

# Pneumatic Micro Hand and Miniaturized Parallel Link Robot for Micro Manipulation Robot System

<sup>1</sup>Satoshi KONISHI, <sup>2</sup>Makoto NOKATA, <sup>3</sup>Ok Chan JEONG, <sup>4</sup>Shinya KUSUDA, <sup>4</sup>Tsuyoshi SAKAKIBARA,  
<sup>4</sup>Miyuki KUWAYAMA, and <sup>2</sup>Hidetoshi TSUTSUMI

<sup>1</sup>Department of Micro System Technology, Ritsumeikan University

<sup>2</sup>Department of Robotics, Ritsumeikan University

<sup>3</sup>Center of Promotion of the COE program, Ritsumeikan University

<sup>4</sup>The Graduate School of Science and Engineering, Ritsumeikan University  
1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, JAPAN

**Abstract** - This paper reports the pneumatic PDMS micro hand as an endeffector of robot and miniaturized parallel link robot (guide robot) for manipulating a tiny and delicate object. Micro finger structure for the micro hand consists of bonded two films having different stiffness. Balloon structures are designed between the two films. Swelling of the balloon structure by applied pressure generates bending motion of the micro finger. This combination of the micro hand is based on the human being's finger and/or hand. The guide robot has several design specifications such as multi degrees of freedom joint as a human, small size, highly accurate directional control and water/ sterilization proof. Micro Manipulation Robot System is developed by assembling the micro finger with two or three degree of freedom, the guide robot and VR (Virtual Reality) interface device. The hybrid motion and the manipulation of a single egg ( $\phi 1\text{mm}$ ) of fish and a hair ( $\phi 100\mu\text{m}$ ) in macro world is successfully realized.

**Index Terms** – Pneumatic PDMS micro hand, Micro manipulation, Miniaturized parallel link, Micro surgery

## 1. INTRODUCTION

Micro Manipulation Robot System (here after MMRS) will allow a close encounters with the micro world as shown in Fig.1. MMRS can manipulate a single egg ( $\phi 1\text{mm}$ ) of fish and a hair ( $\phi 100\mu\text{m}$ ), for example. This hybrid robot system consists of “*PDMS micro fingers*” for grasping motion in micro scale, “*guide robot arm*” for the reaching action in macro scale and “*Virtual Reality human interface system*” as shown in Fig.2.

Recently, a pneumatically driven polymeric micro finger is proposed to overcome the limitation of the silicon-based micro devices [1-2]. Its working principle is based on the pressure-dependent swelling and saturation phenomena of two flexible diaphragms with different thicknesses of PDMS finger was already reported [1]. Several advantages of all PDMS finger structures were also discussed such as the dual bending motions, the possibility of the functional finger

and/or hand. However, one drawback of previous work [1] is highly associated with the bonding strength between two PDMS films. In this paper, to increase its bonding strength, abnormally mixed PDMS films are used for the covalent bond at the interface of stacked PDMS films through the sequential curing process [3-4].

The miniature robot arm which carried out the scale down of our arm can perform detailed and delicate operation in the field of medicine or biotechnology. A two-finger micro hand driven by two 6 DOF parallel mechanisms was developed [5]. The hand realized finger motion based on human usage of a pair of chopsticks. Small-sized robotic forceps for

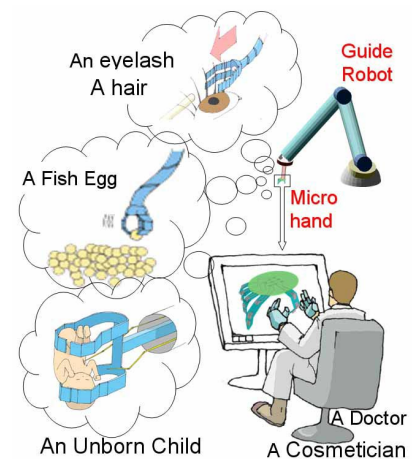


Fig. 1. Schematic view of Micro Manipulation Robot System.

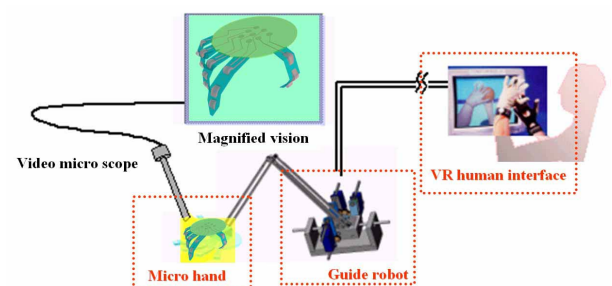


Fig. 2. System composition of Micro Manipulation Robot System.

minimally invasive surgery have been produced [6]. The main function of the robot is making the motion of a human's wrist. Thus, a new robot should be developed, which has several design specifications such as multi degrees of freedom joint as a human's arm, small size and so on.

This paper presents the manufacturing process of the micro hand with pneumatic balloon actuators. Micro hand structure and its assembly sequence are especially presented. Several design specifications for developing the guide robot are presented, such as five degrees of freedom joint, small size, highly accurate directional control. All DC servo motors are built in the base part for water/sterilization proof. Finally, this paper will show Micro Manipulation Robot System with guide robot arm and PDMS micro hand as one of the applications of micro hand exhibited in 2005 JAPAN EXPO.

## II. MICRO FINGER AND HAND

### A. Working Principle of Micro Finger

Fig. 3 shows the working principle of all PDMS micro finger with a single balloon actuator. The micro finger consists of two flexible PDMS elastomer. One layer has the micro chamber structure for the balloon actuator. The other layer is simple PDMS film without any patterns. The bidirectional motion of the normally mixed PDMS structure was already reported [1] as shown in Fig. 3(a). If the pneumatic force is applied to the balloon actuator, the internal pressure in the chamber of balloon actuator increases. The thin top diaphragm is firstly inflated and the pulling forces are generated around the boundary. Thus, the micro finger moves upward. Unlike this motion of the micro finger under low input pressure, the upward bending motion of the micro finger is restricted by the pulling force generated by the thick bottom diaphragm as the input pressure increases. Under high pressure level, the bending direction is changed from upward to downward because the generated pulling force of the thick bottom diaphragm is dominant. However, there are two drawbacks such as the fabrication process and the bonding strength. In practical, the wafer-scale process of the micro finger or hand is not so easy because of the difficulties in the reliable transfer method for two PDMS films treated with the oxygen plasma and the available handling time for successful bonding process. Moreover, in the case of multi-layer and large area bonding process, the oxygen bonding process is not effective.

Fig. 3(b) shows working principle of the micro finger structure with unidirectional bending motion. The micro finger has two PDMS films with different mixing ratio of base polymer and curing agent [3-4]. The micro finger moves only upward because the top PDMS diaphragm with excess of silicon hydride group is relatively stiffer than the bottom PDMS diaphragm with excess of vinyl group.

Because each layer has an excess one of the two parts, reactive molecules remain at the interface between two unstable layers. Two PDMS layers are irreversibly bonded through the sequential hard curing process. The bonding strength of the bonded structure might be equal with the yield strength of the PDMS elastomer itself [3-4].

### B. Manufacturing Process of Micro Hand

Fig. 4 shows the fabrication process of the micro hand. After the fabrication of silicon mold master by using ICP RIE process, a PDMS-A (8:1 mixture of the base polymer and the curing agent, Sylgard 184, Dow Corning Inc.) for the balloon structure as a relatively rigid film is spin-coated and cured at 75 °C for 10 minutes. A PDMS-B (12:1 mixture) as a flexible structure is coated on glass substrate and cured at 75 °C for 4 minutes. The prepared two types PDMS films are bonded at 90 °C for 20 minutes by using sequential hard curing process. After bonding process, the bonded structure is peeled off from the glass substrate.

### C. Micro Hand Structure and Its Assembly Sequence

Fig. 5 shows the structure and assembly sequence of the micro hand. Two PDMS films and three PDMS blocks are used for the fabrication of the human-like hand with five finger structures. The micro finger consists of three or four pneumatic balloon actuators. All balloon actuators are connected with pneumatic supply micro channels. Especially, thumb with four balloon actuators and forefinger with three actuators are connected with individual micro channel for the precise motion control of the micro finger. The others are serially connected with one micro channel.

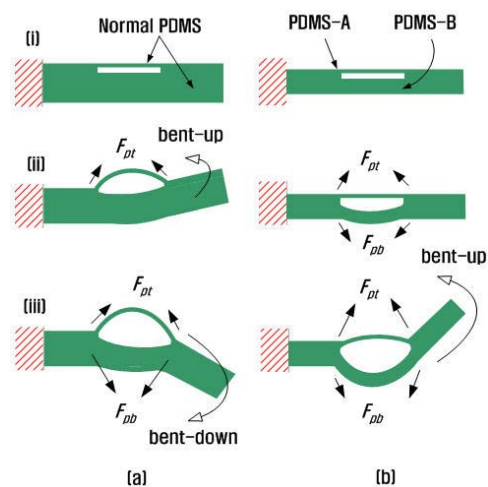


Fig. 3. Working principle of all PDMS micro finger with pneumatic balloon actuator[1]. (a) normal PDMS structure [1], (b) unusual PDMS structure [3], [i] initial state, [ii] under low pressure, [iii] under high pressure. ( $F_p$  : pulling force by inflated balloon actuator diaphragm,  $t$  : top diaphragm,  $b$  : bottom diaphragm).

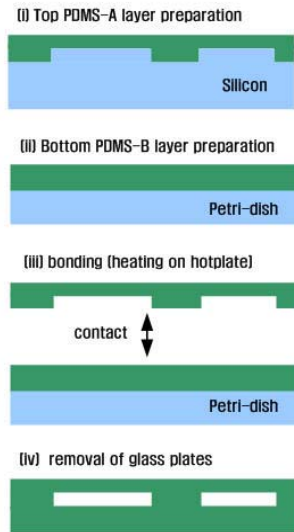


Fig. 4. Fabrication process of the micro finger and/or hand.

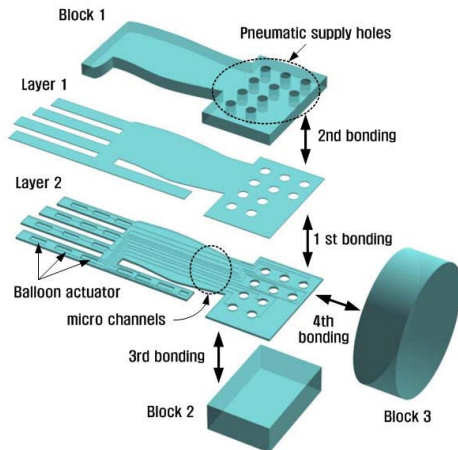


Fig. 5. Structure and assembly sequence of the micro hand with individual controllable five finger structures.

There are four times bonding processes for the micro hand assembly. All components are fabricated through PDMS molding process described in Fig. 4. For bonding process of micro hand, PDMS structures are cured at 90 °C for 20 minutes. Firstly, the prepared layer 1 and layer 2 are bonded for the micro hand structure. After bonding process, the bonded structures are cut by the punching machine with micro hand pattern. Secondly, the patterned micro hand structures are bonded with a PDMS block 1 for the pneumatic supply connection and then a ten-hole for pneumatic supply connection are punched out. Thirdly, the additional PDMS block 2 is bonded with the previously bonded structure for the perfect sealing of the backside of the micro hand structure. Finally, a circular PDMS block 3 as a coupling component with guide robot arm is bonded

again. The film thickness of layers 1 and 2 are 35  $\mu\text{m}$  and 15  $\mu\text{m}$ , respectively. The height of blocks 1, 2, and 3 are about 2 ~ 3 mm. The length and width of micro finger are 800  $\mu\text{m}$  and 7 mm, respectively. The diameter of the pneumatic supply holes is about 600  $\mu\text{m}$ .

#### D. Basic Test of Micro Finger Motion

Fig. 6 shows the schematic view of the measurement setup for the pneumatic test of the micro finger. The pressure level is controlled by the precision regulator and monitored with the pressure sensor [1, 7]. The motion of the micro finger is observed by using a Hi-scope (video microscope), and its generated force are measured with load cell and read out from the strain amplifier.

Fig. 7 shows captured image of the bended micro finger structure as illustrated in Fig. 3 (a). When the external compressed air pressure is supplied to the balloon actuator, micro balloon structure is inflated and the micro finger is bended by using the generated pulling force of the balloon actuator diaphragm.

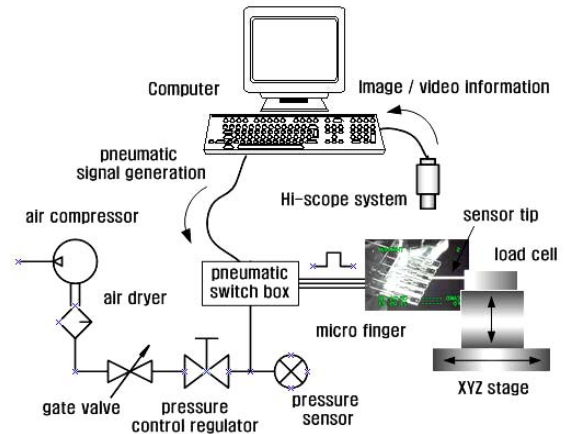


Fig. 6. Measurement setup for the dynamic test of micro finger [1, 5].

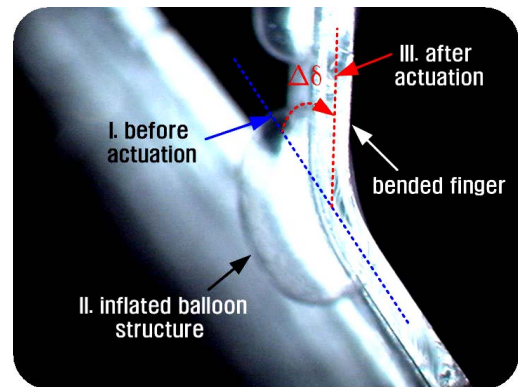


Fig. 7. Captured image showing the bended micro finger with inflated balloon structures. The bending angle,  $\Delta\delta$  and generated force are linearly proportional to the supplied air pressure in the measurement region [1].

### III. GUIDE ROBOT

The guide robot reaches out its endeffector “Micro Hand” for fish egg, cellular, capillary vessel and so on. These objects are tiny or delicate, and are underwater or in the body. So the guide robot must have several design specifications such as multi-flexibility joint, small size, highly accurate directional control and water/ sterilization proof.

Fig. 8 shows the schematic view of our designed guide robot. This robot has five active joints, the total degree of freedom of hand section is five, x, y, z, roll and pitch (Fig.9). Four DC servo rotational motors drive the joint No.1-4 and one linear servo motor moves the whole of the robot to right and left (joint No.6). All servo motors are built in the base part. This robot’s arm is composed of a micro paralleling mechanism. When motor No.1 drives joint O, joint P is rotated. Similarly, motor 2 rotates joint Q, motor 3 rotates joint R. The arms have no electric devices, so the robot is enable to work in water, blood, sterilization procedure and so on.

Fig. 10 shows the picture of our developed guide robot. Four DC servo rotational motors (Maxon Co.) and one linear servo motor (SIGMA KOKI CO., LTD) are built in the base part, the robot can determine the high-precision positioning of the micro hand. The width and length of the arm is 10 mm and 125 mm, the full length is 250 mm, it is possible to insert the micro hand and the arm into the abdominal cavity through the small hole.

Fig.11 shows captured figures of the guide robot’s motion operated by using VR human interface system. The position (X, Y, and Z Cartesian coordinates) and orientation (azimuth, elevation, and roll) of the operator’s hand are measured by magnetic sensor (Fastrak: POLHEMUS Co.), the robot succeeded to follows the hand motion scaled up and down.

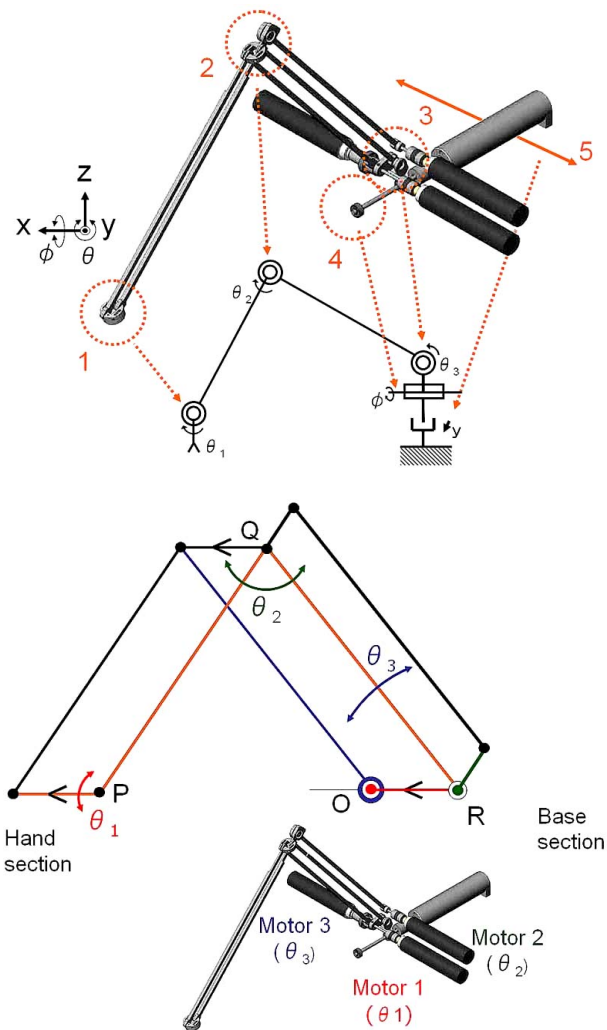


Fig. 9. Mechanism and actuator of miniaturized parallel link.

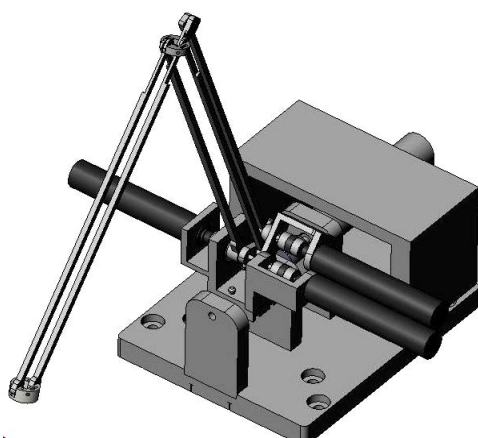


Fig. 8. Schematic view of our designed guide robot.



Fig. 10. Developed guide robot. Four DC servo rotational motors and one linear motor are built in the base part.

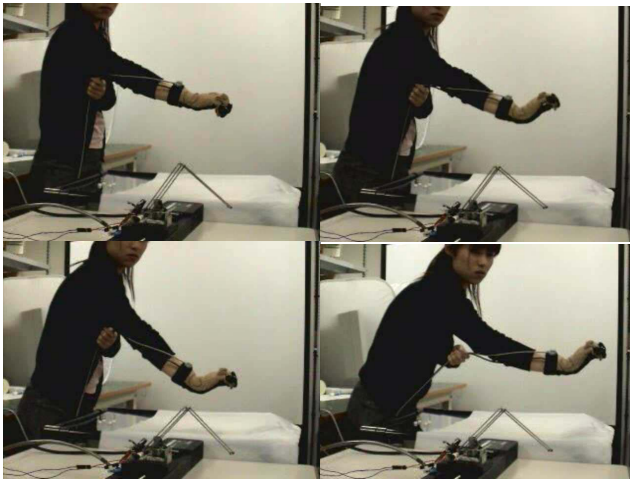


Fig.11 Guide robot's motion operated by using VR human interface system.

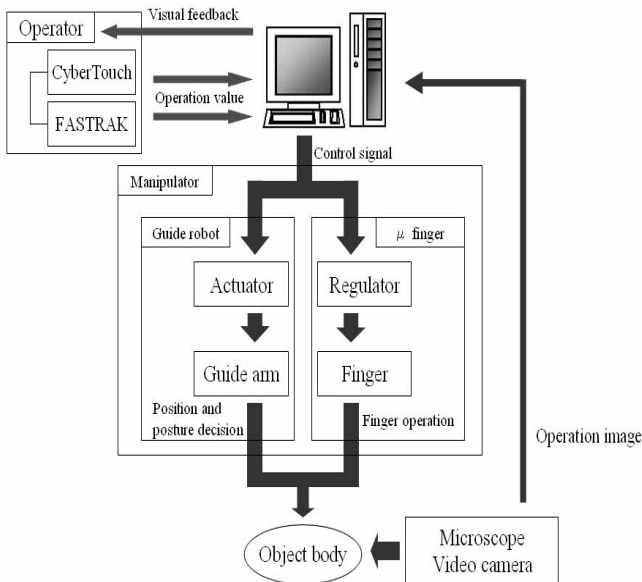


Fig. 12. The block diagram of the system

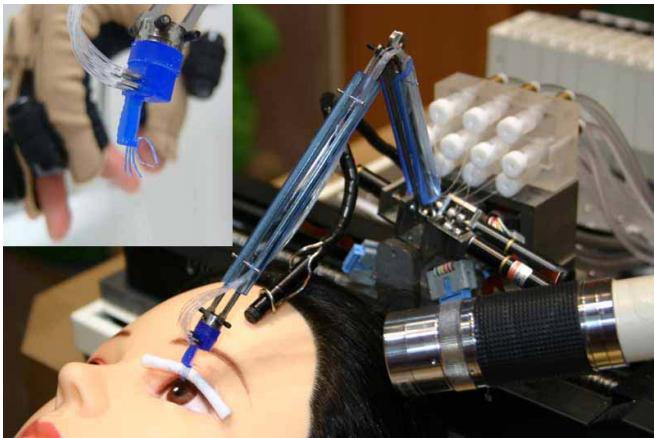


Fig.13. Micro Manipulation Robot System.

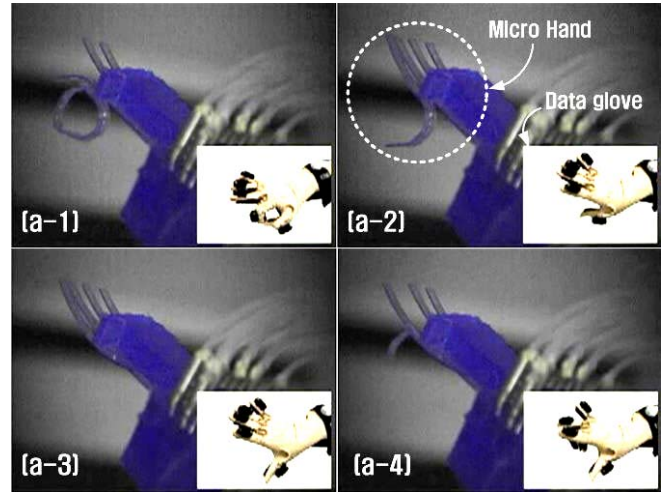


Fig. 14. Captured figures showing the hybrid motions between micro hand and data glove.

#### IV. MICRO MANIPULATION ROBOT SYSTEM

##### A. Micro Manipulation Robot System

The first step of this research was exhibited on June 9-19 in 2005 JAPAN EXPO for the performance inspection, the long-term drive verification and so on.

Fig. 12 shows total system block diagram showing the signal flow from operator's data glove to the micro hand as an end-effector of the macro robot. Once the motion of data glove (CyberGlove: Immersion. Co.) with 16 sensors are generated, 8-bit digital signal per one sensor are properly converted into analog pneumatic pressure signal. All fingers of the micro hand can be individually controlled by using this open-loop control algorithm in real time.

Fig. 13 shows the realized micro manipulation robot system developed by assembling the micro finger with multi-degree of freedom, the guide robot and VR interface device.

##### B. Hybrid Motion between Micro Hand and Human Hand

Fig. 14 shows captured figures showing the individual finger motion test for the hybrid motion between micro hand and data glove. Fig. 15 shows the object-grasping motion of the micro hand controlled by data glove action. The diameter of the used single fish's egg is about 1 mm. Fig. 16 shows the approaching motion of the guide robot and the object-grasping motion of the micro hand in micro scale. The diameter of the used jewel and artificial hair are 3 mm and 100 μm, respectively.

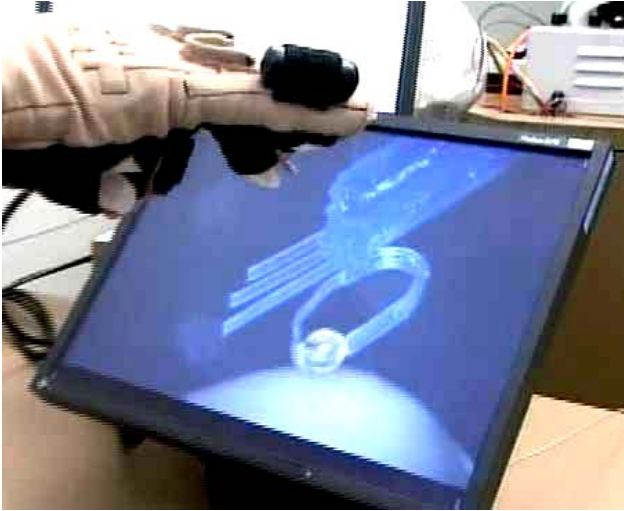


Fig. 15. Object-grasping motion of the micro hand. The diameter of the used single fish's egg is about 1 mm.

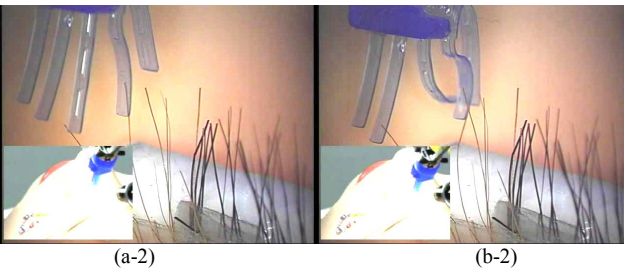
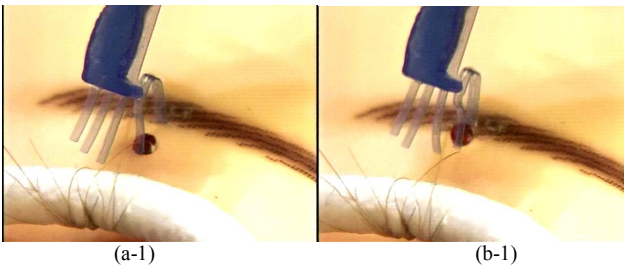


Fig. 16. Manipulation of a single Jewel ( $\phi 3\text{mm}$ ) and a hair ( $\phi 100\mu\text{m}$ ).  
 (a) approaching motion of the guide robot in macro scale, (b) object-grasping motion of the micro hand in micro scale. The diameter of the used jewel and artificial hair are 3 mm and 100  $\mu\text{m}$ , respectively.

## V. CONCLUSIONS

In this paper, all PDMS micro hand is fabricated with the developed manufacturing process and its related working principle are discussed. The guide robot is developed which has several design specifications such as multi degrees of freedom joint as a human, small size, highly accurate directional control and water/ sterilization proof. Micro Manipulation Robot System is developed by assembling the micro finger with two or three degree of freedom, the guide robot and VR interface device. The hybrid motion and the manipulation of a single egg of fish and a hair in macro world is successfully realized. The micro hand of this study could be applicable to the micro surgical treatment as one of the useful medical tools.

## ACKNOWLEDGMENTS

A part of this work was supported by the "Prototype Robot Projects" of New Energy and Industrial Technology Development Organization of Japan.

## REFERENCES

- [1] O. C. Jeong, S. Kusuda, and S. Konishi, "All PDMS balloon actuators for bidirectional motion of micro finger", *18<sup>th</sup> IEEE Microelectromechanical Systems Conf.*, Miami, USA, pp. 407-410, Jan. 2005.
- [2] Y. Lu and C. J. Kim, "Micro-Finger Articulation by Pneumatic Parylene Balloons", *Transducer '03*, Boston, USA, pp. 276-279, June 2003.
- [3] O. C. Jeong, T. Yamamoto, S. W. Lee, T. Fujii, and S. Konishi, "Surface modification, mechanical property, and multi-layer bonding of PDMS and its application", *9<sup>th</sup> International Conference on Miniaturized Systems for Chemistry and Life Sciences*, Boston, USA, pp. 202-204, Oct. 2005.
- [4] M. A. Unger, H. Chou, T. Thorsen, A. Scherer, and S. R. Quake, "Monolithic Microfabricated Valves and Pumps by Multilayer Soft Lithography", *Science*, Vol. 288, pp. 113-116, 2000.
- [5] T. Tanikawa and T. Arai, "Development of a Micro-Manipulation System Having a Two-Fingered Micro-Hand", *IEEE Trans. Robotics and Automation*, Vol. 15, No.1, pp. 152-162, 1999.
- [6] [http://www.intuitivesurgical.com/products/davinci\\_surgicalsystem/](http://www.intuitivesurgical.com/products/davinci_surgicalsystem/)
- [7] F. Kawai, P. Cusin, and S. Konishi, "Thin Flexible End-Effector using Pneumatic Balloon Actuator", *13<sup>th</sup> IEEE Microelectromechanical Systems Conf.*, Miyazaki, Japan, pp. 391-396, Jan. 2000.