Operator and analyst interfaces for monitoring of wear in tool inserts

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Resumen. In the last years computer vision techniques have developed significantly, not with respect to hardware aspects but also to image processing applications. For decades initiatives for application of these techniques in the production facilities were intended, mainly at inspection and control processes. However, only in the last decade this technology has achieved the level of maturity and low cost required for effective installation at the industrial environment. In this work operator and analyst graphical interfaces are showed that allows monitoring tool inserts in the turning of steels. The interface is based on computer vision techniques together with classification techniques using statistical moments and region descriptors.

Keywords: Monitoring tool life, computer vision, classification, descriptors.

Introduction

Nowadys, the industrial environment is under a very high competitive pressure. That fact has brought research groups to optimize particular aspects of the production processes with the aim of reducing costs and lead times. In the context of automated processes the parameters under optimization are several, such as lot sizes, combination of products, machining parameters, sequence of operations and others. This paper is focused on optimization of a very particular aspect, but not for it less important: the optimization of the cutting tool with regard to its useful life. That is, the use of the tool insert until a maximum to minimize its cost, but overalls the non-productive time due to tool change.

Many studies show the high influence that tool change operations have in the productivity of operators and machines. As reported by Teti [1] and Weckenmann et al. [2], the cost of cutting tools and their replacement account for 3% to 12% of total production costs. Though small at first glance, these permanent costs constantly accumulate along the machine life cycle [3]. In addition, about 20% of non-productive time is due, in modern machines, to tool failure [4].

The approaches used in the current industrial practice to determine the time for tool replacement are of very easy verification for the operator. However, at the same time, they are very conservative. They are mainly based on the control of variables such as accumulated time for each cutting edge or the amount of parts produced. It is evident that for the operator it is very easy to control these variables; even an inexpert machinist would not have difficulties in controlling it. However, tool life is not optimized since practical criteria are very conservative in order to preserve part and process integrity. These practical approaches apply a unique and uniform criteria to all the cutting edges. However, the industrial practice indicates that such a uniformity does not exist, at least with regard to degradation of cutting tools under the same machining conditions.

On the other hand, tool wear and its measurement are described in several standards (ISO 3685, ISO 8688, ISO 883, ISO 3364, ISO 6987 and ISO 9361). These standards provide wear threshold values at several points of the worn region as a reference criteria to replace the tool insert. However, the technological advances in machines, tools and part materials have rendered these standards obsolete. The threshold values included in these standards are again too conservative for current technology and, thus, their industrial application is limited. Many studies demonstrate that machining in good conditions is still possible over these threshold values.

If a company aims to be competitive in the global market, and the actual context demands it, all the details must be optimized to maximum. Therefore, new methods of tool control are required. In the last years several methodologies have been proposed for the monitoring of cutting tools using indirect measurements [5]. Some of them are based on measurement of cutting forces during machining, others are based on acoustics or vibration signal measuring, and others in the measurement of power consumption or electrical current. However, direct optical systems are the most reliable, in spite of their high cost, as indicated in references [6-7]. Nevertheless, continuous progress has taken place in sensors technology and, in particular, vision sensors have been specially improved in performance but also in cost reduction [6-7]. For this reason, different researchers have used them for on-line tool wear measurement. In addition, advances in image processing and artificial intelligence technology provide more reliable image analyses and tool replacement strategies. The high number of applications referenced in the state of the art demonstrates that computer vision systems are already a mature technology. In spite of the many efforts focused on this issue, the quest for a satisfactory on-line monitoring solution has not yet reached an end because of the great difficulties involved in wear measurement.

In this research we have adopted the approach of developing a methodology based on artificial vision and classification techniques for the control of the cutting tool at real time. In reference [8] a detailed description of the algorithms and the results obtained with them can be found.

In this paper we show a description of two interfaces for interaction with the operator and the analyst. In the case of the operator interface algorithms are executed automatically, without the need for operator to have specific or technical knowledge in the scope of image acquisition and processing, descriptors or classification techniques. Results of monitoring are shown to operator through a very simply and interpretable interface, independently of his/her experience. In the case of analyst interface the context is quite different. The analyst is a person with a very good theoretical and technical formation and a great capacity for analysis and discernment. The initial requirements for both interfaces are, therefore, different. In the following, these initial requirements are described.

Interface requirements

Therefore, two different interfaces have been developed taking into account the end user of the application: operator interface and analyst interface.

Operator interface: the end user is the machinist that controls the machine tool. In this context the function of the interface is operative. The main purpose of the interface is to provide the operator with measurements of tool wear at real time. Based on the results produced by the developed algorithms, the operator is able to make a decision about the need for tool replacement. It is also possible that the control of the machine decides automatically to change the tool without consulting the operator.

Keeping in mind the context of use for this interface, their requirements should be:

a) Simplicity. The environment should be of easy handling. The environment will be used by machining operators who do not have good knowledges in analytical techniques.
b) Clarity. It is necessary to keep in mind that the interface is designed to be used for people with great experience in machining but also for inexperienced people.

c) Fast. The system should allow measurements at real time with a quick drawn of conclusions, with the aim of making good decisions in the smallest time.
d) Expandable. The interface should be flexible and adaptable to new wear criteria, considering the continuous evolution in tool and part materials and the different behavior to wear.
e) Integrated. The system should be integrated in the control of the machine tool without difficulty. The interface should be integrated in modern controls based on the Windows OS.

Analyst interface: in this case the end user is an analyst. The function of the interface will be now to facilitate the analysis of different wear criteria to be adopted for different combinations of tool material, cutting tool and operation. In this case the interface is not operative. The interface will not operate at real time with the machine control, since it will be used off line. In this context, the requirements of the interface should be:

a) Complete. The aim is to provide the higher amount of information to carry out the analysis and to make optimal decisions. It should consider the available geometrical descriptors and statistical moments to select the most appropriated.
b) Graphical clarity. Taking into account the complexity and amount of information in the analysis activity, the interface should be as clear as possible to facilitate the understanding of results.
c) Fast. Since calculations required for processing of wear images, their segmentation and classification based on the selected descriptors can be time consuming, a main requirement is that algorithms should be time-running optimized.
d) Precise. Precision should be of special emphasis, since the results coming from this interface will have a direct application in the operator interface. The decisions made here will have direct effect in the level of tool life optimization in the industrial practice.
e) Expandable. Given the continuous evolution in the image processing and patterns classification techniques, the interface should be designed so that future develpopments can be incorporated.

Considering these requirements, we have developed both interfaces. Fig. 1 shows the application access window.

Interfaces description

Operator interface. The operator interface has been developed using only the indispensable information for a correct tool monitoring, avoiding any other data that do not contribute to understanding. Considering the requirement of clarity, two approaches have been considered: 1) tool monitoring at real time and 2) analysis of wear evolution for a cutting edge.

Figure 1. Main access window.

1) In the first case, the interface allows the operator to take an image of the insert flank for measurement of its wear. Since the number of images taken along the time will be high, mechanisms have been added so that saving of images is done automatically. The image file name and folder for saving them are representative of the current operation. The image name will be composed by the name of the operation together

with the date and hour in which it was taken. To increase the flexibility of the system, it is possible also to particularize the names of folders and files with customed values.

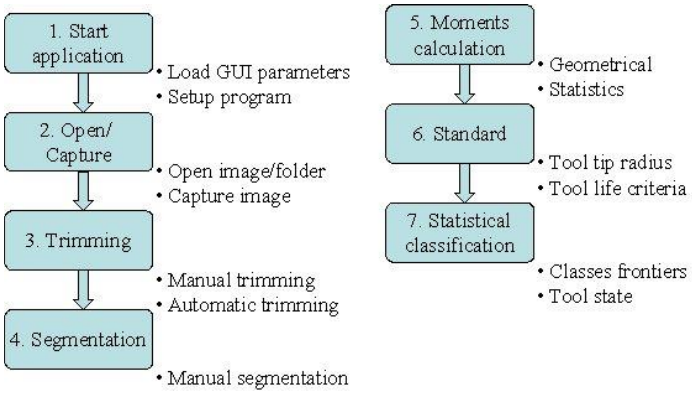

Figure 2. Steps in the interface

To carry out the wear analysis and to draw the tool condition, a set of algorithms have been developed and are executed for the interface. In particular, it is necessary a preprocessing of image and the analysis of descriptors associated with it for its representation in a wear map. Fig. 2 shows these steps.

It is necessary to highlight the following aspects. In the step 2 (open/capture) it is possible to take an image at real time or open a previously saved image for its analysis. With regard to step 3 (trimming), the image is automatically trimmed to include only the worn area. The objective is double, on the one hand it permits to increase the level of detail in the area of interest and, on the other hand, it makes possible to carry out calculations over a more reduced image area, reducing the computational effort. Also, a manual trimming is possible by mean of specification of opposite corners coordinates of the trimming frame. Fig. 3 shows a detail of this trimming step.

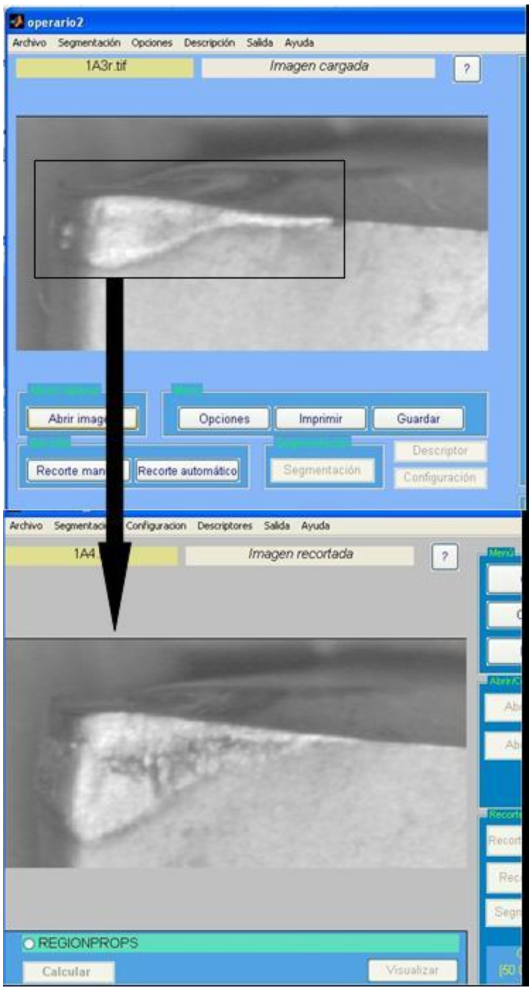

Figure 3. Automatic trimming of the region of interest.

With the image trimmed, thresholding and segmentation is done. Then, statistical moments and geometrical descriptors are applied. Fig. 4 shows the result of binary and gray scale segmentation. Details about the algorithms developed for these activities can be consulted in reference [8]. The analysis stage, that is explained in the next section, will determine the descriptor that better predicts the tool wear for the combination of material / tool / operation used. In this way, the selected descriptor will be hidden for the operator and used automatically. So, the operator will only consider the results from the tool wear calculation.

A classification procedure is carried out with the results obtained after application of selected descriptor. The output from this step is the assignment of the actual image to one of the following classes: low wear, medium wear (working zone) and high wear (tool insert is no longer useful). The condition of the insert is graphically represented by means of a class diagram. This diagram represents the frontiers that separate each one of the three wear classes, so that the operator can estimate the tool condition visually and its proximity to the classes transition frontiers.

Therefore, the operator interface needs information which come from wear maps developed previoulsy in the analyst interface. These wear maps are generated making machining tests for different combinations of part materials and tools and applying different descriptors and classification techniques to the images acquired. The analyst interface, which is explanied in the next section, allows the analysis of descriptors for its implementation in the operator interface.

Another function included in the operator interface is the measurement over the insert image of the parameters provided by the ISO36385 standard. In particular, the values of maximum and average wear in the three areas indicated by the standard (A, B and C) are measured automatically. The results are showed graphically and numerically, so that the operator can interpret them easily. The application reports the tool condition using the calculated measurements and based on a previous choice of a wear criteria (Fig. 5). Also, a Excel sheet is generated that includes these measurements and other additional.

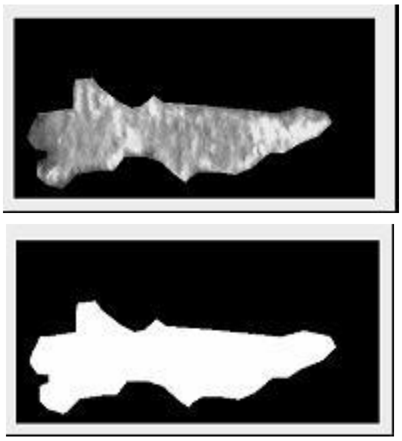

Figure 4. Segmentation results

2) For the study of the tool edge wear evolution, we have implemented a function to represent the position of the tool insert condition in the wear map as long as the tool degrades, holding on the points corresponding to previous states.

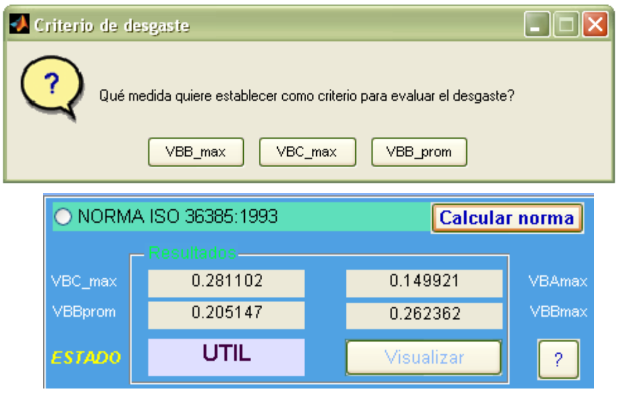

Figure 5. Functionality to compare with ISO criteria.

Analyst Interface. Fig. 6 shows the main window for the analyst interface. Its function is to analyze the descriptors that best adapt to each material / tool / operation combination, using classifying algorithms and generating the class graph or wear map that will be used later on in the operator interface.

The main differences with respect to operator interface are the following:

a) Trimming, thresholding and segmentation operations are developed automatically for all the images saved in a folder. These images come from previous tests carried out for each material/tool. In our tests we have used around 1200 images, so that the study is statistically fundamented.

b) It allows the analyst to do the classification process based on diverse descriptors: a) geometric (area, mayor and minor axis lengths, eccentricity, orientation, convex area, equivalent diameter, solidity and extension) and b) based on statistical moments (the first 18 moments of Zernike were obtained (until order 4), 9 of Legendre, the 7 moments of Hu, 8 moments of Taubin and the 6 of Flusser and Suck). We have chosen these descriptors by their efficiency for description and recognition of diverse patrons.

Fig. 7 shows the graphs generated with the process of classification for each material/tool combination and for a particular descriptor. The graph at the top of the interface indicates the classes and their frontiers. The position of all the worn inserts used for the classification are represented over this graph. The graph at the bottom shows the probability of belonging to each class. Observe that probability reduces until 75% as we come closer to the frontiers among classes. In reference [9] more information can be found relative to these diagrams.

Lastly, it is important to mention that specific help windows have been developed for the operator and analyst interfaces, as shown in Fig. 8.

Figure 6. Main window for the analyst.

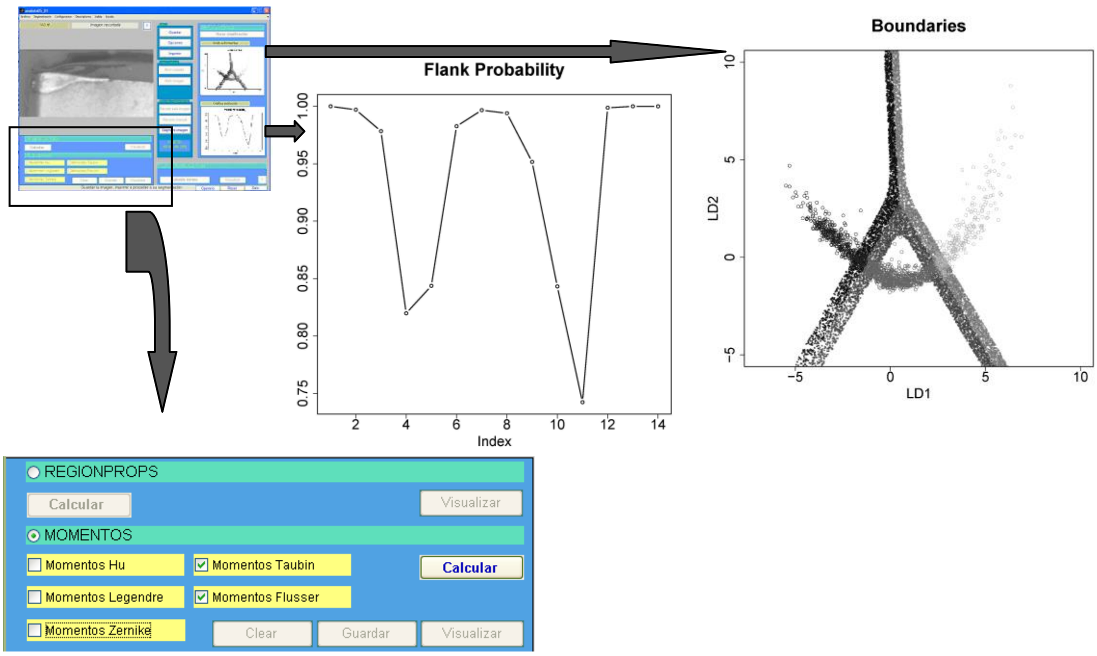

Figure 7. Classes and frontiers graphics.

Results

Two interfaces have been developed for monitoring of cutting tools. In the case of the analyst interface a graphical environment has been developed that helps machinist to carry out the acquisition, processing and classification of images, and also the recognition of patterns based on geometrical and statistical moments descriptors. We have developed specific algorithms that have been applied to 1400 images files. These images have been acquired from tests done over two carbon steels (F1252 and F1430) machined in a CN lathe with carbide tool inserts.

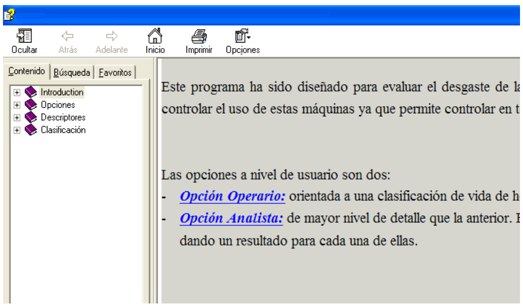

Figure 8. Help window.

This interface allows us to compare the results using the ISO 36385 standard with those obtained using geometrical descriptors and those based on statistical moments, with the following results:

- The analysis with region descriptors determines that 7% of results fix the tool change point at the same moment as determines the ISO standard. Using the statistical moments of Flusser this percentage reduces to 5,88%.
- In accordance with the used descriptors, changing of the cutting egde has not been necessary before the time indicated by the standard.
- In both cases more than 90% of the analyzed data suggest a tool change point over the one established by the standard. That is, the approach used allows us to use the tool during more time. This means that the adopted method is better than the one indicated by the standard.

An operator interface has been developed that allows us to monitoring the tool edge at real time. The interface visualizes quantitatively and graphically the tool insert wear level and its evolution. Based on these results the control of the machine can carry out the tool change automatically at the right moment or, alternatively, indicate it to the operator. This interface has been configured using the results and wear maps obtained with the analyst interface for the tested steels. The interface is open and flexible, since calculation parameters can be adapted for other combinations of tool/material/operation.

Conclusions

The search of newer techniques to determine tool wear is essential for a best use of cutting tools. The definition of auxiliar criteria to determine the tool life and to establish their comparison with criteria defined in the ISO standard and other criteria used in the industrial practice, increases the reliability and the economy by means of the optimization of tool replacement point.

The wear levels settled down by means of artificial vision techniques together with classification techniques using region descriptors and statistical moments descriptors can be used as approach to estimate the tool replacement point. The results obtained using both types of descriptors allow us to assure that tool life is optimized with regard to the most conservative current approaches. It is observed that the margin of security established by the standard is high and not take advantage of optimized tool life, since tool is useful during more time than the one advised.

The developed operator interface allows us to predict the tool life and to visualize the progression of the tool edge wear at real time.

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