Automated Visual Inspection of Cutting Tool Wear

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Abstract
Nowadays, CNC machines have high importance in manufacturing factories and workshops due to its high accuracy and flexibility. Unfortunately it still cannot ensure the quality of machined products. The trend towards automation in machining has been driven by the need to maintain high product quality with improving production rate. These improvements can be possible by monitoring and control of machining process, in this research a new algorithm is introduced for the direct measurement of cutting tool wear by vision system on the basis of edge detection and morphological operations for the captured images. The results showed the efficiency of the proposed method for online monitoring of the tool condition.
Key Words: Visual Inspection, Cutting Tool Wear, Flank Wear

الفحص المرئي المؤتمت لبلى عدد القطع

الخلاصة
في الوقت الحاضر , تحظى مكائن القطع المبرمجة باهمية كبيرة في المعامل والورش التصنيعية بسبب دقتها العالية ومرونتها لكن لسوء الحظ لا تزال هذه المكائن غير قادرة على التاكد من جودة السطوح المنتجة . الاتجاه نحو اتمتة عمليات القطع سُير للحاجة الملحة للحصول على جودة عالية للمنتجات وتحسين معدل الانتاج . هذه التحسينات تصبح ممكنة عند المراقبة والسيطرة على عملية التشغيل . في هذا البحث تم اقتراح خوارزمية جديدة للقياس المباشر لبلى عدة القطع بواسطة نظام رؤية على اساس تقنية ايجاد الحواف وعمليات المعالجة المورفولوجية للصور الرقمية الملتقطة . اضهرت النتائج المستحصلة كفاءة الخوارزمية المقترحة لمراقبة بلى العدة اثناء العمل.
الكلمة المرشدة: الفحص المرئي، بلى عدد القطع، البلى الجانبي

INTRODUCTION AND LITERATURE REVIEW

In any machining process, high quality of the final product is the ultimate aim. Cutting operations like turning and milling play a major role in today's industrial manufacturing processes. Many efforts are made in various fields of manufacture, which aim at the further optimization of cutting operations towards higher stability with low scrap rates and reduced production costs. Also, much research has been undertaken in the past into systems for automated tool wear monitoring, since cutting tools are both an important factor regarding manufacturing costs and for the quality of the workpiece.

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Astakhov (2004) stated that Tool wear significantly increases the cutting force. For steel, VB_B = 0.45 mm causes 2.0–2.5 times an increase in the cutting force when no plastic lowering of the cutting edge occurs (for cutting speeds 1 and 1.5 m/s) and 3.0–3.5 increase when plastic lowering is the case (for cutting speeds 3 and 4 m/s) [1]. Principally tool wear monitoring systems can be classified into two groups, whether if they measure tool wear directly at the cutting edge of the worn tool (direct measurement techniques) or if the measured parameters or signals of the cutting process allow to draw conclusions upon the degree of tool wear (indirect measurement techniques). Indirect measuring techniques are based upon the analysis of typical signals of the cutting process like acoustic emission or power consumption of the feed drives, which are an indicator for the degree of tool wear. Normally, these tool wear monitoring systems are based upon the comparison of a reference signal of an optimized cutting process with the actual process signal. Once the actual signal has changed beyond a threshold value, an alarm is given in order to stop the cutting process and indicate a request for tool change. As a consequence, these systems are only useful for monitoring the production of large batches, where identical cutting operations are repeated many times [2]. Direct tool wear monitoring is preferred due to several reasons Such as, (1) it applies no force or load to the surface texture under examination; (2) it is a non-contact, in-process application; (3) this monitoring system is more flexible and inexpensive than other systems; (4) this system can be operated and controlled from a remote location, so it is very much helpful for unmanned production system; 5) the development of CCD cameras has also contributed to the acceptance of industrial image processing, since CCD cameras are less sensitive to the adverse industrial environment; 6) direct optical measurement techniques allow to measure tool wear with high accuracy [3]. M. Sortino (2003) developed a novel statistical filtering technique for edge detection to suppress the high noise in the worn region of cutting tool which cannot be processed with high pass filtering " such as the most known edge detection techniques ". He got a 92% percentage of success in the detection of flank wear zone in different milling and turning cutting tools [4]. R. Schmitt et al. (2012) implemented a flexible illumination unit that can be used for different geometries and surface properties with special mechanical system for proper alignment of the cutting tool. They defined two region of interest in order to produce an active contour detection and also used a neural network for the classification of the tool wear type [5]. M.A. Mannan et al. (2000) done an investigation on the texture image of machined surface and signal analysis of sound generated during machining to distinguish between a sharp, a semi sharp or dull cutting tool [6]. S. Dutta et al. (2012) online acquisition of machined surface images has been done time to time and then those captured images were analyzed using an improvised grey level co-occurrence matrix (GLCM) technique with appropriate pixel pair spacing (pps) or offset parameter. The variation of texture descriptors, namely, contrast and homogeneity, obtained from GLCM of turned surface images have been studied with the variation of machining time along with surface roughness and tool wear at two different feed rates [7].

Tool Wear According to ISO 3685

Wear is a progressive damage to a surface caused by relative motion with respect to another substance [8]. During the cutting process, deformation, separation and friction processes take place in the area of the cutting edge. The cutting tool materials used are subject to an extremely complex load collective characterized by high compressive stresses, high cutting speeds and high temperatures. Cutting tools reach the end of their service life because of continuously increasing wear on both rake and flank faces [9]. The progressive wear of a tool takes place mainly in two distinct ways

1. Wear on the flank face, including often regions adjacent to the major and minor cutting edges and tool nose, where characteristic land is formed from the rubbing action of the newly generated workpiece surface.
2. Wear on the rake face characterized by the formation of a crater and/or built-up edge resulting from the action of the chip flowing along the face.

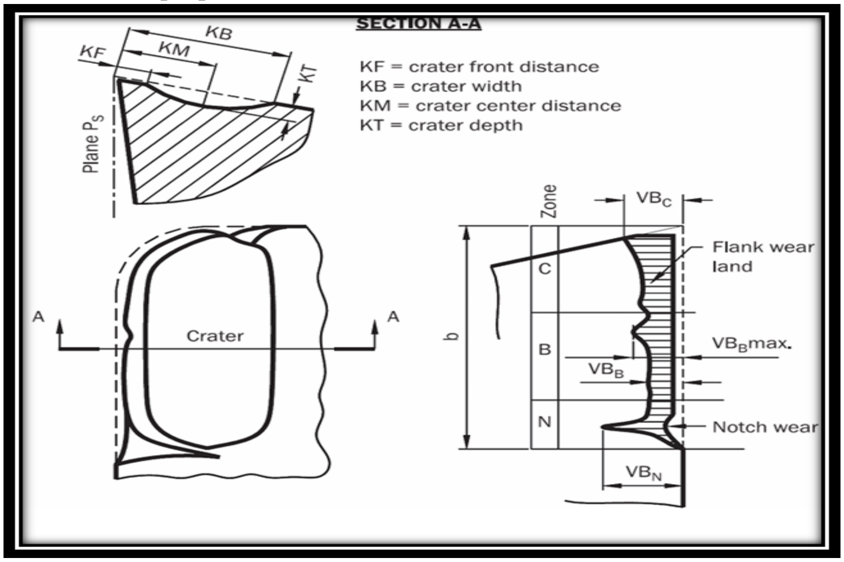
Flank wear is the most common wear form and most of tool life calculations is based on. Its observed on the flank or clearance flank as a result of abrasion by the hard constituents of the workpiece material. This failure mechanism is commonly observed during machining of steels and cast irons where the abrasive particles are mainly Fe_3C cementite and non-metallic inclusions.

Crater wear is observed on the rake face of cutting tools, generally occurs during machining of relatively soft steels and ductile irons at high speeds when continuous chips are formed. It is primarily caused by a chemical interaction between the rake face of a tool insert and the hot chip [10].

The ISO standards for tool wear measurement

Some directly measured dimensional characteristics of typical wear patterns, i.e. Flank and crater wear, for HSS, carbide and ceramics tools, are standardized in ISO 3685 as shown in fig.1.

In practice, the most important practical consideration in selecting cutting tools and cutting conditions is the tool life (T) which defines the time corresponding to the prevailing tool-life criterion. In other words, tool life is determined when the measured wear levels exceed a limit. A standard measure of tool life is the time to develop a flank wear length VB_B of 0.3 mm or VB_B max of 0.6 mm obtained from tool-life curves [10].



Figure(9) Wear forms in turning (acc. ISO 3685) [11].

The Experimental set-up

The vision system used in the experiments mounted in a STARCHIP CNC Turning machine and consists of Fine CT-8881 HQ-ICR color CCD camera with a resolution of 576 × 704 pixels, AVENIR lens vari_focal "18 - 120" mm, digital video recorder, frame grabber, personal computer with Mat-lab program, Fluorescent illumination with a barrier used to prevent the light reflection from the tool cutting edge and to control the background of the captured image. The camera was calibrated using two standard gauge blocks. The cutting tool is programmed to a preset position in front of the camera so the image plane coincide with the flank face of the cutting tool. The images then cropped to a resolution of 200 × 200 pixels to minimize the algorithm operation time and to suppress the unwanted features in the captured image.

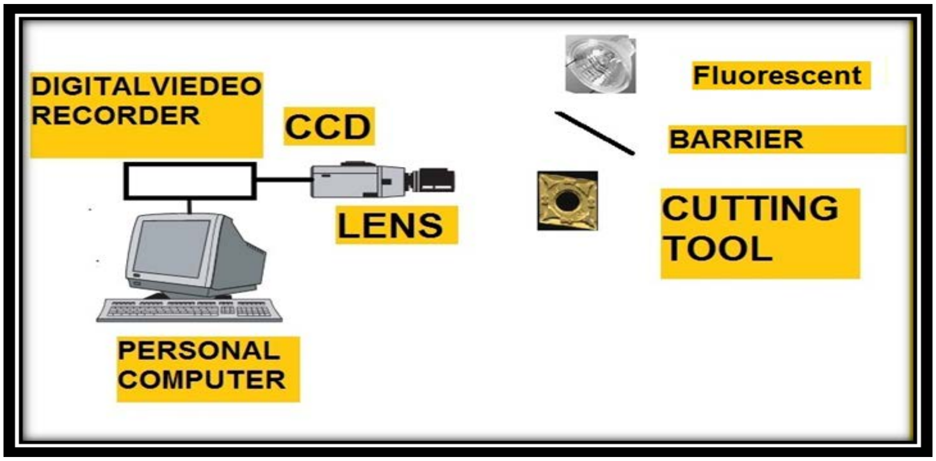


Figure (2). Schematic diagram of the vision based monitoring system.

The proposed algorithm

Typical CCD-captured insert image consists of three different areas "see fig.4":

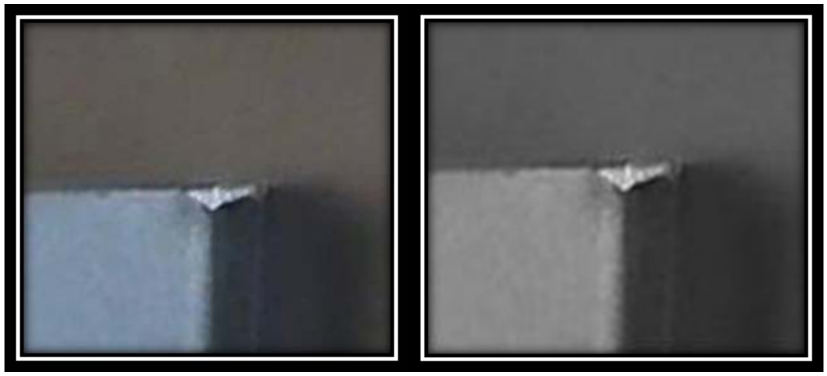
(a) The background (relative to the insert), where each pixel has a low gray level.

(b) The unworn area of the insert, where each pixel has an intermediate gray level.

(c) The flank wear land (of the insert), where each pixel has a high gray level (bright area).

Step 1: The captured image is converted to grayscale version to reduce the algorithm operation time.

Step 2: The image preprocessed with median filtering that reduce the noise introduced in the image without any distortion in the high frequency features 'edges', This is important as in the following steps, edges in the image are used to determine the critical area.



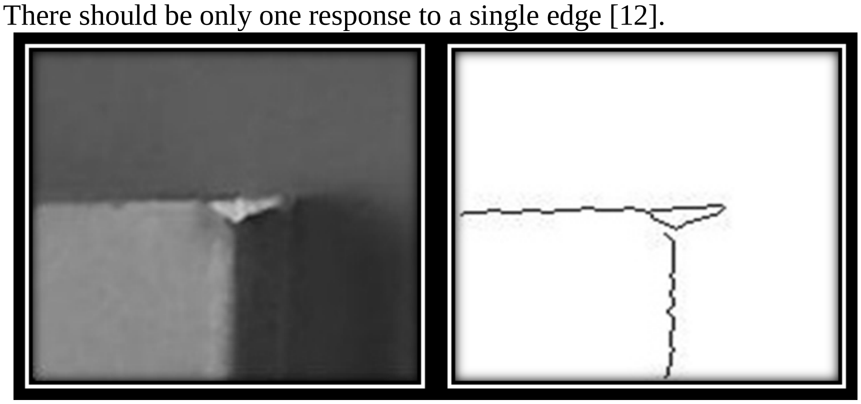
(a) (b)

Figure (3). (a) Captured image (b) Gray scale version of the image (after step 1).

Step 3: The image is segmented using the canny edge detection which is generally acknowledged as the best 'all-round' edge detection method developed to date, "see fig.4 b".

Canny aimed to develop an edge detector that satisfied three key criteria:

- A low error rate. In other words, it is important that edges occurring in images should not be missed and that there should be no response where edges do not exist
- The detected edge points should be well localized. In other words, the distance between the edge pixels as found by the detector and the actual edge should be a minimum.
- There should be only one response to a single edge [12].



(a) (b)

Figure (4). (a) Median filtered image (after step 2) (b) Edge image (after step 3).

Step 4: the resulting contour of worn region in some experimented images have some discontinuities due to noise. These discontinuities cause real problem in the subsequent steps so edge linking must be done to complete the worn region contour. A morphological dilation with 3 × 3 square structuring element (8-connectivety) is used to complete the interrupted contour as shown in fig. 5a.

Step 5: Region filling is applied to fill the pixels inside the worn area contour which is useful in the next steps," If the worn region contour is not closed, this operation will fail and corrupt the image".

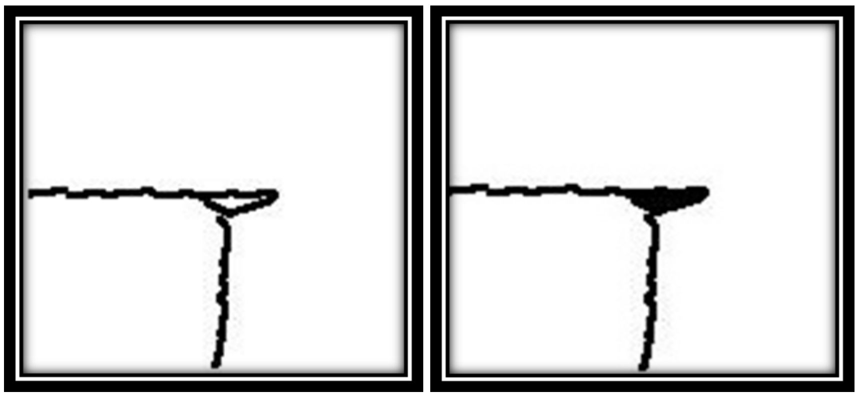


Figure (5). (a) Dilated image (after step 4) (b) Image after region filling (after step 5).

Step 6: Perform morphological erosion with the same structuring element used in step 6 (3 × 3 square 8-connectivity) to remove pixels added by dilation "see fig. 6".
Step 7: Morphological opening is used with 4-connectivity to remove the cutting edge line pixels in order to extract the flank wear land only.

To make sure of the accuracy of the method, boundary extraction is applied to the image in step 7, and then this boundary is superimposed to the captured image, then Orthogonal scanning is done to compute the width of flank wear land V_B.

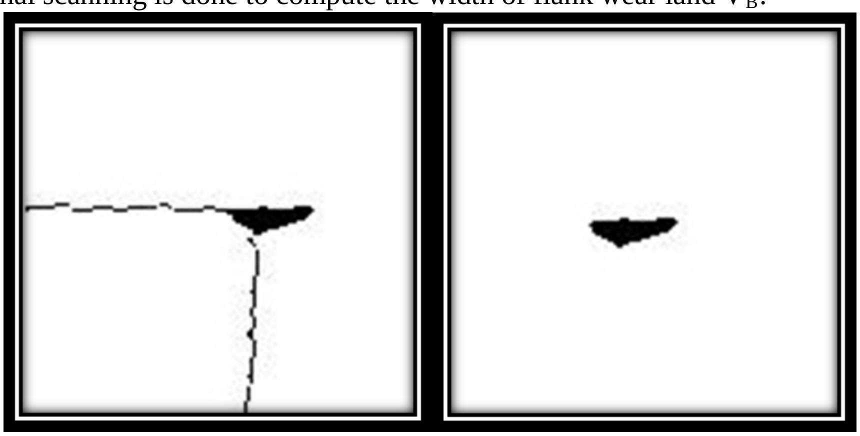


Figure (6). (a) Image after morphological erosion (after step 6) b) Image after morphological opening.

Results & discussion

The images of six worn cutting tools with different machining conditions is experimented with the vision system and the proposed algorithm. The measurements are validated against the manual measurement with microscope and used as reference. The results shown in table 1.

Table (1): Results

The results shows that the algorithm work effectively for the measurement of tool wear. Maximum error in the method resulted in tool no.4 and minimum error happened in tool no.5. The use of improved hardware of the system may increase the precision of the proposed algorithms.

Conclusions

- The canny edge detection is proved to be more efficient than the other edge detection methods such as sobel, prewitt, laplacian of Gaussian, etc.
- Selection of the appropriate thresholds for weak and strong edges has crucial influence in the canny edge detection to eliminate false edges.
- The morphological operations used should be processed with minimum size of the structuring element that can be applied to reduce the resulting errors.

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Tool	V_{Bmax} mm	V_{Bmax}"exact" mm	Error mm	V_{BB} mm	VA mm^2
1	0.414	0.43	-0.016	0.259	0.3516
2	0.598	0.61	-0.012	0.342	0.5134
3	0.322	0.30	0.022	0.251	0.3064
4	0.505	0.46	0.045	0.278	0.3646
5	0.368	0.37	-0.002	0.289	0.4725
6	0.644	0.66	-0.016	0.494	0.6019

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