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Full Length Research Paper

Online tool wear monitoring using portable digital assistant (PDA)

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Real-time tool wear monitoring is an important technique need to be developed to fulfill the demand from the fast development in machining industry. This paper proposed a new method of online tool wear monitoring using portable digital assistant (PDA)-based device to monitor progression of flank wear land during turning process by on-line detecting and analyzing the machining force signals. The machining tests were carried out on turning machine, and Kistler 9255B dynamometer was used to measure the cutting force signal, which was amplified and displayed in the DasyLab software. The measured cutting force signals stored in Dasylab was then analyzed using I-kaz 3D. The analysis was successfully done using newly developed program, C^{++} language and Visual Basic embedded to display the result on the PDA. This new developed program was installed on PDA to monitor the tool flank wear progression by three modes of different color which include: green (good condition), yellow (transition zone) and red (end of cutting). Therefore, it gives early warning related to the damage and failure of cutting tool, consequently helps the operation of machine to be smoothly operated in order to produce an acceptable quality in manufacturing process.

Key words: Real time monitoring, tool flank wear, I-kaz 3D, cutting force signal, portable digital assistant (PDA).

INTRODUCTION

Real time tool condition monitoring is one of the most important techniques to be developed in the automatic cutting processes as it can help to prevent damages of machine tools and work piece. The present world market competition has attract the manufacturer's attention in automation of manufacturing systems for condition monitoring of machine tools and processes in improving the quality of products, eliminating inspection, and increase manufacturing productivity (Li et al., 2000; Al-Habaibeh and Gindy, 2000). The main objective of tool condition monitoring is to obtain the information, and early warning related to wear, damage and failure of cutting tool, and also recognizes their causes.

Tool wear is one of the most important factors in machining operations. It is a complex phenomenon occurring in different metal cutting processes (Li et al., 2001). Generally, worn tools adversely affect surface finish of the machined part. By continuous operation, the worn tools may fail due to plastic deformation, mechanical breakage, cutting edge blunting, and tool brittle fracture or due to the rise of the interface temperature. Therefore, there is a need to develop tool wear condition monitoring systems, which alert the operator about the tool condition, thus avoiding undesirable condition. Besides, maintaining acceptable flank wear below the rejection criterion is very essential to avoid excessive surface and sub-surface damage on the machined components (Nuawi et al., 2007).

There are two methods that had been proposed, direct and indirect methods. Direct monitoring methods are such as vision and optical approaches, which measure the geometric parameters of the cutting tool (Kurada and Bradley, 1997; Wang et al., 2007). The direct methods

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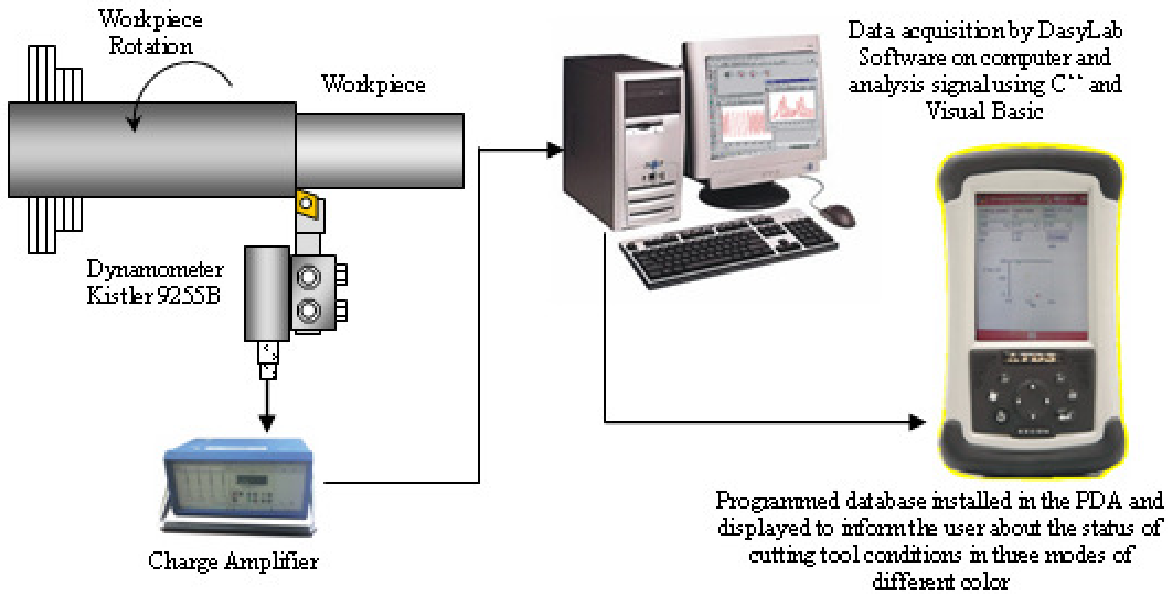

Figure 1. Data acquisition system and PDA for online wear monitoring.

have advantages of capturing actual geometric changes arising from wear of tool. However, direct measurements are very difficult to implement because of the continuous contact between the tool and the workpiece, and almost impossible due to the presence of coolant fluids. The difficulties severely limit the application of direct approach. The indirect methods are achieved by correlating or deducing suitable sensor signals to tool wear states. The advantages are less complicated setup and suitable for practical application. In indirect methods, tool condition is not captured directly, but estimated from the measurable signal feature. This signal feature is extracted through signal processing steps for sensitive and robust representation of its corresponding state. Indirect methods include those based on sensing of the cutting forces, vibrations, acoustic emission, and motor current (Kunpeng, 2009).

In most of the studies done, cutting force signals were widely used as a source for detecting the tool wear and tool failure as studied by Lin and Lin (1996), Dimla and Lister (2000), Kuljanic and Sortino (2005), and Lee et al. (2007). In practice, the application and interpretation of this parameter has been diverse with more effort concentrated on studying the dynamic characteristic of the cutting force signal and interpreting its relation to tool wear levels. Nowadays, most of the signal processing is done digitally, and measured signal commonly consist of variations in amplitude, frequency, phase and energy. Signals can be divided into two main categories which are deterministic and nondeterministic. A deterministic signal can be described by a mathematical relationship between the value of function and time. Many signal in nature exhibit random or nondeterministic characteristic which is challenging to analyze using signal processing technique. Nuawi et al. (2008) developed a new method for analyze random signal based on statistical signal processing which is called by Integrated Kurtosis Algorithm for Z-filter, I-kaz.

This paper focuses on indirect methods for online tool wear monitoring using I-kaz statistical analysis. The objective is to develop a new technique of on-line tool wear monitoring using personal digital assistant (PDA) which can detect and analyze cutting tool wear in terms of flank wear land (VB).

METHODOLOGY

Experimental procedure

The material chosen for the test samples was titanium alloy, Ti-6Al-4V. The main characteristics of titanium are high strength, low density and high corrosion resistance to acid, alkali and chlorine. These special characteristics of titanium made it become the first choice in various field such as chemical industry, automotive, biomaterial, shipping and marine applications (Nuawi et al., 2007). The machining tests were carried out on a CNC lathe machine Colchester Master Tornado T4 in dry cutting condition, and the cutting insert used was cubic boron nitride (CBN). This cutting tool is suitable for turning titanium at high-speed cutting (Haron et al., 2001). A Kistler dynamometer type 9255B was mounted on tool post to measure the cutting force in the three directions, namely tangential/ cutting force (Fz), axial/feed force (Fx) and radial/thrust force (Fy). Figure 1 shows the experimental setup and data acquisition system.

Cutting condition was set at cutting speeds of 180 m/min, feed rates of 0.25 mm/rev, and depths of cut of 0.5 mm. Data acquisition process consists of two sets of data collections; that is, the measurement of the generated dynamic cutting force signal and the flank wear land measurement on the cutting tool edge.

Signals generated by Kistler dynamometer model 9255B are dynamic cutting force signal which are captured and stored by DasyLab software. During the turning operation, the insert was periodically removed from the tool holder, and the flank wear on the flank face was measured using a Mitutoyo toolmaker's microscope equipped with graduated scale in mm. The measured parameter to represent the progress of wear was flank tool wear (VB). The turning operation is stopped and the insert is discarded when VB reach 0.3 mm. It is a standard recommended value in defining a tool life end-point criterion based on ISO 3685 (1993).

Cutting force signals were analyzed using a new developed program (C^{++} language and Visual Basic embedded). C^{++} language was chosen because this programming language was similar to machine language and the process was running more quickly than other languages (Raharjo et al., 2007). Visual Basic embedded was developed to enable the coding program in C^{++} to be readable in the PDA. The system developed (hardware interface with the software) was then used to analyze the cutting force signal in the computer and then displayed on the PDA. This system is able to monitor and inform the user regarding the status of the tool wear condition.

Signal analysis method

The signal analysis methods used is a statistical signal processing based on Kurtosis, I-kaz method. The I-kaz method was pioneered by Nuawi et al. (2008). He studied random or nondeterministic signal characteristics. In order to classify the random signals, the r-th order of moment M_r is frequently used. The r-th order of moment, M_r for the discrete signal in the frequency band can be written as:

$$M_r = \frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^r \qquad (1)$$

Where N is the number of data, x_i is data value at the instantaneous point and $\bar{x}$ is the mean. The Equation 1 has brought to the derivation of kurtosis. Kurtosis, which is the signal 4th statistical moment, is a global signal statistic which is highly sensitive to the spikiness of the data. For discrete data sets the kurtosis, K is defined as:

$$K = \frac{1}{N\sigma^4}\sum_{i=1}^{N}(x_i - \bar{x})^4 \qquad (2)$$

Where N is the number of data, σ is the variance, x_i is the data value at the instantaneous point and $\bar{x}$ is the mean of the data. The kurtosis value is approximately 3.0 for a Gaussian distribution. Higher kurtosis values indicate the presence of more extreme values than should be found in a Gaussian distribution. Kurtosis is used in engineering for detection of fault symptoms because of its sensitivity to high amplitude events.

In this paper, new statistical method will be introduced, called I-kaz 3D method based on I-kaz method which is introduced by Nuawi et al. (2008). This method provides a three dimensional graphical representation of the measured signal frequency distribution. Specifically, the time domain signal was decomposed into three frequency channels. In order to measure the degree of scattering of the data distribution, the I-kaz coefficient calculates the distance of each data point from the signal's centroid. I-kaz coefficient was defined as:

$$I-kaz\,3D\,coefficient = \sqrt{\frac{1}{N}\left(M_4^{I}\right)+\frac{1}{N}\left(M_4^{II}\right)+\frac{1}{N}\left(M_4^{III}\right)} \qquad (3)$$

Where N is the number of data and M_4^{I}, M_4^{II}, M_4^{III} are the 4th order of moment in Channels I, II and III, respectively. The I-kaz coefficient as indirect copyright as in Equation (4) and the symbol of Z_3^{∞} was used to represents the I-kaz coefficient:

$$Z_3^{\infty} = \frac{1}{N}\sqrt{K_I s_I^4 + K_{II} s_{II}^4 + K_{III} s_{III}^4} \qquad (4)$$

Where N is the number of data, K_I, K_{II} and K_{II} are the kurtosis of signal in ch-I, ch-II and ch-III and s_I, s_{II} and s_{III} are the standard deviation of signal in ch-I, ch-II and ch-III, respectively.

RESULTS AND DISCUSSION

Changes in flank wear were known to affect on the cutting force signal generated during the turning process (Kannan and Kishaw, 2008). Cutting force generated by a machining process can be monitored to detect a tool failure or to diagnose the causes of failure in controlling the process parameters, and in evaluating the quality of the surface produced. Figure 2 shows the cutting force signal measured at cutting condition of cutting speed, Vc = 180 m/min, feed rate, f = 0.25 mm/rev and depth of cut, Dc = 0.50 mm. The signals were presented in time domain in Figure 2a and b. From the figures, the cutting force signal increases with the flank wear land. For instance, at VB = 0.05 mm, the maximum force measured is about 120 N, whereas at VB = 0.31 mm, the maximum force increases up to about 165 N.

The cutting force signals contain a large amount of data which is not easy to handle. Therefore, it is necessary to use a signal processing method, in this study I-kaz method was chosen. I-kaz method is a statistical signal processing which is able to measure the degree of data scattering with respect to data centroid for dynamic signal analysis (Nuawi et al., 2008).

Every signal during turning was analyzed using Equation 4, the value I-kaz 3D coefficient (Z_3^{∞}) was calculated, and the calculated I-kaz 3D coefficient using Matlab software and flank wear measured. Table 1 shows the data of experiment for example, result when cutting speed, Vc = 180 m/min, feed rate, f = 0.25 mm/rev and depth of cut, Dc = 0.50 mm.

Figure 3 shows I-kaz 3D coefficient (Z_3^{∞}) decreases when flank wear value (VB) increases. For online tool wear monitoring, a portable digital assistant (PDA)-based device was used to monitor progression of flank wear during turning process based on these I-kaz 3D

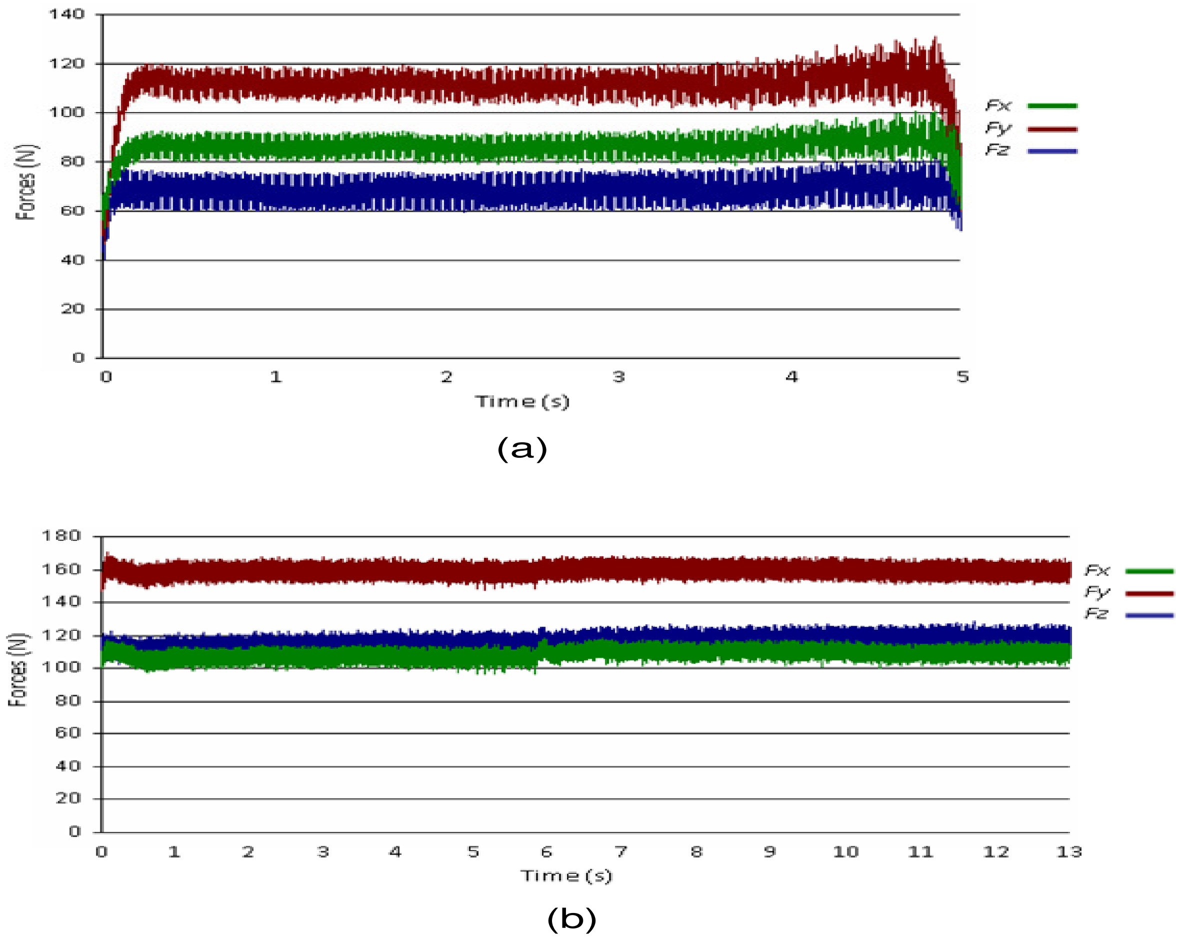

Figure 2. Cutting force signals measured at flank wear. (a) VB = 0.05 mm, and (b) VB = 0.31 mm.

Table 1. Machining time, flank wear land and I-kaz coefficient.

Time (s)	**6**	**10**	**16**	**20**	**26**	**30**	**36**
VB (mm)	0.03	0.05	0.07	0.16	0.17	0.25	0.31
Z_3^∞	0.0207	0.0259	0.0101	0.0099	0.0121	0.0177	0.0043

coefficients (Z_3^∞). The features of PDA are light weight, rugged and portable. Figure 4 shows the display of the wear progression on the PDA.

The main function of this product is to detect and analyze the cutting tool wear in terms of flank wear land (VB). Later, tool wear progression will be displayed to inform the user about the status of cutting tool conditions in three modes of different color, that is, green (good condition), yellow (transition zone) and red (end of cutting). It can be used for monitoring tool flank wear from beginning of cut until VB = 0.3 mm. Therefore, this product is able to give early warning related to the damage and failure of cutting tool, and helps the operation of machine to be smoothly operated in order to produce acceptable quality in manufacturing process. The PDA system also can be implemented in an online tool wear monitoring system which predicts the actual state of tool wear in real time by measuring the other force signals.

Conclusion

This paper discussed on the development of new method for online tool wear monitoring using the I-kaz method and PDA. Tool wear is a time dependent process in which

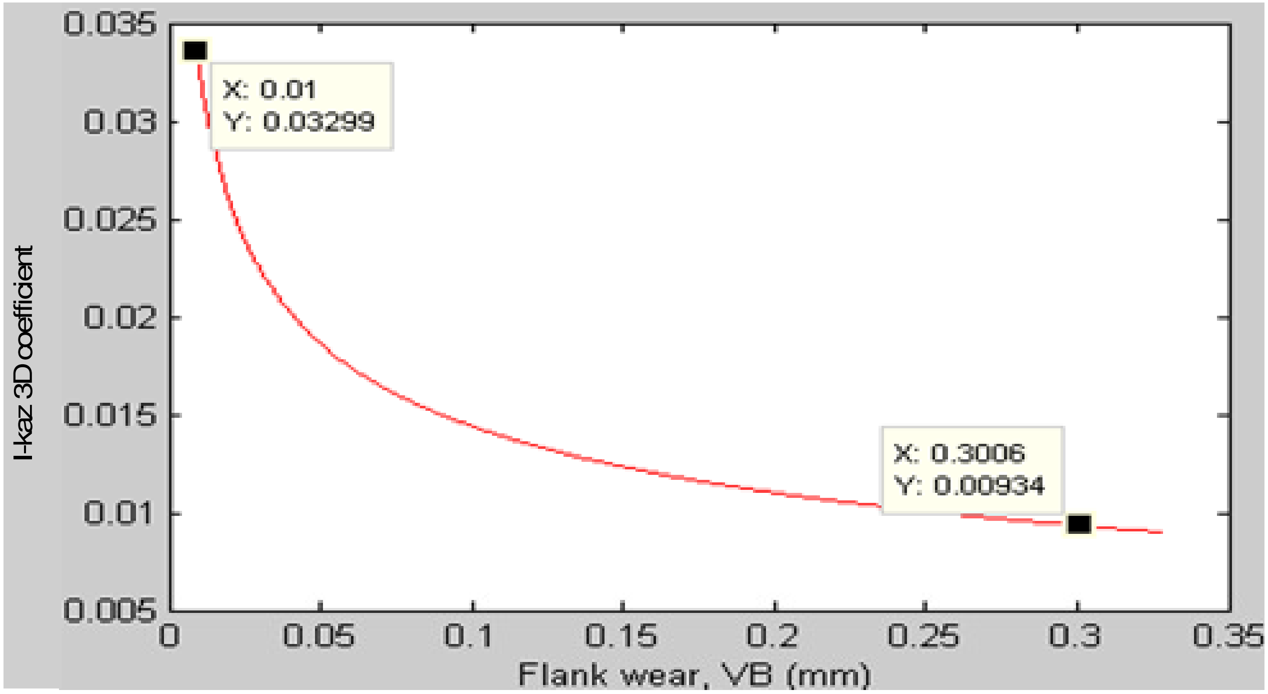

Figure 3. The plot of Z^{∞} versus the value of flank wear.

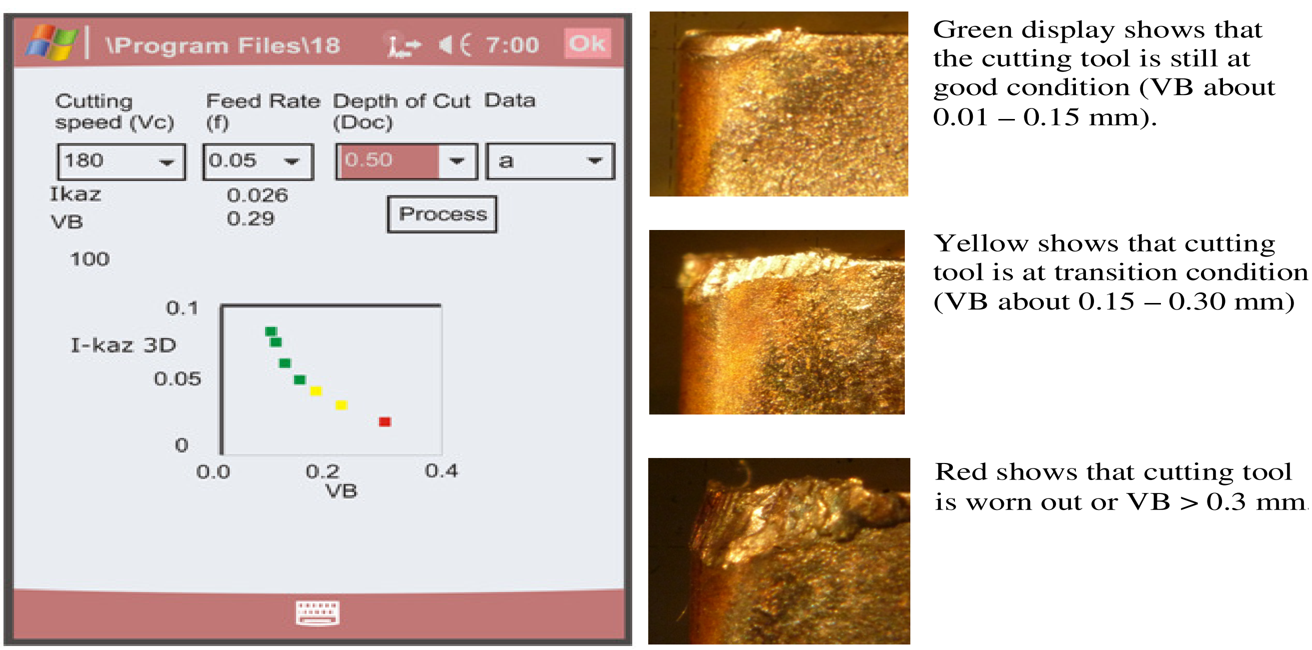

Figure 4. Display of wear progression on PDA.

tool wear increases gradually with the cutting time. The analysis was successfully done using newly developed program that is, using C^{++} language and Visual Basic embedded to display the result on the PDA. This new developed program was installed on PDA to monitor the tool flank wear progression by three modes of different color, that is, green (good condition), yellow (transition zone) and red (end of cutting). This research has successfully developed a new method to give an early warning by detecting the progress of tool wear to improve the machining efficiency. Therefore, this result was proposed to be applied on industries, institution and researchers in machining activity.

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