'95 KACC (1995. 10. 23 ~ 25)

# AUTOMATED MEASUREMENT OF TOOL WEAR USING AN IMAGE PROCESSING SYSTEM

°Nobushige SAWAI*, Joonyeob SONG** and Hwayoung PARK**

* Mechanical Engineering Laboratory, 1-2 Namiki, Tsukuba, Japan
Tel: +81-298-58-7234 ; Fax: +81-298-58-7201 ; E-mail: sawai@mel.go.jp

**Korea Institute of Machinery and Metals, 66 Sangnam-dong. Changwon, Korea
Tel: +82-551-80-3453 ; Fax: +82-551-80-3333

This paper presents a method for measuring tool wear parameters based on two dimensional image information. The tool wear images were obtained from an ITV camera with magnifying and lighting devices, and were analyzed using image processing techniques such as thresholding, noise filtering and boundary tracing. Thresholding was used to transform the captured gray scale image into a binary image for rapid sequential image processing. The threshold level was determined using a novel technique in which the brightness histograms of two concentric windows containing the tool wear image were compared. The use of noise filtering and boundary tracing to reduce the measuring errors was explored. Performance tests of the measurement precision and processing speed revealed that the direct method was highly effective in intermittent tool wear monitoring.

Keywords: flank wear, image processing, ITV camera, thresholding, tool wear monitoring

## 1. INTRODUCTION

A common type of sensor is the indirect sensor, which is used to measure tool wear indirectly through an index such as cutting force, acoustic emission, vibration or the surface roughness of machined parts [1,2]. Dynamic postprocessing of the index readings is required to extract needed information on the tool state. A common defect of this approach is the difficulty of isolating the effects of tool wear on the indices from disturbance phenomena and factors correlated with tool wear. Moreover, indirect methods are highly non-portable, in that extensive work is necessary to adapt them for different sensors and cutting processes.

Another type of sensor is the direct sensor, from whose output a human operator can discern the tool wear without intermediate postprocessing. These include radio-active tracers, as well as cameras and other optical sensors. The radio-active method is still in the research stage, and it requires complex tool preparations which limit its cost effectiveness in industrial applications. On the other hand, commercial availability and recent advances in image processing technologies have made the ITV camera a more attractive option in advanced automation. The ITV camera has attracted considerable attention, and it promises to have a major impact in the field of tool wear monitoring, despite the fact that it can be used only intermittently, when the tool is disengaged from workpiece. This paper presents a method for measuring tool wear parameters based on two dimensional ITV image information. Our system obtains tool wear images from an ITV camera, and analyzes them on an image processor in a three-step approach. The output of this analysis is a set of five parameters which reflect the degree of tool wear based on boundaries extracted from the processed image.

Our research gave special consideration to controlled illumination of the tool's cutting edge, without which it would have been impossible to preserve the contrast in the image between the wear-land, the unworn area, and the surrounding background. Another important focus was assessment of the system's speed and precision, which are major determinants in the system's potential suitability for industrial applications.

## 2. DESIGN OF THE WEAR MEASUREMENT SYSTEM

Fig.1 shows a schematic diagram of the wear measurement system. The cutting tool is located under the holding fixture of a trinocular type microscope, which is adjusted to a magnification ratio of ten. A two-branch fiber optic illuminator concentrates the light of a high-powered halogen source on the flank face of the cutting tool.

We used a five-step brightness controller with neutral density filters to produce a convergent light bundle for homogeneous illumination.

A general purpose ITV camera is mounted on the microscope with a standard C-mount and TV adapter. The ITV camera receives the wear image focused on the 2/3 inch vidicon tube, and produces a RS-130/170 analog signal proportional to the input brightness pattern. The ITV camera has a resolution of approximately 650X600 pixels, and an automatic light compensation of 10,000 :1.

The image buffer receives the video signal using dual stage phase synchronization to assure continuity and consistency in the image, and digitizes it at a rate of 30 frames per second with a flash A/D converter. The image processor is equipped with frame memory which is used to store the digitized images with the resolution of 500X500 pixels, with 8 bits per pixel and a range of 256 gray levels. It also supports panning and scrolling on a pixel-by-pixel basis, and zooming on any portion of the image.

The personal computer(IBM PC/AT) implements the flank image analysis by sending commands to the image processor through a shared memory interface. The commands supported by the interface include input channel selection, setting of gain and offset values for image quantization, timing the image analyzer, frame grabbing, and frame I/O via random memory access of individual pixels. A data tablet on the personal computer offers the operator full interface support, including windows, graphics routines and process menus.

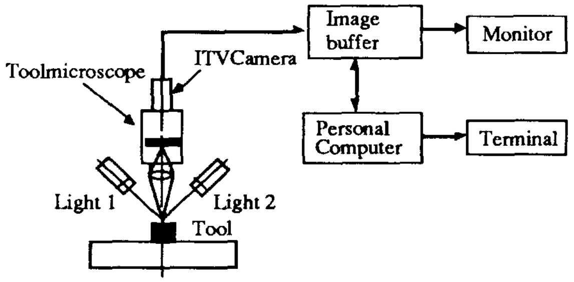


Fig.1 Tool Wear Measurement System

The RGB color monitor uses a three channel D/A converter and programmable look-up tables(LUT) to display the result of each image processing step. This sets it apart from X-Y plotters and other devices which output the wear patterns and parameters in predetermined formats.

## 3. IMAGE PROCESSING SOFTWARE

The image analysis algorithm was implemented in Microsoft C with the help of the ITEX100 image processing laboratory [reference!]. The ITEX100 library, which is commercially available, contains the basic operations needed for image processing applications, including video control commands, look-up table handling, graphics routines and the I/O functions needed to save and retrieve images.

The flank face wear image was analyzed through the image processing steps such as thresholding, noise filtering, boundary extraction and wear parameter estimation. The algorithms for image processing were specially designed to compensate for noise, and to adapt themselves to changes in the cutting process environment.

Thresholding is a technique for converting an input image into high-contrast output in two levels, black and white. It is particularly useful for extracting the boundaries between an object and its background when the gray levels of the two are very close.

To implement thresholding, we compare the gray level of each input pixel with a predetermined threshold value. If the gray level exceeds the threshold value, the output level is white; otherwise, it is black. This algorithm is automated in the following manner, as shown in Fig.2:

1) Define a window A containing the pixels of the flank wear-land, and determine its brightness histogram.

2) Define a window B containing window A and the unworn flank areas, and determine its brightness histogram.

3) Compare the histograms of windows A and B. Above some threshold value T, the B histogram will be identical to the A histogram in the number of pixels, while in the lower ranges the B histogram values will be greater. This is because the unworn flank area and background contained in window B are generally darker than the flank wear-land area contained in both windows. We select this value T as the threshold for boundary extraction.

4) Transform the gray scale image f(i,j) into a binary image g(i,j) as follows:

$$g(i,j) = 1, \text{ if } f(i,j) > T$$
$$0, \text{ if } g(i,j) < T$$

where T=threshold value

f(i,j)=pixel value of input image

g(i,j)=pixel value of output image

$0 < i < x$ (x=horizontal window size)

$0 < j < y$ (y=vertical window size)

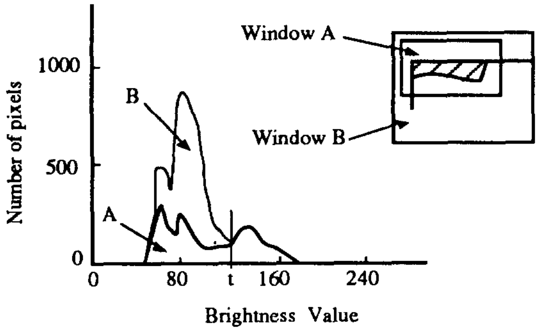


Fig.2 Automatic Determination for Threshold Value

Two-dimensional noise filtering is used to reduce irregularities in an image resulting from noise in the vicinity of a boundary. We use morphological noise filtering to compensate for undesired light reflections on the flank face and/or distortion originating from the image processor itself.

The noise filtering algorithm carried out as follows:

1) Perform the "erosion" operation. Define a pixel set encompassing the pixels to be filtered plus a 1-pixel perimeter. For each pixel in this set, define a 5-pixel neighborhood consisting of the pixel and its neighbors to the east, west, north and south. Assign a new binary gray level to the pixel by applying the logical AND operation to all of the pixels in this neighborhood. Thus, only a white pixel completely surrounded by white remains white.

2) Perform the "dilation" operation. For each pixel in the pixel set of step 1, apply the logical OR operation to all of the pixels in the 5-pixel neighborhood. This process restores the dimensions of the original boundaries without the local irregularities that were eliminated in step 1.

The perimeter of the input pixel set can be widened to eliminate noise over a larger region of the image. However, enlargement of the pixel set may introduce subtle distortions in the object boundaries, since the filtering effect is sensitive to the size of the pixel set.

Boundary tracing is the final step in processing the tool wear image. It consists of removing the black points within the wear-land remaining after the morphological noise filtering, dividing the image into unworn area, background (black region) and wear-land (white region), and estimating the wear parameters.

As illustrated in Fig.3, this step uses the following algorithms which locates a pixel called initial point, and traces the outer boundary of the largest connected set of pixels having the same value as initial point.

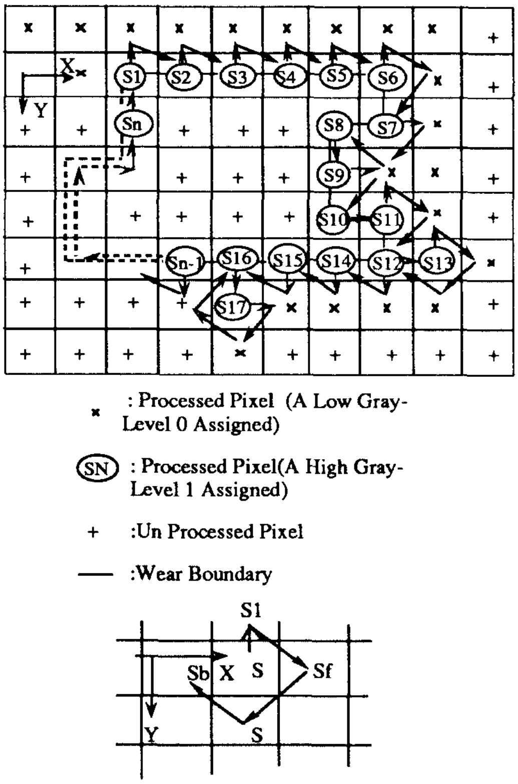


Fig.3 Boundary Tracing Method

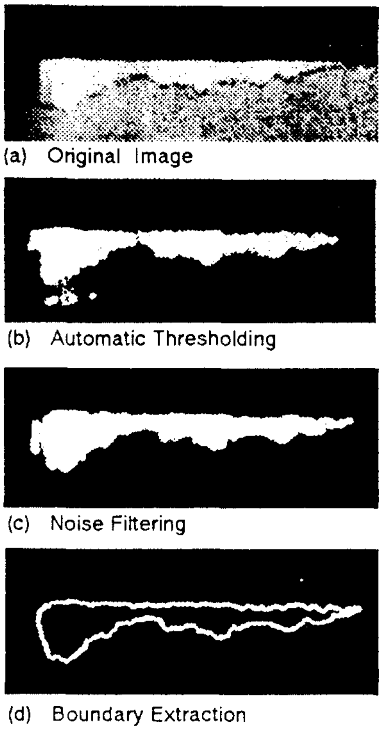


Fig.4 Processing Steps of Tool Wear Measurenmet

1) Determine an initial pixel set, consisting of black pixels in the binary wear image whose southern neighbors are white. These are the points where the gray level transitions from zero to one during downward line scanning. This set is the starting point for determining the boundary between wear-land and background, which can be extracted with more ease and precision than can the wear-land/unworn tool area boundary.
2) Trace the boundaries. Begin by selecting an arbitrary "initial point" from the initial pixel set, from which to begin tracing. Use the following rule to identify a direction of travel (i.e., a "next" pixel) such that no element outside the boundary will have the same binary value as the elements on the boundary: Look at the element to the west of the current pixel ; if this element has the same value as the current pixel, make it current. Otherwise, try the other neighboring points in the following order; south, east, north. Repeat this procedure until the search terminates at the initial point. Subtract the extracted boundary points from the initial pixel set.
3) Repeatedly apply step 2 to the residual initial pixel set until there are no pixels remaining in the set.

## 4. EXPERIMENTAL RESULTS AND ANALYSIS

A series of tool life tests were carried out under cutting conditions which were chosen for progressive generation of tool wear on the flank.The factors that affect the results of the tool life tests were under reasonable and practical control. The tools used had coated carbide edges with a groove-type chip breaker (Material:P20, shape : CNMG120408).

Fig.4 (a,b) shows the flank wear image in the ITV camera window, and the binary wear image which was thresholded on the basis of histogram analysis. The wear-land and unworn flank areas of the image contain a significant amount of noise, which was caused by factors such as irregular illumination, the remnants of built-up edge, and errors in the system itself. Fig.4 (c, d) shows the results of noise filtering and extraction of the wear-land boundary via the morphological filtering and boundary tracing operations. We note that even the particles adhering to the flank under the wear-land had little effect on the wear-land width, since all of the particles which were at the least one pixel removed from the wear-land could be eliminated by the system.

To investigate the effects of illumination direction on the wear image, we used two fiber optic illuminators to emit light on the flank face from four directions: 0, 45, 90, 135 degrees from the direction of the flank wear-land width (y-axis), inclined at a 60 degree angle with respect to flank face (Fig.5). When the angle of illumination was 90 degrees relative to the y-axis, the emitted light was properly reflected from the flank face and so the wear image that most clearly distinguished the wear-land from unworn flank could be captured. This phenomenon is due to the fact that because the flank wear is caused mainly by the friction between the workpiece surface and the contact area on the flank face, the unevenness of flank wear face falls mainly in the resultant cutting direction, which nearly coincides with y-axis for most turning processes, as shown in Fig.6.

Average wear-land width (VB) was measured when the light source was adjusted to each of 5 brightness levels, namely 100, 50, 25, 12.5, 6.3% of the level of the original light source (47000 LUX, at a distance of 100mm). As shown in Fig.7, the variation in VB did not exceed ±00.1mm. The lack of variation shows that the light intensity reflected on the flank face has a negligible impact on the wear parameters. This robustness is attributable to the manner in which the algorithms adapt automatically to the brightness of the wear image.

Fig.8 compares the outcomes of wear analysis using our system and traditional microscope measurement. This comparison reveals that the error in maximum wear-land width (VBmax) did not exceed 0.02mm.

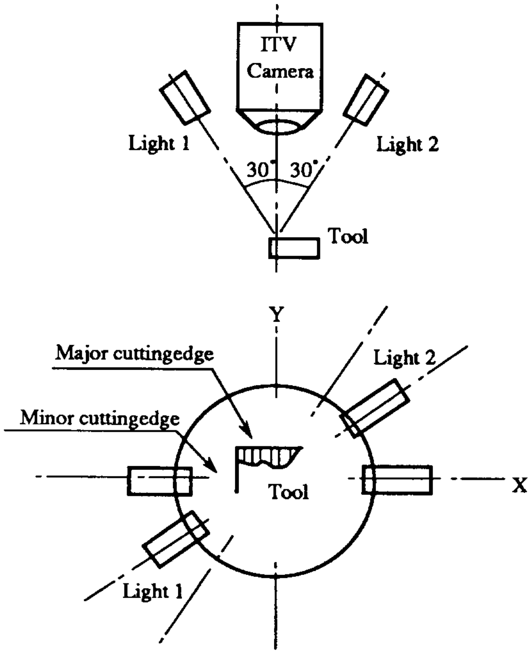


Fig.5 Illumination System

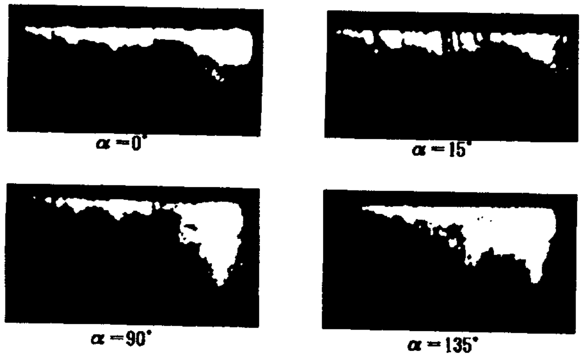


Fig.6 Four Illumination Direction (a)

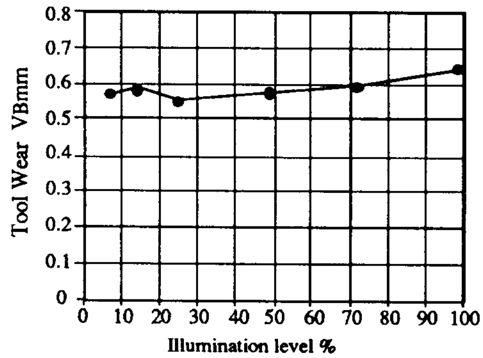


Fig.7 Measurement Error

For purposes of industrial application, the necessary wear parameters for tool monitoring must be computed as quickly as possible. The processing time from image acquisition to wear parameter estimation was about 5 seconds. We can reduce this time considerably by computing only VB and VBmax, or by determining the threshold level only for uniformly distributed illumination. Experimental analysis showed that the latter approach is effective for most wear images, without too much loss of measurement precision.

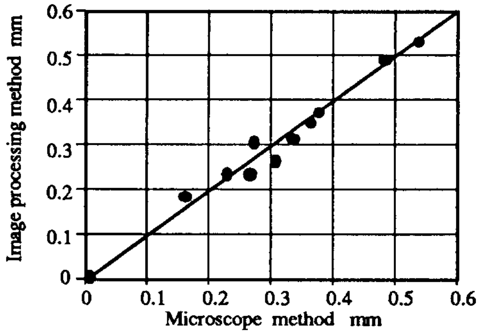


Fig.8 Comparison between Microscope and Processing Method

## 5. CONCLUSION

In this paper, we have explored the use of ITV sensing and image processing techniques for effective tool monitoring. We developed a system that acquires a flank face image with an ITV camera, processes the image to distinguish the wear-land from the unworn area and background, and estimates the tool wear parameters. Experimental testing for robustness and performance revealed the following:

1) The system is capable of analyzing 1 frame of flank wear image every 5 seconds, and of estimating the wear parameters to a precision of 0.02mm. Moreover, it consistently extracts wear patterns which are not discernible by traditional microscope methods.

2) The image processing algorithms which are the nucleus of the system were satisfactory in their ability to accommodate noise effects such as irregular illumination and particles adhering to the flank face, making the system robust enough to withstand a real cutting environment. In particular, the light intensity which is reflected on the flank face had a negligible effect on the values of measured wear parameters. This robustness is attributable to the manner in which the algorithms adapt automatically to the brightness of the wear image.

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