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Three-Fingered Soft Robotic Gripper Based on Pneumatic Network Actuator

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***Abstract*— A lot of research is conducted in the area of gripper on manipulator arm. They still use hard robot technology made from rigid material. Hard gripper will be difficult when it is used to grasp and hold fragile objects such as eggs or grapes. Recently, many engineers and scientists who work in robotics in the world have developed soft robot technology that is applied to the gripper. In this paper, we present the development of three-fingered soft robotic griper based on pneumatic networks. Soft robotics fingers are manufactured using elastomeric material; silicon rubber (RTV 52). Soft finger molding material is produced using Polylactic acid (PLA) material and printed using 3D printer. The gripper can perform in a positive and negative pressure room. The actuator utilized in the soft robotic gripper is a mini air compressor. The performance of the proposed soft robotic gripper is tested for various grasping objects from hard to fragile objects in positive and negative pressure. Based on the test result, the developed soft gripper can take and grasp hard and delicate objects that have a mass less than 500 gr under positive pressure.**

Keywords—Soft robotic, gripper, pneumatic network

I. Introduction

Recently, many researchers and engineers still have used an end-effector (gripper) of a manipulator arm that uses hard robotic technology. The gripper still uses hard robot made from rigid material. The gripper is designed to grasp hard objects without using force feedback control. It will be difficult when the gripper is used to grasp delicate objects such as eggs, grapes or other delicate fruits. Currently, many roboticists in the world develop soft robot technology that is applied to gripper. By using soft robot that can be implemented to the gripper, it can be used to grasp various delicate objects without using force feedback control.

Soft robot becomes a new part of the robotic field study that has several advantages such as lightweight, low-cost, easy to manufacture. Recently, the design, manufacture, and actuation of soft robotics have drawn attention of many researchers from various fields such as physics, biology, electrical engineering, and mechanical engineering. They tried to develop a novel actuation system from multiple materials used in the soft robot system.

Actuation systems based on pneumatic networks and tendons are widely used in the soft robot actuation. The pneumatic network uses air as its driving medium, while the motor-tendon actuation uses tendons (wires) as its driving force. Many researchers have developed pneumatic networks [1-5], and motor-tendon [6-9] that give promising results in the actuation of the soft robotic gripper. Researchers have developed soft robotic gripper with one finger [10], two fingers [11], three fingers [2, 12], and more than three fingers [13]. The result showed that the developed soft grippers could successfully take and grasp fragile objects.

In the process of manufacturing soft robotic using different materials such as silicone rubbers, it can be easier in the manufacturing process of soft robots that use motor-tendons as actuation system, because these types are produced in fewer stages. Whereas the manufacturing process of soft robotic that uses pneumatic networks is made in various stages and is easy to fail when conducting trials such as leaks. If considered based on grasping stability and strength, then the soft robotic type with a pneumatic network will have better performance, because by using the pneumatic network system, it can produce a more evenly distributed force and pressure in the grip of the object. Also it can be used for grasping a delicate object without using force feedback control.

Soft robotic which is driven by a pneumatic network system that uses a small channel / elastic tube with elastomeric material is very attractive to produce sophisticated movements and can be controlled directly. Soft robots with a pneumatic network system have five advantages, such as: (i) perform quick pneumatic compression (because of air low viscosity and it can move quickly); (ii) easy to control and measure; (iii) widely available; (iv) lightweight; (v) pressurized air can be discharged after being used by removing it into the environment [14].

In this study, the selected soft finger actuation is pneumatic network and the material used is RTV 52 type (Room-Temperature-Vulcanizing) silicone. By using a pneumatic system, the weight of the soft gripper will be lighter compared to motor-tendon actuation. The number of fingers used in this study is three fingers. The process of manufacturing soft gripper is discussed in this paper, then it is tested to grasp delicate objects.

II. Soft Robotic finger design and manufacturing

A. *Soft Finger Design*

The geometric air chamber configuration is a soft finger geometry that is higher than other surfaces on the top of the finger, to fill the air to bend the finger for grasping an object. The number of the geometric air chamber in soft fingers that are higher than other surfaces must be suitable to be able to grasp the object as expected. We conducted experiments by trial and error with a quantitative assessment of three soft fingers, with each of the higher surface, six, ten and thirteen surfaces on the top of fingers.

The configuration of a soft finger with a higher number of surfaces is more difficult in the manufacturing process to form soft finger as expected, because the silicon rubber must be slowly poured in the mold, to avoid bubbles (porosity) on the soft finger. The higher number of surfaces in the soft finger, the more bubbles can occur, because a large amount of narrow space can lead to the occurrence of bubbles (porosity).

Regarding stability of the proposed soft finger of the three existing fingers, it can be proved quantitatively that it has better configuration with ten higher surfaces. The reason is that with the number of six higher surfaces on a soft finger, it is only able to bend to approximately 270 degrees. Whereas with thirteen higher surfaces on soft finger, it can bend to more than 360 degrees. When soft fingers have ten higher surfaces, it can bend more than 270 degrees and approximately or equal to 360 degrees. Soft finger configuration that has the heaviest mass is a soft finger configuration that has a higher surface number of 13 surfaces.

The strongest grip strength of the proposed soft finger configuration is that the soft finger configuration has a higher surface number than ten surfaces. The difference in the curved shape of three soft fingers is depicted in Fig. 1 below. Higher surface of soft fingers with ten surfaces are selected for the soft gripper.

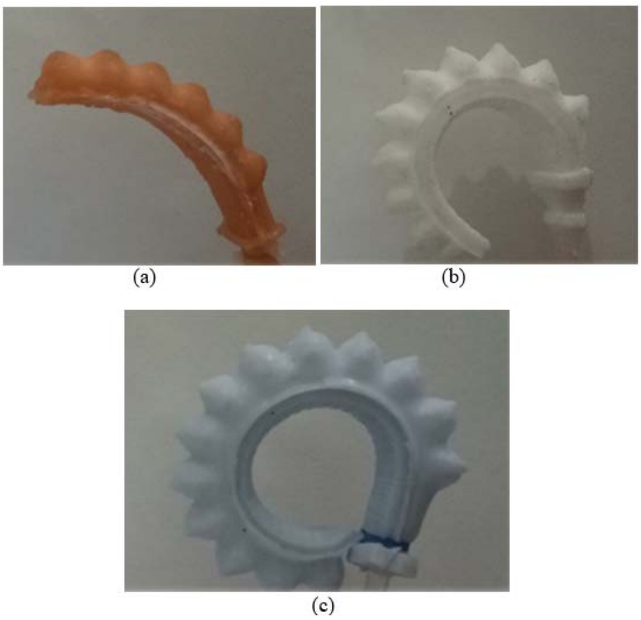


Fig. 1. Soft finger design with different number of higher air chamber/higher surface, (a) Six air chambers, (b) 10 air chambers, (c) 13 air chambers

B. *Soft Finger Manufacturing*

From the aspect of mechanical design, the soft robotic gripper element consists of three components which can be seen in Fig. 2. Three components of the proposed soft robotic gripper comprise of; 1) finger of soft robotics (soft finger), 2) fixator, used to tie and connect the fingers of the soft robotic gripper, housing gripper and pneumatic hose, 3) housing gripper printed using 3D printer with the polylactic acid material (PLA). Three-fingered soft robotics gripper is driven pneumatically using a mini air compressor made using 3D printer. Soft robotic gripper is integrated using housing gripper made by 3D printer with PLA material which is directly connected to the inlet of the soft robotic grippers using pneumatic hoses, and the other parts are connected with a mini air compressor. Pneumatic soft robotics hose joints are tied to a cable tie and joint bolt to close the air duct and avoid air leakage. The soft robotic three-fingered gripper component that has been assembled is shown in Fig. 2.

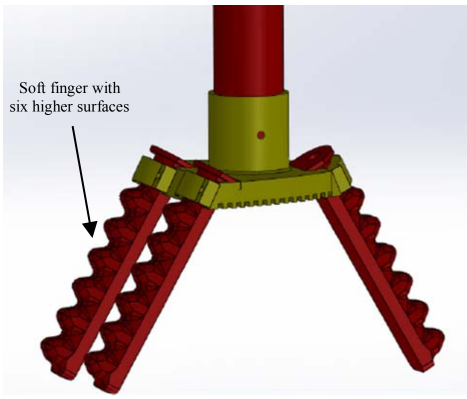


Fig. 2. The proposed 3D design of the three-fingered soft gripper

The soft finger is made using elastomeric silicon rubber material (RTV 52). Rigid molding is designed using CAD software, SolidWorks. Mold material uses Polylactic acid (PLA) material. The process of printing soft fingers is done in several steps as shown in Fig. 3. Upper mold is made to form a top layer which can be expanded by containing topographic features. Lower mold is utilized for the soft finger bottom layer to form a touching surface when grasping an object.

In the process of molding the soft robotic finger, first prepare the silicon rubber liquid, which has been mixed with the dye pigment, and left for a few moments to release air bubbles when stirring takes place. Silicon rubber RTV 52 is mixed with catalyst at a rate of 25% drops of the amount of silicon rubber in units of mass (grams). After that to avoid the air bubbles that occur, the stirring process can be done evenly.

The silicon rubber mixture is poured on the upper mold A slowly to fill the volume of the mold evenly, then upper mold B is placed according to Fig. 3 to fit the upper mold A. After the molded silicon mold has dried up, it can be lifted and separated from the upper mold.

The silicon rubber mixture is poured on the bottom mold slowly until evenly distributed, then the molding result from the upper mold is placed on top of the bottom mold to stick to the whole. After the molding result of the upper mold and the hardened bottom mold, the mold can be released. After the silicon rubber is hardened, the hose is used to drain fluid on the soft finger. The overall manufacturing process for a soft robotic finger is presented in Fig. 3.

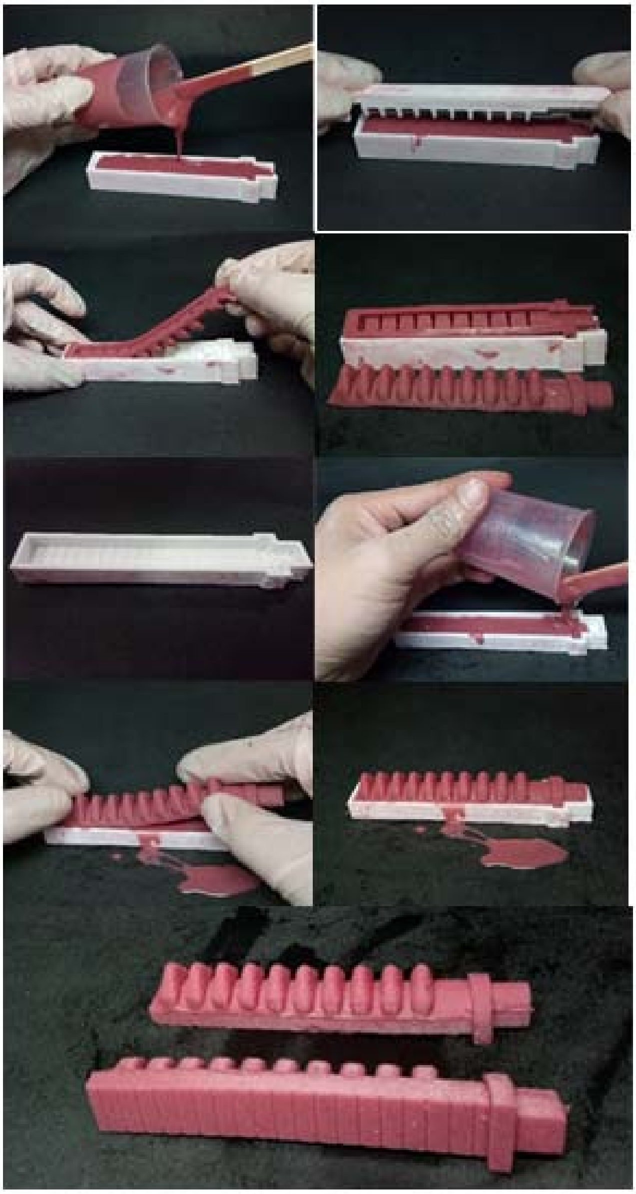


Fig. 3. Manufacturing process of soft gripper

III. PNEUMATIC NETWORK SYSTEM OF SOFT GRIPPER

In order to the soft robotic gripper can bend, an actuator in the form of a pneumatic network is needed. Soft gripper has a working principle resembling pneumatic systems. A compressor is needed to move the soft finger. In addition to the mini air compressor, the valve is also needed to be able to adjust the exit and entry openings of air. Soft robotic gripper, mini air compressor, and valve all connected by hose. The overall configuration of the proposed pneumatic network for soft gripper actuation system is depicted in Fig. 4. The figure is divided in two actuation process, inflation and deflation. This enables the soft robotic gripper can work under positive and negative pressure.

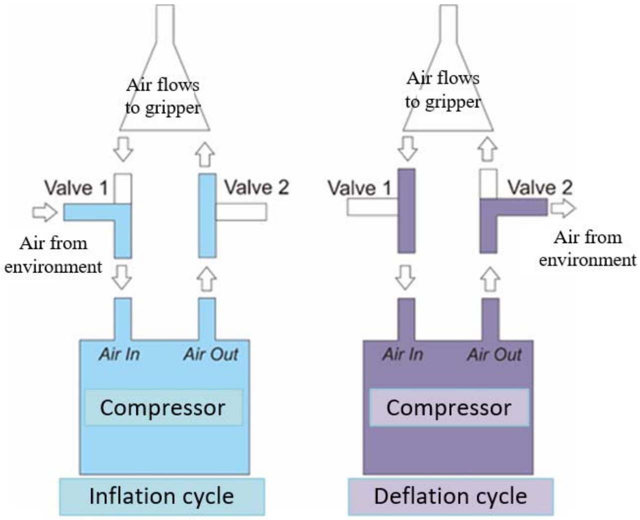
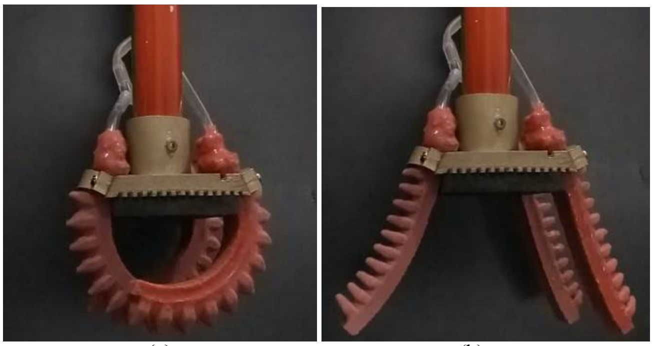


Fig. 4. The configuration of hose, mini air compressor, valve, dan soft robotic gripper

Based on Fig. 4, it can be seen that a mini air compressor and two solenoid valves are needed to drive the soft robotic gripper. The mini air compressor has an air inlet that functions for a vacuum process, and an air outlet to provide compressed air. Both air inlet and outlet are connected to solenoid valves. When the compressor performs an inflation process, the valve is closed and the second valve is on open state so that air from outside enters the compressor, and the compressor exerts pressure towards the air chamber of the soft robotic gripper. Whereas when suction (deflation) process is the opposite of inflation conditions. The inflation and deflation process on soft robotic gripper are illustrated in Fig. 5.



(a) (b)

Fig. 5. Proposed soft gripper, (a) Inflation, and (b) deflation process

IV. RESULTS AND DISCUSSION

To evaluate the soft robotic gripper's performance when gripping various objects in this study, the shaped curve of testing under positive and negative pressure. The bending test of a soft finger is performed by varying the pressure during inflation and deflation. Grasping test for delicate and hard objects is working under positive and negative pressure. The maximum of object weight that can be lifted by a soft robotic gripper is conducted experimentally.

A. *Soft gripper bend using positive pressure*

In this test, a soft finger is given with pressurized air (inflation) or positive pressure. The results of a soft finger curve made of silicon rubber (RTV 52) are shown as Fig. 6. The positive finger pressure varies from 5 kPa to 30 kPa. Fig.

6 shows that the greater the given positive pressure (kPa), the higher the bending angle formed by a soft finger.

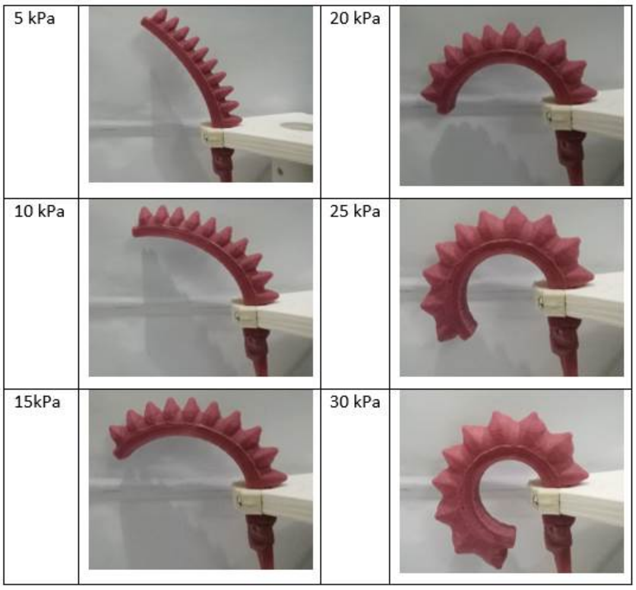


Fig. 6. Soft gripper working under positive pressure

B. *Soft gripper bend using negative pressure*

In this test, a soft finger is given with negative pressure (deflation). The result of the shaped curve of bending angle of a soft finger made of silicon rubber (RTV 52) varied according to the amount of negative pressure in the chamber of the soft finger. The negative presser is altered from -5 kPa to -30 kPa. Fig. 7 shows that the higher the vacuum pressure (kPa) is given, the higher the bending angle that occurs in a soft finger.

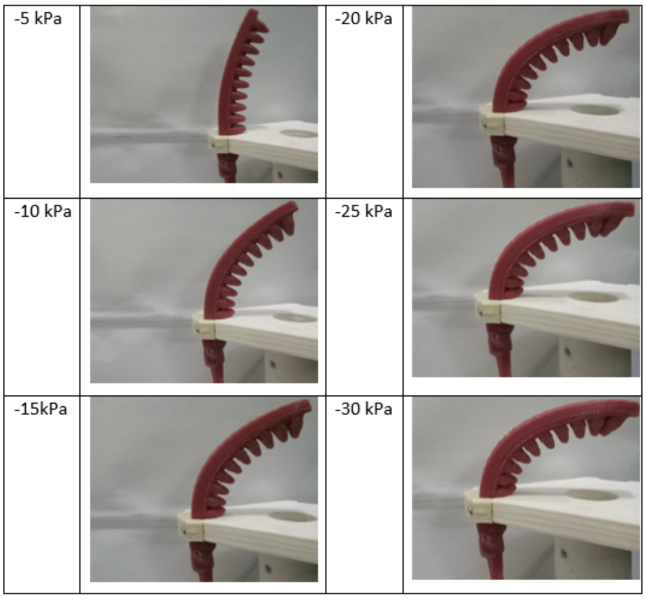


Fig. 7. Soft gripper working under negative pressure

Fig. 7 shows the variation of compression and vacuum pressures given to soft finger from -30 kPa to 30 kPa, with increment of five kPa. The test results in Fig. 7 shows the difference in bending angle that occurs with the pressure applied. Overall, the higher the pressure given, the higher the bending angle produced. The measurement of bending angle can be seen in [15]. The highest bending angle that can be formed by a soft finger is 270 degrees. The highest bending angle is formed when the soft finger working under positive pressure or inflation process at 30 kPa as shown in Fig. 8. Based on this test result, inflation or positive pressure is used in the grasping test for various objects.

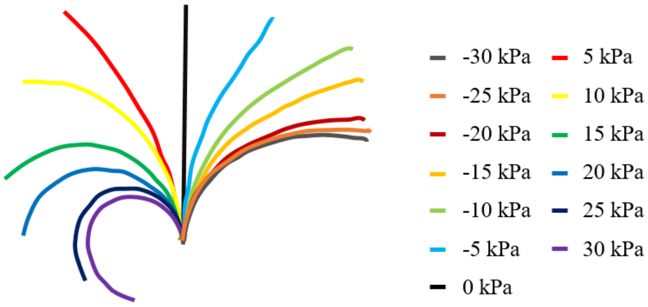


Fig. 8. Soft gripper bending angle under pressure variation

C. *Grasping test of the maximum load mass*

In this test, load testing is carried out which can be lifted by soft robotic gripper with variations in load starting from 16 grams to 500 grams. The test result of lifting an object with varying mass is shown in Fig. 9. The test results show that the greater the burden given, the soft robotic gripper is increasingly unable to hold it. Based on the test result, it can be concluded that the maximum load that can be lifted by the soft robotic gripper is 500 grams, and the soft robotic gripper is not able to lift the load when given an object with a mass of 550 grams.

(a) (b)

Fig. 9. Maximum load test on the soft gripper, (a) An object with a mass of 550 gr, (b) grasping test

D. *Grasping test with negative pressure*

In this test, the soft robotic gripper is tested to grasp and lift a plastic cup by using negative pressure. By using negative pressure, the soft gripper can successfully grasp and lift the plastic cup from inside of the cup without dropping it to the ground as shown in Fig. 10.

Fig. 10. Grasping an object using negative pressure

E. Grasping test with positive pressure

Positive pressure is utilized to grasp objects from delicate to hard objects. The result of grasping delicate objects such as an egg and grapes is depicted in Fig. 11. The soft robotic gripper can stably grasp the delicate objects without breaking it although the given pressurized air is excessive. Another grasping test for hard objects is revealed in Fig. 12 by using positive pressure. The soft gripper can take and grasp various objects that vary in shape, mass, and size. The performance of soft robotic gripper in various objects grasping test for delicate and hard objects can be seen online at http://y2u.be/XvPQfHjHXUY

Fig. 11. Grasping test for delicate objects

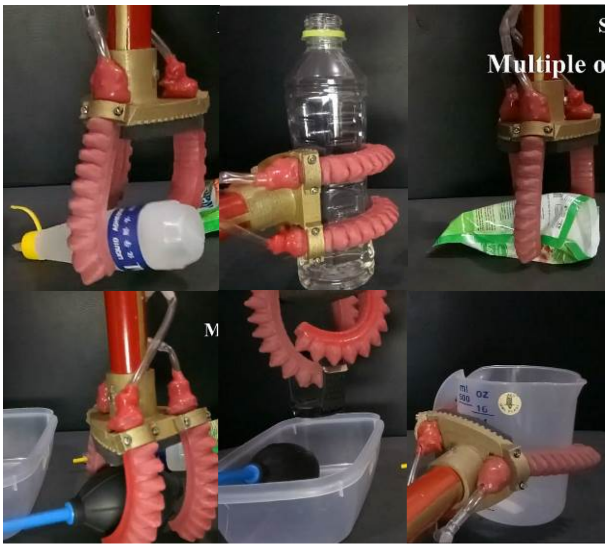


Fig. 12. Grasping test for hard objects

V. CONCLUSION

A three-fingered soft robotic has been successfully developed in this study. The soft gripper is manufactured using RTV 52 silicon. The developed soft gripper can work under positive and negative pressure. The higher the pressure is given to the soft finger, the higher the bending angle produced. The highest bending angle that can be obtained by a soft gripper is 270 degrees at 30 kPa. The highest bending angle is formed when the soft finger working under positive pressure. The grasping test results show that the soft gripper can take and grasp delicate objects such as an egg and grapes without using force feedback control. The soft gripper can stably grasp an object that has a mass less than 500 gr using positive pressure.

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