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ABSTRACT

Although a wide variety of tool wear sensing techniques have been developed over the years, few of them have been used in industries successfully. The need for new and more reliable wear sensors for metal cutting becomes a necessity. In this work a tool wear measurement system based on a computer vision technique is introduced. The system uses CCD Camera, frame grabber, lighting system and Pc computer.

The computer vision image-processing algorithm is developed based on the difference between the intensity of the reflected light from the tool wear surface and that from the background. An appropriate selection of the intensity threshold level yields an acceptable binary image of the tool wear. This image is used for the calculation of the tool wear. A proper algorithm is developed to deal with the two cases of tool wear measurements, tool in-hand and tool in-use. Also the search describes the system, the calibration of the precession of camera, and the processing principles. The performance of the system during tool wear tests and the application of the system on the machine tool are also discussed.

Two techniques are used in this work, the first one, the results based on the program, and the second based on Adob software. This work presents the comparison between the results of two techniques.

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Chapter {1}: An introduction of computer vision technique in field measurement tool wear as well as a survey for this field. Introduction to the basic methods for measurement and the importance of computer vision technique.

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Chapter {5}: Presents the experimental results of two examples, first of this chapter all steps of machining of first case to measure flank and crater wear. Another application case illustrated in appendices.

Chapter {6}: Discussion of the work, the concluded points, and the suggestion future work.

ملخص البحث

نظرا للتقدم السريع والحاجة الماسة لتوفير الوقت والجهد وكذلك الوصول لأكبر كفاءة فى أداء أى عملية إنتاجية فى مجال التصنيع وصولا لأعلى إنتاجية خاصة فى الإنتاج الكمى، ولتقليل تكلفة عمليات القياس والمراجعة وذلك بالتحكم فى جودهما .

وللمساهمة فى حل تلك المشكلات خاصة فى مجال التشغيل " خراطة-ثقب-تفريز...الخ" كجزء هام فى عملية الانتاج . من هذه المشكلات كيفية التحكم فى عمر الحد القاطع وشكل الرايش والعوامل المتعلقة بذلك مثل "ظروف التشغيل وقياس تآكل العدة القاطعة "

توجد طرق مختلفة ومتعددة إستخدمت فى الآونة الأخيرة لقياس تآكل العدة القاطعة . البعض منها فقط الذى يستخدم بنجاح فى الصناعة ، فكانت الحاجة لاستخدام أسلوب سهل وسريع لقياس التآكل الحادث فى العدة القاطعة أثناء التشغيل.

فى هذا البحث استخدم القياس باستخدام الرؤية بالحاسب الآلى وذلك للتحليل وللحصول على قيمة التآكل الحادث فى العدة القاطعة .

هذا الأسلوب استخدم فيه كاميرا "CCD" ونظام إضاءة محدد وكذلك حاسب آلى .اعتمد الأسلوب على تحليل الصورة المأخوذة بالكاميرا معتمدا على إختلاف كثافة الضوء المرتد من سطح التآكل عما سواه .

وبتحليل هذه المساحات أمكن قياس مساحة التآكل ثم الحصول على النتائج المطلوبة لمساحة التآكل باستخدام أسلوبين:-

الأسلوب الأول: بإستخدام البرمجة بإحدى لغات الكمبيوتر "W.C" بالتعامل مع الصورة والفصل بين المساحات وإيجاد مساحة التآكل .

الأسلوب الثانى : بإستخدام برنامج للرسم جاهز "A dob" وأيضا تمت مقارنة تلك النتائج .

وقد احتوى هذا البحث على :-

الفصل الأول :

وقد تناول هذا الفصل الطرق المختلفة المستخدمة لقياس تآكل عدد وأدوات القطع كمقدمة ومفاضلة بين هذه الطرق وأهمية استخدام أسلوب الرؤية باستخدام الحاسب الآلى.

الفصل الثانى:

تعريف لهندسية أداة القطع ذات الحد القاطع الواحد كمحل بحث وتعريف الأنواع المختلفة للتآكل الحادث. وكذلك عرض العوامل المؤثرة فى تآكل عدد وأدوات القطع.

الفصل الثالث :

ويشمل مقدمة عن الرؤية بالحاسب الآلى وكذلك التطبيقات المختلفة لهذا المجال فى النواحى الهندسية ثم تفصيلالمكونات هذا النظام.

الفصل الربع :

يقدم هذا الفصل تفصيلا شاملا لنظام القياس وكيفية تهيئته ويتكون نظام القياس من حامل الكاميرا ونظام الإضاءة والكمبيوتر.ثم يتناول عرض لخطوات كلا الأسلوبين البرمجة وبرنامج "A dob" ثم عرض للبرنامج المستخدم.

الفصل الخامس:

هذا الفصل قد خصص لعرض النتائج والظروف المحيطة بعملية التشغيل، ثم رصد نتائج قلم الخراطة وقياس كلا من "F lank wear, Crater wear" ، وأخذت حالة أخرى وهى استخدام قلم ذى حد قاطع واحد ذى لقمة كربيدية وذلك فى الفهرس.

الفصل السادس:

يعرض هذا الفصل خلاصة البحث ومقارنة النتائج وإقتراحـــــات لاتجـــاه الأبحاث فى هذا المجال فى المستقبل.

تم بحمد الله.

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Mansoura University
Faculty of Engineering
Production Engineering and
Mechanical Design Dept.

In-Process Measurement of Tool Geometry and Wear Using Computer Vision Technique

By

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B.Sc.Industrial Production Engineering
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A Thesis

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Although a wide variety of tool wear sensing techniques have been developed over the years, few of them have been used in industries successfully. The need for new and more reliable wear sensors for metal cutting becomes a necessity. In this work a tool wear measurement system based on a computer vision technique is introduced. The system uses CCD Camera, frame grabber, lighting system and Pc computer.

The computer vision image-processing algorithm is developed based on the difference between the intensity of the reflected light from the tool wear surface and that from the background. An appropriate selection of the intensity threshold level yields an acceptable binary image of the tool wear. This image is used for the calculation of the tool wear. A proper algorithm is developed to deal with the two cases of tool wear measurements, tool in-hand and tool in-use. Also the search describes the system, the calibration of the precession of camera, and the processing principles. The performance of the system during tool wear tests and the application of the system on the machine tool are also discussed.

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Chapter (1)

GENERAL INTRODUCTION

1-1 Introduction

Many factors push the manufacturing of mechanical components towards a higher degree of automation .In a more and more competitive market increasing cost of labor and capital demands increasing productivity and decreasing lead and production times. High manufacturing efficiency has in the past been realized by mass-production, but as the lifetime of component designs decreases this efficiency has to be extended to small and medium size batch production. To reduce the cost of inspection and testing the produced parts have to be of a well-controlled and consistent quality.

Social factors demand that trivial and dangerous jobs be eliminated. Higher automation is generally believed to be one of the major means of meeting these demands and of solving or reducing these problems. Yet befor the fully automated factory can be realized many technological problems remain to be solved, especially in the fields of process modeling and sensor technology. The metal cutting operation (turning, drilling, milling, etc) is the most important mechanical manufacturing processes.

Within this group of processes it is not possible to predict the resulting process conditions (e.g. chip form, tool life) with sufficient accuracy on the basis of the controllable process parameters (tool geometry, cutting data, etc...).

To control these processes, in-process monitoring is therefore necessary as the tool life, and the tool-condition, has a large influence on the manufactured parts, the tool- condition is one of the most important monitoring objects. Unfortunately the tool- condition can be neither measured nor described in any simple way.

To form the bases of automatic metal cutting system, a tool-wear sensor has to fulfill several requirements. The sensor must be very rugged, the correlation between in traditional lathes and/or milling machines and must allow easy integration with other control and monitoring equipment. All these requirements must be fulfilled at a modest cost.

Tool conditions can be defined by wear marks with a complicated geometry, but is also affected by cracks and changes in the tool-material properties due to diffusion and mechanical and thermal stresses. Even the tool performance and remaining lifetime cannot be accurately predicated . Due to all these difficulties in practice very simple tool measures are used to described the tool-condition, typically the width of the flank and/or the depth of the crater[10-11].

1.2 LITERATURE REVIEW

1.2.1 Methods of Measurement

Tool wear sensing can be classified into two major categories:----

Direct, where the actual tool wear is measured.

Indirect, where a parameter correlated with tool wear is measured, as illustrated in (table1-1)

	Procedure	Measurement	Transducer
Direct	Optical	Shape or position of cutting edge	Tv camera; optical transducer
	Wear particles and radioactivity.	Particle size and concentration; Radioactivity activity	Spectrophotometer; scintillator
	tool/work/junction resistance	Changes of junction resistance	Voltmeter
	workpiece size	Dimension of workpiece	Micrometer; optical, pneumatic, ultrasonic, electromagnetic Transducers
	tool / work distance	Distance of workpiece and tool or toolholder	Micrometer; Pneumatic gauge; displacement transducer
Indirect	Cutting force	Changes of cutting force	Dynamometer strain gauges
	Acoustic emission	stress wave energy	AE transducer
	sound	acoustic waves	Microphone
	Vibration	vibration of tools and /or tool posts	Accelerometer
	Temperature	variation of cutting temperature on tool	Thermocouple; pyrometer
	Power input	power or current consumption of spindle or feed motor	ampere meter; dynamometer
	Roughness of machined Surface	changes in surface roughness of workpiece	mechanical stylus; optical transducer

Table (1-1) Methods of measurement [8]

1.2.1.1 Direct and indirect Methods of Tool Wear Measurement

A tool wear land on a single point cutting tool appears clearly because of the higher reflectivity compared with the unworn surface. Optical and electro-optical methods can be used to analysis the image of the illuminated wear zone when the cutting tool is not continuously in contact with the workpiece.

K.C.Tsao and A.B.Husein, [1] Proposed the optical comparator is an obvious tool to use in investigating tool wear. The technique uses a transparent thermoplastic mold of a tool crater, which was lapped to show contour lines on an optical comparator. Contours of the lapped surface boundaries were seen as clear, sharp lines of high contrast. The crater depth, often used as one of the criteria in the evaluation of the crater wear, could be easily and accurately measured by reading the height of the mold on the optical comparator screen.

Giusti et al., [2] presented a method satisfactory on-line flank wear estimation under constant and time varying, cutting conditions in which the feed was intermittently changed stepwise.

F.Gurusti and M.Santochi, [3] presented fiber optical technique using in process measurement of tool flank wear. This technique was able to measure the depth of wear over the whole wearland, not only in its central zone. The technique is relatively to implement and can be applied to either conventional production lathes or NC lathes.

Jeon and W.Kim, [4] developed an optoelectronic method has been proposed for on-line monitoring of the flank wear of cutting tools. The method was based on-line vision technology.

A beam of laser illuminated the tool and the wear zone was visualized using a camera. The image was converted into digital pixel data and processed to detect the width of wear land. The experimental results showed that the method was capable of detecting tool wear accurately.

H.Takeyama and H. Sekiguchi, [5] presented another variation of electro-optical devices consisted of a microscope furnished with a vidicon followed by some electronic circuits and was used to measure the wear land by line scanning the magnified image of the flank wear. A worn tool was examined by a TV camera at every tool change, and the morphology of the tool failure was classified by using a pattern recognition technique. When an undesirable morphology was found, the tool material or the tool geometry was changed according to the decision table, which had been constructed by a learning algorithm in advance. This work was validated using an experimental technique.

The simplest way to measure tool flank wear is to simulate the way human inspectors do it. The amount of flank wear is then calculated using a thresholded binary image, where the worn surface is represented by white and the background by black. However, since the flank wear surface is never completely uniform, the intensity of the reflected light from some worn areas is frequently lower than the threshold value. Thus those areas are incorrectly represented by black..

It is, therefore, not trivial to obtain an acceptable binary image which represents the entire flank wear region as white [12,13] .

Optical sensing can only be used between cutting cycles when the tool is removed from the workpiece and as such is not strictly an "in-process" technique. However, it appears to be accurate and reliable especially when machine vision is used. It has its share of problems though, in that there can be instances when it is difficult to detect tool wear lands if a build-up edge or metal deposits exist. It is well known that most of the wear particles of cutting tool are carried away adhering to both side surfaces of the chip in tuning. Thus, it should be possible to find the amount of tool by chemical analysis.

S.Jetly, [6] Reported Radioactive sensors have been used explored. One of the methods comprised activating the cutting tool with neutron or charged particles, which left a small quantity of activated material on the chip during cutting. Tool wear can be detected using the abraded radioactive wear particles or measuring the radioactive decay of the tool. As one successful application of this technique, a small quantity of radioactive material was attached or implanted to the flank of a tool.

At the end of each cutting cycle the tool was monitored to determine whether the spot was still there. If the spot had disappeared, the tool was considered to be worn. As a cutting tool wears, the contact area of the tool and workpiece increases so that the resistance of this junction decreases. This principle has been used to sense tool wear.

K.Uehara, [7] Presented one method used a thin film conductor bonded on to the tool flank. As the tool wore, part of the conductor also wore and the resistance to the current increased and was found to correlate with the flank wear.

Although this technique sounds promising, it can be argued that in practice, problems due to the variation in cutting forces could complicate the contact resistance at the flank and thus introduce an extraneous component in the measurement.

Workpiece sizes will change as a cutting tool wears particularly on the edge in contact with the final machined surface on the workpiece. So tool wear can be measured directly by measuring the change in workpiece dimensions. Several sensors have been developed for measuring the diameter of workpieces and can be classified as contacting or non-contacting methods [6,8,10].

During a cutting operation, the distance between the tool holder and the workpiece decreases as the tool wears. This distance can be measured directly using techniques such as the tool wears, such as, electronic micrometers, reflected ultrasonic waves, pneumatic gauges, and inductive proximity devices.

However, their sensitivities are likely to be influenced by one of the following variation: temperature of the work surface quality, cutting fluids and workpiece diameter during the operations. A rather simple device was designed using an electric feeler micrometer to measure the tool wear directly [4,12].

K.F.Marten et al, [16,19] Presented One of the parameters that can be relatively easy to measure is cutting force. Cutting forces change as the tool wears and have often been used to detect tool wear in the laboratory.

A.G.Ulsoy et al, [17,18,21-23] Reported some theoretical models based on force measurements for on-line tool wear and breakage sensing have been presented and verified by the experiments. There have been many attempts at using force patterns an indication of tool wear for the turning processing.

A force transducer was developed to measure the dynamic forces from the chip formation process. This sensor used a piezo electric element which, when dynamically compressed produced an electrical output, proportional to the dynamic forces transmitted through it. Extensive cutting tests have shown that it could be used to indicate flank wear. Other results showed that the force signal was more effective than acceleration measurements in detecting tool wear, due to the transfer function of the tool holder and tool holder components.

P.M.Lister and G.Barrow[24] Presented another study has contradicted the above findings and showed that the main cutting force gave the best indication of tool wear at any given time, and that radial and feed force components were not in-process monitoring of tool wear.

Danai and K.Y.Ko [25,26] Developed for some small changes were noted in the signals at the steady state cutting conditions but the influence of tool wear was much more evident during the dwell and set-up periods when the cut thickness was changing.

During the dwell period, the main cutting force *Fc* and feed force *Fn* dropped to equal each other with a sharp tool. The value of *Fc* dropped to a level greater or less than the *Fn* correlating to the flank wear for a worn tool. It was concluded that the feed force alone, or even better, the ratio of the feed component to the velocity component of cutting force was a sensitive means for tracking tool wear. The changes of cutting temperature were also discussed for tool failure sensing.

The ratio of feed of the thrust force component to the power component was also found to be a sensitive measure of "dullness" behavior at all force magnitude.

J.Tlusty and G.C.Andrews[27] presented other experimental work has confirmed the inter-relationship of the three components of the cutting force. *Fc* (the tangential force) *Ff* (the feed force), and *Fn* (the normal force). These forces increased suddenly when a broken tool nose jammed between the tool and workpiece, then dropped to zero due to the gap between the tool and the workpiece as the broken part of the tool insert was released. As the tool continued to move, it approached the workpiece again, closing the gap and forces to increase beyond their original values. These force variations could be used to identify the tool breakage and therefore cease feed motion a broken tool started to gouge the workpiece.

M.S.Lan and D.A.Dornfeld [20] Reported that there are two different viewpoints about total tool fracture in.

The first is based on evidences which showed that cutting forces initially increase due to tool fragments being squeezed between the tool and workpiece, and subsequently decline to zero. Microbreakage causes sudden permanent increases in the feed or thrust force. The second viewpoint adopts the following stance; both tangential and feed forces are sensitive to tool fracture but only the tangential force exhibits a consistent change(decrease) when an insert breaks. The magnitude of the drop in tangential force as a result of tool fracture is proportional to the fractured length along the cutting edge. The level of feed force may increase or decrease due to chipping of the cutting tool depending on the degree and type of microbreakage.

In concluding this section, it can be commented that measuring cutting forces is one of the most commonly used technique in detecting tool failure. However, the mechanisms for causing tool wear and failure have a complex relationship with cutting forces. For example, the relationship of the cutting tool and workpiece, as well as the variation of other cutting conditions. The results can quantitatively different for sensing tool wears in various studies and hence these results can not be used even empirically from one step to another.

E.Kannatey-Asibu and D.A.Dornfeld[28] Acoustic emission(AE) can be defined as the transient elastic energy spontaneously released in materials undergoing deformation, fracture or both. AE can be related to the grain size, dislocation density and distribution of second-phase particles in crystalline materials and is observed during the deformation of these materials.

In the metal cutting process, AE is attributable to many sources, such as elastic and plastic deformations of both the workpiece and the cutting tool, friction, fracture of the workpiece, wear and failure of the tool.

E.Emel et al[29,30] Presented a methodology has been developed for detecting tool wear and breakage using the spectra of AE signals. This methodology is based on pattern recognition concepts and was applied on sample sets of data obtained under fixed cutting conditions. The results of the pattern analysis showed the reliable frequency range to be between 100 kHz and 1 Mhz.

Progressive tool wear was found to be associated with increasing AE power within the 400-700 kHz range, whereas catastrophic tool failure had a spectrum spanning a much wider frequency range. A figure of between 84 and 94% was quoted for reliability in detecting tool failure in this work. In closing this section, AE sensing technique appears to have a quick response time and consistency, and seems to be more sensitive to tool fracture than cutting force measurements and tool vibration analysis, although no experimental evidence of this sensitivity has been made.

Sound from a machining operation measured, for example, near the cutting zone on a lathe contains a variety of cutting informations. Some components of this sound have been used to monitor conditions of the cutting edge. low frequency noise spectra resulting from the rubbing action of the tool and workpiece were used to monitor tool flank wear.

G.Barrow and G.Bthroyd [31,32] The temperature rise in a cutting tool will affect tool life. In fact the final breakdown of the tool is due to this increased temperature. Therefore, the cutting temperature can be used to monitor tool failure. There are several techniques for assessing cutting temperature: (1) thermo-e.f.m. measurements: work-tool thermocouple and tool thermocouples;(2) radiation techniques; and (3) thermo-chemical reactions. The prime contenders are the work-tool thermocouple and tool thermocouple techniques. It was found that approximately 60% of heat generated at the work-tool interface was conducted into the workpiece and the remaining 40% was removed in the chip. The extra heat carried away by the chip resulted in an increase in the temperatures on the tool rake face. The mean temperature taken over the tool wearing surfaces (both the face and the flank) increased with increasing flank wear land length.

D.Spigeon and R.A.C.Slaten[33] It is well known that the surface roughness of a workpiece is influenced by the sharpness of the cutting tool. This phenomenon has been utilized for tool condition monitoring. A fibre-optics transducer was used for in-process indication of surface roughness during a finish turning process. By using adaptive control schemes in small batch size manufacturing environments and optimization(ACO). Optical sensors and micro-isotope sensors are fairly accurate. The dimensional sensor is generally sensitive to thermal expansion and deflection of the cutting tool, the tool holder, or the work piece ,and also sensitive to vibrations of the workpiece and the tool. This model of process and more operations as application" straight turning operations " [34].

Pattern recognition technique for monitoring single crystal diamond tool wear in the ultra precision machining process. Selected features by which to portion the cluster of patterns was obtained by time series AR modeling of dynamic cutting force signals. The wear on a diamond tool edge appears to be classified into two types, micro chipping and gradual, both very small computed to conventional tool wear[35].

Most reasons of tool wear and it's results over chip and quality of operation is classified in [36]. The procedures for detected the wear area or the worn area and model of calculation along variation of time and fixing other parameters[37].

A new strategy has been presented, using a CCD-array camera and a vision system to monitor the flank wear of HSS-drills. In today's practice the wear parameters are measured with a toolmaker's microscope by a well-skilled person.

This method introduces the high subjectivity of the measuring person, but, when using computerized vision systems, the measurement can be objective and automated. Sharp images are important for optical measurement methods and characterized by high contrast, especially at the boundary lines in the image.

The camera must be positioned at such a distance to the object that the edge contrast of the image comes up to a maximum. The diameter range of the measured drills extends from 10 to 24 mm. The gray-scale image is commonly transformed to a binary image and filtering it to obtain the area of wear . The measurement results would be deeply influenced by variations in the intensity[38].

Tool breakage increases production time and costs. There is a large need for monitoring in the drilling process because it covers nearly 40% of cutting operations. Most of the commercial drill wear sensing systems-that monitor one or more parameters of the cutting action, such as cutting forces, temperatures, electrical input to the spindle motor, etc..

Often could not need the specifications of the product process, by using a CCD-array camera and vision system to monitor the flank wear of HSS-drills[40].

Another accurate automatic detection method of directly measuring damage of tool without contacting it using an industrial television (ITV) camera with an auto-focusing device. This newly developed method uses halogen lams for illuminating cutting tools. Three different images are inputted into a computer[41].

Computer vision ,also sometimes called intelligent vision, can be defined as a means to simulate the image recognition and analysis capabilities of the human eye/brain system with electronic and electromechanical techniques. In human vision system, eyes sense the image and brain analysis the information and takes action on the basis of analysis. Similarly in M/C vision system, sensing of information is done

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