Precise manipulation control on three versatile micro robots for flexible micro handling

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1. Introduction

In MEMS technology and precision engineering, there have been developed many reports about micromechanisms and microrobotics. Some are based on advanced technology including microbatteries, micromotors, and miniscule computational facility[1], the others are made by sophisticated precision machining techniques[2][3]. It is still very important to find industrial applications where such microrobots can provide effective benefits. For these years, our group has developed insect size microrobots equipped with microtools and instruments[4]. In-situ micro processing under microscopes is one of interesting application for microrobots[5][6]. For these years, we have developed versatile micro robot for the microscopic manipulation[7][8]. In this paper, we propose flexible micromanipulation organized by three versatile microrobots under microscopes. In order to realize the micromanipulation by the versatile microrobots, we developed the spherical micro manipulator as a microscopic manipulator. In experiments, we demonstrate precise, flexible handling of a minuscule pipe under the good collaboration of these small robots.

2. System Configuration

Fig.1 shows the flexible micromanipulation by versatile microrobots under microscopy which is ongoing development in our laboratory. Operators can control versatile microrobots using a PC in real-time monitoring of microscopic images. All microrobots are set on a steel table. In this basic setup, the operators can execute flexible microscopic tasks with easy operation. All positioning facilities are given by microrobots' movement so all mechanical functions are simply divided. This unique arrangement allows the system good flexibility and high mechanical stability although sophisticated control is required. This may be a good application for microrobots practically. We can easily attach microrobots to microprocessing instruments. This flexibility meets the requirements of users, and the use of small robots avoid reparation of microscopes and easily implements processing with low cost.

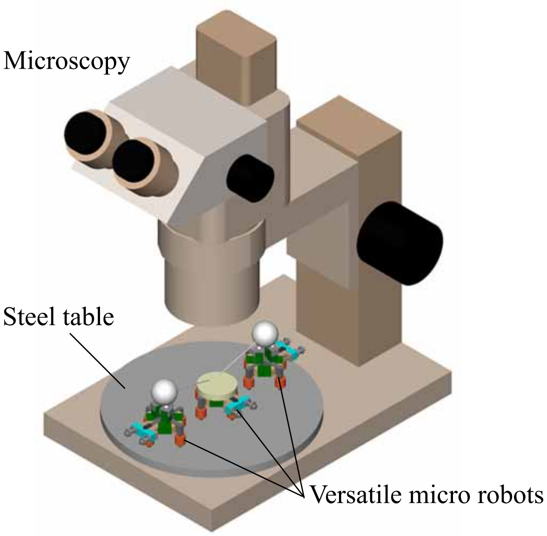


Fig.1 Versatile micro robots for flexible micromanipulation under microscopy

3. Versatile micro robot

Fig.2 shows motion patterns required at microscopic operation. To realize these motion patterns at the same time, we should design the structure which can move in XY directions and in rotation independently. Fig.3 shows the structure of the versatile microrobot which is proposed to satisfy the requirement above. Two U-shaped electromagnets which are arranged to cross each other are connected by four piezo elements so that the microrobot can move in any direction with the manner of inchworm. Also we design the special joint at one of 4 legs to get 4 legs smooth contact on the surface simultaneously. In experiments, we confirmed that the microrobot can move in XY directions and in rotation independently with nanometer resolution at different

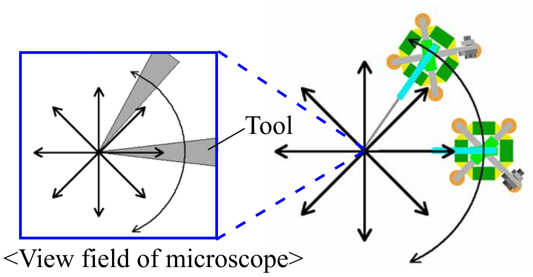


Fig.2 Motion pattern required at microscopic operation

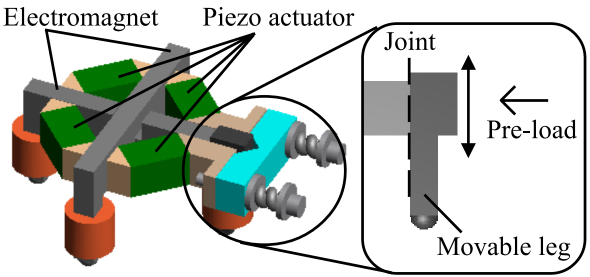


Fig.3 Structure of versatile microrobot

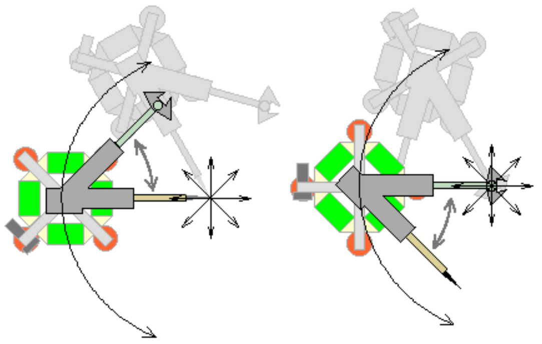


Fig.4 Flexible positiong of several tools by one robot

positioning speed[7]. We also succeeded to compensate for the motion very well[8]. As an interesting function, the robot can position several tools without extra manipulator as shown in Fig.4. We believe this unique function is effective for the advanced microscopic tasks at which we need several tools.

4. Spherical micro manipulator

4.1 Structure and drive sequence

We design the spherical micro manipulator as a microscopic manipulator as shown in Fig.5. The manipulator is composed of three piezo elements with a small accurate sphere and a large accurate sphere on the top of them. Three piezo elements are arranged at the apexes of a regular triangle and support the rotation sphere as shown in Fig.6 to allow the stable contact at any angle. When we apply saw-tooth waves to three piezo elements, the sphere rotate around on A_B axis precisely based on an stickslip model. When the similar sequence is operated, the sphere rotates around on A_{FR} and A_{FL} axes. The electropolishing tungsten needle is attached to the large sphere as shown in Fig.7, and we can control the tungsten needle in Z direction as well as the angle precisely.

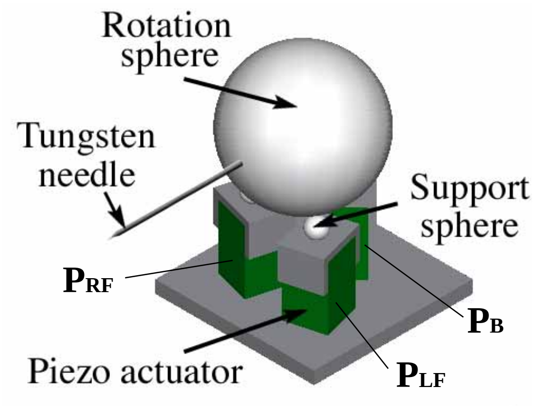


Fig.5 Structure of spherical micro manipulator

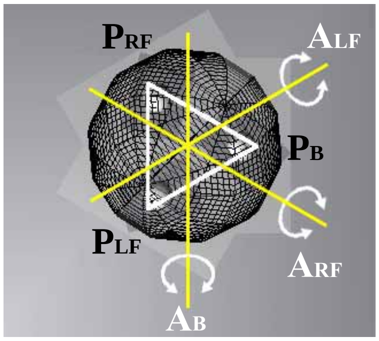


Fig.6 Arrangement of three piezo actuators (top view)

Fig.7 Spherical micro manipulator provided
for microscopic manipulator

4.2 Experimental results

As shown in Fig.7, we fabricated the spherical micro manipulator to check its primary performance. We use the brass sphere for support spheres, the stainless sphere for rotation sphere and stacked type PZT elements of 5mm x 5mm x 10mm. In order to check the angular

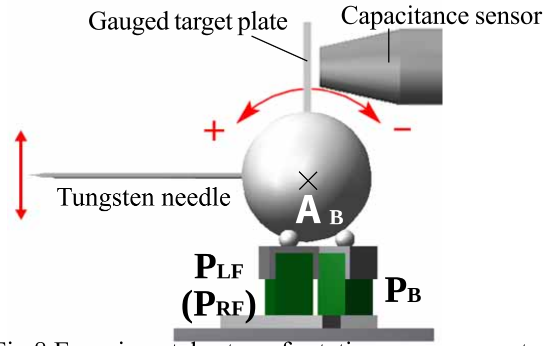


Fig.8 Experimental setup of rotation measurement around on AB axis

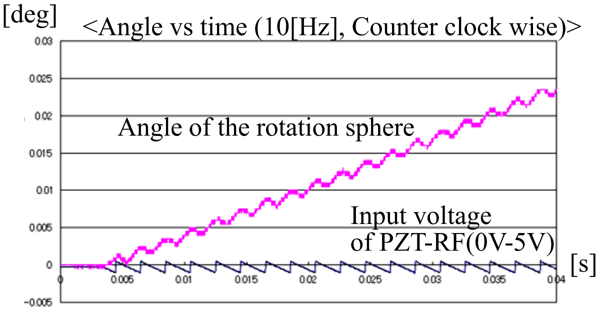


Fig.9 Relation between angular displacement and input voltage

displacement of the rotation sphere by a capacitance sensor, we attach a metal plate to the rotation sphere as shown in Fig.8. Fig.9 shows relation between angular displacement and the input signal of the saw-tooth wave. It is found that the sphere rotate 8.5 x 10^{-4} degrees per one step when the amplitudes of saw-tooth waves are 5 voltage. Hence this means that the end of the tungsten needle which length is 50mm move with the resolution of 0.7 micron per one step in Z direction. We have also confirmed that the angular speed is proportional to frequency very well up to 1kHz. When the drive frequency of 1kHz is given, then the tungsten needle moves 700 micron per one second in Z direction. In these experiments, we confirmed that the spherical manipulator has sufficient angular resolution and angular speed as a microscopic manipulator.

5. Micromanipulation Organized by Three Versatile Microrobots

5.1 Collaboration of Three Robots

Fig.10 shows the layout of micromanipulation by cooperation of three versatile microrobots. We attach the spherical micro manipulator to two versatile microrobots to handle micro samples in cooperation with each other. We also arrange another versatile microrobot with a sample stage under a microscope. Tungsten needles are positioned in X, Y, and rotational direction by the versatile microrobot and positioned in Z direction by the spherical micro manipulator. The sample stage is positioned in X, Y and rotational direction by the versatile microrobot. Both tungsten needles have 4 DOF and the sample stage have 3 DOF, so the manipulation system has 11 DOF. Because the positioning range of our microrobots is only limited by the steel table, the robot positions its manipulator at any point in the steel table. This arrangement of three versatile microrobots provides both flexible and accurate micromanipulation with nanometer resolution.

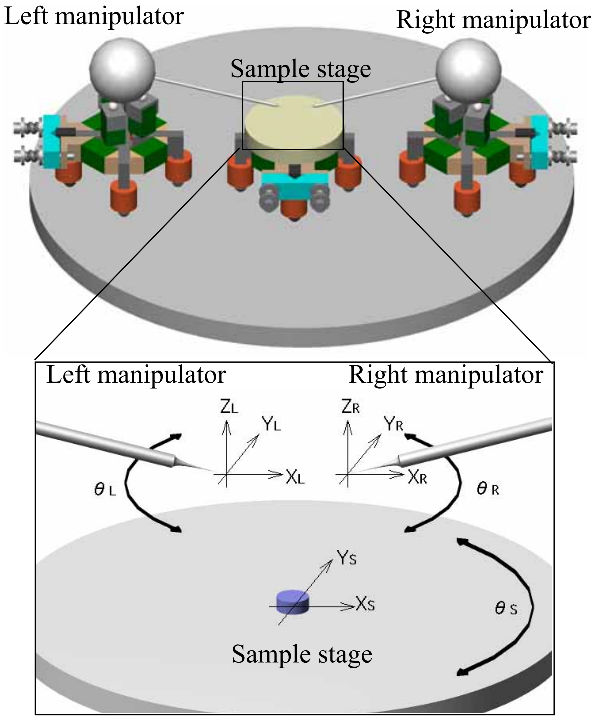
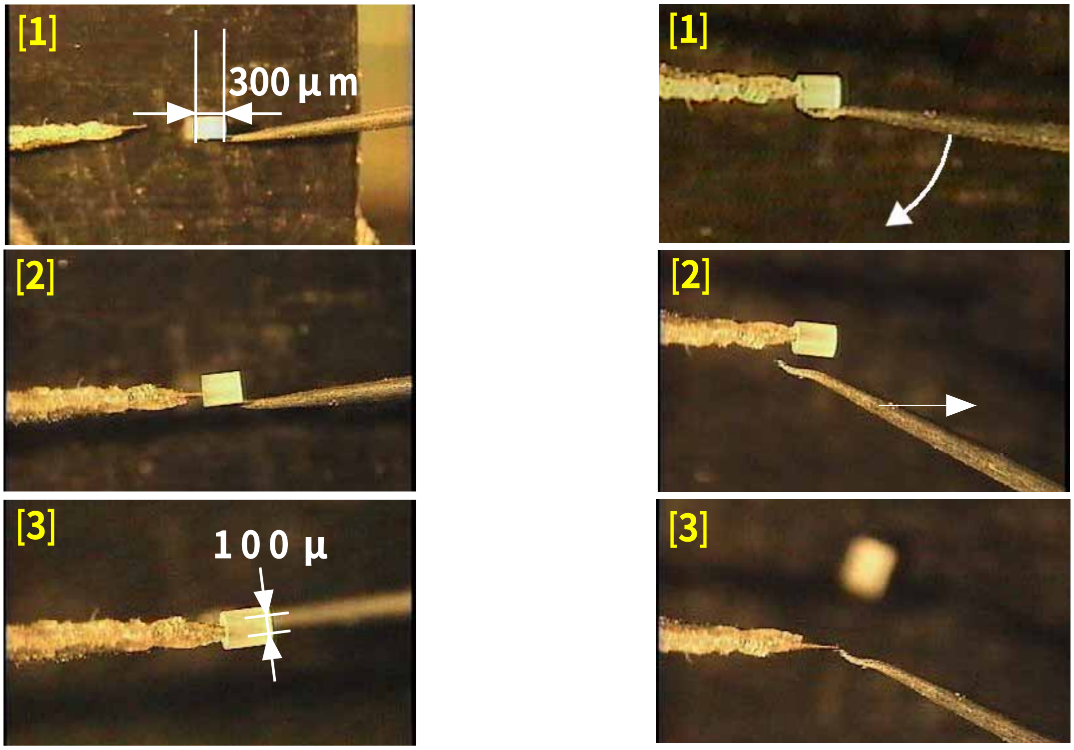


Fig.10 Layout of micromanipulation organized by three versatile microrobots

Fig.11 Flexible micromanipulation by collaboration of three versatile microrobots

5.2 Experimental Operation

Flexible micromanipulation organized by three versatile microrobots are arranged for primary experiments as shown in Fig.11. We also developed the special control software so that each motion could be



<Inserting a needle into a pipe> <Removing a pipe from a needle>

Fig.12 Flexible handling of a miniscule pipe by two tungsten needle

controlled by a simple mouse click and a joystick on the PC for primary experiments. The locomotion frequencies of microrobots are adjusted from 0 to 500Hz to select optimal speed according to magnification of the microscopic image. We succeeded in inserting a tungsten needle into the miniscule pipe and removing it by cooperation of two manipulator robots as shown in Fig.12. We believe that we can apply this performance to operations of biological samples and microdevice repair.

6. Conclusions and Future Works

Flexible micromanipulation organized by versatile microrobots under microscopes was proposed and developed to show the feasibility of microrobots. The demonstrations of primary micromanipulation assisted by the microrobots were described and some unique tasks were achieved. We are now improving the PC controlled system based on visual feedback to make it more precise and reliable. To realize more advanced and complicated work, we are improving the spherical micro manipulator and we are developing the software to control the several tools by one robot. We plan to apply our system to biomedical applications and in-situ micromanipulation in scanning electron microscopy.

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