Optical Image Inspection of Cutting Tool Geometry for Grinding Machines

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Abstract - The purpose of this paper is to develop a tool image inspection and measuring system by C++ Builder. Firstly, tool images are captured online for geometry analysis via a disassembled inspection mechanism mounted on the Z-axis of a five-axis tool grinding machine. One can use the controller of the machine to set the coordinate location of the mechanism and implement the humanized functions of autofocus and automatic measurements. The digital images are calculated by the subpixel approach to improve the measurement resolution, and filtered the edge point location by Hough transform to upgrade the precision. The human machine interface has a tutoring manner for users to operate the measuring procedures. These proposed functions can measure the geometric dimension such as the diameter, radius, and angle of different end mills or drills after finishing the tool grinding processes. Furthermore, the grinding processes can refer to the online measuring results to compensate the tool dimension. Therefore, this online image inspection and measuring system can improve the precision of tool grinding, product quality, and reduce the product cost. Finally, experiments are presented to show that the repeatability errors are ± 1 μm and ± 2 μm for the radius and the diameter measurements of the end mills, respectively. The percentage error is 0.116% for the point angle measurement of the drills. Thus, the results demonstrate the effectiveness of the proposed method that can be employed to measure tool geometry of different cutting tools.

Keywords - Optical, Image inspection, Human machine interface (HMI), Subpixel, Hough transform.

I. INTRODUCTION

The demand for all kinds of high precision cutting tools is increasing due to rapid developments in the modern cutting technology [1-2]. The grinding for cutting edges of tools is known as the most important and the final process of manufacturing. It is also an essential factor for determining geometric shapes, cutting performance, wear on the cutting edges, and tool life [3]. End mills are widely adopted in all kinds of milling applications. They may have square, ball, radius, or chamfer ends, etc [4]. The basic type of end mills is the square end mill. Furthermore, other two kinds of commonly utilized tools are drills and reamers. Drills can be classified into the flat, twist, and step drills.

Digital image processing is generally applied in the field of measuring the micro-size, flaw or defect detection of workpieces. The well-known textbook provides the overall information about digital image processing approaches [5]. Several researchers have studied the tool wear measurement, geometry inspection, or tool condition monitoring by image processing because of the great significance [6-12]. A tool wear measuring system for end mills by using a CCD camera and an exclusive jig was presented in [13]. This technique minimized the error components through the one-parameter experimental way which confirmed its utilization. The measuring method based on the silhouette image processing was presented in [14]. The proposed system can measure five geometric parameters of drills and had more precision than measured by an optical microscope. Reference [15] presented an automated tool flank wear measuring procedure based on the machine vision system. The experimental results showed that the proposed approach can successfully measure the wear of micro drills in PCB product. A neural fuzzy hybrid pattern recognition system was designed for tool condition monitoring [16].

A precision and fast measurement apparatus was presented for three-dimensional cutting edge profiles of micro-tools [17]. Experimental results demonstrated the ability of the proposed system for aligning and measuring a round-nose micro-tool. More recently, a rake angle calculation and cutting edge measurement scheme for twist drills was presented in [18], and this way was free from complex coordinate and mathematical operations. Reference [19] developed a cutting edge measurement in subpixel precision and the method can avoid a refixturing error caused by off-line measurement in conventional tool lapping approaches. Although many studies have been done on tool or flank wear measurements, few studies have reported on the design, grinding, and dimensional inspection combining with the digital image processing techniques of cutting tools. Furthermore, more detailed and useful know-how of milling cutters is possessed by few manufacturers, and it is difficult to acquire. Hence, this paper aims to develop a measuring system and design a tool inspection mechanism. The presented scheme applies to operators and it is useful in its simplicity.

II. MEASURING METHODS OF CUTTING TOOL GEOMETRY

Cutting tools are usually employed in mechanical machining. The parameters of geometry shapes of cutting tools are related to materials of machining, and affect the cutting performance and tool life. Thus, the tool geometry measurement is an important issue for cutting tool manufacturers.

A. Diameter Measurement

The autofocus and pixel calibration functions have to execute before measuring the tool geometry. The purpose of the autofocus is to reduce a factor in human operation, and it combines with the controller of the tool grinding machine to achieve an automatic operation. Furthermore, its search algorithm is based on the Sobel operator to intensify the edge and let the edge segment be more conspicuous. The aim of the pixel calibration is to obtain the relationship between each pixel of an original image and the physical unit. Fig. 1 shows a superimposed image of a cutting tool with 1296×966 pixels. The small square is the region of interest (ROI), and it is only considered for measuring purposes. When operators adopt the mouse button to click on the image to create two ROIs near the same edge and two ROIs near another edge of the image, the designed measuring system utilizes the subpixel technique and the Hough transform [20] to automatically search the edges and find the coordinates of the points P_1 to P_4 of each ROI on these two edges. Therefore, the diameter of a cutting tool is the perpendicular distance between these two line segments connected from P_1 to P_2 and P_3 to P_4.

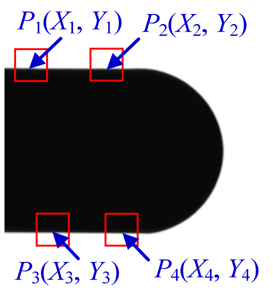

Fig. 1. Diagram for measuring the diameter.

B. Radius Measurement

The arc or circle detections are very important in practical applications. Ball nose or radius end mills have the radius of their ends. Fig. 2 shows a larger ROI for calculating the radius. This radius measurement is based on the randomized circle detection [21] and the ROI has different sizes for selecting an arc to calculate the radius. The subpixel approach is used to detect the edge of the arc. The first, last, and another noncollinear point on this edge are employed to obtain two perpendicular bisectors. The crossing point of these two lines is the first candidate for the center of the arc. Hence, the first set of the candidate radius is from this center point to other edge points. If the selected three edge points are collinear, they cannot construct a circle. In a similar way, the program regularly scans and selects other three points to calculate the second candidate for another center of the arc, and obtain the second set of the candidate radius. The program then proceeds to calculate next one according to the number of the edge points. We compare the values of each radius in each set with the calculated values by utilizing equations (4)-(6) in [21]. The majority of the values of each radius approximate to the calculated values, which are selected as the candidates for the radius. Then, the majority of the radii in the set can be considered as the radius. Finally, the calculated value in (6) of this corresponding set is regarded as the measuring value of the radius.

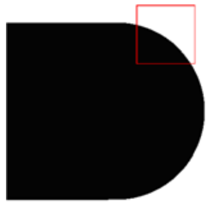
Fig. 2. Diagram for measuring the radius.

C. Angle Measurement

Fig. 3 shows the schematic diagram for measuring an angle. The points P_5 and P_6 form the line $L_1 : a_1x + b_1y + c_1 = 0$. The points P_7 and P_8 form the line $L_2 : a_2x + b_2y + c_2 = 0$. The coordinates of P_5 and P_6, and P_7 and P_8 are substituted into the equations of L_1 and L_2 to solve the constants a_1 and b_1 , and a_2 and b_2 , respectively. Thus, the angle between L_1 and L_2 is θ or $\alpha = \pi - \theta$, and governed by the following relation. The point angle of a drill is generally an obtuse angle.

$$\cos\theta = \pm\left(\left(a_1a_2 + b_1b_2 \right) \Big/ \left(\sqrt{a_1^2 + b_1^2}\,\sqrt{a_2^2 + b_2^2} \right) \right)$$

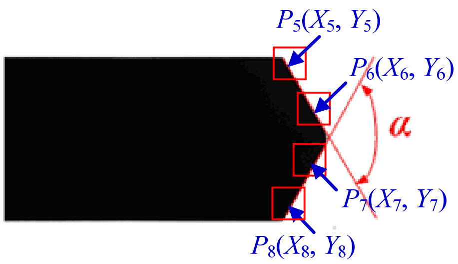

Fig. 3. Diagram for measuring the angle.

III. DESIGN OF HUMAN MACHINE INTERFACE FOR GEOMETRY MEASUREMENT OF CUTTING TOOLS

The human machine interface is developed by utilizing the C++ Builder. Fig. 4 shows the designed HMI which has tutorial windows to assist operators to execute the measuring functions, and it is a user-friendly design. The pixel calibration is to obtain the relationship between a pixel and the physical unit. The calibration value can be gained by clicking the “Origin” icon in the HMI and employed in the program. We apply a CCD camera to capture images of cutting tools. When operators click the mouse button on the “Link” icon in the HMI, the image will be shown on the upper left corner of the window. The measuring results will be shown on the lower middle side. When end users click the mouse button on the “Function” icon, the HMI will be expressed as different icons for operation. Fig. 5 shows the measuring functions, including the distance, diameter, radius, and angle measurements of cutting tools as mentioned in Section II. As shown on the lower left side in Fig. 4, the measuring functions are also designed as a pull-down menu. It is convenient for operators to measure the tool geometry.

IV. EXPERIMENT AND MEASURING RESULTS

The experimental set-up consists of a five-axis tool grinding machine, a rapid assembled and disassembled inspection jig, a progressive scan CCD camera with 1.25 megapixels, a low distortion telecentric lens, and an LED backlight for contour enhancement, etc. Fig. 6 shows the presented measuring apparatus mounted on the Z-axis of the tool grinding machine of the tool grinder for capturing images of cutting tools. The measuring system combined with the machine vision and image processing technology for measuring tool geometry of cutting tools. The controller of the grinding machine is adopted to obtain the mechanical position for purposes of the pixel calibration and the rotation angle calculation of the C-axis.

A tool measuring and inspection machine which has the display accuracy 1 μm, positioning accuracy ± 1 μm, repeatability ± 2μm, and concentricity 2μm. Its measuring results are regarded as the standard values. Tables I-III show the measuring results and percentage errors by utilizing the well-known measuring machine and our designed tool geometry measuring system. The each experiment is repeated ten times. Tables I shows the percentage error is only 0.025% to measure the diameter of a square end mill with two flutes. Table II shows the percentage error is 0.153% for measuring the radius of a ball nose end mill. Table III shows measuring results of the point angle of a drill, and the percentage error is 0.116%. Experimental results show that the proposed measuring system of cutting tool geometry has good measurement performance and accuracy.

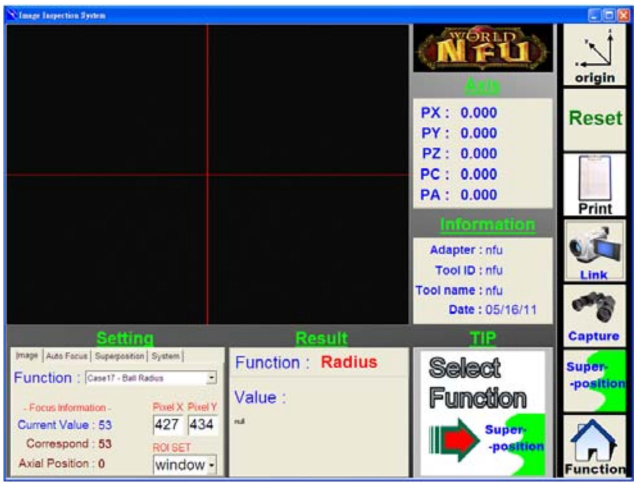

Fig. 4 Designed human machine interface.

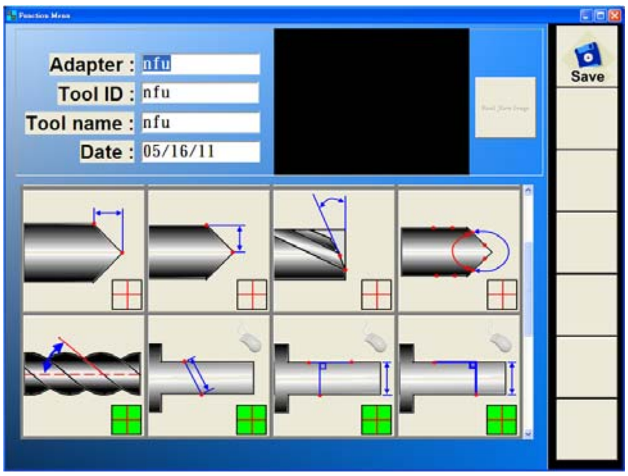

Fig. 5. Window of measuring functions.

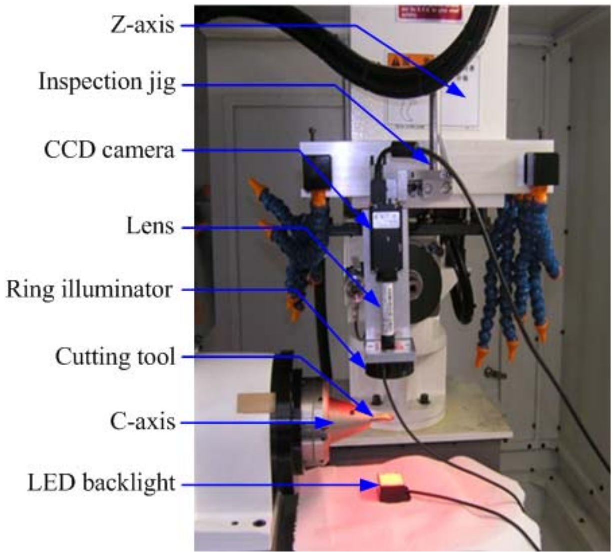

Fig. 6. Measuring apparatus.

TABLE I. Measuring Results of the Diameter

Exp. no.	Measuring and inspection machine		Designed measuring system		Percentage error
	Measuring value (mm)	Avg. value (mm)	Measuring value (mm)	Avg. value (mm)	
1	3.997	3.998	3.996	3.997	0.025 %
2	3.997		3.996		
3	3.999		3.996		
4	3.999		3.997		
5	3.999		3.996		
6	3.997		3.997		
7	3.999		3.999		
8	3.998		3.997		
9	3.997		3.997		
10	3.999		3.997		

TABLE II. Measuring Results of the Radius

Exp. no.	Measuring and inspection machine		Designed measuring system		Percentage error
	Measuring value (mm)	Avg. value (mm)	Measuring value (mm)	Avg. value (mm)	
1	1.306	1.306	1.308	1.308	0.153 %
2	1.305		1.308		
3	1.305		1.308		
4	1.305		1.308		
5	1.306		1.308		
6	1.306		1.309		
7	1.306		1.308		
8	1.306		1.309		
9	1.306		1.308		
10	1.306		1.308		

TABLE III. Measuring Results of the Point Angle

Exp. no.	Measuring and inspection machine		Designed measuring system		Percentage error
	Measuring value (deg)	Avg. value (deg)	Measuring value (deg)	Avg. value (deg)	
1	121.03	121.08	120.97	120.94	0.116%
2	121.10		120.88		
3	121.05		120.98		
4	121.10		120.93		
5	121.09		120.89		
6	121.09		120.92		
7	121.13		121.01		
8	121.12		120.97		
9	121.03		120.88		
10	121.10		121.00		

V. CONCLUSIONS

This paper has designed an inspection jig and developed a tool geometry measuring system for cutting tools. This system used the Sobel operator to execute the autofocus function, and employed the subpixel and the Hough transform methods to detect edges of images. The above experiments concluded that the percent of measuring errors are acceptable and the proposed approach is effective in measuring some geometric parameters of cutting tools. In the grinding processes, the online measuring results can be utilized for compensating the tool dimension. Moreover, the designed measuring apparatus may apply to measure geometry of other different cutting tools, and the measuring system is low-cost and simple to operate.

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