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Multi-axial Micromanipulation Organized by Versatile Micro Robots and Micro Tweezers

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Abstract— **In this paper, we describe development of the multi-axial micromanipulation organized by versatile micro robots using micro tweezers. To conduct microscopic operations, a unique locomotion mechanism composed of four piezoelectric actuators and two electromagnets is proposed. Here two legs arranged to cross each other are connected by four piezoelectric actuators so that the robot can move in any direction, i.e. in X and Y directions as well as rotate at the specified point precisely in the manner of an inchworm. To manipulate micro objects by these versatile micro robots, we have developed micro tweezers driven by 3 piezoelectric actuators. We have also developed an electromagnetic spherical micromanipulator to position the micro tweezers. The electromagnetic spherical micromanipulator rotates in yaw, roll and pitch directions independently. The electromagnetic spherical micromanipulator is a 1-inch cube size, so we can easily attach them on top of the versatile micro robots. We have developed the multi-axial micromanipulation organized by 3 versatile micro robots with the electromagnetic spherical micromanipulator and micro tweezers. The whole manipulation device is very small, 200mm in diameter and 70mm in height, so we can easily attach the device to micro processing instruments even if the working area is very small. This device has 21 DOF with less than 100nm resolution. In experiments, we have demonstrated flexible handling of miniscule glass spheres with a diameter of 20µm. We have also succeeded in fixing miniscule glass spheres on a sample table by an ultraviolet cure adhesive. The design procedure, basic performance and micro-assembling applications of this tiny robot are also discussed as part of the new field of micro robotics requiring especially high precision in certain regions.**

I. Introduction

In MEMS technology and precision engineering, many reports have been written about micromechanisms and microrobotics. Some reports are based on advanced technology including microbatteries, micromotors and miniscule computational facilities[1], [2], and other reports are based on technologies made by sophisticated precision machining techniques[3]-[6]. However, it is still very important to find industrial applications where such micro robots can provide effective benefits. The Micro Factory[7] has the potential applications for production engineering, chemical engineering and biotechnology. Over the last several years, our group has developed insect-size micro robots equipped with micro tools and instruments[8], [9]. We have investigated many unique applications where such micro robots play important roles in micro production. In-situ micro processing under microscopes is an interesting application[10]-[16]. Over the last several years, we have developed versatile micro robots for microscopic manipulations[17]. We have also developed flexible micromanipulation organized by three versatile micro robots under microscopes[18]. In this paper, we propose and develop the micro tweezers which can grasp the micro targets. Micro tweezers are composed of 3 piezoelectric actuators and a mechanical amplified mechanism. We also develop an electromagnetic spherical micromanipulator to position the micro tweezers. This manipulator is composed of 2 electromagnets, piezoelectric actuators and a metal sphere. The manipulator rotates the metal sphere around 3 axes in the manner of an inchworm. The manipulator can fix the metal sphere by electromagnets, so it has an enough payload to control the micro tweezers. We finally develop the multi-axial micromanipulation device which has 21 DOF with less than 100 nm resolution. This device is 200 mm in diameter and 70 mm in height. We can easily attach the device to micro processing instruments even if the working area is very small. The use of small devices avoids modification of instruments and easily implements additional manipulation with low cost. In experiments, we have demonstrated flexible handling of miniscule glass spheres with a diameter of 20µm. We have also succeeded in fixing miniscule glass spheres on a sample table by an ultraviolet cure adhesive.

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II. System Configuration

Fig.1 shows the multi-axial micro manipulation organized by versatile micro robots under microscopy which is an ongoing development in our laboratory. Operators can control versatile micro robots using a PC and a joy stick in real-time monitoring of microscopic images. All micro robots are set on steel tables. In this basic setup, the operators can execute flexible microscopic tasks with easy operation. All positioning facilities are given by micro robots' movement so that all mechanical functions are simply divided. This unique arrangement allows the system to get good flexibility and high mechanical stability although sophisticated control is required. Several experiments are described in section 5, where some of grasping, picking up and fixing by UV resin operations are demonstrated. We can easily attach additional micro processing if we put on the micro robot a tool such as an ultraviolet cure adhesive feeder. This flexibility meets the requirements of users. The use of small devices avoids modification of instruments and easily implements additional manipulation with low cost.

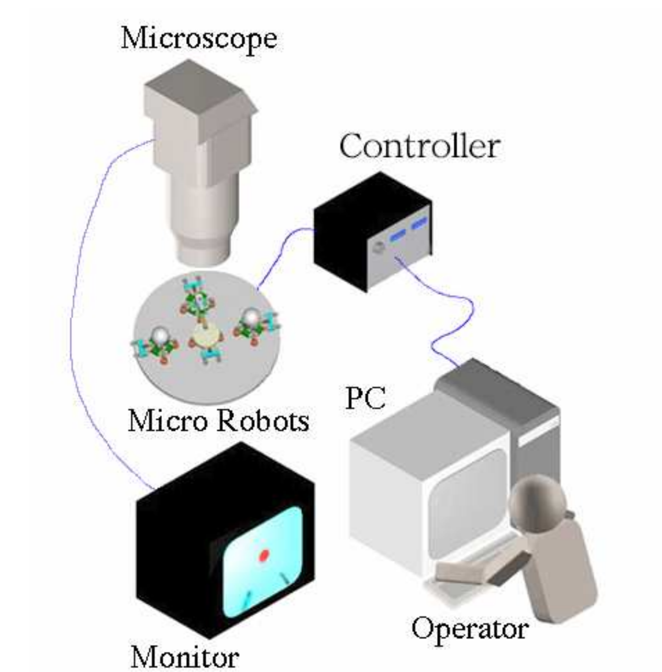


Fig. 1 Control of multi-axial micro manipulation organized by versatile micro robots

III. VERSATILE MICRO ROBOT

Fig.2 shows the motion patterns required at the microscopic operation. To realize these motion patterns at the same time, we should design a structure that can move in XY direction and rotate independently. Fig.3 shows the structure of the versatile micro robot proposed to satisfy the requirement above. Two U-shaped electromagnets arranged to cross each other are connected by four piezoelectric actuators so that the micro robot can move in any direction in the manner of an inchworm. Also we design the special joint at one of the 4 legs to get 4 legs' smooth contact on the surface simultaneously. As shown in Fig.4, the robot is 35 mm in length, 35 mm in width and 15mm in height. We use the stacked type piezoelectric actuators 5 mm in height, 5 mm in width and 10 mm in length. Each piezoelectric actuator is connected to each electromagnet with a plastic insulator. In experiments, we confirmed that the micro robot can move in XY directions and rotate independently with less than 30 nm resolution at different positioning speeds as shown in Fig.2 and table I.

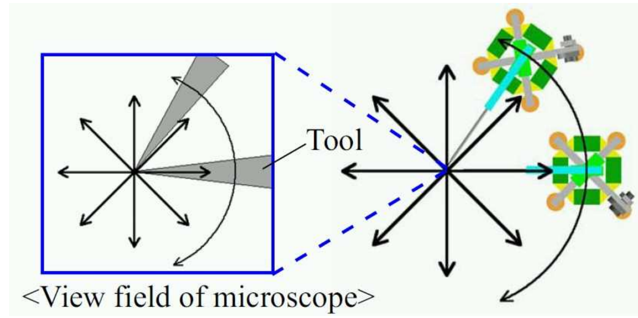


Fig. 2 Motion pattern required at microscopic operations

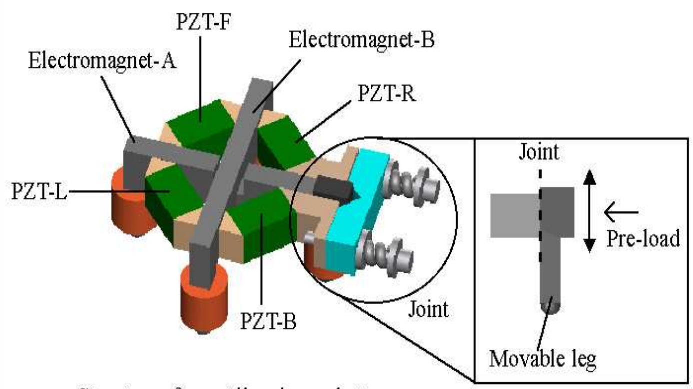


Fig. 3 Structure of the versatile micro robot

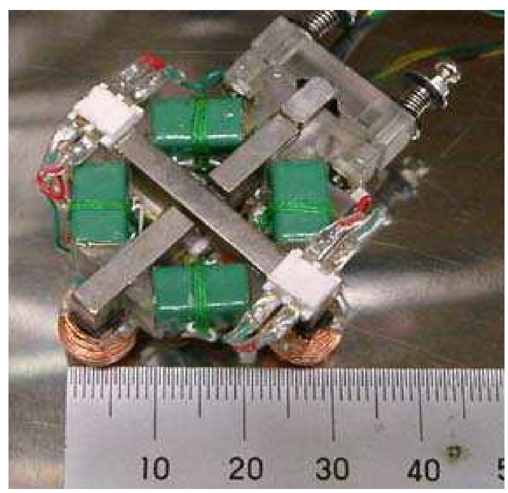


Fig. 4 Versatile micro robot provided for microscopic operations

TABLE I
PERFPRMANCE OF THE VERSATILE MICRO ROBOT

Workable field	wall, ceiling
Step length	30nm-4.5 μm
Maximum Velocity(Frequency)	3mm/s(500Hz)
Weight	35g
Size	34 mm×34 mm×18mm
Size of PZT	10 mm×5 mm×5mm
Displacement of PZT	6.3 μm/100V
Current of electromagnet	0.1-0.7A

IV. MICRO TWEEZERS

We design the micro tweezers in order to grasp the micro objects as shown in Fig.5. The micro tweezers are composed of 3 piezoelectric actuators and a mechanical amplified mechanism. Several coarse positioning mechanisms are also attached for initial tool positioning. As depicted in Fig.6, we have fabricated the micro tweezers 61mm in length, 21mm in height and 45mm in width. The weight of the tweezers is only 20g. Fig.7 shows the amplified mechanism for the glass needle positioning in Z direction. Fig.8 shows the typical experimental result of the relation between the applied voltage and the displacement in Z direction. The displacement of the needle becomes more than 80μm although the displacement of the piezoelectric actuator is only 6μm. We also confirm this positioning mechanism has less than 0.1μm resolution. We plan to use the needle whose tip diameter is more than 1μm, so this height positioning mechanism has enough positioning function in Z direction. Fig.9 shows the amplified mechanism for the grasping motion. Fig.10 shows the experimental result of the distance between 2 needles when we change the applied voltage from -10V to 100V. The displacement is up to 400 μm although the displacement of the piezoelectric actuator is only 6 μm. We also check that the positioning mechanism has about less than 0.4μm resolution. We confirm that the specification of the grasping mechanism is enough to grasp micro objects more than 1μm.

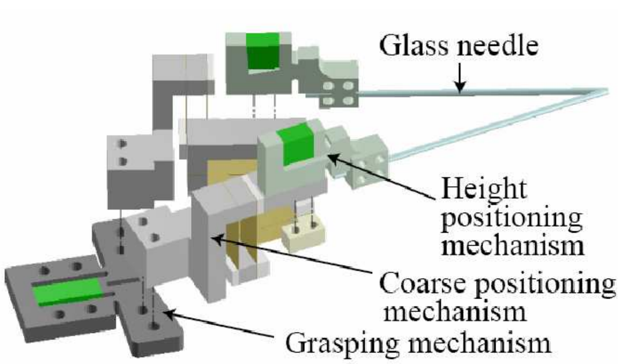


Fig. 5 Structure of micro tweezers

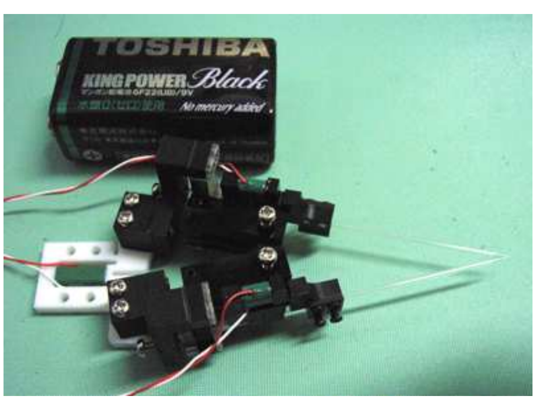


Fig. 6 Micro tweezers provided for operating micro objects

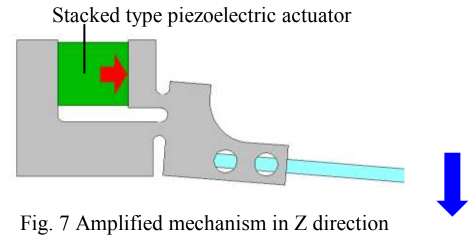


Fig. 7 Amplified mechanism in Z direction

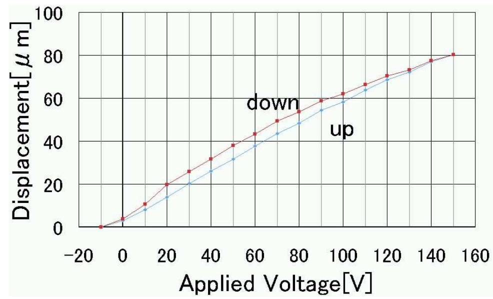


Fig. 8 Relation between applied voltage and displacement in Z direction

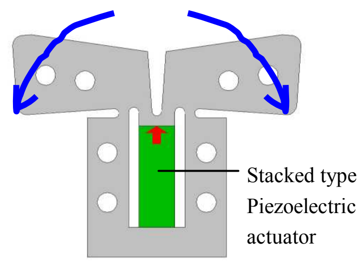


Fig. 9 Amplified mechanism for grasping motion

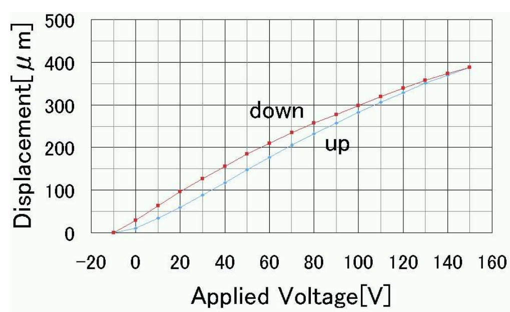


Fig. 10 Relation between applied voltage and distance between 2 glass needles

V. ELECTROMAGNETIC SPHERICAL MICROMANIPULATOR

We have proposed and developed the electromagnetic spherical micromanipulator to control the micro tweezers in Z direction. The design of the electromagnetic spherical micromanipulator is depicted in Fig.11. We turn the versatile micro robot bottom up and put a steel sphere on top of the 4 legs. The manipulator can rotate a steel sphere around three rotational axes in the manner of an inchworm as depicted in Fig.12 and Fig.13. Fig.14 shows the experimental arrangement for measuring the torque. We fix a spring on the sphere. The manipulator rotates the sphere against the force of the spring and we will know the torque if we measure the displacement of the spring. Fig.15 shows the experimental results of the torque around roll and yaw axes. We check that torques in all rotational directions are more than 100g•mm. We check that it has an enough payload to control the micro tweezers in Z direction. Table II shows the specification of the electromagnetic spherical micromanipulator.

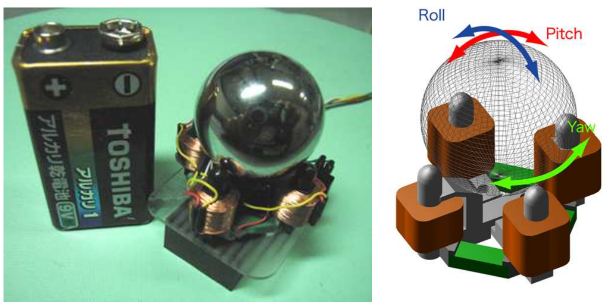


Fig. 11 Electromagnetic spherical micromanipulator

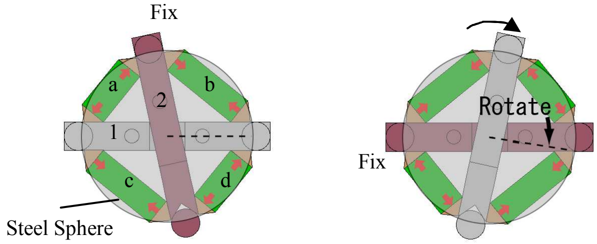


Fig. 12 Sequence of yaw direction (Top view)

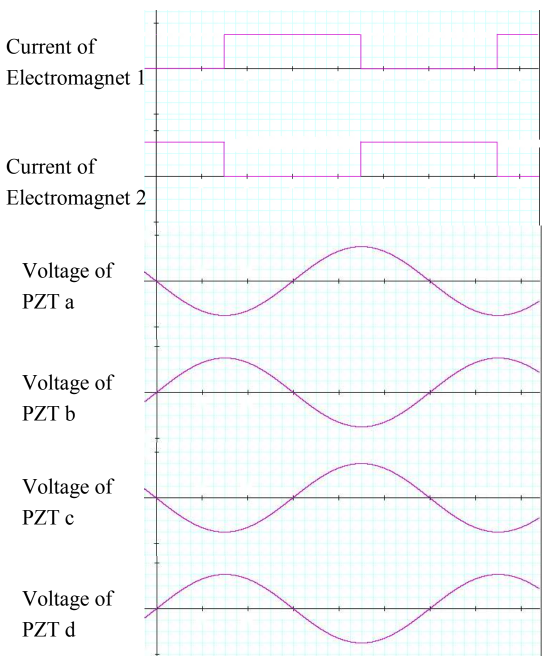


Fig. 13 Input signal of yaw direction

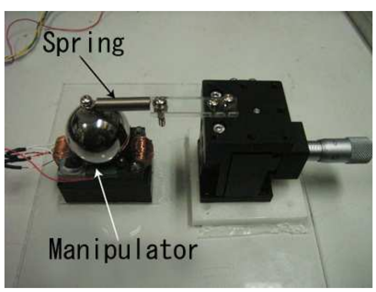


Fig. 14 Experimental setup for measuring the torque

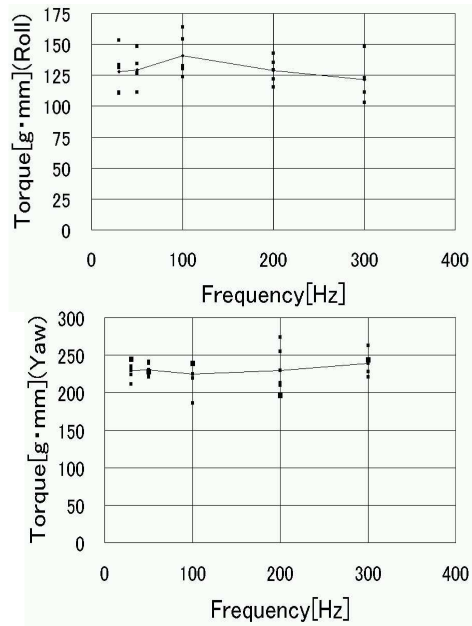


Fig. 15 Relation between the torque and frequency

TABLE II
PERFORMANCE OF THE ELECTROMAGNETIC SPHERICAL MICROMANIPULATOR

Maximum step angle	5×10^{-6}degrees
Maximum Angular speed (Frequency)	15×10^{-4}degrees/s (~300Hz)
Torque(Roll)	100 gmm
Torque(Pitch, Yaw)	200 gmm
Weight	35g
Size(except steel sphere)	32 mm×32 mm×19mm
Size of PZT	10 mm×2 mm×3mm
Displacement of PZT	6.3 μm/100V
Current of the electromagnet	0.1-0.7A

VI. MICROMANIPULATION ORGANIZED BY VERSATILE MICRO ROBOTS WITH MICRO TWEEZERS

A. Micromanipulation organized by Three Robots

Fig.16 shows the layout of micromanipulation through cooperation of three versatile micro robots with micro tweezers. We attach the micro tweezers on two versatile micro robots to handle the micro objects. We also arrange the versatile micro robot between them for sample positioning. We attach the hemisphere to electromagnetic spherical micromanipulators to attach the micro tweezers and sample table. We confirm that we can control the hemisphere by the electromagnetic spherical manipulator as well as the sphere. Table III shows the specification of the micromanipulation. There are 5 DOF for each tweezers, 5 DOF for the sample table and 3 DOF for each pair of glass needles. Total DOF is 21. Because the positioning range of our micro robots is only limited by the steel surface, the robots position their micro tools at any point on the steel surface. The size of this device is very compact, i.e. 200 mm in diameter and 70 mm in height. This device is compact enough to control the robots at a narrow working area such as a table of inverted micro scopes. The use of small devices avoids modification of instruments and easily implements additional processing.

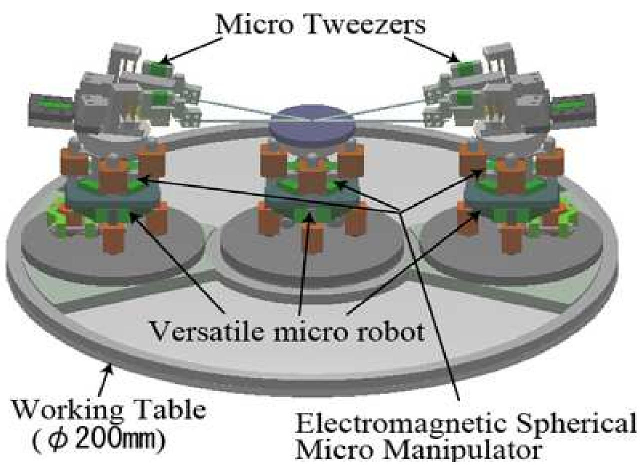


Fig.16 Flexible and precise micromanipulation organized by versatile micro robots with micro tweezers

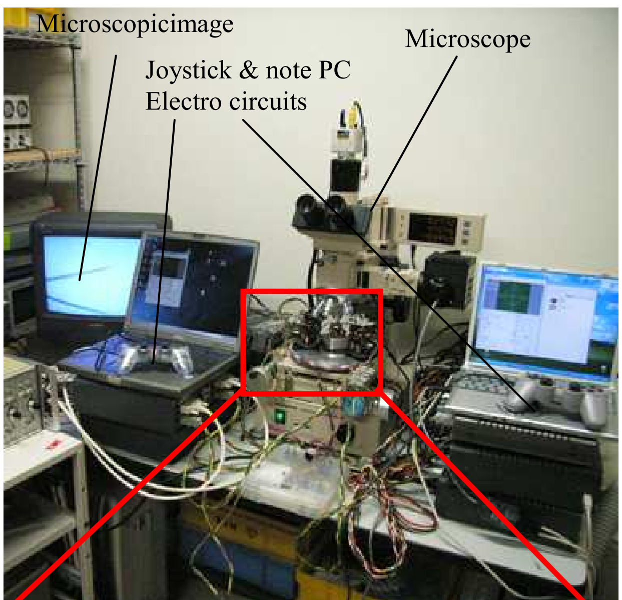


Fig. 17 Experimental setup of micromanipulation

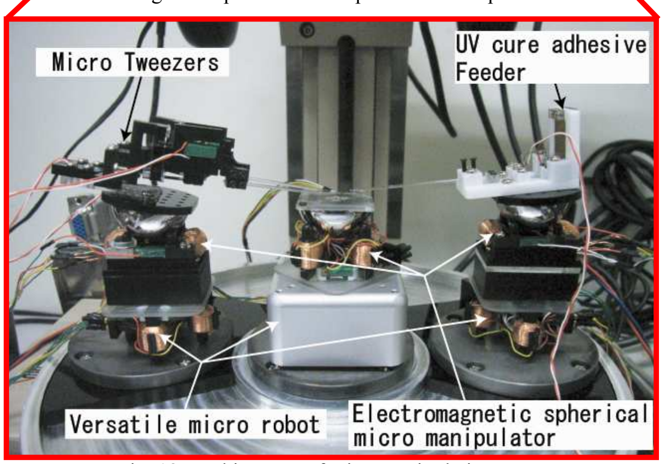


Fig. 18 Working area of micromanipulation

B. Experimental Operation

Multi-axial micromanipulation organized by three versatile micro robots is arranged for preliminary experiments. Fig.17 shows the experimental setup. Fig.18 shows the close-up view of the working area. Here we attach a micro feeder with the

TABLE III
SPECIFICATION OF MICROMANIPULATION

Size		200mm(diameter)×70mm(height)
Weight		400[g]
Maximum velocity (Frequency)		3[mm/s] (500[Hz])
Resolutions(Range)		
Sample Table	X	30nm(40mm*)
	Y	30nm(40mm*)
	Pitch	1.2×10^{-4}deg(20deg)
	Roll	1.2×10^{-4}deg(20deg)
	Yaw	1.0×10^{-5}deg(360deg)
Manipulator	X	30nm(30mm*)
	Y	30nm(30mm*)
	Z(Pitch)	30nm(20mm)
	Roll	1.2×10^{-4}deg(20deg)
	Yaw	1.0×10^{-5}deg(360deg)

* Due to the size of working table

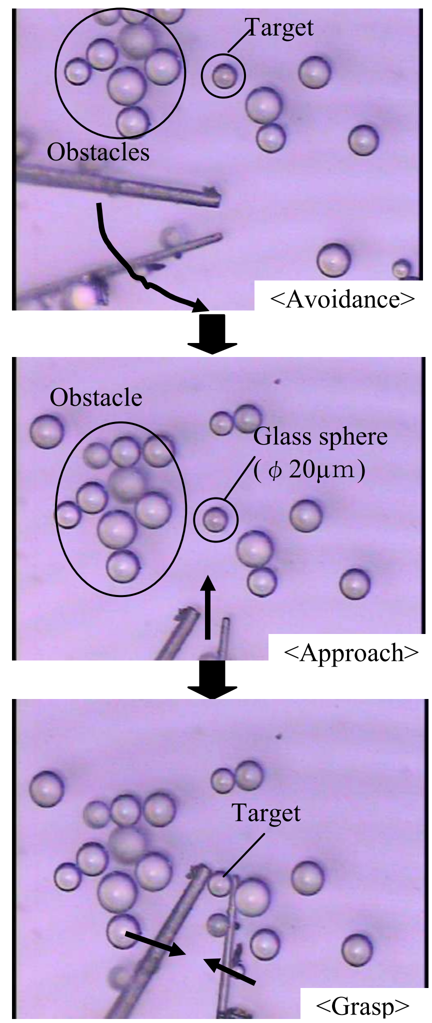
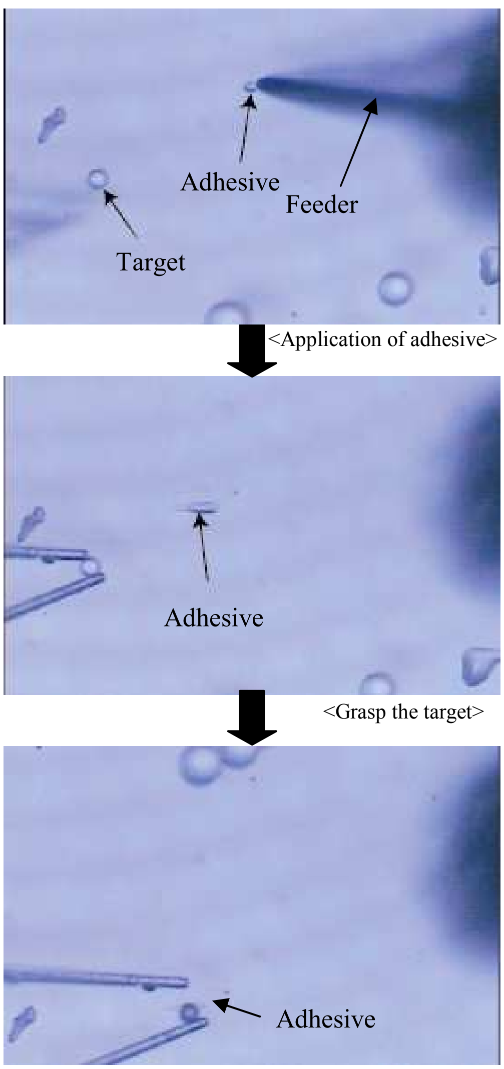


Fig. 19 Pick up operation of a tiny glass sphere (20μm in diameter)

UV cure adhesive instead of the right tweezers to fix the sample. We have also developed special control software so that each motion can be controlled by a simple mouse click on the PC or a joystick. The locomotion frequency of the robot is adjusted up to 500Hz and the step width of the robot is adjusted from 30nm to 4μm in order to select optimal speed and step width according to magnification of a microscopic image. We have succeeded in picking up a glass sphere with a diameter of 20μm as shown in Fig.19. In this operation, we avoid obstacles by circular motion of the manipulator at first, and then approach the target precisely. We finally pick up the target without touching any other spheres. We believe this flexibility and precise operation is useful for delicate operations such as the precise processing of cells for biomedical study. As another interesting operation, we fixed a glass sphere as shown in Fig.20. In this operation, we applied a small amount of the UV cure adhesive on the table, then picked up and put down the target on the adhesive. We irradiated the UV and finally fixed the target on the surface. We plan to apply this function to assemble micro parts such as portable devices.

VII. Conclusion and Future Works

The multi-axial micromanipulation organized by versatile micro robots with micro tweezers was proposed and developed to show the feasibility of micro robots. Several demonstrations as a primary study were achieved. We are now developing a PC-controlled system using a visual feedback



< Put down on adhesive & Fix the target>

Fig. 20 Fixing operation of a tiny glass sphere by an UV cure adhesive

property to make the system more precise and reliable. We are also developing a positioning device for a wide area to control the layout of the micro robots. We plan to develop a special measuring device which can put on the micro robot and measure the robot's motion precisely. We plan to apply our system to biomedical applications and the micro-parts assembling of portable devices.

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