Direct assessment of tool tip in lathe machine - removing the effect of micro dust

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Abstract

Nowadays, lathe machine is an important operation to produce turn parts in industries. Assessing the tool wear is an important field of study in turning operation due to its effect on the lifetime of cutting tool and product quality. On the other hands, decreasing the total cost of goods to have an economic production, encourage manufacturers to decrease the tool wear in machining operation because tool wear affects the useful life of tool and quality of parts. In this study, an algorithm to measure tool wear in the presence of micro dust particles on machine tool is introduced. Since the dust particle is a critical factor that affects the results of a tool wear measurement, its effect is tested in this study. A machine vision was proposed as a direct measurement method to study the tool wear in turning operation. An algorithm used to investigate the wear area of cutting tool in lathe machining. Final results, in this study, shows that proposed method of tool wear measurement can be used to assess the tool scars in nose area of cutting tool in the presence of micro dust particles using machine vision in-cycle.
Keywords: Tool wear, Micro dust particles, Lathe machine, Machine vision, In-cycle monitoring.

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Introduction

All types of machining operations such as turning, milling, grinding, broaching, and drilling are necessary to produce of many goods used in modern life [1, 2]. Producing the industrial parts by machining is an old method. Using the cutting tool is an important difference between machining and other methods of production such as casting, rolling and forging. In other researches, the geometries of actual cutting operations mostly are 3-dimensional (3D) and complex [12], but in this study a 2-dimensinal (2D) method is used to decrease the processing time and the cost of apparatuses we need them. The 2D cutting process in this study is orthogonal method which means the cutting edge is perpendicular to the motion of workpiece.
However, tool wear in machining operations can change the geometry of the tool tip. It can increase of cutting force, change of surface quality and decrease of dimensional deviation in products. Therefore, Tool wear decreases the productivity because it can damage the products [4]. Therefore, many researches have arranged to study the tool wear as a significant research field [1-19]. Although all types of tool wear decrease the tool life, but the most important

types of tool wear which have been studied are flank wear and crater wear. Flank wear appears on relief face due to rubbing the relief face of cutting tool to the workpiece [3, 4]. Crater wear is visible on the rake face of tool, and it changes the chip–tool angle [10]. This could be due to standard ISO 3685 [11] that introduced the thresholds for tool life based on flank wear and crater wear.

Nose wear, which is not studied widely compare to flank wear and crater wear, is a type of tool wear that can be seen on the nose of cutting tool tip, and it is a combine of flank wear and notch wear [11]. Notch wear is a tiny crack that is visible on tool tip face. If notch wear is growing the tool tip can failure. The importance of nose wear is its effect on the surface roughness of workpiece machined. In fact, nose wear appears on the area of tool tip which is rubbing to the surface of specimen to shape the surface roughness of the workpiece [10]. However, tool wear detection needs to use a lightening system.

Lighting is an important factor which illuminates the object in tool wear assessment. The type of illumination used depends on specimen specifications and the output required. There are two main types of lighting: front lighting and back lighting. In front lighting method, both of illumination source and camera are in front of the specimen. The output of this method is an image of object surface. When the specimen is placed between camera and the source of light, this method is called back lighting. The back lighting is used when it is necessary to capture the high resolution images of specimen's contour. If this method is used, the surface of object will be dark thus the surface texture of the object will not be visible [12]. The total numbers of pixels which set as a higher intensities (more bright than the other pixels) using front lighting can be changed by increasing or decreasing the intensity of light source. Therefore, the crater and flank wear area of cutting tool can be evaluated using front lighting [1, 2, 4, 5, 7]. In spite of crater and flank wear measurement methods, the nose wear area of cutting tool should be determined by using back lighting method [6, 7, 10]. In contrary of front lighting, the total numbers of subtracted white pixels using back lighting are not changed by increasing or decreasing the intensity of light source severely [10]. Therefore, backlit is the method that we used in this study to assess the direct micro assessment of tool nose area. The outcome of this research is a micro assessment method which can nullify the effect of micro dust particles from the output results.

Material and method

Experimental details

A triangle carbide cutting tool insert was used to machine the workpiece. The specification of this cutting tool is shown in Table 1. A CNC lathe machine was used to machine the steel bar to assess the feasibility of used system in usual workshop area. Different conditions of machining consist of different cutting speed, feed rate and depth of cut were performed to study the effect of machining parameters on tool wear. The machining conditions are listed in Table 1. The developed machine vision system of this study was used to measure tool wear area. The vision system consists of *JAI CV-A1* high resolution CCD camera (resolution 1296×1024 pixels), 50mm lens and a 110 mm extension tube mounted on CCD camera, Data Translation (DT3162) frame-grabber and a personal computer. The backlit method was used to illuminate the objects. Figure 1 shows the actual set up of used vision system. The horizontal and vertical scaling factors of system were defined as 1.88µm/pixel and 2 µm/pixel respectively using two Mitotyo pin gauges. The system resolution of tool wear evaluation was verified using an optical microscope (*Ken-A-Vision* (USA)) using 100-times magnification. The maximum deviation between results of these two methods is 6.8%.

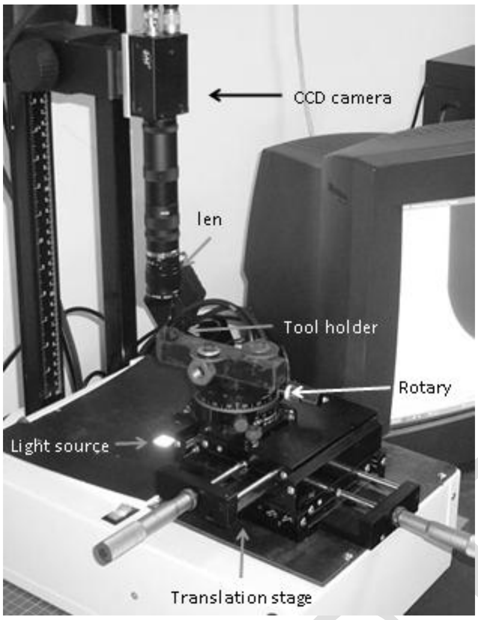


Fig 1: Image of tool scar assessment system.

The field-of-view of the CCD camera is about 2.4×2 mm, and the distance between down side of camera lens and the tool tip is about 59 mm.

Table 1. Machining parameters for tool scar assessing.

Lathe machine	CNC lathe machine **OKUM LB15** Japan
Workpiece	Low carbon steel bar
Tool tip	Uncoated cemented carbide -UX30 Toshiba Tungaloy Co, Ltd
Feed rate	0.04, 0.05, 0.06 mm/rev
Depth of machining	0.5 mm
Cutting speed	90 m/min
Coolant	Air
Time	600, 1200, 1800, 2400 seconds

Result and discussion

Nose wear assessment phases

The various phases involved in the direct assessment of tool wear area are illustrated in Figure 2, and are demonstrated as follows.

Phase 1: Capturing the image

In Phase 1, a digital translation (DT3162) was utilized to connect the digital camera and the computer to capture the images of interested area. In fact, output of the camera was transferred to the computer using the digital translation [$g_1(x,y)$].

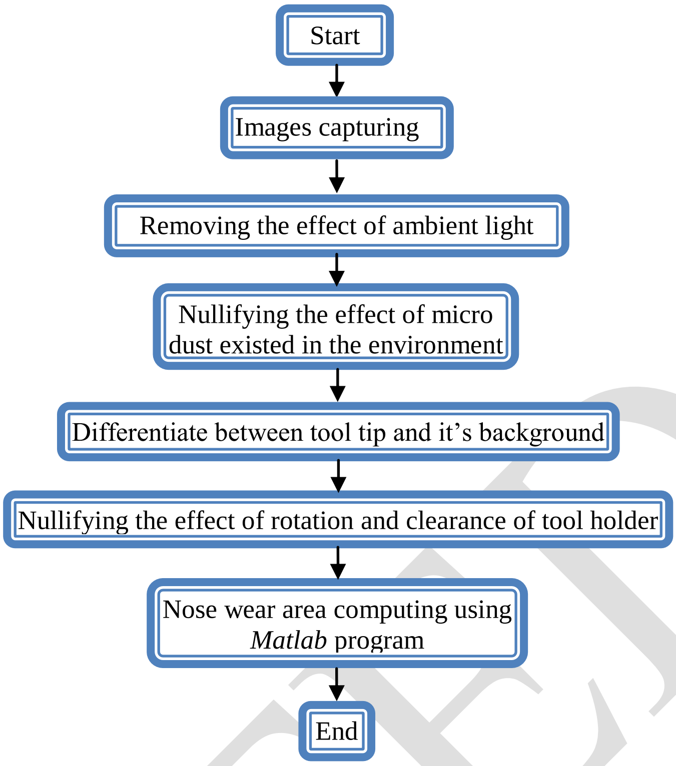


Fig 2: Arrangement phases of this study.

Phase 2: Removing the effect of ambient light

In Phase 2 of the flowchart illustrated in Figure 2, the images were improved utilizing *wiener* filtering method. The image of tool tip $g_1(x,y)$ can be introduced by [20]:

$$g_1(x,y) = h(x,y) * g_2(x,y) + \eta(x,y) \quad (1)$$

where $g_2(x,y)$ is the original image, $h(x, y)$ is the degradation function, $\eta(x,y)$ is the additive noise term in the image and '*' refers to the convolution operation. The effect of *Wiener* filtering on the cutting tool image was studied to recover the image affected by noise.

The *Wiener* filtering method, introduced in 1942, is preferred because it is not sensitive to inverse filtering of noise and suppose as a suitable method to enhance the images. The *Wiener* filter uses statistical parameters to minimize error. Although this method is normally used to restore blurred images, *Matlab* uses this filter to enhance images affected by noise using the *wiener2* command. This command does not need to any information about the noise distribution and applies the *Wiener* filter adaptively using the local statistical parameters given by:

$$\mu = \frac{1}{NM} \sum_{n1,n2 \in \eta} a(n_1, n_2) \quad (2)$$

$$\sigma^2 = \frac{1}{NM} \sum_{n1,n2 \in \eta} a^2(n_1, n_2) - \mu^2 \quad (3)$$

where μ and σ are local mean and variance of intensity around each pixel in the image respectively, η is the N-by-M local neighborhood of each pixel, and $a(n_1,n_2)$ shows the location of each pixel in the local neighborhood mask η. Compared to a linear filter, the *Wiener* filter is more selective, preserves edges and other high frequency components in the image.

The *Wiener* filter determines a restored image to minimize the equation 4.

$$e^2 = E\{(f - \hat{f})\}^2 \quad (4)$$

where, E is expected value operator, f is original image, $\hat{f}$ is restored image and e^2 is statistical error. The solution is obtained by:

$$\hat{F}(u,v) = \left[\frac{1}{H(u,v)} \frac{|H(u,v)|^2}{|H(u,v)|^2 + S_\eta(u,v)/S_f(u,v)} \right] G(u,v) \qquad (5)$$

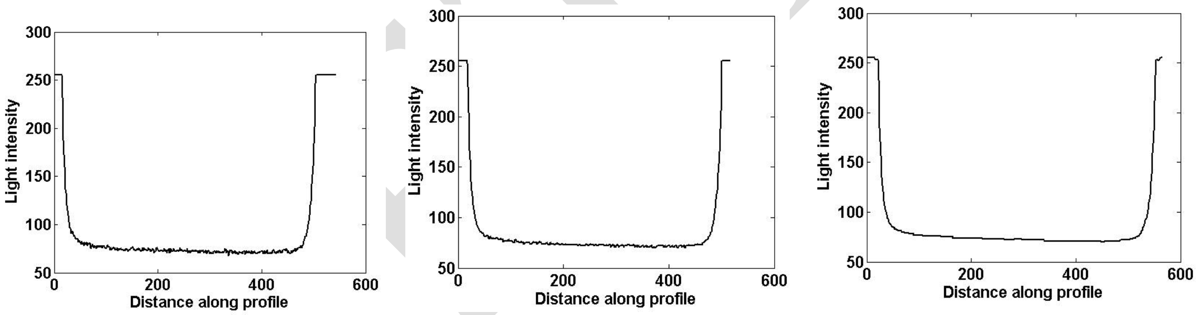
where $H(u,v)$ as shown in equation 5 is function of degradation.

$$|H(u,v)|^2 = H^*(u,v)H(u,v) \qquad (6)$$

where $H^*(u,v)$ *isthecomplex conjugateof* $H(u,v)$

and $S_\eta(u,v)$ is the power spectrum of the noise and $S_f(u,v)$ is the power spectrum of the original image.

Figure 3(a) shows the image of intensity profile of cutting tool. Figure 3(b) shows the intensity profile after implementing *wiener* filtering using a 5×5 window. Also, Figure 3(c) shows the intensity profile obtained using *Wiener* filtering from a 10×10 window. The fluctuations existed on the intensity profile of Figure 3(c) is slightly less than those on Figure 3(b). Since different filter mask sizes produced different results, a total of 10 masks ranging from 2×2 to 11×11 were used to determine the optimum mask size. In this study, the optimum mask size means a mask size that removes the fluctuation on the intensity profile better than others.



(a) (b) (c)

Fig 3: Intensity profile across tool: (a) Before filtering (original), (b) after *wiener* filtering (non-optimum), (c) *Wiener* filtering (optimum).

Phase 3: Micro dust removal effect

In Phase 3 of the algorithm shown in Figure 2, morphological methods were utilized to flat the images by departing pixels affected by micro-dust particles. The opening and closing methods are two important morphological methods that are introduced by joining the dilation and erosion methods [20].

The combination of erosion and dilation are used in opening and closing operations to smoothen the profiles of specimens in the images. The dilation of *A* by *B* means that the binary array of *A* is thickened by array of *B*, and is denoted as [20]:

$$A \oplus B = \{x \mid (\hat{B})_x \cap A] \neq \emptyset\} \quad (7)$$

The erosion of *A* by *B* means that the binary array of *A* is thinned by array of *B*, and is defined as [20]:

$$A \Theta B = \{x \mid (B)_x \subseteq A]\} \quad (8)$$

The opening and closing operations were used to smooth the contour of a cutting tool. Figure 4(a) shows the magnified area of cutting tool before opening and closing methods. The figure reveals that the border line of the tool tip area is not a straight line because the micro-dust particles are stack on the tool tip. The dust particles act as small nubs and grooves in the tool tip. Figure 4(b) shows that the 'grooves' in magnified area were took off after applying opening method, and Figure 4(c) shows that the 'nubs' were removed after using the closing method as well.

(a) (b) (c)

Fig 4: Removing the dust particle by opening and closing methods: (a) interested area before opening and closing, (b) area after opening, (c) area after opening and closing.

Phase 4: Binarization

In Phase 4 of the algorithm shown in Figure 2, the image was binarized to distinguish the tool tip (dark region) and the background (bright region) using a global thresholding model. The simple thresholding model can be presented by:

$$g_2(x,y) = \{1\, if\ g(x,y) \geq T\ , 0\, if\ g(x,y)\ < T \quad (9)$$

where *g(x,y)* is the original image.

Phase 5: Clearance effect

In phase 5 of algorithm shown in Figure 2, a conforming method developed by Shahabi and Maran [10] was used to enhance misalignment of the cutting tool tip. In the off-line measurement method, one tool holder was utilized to fix the tool tip in its place. The image of unused tool tip was captured then the tool tip was removed from the tool fixture to use it on the lathe machine. After machining, the used tool tip was attached onto the fixture to take an image of the used tool tip. The small clearance of tool tip fixture causes a slight rotation and translation movement between the used and new tool image captured. This problem is repeated in the in-process measurement where the movement of tool tip during machining causes misalignment because of machine parts inaccuracy. Therefore, it is necessary to remove the misalignment. Thus, a new tool tip was attached in the tool fixture and an image was taken. The tool tip was opened; reclosed and second image was taken. The tool tip movement caused by the inaccuracy in the tool fixture is shown in Figure 5 based on subtracting the two images.

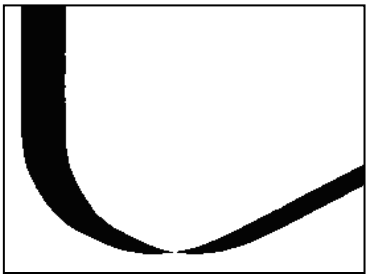


Fig 5: Subtracting two images before developed method.

Assessing the effect of tool holder clearance needs to repeat the process of opening and closing the tool tip from tool holder clamp. Therefore, the image of a new tool tip was initially captured as the reference to assess the deviation resulted from other images affected by clearance of tool holder. Also, for this assessment, 20 images of new tool tips were captured to compare with the reference one. In the second step, all 20 images were captured one by one after opening and closing the tool tip clamps and removing and reattaching the tool tip. The images captured, in the second step, were subtracted, one by one, from the reference image. The conforming method developed by Shahabi and Ratnam [10] was used to remove the effect of tool holder clearance on the subtraction results. The conforming method is based on turning and moving images of tool tip outline to match the position of second image on the reference one. This procedure is automatically performed by using a software program in *Matlab*. The results show that using the conforming method matches two successive images and removes the effect of tool holder clearance.

Phase 6: Nose wear measurement

In Phase 6 of the algorithm of this study, the image of tool tips that were utilized to machine the specimen was subtracted from the reference image of tool tip to assess the cutting tool nose wear. Figures 6 shows the nose wear area obtained from procedure of Phase 6.

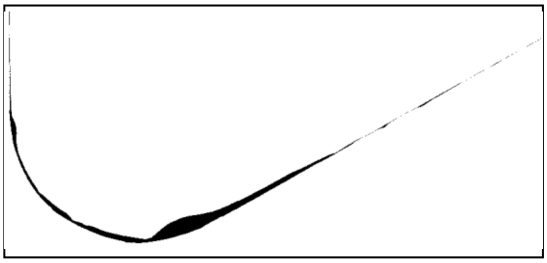


Fig 6: Nose wear area.

Measuring the nose wear area

The algorithm presented in the image 2 was used to measure the wear area of tool tip. One new cutting tool insert was used to do the turning operation on a low carbon steel bar. The machining condition and material used are shown in Table 1. The image of the new cutting tool was captured as the reference one. The images of cutting tool were captured in-cycle of machining the steel bar in different feed rates and machining duration. The images of utilized cutting tool were subtracted from the reference image of new cutting tool based on the algorithm of this study. Removing the noise affected on the captured images was performed using *wiener* filtering method. Different filter mask size can change the results up to 0.76×10^{-3} mm^2 which is insignificant. Therefore, the default mask size of *Matlab* software which is 3×3 was used. This helps to decrease the computation time effectively. The results of nose wear area are shown in Table 2 in mm^2. The results show that the wear area is growing when the machining time and feed rate are increased.

Table 2. Worn area of cutting tools

Feed rate (mm/turn)	10min $(10^{-6} mm^2)$	20min $(10^{-6} mm^2)$	30min $(10^{-6} mm^2)$	40min $(10^{-6} mm^2)$
0.04	2132	3362	5437	9625
0.05	2251	2852	9097	11370
0.06	4115	4807	7399	16032

Conclusion

This research was carried out to study the effect of nose wear on the cutting tool tip in finish turning operation developing a vision system. The following conclusion can be made based on the results of this research: a method using the matrix of 2-D geometry of cutting tool, which was formed by tool nose wear, was developed to measure the nose wear area of cutting tool tip in turning operation.

This research aim is to introduce a method which is not sensitive to the micro environmental parameters such as clearance of tool holder, dust and intensity of light source. The employed algorithm using conforming method, and some image processing methods used in this study, are useful to decrease the effect of environmental factors. Binarizing method, which was utilized to change the gray scale images of cutting tool to binary images, is reliable and fast method to distinguish the interesting area. *Wiener* filtering which is a suitable filtering method is used to remove the noises, Also, morphological closing and opening operations were used to decrease the errors caused by micro particles stuck to the cutting tool. An optical system using back lighting was employed to measure the worn area of cutting tool insert. The system error due to opening and fastening the cutting tool insert, and moving the tool holder or camera was decreased using a software method. This study has some advantages due to using simple methods such as thresholding, *Wiener* filtering, closing and opening operations. Developed algorithm of this study increases the ability of optical measurement system to use it outside of laboratories because this method is able to decrease the effect of noise, micro dust, light intensity of environment and movement and rotation of cutting tool insert or camera.

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