Visual Feedback Control of a Micro Lathe

Hirotaka OJIMA[1], Katsuhiro SAITO[1], Libo ZHOU[1], Jun SHIMIZU[1], Hiroshi EDA[1]
[1]Ibaraki University

Keywords: Micro lath, Visual feedback, Position control

Abstract

Micromachining progresses rapidly in recent years. In this research, a micro lathe which is installable and operational inside SEM vacuum chamber has been designed and developed. As a first step, visually guided micro lathe system is developed with image of CCD camera device instead of SEM image. Unlike the conventional feedback control which positions the X-Y table only, this scheme offers a direct control of the position, path and speed of the tool tip. Using proposed method, cutting experiment was achieved, and it is confirmed that developed micro lathe system is effective to do cutting.

1 Introduction

Recently, the system capable of producing the micro parts are requested along with the miniaturization[1]. Micromachining progresses rapidly in recent years. The exploratory research has approached to a level of accessing a single molecule or atom. As a driving force, MEMS (micro electronic-mechanical system) has been playing a major role in making micro components and devices. However, MEMS is based on the photolithography technology and thereby applicable into limited materials such as silicon monocrystalline. In order to meet the demands of miniaturization in electronic and optical applications, alternative micromachining technology which is able to access a variety of materials in a 3 dimensional way is required[2].

Micro-Meso Mechanical Manufacturing (M^4) offers accessibility to different kinds of material according to each objective, and attains high repeatability and accuracy with the latest ultraprecision means. There are, however, many scientific and technological barriers encountered in pragmatic implementation of M^4. One of them is the surface chemistry effects. When machining parts are at micro scale, it is recognized that the surface-area-to-volume ratio will be increased in both chips and the resulting part as compared to conventional (macro) machining process. Another problem is the direct motion and position control. Sensors that are capable of directly measuring the relative displacement between the tool and workpiece are not yet available.

In this research, a micro lathe which is installable and operational inside SEM vacuum chamber has been designed and developed[3]. Fig. 1 shows the concepts of the developed micro lathe. At such oxygen-free condition, cutting tests are conducted to understand surface chemistry effects on micromachining. However, since developed micro lathe is small in size, rigidity of the lathe is low. Thus the position of the tool of the lathe is not able to be controlled accurately with a conventional method which controls X-Y table only. Therefore, the vision guided control method is proposed.

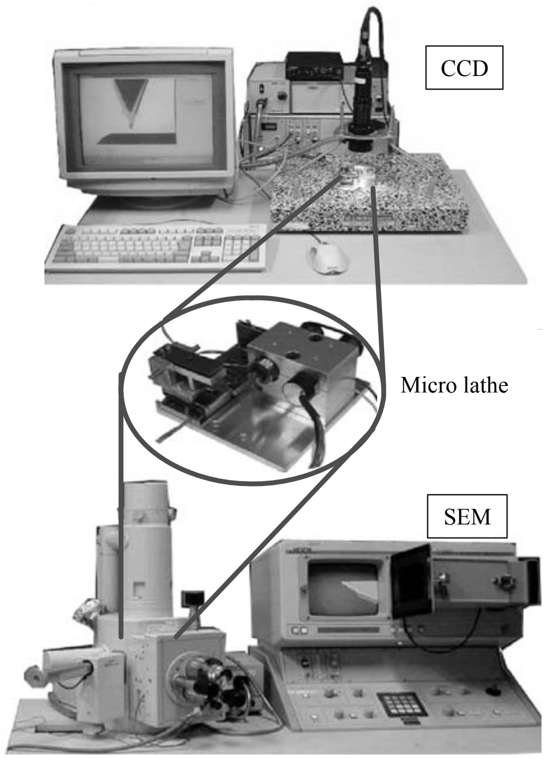


Fig. 1. Concept of the developed micro lathe

The image from the SEM (scanning electron microscope) is digitized by CCD into pixels with 8-bit gray scale. Since each pixel contains 2D positional information, the vision system thus offers an orthogonal coordinate (hereafter referred as the pixel coordinate) for objects in view to refer to. The pixel coordinate is free from the mechanical inaccuracy and offers a direct measurement of the relative position of tool and workpiece. The resolution increases together with the magnification of the microscope and the number of CCD pixels. In this research, a vision control scheme has been proposed and implemented for feedback control of the tool movements. Unlike the conventional feedback control which positions the X-Y table only, this scheme offers a direct control of the position, path and speed of the tool tip. As a first step, visually guided micro lathe system is developed with image of CCD camera device instead of SEM image.

2 Overview of system

Shown in Fig. 2 is the block diagram of developed micro lathe system, which consists of three main modules; the actuating module that drives micro lathe, the sensing module that imports images and the processing module that implements feedback control. Each module is responsible for different function. The actuating module is the core element where the cutting operation is carried out. The sensing module imports images from CCD image device, and obtains the position of the tool and the workpiece. The other tasks including the image processing and feedback control are executed by the processing module. Upper picture of Fig. 1 shows the overall appearance of the system. Table .1 shows the specifications of the system.

The actuating module further incorporates a diamond tool with a XZ linear stage, and the sensing module includes a high resolution CCD image device. Through sensing module, the appearance of the working area is not only displayed on the monitor to the give the operator the visual information, but also converted into digital signal for subsequent processing.

As the control diagram show in Fig. 2, the movements of the diamond tool are governed with the visual feedback control. The sensing module first abstracts the positions of the tool and workpiece by comparing the pre-registered templates with the captured visual information. Corresponding to the relative positions of tool and workpiece, the tool path and speed are calculated and converted into appropriate pulse train.

3 Actuating module

The developed micro lathe is shown rightward in Fig. 3. This lathe consists of the main spindle with the collet chuck with the DC motor, the center high adjustment using a piezoelectric actuator and XZ-stage which performs both depth of cut (X-axis) and traverse feed (Z-axis). The XZ-stage is driven by the inertial sliding, and is composed of a piezoelectric actuator and the linear guide.

XZ-stage is shown leftward in Fig. 3. An accurate tool positioning is achieved by driving the XZ-stage precisely. Important points of driving the XZ-stage are the control of the driving direction, distance and velocity. Figure 4 shows the inertial sliding mechanism by the saw-tooth wave. The direction of the movement is decided by the rising/trailing edge of the saw-tooth wave as shown in Fig. 4. For example,

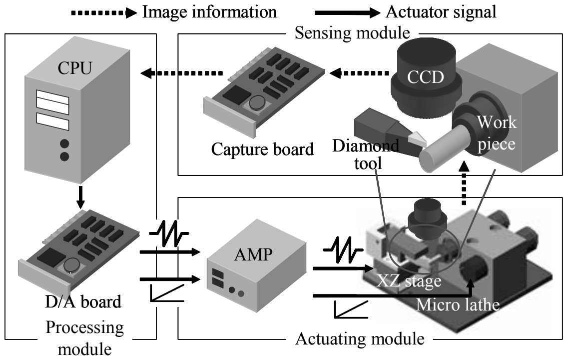


Fig. 2. Block diagram of system

Table 1. Specification of system

Size of micro lathe (W×D×H)	90×90×42 (mm)
Spindle rotational speed	0～8000 (rpm)
Depth of cut × Traverse feed	10×10 (mm)
Center high adjustment	30 (μm)
Tool	Diamond
Nose angle / nose radius	40(°) / 2 (μm)
Scanning rate	20 (frame/s)
Total pixels	0.3 mega pixel

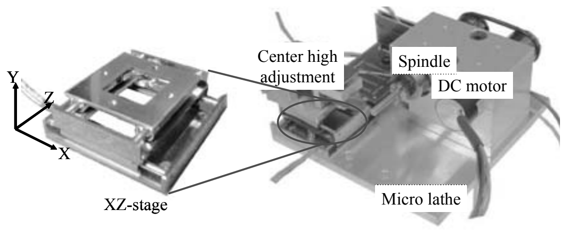


Fig. 3. XZ-stage and micro lathe

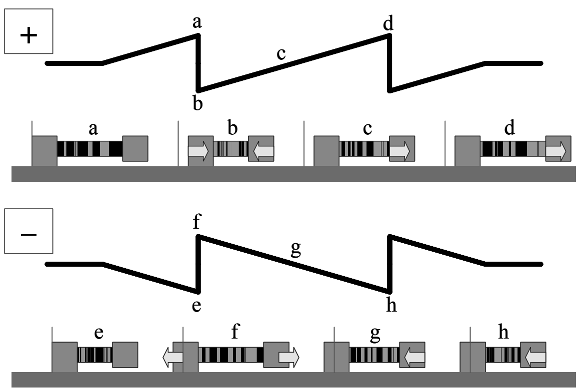


Fig. 4. Driving principle of XZ-stage

the mechanism in the right direction (+) is explained as follows. The voltage gradually rises, and a piezoelectric actuator stretches most in (1). The actuator shrinks based on the centroid in (2) by falling rapidly of the voltage. Only the side where the frictional force is small moves as the actuator stretches gradually with the ascent of the voltage in (3). The actuator is stretches again in (4), and advances toward the right direction. The actuator similarly advances also toward the left direction (-) if a reverse pulse train is given.

Next, the velocity control of this mechanism is described. As shown in Fig. 5, the velocity is proportional to both frequency of the pulse train and driving voltage.

Finally, driving distance can be controlled according to the number of pulses, because the driving distance by one plus is about 500μm at ±80V or 250μm at ±40V.

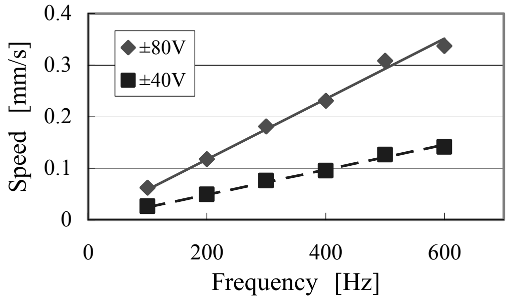


Fig. 5. Velocity change depending on frequency and voltage

4 Sensing module

The diamond tool is mounted on XZ-stage, which uses piezoelectric actuator to drive tool. Those mechanical inaccuracies, mainly caused by thermal expansion, hysteresis/drift in actuators and misalignment of orthogonal axis, may directly deliver a negative effect to the system performance. To solve these problems, a vision control scheme as shown in Fig. 6 is developed. The left picture in Fig. 6 shows the micro lathe and CCD image device located in Y-axis. From the right picture in Fig. 6, the incoming visual information from the CCD is digitized into pixels with 8-bit gray scale by the sensing module. As each pixel bears 2D positional information, the vision system thus offers an orthogonal coordinate (referred as the pixel coordinate) for objects in view to refer to. The pixel coordinate is free from the mechanical inaccuracy and its resolution increases together with the magnification of the CCD.

At a 480×640 pixel frame used in the current research, for example, the resolution of the pixel coordinate is about 6μm when the view of the CCD is twofold magnified. When the CCD is aligned along Y-axis, the position of the tool tip and workpiece is projected into a 2D pixel coordinate (XZ) which is commonly shared by the XZ-stage and workpiece. Driven and controlled by the pixel coordinate, the tool is able to be positioned and moved at the accuracy of pixel resolution with no effect by the mechanical inaccuracy. In addition, if the rigidity between XZ-stage and tool is low, positioning of tool tip is not achieved by driving XZ-stage accurately. Thus, more importantly, this operation is an effective method of positioning for the micro lathe with a low rigidity.

Figure 7 shows the recognition accuracy that is made by use of shape based pattern matching[4] to recognize the actual tool tip repeatedly 500 times. We comprehend from the graph that 88.5% reliability can be achieved within the limes of ±1pixel (6μm).

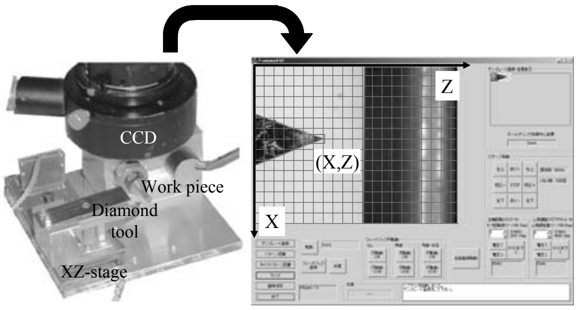


Fig. 6. Visual sensing system

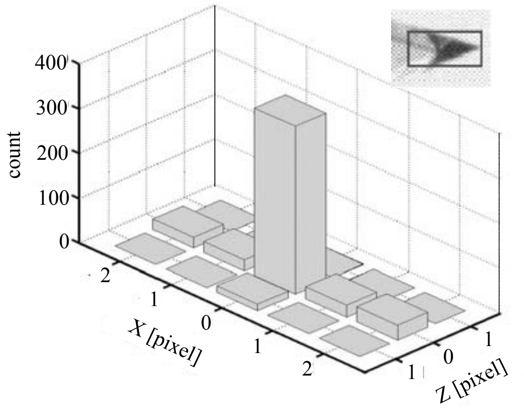


Fig. 7. Recognition accuracy of tool tip

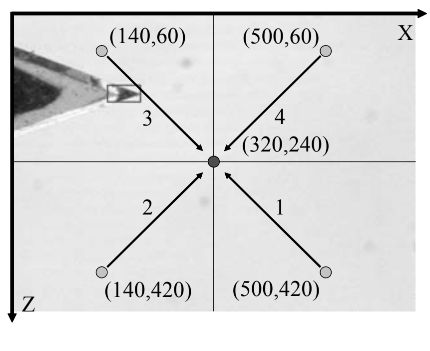


Fig. 8. Experimental condition of linear path control

5 Processing module

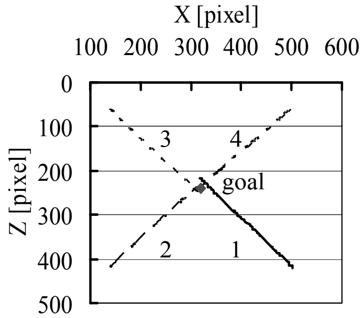
For the system which is consisted of the actuating and sensing module in previous section 3 and 4, the visual feedback control method is described in this section. The tool tip is driven by visual feedback control method with positions of the tool tip and targets from CCD image device.

As a first step, we examined linear path control and circular path control of the tool tip. In these path controls, driving frequency is 300Hz (162μm/s). At first, liner path control of tool tip is described. As shown in Fig. 8, the target position is defined as (320, 240) which is the center of the image from CCD, and four kinds of path control are examined. In the case of liner path control, the angle formed by the target position and the present position of the tool tip is fed back to achieve the path control.

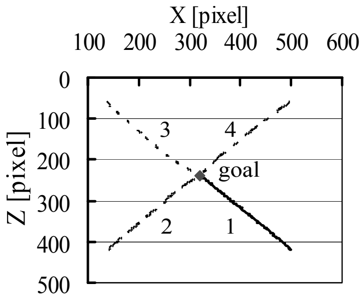
Figure 9 (a) shows the resultant path of the tool tip without feedback control, and (b) shows that with feedback control. In the case of the path without feedback, final errors of four paths are between 5pixels (30μm) and 15pixels (90μm). On the other hand, the path with feedback follows along the target path, and final error is within 2pixels (12μm).

Next, the circular path control which is multi-axial interpolation is described. The condition of the circular path control is shown in Fig. 10. The center of the target circular path is defined as (320, 240) which is the center of the image from CCD, and the radius of the target path is 100pixels (600μm), moreover the tool tip is driven from starting point (220, 240) along counterclockwise direction repeated 3 times. In the case of circular path control, we consider to feed back not only the angle formed the center of the target circular path and the present tool position, but also the deviation of the radius which is the error between the radius of the target circular path and the distance from the center of the target path to the present tool position. In the case of the driving the path without feedback control, the tool is driven by the angles prepared in advance.

Figure 11 (a) shows the resultant path of the tool tip without feedback control, and (b) shows the path with feedback control of the angle only, and (c) shows the path with feedback control of the angle and radius. Figure 11 (a) shows that the resultant path departed from target path, and the center and the radius of the path are deflected from those of the target path. Figure 11 (b) shows the center of the resultant path matches the center of the target path, but extends the radius of the resultant path as the path goes around. Moreover, Fig. 11 (c) shows that the resultant path



(a) without feedback control



(b) with feedback control

Fig. 9. Experimental results of linear path control

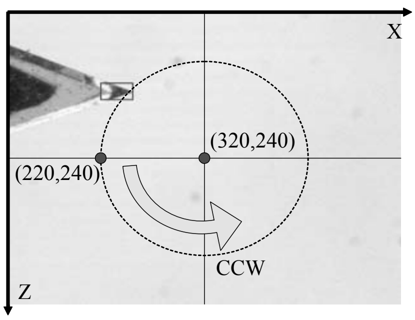
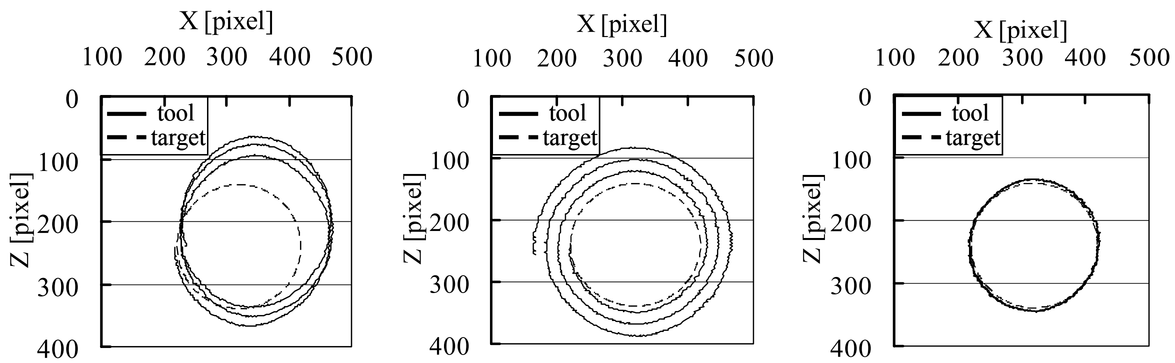


Fig. 10. Experimental condition of circular path control



(a) without feedback control (b) with feedback control of the angle (c) with feedback control of the angle and radius

Fig. 11. Experimental results of circular path control

follows the target circular path closely, and errors are ±5pixels (30μm). From mentioned above, it is confirmed that proposed feedback control method is effective to position the tool tip of the micro lathe.

Finally, using the proposed control method, cutting of a brass bar is experimented. As shown in Fig. 12, the tool tip is driven with circular and linear paths. The target path moves 1pixel (6μm) rightward every 1 lap, then the tool tip is achieved to cut. In this experiment, total depth of cut is 150μm. Figure 13 shows the appearance of cutting experiment, and cutting of a brass bar advances from (1) to (4). Figure 14 shows the resultant brass bar which is taken a picture by SEM. From this picture, developed micro lathe system can implement cutting well.

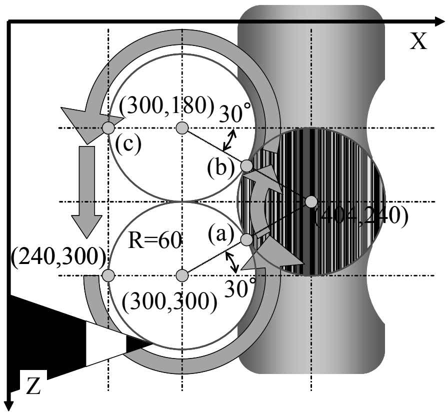


Fig. 12. Tool path strategy

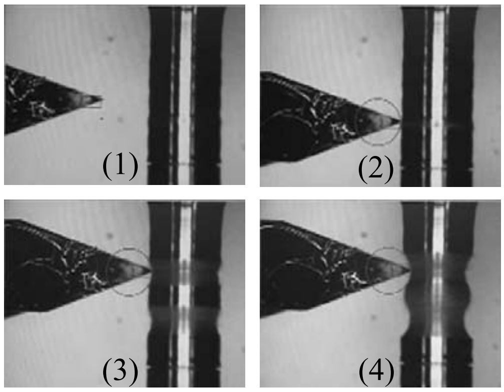


Fig. 13. Experiment of cutting a brass bar

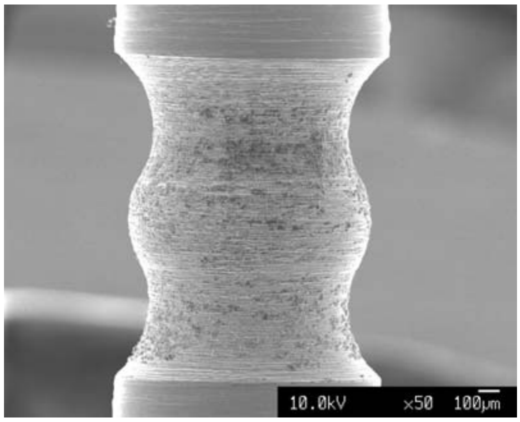


Fig. 14. SEM picture of a resultant brass

7 Conclusion

This paper described a vision guided micro lathe which is developed for fundamental research. The system consisted of the actuating module and the sensing module was made up and the visual feedback control method was proposed.

Driving principle of the XZ-stage of the micro lathe was investigated, and control method of the XZ-stage was proposed. Using the CCD image device and image processing, the accurate position of tool and workpiece on the micro lathe was obtained. The visual feedback control method for the system cosisted of the actuating module and the sensing module was proposed. Using the proposed control method, linear path control and circular path control was experimented and was able to be controlled that error is within the limes of ±5 pixels (30 μm). Moreover, cutting excperiment of a brass bar was achieved, it is confirmed that developed micro lathe system is effective to do cutting.

8 References

[1] Okazaki Y., (2001) NC micro lathe, Journal of Society of Grinding Engineers (in Japanese), Vol.45, No.6: 279-282.

[2] Libo Z., Kuriyagawa T., (2002) M4 trends in America, Journal of the Japan Society for Abrasive Technology (in Japanese), Vol.46, No.12: 594-597.

[3] Yokoyama I., Nishida K., Zhou L., Eda H., Kawakami T., (2003) Experiment & Design of Ultra-precision Machine tool, Proceedings of Ibaraki District Conference (in Japanese) : 165-166

[4] Qiu Z., Zhou L., Nishida K., Shimizu J., Eda H., Ishikawa T., (2004) Development of Cell Manipulation System under Microscope, Proceedings of the 1st International Conference on Positioning Technology : 457-461