Peduncle Gripping and Cutting Force for Strawberry Harvesting Robotic End-effector Design

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Abstract—Robotic harvesting of strawberries has gained much interest in the recent past. Although there are many innovations, they haven’t yet reached a level that is comparable to an expert human picker. The end effector unit plays a major role in defining the efficiency of such a robotic harvesting system. Even though there are reports on various end effectors for strawberry harvesting, but there they lack a picture of certain parameters that the researchers can rely upon to develop new end effectors. These parameters include the limit of gripping force that can be applied on the peduncle for effective gripping, the force required to cut the strawberry peduncle, etc. These estimations would be helpful in the design cycle of the end effectors that target to grip and cut the strawberry peduncle during the harvesting action. This paper studies the estimation and analysis of these parameters experimentally. It has been estimated that the peduncle gripping force can be limited to 10 N. This enables an end effector to grip a strawberry of mass up to 50 grams with a manipulation acceleration of 50 m/s² without squeezing the peduncle. The study on peduncle cutting force reveals that a force of 15 N is sufficient to cut strawberry peduncle using a blade with a wedge angle of 16.6° at 30° orientation.

Keywords—selective harvesting robots, end effectors, strawberries, peduncle

I. INTRODUCTION

Strawberries are one among the high-yield crops that have received great attention from researchers in developing robotic solutions for harvesting. Robotic harvesting of strawberries has been predominantly researched and developed for those which are grown in greenhouse scenarios[5]. A selective harvesting method is primarily utilized to harvest the strawberries because all fruits on the plant may not be ripe at the same time. And moreover, it needs some judgment to pick the ripe fruit which may be staying in isolated condition or as partially/completely occluded by adjoining fruits or by the parent plant. The clustered nature of strawberries makes it troublesome for any robotic intervention to reach an efficiency competent to a human picker. Several strawberry harvesting robots are reported in the literature [9, 8, 7, 2, 15, 16, 3, 11].

In these robots, the end effector (EE) is the unit that directly and physically interacts with crops. Across different EE technologies for strawberry harvesting, these physical interactions include: (i) gripping/grasping the strawberry by its peduncle or fruit body (attachment), (ii) detaching from the plant by pulling, twisting the fruit, or cutting the peduncle, (iii) facilitating the fruit transport from the detachment location to the storage, and (iv) pushing/parting of strawberries in the cluster for obstacle separation during detaching action [14] which is a recently explored functionality.

Fig. 1. Strawberry harvesting end effectors: [a]. Parallel jaw mechanism for simultaneous attachment and detachment[9], [b]. Suction head for attachment and blade action for detachment[2], [c]. Suction head and two jaw fingers for attachment and bending action of end effector for detachment[16], [d]. Suction cup for attachment and thermal based detachment[7], [e]. Soft gripping for attachment and followed by rotation with pulling action for detachment[4], [f]. Detachment without any attachment[13]

Among the attachment and detachment actions, some EEs perform simultaneous gripping and detachment of the strawberry peduncle using a parallel jaw mechanism [9, 10] (Fig. 1a). In such a mechanism, one jaw will be shaped in the form of a cutting blade or is provided with a provision to attach replaceable blades. One such EE design makes use of a suction cup to provide an additional grip by sucking the fruit body to avoid any positional errors during this simultaneous gripping and cutting actions [9]. A suction-based approach is used by another end effector which uses a suction head to grip the fruit body and then rotates so that a blade arranged on the curved opening of the suction head trims the peduncle [2] (Fig.1b). Instead of using any blades for cutting the peduncle, the EE

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reported by Yamamoto S et al. [16] uses a bending action to
detach the strawberry after gripping the fruit body by a suction
head and a two-jaw gripper (Fig. 1c). Also, a thermal-based
cutting is reported for another EE that uses an electrically
heated wire on the gripping jaw to cut the peduncle [7]. In this
EE, once the fruit body is gripped by the suction cup to position
the peduncle between the two jaws (cutting device), the jaws
then close and cut the peduncle using the heated wire (Fig. 1d).
The end effector developed by Octinion uses a soft gripper to
grip the strawberry fruit body and imposes a rotational motion
while pulling the strawberry to detach it from the peduncle [4]
(Fig. 1e). The EEs reported above make either a gripping
contact with the fruit body or with the peduncle during the
harvesting action. But the EE reported by Xiong Y et al. [13]
doesn’t grip the fruit body or the peduncle during the harvesting
action. Instead, a combination of three active and passive
fingers guides the strawberry into the EE housing. Once the
fruit reaches the cutting location, scissor shaped blades cut the
peduncle to detach the strawberry (Fig. 1f).

Considering the different options for gripping and cutting, it
is always beneficial to avoid applying any forces on the fruit
body by the EE contact surfaces. Since strawberry is a very soft
and delicate fruit, there are higher chances of bruising during
such operations. Aliasgarian et al. [1] showed that the
strawberry fruits are more damaged when exposed to
compression forces on their body. Hence, from the EE design
point of view, it is recommended to target the peduncle for
gripping/cutting actions or to avoid any grip action as
demonstrated by Xiong Y et al. [13].

To develop an end effector solution that attempts to detach
strawberries by cutting the peduncle, it is essential to
understand certain design parameters. This includes the
estimation of the required cutting and the gripping force that
can be applied on the peduncle. Knowing the limit of gripping
force eliminates the chances of a loose grip or crushing the
peduncle during the gripping action. These situations can lead
the detached strawberry to fall off from the grip while
manipulating it during the harvesting cycle. Moreover,
knowing these force gives an insight for the selection of
actuation system for the EE.

The only study that we are aware of which reports the
measurement of the force required to detach the peduncle from
a strawberry is by Dimeas F et al. [6]. This considers the use of
a pulling effort (technique A) and a combination bending-
pulling effort (technique B). Technique A needed a force of
13.94 N for a peduncle with mean diameter of 2.17 mm, while
technique B took 3.17 N to detach a peduncle with a mean
diameter of 1.78 mm. Moreover, Dimeas F et al. [6] also
reported that a safe gripping force below 10 N can be applied
on the strawberry fruit body for detaching the peduncle by
technique B such that it won’t bruise the fruit body. Apart from
these measured forces, no work has been reported which
studied the cutting force and the limit of gripping force that can
be applied on the strawberry peduncle. Given this lack of data,
this paper studies, the cutting and gripping force that must
be applied to the strawberry peduncle, helping future work on EEs
targeting peduncle for the selective harvesting of strawberries.

For presenting the study details, this paper is organized in
the following order. Section II outline the experimental studies
conducted, and section III discusses the results obtained. The
conclusive remarks of the paper are presented in section IV
followed by study limitations in section V.

II. EXPERIMENTAL STUDY

For these experimental studies, we have used two varieties
of strawberries namely, Katrina and Zara grown in the
polytunnel at Riseholme Campus of the University of Lincoln,
UK. The peduncles specimens were collected from both varieties
in such a way that there will be uniformity in their diameter
ranges for better results comparison.

A. Study on Gripping Force Limit

This study intended to estimate the limit of the gripping force
that can be applied on the strawberry peduncle without crushing
it. To understand this force limit, experiments were conducted
by applying compression force (analogous to the gripping force)
to the peduncle specimens using a Universal Testing Machine
(UTM). The peduncles of ripe strawberries of both varieties
were selected for preparing the specimens. 15 specimens of each
variety were prepared so that the peduncle was 10 mm in length
and were trimmed at a distance of 10 mm from the top surface
of the ripe strawberry fruit. This specimen measurement can
simulate the situation where a two jaw parallel end effector grips
the peduncle within 10-20 mm from the top surface of the
strawberry during harvesting. The specimen diameter
varied from 1.40 mm to 2.22 mm for Katrina with a mean
and standard deviation of 1.75 mm and 0.24 mm. And for Zara,
the diameter varied from 1.43 mm to 2.33 mm with a mean
and standard deviation of 1.76 mm and 0.25mm.

During the experiment, each specimen was placed on the
base plate of UTM as shown in the Fig. 2. The UTM was
configured in such a way that the vertical ram (with load cell
attachment) approached the base plate at a rate of 1.5 mm/min.
Once the ram starts touching the specimen, the connected PC
records the interaction force at a resolution of 0.0001 N. The
force values recorded during the study are presented in section
III.

![Universal testing machine (UTM) for applying and recording the compression force on specimens used for our experimental study](image)
B. Study on Cutting Force

This study aimed to estimate the force required to cut the peduncle of a ripe strawberry using an off-the-shelf blade profile. As an extension to this, the variation of this force at different cutting orientations was also studied. The profile of the selected cutting blade was studied using a scanning electron microscope. The blade had a double bevel cutting edge with a wedge angle of 16.6° and a thickness of 0.22 mm (Fig. 3).

As shown in the Fig. 4a, we designed and 3D printed some fixtures in order to conduct the experiment. These include a blade holder for holding the blade, a peduncle support to place the peduncle specimen, and a pair of press fit clips for positioning the specimen on the support. Also, angular wedges of 10°, 20°, 30° were made that can be used to tilt the peduncle support loaded with the specimen. This allowed us to study the cutting force variation for 0°, 10°, 20°, 30° orientations. The same UTM used in the previous study was used here as well. The blade holder was attached to the vertical ram of UTM using a thin layer of adhesive and the peduncle support to the base plate as shown in the Fig. 4b-c.

15 peduncle samples from both Zara and Katrina varieties were prepared for this study, i.e., 15 samples from each variety for each orientation of cut. These specimens were prepared by cutting the peduncle at a length 30 mm from the top surface of the ripe strawberry. The diameter range of the specimens used for each trail are shown in the Table I.

| Specimen Diameter (mm) | Trials | Zara | Katrina |
|------------------------|--------|------|---------|
|                        | Minimum | Maximum | Minimum | Maximum |
| 0°                     | 1.03    | 2.14  | 1.10    | 2.00    |
| Mean (SD): 1.53(0.31)  | Mean (SD): 1.51(0.29) |
| 10°                    | 1.20    | 2.10  | 1.10    | 2.00    |
| Mean (SD): 1.59(0.30)  | Mean (SD): 1.54(0.27) |
| 20°                    | 1.11    | 2.20  | 1.10    | 2.13    |
| Mean (SD): 1.54(0.31)  | Mean (SD): 1.58(0.32) |
| 30°                    | 1.12    | 2.10  | 1.00    | 2.00    |
| Mean (SD): 1.52(0.28)  | Mean (SD): 1.54(0.30) |

During the trails, the cutting blade moved along with the vertical ram of the UTM (at the rate of 1.5 mm/min) pierced the specimen center and cut the specimen peduncle into two halves.

Fig. 3. Blade profile measured using Scanning Electron Microscope (SEM)

Fig. 4. (a) 3d printed fixtures (b). Experimental setup of studying cutting forces and its variation with change in angle of cut

III. RESULTS AND DISCUSSION

A. Gripping Force Limit

During the experimental trials, all tested specimens showed a common force profile under compression load which is shown in the Fig. 5. While applying compression load (by the extending UTM ram) to the specimen, there was a gradual increase in the resistive force to a certain point, from then it showed a sudden drop. After then, the specimen got squeezed completely on further application of compression load. It has been noticed that, after the drop in the resistive force, the specimen went to permanent deformation before getting completely squeezed. The peak force before the drop (F_C), is considered as the point of interest and is recorded for all specimens against their respective diameter (Fig. 6). The trend of this force (F_C) can be studied to limit the gripping force on the peduncle such that there is a lesser chance of squeezing the peduncle during the gripping action.
Fig. 5. Force profile recorded for the specimens while applying compression load by the extending UTM ram. The final squeezing force is not presented here as the peak force ($F_C$) before sudden drop is the point of interest.

Fig. 6. Variation of $F_C$ with respect to the specimen diameter

Fig. 7. Frequency distribution of $F_C$ measured for all specimens

Considering the peak forces ($F_C$), presented in the Fig. 6, we can determine that the lowest of these peak forces recorded is about 26.83 N and 22.53 N for Katrina and Zara respectively. This means that after these lowest values of peak compression force ($F_C$, analogous to gripping force), the respective test specimen went into permanent deformation before squeezing. Hence if we allocate a factor of safety of 2 to the lowest of these two values of forces (26.83 N and 22.53 N), the gripping force should be limited to around 10 N. Assuming that for a two-jaw parallel gripper, if we use a soft material lining on the gripping surface with a coefficient of friction of 0.3, then under static condition (see equation 1, $a = 0 \text{ m/s}^2$), the end effector will be able to handle a mass of 300 grams. Assuming that the mass of the strawberry to be gripped in the end effector is about 50 grams and keeping other parameters the same, under dynamic conditions, the end effector would be able to handle this 50-gram strawberry for a manipulator acceleration of up to $50 \text{ m/s}^2$.

\[ F_g = \frac{m \cdot (g + a) \cdot S}{\mu} \] (1)

where; $F_g$ is the net gripping force (N), 'm' is the mass to be handled (Kg), 'g' is the acceleration due to gravity (m/s$^2$), 'µ' is the co-efficient of friction, and 'S' is factor of safety[12].

This computed load carrying capability at 10 N is more than enough for an end effector to handle a ripe strawberry in static and dynamic conditions of a harvesting cycle. It is to be noted that, in dynamic conditions, for the same gripping force, the loading capacity can be increased by regulating the manipulator acceleration.

The frequency distribution of the peak forces ($F_C$) of the tested specimens is shown in Fig. 7. The majority of the forces ($F_C$) fall in the range of 31.00 N to 40.99 N for both the varieties, when the diameter of the specimens shares a close mean of 1.75 mm and 1.76 mm (with a standard deviation of 0.24 and 0.25) for Katrina and Zara respectively. Since the computed compression/gripping force limit (10 N) is well below this range, it can be concluded that 10 N would be a safe force that can be applied to the peduncle for an effective gripping.

B. Cutting Force

While analysing the force values recorded during the cutting trials, again a common force profile has been noticed for all the tested specimens. A sample force profile is shown in the Fig. 8. In the profile, there is an increase in force value during the cutting action but with two sudden drops after two force peaks ($F_{P1}$ and $F_{P2}$). After the second peak force, there is a flat profile and followed by a sharp rise in force after a point (E). This sharp increase happens when the blade touches the peduncle support after cutting the peduncle off. So from the force profile for each specimen, the maximum of the two peak forces ($F_{P1}$ or $F_{P2}$) is taken as the peak cutting force ($F_P$) required for that specimen. The peak cutting forces ($F_P$) recorded for all specimens against their diameter and at different orientations are shown in the Fig. 9 and 10.

From the force values recorded at different cutting orientations, it has been noticed that the mean cutting force shows a relative lowest value at $30^\circ$ orientation compared to other studied orientations. These mean cutting force values ($F_{PM}$) with respect to the mean diameter ($D_M$) of the tested specimens at different orientations are presented in table II. Also, it is seen that at $10^\circ$ orientation, the mean cutting force ($F_{PM}$) shows a slight higher value. These variations are found to be true for both the strawberry varieties studied.
At 30° cutting orientation, the maximum of the peak cutting force ($F_p$) recorded is about 7.20 N for Katrina, and 5.80 N for Zara. And hence, with a factor of safety 2, the cutting force requirement can be approximated to 15 N which could be considered sufficient to cut the strawberry peduncle at 30° orientation. Also, this force would be sufficient to handle other
cutting orientations studied. It is to be noted that this cutting force is measured at a blade speed of 1.5 mm/min, so at higher blade speed, the required force will be lesser than 15 N.

### References

1. Saeed Aliasgarian et al. “Mechanical damage of strawberry during harvest and postharvest operations”. In: World Applied Sciences Journal 22.7 (2013), pp. 969–974.

2. Seiichi Arima, Naoshi Kondo, and Mitsuji Monta. “Strawberry harvesting robot on table-top culture”. In: 2004 ASAE Annual Meeting. American Society of Agricultural and Biological Engineers. 2004, p. 1.

3. Y Cui et al. “Study on cartesian-type strawberry harvesting robot”. In: Sensors Letters 11.6–7 (2013), pp. 1223–1228.

4. Andreas De Preter, Jan Anthonis, and Josse De Baerdemaecker. “Development of a robot for harvesting strawberries”. In: IFAC-PapersOnLine 51.17 (2018), pp. 14–19.

5. Sinem Gozde Defterli et al. “Review of robotic technology for strawberry production”. In: Applied Engineering in Agriculture 32.3 (2016), pp. 301–318.

6. Fotios Dimeas et al. “Towards designing a robot gripper for efficient strawberry harvesting”. In: Proceedings of 22nd International Workshop on Robotics in AlpeAdria-Danube Region–RAAD, Portoroz, Slovenia. 2013, pp. 220–226.

7. Qingchun Feng et al. “New strawberry harvesting robot for elevated-trough culture”. In: International Journal of Agricultural and Biological Engineering 5.2 (2012), pp. 1–8.

8. Kil-Su Han et al. “Strawberry harvesting robot for bench-type cultivation”. In: Journal of BioSystems Engineering 37.1 (2012), pp. 65–74.

9. Shigehiko Hayashi et al. “Evaluation of a strawberry harvesting robot in a field test”. In: Biosystems engineering 105.2 (2010), pp. 160–171.

10. Shigehiko Hayashi et al. “Field operation of a movable strawberry-harvesting robot using a travel platform”. In: Japan Agricultural Research Quarterly: JARQ 48.3 (2014), pp. 307–316.

11. Naoshi Kondo, Mitsuji Monta, and Seiichi Arima. “Strawberry harvesting robot on hydroponic system”. In: IFAC Proceedings Volumes 31.5 (1998), pp. 181–185.

12. Intelligent Peripherals for Robots. "Calculation of Gripping Force". In: https://en.iprworldwide.com/calculation-of-grippingforce/ ([Accessed 20.05.2022]).

13. Ya Xiong, Pal Johan From, and Volkan Isler. "Design and evaluation of a novel cable-driven gripper with perception capabilities for strawberry picking robots". In: 2018 IEEE International Conference on Robotics and Automation (ICRA). IEEE. 2018, pp. 7384–7391.

14. Ya Xiong, Yuanyue Ge, and Pal Johan From. “An obstacle separation method for robotic picking of fruits in clusters”. In: Computers and Electronics in Agriculture 175 (2020), p. 105397.

15. Ya Xiong et al. “Development and field evaluation of a strawberry harvesting robot with a cable-driven gripper”. In: Computers and electronics in agriculture 157 (2019), pp. 392–402.

16. Satoshi Yamamoto et al. “Development of a stationary robotic strawberry harvester with a picking mechanism that approaches the target fruit from below”. In: Japan Agricultural Research Quarterly: JARQ 48.3 (2014), pp. 261–269.