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Development of Universal Robot Gripper Using MRα Fluid

Takeshi Nishida* and Yuki Okatani†
Department of Mechanical and Control Engineering,
Kyushu Institute of Technology, 1-1 Sensui,
Tobata, Kitakyushu, Fukuoka 8048550, Japan
**nishida@cntl.kyutech.ac.jp*
†*o344210y@maill.kyutech.jp*

Kenjiro Tadakuma
Graduate School of Information Sciences,
Applied Information Sciences,
Information and Applied Technology,
Human–Robot Informatics, Tohoku University,
6-6-01 Aramaki Azaaoba, Aoba
Sendai 9808579, Japan
tadakuma@rm.is.tohoku.ac.jp

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In this paper, we developed a universal robot gripper using an electromagnet and a novel reforming magnetorheological (MR) fluid. First, we added nonmagnetic particles to an MR fluid to develop a novel reforming MR fluid called MRα fluid; this fluid resolved several issues faced with MR fluids. The developed fluid's specific gravity is one-half and solidification hardness is two times that of MR fluid. The characteristics of the MRα fluid and an application that can control solidification under a magnetic field are described. Next, the developed gripper, which consists of an electromagnet and an elastic membrane that encloses the MRα fluid, is described. Further, several experimental results of the features and capabilities of the gripper are presented.

Keywords: Industrial robot; universal gripper; MR fluid.

1. Introduction

The end effectors used to grip objects are called grippers. The general industry practice is for grippers to employ automatic exchange equipment in accordance with the position and shape of the target in the working process. Figure 1 shows examples of the end effector of industrial robots. However, these equipment require several

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*Corresponding author.

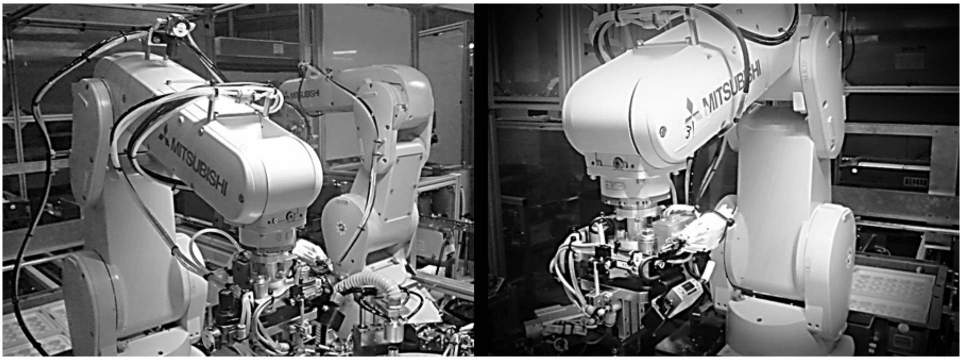

Fig. 1. Examples of end effectors of industrial robots. In recent years, complicated end effectors have been developed for application to various manufacturing processes.

procedures such as the selection of an appropriate gripper and the design of a grip plan according to the estimated position of the target. These issues have limited the applications of grippers in high-speed automatic factories.

Various types of end effectors have been developed to adapt industrial robots to various tasks. Many studies have been conducted on the mechanism and shape of end effectors,[1–3] target grip planning,[4,5] and selection of grippers.[6,7]

A novel gripper to improve work efficiency was developed to curtail the position estimation of the grip target and the exchange of the gripper.[1,8] This gripper is called the universal jamming gripper,[8] and it can grip objects of arbitrary shapes using the jamming phenomenon,[a] which occurs in ground coffee that fills an elastic membrane, and an air compressor is used to relieve air pressure in the elastic membrane. In the early stage of this study, we developed the universal jumming gripper shown in Fig. 2 based on literature.[8] This gripper grips a target as follows: (i) the gripper is pressed against the target, and the elastic membrane part copies the shape of the target; (ii) the elastic membrane part is sucked by the air compressor, and it hardens with the jamming phenomenon; and (iii) the target is lifted and manipulated. Because the gripper can grip targets of arbitrary shapes and positions, the exchange of the gripper is not required in the working process. Moreover, complicated calculations of the target hold plan, posture estimation of the target object from a hold start to completion, and so on are unnecessary. On the other hand, through several preliminary experiments, we confirmed that the grip force of the universal jamming gripper fluctuates according to the adjustment of the amount of filling. This fact suggests that changes in the volume of air in the elastic membrane may affect the grip force. Because the grip force depends on the balance between the environment inside the elastic membrane and the external environment, it is difficult to use the gripper in an

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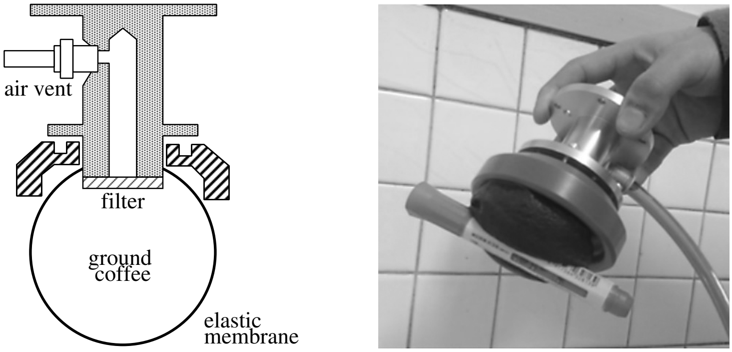
[a] This phenomenon is characterized by the loss of mobility and solid-like behavior if the density of the granular material becomes high.



(a) (b)

Fig. 2. Developed universal jamming gripper (conventional gripper). (a) Schematic diagram and (b) overview.

environment in which the surrounding pressure is high and the surrounding temperature is changed easily. Moreover, underwater use is clearly difficult, and the air pump is loud.

Therefore, to remove these constraints on the operation of the jamming gripper, we focus on a magnetorheological (MR) fluid. An MR fluid is a smart magnetic fluid, and it can be transformed instantly between the fluidized and the solidified states at any shape by applying a magnetic force under the above-mentioned constraints. First, we reviewed the properties of the MR fluid. Then, we added nonmagnetic particles to the MR fluid to obtain the novel reforming MR fluid called MRα fluid; the new fluid showed increased hardness upon solidification. Next, we developed a novel universal gripper using an electromagnet and an elastic membrane that enclosed the MRα fluid.

Over the last few years, several studies have focused on the combination of an MR fluid and a multifingered robotic hand. For example, one study improved the hold performance by attaching bags in which MR fluid was enclosed at the fingertips of a pneumatic chuck.[9] However, these studies have focused on improving the performance of a multifingered robotic hand. No study has tried to develop a mechanism for grasping objects using a single elastic membrane that encloses an MR fluid. Therefore, we conducted some experiments on the MRα fluid to investigate the grip force and its characteristics. Furthermore, we installed the gripper in an industrial robot and verified its effectiveness through some experiments.

The remainder of this paper is organized as follows. In Sec. 2, the preparation of the proposed MRα fluid and the construction of the gripper are described. In Sec. 3, the performance of the proposed gripper is verified through experiments. In Sec. 4, the performance and characteristics of the MRα fluid are investigated. Finally, in Sec. 5, the findings of this study are summarized.

2. MR Fluid for Universal Gripper

2.1. *Smart fluids with controllable solidification*

The solidification of electrorheological (ER) and MR fluids can be controlled by applying electric and magnetic fields, respectively. Recently, these fluids have often been used as components of robotic peripherals, and the associated control methods and characteristics are widely known. The viscosity of an ER fluid changes according to the electric field, and it has a homogeneous and dispersed system.[10] An ER fluid is a Newtonian fluid, whereas an MR fluid is a Bingham fluid. The shear stress of a Newtonian fluid is proportional to its shear rate, and its shear stress is 0 kPa when its shear rate is 0 s^{-1}. In other words, its viscosity can be changed, but it does not behave like a solid. On the other hand, because a Bingham fluid has a shear stress when its shear rate is 0 s^{-1}, it behaves like a solid. In other words, a dispersed MR fluid behaves like a solid in an electric field.

Next, the viscosity of the MR fluid increases by 106 times in several milliseconds under an applied magnetic field. In the absence of a magnetic field, an MR fluid has much higher liquidity than other magnetic fluids. However, when a magnetic field is applied, a large shear stress of several kilopascals is produced in the fluid, which makes the fluid solid.[11,12]

As mentioned above, a dispersed ER fluid and MR fluid are candidate fluids that can achieve an effect similar to the jamming phenomenon. These two types of fluids afford the advantage of a rapid response to magnetic field changes. On the other hand, in general, an MR fluid can produce a larger shear stress than the dispersed ER fluid under the same electric field. Therefore, we constructed the novel universal gripper using the MR fluid.

2.2. *Problems with MR fluid*

The shear stress of a conventional MR fluid becomes saturated at 90 kPa under a magnetic flux of 0.3 T.[11] To confirm whether the elastic membrane enclosing an MR fluid can be solidified sufficiently using a neodymium magnet, which is the most powerful type of magnet, we conducted a preliminary experiment. In this experiment, a latex balloon filled with 100 mL of MR fluid was kept in contact with a neodymium magnet under a magnetic flux density of 0.3 T, and whether a lightweight cable can be gripped by the solidified balloon was investigated. The results of this experiment are as follows:

- The MR fluid almost did not solidify at a large distance from the neodymium magnet, because the magnetic flux density decreases rapidly with the distance from the magnet. In other words, sufficient solidification of the entire MR fluid for gripping the object did not occur.
- Because the MR fluid had a comparatively large specific gravity, the balloon hangs down in the direction of gravity.

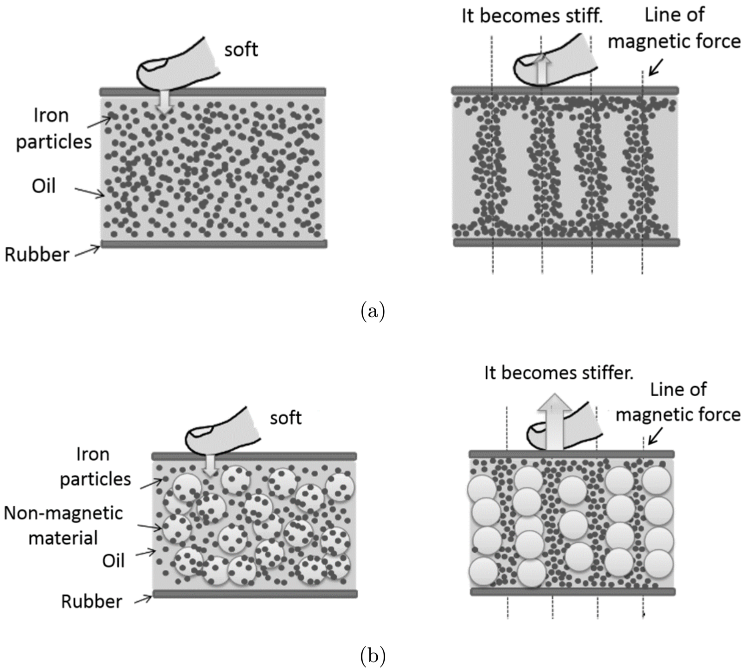
- A strong force was required to pull apart the neodymium magnet and the balloon. This suggests that the use of an electromagnet is desirable for quick control of the MR fluid.
- The latex balloon, made of natural rubber, dissolved with the passage of time. It was determined that the oil contained in the MR fluid dissolved the natural rubber.

3. MRα Fluid Gripper

In general, because the magnetic flux density of electromagnets per unit weight is lower than that of neodymium magnets, we must prepare a large, heavy electromagnet to generate sufficient magnetic flux density for the solidification of the MR fluid. Furthermore, the specific gravity of the MR fluid is comparatively high. Therefore, installing a gripper that includes many MR fluids in a general industrial robot whose payloads are of the order of 10 kg may be difficult. We developed a novel MR fluid called MRα fluid to solve these problems. Below, we describe the solidification principle of the MRα fluid and the details of its experimental study.

3.1. *Solidification principle of MRα fluid*

The principle underlying the solidification of the MR fluid under a magnetic field is shown in Fig. 3(a). A conventional MR fluid consists of iron particles with diameters



(a)

(b)

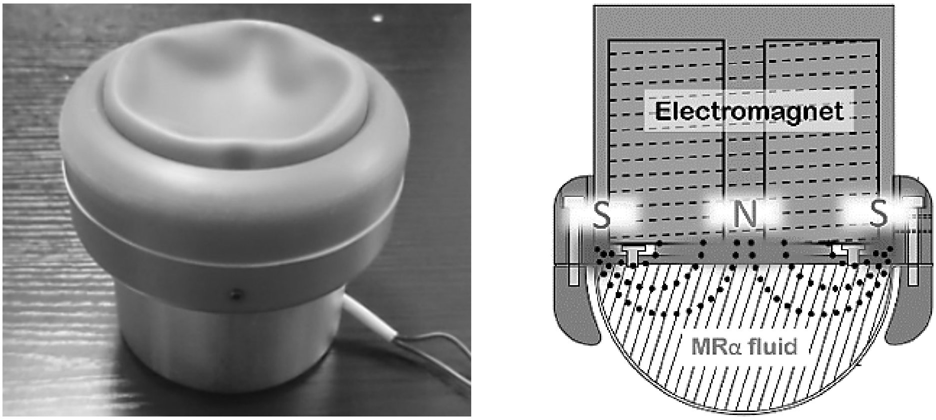
Fig. 3. Solidification principle of: (a) MR fluid and (b) MRα fluid.

of a few micrometers, oil, and additives that prevent the precipitation of the iron particles. When a magnetic field is applied, the iron particles align themselves along the lines of magnetic flux and form a columnar structure, and the elastic membrane enclosing the MR fluid solidifies. When a force greater than the shear stress of the MR fluid is applied externally, the columnar structure is destroyed and deformed. Then, when the magnetic field is removed, the iron particles revert to the random distribution state. Although the solidification hardness of the MR fluid can be improved by changing the mixing ratio of iron powder and oil to a value that can generate a sufficiently large shear stress to increase the amount of iron powder, its fluidity decreases remarkably and weight increases.[12]

The solidification principle of the MRα fluid with a magnetic field is shown in Fig. 3(b). This fluid is prepared by mixing the MR fluid and the nonmagnetic particles, and it has the following features: the solidification force with a fixed magnetic flux density is more than two times as strong as that of the MR fluid, and the specific gravity is approximately one-half that of the MR fluid. When a magnetic field is applied, the iron particles align themselves along the lines of magnetic flux and form a columnar structure, and the nonmagnetic particles enter the crevice between the iron column structures. When an external force is applied, the nonmagnetic particles act as an aggregate of the columnar structure of the iron particles. With such a mechanism, the shear stress of the MRα fluid becomes strong against an external force.

3.2. *Construction of MRα fluid gripper*

We developed a universal gripper using the MRα fluid called the MRα fluid gripper, which is shown in Fig. 4. Because it was found that the oil in the MR fluid dissolves



(a) (b)

Fig. 4. Prototype of MRα gripper. (a) Overview of MRα fluid gripper and (b) structural diagram of MRα fluid gripper.

the natural rubber, we used hydrogenated nitrile rubber as the elastic membrane of the gripper. The hydrogenated nitrile rubber is filled with a fixed quantity of the MRα fluid. Moreover, an external collar was made to pinch the hydrogenated nitrile rubber and connect the rubber and the electromagnet.

3.3. *Characteristics of MRα fluid*

The experiment was conducted to investigate how the properties of the MRα fluid are influenced by the size of the nonmagnetic particles. The prototype of the MRα fluid gripper shown in Fig. 4 was used for the experiment. We used nine types of nonmagnetic particle sizes, and the maximum and minimum diameters were 2.0 mm and 0.0055 mm, respectively. The experiment was conducted as follows: (i) the mixed volume ratio in the MRα fluid of the MR fluid and nonmagnetic particles was 50%; (ii) the elastic membrane was filled with MRα fluid; (iii) the perpendicular upper part of the gripper was pressed to a target object connected to a force gage, a power supply was connected to the electromagnet, and the target object was gripped by the gripper; and (iv) the gripper was pulled up, and the maximum force on the target object was measured as shown in Fig. 5. Nonmagnetic particles of various sizes were mixed with the MR fluid, and the maximum grip forces of the gripper for various particle sizes were measured by the above procedure. The experimental results are shown in Fig. 6. The results show that the grip force of the gripper is maximized when the nonmagnetic particle diameter is 0.0221 mm. It was found that the gripping force of the gripper can be increased by mixing smaller particles. On the other hand, when very small particles were mixed, the gripper could not hold any object.

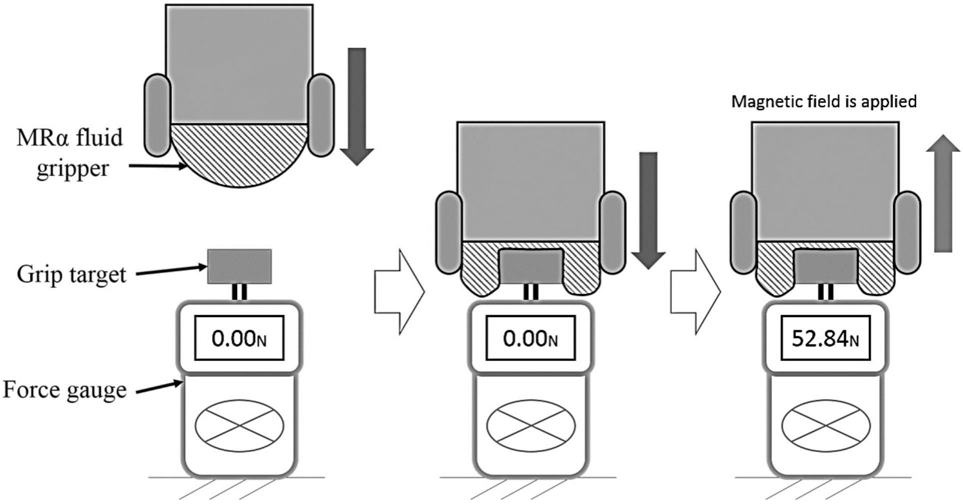


Fig. 5. Measuring gripping force of MRα fluid gripper.

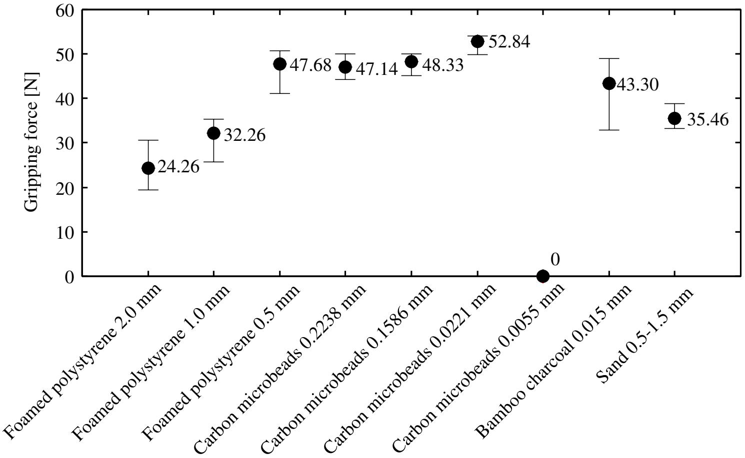


Fig. 6. Gripping force versus sizes of nonmagnetic particles.

3.4. *Mixed volume ratio of nonmagnetic particles*

The above experiment showed that a nonmagnetic particle diameter of 0.0221 mm was suitable for preparing the MRα fluid. Therefore, next, we investigated the properties of the mixed volume ratio of the nonmagnetic particles. This experiment was conducted by measuring the grip force when the mixed ratio is changed as follows: (i) several samples of MRα fluid with the same volume were prepared by changing the mixing volume ratio of the MR fluid and the nonmagnetic particles; (ii) the elastic membrane was filled with the MRα fluids in order; (iii) the perpendicular upper part of the gripper was pressed to a target object connected to a force gage, a power supply was connected to the electromagnet, and the target object was gripped by the gripper; and (iv) the gripper was pulled up, and the maximum force on the target object was measured as shown in Fig. 5. The results of the experiment are shown in Fig. 7. The results show that the grip force of the MRα fluid gripper is maximized at 50% mixing ratio of the MR fluid and nonmagnetic particles.

3.5. *Thickness of hydrogenated nitrile rubber*

Next, an experiment was conducted to determine the relation between the thickness of the rubber and the gripping force. We used hydrogenated nitrile rubber of three thicknesses: 0.3 mm, 0.5 mm, and 1.0 mm. The following experiment was conducted by measuring the grip force when the thickness of the hydrogenated nitrile rubber was changed as follows: (i) the mixed volume ratio of the MR fluid and nonmagnetic particles was 50% in the MRα fluid; (ii) the hydrogenated nitrile rubber was filled with the MRα fluids in order; (iii) the perpendicular upper part of the gripper was pressed to a target object connected to a force gage, a power supply was connected to the electromagnet, and the target object was gripped by the gripper; and (iv) the

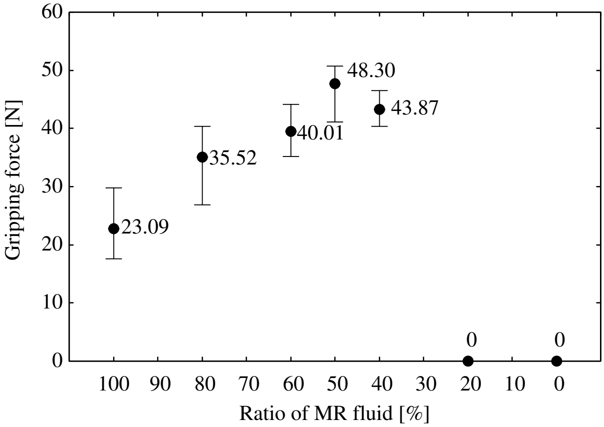


Fig. 7. Grip force versus mixed volume ratio of nonmagnetic particles.

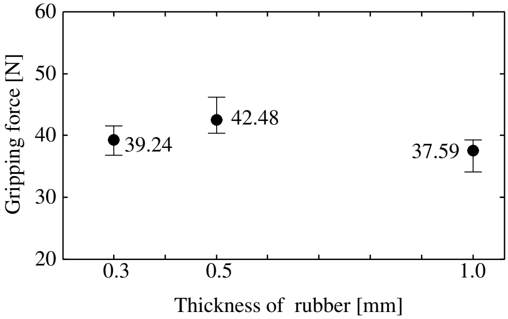


Fig. 8. Grip force versus thickness of hydrogenated nitrile rubber.

gripper was pulled up, and the maximum force on the target object was measured as shown in Fig. 5. The results of the experiment are shown in Fig. 8. Within the limits of this experiment, it was found that the maximum gripping force is generated by using rubber of 0.5-mm thickness. Although the grip force of rubber with 1.0-mm thickness was 92.4% of that of rubber with 0.5-mm thickness, its durability can be expected to improve.

4. Installation in an Industrial Robot

We installed the MRα gripper in a six-axes industrial robot and conducted several grip experiments. First, we installed the MRα fluid gripper in the robot and programmed the robot so that it could manipulate the target object by teaching playback. Next, we conducted several experiments to confirm the gripping ability with

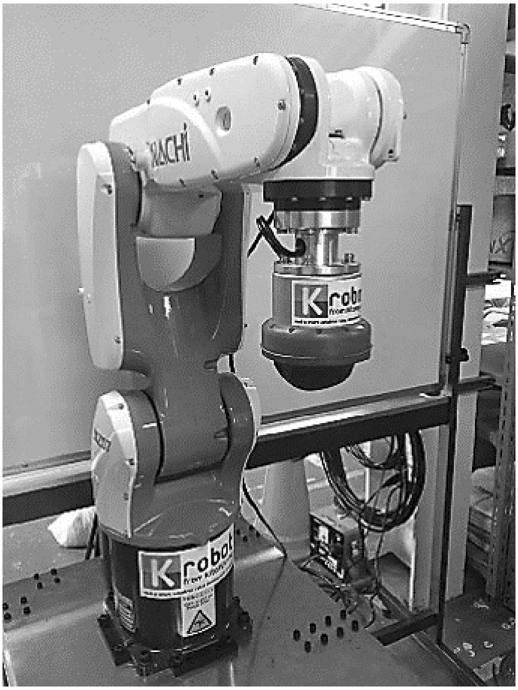
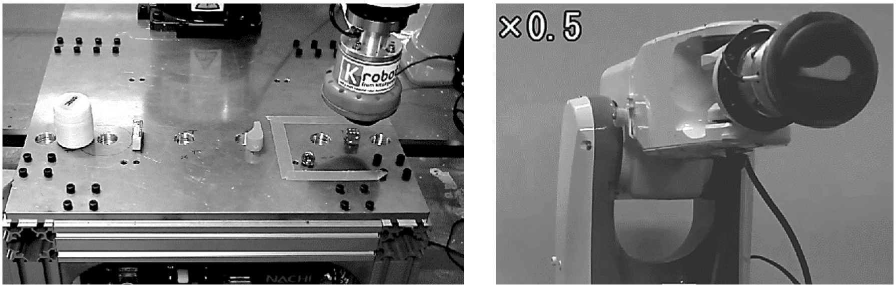


Fig. 9. Six-axes industrial robot equipped with developed novel gripper using MRα fluid.

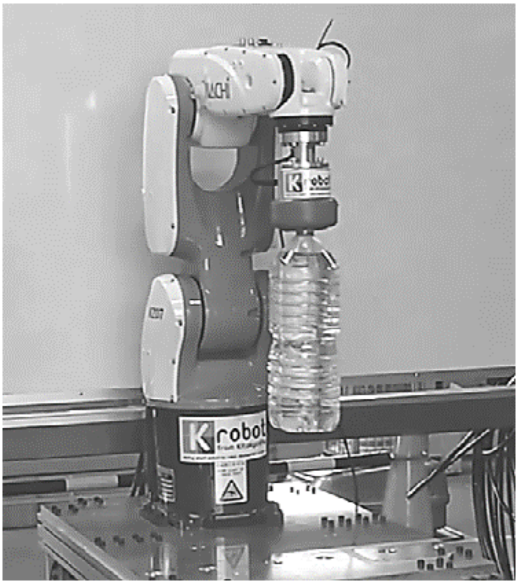
various nonmagnetic objects, as shown in Fig. 10(a). These experiments confirmed that nonmagnetic objects of various shapes can be gripped by the developed gripper, as shown in Fig. 10(b). Moreover, a 2-L bottle filled with water could be lifted satisfactorily. The ability to generate a maximum payload of 52.84 N was confirmed. The 70-N payload of this industrial robot could be handled successfully.



(a)

(b)

Fig. 10. Operation of developed gripper using MRα fluid. (a) Gripping several targets: dice, marble, whistle, eraser, and small container. (b) Gripping a whistle. (c) Gripping a water bottle.



(c)

Fig. 10. (*Continued*)

5. Conclusion

First, the advantages and disadvantages of the universal jamming gripper developed in recent years were reviewed, and the characteristics of ER and MR fluids were described. Next, the solidification principle of the MR fluid as well as that of the MRα fluid, which compensates for the disadvantages of the MR fluid, was described. Then, through an experiment to investigate the influence of the size of the mixed nonmagnetic particles, it was found that the suitable diameter for maximizing the grip force of the gripper is 0.0221 mm. Moreover, through an experiment to investigate the influence of the mixing volume ratio, it was found that the grip force of the MRα fluid gripper is maximized at a 50% mixing ratio of MR fluid and nonmagnetic particles. Next, through an experiment to investigate the influence of the thickness of the hydrogenated nitrile rubber, it was found that the grip force of the MRα fluid gripper is maximized at a thickness of 0.5 mm. Finally, we developed a novel gripper using the MRα fluid and verified its performance by installing it in an industrial robot. The experiments confirmed that nonmagnetic objects of various shapes could be gripped by the developed gripper, and a maximum gripping force of 50.67 N could be generated.

In future studies, the components, i.e., silicone rubber, electromagnet, and external collar of the gripper, will be improved.

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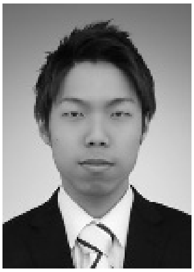
Takeshi Nishida received his M.Sc. and Ph.D. degrees from Kyushu Institute of Technology in 1999 and 2002, respectively. From 2002–2012, he was an Assistant Professor at the Kyushu Institute of Technology. From 2013, he has been an Associate Professor at the same institution.

His research interests include control engineering, artificial intelligence, and robotics. He is an active member of the Society of Instruments and Control Engineering, Robotics Society of Japan, and so on.



Yuki Okatani received his B.Engrg. degree from Kyushu Institute of Technology in 2014. He is currently a Master's student in the Department of Control Engineering, Kyushu Institute of Technology.

Kenjiro Tadakuma received his Ph.D. degree in Mechanical and Aerospace Engineering from Tokyo Institute of Technology in 2007. He was a Visiting Researcher at the Massachusetts Institute of Technology from September 2006–March 2007. He was a Postdoctoral Associate at the same institute from April 2007–December 2007. From January 2008–March 2008, he was a Postdoctoral Research Fellow at the Department of Aerospace Engineering, Graduate School of Tohoku University.

From April 2008–July 2009, he was an Assistant Professor at the University of Electro-Communications. From August 2009–April 2015, he was an Assistant Professor at the Graduate School of Osaka University. From May 2015, he has been an Associate Professor at the Graduate School of Tohoku University. His research interests mainly include mechanisms and omnidirectional mobile robots.