Improvement of Visual Based Motion Error Compensation for Precise Versatile Micro Robot

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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, the others are made by sophisticated precision machining techniques. However it is still very important to find industrial applications where such microrobots can provide effective benefits. Recently, in-situ microprocessing becomes more important for biochemical operation and real time processing inside SEM vacuum chamber[1][2]. In order to provide microscopic manipulation, we have developed the unique locomotion mechanism which is composed of four piezoelectric elements and two electromagnets. Here two legs arranged on cross each other are connected by four piezoelectric elements so that it can move in any directions, i.e. in X and Y directions as well as rotate at the specified point precisely with the manner of an inchworm as shown Fig.1. Moreover the combination of particular wave forms for piezoelectric elements can provide "arc trajectory with facing center", that is important for the micro manipulator to keep its tip end within the microscopic view area as shown Fig.2. In previous report, we attached three miniature robots under microscopes and demonstrated the precise and flexible control of miniscule pipe as shown Fig.3[3]. We have concluded that our robot is effective for microscopic operations such as microinsemination, in-situ manipulation inside the SEM vacuum chamber because we could easily install our robots under various microscopes and our robots are more reasonable and more flexible than conventional

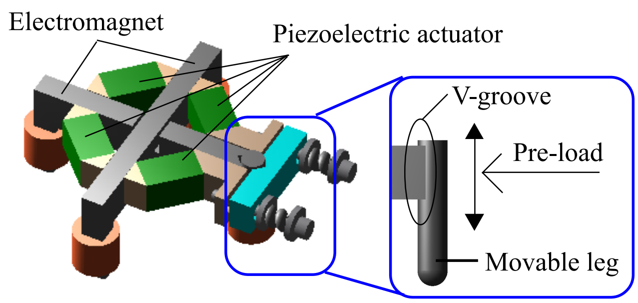


Fig.1 Structure of versatile microrobot

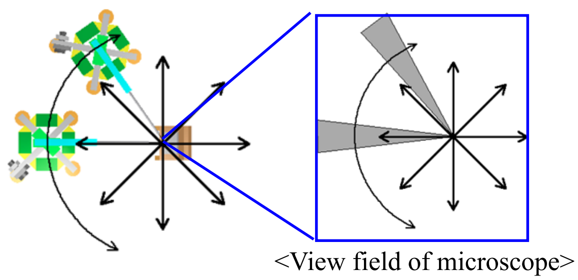


Fig.2 Motion pattern required at microscopic operation

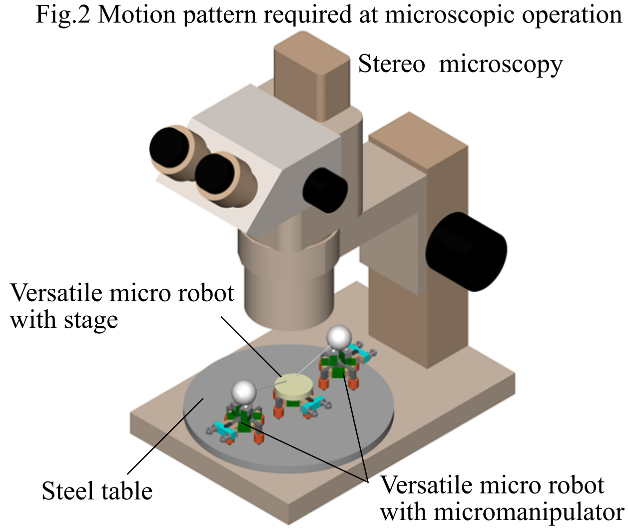


Fig.3 Flexible micromanipulation collaborated by three versatile micro robots under microscopy

instruments.

However, the versatile micro robot could not move precisely without the motion compensation because of the difference of characteristics of four piezoelectric elements and the assembling error of four piezoelectric elements and two electromagnets. In previous report, we analyzed the mechanical kinematics for locomotion and propose the competitive compensation system supported by the CCD camera based image tracking system as shown Fig.4[4]. In this paper, we analyze the mechanical kinematics of our robot more precisely to improve the competitive compensation. In experiments, we confirm that newly developed compensation system is more effective than previous one especially in forward, back, right and left directions. The design procedure, basic performance and biomedical application of this tiny robot also are discussed to open the new field for micro-robotics in precision region.

2 Sequence of Compensation

In order to explain the problem of the previous compensation, we describe the sequence of the previous compensation. We analyze the motion mechanism at a half step to investigate relationship between displacements of 4 piezo elements and motion of the free electromagnet as shown Fig.5 and FIg.6. Fig.5 shows the kinematic model of this small robot. In this figure, we consider that the displacement of each PZT element A0, A1, A2 and A3 move the specified points K1 and K2 on the free magnet to K1' and K2'. Fig.6 shows the definition of parameters at a step motion. In the experiment, the robot are measured by the CCD camera based microscope image tracking system. We calculate experimental displacements of 4 piezo elements by the geometric analysis of the orbit and the kinematic model of the robot as shown Fig.5 and Fig.7. Finally, we apply the compensation formula to compensate the robot motion as depicted in Fig.8. The robot can move more precisely with repetitive these procedures. The best calculation results are stored in PC as unique parameters. Fig.9 shows the experimental results of previous compensation. We know that four diagonal motions are well compensated, but the forward, back, right and left straight motions are not compensated very much. We have concluded that we should improve the kinematic model in order to involve the assembling error of four piezoelectric elements and two electromagnets into the procedure of compensation.

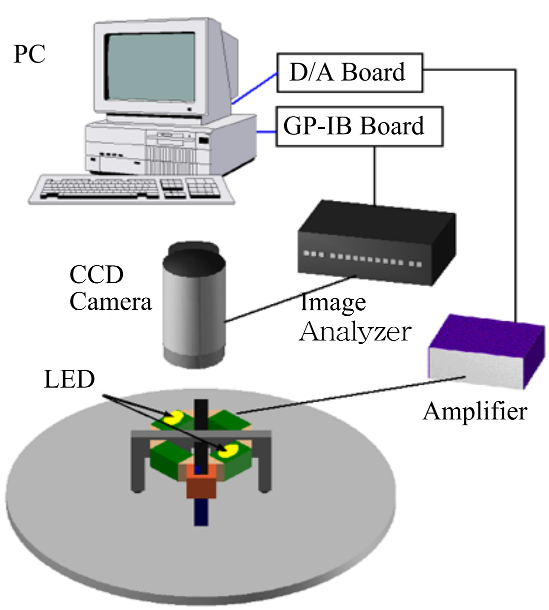


Fig.4 Experimental set up of repetitive compensation

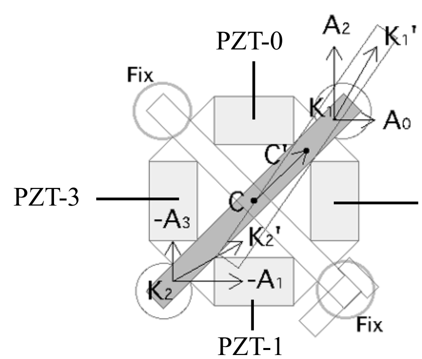


Fig.5 Previous kinematic model

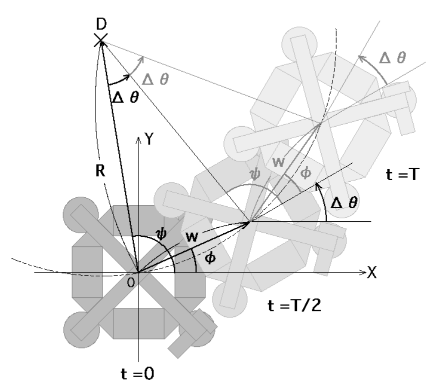


Fig.6 Definition of parameters at a step motion

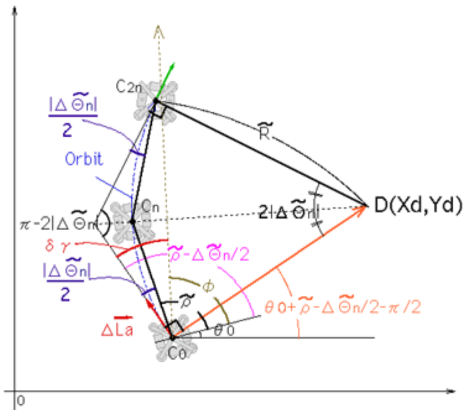


Fig.7 Geometric analysis of the orbit

$$PGain[k]' = PGain[k] \times \frac{Ak'}{Ak}$$
$$(k = 0,1,2,3)$$

Ak': Ideal displacement of PZT-k

Ak: Experimental displacement of PZT-k

$PGain[k]'$: Sinwave's amplitude of PZT-k after compensation

$PGain[k]$: Sinwave's amplitude of PZT-k at experiment

Fig.8 Compensation equation

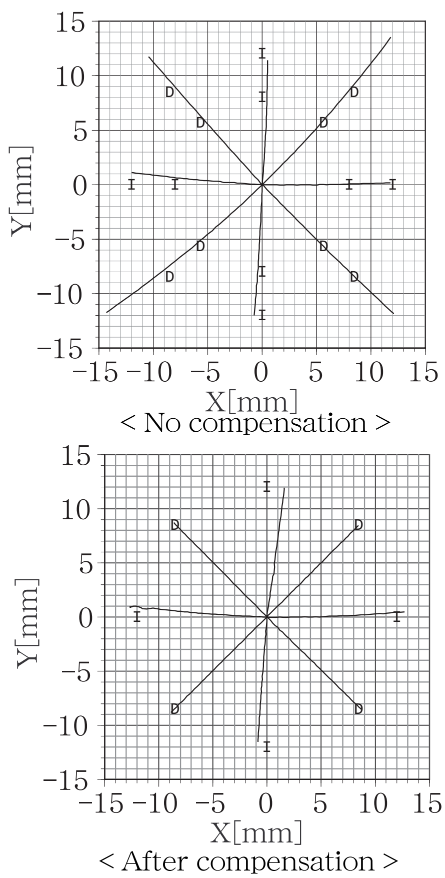


Fig.9 Experimental results of previous compensation

3 Improvement of the Kinematic Model

In order to involve the assembling errors of four piezoelectric elements and two electromagnets into the kinematic model, we define the four unique angles. When the robot moves to forward, back, right and left, we use the two piezoelectric elements. If we adjust the two piezoelectric elements so that the robot

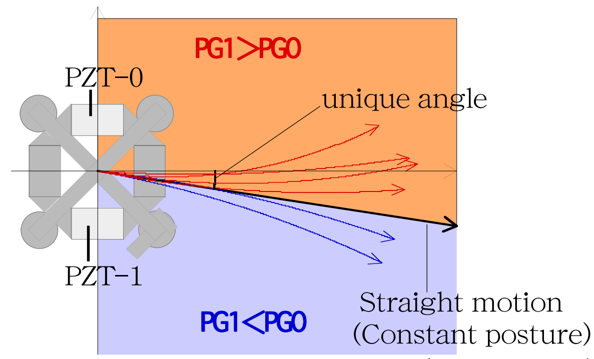


Fig.10 Definition of a unique angle (right motion)

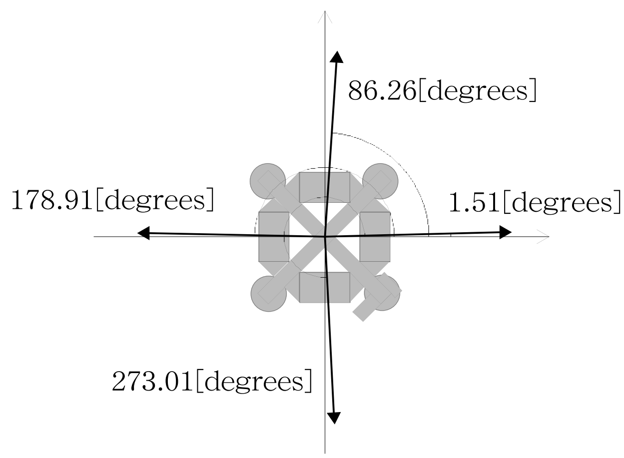


Fig.11 Experimental results of unique angles

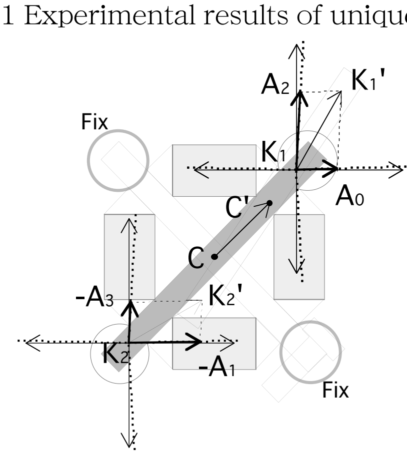
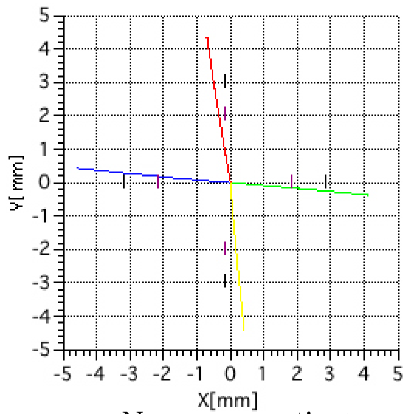
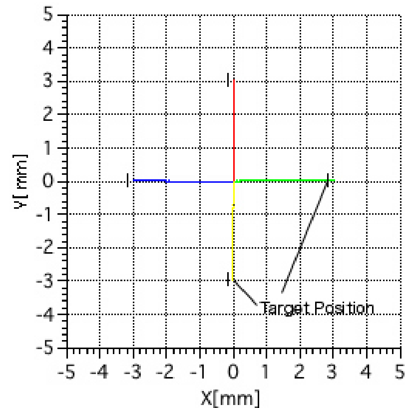


Fig.12 Kinematic model by use of unique angles



<No compensation>



<After compensation>

Fig.13 Experimental results of newly developed compensation

would not change its own posture, the robot should move straight to the unique angle. Fig.10 shows the how to get the unique angle at right motion. In this figure, PG0 means displacement of PZT-0 and PG1 means that of PZT-1. We could adjust the PG0 and PG1 so that the robot would not change its own posture. Fig.11 shows the experimental results of unique angles. If there are not assembling errors, the four unique angles should become 0, 90, 180 and 270. We define the new kinematic model which is involved the four unique angles as shown Fig.12. In this figure, we consider the four piezoelectric elements push the free magnet to the corresponding unique angles.

4. Experimental Results

We recalculate the compensation equation by use of the newly developed kinematic model. And then we conducted the repetitive compensation 5 times at each motion. Then we have checked its motion accuracy by use of CCD based image analyzer. Fig.13 shows the compensational results of forward, back, right and left straight motion. The ratios of locational errors to length of path become less than 1%. We also check that the posture errors become less than 0.2 degrees in the experiments. We confirm that we could compensate the robot motion in forward, back, right and left straight motion very well if we use the newly developed kinematic model.

5. Conclusions & Future Works

Visual based motion error compensation system for precise versatile micro robot is improved by use of newly developed kinematic model. We define the unique angles to involve the assembling error into the kinematic model. We confirmed that we could compensate the robot motion in forward, back, right and left straight motion very well if we use the newly developed kinematic model. Furthermore, in order to develop the motion performance, improvement of the whole system by both side of hardware and software is required. In addition, development of the PC controlled system with the help of the visual feedback system is also required. Moreover, micro tools which can be implemented on this robot to achieve the flexible micro processing under the collaboration by this versatile micro robots have been developing.

References

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