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Bellow Soft Gripper for Agriculture

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ABSTRACT

The surge in population has led to an increment in demand for food and also evolve the development of technology for agriculture. The challenge in producing large quantities of fruits and vegetables is to ensure the appearance and the freshness durability of fruits and vegetables. Therefore, the purpose of the soft gripper is to help keep the appearance of fruits and vegetables without scratching and bruising during the plucking. Thus, this research proposing the development of Bellow shape soft gripper for agriculture application. The gripper consists of three-fingers and a base holder. The mould for soft gripper and the holder were printed using 3D printer and the Bellow gripper is made from silicone rubber. A flex sensor is embedded in the soft actuator to measure the bending angle performance for the gripper and the angle values will be displayed on LCD. Then, the relationship between the air pressure supplied to the actuator and bending angle produced by the gripper is discussed. From the experiment, it shows that the Bellow gripper could successfully grip and hold several types of fruits from 6.00 cm to 7.20 cm with the soft gripper perform the bending from 17 degrees to 23 degrees.

Key words : Bellow, flex sensor, soft actuator, soft gripper.

1. INTRODUCTION

Soft actuator is an emerging technology that have been explored for a wide range application. In recent years, the soft actuators have drawn great attention due to its characteristic such as high flexibility, simple structure, water resistance, high compliance and light weight [1]. Basically, the soft actuators are made by the highly stretchable elastomer materials or silicone rubber which give an advantage for the actuator to flexibly move compared to the conventional actuators such as electric motor, pneumatic and hydraulic actuators. Usually, the conventional actuators are heavy, rigid and have limited degree of freedoms, thus it offers advantages for the soft actuator in industrial application especially for robotic gripper. Various shapes of soft actuator designs have been invented to suit the application such as in mimicking flexible motion [2] and assisting human hand grasping for a stroke patient [3]. For Bellow shape soft actuator, several projects had been conducted such as flexible pneumatic actuator (FPA), flexible micro-actuator (FMA) and asymmetric flexible pneumatic actuators (AFPA). The AFPA was developed using asymmetric polymer or rubber tube with proper reinforcement [4]. The working principle of asymmetric Bellow actuator is similar as a straight asymmetric (eccentric) Bellow tube with circular or semi-circular cross section. Under the application of pressure, the Bellow soft actuator will become curved and elliptic in cross section.

Difference shape and size of Bellow type soft actuator may cause from difference requirement performance in bending of soft actuator and the ability of them in some applications. In previous research, the single and dual chamber Bellow structures soft actuator was designed [5]. The shape of both bellow structures soft actuators was designed in a circular. In a single chamber structure, one-half of the body part was design in Bellow share whereas another side of the actuator was designed in a semicircle. Furthermore, the research of miniature pneumatic curling rubber pneumatic actuator had been conducted by Wakimoto *et al.* [6], [7] using Bellow type actuator. In their studies, the nonlinear finite element analysis is used to resolve the optimum design in which the actuator is able to generate a maximum curling motion. The different parameters such as the thickness of the flat plate side and the half bellow side were set to be similar and the thickness of the actuator, the outer layer to flat surface size and air gap inside bellow chamber were manipulated. The material used to fabricate the soft actuator is using Room Temperature Vulcanizing (RTV) type of silicone (KE-1603-A and KE-1603-B made by Shin Etsu Silicones Corp). The model with the thickness, T = 150µm, distance between outer layer Bellow to flat surface, A = 700µm and air gap, B = 550µm had been chosen as the best design which could produce the largest bending performance.

In designing the base for gripper palm, some researchers use three female interfaces distributed circularly and embedded the soft actuator in each interface as the robotic fingers [8]. Other practical technique to be used as attach-detach between the base and the soft fingers is a snap-lock design because it can prevent the soft actuator flop from the base during grasping. After assemble the soft fingers with the base, a robotic gripper with three-fingers was completed. Other researchers present a soft robotic gripper module with 3D printer compliant fingers for grasping fruits [9], [10]. In their study, the soft robotic gripper was developed to resolve the problem in automation industry for grasping the fragile and irregular objects. The grasping system in this research consists of compliant gripper module, a selective compliance assembly robot arm (SCARA), and a machine vision module (DynaColor MVC-2). A camera was assembled in the system to detect the size and position of the object. The soft robotic gripper prototype was fabricated by 3D printing machine. The filament material used for printing was made by an elastic material, thus it reduced the time taken for fabricating an actuator. A force sensor is equipped at the end of soft gripper fingers to measure the force that applied on the object, thus able to prevent over forced applied on the fruits surface. Some of other the soft gripper design is built based on three soft pneumatic actuator fingers mounted to a laser cut acrylic frame [11]. The condition of the three modules are radially symmetric to the central of the gripper palm. The gripper then was able to perform grasping and rotating the objects. Such applications are to unscrew a bottle cap and rotating the screwdriver. In order to measure and control the bending angle of soft actuator, a resistive flex sensor has been used [12]. Previous work demonstrates that, flex sensors were embedded in the soft pneumatic actuator body as the part of the soft body. The function of the resistive bend sensor is to measure the bending angle of the actuator when supplied with pneumatic pressure. By having the resistive data related to the bending angle, the pneumatic pressure supplied into the actuator could be controlled.

Despite of using three fingers actuator for grasping, several researchers proposing other ways to grip the fruits using two [13] or four fingers actuator [14]. For example, Guo *et al.* [15] developed a two-fingered soft gripper that can actuated by pneumatic supply to grasp the objects with complex geometries and delicate nature. They started by preparing a mould of the two-fingered soft gripper using 3D printer. During the fabrication of the gripper, the inlet tube was plugged into the center of the actuator mould. The inlet tube used to allow the air pressure from the compressor to move into the actuator for fingers actuation. The researchers also embedded a stretchable electro adhesion into the gripper with segmentation conductive silicon sheet, resulting it to pick and place various material shapes either flat or flexible such as a porous cloth, volleyball and light bulb. The conventional technique of soft actuator fabrication is by pouring the silicone rubber into the mould. The mould of the soft actuator can be built by using either the CNC milling machine or printing directly with 3D printers. After that, the bonding steps is continuing after the cure process to complete the soft actuator fabrication [16].

2. SOFT GRIPPER DESIGN AND FABRICATION

Current trend in agriculture sector focusing more on improvement the quality of the crops by inventing methods to reduce the damage of the crops as well as monitoring condition of the crops using Internet of Things (IoT) technology [17], [18]. In this article, solution for reducing potential of the fruits and vegetables to be damage has been proposed by implementing a soft gripper to replace the conventional metal robot gripper. The design of the soft actuator in this project follows the half Bellow type, which consists of the flat plate at half of actuator body, and another half with corrugated shape. A flex sensor for measuring actuator bending performance is suitable to be placed on the flat shape on actuator’s body. Currently, the gripper is developed to grip round shape or spherical shape fruits. The design of the Bellow type soft actuator had been developed by referring through the optimized parameters that had been conducted by previous researchers [6]. The parameters from the previous studies has been amplified to 13 times larger to suit with the sensors and fruits size. Figure 1 and Figure 2 show the basic structure and shape parameters of the half Bellow soft actuator. The parameters of Bellow actuator used in this project are 2 mm thickness and 130 mm length. In this project, the method used to build the mould for fabrication is using the Ultimaker 3 Extended 3D printer. For this project, there are 6 main parts of the mould needed in the fabrication which are the bellow side outer layer, bellow side inner layer, flat plate side outer layer, flat plate side inner layer, header chamber side and header flat plate side. Figure 3 shows the printed mould for the bellow side outer layer and bellow side inner layer. The materials used for the fabrication are the RTV (Room Temperature Vulcanizing) silicone type KE-1603-A and its curing agent KE-1603-B).

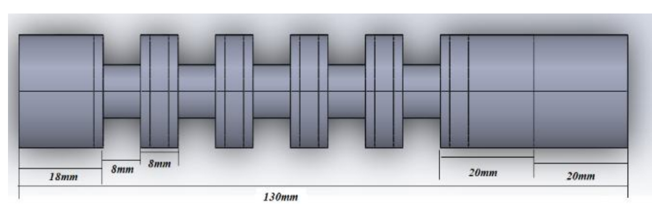

Figure 1: The basic structure of bellow shape actuator

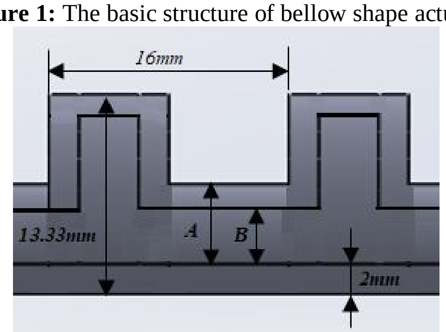

Figure 2: The shape parameter of half Bellow actuator

Figure 3: The 3D printed mould; (a) bellow side outer layer (b) bellow side inner layer

The fabrication process has five stages. The first process is mixing and pouring the silicone rubber into the mould. Initially, the KE-1603-A and KE-1603-B silicone is mixed with an equal volume. Then, the mixed silicone needs to be stirred well for a minute. Then the mixed silicone is poured into the 3D printed mould. To get the imprinted feature of the mould, the silicone is poured into the outer layer mould only. After silicone is poured in the mould is degassing the air bubbles in the silicone mixture. This is the most important steps in fabricating the soft actuator. During the stirring and mixing the silicone with its curing agent, a lot of bubble is produced. The air bubbles that trap inside the stretchable body will become the weak area that may cause the soft actuator easier to broken when pressurized. Therefore, the degassing process is necessary to remove the air bubbles out from the silicone mixture. During degassing process, the moulds are placed into the vacuum chamber at -800 kPa for about 6 times. After the degassing process completed, the mould was taken out and excess bubbles are manually pierced with a needle. After that, the moulding process will take part. The mould with the silicone will be covered up using the inner parts of each body side. Then, the mould is left for curing in room temperature for about 6 hours. The duration for curing process could be reduced if they are putting in higher temperature at about 80 degree Celsius. But for this project it left at room temperature because of the mould that prepared using PLA material. After the curing process has completed, the cured silicone rubber body with Bellow shape and flat plate side is attaching together by using the similar material which is silicone rubber. The next procedure is embedding flex sensor into the actuator. During this process, the flex sensor will be embedded at the flat plate side of the soft actuator. Then, another thin silicone rubber layer is coated on the sensor surface. Finally, after fabrication of soft actuator body has been completed, the header is connected together with the body. The body and the header are tighten using cable tight and the interface between the body and the header is glued together using the silicone rubber. Then, the actuator is ready to be used as finger in soft gripper. Figure 4 shows the complete bellow type soft actuator.

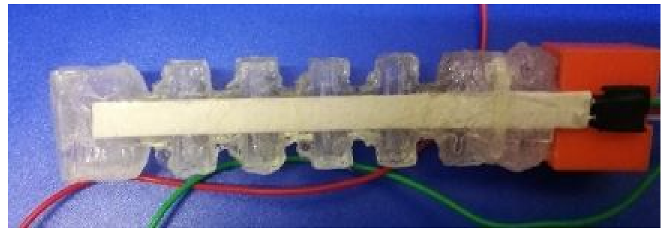

Figure 4: The bellow type soft actuator with embedded flex sensor

3. SOFT GRIPPER SYSTEM

The flowchart of soft gripper system is shown as in Figure 5. When the system is on, compressor, electro-pneumatic valve and Arduino Mega will be supplied with 240 V_{AC}, 12 V_{DC} and 5 V_{DC} respectively. The electro-pneumatic valve that used in this project is SMC ITV0031-2ML model and its function is to receive the digital signal from the Arduino Mega board. When the switch in the circuit is turned on, the electro-pneumatic valve will receive the signal and load air pressure into the chambers in soft fingers. The input voltage pro-vided by Arduino Mega to the electro-pneumatic valve ranging from 0 to 5 V. During the bending motion, the flex sensor that embedded in soft fingers body will read the changes in term of resistive values and convert it to the reading in degrees. Then the reading will be displayed on the LCD. If the switch does not turn on, the electro-pneumatic would not function and it does not load any pneumatic pressure to the soft gripper.

The circuit connection of the soft gripper is shown in Figure 6 and the experiment setup for the soft gripper is shown in Figure 7. In circuit connection, a potentiometer is used to control the supplied voltage to the electro-pneumatic valve ranging from 0 to 5 V. Referring to Figure 7, it shows that the DC power supply is powered the electro-pneumatic regulator valve with 24 V_{DC}. The Arduino Mega 2560 board is connected to a DC supply with 5 V_{DC} battery. The digital output port of the Arduino Mega 2560 board is connecting to the input port of the electro-pneumatic regulator valve. The output from Arduino Mega 2560 is programmed to produce voltage from 0 to 5 V because it will determine amount of pneumatic output from the electro-pneumatic valve. For pneumatic supply, a general compressor is used and it is powered by 240 V from direct domestic electrical power point. The compressor able to supply pneumatic pressure up to 6 MPa. In soft gripper, low pressure supplied is required, thus the output pressure that been used for soft gripper is reduced to less than 1 MPa. In between the compressor and the electro-pneumatic regulator valve, a pneumatic air regulator is linking to a filter and regulate to have a stable pneumatic supply. After that, the electro-pneumatic regulator valve is linking to the soft actuator. The flex sensor that has been embedded with the soft actuator is connected to the analogue input port of Arduino Mega 2560 board to provide a real time bending values displayed on the LCD.

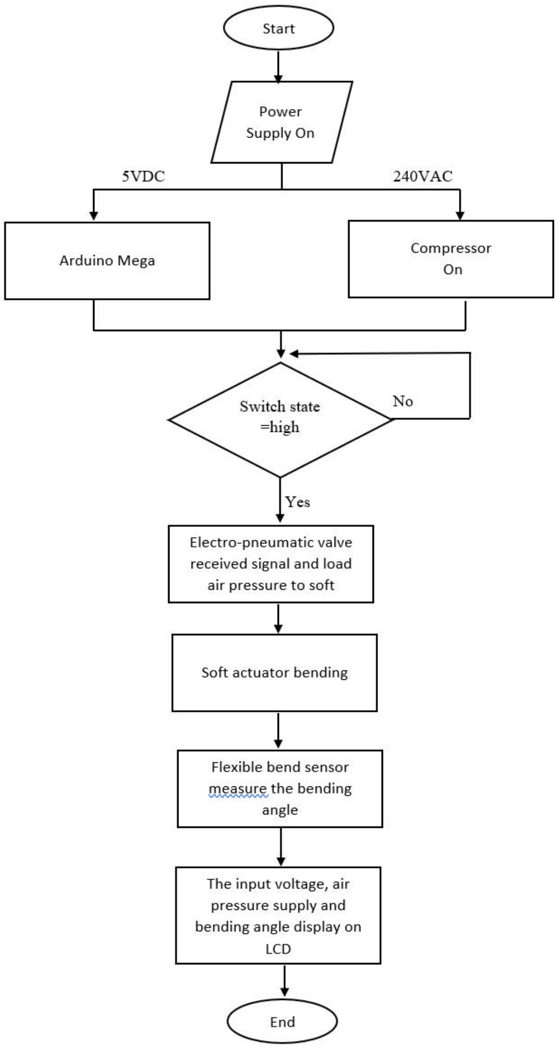

Figure 5: The flowchart of the soft gripper

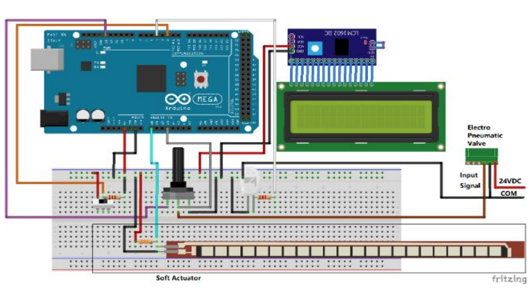

Figure 6: Circuit connection of the soft gripper system

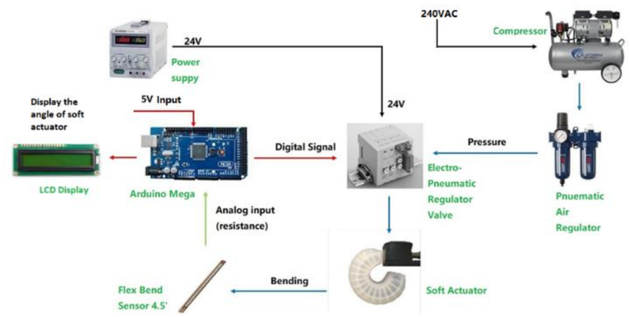

Figure 7: The experimental setup of soft gripper

4. RESULTS AND DISCUSSION

Development of the soft gripper with flex sensor for agriculture application is focused on the soft actuator bending mechanism and its performance for gripping the fruit. The data measured and recorded are through experiment. Initially, the relation between pneumatic pressures supplied into the gripper fingers against input volt-age from Arduino are measured. The voltage is increased by 1 V until it reached 5 V. From the data plotted in Figure 8, it shows that the pressures supply increase linearly as the input voltage increase with the slope value 100. Figure 9 displayed the snapshot of the soft actuator bend at different supplied pressures starting from 0 kPa to 90 kPa.

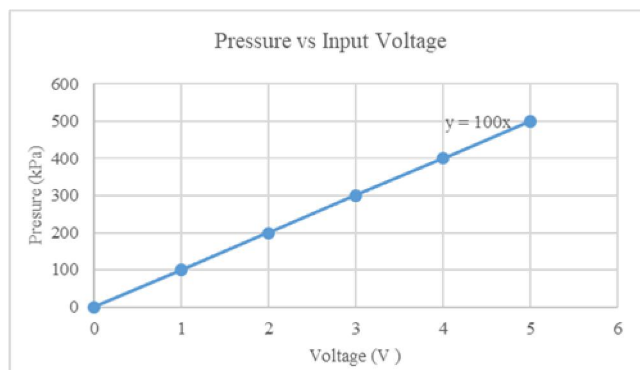

Figure 8: The relationship between the air pressure and input voltage

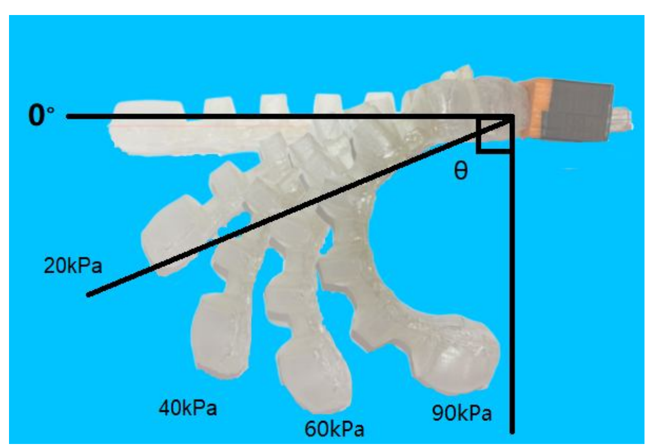

Figure 9: Snapshot of the soft actuator when different air pressures are supplied into soft actuator

To investigate the relationship between the air pressure supplied and the bending angle, two methods has been used which are measuring bending angle through the IC Measure software based on the snapshot of the image and measuring bending angle using flex sensor. From the measurement of the bending angle through flexible bend sensor, the bending angles were programmed to be displayed on the LCD. The relationship between bending angle and air pressure supplied is shown in Figure 10. From the figure, it shows that the angle measured by IC measures software and flex sensor are almost the same with the flex sensor providing more stable trend. The relation between bending angle and the pressure supply for the actuator could be computed using (1) where x is the pneumatic pressure supplied in kPa and y is the bending angle in degrees. The completed soft gripper after all the fingers are assembled with the holder is shown in Figure 11 and its bending angle measured during gripping is shown in the LCD display as in Figure 12.

$$y = 0.9493x - 1.3242 \quad (1)$$

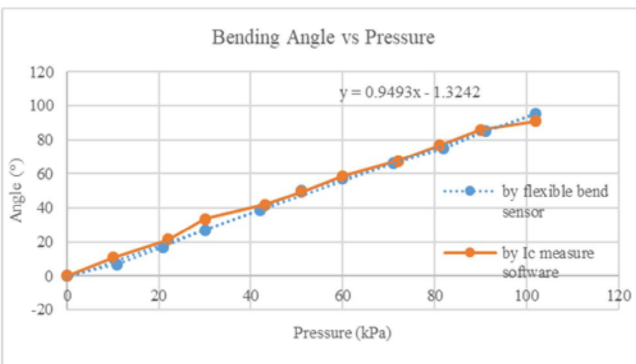

Figure 10: The graph of the bending angle versus supplied pressure

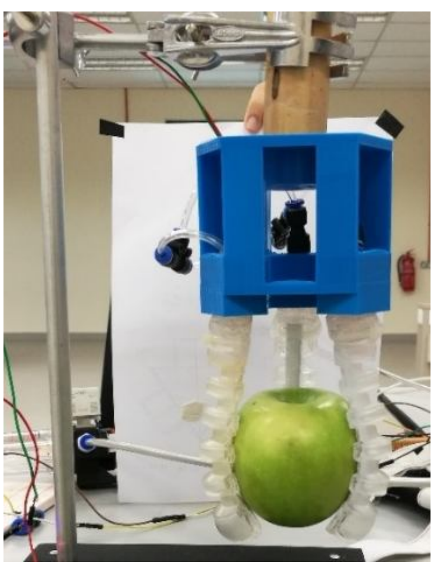

Figure 11: The soft gripper is gripping the fruit

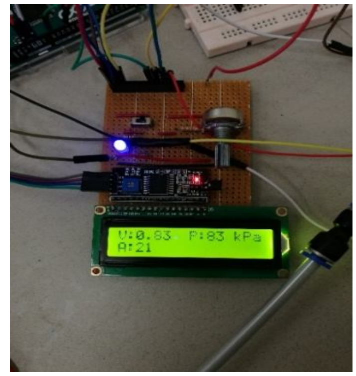

Figure 12: LCD display the bending angle of the soft gripper

For the soft gripper testing, two conditions have been considered which are taking the fruit with load and without load. For testing the soft gripper bending with load, some fruits and vegetables that easily bruise or scratch have been chose. The testing of the soft gripper with difference pressures applied in grasping different fruits and vegetables is shown in Table 1. Based on Table 1, it shows that the object of soft gripper grasping will affect the bending angle of soft gripper. With the same supplied pressure, 80 kPa, the gripper able to bend up to 29 degrees without load whereas bending angle is less than 29 degrees with load, depending on the size of the object. The bending angle of the soft gripper without load is higher compared to the bending angle of soft gripper without load because the flexibility of the soft gripper limits the movement in angular motion and makes the gripper match the shape of the object when bending. Next, the performance of soft gripper to grip an object at different pneumatic pressure is conducted. Based on the results in Table 2, it shows that, generally as the diameter of the fruits increased, the bending angle of the gripper also increased because the gripper needs to bend more to hold the fruits. The gripper able to grip and hold the fruits with diameter ranging from 6.00 cm to 8.10 cm with gripping angle 17 degrees to 23 degrees. The data also present the ability of the gripper to hold the fruits when the supplied pressure changes. From the experiment, it shows that the soft gripper is not able to hold the apple with less than 70 kPa supplied pressure because of the apple's weight is too much for the gripper to handle. However, the gripper able to hold the bell pepper with supplied pressure as low as 50 kPa, even the size of the bell pepper is bigger than the apple. Therefore, it shows that the gripping performance of soft gripper is not affected by the size of object only, but the weight of the object as well.

Table 1: The bending angle of soft gripper in a constant supplied pressure

With Loads		**Without Loads**	
Pressure = 80 kPa		**Pressure = 80 kPa**	
Object	**Bending Angle, (°)**	**Object**	**Bending Angle, (°)**
Orange	17	None	29
Apple	21		
Small tomato	18		
Big tomato	23		
Bell pepper	23		

Table 2: The gripping performance of soft gripper with different air pressures for different objects

Object	Fruit Diameter (cm)	Gripper Bending Angle (°)	Gripper supplied pressure (kPa)			
			50 kPa	60 kPa	70 kPa	80 kPa
Orange	6.00	17	×	/	/	/
Apple	6.30	21	×	×	/	/
Small tomato	6.50	18	/	/	/	/
Bell pepper	7.20	23	/	/	/	/
Big tomato	8.10	23	×	×	/	/

5. CONCLUSION

This project has been completed starting from designing the soft fingers, fabricating the actuator, assemble the gripper and controlling the gripper. For the design of the soft actuator, the half Bellow type able to show good performance in gripping and holding the fruits at suitable condition. With the used of flexible material, the gripper able to grip the fruits which have larger diameter than the gripper. The flex sensor which attached on the soft actuator also providing good and stable reading for measuring the bending angle. There are some recommendations for future improvement of the soft gripper in design and control system. The material of the finger can be improved to withstand higher pressure because current material used cannot withstand higher pressure more than 110 kPa. This is important as the low pressure supplied in current soft gripper material may limit the ability to grip heavier object. For the control system it is suggested to apply PID controller to get the smooth and more accurate bending performance. The design of the actuator could be improved to grip various shapes of the objects.

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