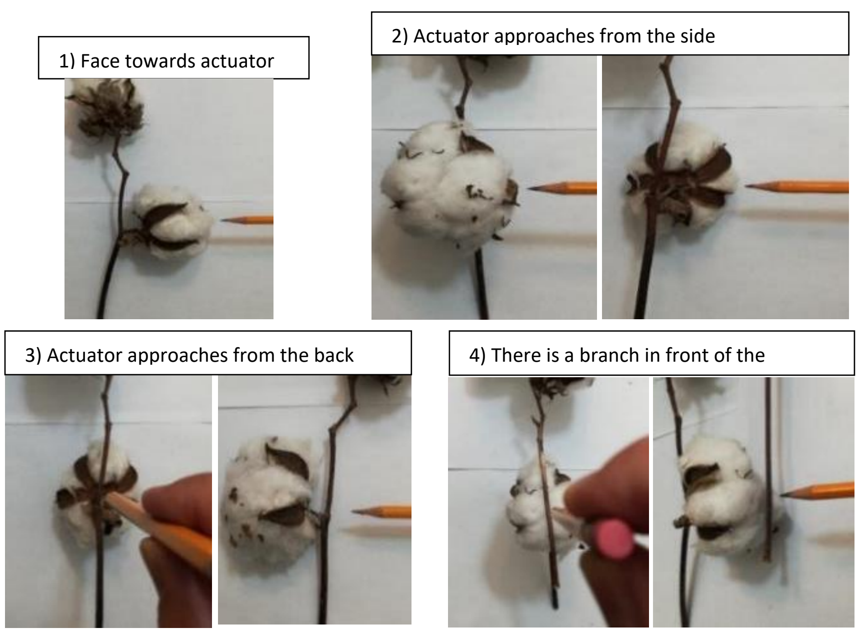

Figure 6. Different orientations of a cotton boll on the plant, pencil tip represents the end effector tip

We categorized cotton boll orientations on the plant into four major orientations (Figure 6). A preliminary design of a five-spindle end effector was developed and tested (Figure 7). According to lab tests the required power is only 10 W. However, this design has two important problems: (1) sometimes it picks only a part of the seed cotton and leaves behind the rest; and (2) a batch of seed cotton that is wound on two or more spindles can get stuck on a branch among them, keeping the end effector from pulling out of the plant.

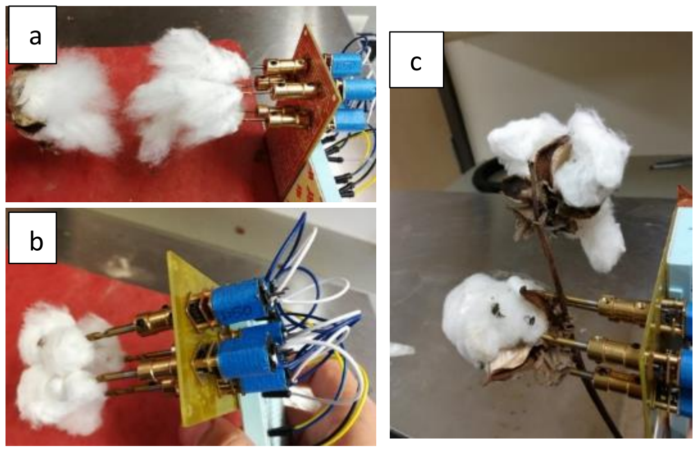

Figure 7. A five-spindle end-effector, (a) seed-cotton isn't plucked completely, (b) seed-cotton is wounded on two or more spindles at the same time which cased spindle bending, (c) a branch got stuck among spindles

A potential end effector must have the following properties: (1) being able to pick the seed cotton regardless of its orientation as much as possible; (2) picking the all seed cotton; (3) easy doffing and transfer. Figure 8 shows a design which can meet these requirements. It contains two-directional moving teeth. The picked seed cotton would be transferred through the fingers and would be doffed at the endpoint of the fingers.

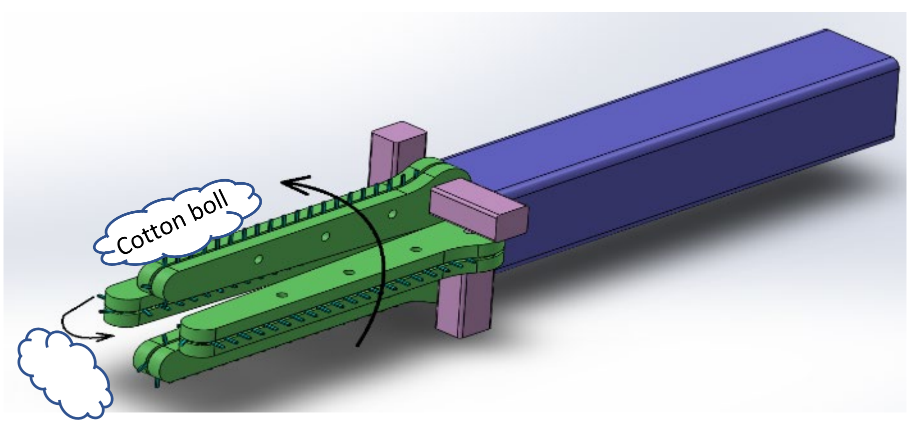

Figure 8. A preliminary design of the end-effector which has two-directional moving teeth

The field images of the cotton plants (Figure 2) showed that only about 70% of the cotton bolls were fully or partially detectable by the robot. However, since the robot will harvest during multiple cycles, detection could be improved because the plant is less bushy in early growing stages. However, the cotton boll detection problem must be considered and addressed in this project.

Regarding using UAV remote sensing to find open cotton bolls in the field, we found a poor correlation between actual boll numbers and the number of white spots (representing cotton bolls) within a zone in the images. For example, the oval with 42 cotton bolls (Figure 9) does not have clear white spots, while the oval with 25 cotton bolls has several white spots.

Another issue that must be considered is cotton boll distribution in the field. If there are 25 harvesting cycles, then the average distance between two cotton bolls on a row is 32 cm (based on the average yield in a cotton field). Therefore, after picking the seed cotton from a cotton boll the robot must go forward about 1ft and harvest the next boll. If the robot goes forward at 3 mi/hr speed, then it has only 0.26 s to pick the seed cotton. This is a very short time to perform the task.

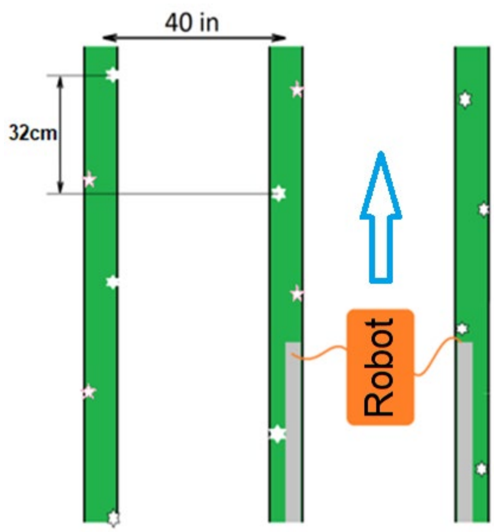

Figure 9. Cotton boll distribution in the field

Conclusions

Field fiber seed separation requires a large amount of power and currently appears to be impractical. Therefore, we are not inclined to study this subject any further. We tested different ideas of end effector designs and have arrived at a preliminary design to build and test in the near future. Remote sensing with UAVs does not appear helpful for directing robots in the field due to the lack of visibility of cotton bolls on non-defoliated plants. Cotton boll detection and accessibility, robot speed and control are very challenging issues.

References

https://www.ers.usda.gov/topics/crops/cotton-wool.aspx#.UappautAuwY

Jung, J., Maeda, M., Chang, A., Landivar, J., Yeom, J. and McGinty, J. (2020). Unmanned aerial system assisted framework for the selection of high yielding cotton genotypes.