A Soft Pneumatic Finger with Different Patterned Profile

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***Abstract*— Recently, the soft gripper is widely used for packaging food in industrial, because it can grip both the soft and hard material objects without deforming them by controlling the air pressure in the soft fingers. In this study, we presented two different patterned profiles of pneumatic soft fingers. These patterned profiles were experimented to grip objects in three cases: three-; and four-soft finger gripper. These soft actuators were experimentally tested by picking and placing objects with different weights, shapes, and sizes. The material of the soft actuator is platinum silicone rubber. The casting process was used to create two molds that were fabricated by 3D - printing technology. The molds consist of two parts (a soft chamber and a cover). The soft chamber was connected with the cover by gluing on it. The results showed that the prestressed gripper could stably handle many different types of food and still remain compact with a simple controller and different patterned profiles.**

***Index Terms*— Soft finger hand, soft actuator, pneumatic soft gripper, patterned profile**

I. Introduction

Robots can be programmed to do the same task a million times with minimal error, some are difficult for people. In industrial, a robot arm with rigid links is used to pick something up, but it has to know exactly the position of an object, calculate the path with a lot of numerical computation, and grasp that with enough force. In recent years, Pneumatically actuated soft grippers have paid a great attention to researchers because they are flexible and adaptable.

The soft finger was fabricated following the traditional casting process. Casting molds were fabricated by 3D printing technology [1]. A smaller interval between neighboring chambers yields easier bending deformation during inflation. However, it also limits the reverse bending deformation [2]. According to [3], by using three fingers, they can also lift the container with some effort and the container was deformed more significantly compared with five-finger grasping. Based on their experiences, it was not always possible to pick up the container with only two fingers. Then they designed a three-finger gripper with easy assembly and replacement. In [4], a rigid connector for easy assembly, a rigid stretcher for stretching the chambers, and a cover to seal the chambers. The chamber part was stretched to the same length as the cover and then glued to the cover.

Gripping by actuation consists of bending gripper fingers or elements around the object, as we do with our fingers when picking up an egg or glass of water. The bending shape can be actively controlled, or one can exploit contact with the object to induce deformation [5]. In [1], A perpendicular configuration, in which the neighboring fingers are perpendicular to each other, is designed to grasp circular and square targets. In contrast, a parallel configuration is suitable for handling elongated targets because the neighboring fingers are parallel to each other. When the human hand grasps an object, it forms enveloping grasping for the shape and dimension of an object at first, and then power grasps. It is noteworthy that the hand pose is invariable in power grasping process, that is to say the object size determines the hand operation pose [6]. To recognize the object distance, tri-mode sensor that performs distance measurement, motion tracking, and profile recognition [7].

In this study, we introduce the casting process for the soft finger fabricated by 3 – D printing technology to make the molds for a air chamber and a cover, design the two patterned profile, how to measure and control the grasping force and the bending angle of the silicone soft finger, and conduct an experiment to lift objects, then we compare the three – finger soft gripper to four – finger soft gripper that were used the new pattern profile.

II. Design Patterned Profiles and Fabrication

A. Design Patterned Profiles

This soft finger hand design and fabrication we have creative ideas and manipulations from researching, comparison of different soft grippers for lunch box packaging. Still based on the principle of supplying compressed air to pre-stressed soft fingers, but we do not use the 3D printing method because a finger could leak. After all, the 3D printed layer bonds may not guarantee finger airtightness. So we came up with a method to design molds with Anycubic i3 Mega 3D printer (Anycubic), then pour in liquid silicone Platinum so that they solidify. Finally, the soft fingers are not deflated and still meet the following specifications. The first, soft fingers can handle almost any material with profiles:

Manuscript received November 14, 2020; revised March 1, 2021.

doi: 10.18178/ijmerr.10.10.577-582

circle, square, rectangle, triangle, and many more complex shapes that we are going to show. The second, these fingers can work in high-temperature environments while maintaining the design of the finger, and the fingers have a tight grip on complex objects when picking them up.

The design and dimensions of the soft figure is shown in Fig. 1. The soft finger profile measures 102 mm x 22 mm x 15 mm (L x W x H) without the suction pad, which is slightly smaller than a human finger. The finger consists of four parts (Fig. 1(a)): Air chamber, pneumatic supply, cover 1, cover 2. Fig. 1(d) and (e), the chamber section consists of twelve air chamber for easy inflation and deflation. A gas pipe with a diameter of 4 mm is designed by us to provide compressed air from the source to the gas chambers of the soft actuator for inflation and deflation.

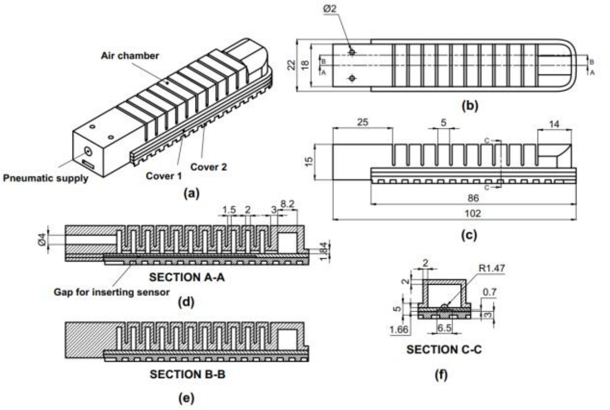


Figure 1. Design and dimensions of the soft finger: (a) an isometric view, (b) a top view, (c) a side view, (d) a section A–A, (e) a section B–B, and (f) a section C–C.

Among the twelve air chambers, eleven chambers have a wall thickness of 1.5 mm, and one larger chamber has a wall thickness of 3 mm. The thicker wall of the last chamber makes the FEA end stiffer than the rest part to mimic the function of a fingernail (Fig. 1(d)). A smaller interval between neighboring chambers yields easier bending deformation during inflation. However, it also limits the reverse bending deformation. To meet the third requirement, we set the interval to 1 mm (Fig.1(f)) a 0.7 mm deep groove designed to attach a curved sensor to measure the curvature of soft fingers when picking up food. Skewed slot structure was designed on the bottom surface of cover 2 to increase the grasping stability and mimic the human fingerprint. Besides, we designed an experimental comparison between skewed slots and ripples.

B. *Design of Connector and Base*

To connect the discrete soft fingers to form a complete grip structure, we have come up with two designs: the three-finger grip Fig. 2(a) and the four-finger grip Fig. 2(d). With the 4-finger construction, we use screws to fix the soft fingers to the grab structure to increase the firmness when picking up food, the advantage of this structure to handle shaped objects long and complex form.As for the 3-finger pick-up structure because of the 360-degree design nature to be able to pick up objects with a rounder and more diverse shape, it is impossible to use the screwing mechanism like the 4-finger type, it will lose the aesthetics and hardness. So we designed a connection between the finger and the structure grip Fig. 2 (b) will be made by 3D printing PLA plastic material, use the multi-purpose adhesive Deli (Deli, China) to stick between the soft finger part and connect the background without distorting the finger design. Finally, we get the complete gripping structures for the 3-fingers Fig. 2(c) and 4-finger grip structure Fig. 2(e) features two types of surface grip profiles for each structure, skewed slots, and ripples.

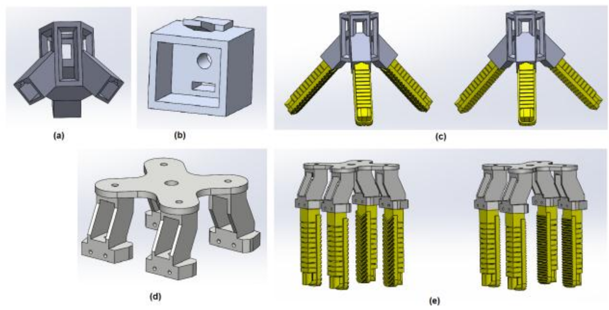
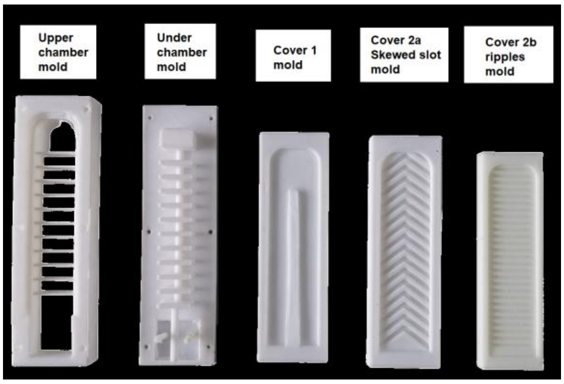


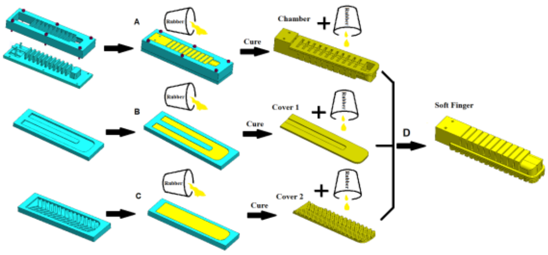
Figure 2. Design of connector and base: (a) 3-finger gripper structure, (b) connection base, (c) Assemble complete 3-finger grip structure, (d) 4-finger gripper structure, (e) Assemble complete 4-finger grip structure.

C. *Fabrication*

Soft actuators are made with die casting, a fairly popular method nowadays. Mold Fig. 3 (a) made by drawing the simulation design on software then 3D printing with Anycubic i3 Mega 3D printer (Anycubic, China), mold materials are PLA, which is self-biodegradable and is used to produce everyday items such as food packaging, trays, cups. So it is optimal when the finger design is used for folding food. The fabrication process consists of several consecutive steps, shown in Fig. 3 (b). First, we use a graduated cup to mix two liquid rubber solutions in the ratio of 1: 1 A, B (Silicone Platinum, Vietnam). Next to the gas bubble reduction stage divided into 2 times to remove. 1st time: after mixing the mixture, wait about 5 to 7 minutes for the bubbles to float and remove them manually or use the mixed liquid silicone was first degassed for two minutes at a method vacuum pressure of approximately −70 kPa. Then the liquid rubber mixture is poured into the molds: the gas chamber (step A) has been arranged and fixed with the screw, mold cover 1 (step B), mold cover 2 (step C). The mold containing liquid rubber should be degassed a second time by vacuum method to ensure that after removing the finished mold there are no air bubbles, even a third time can be removed if air bubbles are detected. After 6 to 8 hours, the mold was split to obtain separate semi-finished products. Finally, stick each part together with the same liquid rubber to get the complete soft finger (step D).

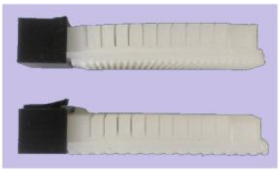


(a)



(b)

Figure 3. Fabrication Patterned Profiles: (a) 3D printed molds (b) soft finger fabrication summary.



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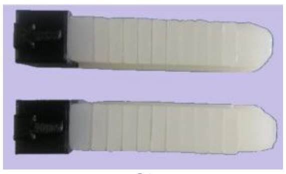

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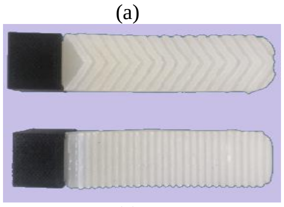
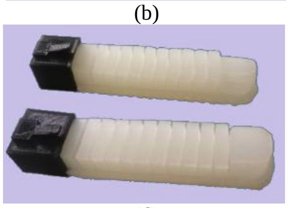


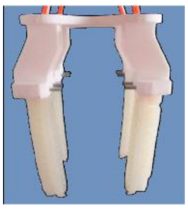
(c)



(d)

Figure 4. Realistic soft fingers: (a) a front view , (b) a top view, (c) a bottom view, (d) a isometric view

(a)



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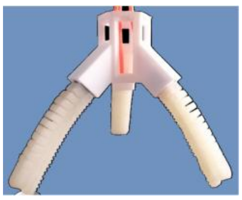


(c)

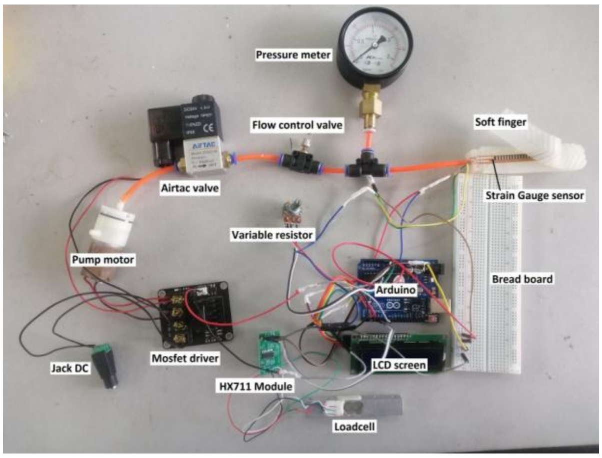
Figure 5. Assembled grippers: (a) Structure base (b) four-finger gripper structure (c) three-finger gripper structure.

Gripper assembly: From the above designs, the soft robotic fingers are obtained as shown in Fig. 4 and the complete gripper assembly Fig. 5.

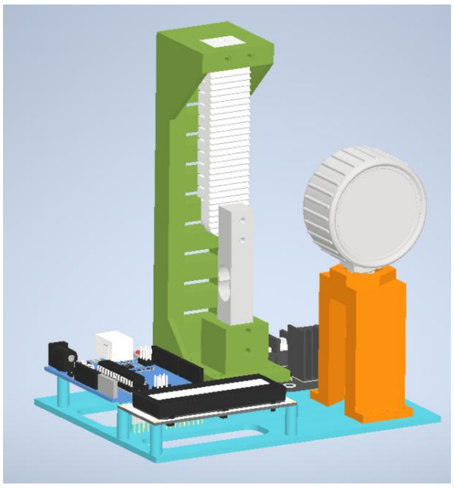
III. Experiments

A. Experiment Table

Experimental tests were performed to evaluate single finger bending, gripper lifting force, and grasping of various types of objects of three-finger and four-finger gripper. In this test, we focus on the lifting force of the soft gripper and compare the ability to grip some food with some different pressure values and figure out the pressure value that can deform the objects.



(a)



(b)

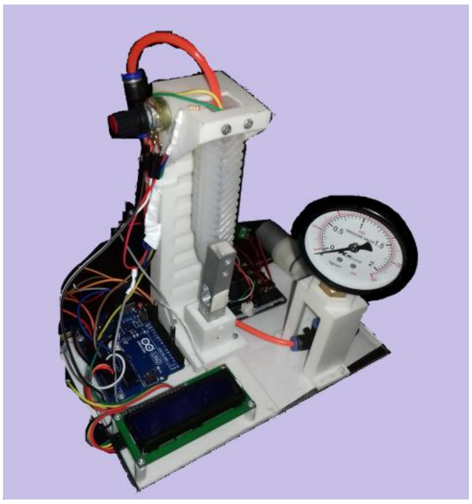
Figure 6. All components for the test (a), base for attaching all components 3D – design (b).

The components for this experiment were shown in Fig. 6 (a), which is the control system for the soft gripper. We design a base Fig. 6 (b) for the system and fabricated it by 3D – printing technology to attach all components to it. The flex sensor was inside the soft actuator to measure bending angle. The soft finger was attached to the base by two M3 screw. Firstly, we tested with the load cell sensor for getting the grasping force value, then we moved out the load cell sensor for measuring the bending angle.

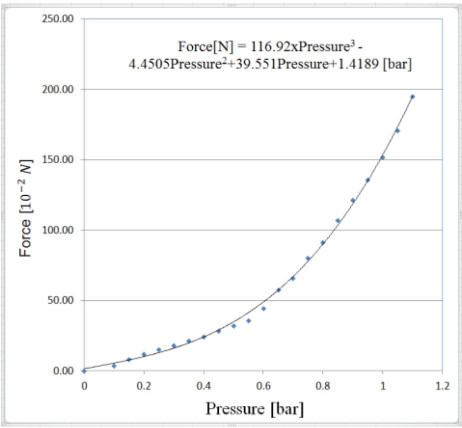
B. Results

1) Grasping force measurement

The experiments were performed by using the load cell sensor, pressure meter (KK GAUGES), and flow control valve were shown in Fig. 7(a). The Arduino board controlled all devices, it received the voltage signal of a variable resistor and transferred the pulse width modulation signal to the MOSFET driver (HA210N06) to control the pump motor pressure. The load cell was used to measure the grasping force of the soft finger with the corresponding pressure. We adjusted the flow control valve to achieve the desired pressure from 0,1 bar to 1,1 bar and the pressure was increased 0,05 bar each time, then we got the force value from the 16x02 LCD screen.



(a)



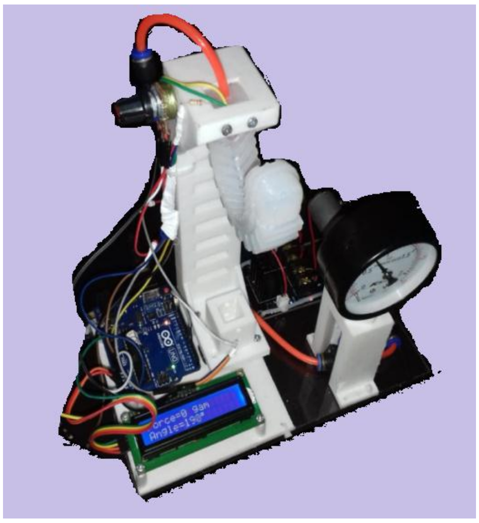
(b)

Figure 7. Experiment system for the measurement of the relationship between force and pressure (a), and the test result (b).

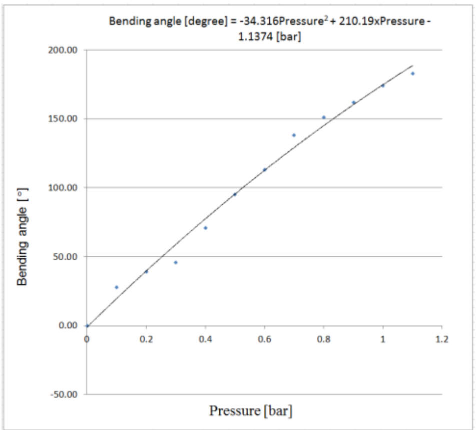
Those results experimented with ten times because all the values were nearly the same. Next, we got the mean value of those tests to have the final result Fig. 7(b). The result showed that the relationship between the pressure value and the grasping force is nearly linear from 0 to 0,55 bar and 0,85 to 1,1 bar. You can follow the equation and the line chart which were shown in Fig. 7 (b) to calculate the desired pressure for any purpose. We measured that at the 1,2 bar pressure, the soft actuator started to leak, when the pressure was about 1,5 bar, it was destroyed at the face of the cover and the chamber. Three soft fingers were tested and had the same result.

2) Bending angle measurement

The experiments were performed by using the flex sensor 2.2" and pressure meter (KK GAUGES) show in Fig. 8(a). The flex sensor was integrated inside the soft actuator and was on a patterned profile cover. The Arduino board read the analog signal output of the flex sensor, and it converted the analog signal to a digital signal. We adjusted the flow control valve to achieve the desired pressure from 0,1 bar to 1,1 bar and the pressure was increased 0,1 bar each time, then 16x02 LCD screen displayed the values of the bending angle. Those results Fig. 8(b) experimented with five times because all the values were nearly the same. Next, we got the average value of those tests to have the final result.



(a)

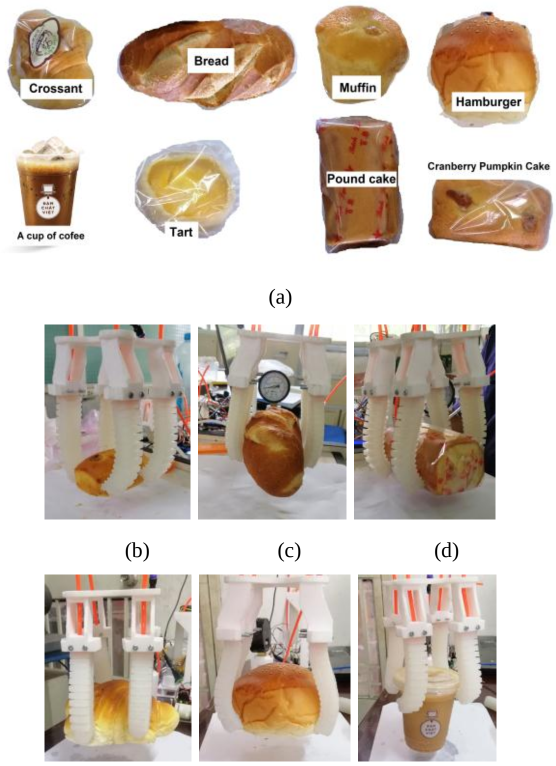


(b)

Figure 8. Experiment system for the measurement of the relationship between bending angle and pressure, Flex sensor wiring diagram (b), the test result (c).

3) Lifting force tests

Grasping tests of real food materials (Fig.9 and Fig.10) were carried out. Different sized and shaped objects were lifted (Fig 9). We conducted the test ten times for each target, and a 15s lift without dropping was considered a successful lift. The weights and approximate sizes of the whole targets are listed in Table I and Table III. Examples of successful lifting are shown in Fig. 10. Grasping and lifting food materials on their surface, and there were also no difficulties in lifting Cranberry Pumpkin Cake, bread, croissant, hamburger. However, picking up targets with heavy weight, such as a pound cake and a cup of coffee, had lower success rates compared with other targets. Increasing the input pressure could increase the success rate of picking up them but did not work with the performance of picking the thin or slim geometry objects (Tart) because the soft actuator can not stably handle that type of object. The different pressure values for the test are shown in Table II and Table IV.



(a)

(b) (c) (d)

(e) (f) (g)

Figure 9. Snapshots of grasping tests on four – finger gripper test: (a) Objects for the test, (b) Cranberry Pumpkin Cake, (c) bread, (d) pound cake in plastic, (e) croissant, (f) hamburger, (g) a cup of coffee.

(a) (b) (c)

Figure 10. Snapshots of grasping tests on three – finger gripper test: (a) Muffin, (b) a cup of coffee, (c) croissant.

TABLE I. TARGET WEIGHTS, SIZES FOR FOUR – FINGER TEST

Target	Weight [g]	Size (mm) L x W x H
Cranberry Pumpkin cake [A]	62	62×38×25
Bread [B]	3	125×56×40
Pound cake in plastic [C]	136	120×60×50
Croissant [D]	38	100×60×35
Sweet round bakery [E]	38	R80×H45
A cup of coffee [F]	361	R80×H120

TABLE II. THE REQUIRED AIR PRESSURES (P) FOR GRASPING TESTS. SYMBOL ‘‘×’’ INDICATES FAILED LIFT, ‘‘✓’’ INDICATES SUCCESSFUL LIFT, ‘‘Δ’’ INDICATES OBJECT DEFORMATION. THIS TABLE IS FOR FOUR – FINGER GRIPPER TEST

Target	0,3 bar	0,4 bar	0,5 bar	0,6 bar	0,7 bar	0,8 bar	0,9 bar
[A]	×	×	×	×	✓	✓	Δ
[B]	×	×	×	✓	✓	✓	✓
[C]	×	×	×	×	×	✓	✓
[D]	×	×	✓	✓	✓	Δ	
[E]	×	✓	✓	✓	Δ		
[F]	×	×	×	✓	✓	✓	✓

TABLE III. TARGET WEIGHTS, SIZES FOR THREE – FINGER TEST

Target	Weight [g]	Size (mm) L × W × H
Muffin [A]	30	R50×H40
Croissant [B]	38	100×60×35
A cup of coffee [C]	361	R80×H120
Tart [D]	40	R60×H18

TABLE IV. THE REQUIRED AIR PRESSURES (P) FOR GRASPING TESTS. SYMBOL ‘‘×’’ INDICATES FAILED LIFT, ‘‘✓’’ INDICATES SUCCESSFUL LIFT, ‘‘Δ’’ INDICATES OBJECT DEFORMATION. THIS TABLE IS FOR FOUR – FINGER GRIPPER TEST

Target	0,3 bar	0,4 bar	0,5 bar	0,6 bar	0,7 bar	0,8 bar	0,9 bar
[A]	×	×	✓	✓	✓	Δ	
[B]	×	×	×	✓	✓	✓	✓
[C]	×	×	×	✓	✓	✓	✓
[D]	×	×	×	×	×	×	×

IV. CONCLUSION

This study presented a soft gripper designed, modeling, and fabricated 3D printing of the mold. Soft actuator performance has been performed to evaluate single finger bending, gripper lifting force, grasping with different patterned profiles for improved surface grip and wide range of grip the type of geometry that keeps the foods from distorting or falling apart. These patterned profiles were tested to grip objects in three cases: three-; and four-soft finger gripper. The results showed that the gripper could stably handle different types of food and still remain compact with a simple controller and different patterned profiles. The design of the reptile profiles to increase the ability to grip and identify objects to automatically change the structure to suit the gripper object will be considered in the future.

CONFLICT OF INTEREST

The author declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Phuong H.Le instructed and conducted research, Thien P.Do did the experiment, analyzed the data, and wrote the paper, Du B.Le designed the soft finger and test experiment. All author had approved the final version

ACKNOWLEDGMENT

This research is funded by Vietnam National University HoChiMinh City (VNU-HCM) under grant number C2020-20-07.

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