Design of a Novel Tomato Harvesting Gripper

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Abstract. The robotic harvesting of tomatoes in a greenhouse setting presents many challenges in grasping, separation and manipulation of the produce. Presented is the design and development of a tomato harvesting tool, using a minimal amount of sensors and actuators to overcome the associated challenges.

Keywords: Gripper, Agri-food, Smart farming, Tomato harvesting

1 Introduction

The agri-food sector is currently experiencing its own renaissance, where the application of robotics takes the forefront. The FlexCRAFT project attempts to tackle many of the challenges in different use-case projects. One of these use-case projects is the robotic harvesting of tomatoes within a greenhouse.

Within the context of the manipulation of agricultural products, there are many unique requirements. These include, but are not limited to: the variation in physical produce dimensions and shape, complex plant structure, plant movement during interaction, occlusion (leading to positioning inaccuracies), and hygiene requirements.

This research attempts to explore and address the unique issues presented in robotic tomato harvesting from a grasping perspective, through the use of mechanical guidance and combined grasping/cutting mechanism with minimal usage of sensors and actuators.

Fig. 1: The gripper attempting to grasp a tomatoe truss in a greenhouse environment.

2 System overview

2.1 Targeted produce

Tomatoes grow clustered together as 'trusses', which are connected to the main stem of the vine-like tomato plant through side-vines called 'peduncles'[1].

By targeting the trusses, instead of the fruits directly [2], risk of produce damage[3] is reduced and fruit obstructions are avoided. Additionally, packaging complete trusses is desirable for aesthetic reasons.

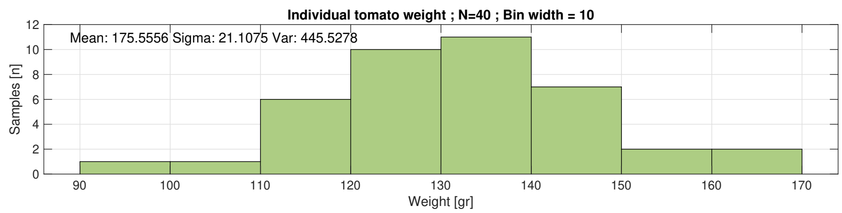


Fig. 2: Statistical measurements on individual tomato weights.

Of primary importance for a gripper is the mass of the targeted items. In order to better deduce the requirements of the gripper, the mass of N=40 tomatoes have been measured (Fig. 2) using an electronic scale. The exact amount of tomatoes on a truss varied between 4 and 7. This provides a guideline for the mass that the gripper has to be able to cope with during harvesting.

2.2 Harvesting procedure

To be able to deduce the required functions of the gripper, it is important to distinguish the different phases during harvesting.

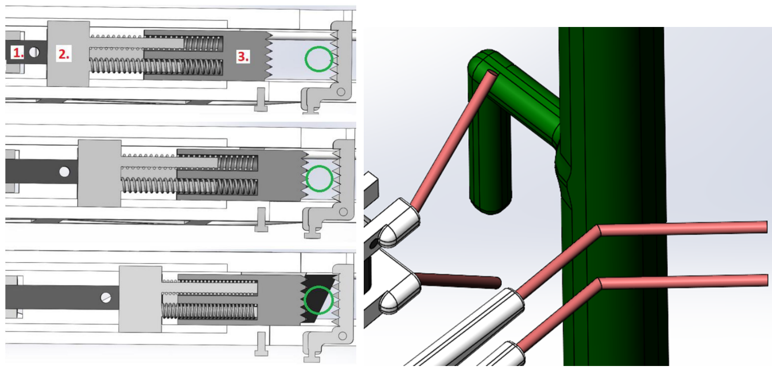
1. Detection and scanning phase - Determine the exact locations and orientations of trusses, and select a target truss.
2. Approach - The robot arm moves towards the targeted truss.
3. Grasp - The truss is grasped by the robotic arm.
4. Cutting - The truss is cut as close as possible[1] to the the main stem.
5. Transport - The truss is carried from the plant, to the target container.
6. Release - The item is dropped in the container awaiting further processing.

2.3 Subsystems

The manipulator has to perform three main functions in order to successfully perform the afromentioned harvesting tasks.

- Guidance - To successfully guide the robot towards the targeted peduncle.
- Grasping - To hold the truss during cutting and subsequent manipulation.
- Cutting - To separate the truss from the tomato plant.

[1] This reduces the chance of infection, which could damage the health of the host plant.



(a) Cutting and grasping procedure. **(b)** Guidance mechanism.

Fig. 3: Highlights of the structural design.

3 Structure design

3.1 Grasping and cutting mechanism

In order to reduce the overall size and number of actuators, the grasping and cutting functionality can be integrated into a single mechanism, similar to Jia et.al.[4]. A cutaway view showing the mechanical working is shown in Fig. 3a.

The mechanism works through two linear carriages. The first carriage (marked as 2 in Fig. 3a, from here on referred to as 'A') is driven by a linear actuator[2]. Directly attached to A is a blade. Carriage B features an integrated jaw element, which is opposed by a jaw connected to the frame through a rotational joint (forming a gate). Each jaw has a spiked surface pattern to bite into the peduncle to help with retention. The carriages are connected together through a set of compression springs.

During grasping, the peduncle will pass through the gate, after which it is effectively locked in the gripper. Next by applying actuator force to A, both carriages move in unison closing the jaw. After the jaw contacts the peduncle, any additional actuator movement will result in spring compression. This in effect increases the applied grasping force as described in Eq. (1), as well as moving the blade forward, facilitating cutting functionality.

$$F_{grip} = K_{spring}(\Delta x_{spring}) = K_{spring}(x_{rest} - (x_{car,3} - x_{car,2})) \tag{1}$$

Maximum spring compression thus implies full blade extension and maximum clamping force. This in effect determines the stroke of the blade through relative movement of the carriages. Assuming a spring resting position of x_{rest}, the spring rate can be determined with help of Hooke's law[3].

[2] Unknown manufacturer, voltage:12[V], stroke:50[mm], max force:90[N], no-load speed:9.5[mm/s].

[3] The constructed prototype features a stroke (Δx_{spring}) of 12[mm] combined with a spring rate of 2.5[N/mm], resulting in a clamping force 30[N] and cutting force of >40[N].

3.2 Guidance mechanism

Try-outs in the greenhouse show that positioning accuracy of the robot is relatively poor due to tolerance stacking of various errors in the system. In order to increase robustness and compensate for this, we propose the implementation of mechanical guidance as shown in Fig. 3b. The mechanical guidance consists of 'prongs' which help guide the plant into the correct position. One pair of prongs guides the main stem, whilst the other set guides the peduncle into the jaws. Initially these were constructed of metal wire, later iterations feature a more rounded profile, constructed out of polymer.

4 Results

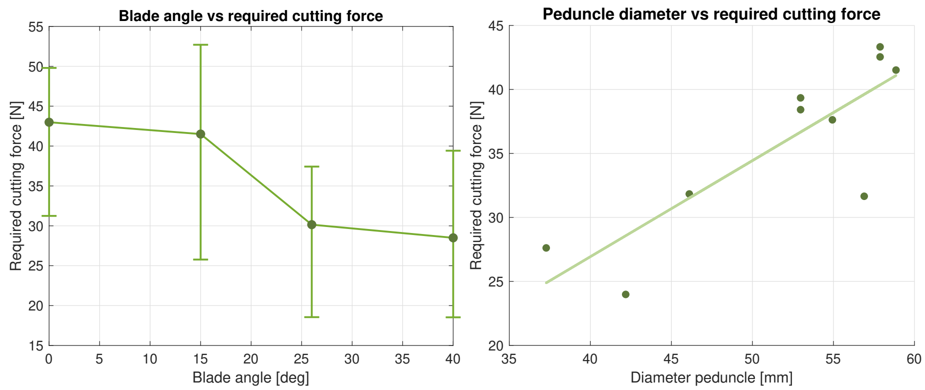
Fig. 4 shows the developed (2nd generation) gripper in a payload testing scenario. It illustrates the ability to successfully manipulate twice the nominal payload.

Fig. 4: The second generation gripper successfully manipulating a total of 11 tomatoes.

Experiments on the effect of both blade angle and peduncle diameter on cutting force are shown in Fig. 5a and Fig. 5b respectively.

5 Discussion

Testing highlighted various qualitative results. Firstly, although guidance helps in compensating for positioning inaccuracies, over-constraint in complete system loop, can cause jamming and excessive friction. Control methods or mechanical changes could help solve this. Additionally, deposits and blade dulling significantly increase the required cutting force. This results in bending of the blade and peduncles which are not fully separated. Lastly, the current mechanism is physically quite long due to the linear actuator used, which can cause interference during the approach phase.



(a) Blade angle versus cutting force.

(b) Peduncle thickness versus cutting force.

Fig. 5: Experimental results on parameters influencing required cutting force.

6 Conclusions and future work

Presented is the design and construction of a tomato truss harvesting tool. It features a single actuator combined with passive mechanisms to enables cutting, grasping and holding functionality required for produce manipulation. Additionally, it includes mechanical guidance to aid in increasing the success-rate during initial approach of the truss. demonstrate the ability to effectively locate, grasp, cut and transport the trusses. Some practical issues with the guidance and cutting have been uncovered, which can be addressed in future iterations.

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Note from authors

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