

# Merging micro and macro robotics toward micro manipulation for biomedical operation

<sup>1</sup>S.KONISHI, <sup>2</sup>M.NOKATA, <sup>3</sup>O.C.JEONG, <sup>1</sup>T.SAKAKIBARA, <sup>1</sup>S.KUSUDA, <sup>2</sup>M.KUWAYAMA, <sup>2</sup>H.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

1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan

*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. The micro hand structure consists of two PDMS films with different mixing ratio of the base polymer and curing agent. The top PDMS layer with excess Si-H group is stiffer and more rigid than the bottom one with excess vinyl group. This combination of the micro finger or hand is based on the human being's finger or hand. The out-of-plane motion of the transparent micro hand is generated and controlled by using the applied air pressure.*

*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 Realty) interface device. The hybrid motion and the manipulation of a single fish's egg ( $\phi 1\text{mm}$ ) and a hair ( $\phi 100\mu\text{m}$ ) in macro world is successfully realized.*

## 1. INTRODUCTION

Fig.1 shows the symbolic representation named 'u-TAN' which is a micro manipulation robot system for 2005 AICHI EXPO. u-TAN will allow a close encounters with the micro world through micro fingers with guide robot and virtual reality (here after VR) human interface system as shown in Fig.2. u-TAN can manipulate a single fish's egg ( $\phi 1\text{mm}$ ) 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.

The working principle based on the pressure-dependent swelling and saturation phenomena of two flexible diaphragms with different thicknesses of all PDMS finger was already reported [1]. Several advantages of all PDMS finger structures was also discussed such as a film thickness dependent dual bending motions, the possibility of the attachment of functional devices on the surface of finger structure, and its better mechanical behavior compared with micro hand jointed with the Parylene balloon actuators [2]. However, there is one drawback of the plasma bonded PDMS finger structure. It is highly associated with the bonding strength between two PDMS film. To solve this problem, abnormally mixed PDMS films are used for the covalent bond at the interface of stacked PDMS films through the sequential curing process [3-4].

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.

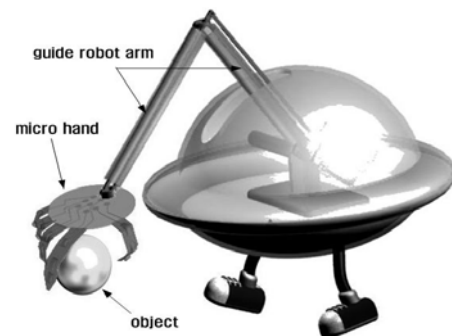


Fig.1 Schematic view of 'u-TAN'

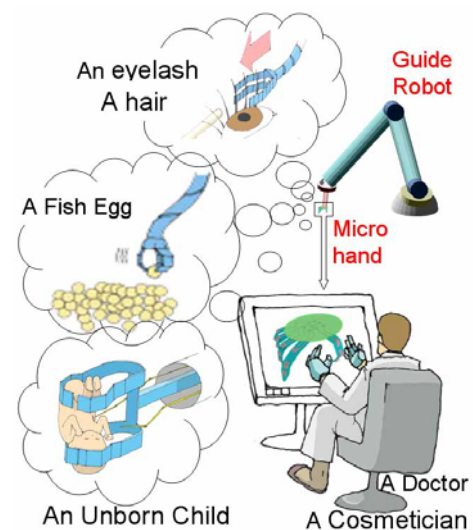


Fig.2 Schematic view of Micro Manipulation Robot System.

## 2. TOTAL SYSTEM OF *u-TAN*

*u-TAN* (Micro Manipulation Robot System) was exhibited on June 9-19 in 2005 JAPAN EXPO for the performance inspection, the long-term drive verification and so on.

Fig.3 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. 4 shows the realized the total system of *u-TAN* developed by assembling the micro finger with multi-degree of freedom, the guide robot and VR interface device.

Fig. 5 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  $\mu\text{m}$ , respectively.

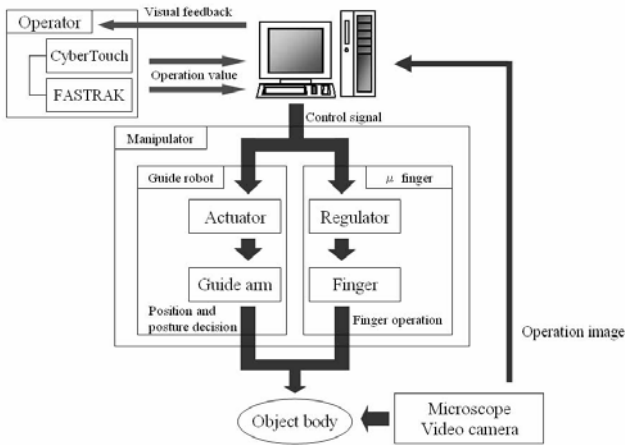


Fig.3 The block diagram of the system

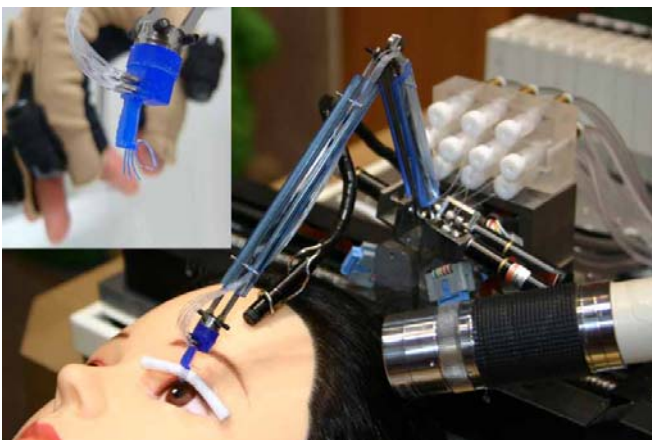
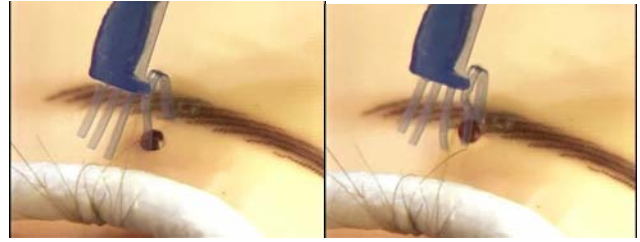


Fig.4 Micro Manipulation Robot System



(a-1)

(a-2)



(b-1)

(b-2)

Fig.5 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.

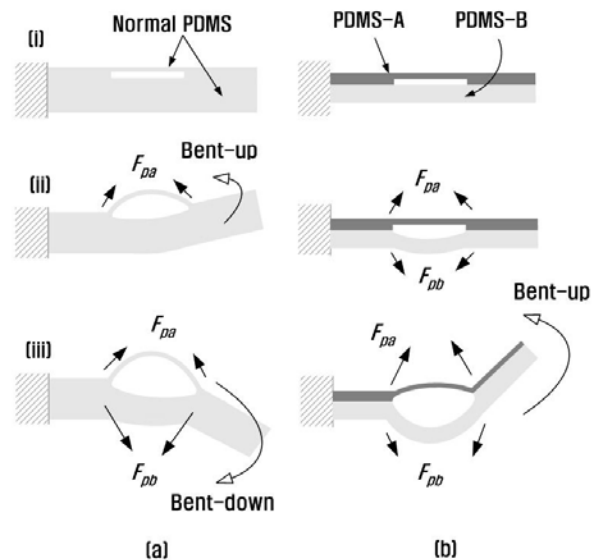


Fig.6 Working principle of all PDMS micro finger with balloon actuator. (a) normal PDMS structure [1], (b) unusual PDMS structure, [i] initial state, [ii] under low pressure, [iii] under high pressure.

## 3. WORKING PRINCIPLE OF MICRO FINGER

Fig.6 shows the working principle of micro hand with balloon actuator. Fig.6 (a) shows the bidirectional motion of the normally mixed PDMS structure. Fig.6 (b) shows the unusual case of PDMS structure. In this case, the material properties of PDMS may be changed [3] because the chemical structures are different. It means that the bending direction of micro finger is controllable by the mixing ratio

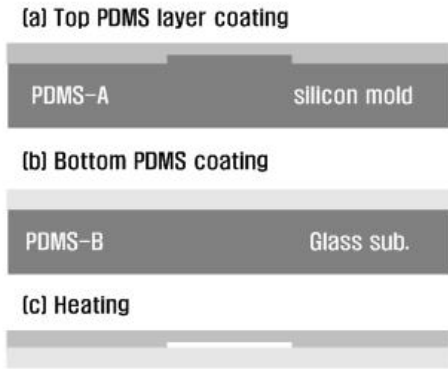


Fig.7 Fabrication process of the micro finger.

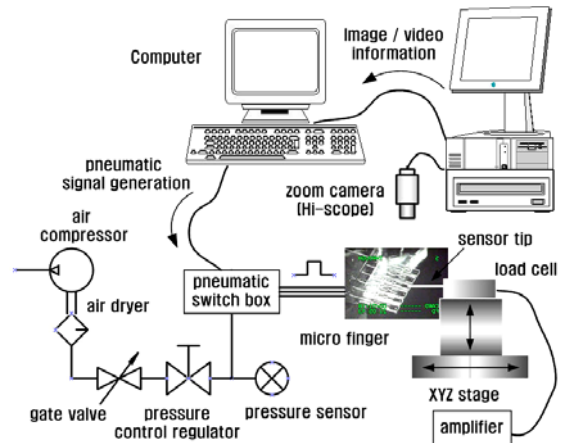


Fig.9 Measurement system for micro finger.

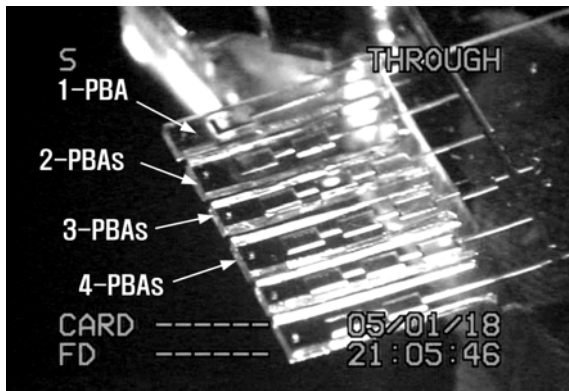


Fig.8 Fabricated finger array with different number of balloon actuators for study on the effect of balloon number. (PBA : Pneumatic Balloon Actuator)

of each PDMS layers as shown in Fig.6 (b). It may be flexible design issues on the PDMS finger structures and its potential devices in MEMS and micro TAS.

#### 4. FABRICATION PROCESS OF MICRO FINGER

Fig.7 shows the conceptual fabrication process of the micro hand and the schematic view of the design micro hand. After silicon mold for balloon chamber and pneumatic supply connection hole, a PDMS-A for the balloon structure as a rigid film is coated and cured at 75 °C for 10 minutes. A PDMS-B as a flexible structure is coated on glass substrate and cured at 75 °C for 4 minutes. After bonding process of two types PDMS films at 90 °C for 20 minutes, the bonded structures are cut by the punching machine with micro hand pattern. Finally, PDMS block with pneumatic supply holes are bonded again with the patterned micro hand structure. Fig.8 shows the fabricated micro finger and array for the proper design rule of the micro hand. The length and width of micro finger are 0.8 mm and 7 mm, respectively.

#### 5. BENDING MOTION OF MICRO FINGER

This paper focuses on the design issue for the micro finger with effective bending angle an endeffector of robot. The micro finger with different balloon dimension and the number of balloon actuators are fabricated. The design issue for micro finger is necessary because any analytical method or simulation tools for the estimation of mechanical behavior of PDMS finger in large deformation region of rubber material are very limited for us. Single micro finger with the different dimension and micro finger array with different number of balloon actuators are fabricated and tested for a study on size effect of a single balloon actuator and the number of balloon actuators.

Fig.9 shows the measurement system for the dynamic bending motions of micro finger. The air pressure source consists of the air compressor, the air dryer, the pressure regulator, and the pressure sensor. The pneumatic switch box is controlled by computer. The hi-scope system is used for the motion capture.

Fig.10 shows the measured maximum bending angles of the micro finger with single balloon actuator when the DC pneumatic force are applied to the micro finger with a single balloon actuator. The width and length of the balloon actuator are 300 μm and 1500 μm, respectively. The length of the micro finger is about 3 mm. The top diaphragms of the micro finger are fixed as 15 μm for the study on the effect of the thickness of the bottom layer on the bending angle of the micro finger. When the thickness ratio of the bottom layer and the top one is about 3, the bending angle of micro finger is most sensitive to the applied air pressure.

Fig.11 shows the measured maximum bending angles of the micro finger with different size of the balloon actuator. As the length of the balloon structure increases, the bending angle of the finger structures increases.

Fig.12 illustrates the repeat test result of the measured bending angle of the micro finger when the sinusoidal input pneumatic signal is applied to the micro finger at 1 Hz. The length of the micro finger is 3 mm. The width and length of

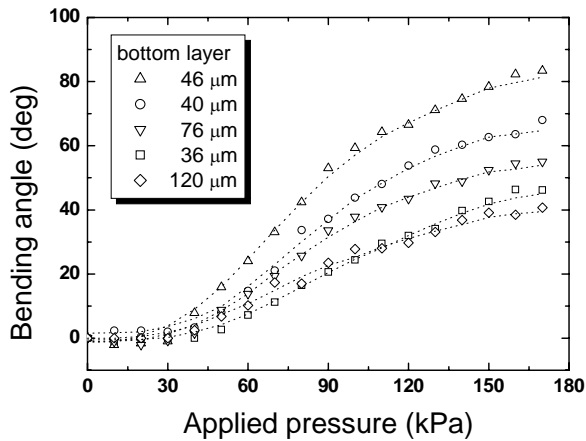


Fig.10 Effect of the thickness of the bottom layer on the bending angle of the micro finger

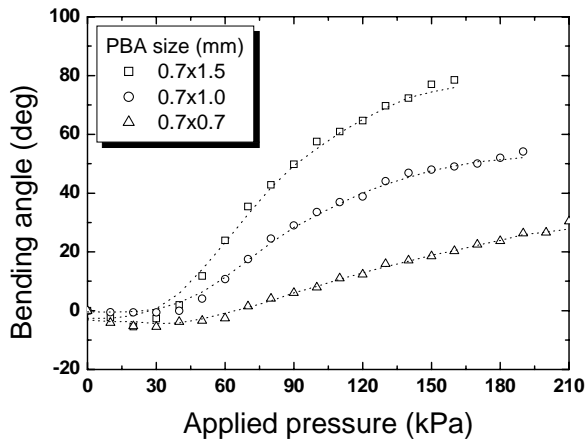


Fig.11 Effect of the size of the balloon actuator on the bending angle of the micro finger.

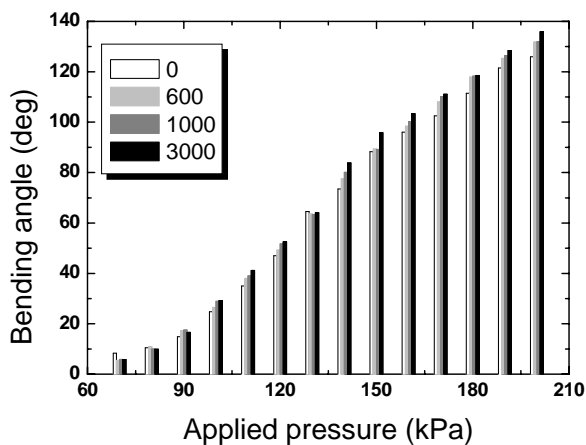


Fig.12 Repeat test of the micro finger showing its robust performance.

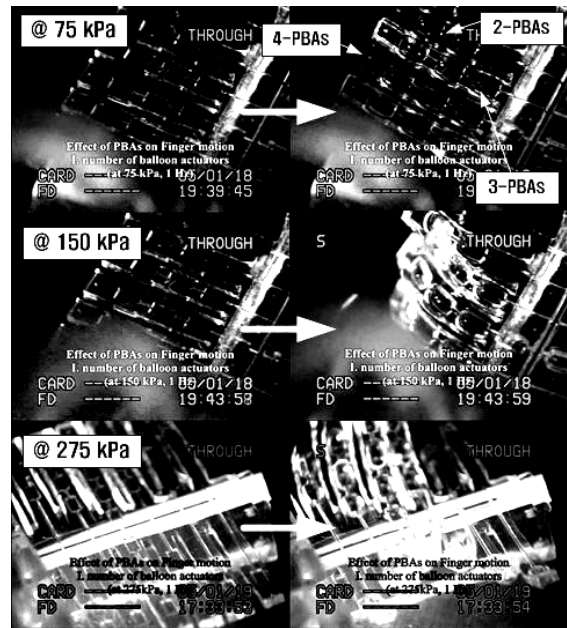


Fig.13 Dynamic motions of micro finger array with different balloon actuators when the square wave input pneumatic pressure is applied to micro finger.

the balloon actuator are 700  $\mu\text{m}$  and 1500  $\mu\text{m}$ , respectively. During the repeat test for about 5 hours, there are no any noticeable degradation on the bending motion and the structural failure. It is confirmed that PDMS is a useful material for the fabrication of the mechanical device.

Fig.13 illustrates captured images showing the effect of number of the balloon actuators on the bending angle of finger structures while the square wave input pneumatic force is supplied to micro finger structures. Its duty ratio and frequency are 50 % and 1 Hz, respectively. As the number of balloon actuators increases, the bending angle of micro finger increases under same pneumatic force.

## 6. FABRICATION OF MICROHAND

Fig.14 shows the schematic view of the micro hand with five fingers. A Thumb and a forefinger have three degree of freedom for the effective manipulation. The main fabrication and design issue of this micro finger are based on the previously discussed fabrication process and the basic bending motion test result.

Fig.15 shows captured figures showing the simple action test of the hybrid motion of micro hand and data glove. 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. Each fingers of the micro hand can be controlled by using this open-loop control algorithm in real time.

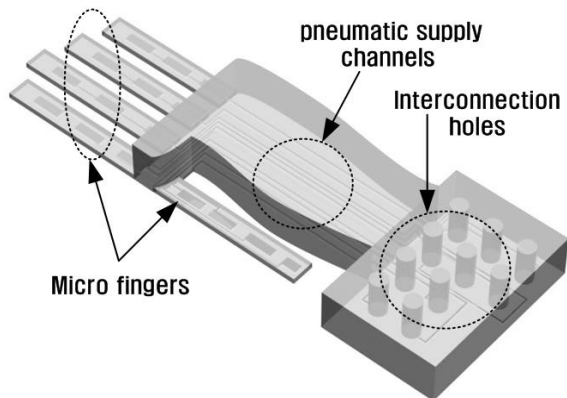


Fig.14 Schematic view of micro hand with five fingers.

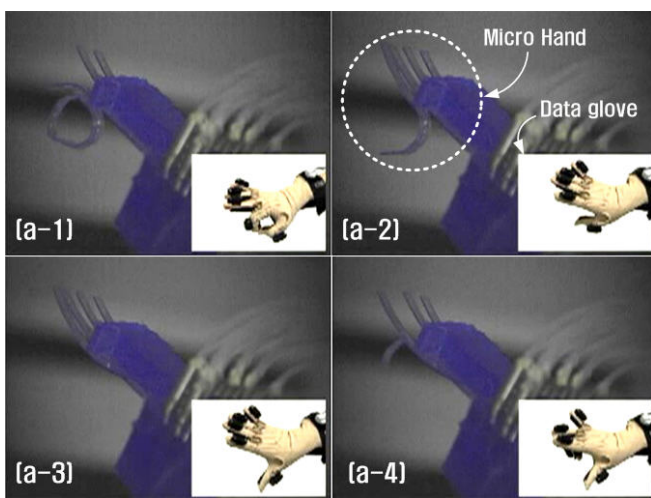


Fig.15 Captured figures showing the hybrid motions between micro hand and data glove.

## 7. 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. 16 shows the schematic view of our designed guide robot. The robot is composed of a micro paralleling mechanism. Total degree of freedom is five shown in Fig. 17 and each joint is individually driven by DC servo motor built in the base part. These arms have no electric devices, so the robot is enable to work in water, blood, sterilization procedure and so on.

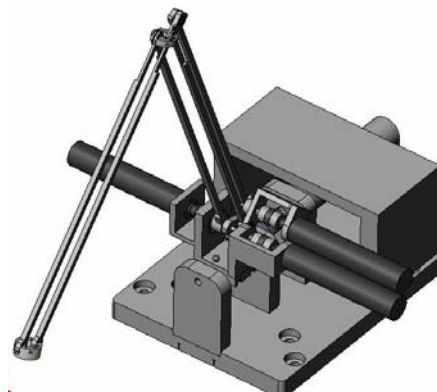


Fig.16 Schematic view of our designed guide robot

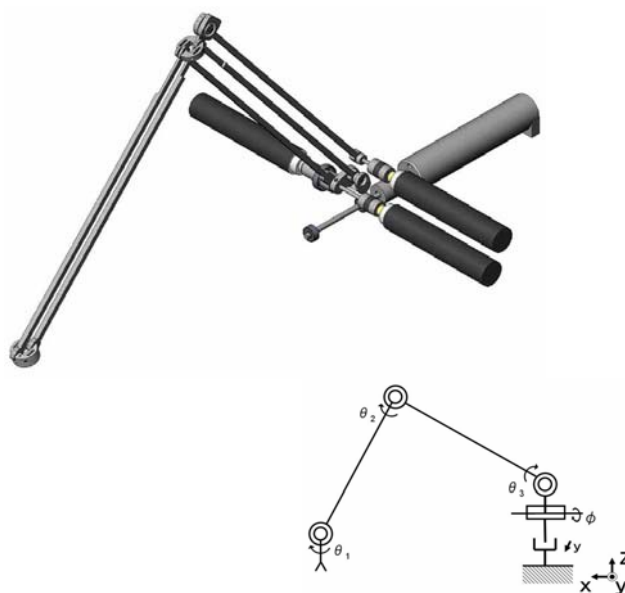


Fig. 17 Mechanism and Actuator of miniaturized parallel link

Fig. 18 shows the picture of our developed guide robot. Four DC servo rotational motors (Maxon co.) and one linear 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.19 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.

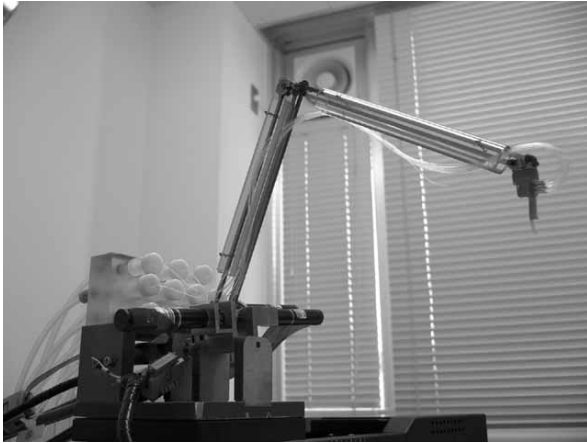


Fig. 18 Developed guide robot. Four DC servo rotational motors and one linear motor are built in the base part

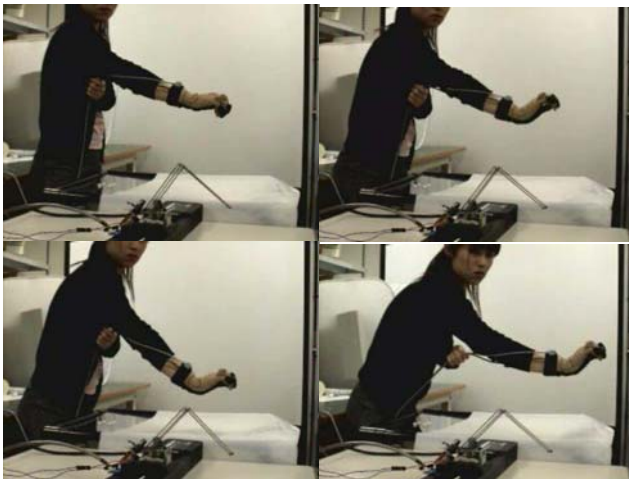


Fig.19 Guide robot's motion operated by using VR human interface system

## 8. 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. *u-TAN* (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 fish's egg 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] Ok Chan Jeong, Shinya Kusuda, and Satoshi Konishi, "All PDMS balloon actuators for bidirectional motion of micro finger", IEEE MEMS 2005 Conf., Miami, FL, USA, pp. 407~410, Jan. 2005.
- [2] Yenwen Lu and Chang Jin Kim, "Micro-Finger Articulation by Pneumatic Parylene Balloons", Transducers' 03, Boston, USA, pp. 276-279, June 8-12, 2003.
- [3] Ok Chan Jeong, Takatoki Yamamoto, Sang Wook Lee, Teruo Fujii, and Satoshi Konishi, "Surface modification, mechanical property, and multi-layer bonding of PDMS and its application", be presented in Ninth International Conference on Miniaturized Systems for Chemistry and Life Sciences (u-TAS) 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] F. Kawai, P. Cusin, and S. Konishi, "Thin Flexible End-Effector using Pneumatic Balloon Actuator", IEEE Microelectromechanical Systems Conf., 2000, pp. 391-396.