PIEZO DRIVEN XY STAGE WITH NANO-MANIPULATORS FOR SEM OPERATION
Shunsuke Kanegae, Chiba Hiroyuki, Hisayuki Aoyama, Yuka Irie, Futoshi Iwata, Tatsuo Ushiki

1Mechanical Engineering and Intelligent Systems
The University of Electro-Comunications, Chofu, Tokyo, Japan
2Faculty of Engineering Shizuoka University
Hamamatsu, Shizuoka, Japan
3Graduate School of Medical and Dental Sciences, Niigata University
Niigata, Niigata, Japan

INTRODUCTION
In biotechnology and Micro Electro Mechanical Systems (MEMS), the development of the manipulation system with higher resolution is important for handling a micro-target. In order to observe a small sample such as an animal cell and tissue in a Scanning Electron Microscope (SEM), some special tools that can cut and manipulate the sample in situ are often required. However the conventional XY stages with the lead screw and motor are difficult to install into the small chamber of the SEM because they are too big or adverse effects for SEM imaging.

Therefore this paper discusses that a self-walking small XY stage and manipulation tools with piezo actuator are developed and the performances are checked for the practical application in the SEM.

DESIGN AND DEVELOPMENT OF PIEZO DRIVEN SELF WALKING XY STAGE
For the observation of biological structures (i.e., animal and plant cells and tissues) in the SEM, it is necessary to move manipulation tools from an initial position to the target.

Thus both coarse and fine positioning functions are essential to these stage as well as the size of the stage should be small enough to set up into the small SEM chamber. Figure 1 shows the top view of the newly developed stage.

This stage is composed of three piezo elements. Two piezo elements clamp the guide gauge. The third piezo element expands and contract. The stage can move along the guide gauge by combination of these piezo movement.

Driving principle
This stage moves using inchworm locomotion. Detail motion is shown as follows.

First, the back is clamped, the front is unclamped, and the middle piezo element is contracted.
Next, the middle piezo element is expanded.
Third, the front piezo element is clamped.
Last, the middle piezo element is contracted. The stage moves by repeating this operation.

Despite such a small displacement of piezo element, this stage is realized coarse motion.

Measurement of 1 step displacement
Figure 3 shows the assembled XY stage in which two linear stages were stacked so that positioning in plan can be performed.

We confirmed that this stage can be used as XY stage from experiment of 1 step locomotion. The each X stage and Y stage was moved to forward and backward by 1 step locomotion. And, we measured the movement using a capacitance gauge.
Figure 4 shows results of our experiments using the XY stage. These graphs show the relationship between stage displacement and applied voltage of piezo for driven. (a) This graph shows the data of the X stage going forward. (b) This graph shows the data of the X stage going backward. (c) This graph shows the data of the Y stage going forward. (d) This graph shows the data of the Y stage going backward. The each graph shows that displacement is proportional to the piezo applied voltage, indicating that we can control the stage displacement by changing voltage and inchworm movement in this XY stage become successful.

Minimam displacement of XY stage

Figure 5 shows a reproducible minimum displacement of the XY stage. In this time 6V voltage was applied to the piezo for driven three times. The graph shows the stage moves 2um with three steps and one step displacement is about 0.7um. Our target size of animal cell is 100um. We judged that 0.7um is enough for manipulate these cells.

Experiment of withstand load

Experiment of withstand load was performed because some tools should be mounted on the XY stage. Thus, we examined how the weight changes the behavior of the XY stage. The weights which were increased 0g to 400g by 50g increments were put on the stage, and the behavior of the XY stage was measured each time. Figure 6 shows the results of experiments. At the initialize state, the X axis has load of 200g because the Y axis stage is on X axis stage. (a)This graph shows X axis locomotion. (b)This graph shows Y axis locomotion. Seeing data of the Y axis indicates instability behavior until 100g. This is responsible for accuracy of the assembly, and occurred the stage lifting. After loading 100g constant displacement was recorded. But the stage can be loaded the weight of 400g or less by experiment of withstand load.

DEVELOPMENT OF MICRO TOOL TURRET

The tool for the cell manipulation also has been developed as a simple fine tool which can handle biological samples implemented on the XY stage. Because it was necessary to move those tools up and down to do such precise manipulation, the micro tool turret mechanism using 3 piezo elements was developed. Figure 7 shows the isometric view of the micro tool...
The turret rotates by applying the saw-tooth voltage to each piezo elements.

**FIGURE 7. Configuration of tilting stage**

**Experiment of the micro tool turret**
We confirmed that the turret can tilt using the autocolimator. Figure 8 shows the result of our experiment. In this time piezo elements are placed like Figure 9. Blue dots are data of tilt down by using the piezo element of ch0. Red dots are data of tilt up by using piezo element of ch1 and ch2. 50 steps saw tooth voltage was applied dots are pointed each 10 steps. When Voltage was applied only to the piezo 0, this stage tilts Y direction 0.33 degrees in 50 steps. X direction is -0.03 degrees. The gap of between ideal direction and experimental direction is 10%.

It became apparent that the micro tool turret can tilt from this result. But there is a problem. The problem is the change of the surface condition. Changing of the surface condition makes difficult to adjust tilting of hemisphere. As a future works we have to control the hemisphere by considering the surface condition.

**FIGURE 8. Tilting angle of the turret**

**FIGURE 9. Piezo place design**

**MICRO MANIPULATION TOOL FOR BIOLOGICAL STUDIES IN THE SEM**
As a cell manipulation tool, we developed a needle that moved back and forth by using the piezo element. Because the target cell size is about 100um. The developed needle moved the back and forth in a wide range by the width of 33um which is one third of cell size. Because the displacement of the piezo element is low, the displacement amplification mechanism was developed. Figure 10 shows a developed piezo driven needle. It was confirmed that the displacement of piezo element is proportional to applied voltage, and it expands to 30um.

**FIGURE 10. Piezo driven needle**

**Development of piezo driven tweezers**
We also developed piezo driven tweezers that is one of cell manipulation tools. Because the size of the target bio-structures is about 100um, we decided to develop piezo driven tweezers that can open 100um. We developed a lever mechanism to amplify displacement again, and made the tweezers. Figure 11 shows new tweezers.

**FIGURE 11. Piezo driven tweezers**

**CONTACT FORCE OF MICRO TOOL**
This needle is pasted on thin copper board. If something contacts the needle, the contact force is reach to the copper board and makes strain. The strain of the copper board is measured by the strain gauge. The needle is pasted on the liner actuator. The actuator downs the needle 20um steps at five times and measures the voltage of the strain gauge.
The result of measurement is shown in Figure 12. We can measure the force which coursed when the needle was pressed 20 micro meters.

\[ \text{strain gauge output[mV]} \]

\[ \text{displacement [um]} \]

**FIGURE 12. Sensitive of strain gauge on the needle**

**MANIPULATION AND REAL TIME OBSERVATION EXPERIMENT IN SEM**

In the SEM chamber there are some bad effects for manipulation such as high vacuum state and electron beam for SEM observation. So that operation in the SEM might not be the same as in the atmosphere.

Figure 13 shows the XY stage in a SEM. We operated the XY stage and the manipulation tool (piezo driven needle) in SEM. We also checked either vibration by clamping that we confirmed in basic experiment makes bad effects for SEM observation or not.

The XY stage and manipulation tools for operation of biological samples were placed in the SEM. The tool is mounted on the stage. The condition in the SEM chamber was ultra vacuum and electron beam was close to the target. Then vibration waveform was inputed to the needle. SEM images are shown in Figure 14. Images shows the top of the needle.

There is no bad effect in SEM images. This clear images indicate that we can operate biological samples with real time observation in this system. The size of the SEM image is 600x500um. (a)This picture shows before moving needle. (b)This picture shows after moving it.

The piezo driven needle is at the top of the sem pictures. AFM needle is found at the bottom. The stage was successfully controlled and The needle was moved forward and backward. This micro movement enabled us to cut the biological soft sample.

**FIGURE 13. Stage with manipulator in SEM**

**FIGURE 14. Clear picture by SEM observation**

**CONCLUSION**

In this experiment, we successfully designed and fabricated a novel self walking XY stage and fine rotating turret with micro manipulators. The XY stage can move precisely and mount the weight up to 400g. The micro tool turrets rotate finely.

These stage and tools were installed in the SEM, and succeeded in manipulating biological soft samples with this system.

In the future work, improvement will be achieved to make the system more useful for image processing or some sensor and feedback control might be needed.

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**REFERENCES**