

# Visual Based Motion Error Compensation for Precise Versatile Micro Robot

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## 1. Introduction

In the field of micro system and precision engineering, there are many reports concerning micro robotics and its trial applications. Some of them are based on the advanced technology including micro battery, micro motor and tiny computational facility<sup>(1)</sup>, the others are made by the sophisticated precision machining techniques<sup>(2-4)</sup>. However it is still very important to find the industrial applications where such micro robots can provide effective benefits. It is well known that the *Desk top Factory*<sup>(5)</sup> has the potential application not only for the production engineering but also for the chemical and biotechnology. For years, our group has developed insect size robots equipped with various micro tools and instruments<sup>(6)</sup>. Particularly the in-situ micro processing in the scanning electron microscope can be one of feasible applications although it needs much of cost to install the fine positioning mechanism into the small chamber<sup>(7)</sup>. For the period of research, we have proposed the flexible micro-processing system organized by multiple miniature robots in SEM vacuum chamber as depicted in Fig.1<sup>(8)</sup>. In previous experiments for years, we concluded that we need the arc trajectory motion with facing center to keep its tip end within the microscopic monitoring area as well as XY orthogonal motions as shown Fig.2. Moreover we designed and controlled the newly developed versatile micro robot which can move any directions as shown in Fig.3<sup>(9)</sup>. In this paper, visual based motion error compensation system for this precise versatile micro robot will be discussed.

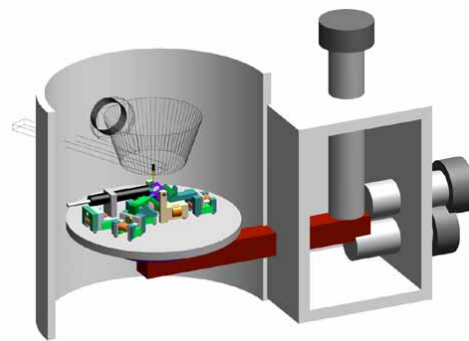


Fig.1 Flexible micro processing system by micro robots in SEM vacuum chamber

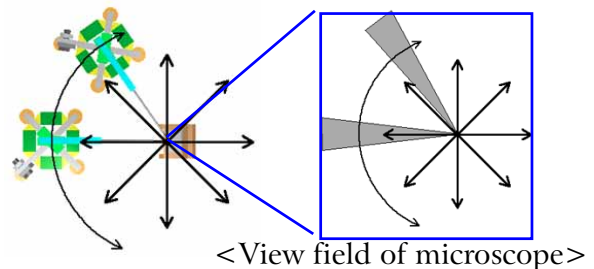


Fig.2 Motion pattern required at microscopic operation

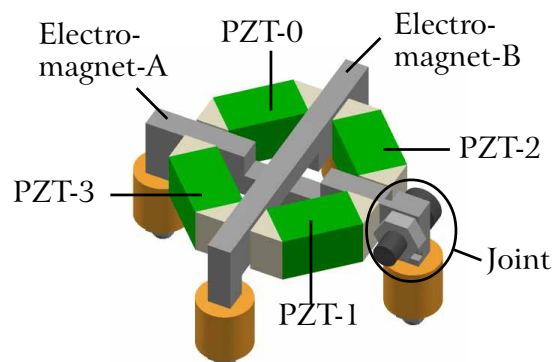


Fig.3 Structure of versatile micro robot

## 2 System Configuration

Fig.3 shows overview of the micro robot's structure. Where two closed loop electromagnets which are arranged to cross each other as like X character are connected by four piezo elements so that it can move in any directions with the manner of inch worm as depicted in Fig.2. Also we design the special

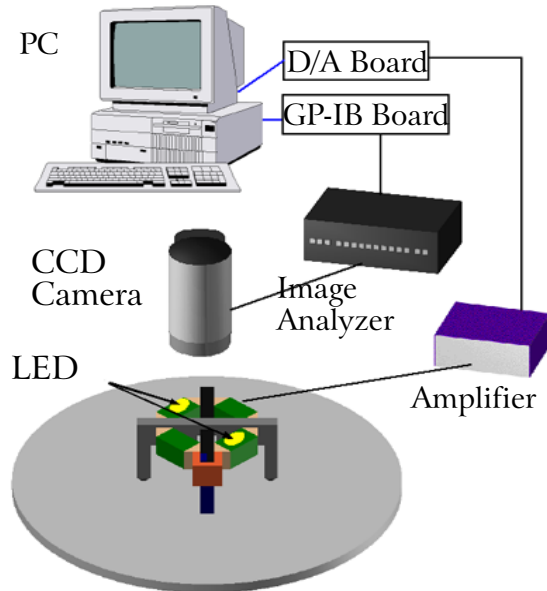


Fig.4 Experimental set up of calibration system

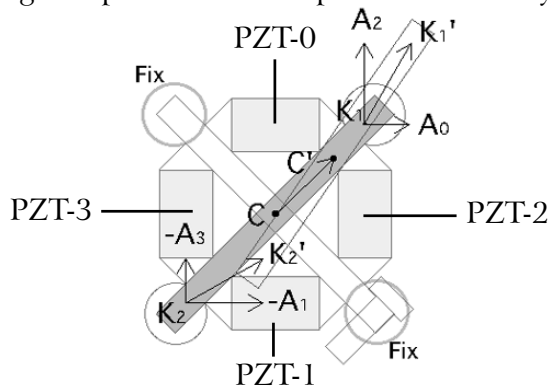


Fig.5 Model of versatile micro robot

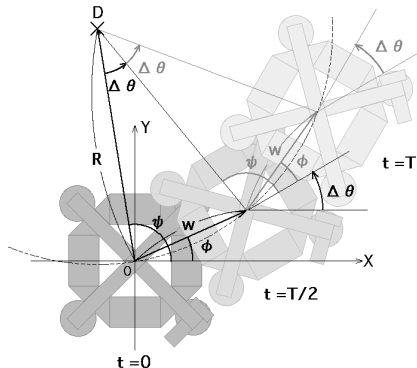


Fig.6 Definition of parameters at a step

joint at one of legs to get 4 legs smooth contact on the surface simultaneously.

Fig.4 shows the overview of whole system of this compensation system. We attached two LEDs on the robot to measure the position and direction of the robot by the CCD camera based microscope image tracking system.

## 3 Compensation Sequence

First of all, we analyse the robot's motion mechanism at a half step to investigate relationship between 4 piezo elements' displacements and motion as Fig.5 and Fig.6. Fig.5 shows schematic structure model of this small robot actuated by piezo elements. In this figure, we consider that the displacement of each PZT element A0, A1, A2, and A3 make the specified points K1, K2 on the free magnet move to the K1', K2'. Fig.6 shows the definition of parameters at a step motion. Then, the robot motion are measured by the CCD camera based microscope image tracking system. We calculate 4 piezo elements' experimental displacements as shown in Fig.7. Finally, we apply the compensation formula to compensate the robot motion as depicted

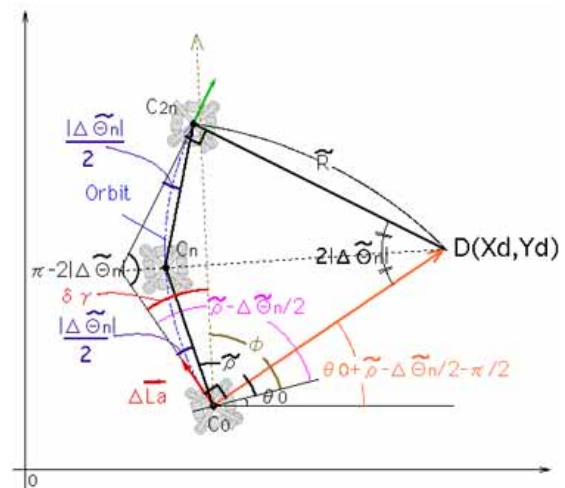


Fig.7 Geometric analysis of robot motion

$$PGain[k]' = PGain[k] \times \frac{Ak'}{Ak}$$

$$(k = 0, 1, 2, 3)$$

$Ak'$ : 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

in Fig.8. The robot can move more precisely with repetitive these procedures. The best calculation results are stored in PC as unique parameters.

## 4. Experimental Results

### 4.1 Round-trip movement in 8 directions

Fig.9 shows the experimental results of round-trip movement in 8 directions. Fig.10 shows the results of angle alternation in the robot's back and forth movement. In the experiment, we used the microscope with CCD based image analyzer to measure its motion accuracy. We confirm that we can compensate the robot motion in both the orthogonal and the diagonal directions.

### 4.2 Rotation and Arc Trajectory Motion

#### (1) Rotation

As shown in Fig.11, we attach the two LEDs to the robot to measure its rotational motion accuracy. Fig.12 shows the results of the experiment. If we compensate values of amplitude of 4 PZT elements' sine wave control signal, we can improve the rotational

accuracy of the robot dramatically.

#### (2) Arc Trajectory Motion

In another experiment, we attach the two LEDs to the center of the robot and the ideal rotation center of the arc trajectory to measure its accuracy as shown in Fig.13. Fig.14 shows the results of the experiment. If we compensate values of amplitude of 4 PZT elements' sine wave control signal, we can improve the motion accuracy as well as rotation. This performance can be useful when we manipulate small objects in the focused area, such as microscope.

## 5. Conclusion & Future Works

Visual based motion error compensation system for precise versatile micro robot is proposed and developed. We confirm that the robot can move more precisely by this compensation system automatically. 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 the PC controlled system with the help of the visual

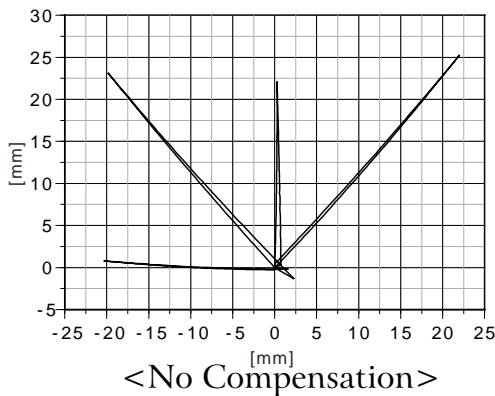


Fig.9 Experimental result of round-trip movement in 8 directions(100Hz)

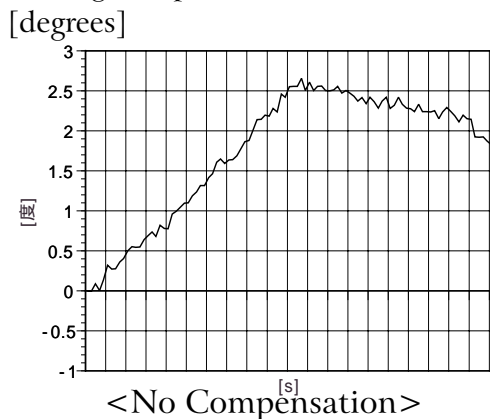
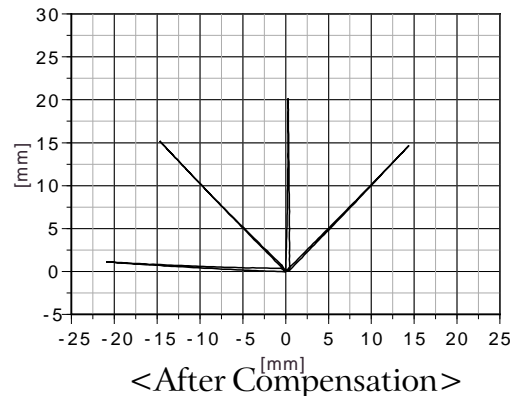
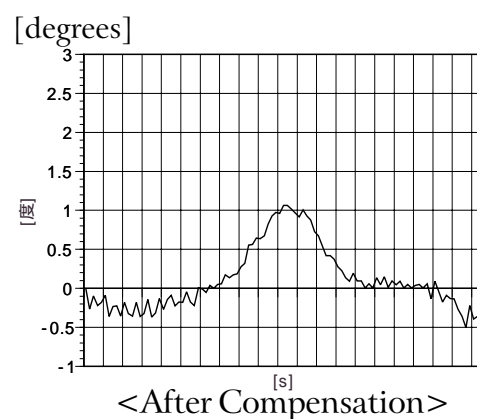


Fig.10 Experimental result of the robot's directions at forward-back movement



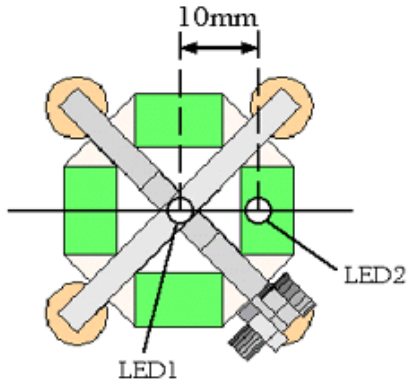


Fig.11 Arrangement of two LEDs in the rotational experiment

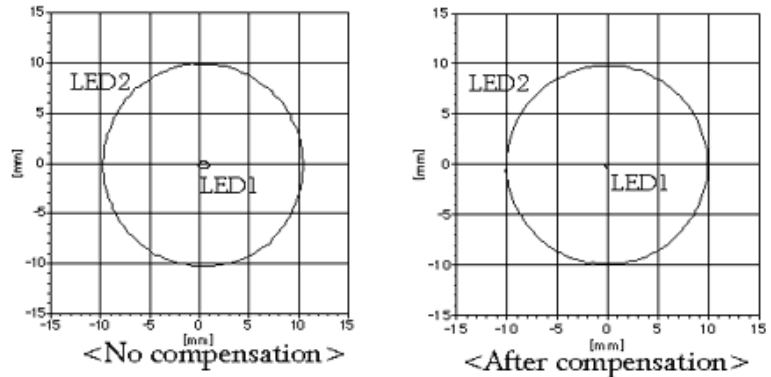


Fig.12 Experimental result of the rotation

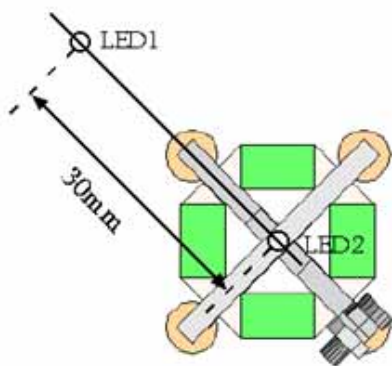


Fig.13 Arrangement of two LEDs in the arc trajectory's experiment

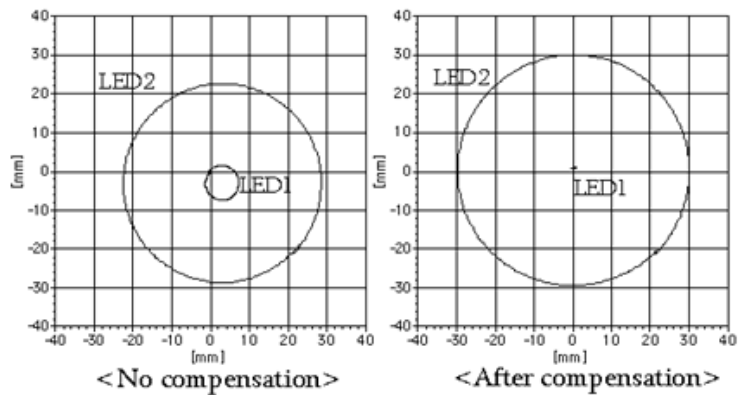


Fig.14 Experimental result of the arc trajectory

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.

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