MEASUREMENT OF 3-D TOOL WEAR BASED ON FOCUS ERROR AND MICRO-COORDINATE MEASURING SYSTEM

Kah W. Ng and Kee S. Moon
Department of Mechanical Engineering and Engineering Mechanics
Michigan Technological University, Houghton, Michigan

Abstract

This paper presents a technique for measuring micromachining cutting tool dimensions. The technique uses machine vision and a geometric modeling platform (CAD software) as the means of constructing the 3-D shape of a cutting tool and obtaining the 3-D metrological data. In the technique, a sequence of images is obtained by continuously varying the distance between the cutting tool surface and the image detector. The focus information from the obtained images provides the 3-D shape of the cutting tool. In addition 3-D metrological measurement is conducted by a micro-coordinate measuring system. In the system, the 3-D shape of the cutting tool is converted into the form of IGES file. The IGES file is read by the geometric modeling platform (IDEAS). The available tools in the geometric modeling platform can be used as the coordinate measuring means. In particular, pointing tool can be used as a "virtual touch probe". The system provides the capability of measuring linear and angular quantities, establishing datum lines and planes from the imported shape of the cutting tool. The capability can be useful for measuring tool wear. Experimental results are presented and discussed to demonstrate the technique.

Keywords: machine vision, micro-machining, 3-D measurement, cutting tool

Introduction

In micro machining, dimensional accuracy and quality surface finish are the key elements of a desirable machined product. The dimensional information of a cutting tool including tool wear can help to achieve the precision machining. The tool wear changes the chip-tool/tool-workpiece interface, thus affecting the cutting process. While the tool wear might be an important factor in micromachining, there are not many instruments available for the measurement.

In this paper, a tool wear measuring technique based on machine vision, image-processing technique and virtual contact probe is presented. There are two main phases in this study. The first phase is to reconstruct the 3-D shape from a cutting tool images using a digital focus measure (Moon and Ling 1999, Moon and Ling 2000). The second phase is performed on CAD software (IDEAS), which serves as the geometrical platform (Ng et al. 2000). Pointing tool like the mouse cursor can be used as a "virtual touch probe". By picking appropriate points using the "virtual touch probe", the 3-D metrological analysis such as defining a datum line and plane of a surface is practicable. This concept is similar to a conventional coordinate measuring machine (CMM).

A digital focus measure

When varying the distance between a sample and the camera image plane, a sequence of images can be captured. It is well known that in a microscopic image the depth of focus decreases as the magnification of an objective lens increases. As a result of this, a tall feature in the sample, which exceeds the depth of focus, will be out of focus and become blurred. A simple measure of focus can be computed from the gray level variance in the pixel data (Soatto 1998, Subbarao and Choi 1995). A high pass digital filter is a good focus measure. It is from the fact that the digital high pass filter can attenuate low frequency components (blurred area) as well as enhance high frequency components (focused area) in a digital image.

A 2-D spatial differentiation operator is also one of the excellent means of obtaining the focus measure from a digital image. The spatial derivative of a digital image is defined as the difference between the intensities of adjacent pixels. Upon investigating the trend of the spatial gradient, it has been found that the spatial difference between its adjacent pixels is highest at the focal point. Since each digital image is a 2-D matrix, combining all the digital images together can form a 3-D matrix. The simple form of spatial gradients for x, y, and z direction can be computed by

$$F_x(i,j,k) = p(i+1, j, k) - p(i, j, k) \tag{1}$$

$$F_y(i,j,k) = p(i, j+1, k) - p(i, j, k) \tag{2}$$

$$F_z(i,j,k) = p(i, j, k+1) - p(i, j, k) \tag{3}$$

Where *(i, j, k)* represents a pixel position in the 3-D matrix. *p(i, j, k)* is the gray level of the pixel at *(i, j, k)*. The x and y directions are the column and row directions of a digitized image. The z direction is the same as the direction of sample height or the image sequence. In this study, a new focus measure has been developed. It is defined as the sum of squared spatial gradients. The focus measure of a pixel $Q_{xyz}(i,j,k)$ is then given by

$$Q_{xyz}(i,j,k) = \sum_i \sum_j \sum_k \sqrt{F_x(i,j,k)^2 + F_y(i,j,k)^2 + F_z(i,j,k)^2} \tag{4}$$

During the experimental procedure, it was found that the proposed focus measure could provide a better performance than the conventional focus measure based on the 1-D or the 2-D spatial gradients. The next section summarizes the experimental results.

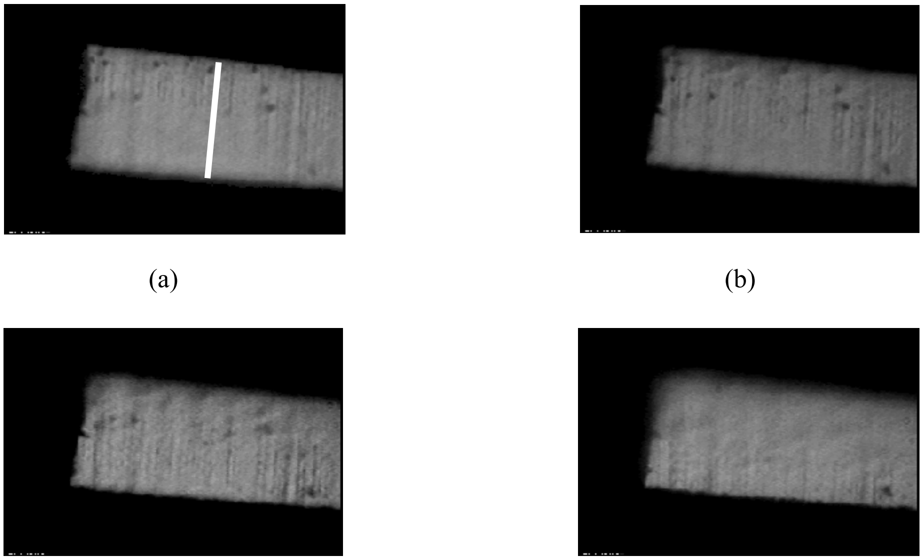
Experimental result

A set of 21 images frame were captured for the purpose of reconstructing its 3-D shape. Each image frame was spaced at a distance of 1.5μm using a computer controlled PZT stage. Each digital image has a 151x252- pixel data and 8-bit gray level. In general, an image formed by the machine vision contains gray-level (or color) pixel data, which is the 2-D information of a 3-D feature. As clear in Fig. 1, different sample surface heights with respect to the camera image plane make the pixel data contain both of sharp (focused) portions and/or blur (unfocused) portions in the same image. From Fig. 1(a), the width of the cutting tool (the line segment shown in the figure) was given by 36.4 μm. Note that it is a 2-D measurement by simply counting the number of pixels.

Continuously varying the distance between the surface of the sample and the camera image plane can be one of techniques to obtain the entire focus information of all the image pixels. Figure 2 shows the result of the reconstructed 3-D shape of the tool using the digital focus measure defined in the previous section. The circled areas do not represent the actual shape of the tool because the limited scanning range used for the measurement (30 μm). With the reconstructed 3-D shape of the tool, the 3-D metrological measurement can be preformed using the micro-coordinate measuring system.

In this study, the system uses IDEAS (a commercial CAD software) as the measuring system. An IGES (Initial Graphics Exchange Standards) file was generated based on the shape (surface) data (Fig, 2) to be read in the CAD software. This file represents the 3-D shape of the measured object. The available tools in the geometric modeling platform can be used as the coordinate measuring means. The measuring process uses the "virtual touch probe" and other tools including measuring linear and angular quantities, establishing datum lines, planes, and surfaces, determining surface normal, viewing the object from various perspectives, zooming in and out of the surface, and etc. The measuring process using the tools in IDEAS is shown in Fig. 3. The summaries of the measurement results are as follows:

The width between the two side cutting edges (the arrow length in Fig. 3): 44.0 μm
The angle between the two side cutting edges (between the two planes): 59.8 degree
The end relief angle (the angle between the two line segments): 167.9 degree



(a) (b)

(c) (d)

Figure 1. The raw image data for a 50-micron end mill at different distance from the lens (image frames 1(a), 5(b), 10(c) and 20(d)).

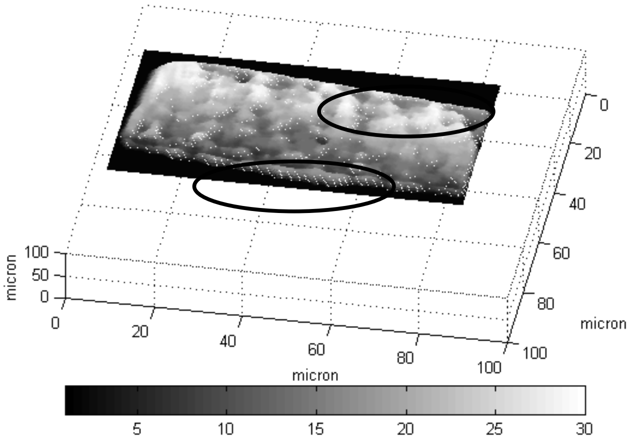


Figure 2. The reconstructed 3-D shape of a 50-micron end mill.

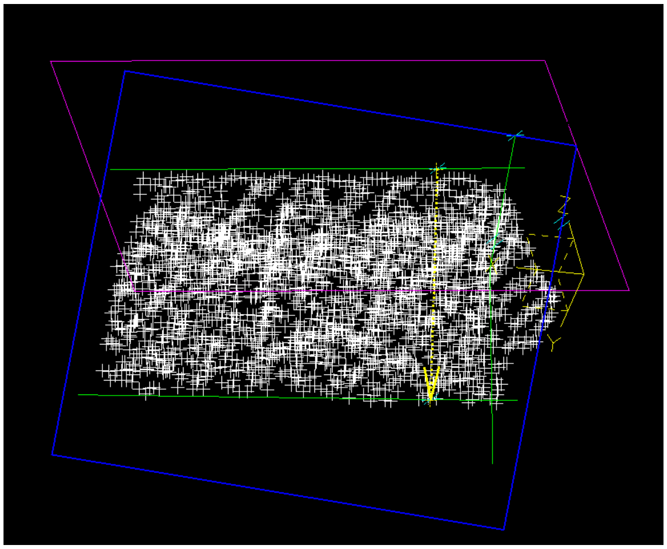


Figure 3. The reconstructed 3-D model of a 50-micron end mill represented by its coordinate point in the geometrical platform.

Conclusions

The paper has presented a technique that has the ability to make 3-D tool wear measurement. Integrating machine vision, image processing and micro-CMM has developed this technique. The experimental results have shown that the technique has the capability of making accurate measurement on micro-machining tools, which have sizes as small as 50 microns. Although the paper has presented the experimental results from a brand-new end mill tool, it is clear that the technique is readily available for making the 3-D tool wear measurement.

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