DESIGN AND TEST OF DIFFERENT END EFFECTORS FOR ROBOTIC COTTON HARVESTING

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Abstract

Very large mechanical machines harvest most of the cotton in the U.S. Although these machines are very efficient they compact the soil that leads to less water and fertilizer efficiencies. The next drawback of these machines is that they harvest just in one pass and so cotton plants must be defoliated and many opened cotton bolls have to wait for a long time until being harvested. Exposure to weather results in low lint quality. If cotton could be harvested with small robots these issues could be addressed. Robots can mimic the human job. They could perform multiple harvesting cycles and they could pick the seed cotton as soon as cotton bolls open. Also, no defoliation would be necessary. Such robots would be light and so they wouldn't compact the soil.

End-effector is a key part of the robotic cotton harvester. A decent end-effector can pick the seed cotton quickly and its power consumption could be relatively low. For this reason, multiple end-effector concepts have been assessed and different prototypes have been manufactured. The best concept is a finger that has rotating pins on that. The end-effector can have one or multiple fingers. Two of those configurations that showed better results during lab and field tests are two and three-finger end-effectors. The end-effectors will be attached to a system of linear actuators to perform more tests and optimizations.

Introduction

According to the U.S. Department of Agriculture, almost all cotton grown in the U.S. is harvested with large mechanical cotton harvesters. These machines are expensive and very heavy, potentially compacting the soil and resulting in a hard layer of soil that reduces fertilizer and water usage efficiencies. Manual cotton harvesting does not produce these problems but is very expensive. If small robots could harvest cotton, they could provide the advantages of both manual and machine picking. Robots could potentially go to the field multiple times in a season and pick the seed cotton as soon as the cotton bolls open. Doing this would result in high fiber quality and could reduce yield losses due to extreme exposure to weather (Barnes et al., 2020). Small robots would not compact the soil and could potentially use solar charging solutions for battery operation. A swarm of small robots could potentially do the job of a large cotton harvester.

Fue et al. (2019) developed a robotic cotton harvester with a vacuum-type end-effector on two orthogonal linear actuators. They used the robot's horizontal movement as the third degree of freedom for end-effector positioning. One of their main challenges was the high-power requirement for the end-effector, which involved a vacuum pipe with rotating gears at the tip. Maja et al. (2019) also used a vacuum machine to pick seed cotton. The Grobomac company (Bangalore, India) developed a vacuum-type robotic cotton harvester prototype. Gharakhani and Thomasson (2020) stated that picking seed cotton with a vacuum machine required a large amount of energy. Because small robots would have power limitations, it is necessary to consider a low-power end-effector for robotic cotton harvesting. An idealized end-effector could pick seed cotton in a reasonable time and with a small amount of energy. A mechanical end-effector, as opposed to a vacuum-type, could be an appropriate solution. The end-effector should be able to pick seed cotton, transfer it with minimal loss, and finally doff it.

The objective of this research is thus to design an end-effector for a small robotic cotton harvester. The end-effector should be light, low-power, penetrate easily through the plant, pick the seed cotton, transfer it and doff it.

Materials and Methods

Different End-effector Ideas

The first design was a gripper constructed of a piece of plastic covered with a piece of sandpaper. As shown in Figure 1, this type of gripper failed to pick all the seed cotton from the boll.

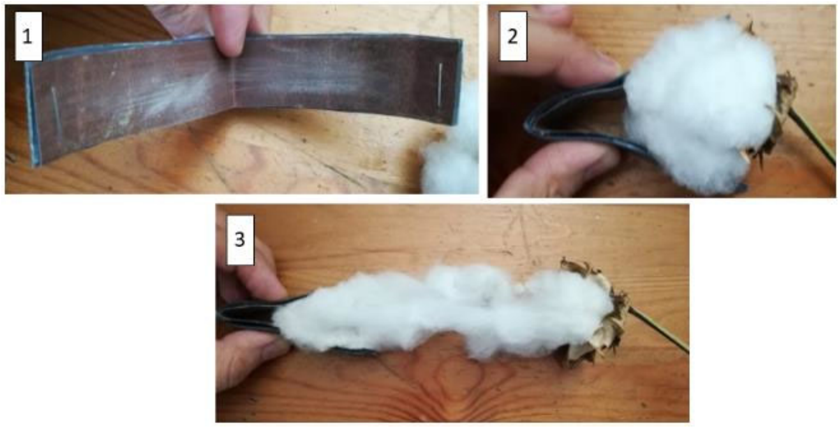

Figure 1. Picking the seed cotton with two sanding paper fingers

A second idea included eight expandable fingers (Figure 2) to create a different type of gripper. The tip of the fingers was covered with sandpaper to provide friction. To pick the seed cotton, the end-effector surrounds the cotton boll and then is pulled backward. This procedure bends the branch and sometimes removes the entire cotton boll or breaks the branch. As shown in Figure.2 (3), the end-effector commonly cannot pick all the seed cotton from the cotton boll.

Figure 2. Picking seed cotton with expandable fingers

A third idea is a spindle-driven end-effector (Figure 3). This design is motor-powered and does not bend the branch, but this end-effector also cannot pick all the seed cotton from the boll. Also, if there is a branch among the spindles, the end-effector may get stuck.

Figure 3. Spindle-driven end-effector

Two common problems that all three of the aforementioned designs have are not being able to pick the whole seed cotton and difficulty in doffing. A good end-effector should be able to work continuously to pick all the seed cotton from the boll, transfer it to the doffing device, and doff the seed cotton.

A final idea met the above-mentioned requirements. It is a finger with rotating pins. The body of this end-effector was constructed with a 3-D printer. Figure 4 shows the first three prototypes, on which pins are attached to a timing belt, and the timing belt runs around the length of the finger. A DC motor at the rear of the finger provides the required motion. In the right image of Figure 4, a green plastic "keeper" is used to retain the seed cotton and push it against the pins so the end-effector can convey the seed cotton to the doffer. The picked seed cotton is transferred to the back of the finger and then doffed. During testing, this end-effector could pick, transfer, and doff the seed cotton continuously.

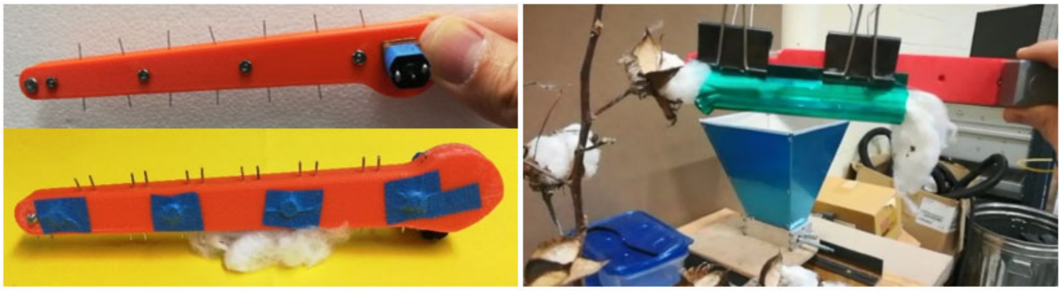

Figure 4. The first three prototypes of continuous seed cotton picker

Although the one-finger design met the main requirements, it had two important issues. The picking speed was low, and the picked seed sometimes cotton got stuck in the middle of the finger while being transferred to the doffer (Figure 5). If the number of fingers was increased then the picking speed would increase because the picking surface of the end-effector increased. Also, increasing the number of fingers can help the seed cotton be transferred to the doffer more easily. Therefore, a multi-finger design was considered (Figure 6).

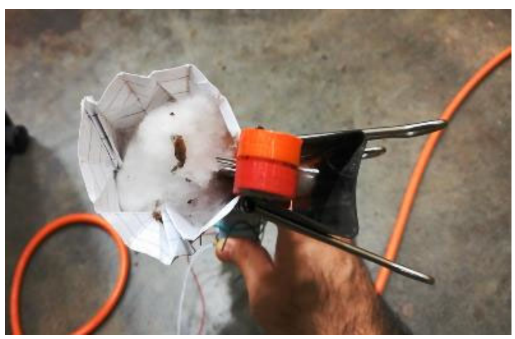

Figure 5. The picked seed cotton got stuck between finger and keeper while transferring it

<u>Multi-finger End-effector</u>

The multi-finger end-effector must have just one inlet. All the fingers must pick the seed cotton together, but the picked seed cotton must be led into one common inlet. Otherwise, the seed cotton can wrap around the end-effector. Besides higher picking speed and better seed cotton transfer, the multi-finger configuration can help a camera to have a better view of the target cotton boll. While approaching a cotton boll the end-effector can operate in the reverse direction and push the leaves and branches away, enabling the camera to see the cotton boll more easily.

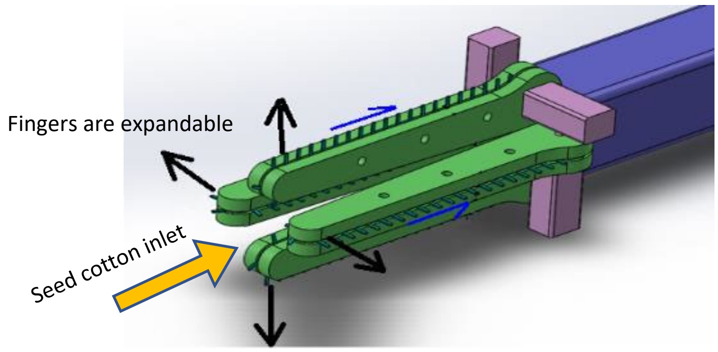

Figure 6. Multi-finger end-effector

Figure 7 shows a three-finger end-effector. Each finger had an independent motor. The bottom finger serves as the base, and the two top fingers are connected to it with a pivot connection. Elastic is used to retract the fingers and hold them together.

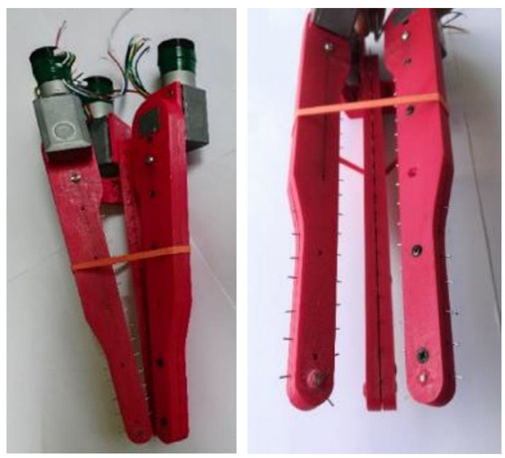

Figure 7. Three-finger end-effector, the fingers are expandable

<u>Results and Discussion</u>

Figure 8 shows the three-finger end-effector during field tests. The end-effector was attached to an adjustable arm. During testing, this end-effector grabbed the seed cotton easily, but it tended to ingest not only the seed cotton but the entire cotton boll. It also sometimes ingested leaves and branches. There are at least two potential solutions to this problem. One is decreasing the number of fingers. The second is to run the end effector forward and backward to not allow it to ingest the entire cotton boll.

Figure 8. Field tests of the three-finger end-effector

While fewer fingers than three appeared to be preferable, the one-finger configuration had speed and transfer problems, so a two-finger end-effector appeared to have potential. The picking surface is greater than that of the one-finger design, and because it has more moving pins it should not have the transfer problem. Figure 9 shows a two-finger end-effector in which the sets of fingers are side by side. The main reason the three-finger end-effector ingests the entire cotton boll is that the pins are arranged against each other, so when they rotate at the same time they pull inside everything they can catch. In the two-finger configuration, the pins move together and tend to mitigate the problem. On the other hand, field tests have shown that if a cotton boll is not face to face with the two-finger end-effector, it is better to rotate the end-effector until its bottom side is face to face with the cotton boll. Therefore, a two-finger end-effector requires an extra degree of freedom for manipulation. The other disadvantage is that this configuration requires a keeper. Also, its penetration through the plant leaves is not as good as the three-finger configuration.

As mentioned earlier, another solution is to prevent the three-finger end-effector from undesired material by having it rotate forward and backward multiple times while picking the seed cotton. In this case, the foreign material would not have enough time to be grabbed and pulled inside. Therefore, both two and three-finger configurations have potential and more precise tests will be conducted to find the best configuration.

Figure 9. Two-finger end-effector during field tests

Next Step

The next step is to test the end-effector configurations more precisely. Therefore, the end-effector will be connected to a 3 degree-of-freedom linear actuator configuration. A ZED-2 camera will be used to capture images of a cotton plant. An NVIDIA Jetson TX2 board will serve as the main computer. A Raspberry Pi microcomputer will be used to provide extra GPIO pins so the speed and direction of the end-effector motors can be readily controlled. Gharakhani and Thomasson (2019) reported that small robots like the Jackal (ClearPath, Ontario, Canada) are not appropriate platforms for robotic cotton harvesting. Therefore, the entire configuration will be attached to an aluminum platform. The Z-axes that hold the end-effector will be attached at different angles of 0-45 degrees to assess the effect of inclination on seed cotton-picking efficiency.

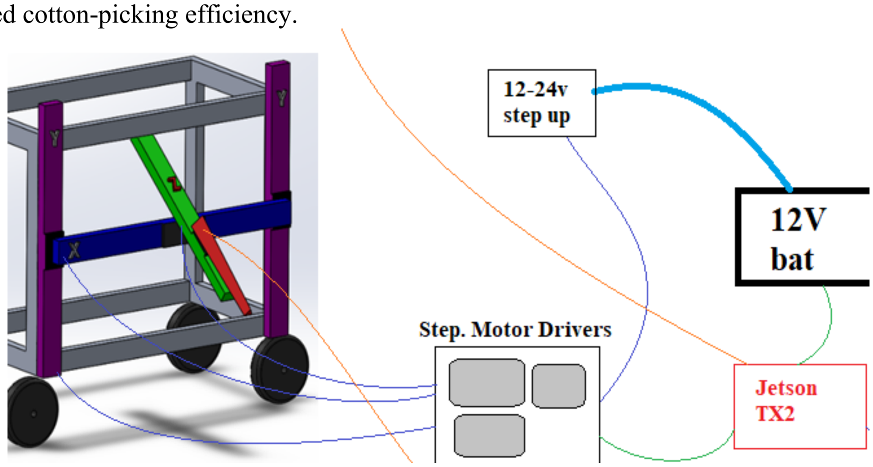

Figure 10. A setup to perform future tests on the end-effectors

Conclusions

During this research different cotton-picking end-effector ideas were assessed. The latest design is a finger with moving pins on it, which can pick the seed cotton, transfer it and doff it continuously. Multiple prototypes of this idea have been made, and the best configurations are the two and three-finger end-effectors. The three-finger end-effector has the highest picking speed and canopy penetration, but it ingests not only the seed cotton but other undesired material like calyx, leaves, and branches. On the other hand, the two-finger design requires an extra degree of freedom. To achieve more reliable results and optimize the design, more tests will be performed. In this regard, the end-effectors will be attached to a set of linear actuators as the robotic arm and will be controlled automatically.

Acknowledgment

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