

MINIATURE FIVE-FINGERED ROBOT HAND DRIVEN BY SHAPE MEMORY ALLOY ACTUATORS

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ABSTRACT

Miniature five fingered robot hand is developed for dexterous manipulation of small tissues and parts in medical and industrial fields. The size of the robot hand is about one third of human hands. It has 4 DOF (degrees of freedom) per a finger that is almost the same as humans. The entire DOF of the hand is 20. The hand is driven by SMA (shape memory actuator) wire actuator with diameter of 0.05 mm. The maximum strain of the SMA wire is about 0.04. Time constant of the finger movement is about 0.2s. It means that the frequency response of the developed hand is almost in the same range as human fingers. The developed robot hand can be used in dexterous remote manipulations of small things.

KEY WORDS

Miniature robot hand, shape memorizing alloy actuators, dexterous manipulation

1. Introduction

Numbers of robot hands have been developed in recent years [1]-[11]. They can be divided into two categories. The one is the robot hands that are developed without imitating human hands' design. The other is human-hand-like hands. Those robot hands are made by trying to mimic human hands' design. Merits of the former hands are that there are no limitation in DOFs, movable range, size and geometry. Wide variety of design variables can be selected to make specific robot hands. Some of them are commercialized and utilized in various fields. The merit of the other hands is that they are suitable for remote operation by humans because the most of the DOF (degrees of freedom) of the robot fingers are easily controlled by moving corresponded DOF of human fingers. There are numbers of human-hands-like robot hands. They are developed mainly to realize the remote operation as a master-slave system to transfer humans' dexterous and skilful grasping and manipulation in special environments including medical, welfare, space, extreme and virtual environments. Those hands are especially effective when humans have to do unexpected operations

in unexpected environments. If the task is known, human usually use the conventional pattern of movement of fingers or even tools having less DOFs. On the other hand, human and robot hands having approximately 20-DOF has redundant DOFs. It means that the most of the DOF are not used in the conventional operations. However, the redundancy is important when the unexpected manipulation in unexpected situation is needed. This is why human has redundant DOFs. Hence, the robot hands having DOFs and geometry similar to humans are useful in the dexterous remote operations. Especially, miniature robot hands are needed in order to manipulate small tissues and parts that are too small for human hands to manipulate. However, miniature robot hands having DOFs similar to humans have not been realized yet. The reason is that it is not easy to develop small-sized, rapid and dexterous human-like hands. One of the key technologies to realize such hands is actuators. It is not easy to find small, rapid and easy-to-control actuators. SMA (shape memorizing actuator) is one of the candidates of such actuators. It has a large power per unit volume. However, it is usually thought that response of the SMA is too slow to be the kind of actuators because it needs the long heating and cooling time. Heat transfer speed is proportional to surface area. Smaller the SMA is, larger the surface area per unit volume becomes. Hence, SMA has a possibility to be a rapid actuator when the size is small enough.

In the present paper, SMA wire is used as an actuator in order to develop a miniature human-hand-like robot hand having 20-DOFs with rapid response for dexterous remote manipulation by humans. In the section two, human's ability of manipulating small object is shown. In the section three, development of the robot hand is described. In the section four, results of experiment for evaluating the developed robot hand is shown. Finally, in the section 5, the research is concluded.

2. Experiment on human's manipulation

It is important to show the difficulty of human hands to manipulate small objects in order to indicate the needs of remote manipulation by use of small robot hands. Hence,

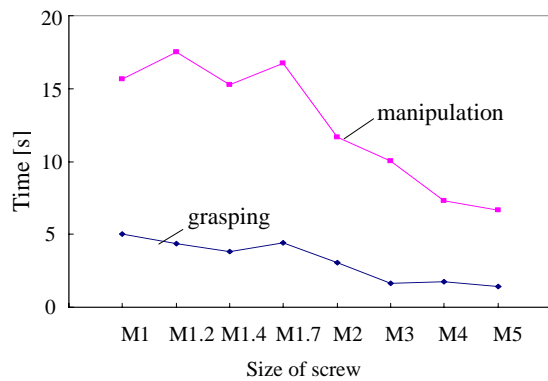


Fig. 1 Result of grasp manipulate experiments

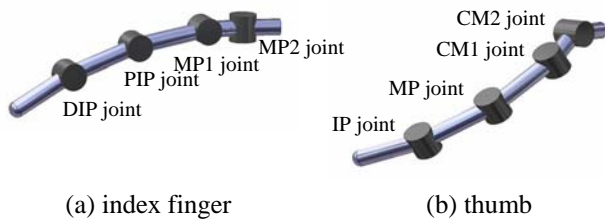


Fig. 2 Arrangement of degrees of freedom

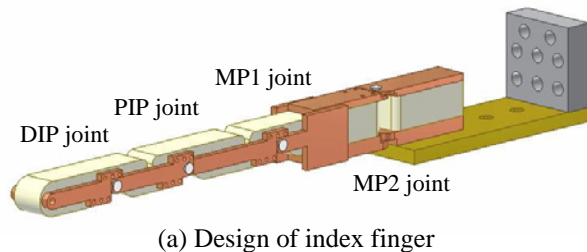


Fig. 3 Three-dimensional CAD image of index finger

authors have investigated on the difficulty for humans in treating bolts and nuts. Subjects are asked to complete two tasks. One is to grasp the bolts having different diameter and the same length. The other is to screw the same bolt into the nuts that fit the selected bolts by using their finger pads of index finger and thumb. They are asked not to use their nails in order not to change the method of grasping and manipulating. Smaller the size is, more difficult the achievement of the tasks are. Sizes of the bolts are M1, M1.2, M1.4, M1.7, M2, M3, M4 and M5. M stands for the mater standard series screw. Numbers followed by M stand for the diameter. Length of all the bolts are 5mm. Average time for achieving a couple of tasks is shown in Fig. 1. Tendency can be seen that the grasping/manipulating time increases when the size of the bolt decreases. Especially, when the diameter is approximately less than 2mm, grasping/manipulating time becomes large. Hence, we can conclude that small hand is needed in order to grasp/manipulate small object less than 2mm. From this, we decide the robot hand size to be about one third of average human hand size.

3. Development of 20-DOF miniature robot hand

3.1 Design

DOF (degrees of freedom) of the robot finger is decided to be four by imitating human finger. Hence, total DOF is 20. Figure 2 shows the arrangement of DOFs. It is shown that the DIP and PIP joints have one DOF and the MP joint has two DOFs. Joint angle is set to be almost the same as that of the humans. Maximum frequency of the robot finger is set to be about 5Hz by imitating human fingers' response.

SMA (shape memory alloy) wire made of Ni-Ti alloy with diameter of 0.05mm is used as an actuator. The maximum strain of the SMA wire in the longitudinal direction is 0.04.

Outline of the robot finger and its driving mechanism is shown in Fig. 3. A couple of wires are connected to each joint through a wire guide as shown in Fig. 3 (b). Wire guides are for making the pass of the wire through the rotational center of joints. Wires are connected to SMA wires after going through the holes shown at the right side in Fig. 3 (a). If one of the SMA wire is heated by applying voltage, the SMA wire shrinks and the joint moves to one direction. If an opposite SMA wire is heated, the finger rotates to the opposite direction. Total of eight SMA wires are connected to four DOFs shown in Fig. 2. Eight SMA wires are fixed at the end. Fixed end is a metal that is an electrical ground. Another side of the SMA wire is connected not only to the wire but also to an electrode. Length of SMA wires is about 130 mm. The maximum displacement of the SMA wires is about 5.2 mm because the strain is 0.04. It means that the SMA is located at the robot arm similar to the muscles of humans for moving finger.

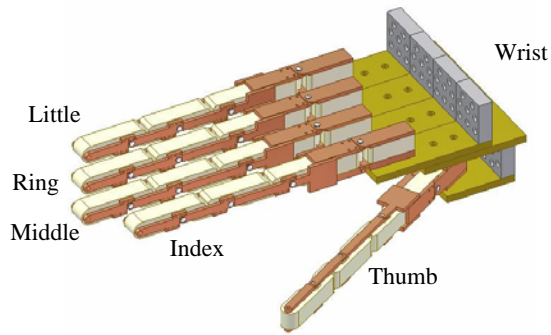


Fig. 4 Three-dimensional CAD image of five fingered robot hand

Table 1 Length of finger

	Distal	Middle	Proximal	Proximal 2	length	width
Thumb	6.60	6.60	10.50	11.00	34.70	4.00
Index	6.60	6.60	9.95	11.00	34.15	3.00
Middle	6.60	6.60	10.50	11.00	34.70	3.00
Ring	6.60	6.60	9.95	11.00	34.15	3.00
Little	6.60	6.60	8.95	11.00	33.15	3.00

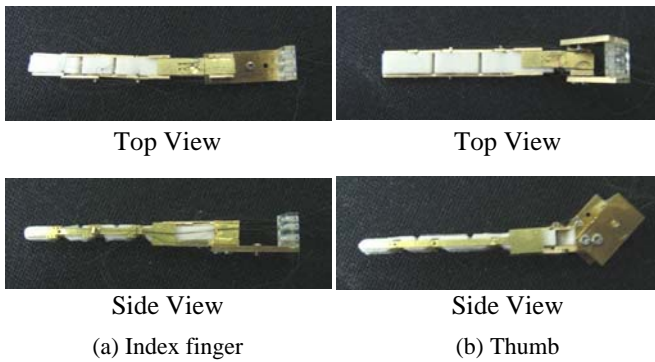


Fig. 5 Developed robot finger

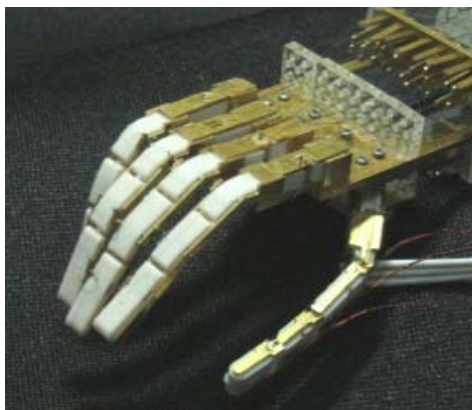


Fig. 6 Developed five-fingered robot hand

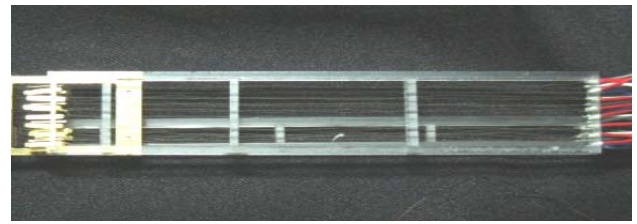
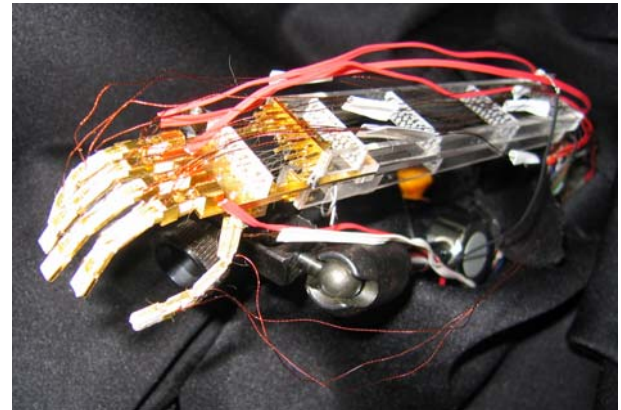
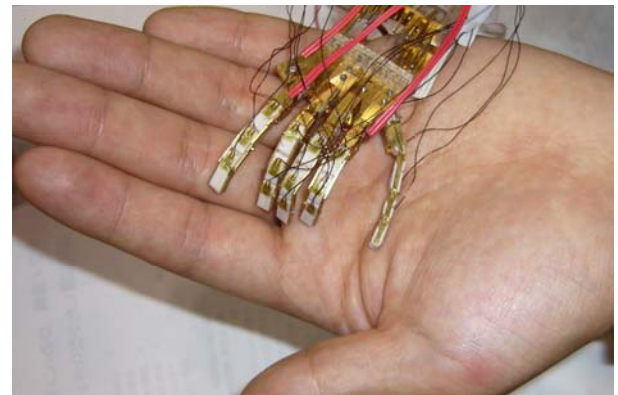


Fig. 7 Developed SMA actuators



(a) Entire view of robot hand



(b) Comparison between robot/human hands

Fig. 8 Developed five fingered robot hand

Fig. 4 shows the entire view of the designed robot hand (SMA wires inside the arm connected to the wrist are not shown.) We can see that the geometry and DOFs are similar to those of humans. Table 1 shows the length of each part. We can conclude that the size is about one third of average human hands.

Finger itself is made by use of plastic material. Joints are made of elastic silicone material. It works as an elastic

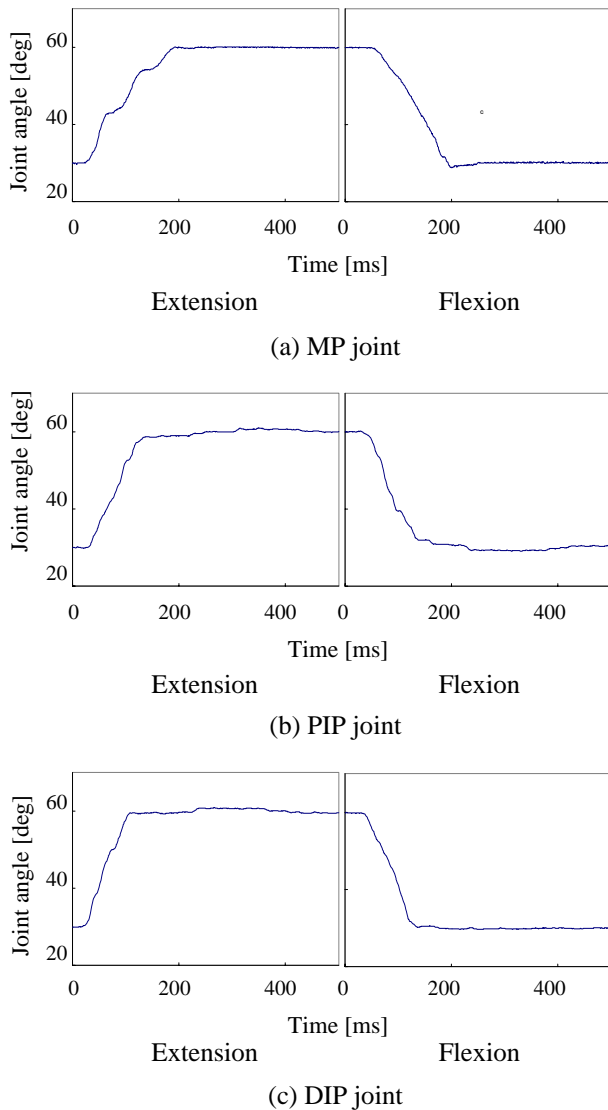


Fig. 9 Result of step response

hinge. Inside the each elastic silicone at the joint, a strain gage is incorporated. The strain gage is used as an angle sensor.

3.2 Manufacturing

The designed robot hand is manufactured. Figure 5 shows the developed robot finger.

Figure 6 shows the developed robot hand. Figure 7 shows the SMA actuator part that is in the arm connected to the wrist. Figure 8 shows the entire view of the robot hand.

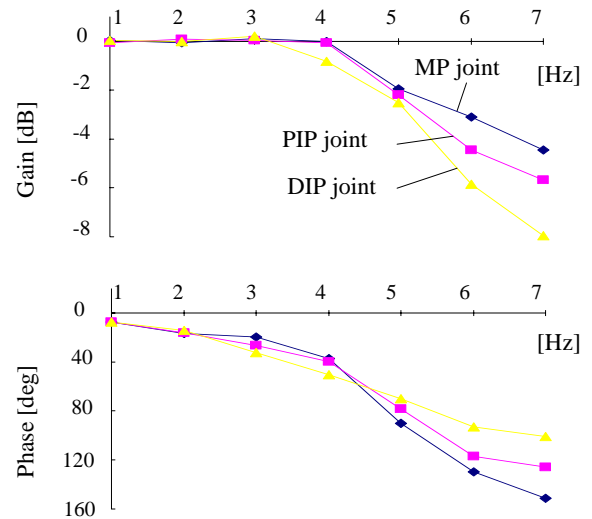


Fig. 10 Frequency response of finger joints

4. Evaluation

4.1 Step response

In order to clarify the response time, we have conducted the step response test. Step voltage is applied to the SMA wire and the angles of each joint are measured. Figure 9 shows the results. It is shown that the time constant is less than 200ms. It means that the response speed of the actuator is about the same range compared with human fingers. It is shown that the MP joint is the slowest. It is because the inertia of the driven part is larger compared with that of PIP and DIP joints.

4.2 Frequency response

We also conducted the frequency response test to analyze the response of the fingers in detail. Some of the results are shown in Fig. 10. Initial posture is that fingers are bent for 20 degrees. Amplitude is 20 degrees. It is shown that the responsibility is good when the frequency is less than 4Hz.

4.3 Output force

We measured the output force of fingers. Maximum force at the top of the index finger perpendicular to the longitudinal axis is 75mN. It is enough for manipulating small parts using the miniature robot fingers.

4.4 Grasp experiment

Napier [13] has shown that grasping can be categorized into power grasp and precision grasp. Grasping pattern of both categories is also shown. In this study, we have conducted grasping experiment to show Napier's grasping can be realized. Fig. 11 shows that all the grasping can be

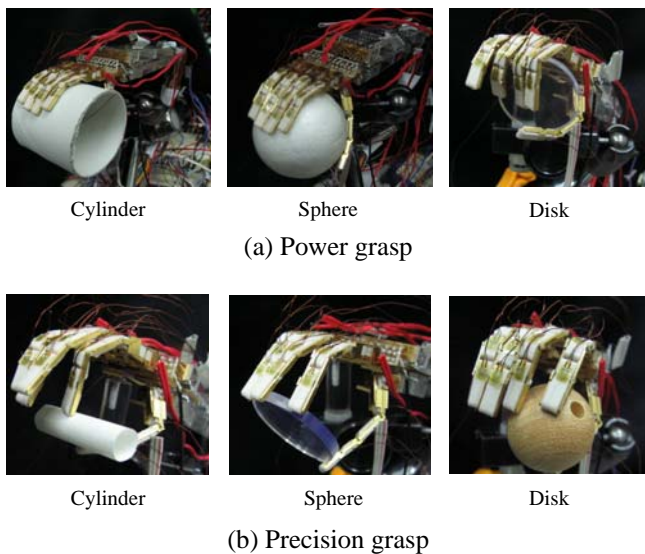


Fig. 11 Result of grasping experiment

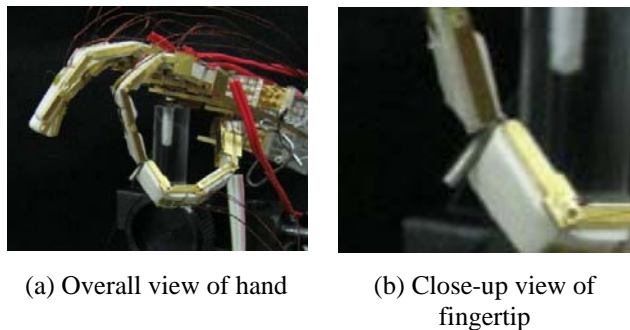


Fig. 12 Grasp miniature screw

successfully conducted using the developed robot hand. We also conducted a grasping test on screws same as the one used in the section 2. It is shown in Fig. 12 that the robot hand can grasp M1 screw that is usually difficult for human to treat.

We are planning to conduct a manipulation test as well as the grasping test to show the advantage of the developed robot hand in the future.

5. Conclusion

The miniature human-hand-like-five-fingered robot hand is developed for dexterous remote manipulation. The size is about one third of humans. The SMA actuator is used for the finger movement. It has 20 DOFs and 40 SMA wires. Time constant is about 0.2s. Hence, the speed is almost the same as humans. It is also shown that the manipulability is better than human's because it can grasp

a small object. Manipulation test as a master-slave system for remote operation by humans is a future topic.

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