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DESIGN AND FABRICATION OF A GRIPPER PROPOTYPE FOR A FRUIT HARVESTING MACHINE

Tung TT[1], Quynh NX[2] and TV Minh[2*]

Tran Vu Minh

*Corresponding author email: minh.tranvu@hust.edu.vn

[1]Faculty of Engineering Mechanics and Automation, University of Engineering and Technology, Vietnam National University, Hanoi, Vietnam

[2]School of Mechanical Engineering, Ha Noi University of Science and Technology, Ha Noi, Vietnam

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ABSTRACT

In Vietnam, post-harvest losses of fruits and vegetables are very high. According to analysis reports, Vietnam must invest more in harvesting and post-harvest technologies to enhance the global competitiveness of agricultural products, including fruits and vegetables. Fruit harvesting machines are an effective solution to enhance the quality of agricultural products, including fruits and vegetables. The gripper can be considered the most important component of a harvesting machine when it comes to horticulture products, since it acts as interface between the robotic system and product. To pick up fruits, which frequently have complex shapes and poor mechanical properties, a gripper must be designed carefully. In addition to being able to pick the produce, it is crucial that a gripper does not damage the fruit during harvest. The weak force may cause the gripper to be unable to pick the fruit. If excessive force is applied or improper picking technique is used, the grippers could damage fruits. However, Vietnam has not widely adopted the use of automatic machine in agriculture. This is due to the uniqueness of fruits in each region; for example, fruits in Vietnam have their own shape and mechanical properties. Therefore, it is occasionally inappropriate to utilize harvesters that have already been imported. This paper shows the development and fabrication of a gripper for common Vietnam fruit grasping. A new prototype has been fabricated by 3D printing method and tested in the laboratory. The prototype of a gripper has been subjected to simulation and experimental testing with real fruits to verify that the proposed model is capable of meeting all objectives' requirements. The proposed gripper was straightforward and efficient. The developed device exhibited dependability and stability and is suitable for farmers who require independent harvesting. In addition, the designed gripper can be produced at a lower cost than comparable machines developed by other commercial products.

Key words: Harvesting machine, gripper, Solidwork, prototype, 3D printing, low-cost production

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INTRODUCTION

Fruit is one of Vietnam's most important export products, but harvesting and post-harvest processing have encountered many challenges in recent years due to a severe labor shortage caused by rapid urbanization and the impact of the Covid pandemic [1-3]. In Vietnam, post-harvest losses of fruits and vegetables are very high. Fruit post-harvest losses in Vietnam are estimated at 20% to 25% [4]. Manual harvesting is monotonous work, this causes workers to have to perform the same actions over and over again for a long time. The boredom and monotony of work will make workers feel tired, stressed and reduce work efficiency.

Many manufacturing industries today use robots for a number of different works. According to analysis reports, Vietnam must invest more in harvesting and post-harvest technologies to enhance the global competitiveness of agricultural products, including fruits and vegetables [5-7]. Many research have proposed automated machine designs to increase the efficiency of fruit harvesting [8-17]. However, many obstacles remain in the way of fruit harvesting by machine [18-24]. The gripper is a significant factor limiting the efficiency of the application of automation in harvesting technology [25-28]. The gripper is the most crucial component of the machine, as it is the component that comes into direct contact with the product. To pick up fruits, which frequently have complex shapes and poor mechanical properties, pickers must be designed appropriately [29-34]. In addition to being able to handle the produce, it is crucial that the mechanism must not damage the fruit during harvest. When excessive force is applied or improper picking technique is used, grippers can damage fruit [34-38]. Numerous studies on the design and manufacture of gripper have been proposed and proven effective for handling agricultural products around the globe [39-42]. However, Vietnam has not widely adopted the use of automatic machinery in agriculture. This is due to the uniqueness of fruits in each region; for example, fruits in Vietnam have their own shape and mechanical properties. Therefore, it is imperative to design and manufacture a separate set of fruit-specific gripper for Vietnam.

This research focused on reducing the harvesting cost and time for labor with minimal fruit damage by using automation technology. To achieve this purpose, a gripper was examined by calculating and analyzing the grasping force required to remove some fruit from the tree.

This paper presents the development of a gripper that can be applied to automatic machines to handle the harvesting and post-harvest tasks of common fruits commonly grown in Vietnam. The focus of this paper is on the conceptual design and fabrication of a fruit-picking gripper. The first part of the report looks at some of the special challenges posed by robotic fruit harvesting and presents the design goals for this system. Then, after describing the mechanical design of the robot controller, the conceptual design and kinematic analysis of the end effect device was presented by using Solidwork sofware. Finally, the product to complete the analysis, design, optimization and testing of the system is outlined.

DESIGN OBJECTIVES REQUIREMENTS

Natural fruit products are often variable in size and shape, making them very difficult to pick by automated machines. It is very difficult for an end-efforts devices to compare with human workers in terms of flexibility in harvesting fruits. A human worker can easily pick the most fruits from a tree with many complex action quickly with no problem .

In the simplest definition, the gripper is a mechanical mechanism end-effector of a harvesting machine that supports holding the product, designed based on the effect of a human hand. A gripper can hold and release objects when receiving signals from the processor. This is the main obstacle to designing the efficiency of grippers, since a gripper should be able to carefully grasp and hold fruits. This can lead to low-cost production and to decrease the time of harvest. There are many different types of grips available on the market, each has its own advantages and disadvantages. It is difficult to conclude which is the best. Possible end-efforts solutions can be examined through general considerations among the following structures:

- ✓ Grippers, which consist of many rigid fingers and a mechanism to move them pick the fruit. The gripper has the advantage of being easy to control due to its few degrees of freedom (usually no more than 3), but the disadvantage is its poor flexibility.
- ✓ Artificial human hand which consists of multiple fingers similar to a human hand. This gripper has the advantage of being extremely flexible and can grasp almost any shapes, but this kind of design makes the control process more difficult, in terms of costs, time and money.
- ✓ Other end-effectors are using compressed air and vacuum suction. These devices are relatively flexible and can be used for many types of object shapes. However, these are relatively expensive devices, difficult to control and force control. Sometimes they are not suitable for fruits with poor mechanical properties such as tomatoes, tangerines etcetera.

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Most of the fruits harvested in Vietnam such as oranges, tomatoes, plums, apples can be approximated as spherical in shape. Therefore, the gripper is considered a suitable design, both ensuring the ability to hold, easy to control and also an inexpensive solution as shown in Figure 1.

Because the gripper comes into direct contact with the fruit, the gripper is the most important component of the automated fruit harvesting machine. In order to create an effective gripper, it is necessary to first analyze the processing of the object it is intended to grasp, in this case the fruit, including its sizes and mechanical properties.

a) b) c)

Figure 1: A gripper versus real hand: a) Model design in Solidwork software, b) gripper holding ability, c) real hand

In order to design a gripper for a harvesting machine, fruits analysis was required. This article describes development of a gripper for popular Vietnamese fruits such as apples, pomelo, oranges and guava. In general, oranges have the worst mechanical properties of the above fruits. In this study, oranges were selected to design the gripper. The shape of oranges in Vietnam is almost spherical. Some previous studies show that the average size of oranges in Vietnam is usually between 50 and 140 mm with an average fruit weight of 150–250 g [41-43]. The limit stress for orange fruits under axial and radial compression is as shown in Table 1. The limit yield strength of orange fruit is recommended as 0.03 Mpa based on the distortion energy theory and is 0.01 Mpa based on the maximum shear stress theory [43].

The basic functional requirements of a fruit harvester are to reach the fruit, then separate the fruit produced from the tree. In addition to being efficient, productive and economically viable, it is important that the system does not damage the picked fruit, damage adjacent fruit or damage the tree branches. For example, grippers can damage fruit by applying too much force during picking or using improper picking techniques.

After evaluating those aspects, Matteo Russo *et al.* [43] proposed a 1-DoF gripper with compliant fingers which was selected as a suitable design for the grasp of horticulture products.

As depicted in Figure 2, a gripper typically consists of two or more rigid fingers and a mechanism for moving them to grasp an object. One to three degrees of freedom are typical for a clamp. Despite its low flexibility, this type of gripper has the advantage of being easy to control and fabricate.

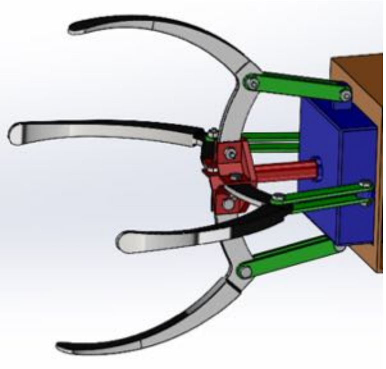


Figure 2: Gripper grasping fruit

GRIPPER DESIGN

The choice of a clamp mainly depends on the task it could do. Each clamping task is characterized by the following elements and requirements:

- Technological requirements: ease of fabrication, maintenance and replacement.
- Requirements for making gripper: including volume, design, size and durability.

The relationships between the gripper and the object can be summarized as in Table 2.

The proposed solution is a four-finger gripper based on the handwheel slider mechanism, as shown in Figure 3. The gripper is shaped like a picker with four fingers. The mechanism consists of a single joint that moves up and down to create the effect of the fingers opening and closing to grasp the fruit. This opening-closing motion is created by a lead screw-sliding nut system. The lead screw attached to the stepper motor can be rotated to generate forward-counterclockwise rotation, and the fingers are connected to the slide nut mounted on the slide (up and down movement along the lead screw) by tie rod. There is also an additional stepper motor on the arm that creates a staggered 360^0 degree left and right rotation for the hand to detach the fruit from the stalk, as well as staggered left and right movement to prevent the device wires mounted on the motor from becoming twisted or broken when the handle rotates excessively to one side.

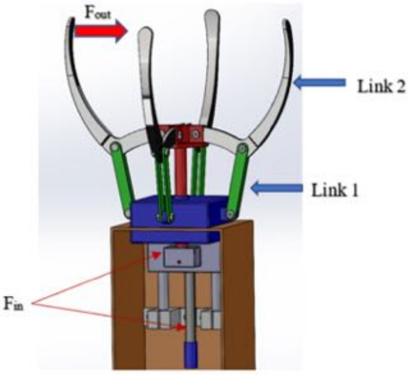


Figure 3: The proposed gripper solution

Mechanical advance (MA) was used as design criterion, since it is a compact expression to evaluate the performance of a gripper mechanism. The MA is expressed by as:

Mechanical Advance = Fout / Fin

Where Fout is the grasping force, Fin the force from the actuator. Of course, if the input force remains constant, the larger the MA, the more efficient the machine. The dimension of link 2 is constrained by the dimension of the product since it must be more than half the maximum diameter of the grasped object.

The selection of materials for the designs is contingent on the system's operating conditions. The design of the fruit grabber prioritizes the gripper's lightness in order to maintain the system's equilibrium.

Due to the fact that the gripper is responsible for collecting fruit and the operating environment is primarily outdoors, it is necessary to use anti-rust and anti-corrosion materials. In order to satisfy the aforementioned specifications, the fruit collecting machine will be constructed from PLA (Polylactic Acid) plastic and 3D printing technology as shown in Figure 4.

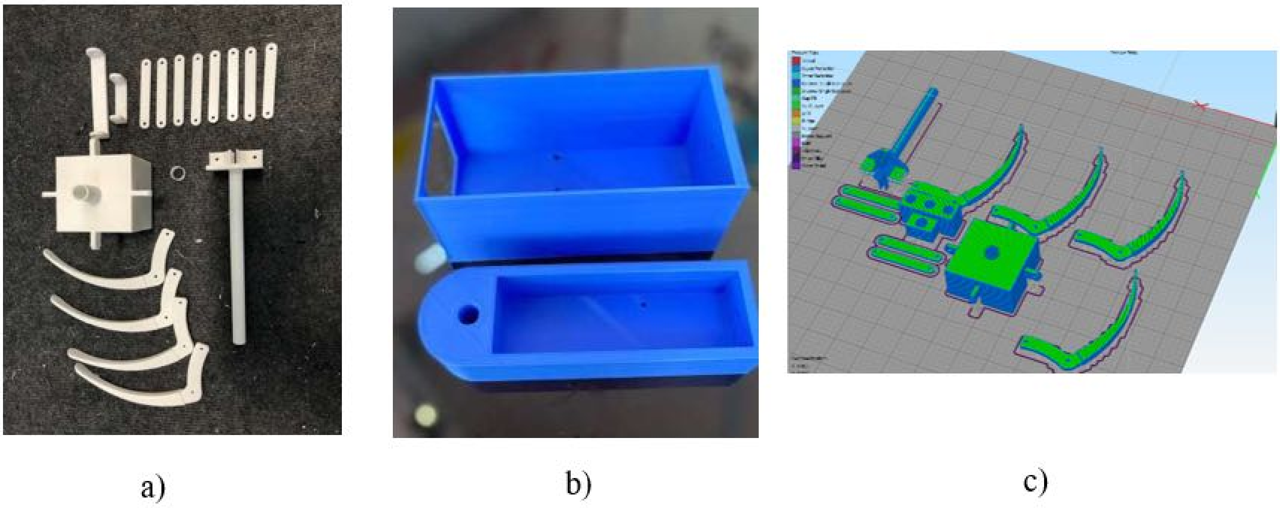

a) b) c)

Figure 4: 3D print parts: a) finger parts, b) holder parts, c) 3D print processing simulations

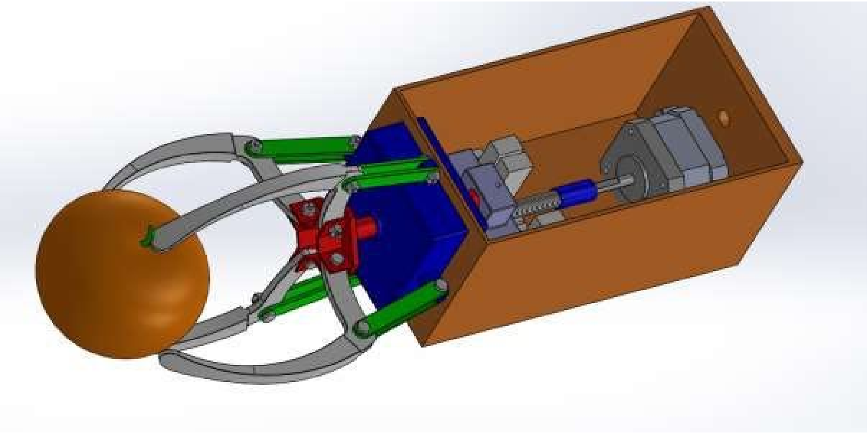


Figure 5: Simulation of the gripper in working state

Because the gripper is designed with four fingers evenly distributed on the fruit, the forces acting on the fruit will be symmetrical as shown in Figure 5. The grasping force is the force exerted on the fruit by the fingers clamping around it. This force must be just sufficient to not only hold the fruit, but also prevent surface deformation. Therefore, understanding the effects of gripping force is essential for assisting gripper development in reducing harvest damage.

The grasping force is the force exerted by the clamping fingers on the fruit. This force can be different depending on air pressure, coefficient of friction. To ensure that the fruit does not fall when clamped, the clamping force is calculated as follows:

$$F \geq W + F_{ms}$$

In which:
F: The grasping force
W: Weight of fruit
F_{ms}: Friction force between gripper and fruit

The grasping force applied to fruits by each finger was measured using Finite element method on Solidwork software.

RESULTS AND DISCUSSION

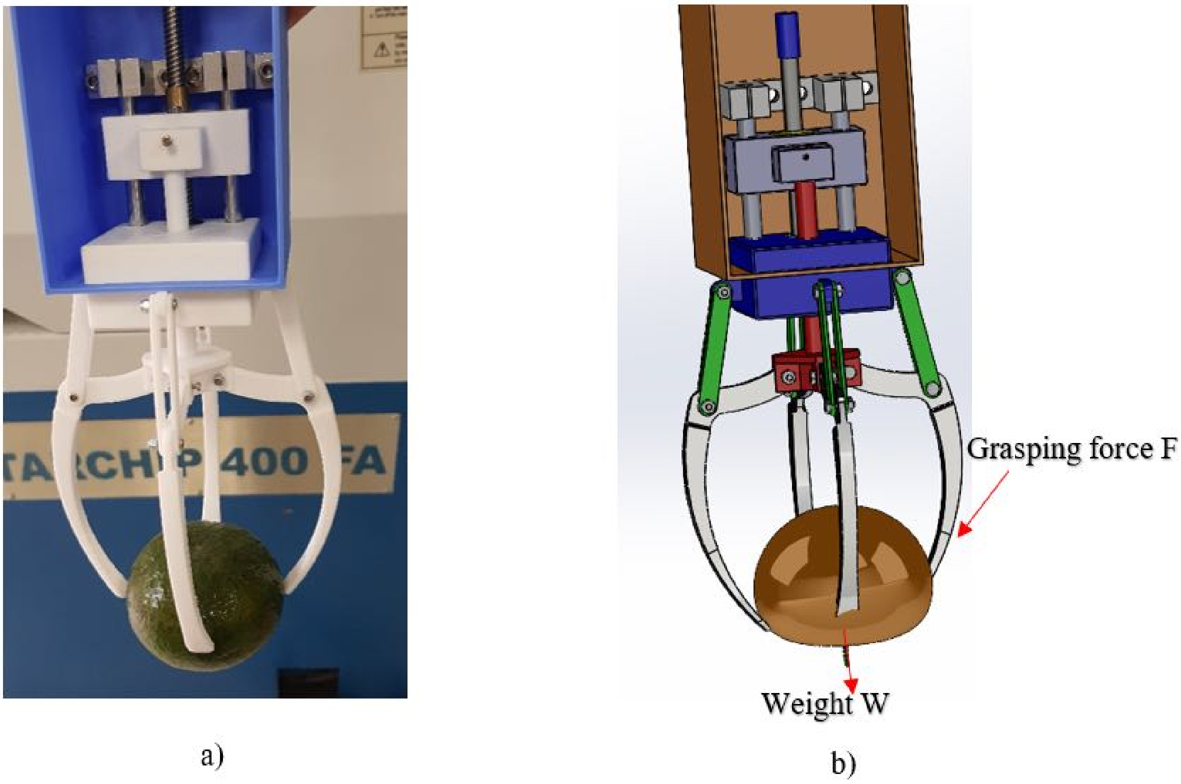
A prototype gripper was fabricated by using 3D printing technology at Faculty of Engineering Mechanics and Automation workshop, University of Engineering and Technology, Vietnam National University, Hanoi, as shown in Figure 6. Printing parameters were set on Cura software: print layer height was 0.2 mm, printing temperature 200 degrees with Fused Deposition Modeling (FDM)technology.

Figure 6: 3D printing machine

The designed gripper was created with Solidwork software. The material that was used was plastic. The prototype was shown in Figure 7. The gripper was produced by 3D printing with a plastic material weighing approximately 0.8 kg. The grip has a maximum opening of approximately 150 mm and a minimum opening of 15 mm, allowing it to be used with a variety of fruits, including apples, oranges, tomatoes, papayas, strawberries and lemons. With the speed of the motor as 40 rev/ min, the handgrip can complete one cycle of opening and closing in six seconds, allowing to calculate the productivity of the gripper, which can collect approximately eight fruits per minute. With the enlarged design at the end of the fingers, the handle functions as a container, allowing the harvester to collect multiple fruits with a single pick, thereby saving time and increasing productivity for equipment.


a) b)

Figure 7: The Gripper in action, a) maximum and b) minimum opening



a) b)

Figure 8: Testing for static grasping force, a) Product test, b) simulation in Solidwork

Tests were carried out in the laboratory, with handles holding the most common orange in Vietnam, as shown in Figure 8. Grasping was repeated many times. The grasping tests motion were performed similar to picking motion by hand in the harvest. As the results, the prototype model could achieve the maximum velocity of 1.5 m/s, the grip force is 2.5 N and contact time is 5s. The results show that the gripper did not damage and could hold the orange. The experimental results are shown in Table 3.
During the next test, each orange was lifted from its original position, transported with different movement directions such as up, down and sideways at the speed of 0.6 m/s in order to check the firm of the gripper during motion. In all tests, the orange was in the grip and did not fall. As observed in many tests, the gripper did not only damage the oranges, but also did not allow relative movement between the oranges and the fingers.

Then, similar to the manual picking sequence, the manipulator rotates the fruit 90^{o} degrees and exerts a downward force to remove the fruit from the tree. If the product is correctly recognized by the vision system, the gripping is usually successful. Moreover, it is challenging to design a universal clamp that works effectively for a variety of fruits. In this study, lemon and orange were the preferred products for the design of the gripper. The results of planned experimental tests to determine the dynamic forces that occur during manual fruit harvesting will be used to develop a control scheme that ensures that applied forces will not damage the harvested fruit. After completing fabrication, the gripper will be optimized in preparation for full-scale laboratory and field tests with the complete system. However, the speed of the proposed gripper was still less than that of human harvesting due to the flexible skills of human hand being very hard to mimic by any modern gripper structure. The main advantage of the gripper was its simplicity in structure, low cost and the grasping force is calculated quite accurately, greatly reducing the risk of crushing the fruit. Furthermore, it is important to evaluate suitable dimensions of the gripper to harvest, as even a universal gripper has a limited range. In this research orange and lemons have been the targeted products.

The parameters used to compare the proposed gripper to two commercially available products from Hiwonder and Devooka hand gripper on Amazon are listed in Table 4. Due to its simple structure and design, the production cost of this gripper is lower than that of comparable products, and it is easy to fabricate and maintain. However, the proposed gripper's operational performance is not inferior to that of existing products.

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

This research aimed at investigating the harvest of fruits under different picking methods, focused on understanding those processes using a few key picking parameters. It also aimed at identifying an effective end-effector picking method using a four-finger gripper. In this paper, a new gripper for Vietnam fruit was proposed as the result of a specific design and fabrication procedure that takes into account the requirements and peculiarities of fruit product grasping. The 3D gripper model was developed from Solidwork software and manufactured from 3D printing technology. The prototype has been subjected to simulation and experimental testing in multiple pick-and-place operations to demonstrate that the proposed gripper is capable of meeting all task requirements. The study's proposed gripper can not only pick up popular fruit products in Vietnam without damaging them, but it can also hold them, thereby contributing to increased productivity and economic efficiency. The proposed gripper is expected to be assembled on an auto-mobile robot in the next research.

Table 1: The limit stress for orange fruits

Variables	Elastic limit force (N)	Elastic modulus (Mpa)	Poisson's ratio	Bioyield stress (Mpa)
Axial compressior	18	0.691	0.367	0.009
Radial Loading	15.69	0.645	0.123	0.01

Table 2: Gripper design requirements

Objectives	Calculate
Ease of fabrication, maintenance, and replacement	Fabrication method
Shape of fruits	Gripper finger surface
Fruit size	Grasp range
Weight of fruits	Clamping Force

Table 3: Experimental results

Parameters	Value
Grip velocity	0.6 - 1,5(m/s)
Grip force	2.5 N
Contact time	5s

Table 4: Comparison to industrial models

Model	Grasp range (mm) Min-Max	Price(USD)
Proposed model	15-150	20
Black metal claw- B088NYMC1B	38-125	32.99
Deevoka 3D Printing Robotic Arm	10-75	23

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