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# Development of Flexible Robot Gripper Holding Deformation by Electromagnetic Brake

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**Abstract:** We developed a flexible robot gripper which holds the deformation of a flexible bag enclosing an object by a magnetic brake. Since the gripper has no fluid in the flexible bag, it is not susceptible to gravity during the gripping operation, and can grip the object in various postures. Also, there is no concern of liquid leakage, and most of the component parts can be easily manufactured by 3D printing. Furthermore, it can be operated by supplying power to the electromagnet brake without complex control.

**Keywords:** flexible robot gripper, magnetic brake, 3D printing

## 1. INTRODUCTION

Object transportation work performed by industrial robots is called pick & place (P&P), and its execution uses a dedicated end effector suitable for the shape, material and work content of the object. The end effector used for P&P is called gripper, and many studies are carrying on about universal gripper which are enhanced the versatility of them.

Among them, the universal gripper which grips by wrapping an object is composed of a flexible membrane and a fluid filled in it, realizing high versatility. For example, the jamming gripper [1] uses powder and air, the MR fluid gripper [2] uses MR fluid, and the water gripper [3] and SSA gripper[4] use water as inner fluid. On the other hand, these flexible membrane grippers have a possibility of fluid leakage and are susceptible to gravity, so there are cases where it cannot cope with the posture change of the robot in some cases. Also, a torus type gripper [5] has a gel sealed inside a flexible bag, and has a mechanism for drawing the inner membrane by a servo motor. Then, the gripping operation requires two-axis control. FESTO's flex shape gripper [6] enclosing water inside the flexible bag, presses the flexible bag against the object, and performs a gripping operation by holding the resulting deformation using a vacuum pump.

However, depending on the factory and work content, there are cases where it is difficult to use a vacuum pump. Therefore, we propose a novel soft gripper that improves the various problems of conventional grippers. The proposed gripper consists on a flexible bag for pressing target object and a part for holding the deformation of the flexible bag, and uses an electromagnet brake to maintain the deformation of the flexible membrane. The gripping action can only be performed by the current of the electromagnet, since only the braking force by the electromagnet holds the deformation of the flexible bag. In addition, in order to properly release the gripping object and decompress the flexible bag, a sponge is enclosed inside the flexible bag. Conventional grippers use inner fluid such as water or gel to generate drag due to volume change inside the flexible bag. The proposed gripper does not contain liquid inside the flexible bag, thereby it can be eliminating the risk of leakage of the inside fluid. In order to optimize the flexible bag deformation, the thickness of each part of the bag was developed using a 3D printer and tested by trial and error. In this paper, we describe the configuration and operation principle of the proposed gripper, and the results of performance verification.

## 2. PRINCIPLE OF OBJECT GRASPING

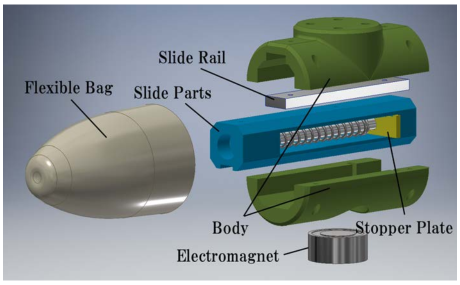
### 2.1 Construction

The proposed gripper consists of a gripping part and a holding part. The overview and structure of the gripper are shown in Fig. 1. A flexible bag that wraps around and holds the object is internally connected to the tip of a slide part. The slide part is connected to the body via a slide rail, so they can move along the central axis of the body. A stopper plate is fixed to the body and not connected to a slide part. A spring installed on the axis of the slide part is for returning the slide part that moves by the gripping operation to the initial position.

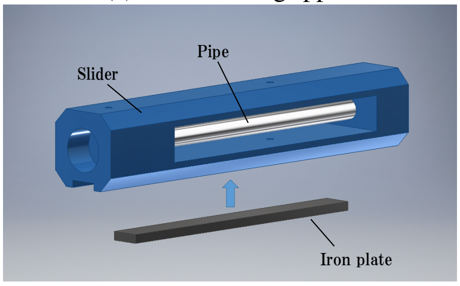
The operation of gripping and releasing the object by the robot equipping this gripper is performed as follows: (1) Press the flexible bag against the object so as to wrap. (2) Apply an electric current to the electromagnet to activate the electromagnetic brake. (3) The deformation of the flexible bag is maintained in that state, and the object is gripped. (4) At the time of release, by interrupting the current supply to the electromagnet, the slide part and the flexible bag return to the initial position by the repulsive force of the spring installed inside, and the object is released.

### 2.2 Force balance in object gripping

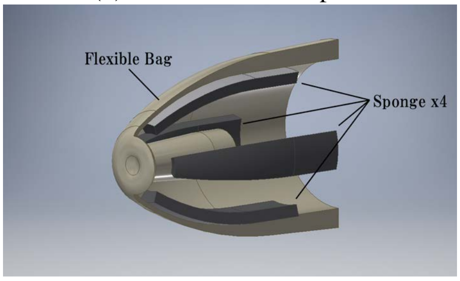
The Fig. 2 shows the outline of the contact force generated by deformation of the sponge when the gripper is



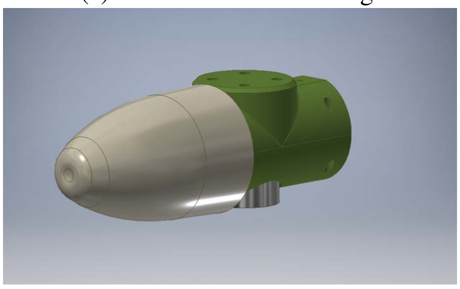

(a) Structure of gripper.




(b) Structure of slide part.




(c) Structure of flexible bag.



(d) Appearance of the proposed gripper.

Fig. 1 Overview of the proposed gripper.

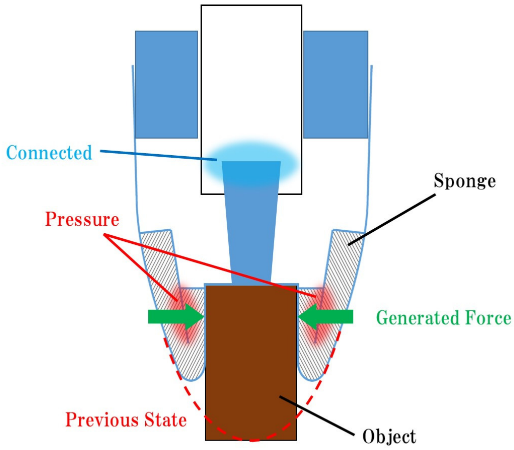



Fig. 2 Outline of gripping the target due to deformation of the flexible bag.

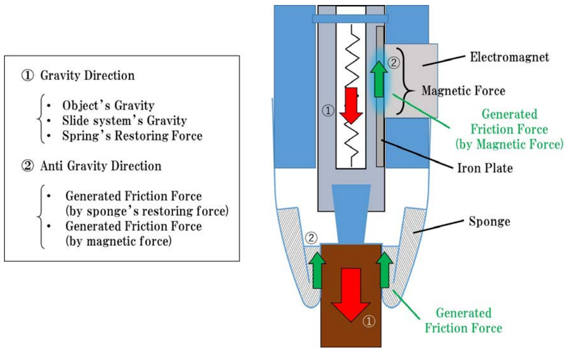



Fig. 3 Relationship of forces.

pressed against a target. By pressing the flexible bag to the object, the flexible bag conforms to the surface of the object to increase the contact area. In addition, the object is gripped by the frictional force generated by the restoring force of the compressed sponge is applied to the object to be grasped.

Next, the relationship of the forces related to deformation of the flexible membrane in the state where the proposed gripper grips the object with the flexible bag facing downward is shown in the Fig. 3. The adsorption force generated between the electromagnet and the iron plate generates a static friction force in the shear direction. This static friction varies with the coefficient of friction between the materials, and the developed one is possible to generate sufficient holding force to hold the deformation of the flexible bag. When the object is heavy and the holding power is insufficient, it is necessary to increase the holding power of the electromagnetic brake.

The sponges are glued to the inside of the flexible bag, and the resilience of a sponge depends on its material, size and shape. These sponges play an important role in generating adhesion when gripping an object, and are important for quick recovery of the flexible bag to its initial shape when releasing the object.

## 3. PERFORMANCE VERIFICATION OF PROTOTYPE

In order to verify the performance of the proposed gripper, a prototype shown in the Fig. 4 was developed. The prototype has a diameter of 50 mm and a total length of 170 mm. Since the stroke of the tip of the flexible bag is 80 mm, the stroke amount of slide rail, which is a component of this gripper, is also 80 mm. In addition, since the slide rail sticks out from the rear end during the gripping operation, the connecting flange has been designed the side surface of the gripper. The distance of between the connecting flange and the tip of the flexible bag is 120 mm.

In the proposed gripper, there are various adjustable parameters such as the shape, the material and size of the sponge, the strength and size of the electromagnet, the stroke length of the holding portion, and so on. However the experimental analysis of the gripping performance of

(a) Gripping part.

(b) Holding part.

(c) Appearance of prototype.

(d) State of grasping.

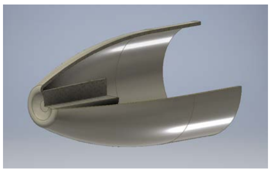
Fig. 4 Prototype of verification.

the proposed gripper is difficult to implement as it requires trial and error. Therefore we developed the flexible bag by using a high-precision 3D printer capable of forming silicone material. The modeling accuracy of the 3D printer was $\pm 0.5$ mm. The physical properties of used silicon used in this research are shown in Table 1. By using 3D printer, flexible bags of various shapes were manufactured, and changes in shape during gripping operation and changes in gripping force due to changes in size of object were investigated.

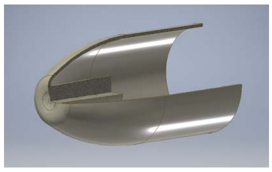
### 3.1 Shape design of a flexible bag

The structure of the flexible bag verified in this research is shown in Fig. 5. The type 1 shown in Fig. 5(a) has a uniform membrane thickness of 1.5 mm, and the curved surface to the tip has a radius of 160 mm. Type 2 shown in Fig. 5(b) has a uniform membrane thickness of 1.5 mm as in the type 1, and the curved surface to the tip has a radius of 90 mm. The membrane thickness has designed so that the silicon membrane is not easily broken and the 3D printer can form a minimum thickness.

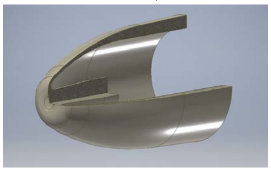
The proposed gripper wraps the target object, and the flexible bag adheres to the surface of the object for gripping. Therefore, when the gripper is pressed against the object, a grip that collapses from the tip of the flexible bag into the inside of the bag is ideal. On the gripping test by the type 1, it was possible to wrap the entire object when the object first contacted the center of the flexible bag. However, when the target object came in contact



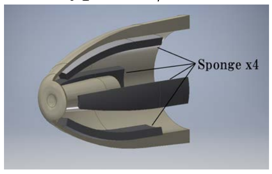
(a) Type 1 (3/4 view).



(b) Type 2 (3/4 view).



(c) Type 3 (3/4 view).




(d) Type 4 (1/2 view).

Fig. 5 Shape design of flexible bag.

with a position away from the central axis of the flexible bag, the entire bag simultaneously distorts, and the bag could not wrap the entire target object. The situation at that time is shown in Fig. 6. The same phenomenon was observed in the type 2, however the radius of the curved surface was smaller than the type 1, and it was found that the robustness for position deviation were improved compared to the type 1. The type 1 and type 2 have uniform membrane thickness, and the entire flexible bag is very flexible. Therefore, when the tip of the flexible bag comes in contact with the object, stress is applied to the entire membrane having a uniform flexural rigidity, and it is considered that the phenomenon that the entire flexible bag is crushed at the same time occurs.

Next, type 3 was designed not to make the membrane thickness of the flexible bag uniform, in order to solve the problem that the whole flexible bag collapses simultaneously. In the gripping method of the proposed gripper, it is desirable to crush from the tip of the flexible bag. Therefore, in the type 3, the membrane thickness is designed to be thickened from the front end to the rear end of the flexible bag, and the membrane thickness at the front end is 1.5 mm and the membrane thickness at the rear end is 6.5 mm. Even if the object comes in contact with the type 3 flexible bag from a position away from the central axis of the flexible bag, it is crushed from the tip of the flexible bag and wraps around the entire object. From these results, it has been found that it is effective to increase the membrane thickness of the flexible bag from the front end to the rear end of the flexible bag in order for the flexible bag to properly wrap the object.

Table 1 Physical property value of silicone (shore durometer is 35)

| Chemical name | Concentration |
|---|---|
| Silicone | 65 % |
| Acrylic monomer | 30 % - 35 % |
| Organophosphorus compounds | 1 - 5 % |
| Phenone compound | 1 % - 5 % |

### 3.2 Sponge inside the flexible bag

From the previous experiments, it was found that by changing the membrane thickness, the flexible bag was deformed properly. However, for small objects and thin objects, even if the objects are appropriately wrapped, there is a case where the object and the film do not adhere to each other.

Therefore, in type 4, four sponge pieces is attached to the inside of the type 3. The sponge generates an elastic force against deformation as described in Sec. 2.2.Therefore, when the object is gripped as shown in Fig. 2, the

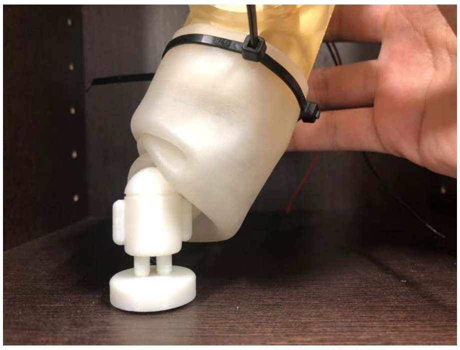


Fig. 6 Gripping failure example.

sponge adhered inside the flexible bag exerts an elastic force from the inside of the bag, and it becomes possible to fill the gap between the small object and the membrane.

## 4. EXPERIMENTS

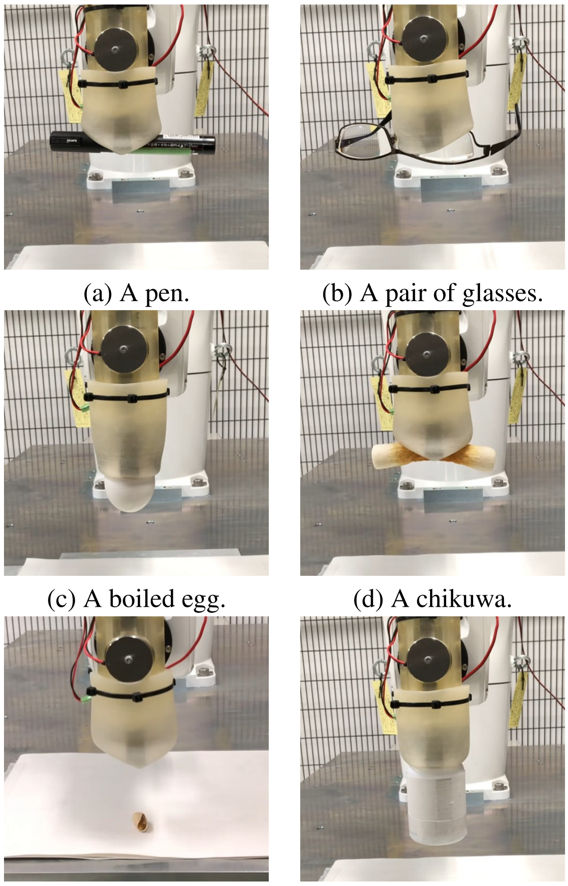
In order to confirm the performance of the proposed gripper, we conducted gripping experiments on several objects by the prototype described Sec. 3. We used a pen, a pair of glasses, a boiled egg, a chikuwa (Japanese fish sausage), a pistachio and a bottle as target objects. The pressing of gripping operation was performed from the vertically upward direction of the target object. After pressing the flexible bag against the object appropriately, the electromagnetic brake was turned on and maintained the deformation of the flexible bag. When the flexible bag deformation was maintained and the object did not fall, we determined that the gripper succeeded in gripping the object. On the other hand, when the object fell, it was judged that the grip was a failure.

The results of the gripping experiments are shown in Fig. 7. From these experiments, it was confirmed that the developed gripper can grip objects of various shapes. On the other hand, it was confirmed that the pistachio smaller than half the contact area of the gripper could not be gripped. The cause of this result is considered to be that the flexible membrane does not fully wrap around and contact the shape of the small object, as described in Sec. 3.2.

## 5. CONCLUSION

We proposed a novel soft robot gripper that does not use inner fluid and holds the deformation of the flexible membrane by using electromagnet brake. In addition, we describe its gripping principle and structure, and conducted a performance verification experiment using a prototype manufactured using a 3D printer.

The proposed gripper is light in weight and has no inner fluid in the flexible bag, so it can grip the object in various postures with little influence of gravity. Also, there is no risk of fluid leakage and most of the component parts can be easily manufactured with a 3D printer. Furthermore, it does not require a controller and operates only by supplying current to the electromagnet.



(a) A pen. (b) A pair of glasses.

(c) A boiled egg. (d) A chikuwa.

(e) A pistachio. (f) A bottle.

Fig. 7 The results of grasping experiment.

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