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Assessing the Environmental Vibration Effects on Tool Wear Evaluation in Lathe Operation

Shahabi H.H.[1] and Ratnam M.M.[2]
[1]Industrial and Management Systems Department of AUT, 424, Hafez st. Tehran, IRAN
[2]School of Mechanical Engineering, USM, 14300 Nibong Tebal, Penang, MALAYSIA

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Abstract

Lathe operation is an important method to produce turn parts in industries. Tool wear detection is an important subject due to its effect on the useful life of cutting tool and also quality of products. In other words, an economic production, using machining method, affected by tool wear thus this field of study is important to decrease the total cost of products and increase productivity. This work introduces the algorithm used for assessing the effect of environmental vibration on tool scar evaluation on machine tool. Since the vibration is a critical factor that affects the results of a measurement method for tool wear, thus the effect of vibration is tested in this work. A machine vision was used to study the tool scar in CNC lathe operation. An algorithm was utilized to investigate the nose scar of tooltip in lathe operation. The outcomes of this research show that tool scar assessment is possible where the environmental vibration is existed using machine vision in-process.

Keywords: Environmental vibration, lathe operation, machine vision, In-process, nose wear.

Introduction

Several types of machining operations like turning, milling, grinding and drilling are necessary to produce the products used daily[1-2]. Tool wear during the machining operations, however, changes the geometry of cutting tools and decreases productivity[2]. Therefore, many researchers have studied tool wear as an important research area in the past[1-29]. Nontraditional machining such as EDM is a modern method for machining the workpieces [30] but nowadays it does not mean the traditional machining methods listed above can be replaced by modern techniques easily. One common type of tool wear which can reduce cutting tool life is flank wear[4]. Flank wear is due to rubbing effect between the cutting tool and the surface of specimen. Flank wear also increases the deflection of the cutting tool during machining, thus causing geometrical inaccuracies. Nose wear is another type of tool wear. Nose wear appears on the nose of a cutting tool tip, and it is a combination of flank wear and notch wear. Notch wear is a micro crack which appears on cutting tool face, and growing notch wear can cause cutting tool failure[3]. Flank wear and nose wear are important factors affecting cutting tool life when the cutting speed is increased[6]. Nose wear can cause failure of the cutting tool because it reduces the contact area of cutting tool on the workpiece[7]. There are different ways to estimate tool wear and they are briefly demonstrated as follows. Cutting force assessment, Acoustic measurement of signals, process of Temperature monitoring, analysis of Vibration indicators and Energy evaluation are some important techniques of indirect assessment of tool wear[8]. These methods are expensive for assessment of tool wear due to their complex system, also these methods are not easy to utilize in the workshop[1,2]. In contrary, direct techniques such as machine vision methods using a CCD or CMOS cameras**,** can be used to determine and assess tool wear directly.

Machine vision systems are well suited for measuring tool wear and roughness of workpieces because they can identify different forms and structures, and are able to transfer information at a high rate for processing by computers[9]. In addition, vision measurement systems can be adapted for use in different types of machines such as turning, drilling, milling and grinding machines. Output of machine visions are also not affected by workpiece materials, cutting tool types and other machining parameters. Also, machine visions do not damage the cutting tools or workpieces because they are non-contact methods. Despite of the benefits of the machine vision techniques for tool wear assessment, they cannot utilize in uncontrolled area in-process. Therefore, these techniques are usually used in laboratories or controlled area. This is because high-resolution vision systems are sensitive to ambient parameters[9]. In this research, a vision technique which its sensitivity to environmental variables is less than usual machine vision techniques is introduced to assess the tool wear.

Several machine vision techniques to assess the tool scar have been introduced in the past. Yang and Kwon[10] used an edge detection algorithm and low-pass filter to measure the crater wear region which was a suitable technique for noisy image. Wang et. al.[11] used the edge detection method using thresholding to determine the flank wear area. Kurada and Bradley[12] introduced a vision system to observe the flank wear using textural and gradient operators. Jurkovic et. al.[4] proposed a vision method to measure the parameters of tool wear using a macro program software. Dawson and Kurfess[5] used a new method to measure the volume of crater and flank wear using white light interferometry. Some other investigators have proposed several optical techniques to assess the surface quality of specimen to forecast the tool wear[8,13,25,26]. Most of the vision systems developed in the past are, however, applicable only in the laboratory environment or require accurate parking of the cutting tool when used on-line.

Another important factor affecting the direct assessment of tool scars is light ambient factor. Actually, lighting is a significant parameter which affects the outcome of the grabbed images in tool wear assessment utilizing machine vision. The type of lighting used relies on workpiece characteristics and the outcome image interested. The systems of machine vision lighting utilized in tool wear assessment departed into front-lighting and back-lite. Some researchers have used front-lighting to study tool wear[2,4,5,9-12,14-16], whereas others used back-lighting to observe the nose wear of cutting tool[9,17]. In this study back-lit is used to study tool wear and an algorithm was developed to assess the nose wear area of tool tip in presence of environmental vibration using machine vision.

Material and Methods

Machine vision: The images were captured using a high-resolution CCD camera. The configurations of camera are: Model JAI CV-A1 and resolution 1296×1024 pixels. One 50 mm lens was fitted on it and one 110 mm extension tube was used to increase the magnification of captured images of cutting tool. In order to highlight the profile of the tool tip, back-light method was used. Figure 1 illustrates an outline of the system utilized to detect the tool wear.

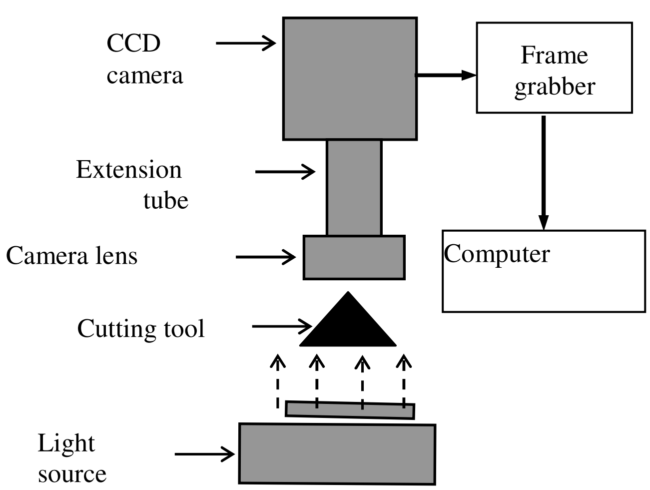


Figure-1
Diagram of nose wear measurement system

CCD camera's output is in pixels but mm^2 is used to measure the scar area of tool tip nose. Therefore, the scaling factors of captured images were horizontally and vertically determined in mm/pixel. Two standard pin gauges (Mitutoyo Co. Japan made) were used to find the horizontal and vertical scaling factors. The results showed that horizontal and vertical scaling factors are 1.88 µm/pixel and 1.99 µm/pixel.

Experimental Setup: Some important parameters that can change the tool wear in lathe machining are: machining time, cutting speed, feed rate, cutting tool material and its form, workpiece material and type of coolant. All machining parameters used to assess the nose wear in this study are shown in Table 1.

Table-1
Machining condition

Machine tool	CNC lathe machine OKUM LB15 Japan
Workpiece	Low carbon steel bar
Cutting tool tip	Uncoated cemented carbide UX30 Toshiba Tungaloy Co.
Feed	0.04, 0.05, 0.06 mm/rev
Depth of cut	0.5 mm
Cutting speed	90 m/min
Coolant type	Air
Machining time	10-40 min

Algorithm of nose wear evaluation: Figure 2 shows several steps used to assess the scar area of tool tip. The steps are detailed in following sections.

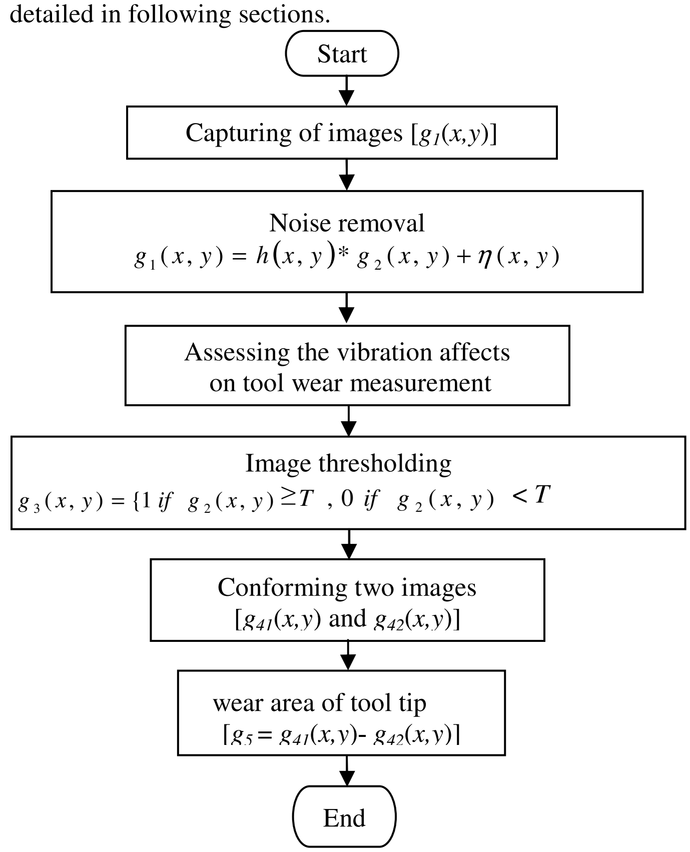


Figure-2
Algorithm of nose wear Assessment

Image acquiring: In Step 1, in order to connect the digital camera to the computer for processing the input images a frame-grabber (Data Translation-DT3162) was utilized. The frame grabber interfaced the captured images of digital camera [$g_1(x,y)$] to the computer. Output images of the camera needs to be sharpened in this study because the accuracy of nose wear measurement would be decreased if the images were blurred. The profiles of intensity of the captured image of nose area of cutting tool were studied to make sure the sharpness of the images. The maximum intensity gradient between the bright and dark regions belongs to the sharp image (90 degrees). In order to make sure the intensity of image, the command of *improfile* in *Matlab* was utilized to show that the pixels were located on a vertical line. The sharp grayscale (ideal) images using *improfile* demonstrate a vertical line in the boundary between white pixels and black pixels. The gradient of this vertical line depends on the image captured. The more blurred the image is the smaller the gradient. The profile of intensity was used to manually adjust the camera focusing ring to capture the sharpest images.

Since the digital camera's distance from the specimen is fixed, the intensity profile was used only at the start of the image capturing process. Figure 3 (a) shows a blurred image of cutting tool and its intensity profile. As figure 3 (a) shows α is the gradient of intensity profile that is far from the best focus value of 90^o. Thus, the CCD camera was adjusted to capture a sharp image. Figure 3 (b) shows the images captured after adjusting the CCD camera, and its intensity profile of the detection *A-A* line. The gradient of intensity profile of this image is nearly 90^o showing that the CCD camera was adjusted to capture sharp images.

Image noise filtering: In Step 2 of the algorithm shown in Figure 2, the image is improved using a noise filtering method. The acquired image $g_1(x,y)$ is determined by[18]:

$$g_1(x,y) = h(x,y) * g_2(x,y) + \eta(x,y) \tag{1}$$

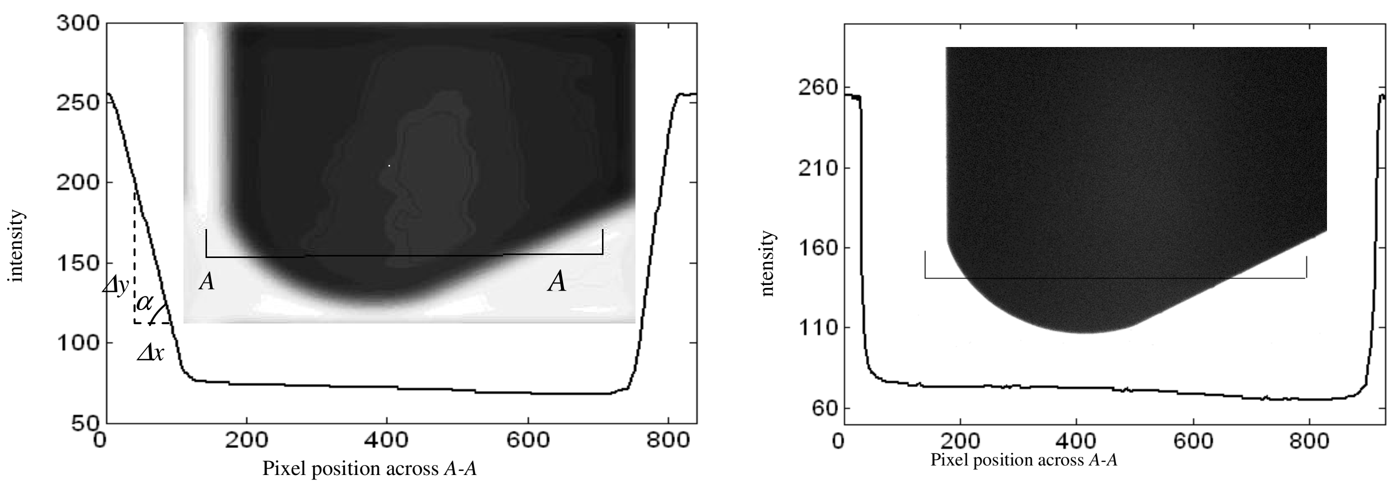
where $g_2(x, y)$ is the original image, $h(x, y)$ is the degradation function, $\eta(x,y)$ is the additive noise term in the image and '*' refers to the convolution operation. The output of median filtering on the cutting tool image was studied to recover the image affected by noise.

The median noise removing is a technique utilized widely to decrease the noise without increasing the blurring in the image. The technique changes the present pixel by the median of surroundings pixels using a widow mask given by:

$$\hat{g}(x,y) = \underset{s,t \in R_{xy}}{median} \{f(s,t)\} \tag{2}$$

where $\hat{g}(x,y)$ is the recovered image and R_{xy} is the set of coordinates in a window of dimension $m \times n$[18]. Median filtering utilizes to save the profile characteristics in the primary image while decreasing the noise[9].

Figure 4(a) shows the image of cutting tool before filtering and its intensity profile across *A-A*. The window size 3×3 and 5×5 were used for median filtering and Figure 4(b-c) show the intensity profiles respectively. The results show that different filter mask sizes make different outputs, thus different mask dimensions varying between 2×2 and 11×11 to reach the best window dimension. In this study, the optimum mask size means a mask size that removes the fluctuation on the intensity profile better than others. The fluctuations existed on the intensity profile of figure 4(c) (optimum mask size) is slightly less than those on figure 4(b).



(a) (b)

Figure-3
(a) Blurred image of cutting tool and its intensity profile across *A-A* (b) Sharp image of cutting tool and its intensity profile.

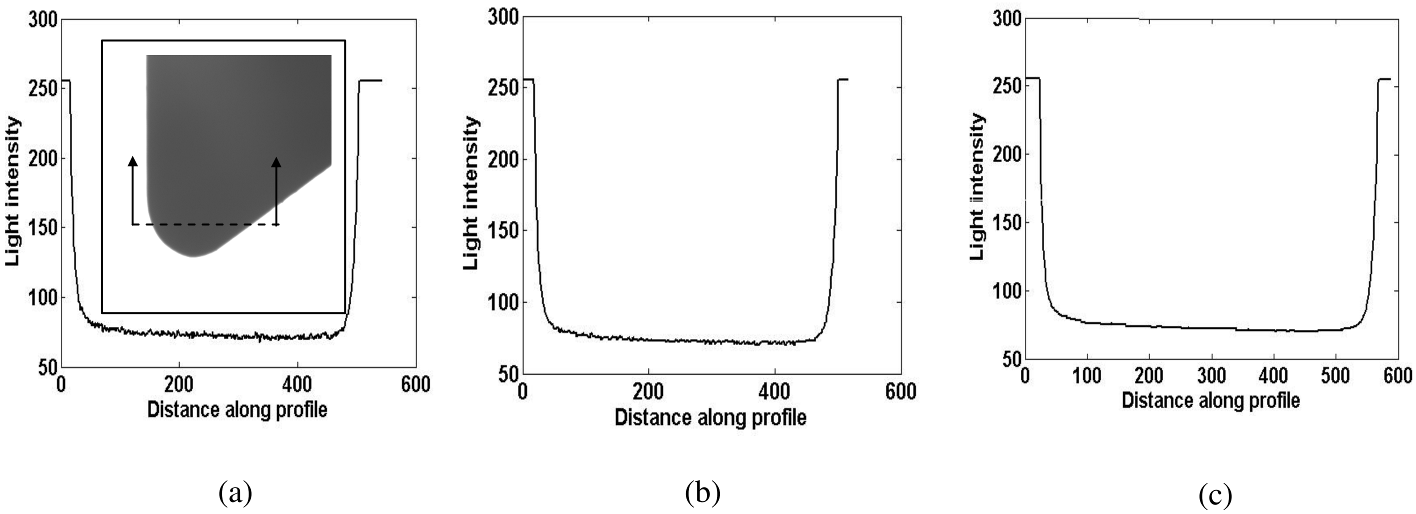


Figure-4
Intensity profile of tool tip: (a) Before filtering, (b) after filtering (non-optimum), (c) after filtering (optimum)

Effect of workshop vibration: The real operation of this study was completed in a workshop that was not designed as a vibration free environment. Since sever vibration can affect the outcome of digital camera in workshop which is not controlled against vibration, study on the effect of workshop vibration on the captured images is critical. The image capturing speed of CCD camera used in this report (JAI CV-A1) is about 0.4 second/frame. Also, the area captured from a tool tip is about 2.4×2 mm that is a small region. Therefore, it is essential to assess the effect of vibration on the images of nose wear area.

In order to assess the impact of workshop vibration on acquisitioned images, 11 images of one nose area were captured. The intensity of light used was fixed on 50 lux (usual condition of our workshop area). First image was set as original image. Then other 10 images were subtracted, one by one, from the first image to assess the effect of ambient vibration on the images captured. Figure 5(a) shows the image of subtraction of two selective images as the effect of workshop vibration. Also, figure 5(b) shows a drawing of pixel error as the outcome of workshop vibration on ten images. The drawing of error which is demonstrated in figure 5(b) is combination of rapid variations in the signal due to electric disturbance and the effect of workshop vibration on the images, which cannot be separated. The average and standard deviation of inaccuracy of workshop vibration and pixel jitter was determined 0.000139 mm^2 and 0.00059 mm^2 relatively. The results show that this error varies between min and max error in similar light condition. Therefore, digital system is not affected by sever vibration. In other words, this system is insensitive to environmental and workshop vibration.

Segmenting: In Step 4 of the algorithm shown in Figure 2, a global thresholding method was utilized to divide the tool tip (dark region) from its background (bright region) in captured image. In image processing, this process called segmentation. Thresholding is used to prepare a binary image by setting a *T* value (called threshold value). In this process, all pixels in grey image, having the intensity more than a given number (threshold value), set to number one and the other values to number zero. In fact, the threshold value *T* is utilized to restrict the domain of gray scale values in the image that are replaced by 0 and 1. The global thresholding process can be presented by following equation:

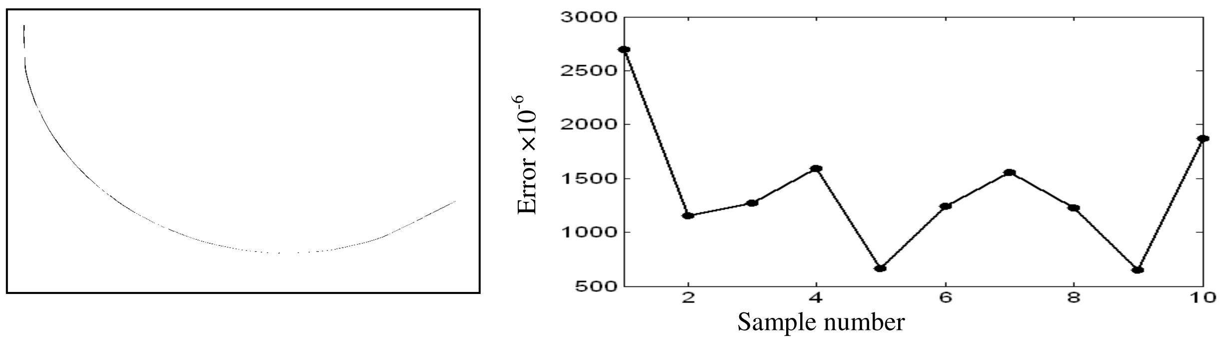
$$g_3(x, y) = \{1 \; if \; g_2(x, y) \geq T \; , 0 \; if \; g_2(x, y) < T \tag{3}$$

where $g_2(x, y)$ is the input image.

T Value can be automatically evaluated utilizing a command phrase "*graythresh*" in *Matlab.* This command uses the Otsu's technique to separate the dark area from the bright area in the image (1979).

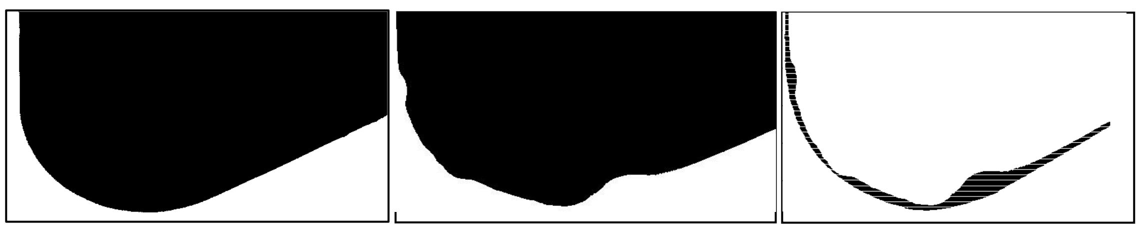
Conforming the used and new cutting tool: In Step 5 of algorithm shown in figure 2, a conforming method developed by Shahabi and Maran[26] was utilized to decrease the misalignment of tooltip position effectively.

Tool wear evaluation using digital subtraction: In Step 6 of the algorithm shown in figure 2, the image of cutting tool used for machining the workpiece (obtained from the Step 5) was subtracted from the image of new tooltip to evaluate the tool wear area. Figures 6(a)-(b) demonstrate the images of new and implemented tool tip respectively, and figure 6(c) demonstrates the wear area.



(a) (b)

Figure-5
Effect of vibration on results: (a) Two successive images subtracted and (b) graph of error of ten successive images subtracted



(a) (b) (c)

Figure-6
(a) Original cutting tool tip, (b) Cutting tool tip after 40 minutes machining, and (c) wear area

Assessing the wear scar by toolmakers microscope: Cutting tool wear of tool tip was evaluated based on the algorithm described in this study (figure 2). The results were verified utilizing a microscope (Ken-A-Vision-American). The toolmakers microscope used to enlarge 100 times the region of interest. A digital camera (Ken-A-Vision- USA, pixel resolution 77000) adding an 8 mm lens was utilized to acquire the images. The camera attached to the toolmakers microscope to magnify the image of the land wear area in the nose position of tool tip. The back-lit method was utilized to make brightened the outline of tool tip. The microscope using the digital camera was utilized to acquire image of one 0.25 mm pin gauge (Mitutoyo) to determine the dimension of each pixel horizontally and vertically. The results showed that the horizontal and vertical scaling factors were about 3.3µm/pixel and 2.8µm/pixel relatively. Also, the captured area of the camera was about 1 × 0.7mm.

Determining the wear area: A CNC lathe machine was utilized for machining an unalloyed steel shaft to shape the nose wear on tool tip. The cutting tool utilized was an uncoated cemented insert (table 1 demonstrates its specification). The images of tool tips were acquired before starting the lathe operation. Then the tool tips were utilized to do the lathe operation on the steel shaft. The images of cutting tool, used to do the machining, were acquired in-process for each machining duration. The cutting speed used was 90 m/min and the feed rates vary between 0.04 and 0.06 mm/turn. The algorithm shown in figure 2 was used to evaluate the nose wear of cutting tool tip. The images were enhanced utilizing the median filtering approach to decrease the noise affected on the images in workshop area. The results in figure 7 show that the cutting tool scars in the nose region are raised when the time of machining is added. Also, the results show that growing of nose wear was recorded when the feed rate is raised.

Results of this study agree with the Taylor's theory that showed increasing the time of machining operation in the same condition of machining, decreases the tool life. Therefore, nose wear of tool tip can be used to find the maximum useful life of cutting tool.

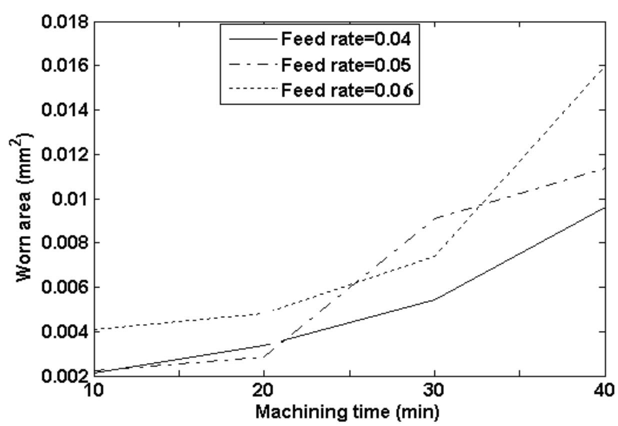


Figure-7
Wear area of cutting tools for various machining time and feed rate

Conclusion

In this research, an in-process tool nose wear measurement method was developed that can be used in workshop area where the ambient vibration is existed. The results show that the ambient vibration did not change the final results seriously. Also, this method can be utilized when it is essential to nullify the effect of tool tip misalignment and reducing the noise added from the ambient light to the cutting tool image. The Median approach, which is known as a powerful method, was utilized to enhance the degraded picture of cutting tool tip. Also, the results were verified using an optical toolmakers microscope. This study shows that a 2-D image can be utilized to evaluate the nose wear effectively. Therefore, unlike the past research, using the 3-D methods which are time consuming, this study can evaluate the tool wear fast and accurate. In this study, back lighting, that may less affected by ambient light compared to front lighting, was utilized to reduce the system inaccuracy. Thus the introduced algorithm can be utilized in uncontrolled area where the workshop vibration, tool tip misalignment and light intensity vary.

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