Simple Structured Gripper Using Electromagnet and Permanent Magnet

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***Abstract*—In this study, we propose a novel gripper with a simple structure for industrial robots. The gripper consists of a permanent magnet, an electromagnet, an elastic membrane, and water. It can grip and transport objects of various shapes without consuming electric power/vacuum power, and it requires electric power only when it releases a gripping object. This gripper has several advantages: easy downsizing without detailed designing, easy waterproof designing, low cost, light weight, and robustness against misalignment of objects. In this paper, we illustrate its structure, working principle, and experimental results.**

Keywords—universal gripper, permanent magnet, electromagnet, elastic membrane, industrial robot.

I. Introduction

The end effector used by industrial robots to transport objects is called a *gripper*. Recently, various universal grippers have been proposed to grip objects of various shapes and materials. Numerous researches exist on universal grippers, such as those constructed using an elastic membrane, jamming effect [1, 2], or magnetorheological (MR) fluid [3, 4]. In particular, the universal gripper using magnetic force has less operational constraints posed by the environment, as compared to grippers using air pressure. The MRα fluid gripper [3] consists of an elastic membrane enclosing the MRα fluid and an electromagnet. The MRα fluid is reformed MR fluid generated by adding nonmagnetic particles to a typical MR fluid. This gripper has numerous features; for example, it can grip objects readily because it can control the stiffness of an elastic membrane rapidly using magnetic force. Moreover, it can grip objects stably. However, detailed design and construction mechanism are required to downsize the MRα fluid gripper because of the use of MR fluid and the electromagnet [4].

In this research, we propose a novel gripper to further facilitate the construction of conventional universal grippers. The proposed universal gripper has simple structure that uses an electromagnet, a permanent magnet, an elastic membrane, and water. We have named the novel gripper as *water gripper*. The water gripper, with its simple structure, can grip objects having various shapes without consuming electric power. Electric power is required only when the gripper releases the objects. In this study, we demonstrate the structure, operating principle, and experimental results with regard to the water gripper.

II. Related Works

Various universal grippers with an elastic membrane have been developed that use air, motor (actuator), or magnetic force. Bacon et al. [1] and Amend Jr et al. [2] proposed a jamming gripper that uses an elastic membrane containing powder and an air compressor. Setiawan et al. [5] proposed an internal expansion gripper. This gripper grips objects by enclosing them and expanding its elastic membranes using air. Zhu et al. [6] proposed SSA gripper with an elastic membrane enclosing water. This gripper grips objects by raising a wire connected to the lower part of an elastic membrane using a motor. We proposed a gripper with an elastic membrane enclosing the MR fluid [3, 4]. The water gripper proposed in this study is similar to our MR fluid gripper in that it uses magnetic force. However, the water gripper does not require MR fluid and can be downsized easily without an extensive design process.

III. Design of Water Gripper

A. Components

The structure of the water gripper is shown in Fig. 1. We used hemispheric elastic membrane composed of natural rubber. By replacing the natural rubber materials with HNBR or fluoride rubber, the durability and stiffness of the elastic membrane can be improved. Water is enclosed inside the elastic membrane; oil, gel, or gas can be used instead of water. The permanent magnet is placed on the lower part of the elastic membrane. In addition, a gap between the permanent magnet and the electromagnet should be designed to separate the two. In this study, we inserted a cover made from nonmagnetic materials in the gap.

B. Principle

The gripping and releasing sequence of the water gripper is shown in Fig. 2. First, the gripper presses onto the object and covers the target with the elastic membrane. Subsequently, the gripper is lowered until the permanent magnet adsorbs the electromagnet; the elastic membrane fits to the shape of the object as shown in Fig. 2 (a). The elastic force owing to the restoration of the elastic membrane and the force due to the

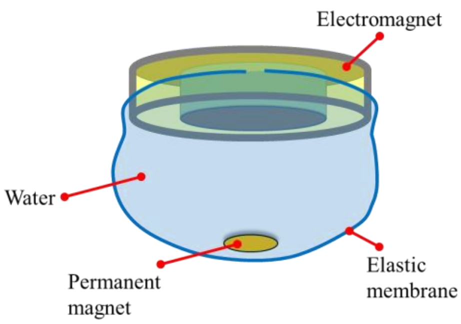


Fig. 1. Structure of water gripper

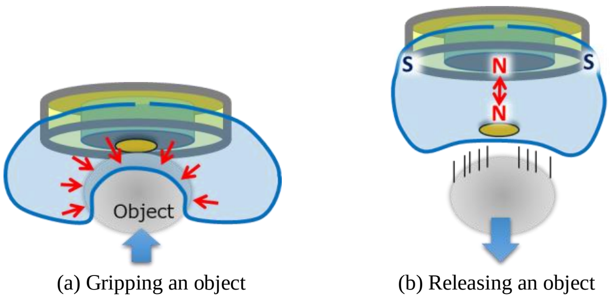


Fig. 2. Gripping and releasing sequence of water gripper

gravity of water are applied to the object. The frictional force proportional to a normal force against these resultant forces is generated on the contact surface between the object and the elastic membrane. Owing to this frictional force, the gripper can grip the object.

Subsequently, the electromagnet is supplied with electric power and the magnetic flux in the direction opposite to that of the permanent magnet is generated. Thereafter, the permanent magnet repels the electromagnet, it is peeled off, and the gripper releases the object owing to the elastic membrane returning to its original shape.

Here, we describe the forces between the permanent magnet and the electromagnet in the water gripper. The equilibrium forces are shown in Fig. 3. A vertically upward force is only an adsorption force between the permanent magnet and the electromagnet. This force depends on the thickness and magnetic permeability of the nonmagnetic cover. In addition, the vertically downward force is the resultant of the force due to gravity, elastic force, and repulsive force between the electromagnet and the permanent magnet. An elastic force depends on certain factors: the enclosed volume of water, direction and size of the target object, and material and thickness of the elastic membrane. Thus, when a target object is pressed onto the gripper and the permanent magnet adsorbs the electromagnet, a gripper can grip objects only if the vertically upward force is stronger than the vertically downward force. Moreover, when the repulsive force is generated by supplying electric power to the electromagnet, the vertically downward force is stronger than the vertically upward force, and the gripper can release objects.

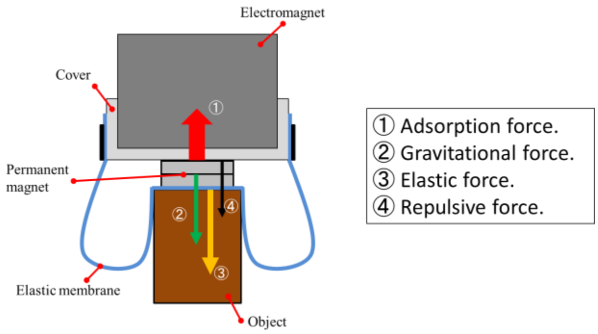


Fig. 3. Equilibrium of forces between the permanent magnet and the electromagnet in water gripper

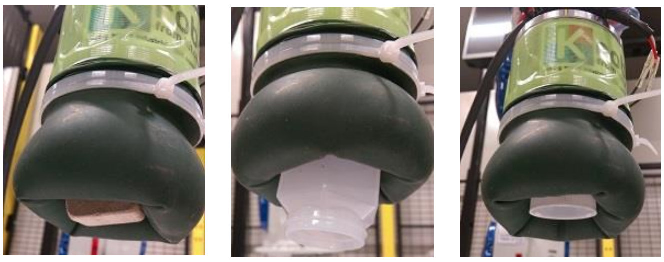
IV. Prototype of Gripper and Experiments

We developed a prototype of the water gripper as shown in Fig. 4 for proof of principle. We used an electromagnet with a diameter of 76 mm and length of 60 mm. To prevent direct contact between the permanent magnet and the electromagnet, the cover of the electromagnet was designed to be 2 mm thick and composed of ABS resin. The elastic membrane was composed of natural rubber and enclosed water (200 ml). We determined the volume of water by trial and error.

We conducted experiments to investigate the performance of the prototype gripper using objects with various shapes, such as a wood block, hexagon bottle, and bottle cap. All of them were composed of nonmagnetic materials. The gripping of objects by the water gripper is illustrated in Fig. 5. It was observed in these experiments that objects of various shapes and composed of various materials could be grasped by the water gripper without any damage. Moreover, high-precision alignment was not required. It was also confirmed that gripping and releasing cannot be performed accurately when the object is made of metal or is larger than the elastic membrane.

We conducted object-transport experiments by equipping an industrial robot with the gripper and using the following procedure: (1) the target object was gripped by the gripper; (2) the object was lifted to a height of 200 mm; (3) the object was transported 400 mm horizontally; (4) the object was lowered and released at the target position. A plastic bottle filled with water (500 ml) was used as a target object and its cap was set to the gripping point. From the experimental results, it was observed that the gripper could grip, transport, and release the target object; however, the bottom of the bottle was vibrating against the transporting direction during the transport process.

Fig. 4. Overview of water gripper



(a) Wood block (b) Hexagon bottle (c) Bottle cap

Fig. 5. Gripping objects of various shapes

V. DOWNSIZING OF WATER GRIPPER

The water gripper can be driven with less magnetic flux owing to the downsizing; thus, we can use a small electromagnet for the gripper. We addressed the downsizing of the components of the water gripper. The structure of the downsized gripper was the same as that of the above-mentioned gripper, and we used an electromagnet with a 50% reduced size compared to the original (diameter is 34 mm, height is 15 mm). We conducted the same experiments and confirmed that the gripper could grasp objects of various shapes. The overview of the downsized water gripper is shown in Fig. 6 and the object-gripping aspects are shown in Fig. 7. It was confirmed that the gripper could hold about 30 [g] materials. Moreover, we found that the gripping force and the stability of it depend on the shapes of objects and the filling ratio of water. Next, we equipped the water gripper into an industrial robot and conducted gripping experiments to evaluate the efficiency. Here, we used a boiled quail egg as a target object. The overview of gripping experiment is shown in Fig. 8. From this experiment, it was proved that the water gripper could grip a fragile and wet object such as the boiled quail egg.

Subsequently, we investigated the relation between the volume of water and the size of the object against the gripping performance. Here, a cylindrical object was used as the target object as shown in Fig. 9. First, we prepared a water gripper with a certain volume of water in the elastic membrane. Subsequently, we tested the gripping performance of the gripper against several objects with different diameters (i.e., $r = 10, 15, 20, 25, 30, 35, 40$ mm) and derived the gripping success rate as an average of ten iterations. The result is shown in Fig. 10. It is observed from the results that the size range of the object that could be gripped was the widest when approximately 60% of water was enclosed in the elastic membrane of the gripper.

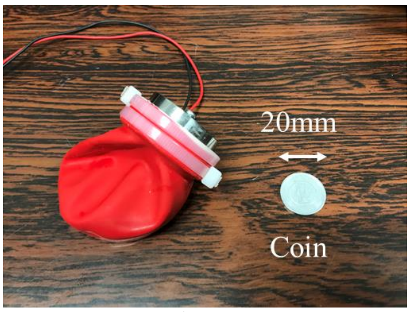
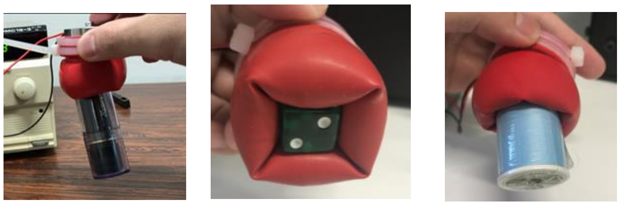
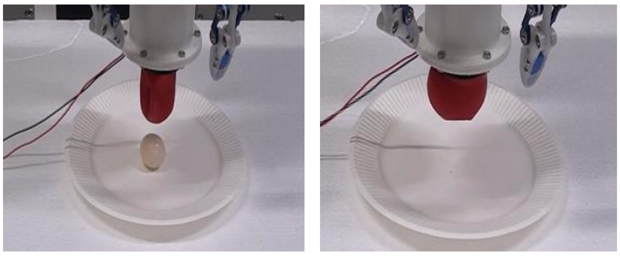


Fig. 6. Prototype of downsized water gripper



(a) Cylinder case (b) Dice (c) Column

Fig. 7. Gripping objects of various shapes



(a) Initial position. (b) Gripping.

Fig. 8. Gripping of a boiled quail egg by the small water gripper.

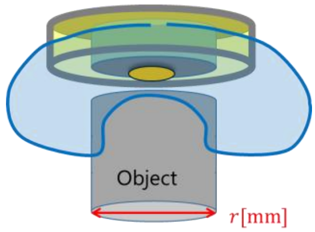


Fig. 9. Experimental environment

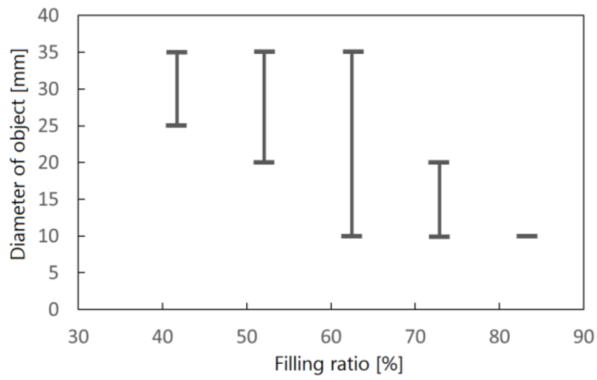


Fig. 10. Gripping performance: object diameter versus water filling rate of elastic membrane

VI. CONCLUSION

We proposed a novel universal gripper with simple structure. Furthermore, we constructed a prototype gripper, proved its driving principle via basic experiments, and demonstrated that the gripper could grasp objects of various shapes. In addition, we equipped a gripper in an industrial robot and conducted several experiments to investigate the performance of the gripper. With regard to this system, it was confirmed that the object could be grasped, transported, and released at a desired position. A phenomenon wherein the object vibrated during transportation was observed, however, it had no influence on the series of operations. This gripper does not require large electric power and complicated power supply circuit for operating. Because the elastic membrane can be composed of fluoride rubber or HNBR, it is easy to improve the durability. This gripper can be manufactured at low cost, and even when it is damaged, it can easily be repaired by replacing the gripper.

REFERENCES

[1] G. Bacon, B. Huber, "Depression and grippers with their possible applications," *12th ISIR*, Paris, pp. 321–329, 1982.

[2] J. R. Amend Jr, E. Brown, N. Rodenberg, H. M. Jaeger, H. Lipson, "A positive pressure universal gripper based on the jamming granular material," *IEEE trans. on Robotics*, vol. 20, pp. 341–350, 2012.

[3] T. Nishida, Y. Okatani, K. Tadakuma, "Development of universal robot gripper using MRα fluid," *Int. Journal of Humanoid Robotics*, vol. 13, No. 4, 16500171(13 pages), 2016.

[4] Y. Tsugami, T. Barbié, K. Tadakuma, T. Nishida, "Development of universal parallel gripper using reformed magnetorheological fluid," in printing, 2017.

[5] A. I. Setiawan, T. Furukawa, A. Preston, "A low-cost gripper for an apple picking robot," *Robotics and Automation, 2004. Proceedings. ICRA '04. 2004 IEEE Int. Conf. on*, vol. 5, pp. 4448–4453, 2004.

[6] T. Zhu, H. Yang and W. Zhang, "A Spherical Self-Adaptive Gripper with shrinking of an elastic membrane," *International Conference on Advanced Robotics and Mechatronics (ICARM)*, Macau, pp. 512–517, 2016.