COMPUTER AIDED MODEL DEVELOPMENT FOR AUTOMATIC TOOL WEAR DETECTION IN MACHINING OPERATIONS

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ABSTRACT
A computer image processing system was used to analyze the image of tools wear. The images of tools were used as a case study. The cutting tools with the different shapes (High Speed Steel cutting tool and Parting-off tool) were taken with the use of a digital camera. The pre-processing operations on the images (taken on photographic cards) included scanning, in order to transfer onto a computer and convert them to digital images. Thresholding and segmentation were done in order to convert the altered background of the scanned images to a pure white background; the images were enhanced by flood filling. For the purpose of detecting the edges of the images after segmentation, the images were read and then saved as Portable Pixel Map (PPM). The edges of the images were then detected using an algorithm developed in FORTAN based on the principle of edge detection algorithm. The functions relationship above is expressed mathematically and the particular image whose edge was to be detected after being saved as Portable Pixel Map (PPM) was read and processed through the use of edge detection oracle j model developed using JAVA language default package.

Keywords: *Computer Aided, Model, Tool Wear, and Machining*

INTRODUCTION

Machining operations have been age-long, witnessing development from one state to another as a result of technological development. The development over the ages has been closely related to finishing, it is not just enough to finish a product, but finishing to specification is very important.

An important problem in the area of manufacturing or machining is to continually monitor metal -removal processes and detect changes whenever, and as soon as they occur. Tool wear monitoring is a critical operation in manufacturing, as it is directly related to production efficiency and quality of the finished product. Most tool wear monitoring systems involve sophisticated sensors, which make them cost-inefficient and virtually unavailable for real applications.

Human operators can assess tool wear by simply inspecting the machine surface. Thus, the ultimate objective of automatic tool wear monitoring is not simply to out perform the ability of the operator's in recognizing, but to go a step further and detect wear quickly enough to take preventive action.

Image analysis and machine vision can offer a lasting solution to problems encountered in sorting and detecting of wears in tools using sensor technology and system automation. The challenges are greatest in a developing country like ours (Nigeria) where most machining operators are not up to date in terms of technology, so emphasis should be made for better research and approach to systems automation using image analysis and machine vision for future purposes.

Interestingly, sensor technology has been in rapid use over the years but it has not been fully utilized in the machining industries especially in the developing countries. One of the reasons is that quality images are required for effective functioning of sensing systems. In the past few decades, images were extracted from photographs and the use of scanners to transfer the photo image into computer, which makes it easy for processing. Recently digital photograph takes this process one step further by passing the need to develop film, make print and scan the print into the computer.

Therefore, the specific objectives of this research are to:

- develop a computer model for automatic tool wear detection using image analysis.
- test the computer programme and compare its result with theoretical original image, and
- establish tool wear rate in determining the life of the cutting tool.

Computer Aided Manufacturing

Computer Aided Manufacturing (CAM) is a term that was coined to highlight the use of computers in the manufacturing process (Da Miliner and Vasilium, 1987, Chao-Hwa *et al.,* 1989; Adejuyigbe, 2002). There are literally thousand of uses for special purpose computers in the manufacturing environment. The use of this technology has led to the increase in the level of output of most industries. And there are programmed task that should be perform to a specific precision, large jobs accurately done and fast which cannot be attain by human operator. A model can be programmed to achieve this.

Modeling

Modeling is a representation of an object process or simulation. It is an abstraction of reality (Chao-Hwa *et al.*, 1989; Adejuyigbe, 2002; Da Miliner and Vasilium, 1987). A similar technical model is that of metal cutting. The metal removal model represents the forces on a cutting tool while cutting particular material. This model can be used to predict the quantity of heat delivered to the work pieces, the energy required for cutting the resulting surface finish and the risk of the tool breaking. A physical model of assembly relates the physical variables, size and shape of work piece, friction during assembly, stiffness of tools, and rippers and relative error between parts) to the performance variable, likelihood of assembly failure and forces exerted on the parts by tools and on each other.

The Basic Metal Cutting Operation

Although the variety of metal-cutting processes is very large, it is common to use the characteristics of surface layer of constant thickness, which is removed by the relative movement between a cutting tool and work piece. The cutting tool is characterized by two angles; the rake angle, the relief angle (or clearance angle). The relief angle provides clearance to prevent rubbing between the cutting tool tip and the machined surface: its value is dependent on the strength and wear resistance of the tool material and, to a lesser degree on the wood material (Adejuyigbe, 1997; Aderoba, 1991; Ulsov and Kamatey, 1989; Li-Ma and Nickerson, 1991).

The rake angle is very important in chip formation. The sum of the rake, relief, and wedge angles is equal to 90, the wedge angle is the included angle between the rake and flank surfaces of the cutting tool.

Chip Formation

Traditionally, three types of chips are common in machining process, they are classified with corresponding theories developed-Type 1, discontinuous or segmented chip formation; – Type 2, continuous chip formation; and – Type 3, chip formation with a built-up edge (BUE). Of these three, the second type, continuous chip formation, is the most commonly analyzed.

Tool failure can be due to:

- Excessive Temperatures
- Excessive Stress
- Gradual Wear on the Tool Flank Surface
- Gradual Wear on the Rake Surface

Retardation of Tool Wear

As noted earlier, tool wear is an unavoidable consequence of the metal-cutting operation. Hence, the retardation of tool wear is a subject that has received considerable attention. There are two primary methods by which the gradual or progressive wear of a cutting tool can be retarded; namely, the use of a cutting fluid and the use of a protective coating on the cutting tool itself. Tool wear can also be retarded by means of a protective coating on the cutting tool. For a given tool life, the coated tools provide an increased metal-removal rate because higher cutting speeds can be used. In a sense, the coated tools combine the advantages of titanium carbide based tools (Ulsoy and Kannatey, 1989; Trent, 1984).

RESEARCH METHODOLOGY

The main objective of an image processing system is to reduce a huge quantity of apparently random data into a few deciding features to represent the interesting information in a scene. These features could be irregularities in size, shape, color and surface configuration of various biological, chemical and physical materials that are classified as defects.

Although there is no common method which may be applied to all the fields enumerated above, but it can be done by the use of a combination of techniques based on mathematical morphology, region segmentation and edge detection; all combined in a clever manner. Image processing is basically classified into four major stages namely;

1. Image Acquisition
2. Image Pre-processing
3. Image Analysis
4. Image Interpretation

Image Acquisition

This involves the acquisition or capturing of an image to be fed into a computer. This can be done by many types of sensors, equipment or devices. The most popular ones include**;**

- TV cameras with a typical resolution (i.e. number of pixels displayed across and down on a display screen) of 512x512 on 8 bits in monochrome systems. Usually color cameras require 8 bits for each of the primary colors; red, green, and blue. Often, cameras with resolution of 1024 x 1024 or even higher with linear sensors are encountered.
- Medical scanners, which provide a series of 2-D images, called CT scans.
- Standard scanners and micro densitometers to acquire very large images
- Sensors found on satellite, which are usually very high quality cameras
- Scanning, transmission tunnel and electron microscope, fluoroscopic and ultrasonic devices**.**

The image sizes usually vary from 256–1024 on 8 bits and all images will be digitized on a square or hexagonal lattice. The grey level intensity will then vary from 0 (pure black) to 255 (true white) i.e. $256 = 2^8$ bits.

Image Pre-processing

This can be divided into two groups namely, the linear group and the non linear or increasing group. The first one includes all techniques based on image filtering and restoration i.e. low level techniques such as Fast Fourier transform (FFT). Convolution i.e. replacing the values of each pixel with the average of its nearby neighbors, and edge extraction based on local information.

The non-linear group includes techniques such as morphology and its generic function, the erosion. It is based on the structure and texture of objects and considers the inside part of the object rather than the transition between objects and background.

Image Analysis

This third image-processing step is the extraction of symbolic information quantifying a phenomenon. The symbols might be simple features such as measurements (number, direction, size, histogram etc) or more complex representations such as region graphs.

In general, the type of representation selected will depend on the level of knowledge required to interpret the image. Dividing the application of image analysis into two groups, it can be said that navigation and remote sensing images usually require very high level knowledge such as 3 -D maps and graphs while for medical, metallographic and quality control systems, a set of measurements usually suffices.

Digitization and Representation of Images

The digitizing of an image entails the representation of the image as dot of picture elements (pixels) on the computer screen. Since the arrangement of these dots of pixels is in matrix form, it becomes easy to extract whatever feature of interest from the image based on the principle of matrices processing. However, the resolution or brightness of an image depends on the size of the pixels. The normal size (length/ breadth) is usually about ¼ mm. The storage of pixels in computers is either in binary digits (bits), that is 0 and 1 or as a byte i.e. 8 bits, having a minimum of 0 representing black and a maximum of 255 representing white. Coloured image is a combination of three numbers (Red, Green and blue pigments in each color) used to represent the pixels' color. For instance, it is possible to have (0, 0.0) representing dark color and (255,255,255) for light color, while other colors are formed by a combination of Red, Green, Blue (RGB) components each being a number between 0 and 255.

Thresholding

This is a method used to extract a figure or a feature of a particular interest from within an image. The most apparent way of locating objects in grey scale images is by thresholding. A form of thresholding can equally be used to detect edges. In this case, the binary image is usually set to 1 for the set of pixels of interest and to 0 for all other pixels (background). The feature of interest from a coloured image can be threshold to a black and white image by selecting a grey value t, which represents the minimum grey scale, for the feature required.

The thresh operator returns the image with value 1 whenever the grey level of the image is greater than or equal to t. Whenever the grey level is less than that of t, the value 0 (background) is assigned. Therefore, the thresh operator can be expressed as:

$$\text{Thresh}\,(B_1, t)\,(i, j) = 1 \text{ if } B_1\,(i, j)\ ^{3}\ t$$
$$0 \text{ if } B_1\,(i, j) < t$$

Where

B_1 = feature of interest

t = reference grey scale

(i, j) = total pixel in row and column

Usually, the condition to threshold a particular feature is based on whether its grey scale is less than or greater than the reference grey scales. The reference grey scale can be retained or changed to another, while the value of the grey scale are changed to the same scale of 0 and 1 (black and white) for binary images. Thresh is defined generally for an image Z (i, j) within a grey scale $0 \leq t \leq 1$ having a total pixel of (i, j) and ti as the reference scale expressed as:

$$\text{Thresh}\,(z, t)\,(i, j) = t \text{ if } Z\ ^{3}\ (i, j)$$
$$* \text{ if } Z < (i, j)$$

However, the thresh operator can be modified and used to detect the edge images such that an edge map which produces only the object boundaries is obtained instead of thresholding the intensity of the image. In order to obtain the edge map at the transition points between two range of scales defining the edge of an object, the pixel number ($x \leq i$ and $y \leq j$) are returned rather than grey scale, while for the pixel numbers outside those ranges, no value is returned.

Image Interpretation

This involves comparing the results of pre-defined database to be able to identify, analyze and evaluate the elements. This interpretation may require very complex techniques such as artificial intelligence, neural network or fuzzy logic.

Alternatively, simple comparison of measurements to pre-defined limits may be sufficient. The use of numbers and information obtained from the previous stages makes it possible to interpret images. They prove very useful when one seeks to extract one or more objects from complex or changing environment, or even to describe an entire scene.

PROGRAMME DEVELOPMENT

In order to detect the edges of the images, a FORTRAN 90 program was developed based on the principle of image processing for edge detection using the boundary conditions developed from the 8 connectivity method. The image whose edge is to be detected having been saved as a bitmap image (bmp) is read and processed through the program and the coordinate points generated for the edges are then plotted using the graphical application Microsoft Excel.

It is important to note that the images were initially saved with JPEG extension since it occupies less space but the images were converted to bitmap images and the computer program written to suit the bmp format. The generated edges of the images can be displayed on the computer on a defined background while executing the program but the graphics or Borland C++ compilers were not readily available.

Several stages are involved in analyzing an image. The pictures of the original materials of the images were scanned with the aid of a scanning machine and saved onto the computer. The three pictures were taken in sets of 3 images. The procedure of edge detection was however repeated for each of the nine images being considered in this study and the edges obtained respectively. During the development of the computer program, certain conditions to ensure that there is no noise in and around the generated edges of the images were carefully considered (Lucas, 1980; Fang, 1992; Raji, 1999).

The following steps were taken during the program development;

The algorithm

STEP 1

Define the header file

STEP 2

Define the function main (int., num write, cols, rows, k, n, element, size, and pixel)

STEP 3

Get the image attribute (number of columns and rows of pixels)

Open the image file (input file) and the output file. Skip the header for the image

STEP 4

Read the pixels into an array
Use the 8-connectivity algorithm to detect an edge pixel
For (k = 1; k ≤ rows; k ++)
For (n = 1; n ≤ cols; n ++)
Pixel = (k – 1) * cols + n

STEP 5

Write the coordinates k, n of the pixels that satisfies any of the conditions into the output file.

RESULTS AND DISCUSSION

The use of the computer to analyze the image of tools wear involves several processes. There is need for image acquisition through the process of capturing the images. This can best be done using a digital camera because it maintains the features of the images with little 'noise' due to its variable resolution. Digital images are also easy to manipulate and requires less pre-processing and compared to the images taken with a photographic camera. An algorithm was developed in FORTRAN 90 using the principle of edge detection. Java language is used to develop the screen using the coding from FORTRAN 90 developed.

In this study, images of the tools used as case study, cutting tools with the following materials, (HSS cutting tool and Parting-off tool) were taken with the use of a photographic camera, before machining operation and after, hence the need for pre-processing.

Pre-processing

The pre-processing operations on the images (taken on photographic cards) include scanning in order to transfer onto a computer and convert them to digital images. Digital images are arrays of tiny dots or picture elements (PIXELS) representing the real objects. Each element is represented by a digit corresponding to the colour of that portion of the image.

Image Enhancement

Thresholding and Segmentation in order to convert the altered background of the scanned images to a pure white background; the images were enhanced by flood filling. Hence, all the images of interest appeared on a pure white background which is a similitude of thresholding or extracting a particular feature of interest from within an image. The images were thereafter segmented. Segmentation is a process in which each of the enhanced images is separated into different entities, these results in different images of the samples. Each of the segmented was then resaved so that it becomes easier to process each of them individually.

Edge Detection

For the purpose of detecting the edges of the three images after segmentation, the images were read and then saved as Portable Pixel Map (PPM ASCII). However, due to the large size or space occupied by each of the images on the UNIX workstation after conversion into portable pixel maps (PPM), each of the images was compressed before transferring them back to the PC. The edges of the images are then detected using an algorithm developed in FORTRAN based on the principle of edge detection algorithm developed. The function relationship for detecting the edge of each of the images is expressed mathematically below:

Table 1: Showing Material, Time and Speed of Machine

Tool Material	Time (hr)	Speed of machine (rev/	Working Piece
HSS	4hrs 30mins	95.00	Mild-steel
Part-off	4.00hrs	179.00	Bronze
HSS	4hrs 45 min	120.00	Stainless
HSS	10hrs 15mins	180.00	Mild-steel
HSS	6hrs 25mins	160.00	MCS

Source: Authors Results (2007)

x = k, y = n, if z (k – 1, n) ≥ t and z (k, n) < t
x = k – 1, y = n, if z (k – 1, n) < t and z (k, n) ≥ t
edge (z, t) (I, j) = skip if z (k – 1, n) ≥ t and z (k, n) ≥ t if z (k – 1, n) < t and z (k, n) < t
where t = boundary element grey scale
(k, n) = picture element row and column position in matrix [z] respectively.

For each of the images with a background grey scale t, an element (k – 1, n) is regarded as an edge element if its grey scale is greater than or equal to the reference grey scale while its neighboring grey scale (k, n) is less than the reference grey scale or vice versa. The grey scale (skip) is employed where both elements (k – 1, n) and (k, n) have their grey scales either greater than or equal to the reference grey scale or both have their grey scales less than the reference grey scale. Hence, no edge is shown on the monitor.

Having established the functional relationship above in the written program, the particular image whose edge is to be detected after being saved as portable pixel map (PPM) is read and processed through the program. Online graphic display could be incorporated into the program to display the edges of the images. Figures 2-9 shows the computer interface development. Alternatively post processing of the data for images could be done using any graphic application for report presentation (the method used in this study) while in automated system the results can be transferred electronically to a computer system which will send signals to the mechanical arm that will remove any wear tool in the production line. Edge detection oracle.j model is developed using java language default package <Application1-edgedetector><com.adeoye. project>"java.lang.string" encoding package (Encoding version "oracle.jdeveloper.model") is attached as appendix-5.

During the image analysis of the above Figures 9.1 to 9.4. The background obtained is in contrast to the plain white background on which the

Fig. 2: Showing Welcome Screen
Source: Developed by the Author (2007)

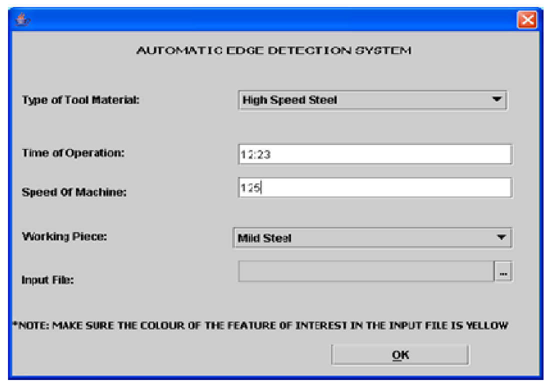

Fig. 3: Showing the Interface
Source: Developed by the Author (2007)

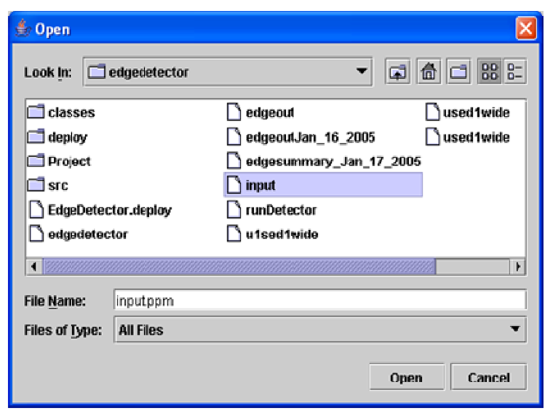

Fig. 4: Showing Edge detector Interface
Source: Developed by the Author (2007)

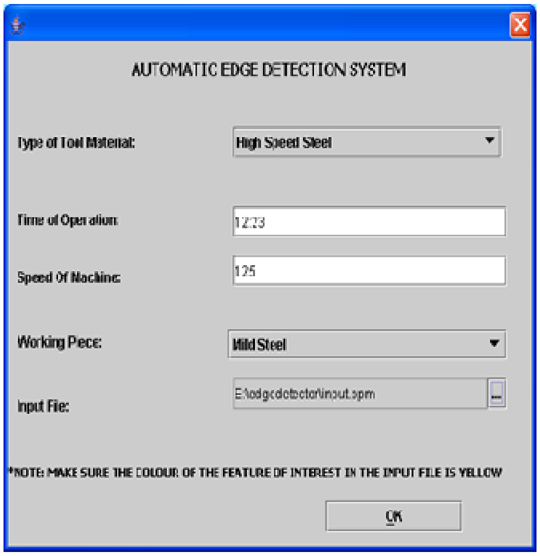

Fig.5:Showing Edge detector Input Interface
Source: Developed by the Author (2007)

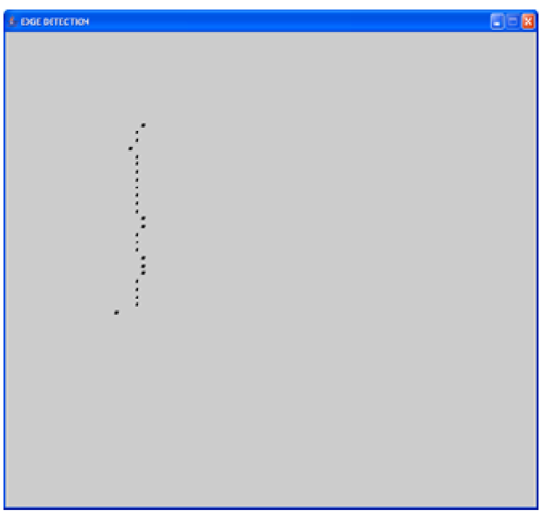

Fig.6: Showing Wear Detection
Source: Developed by the Author (2007)

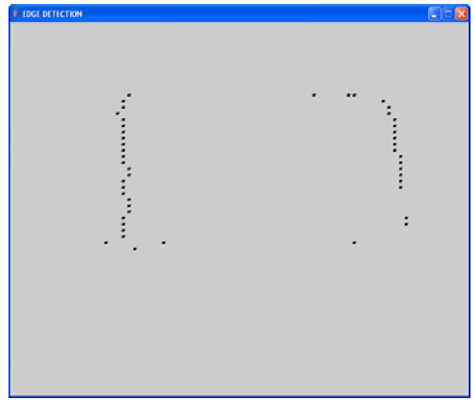

Fig. 7: Showing Wear Detection
Source: Developed by the Author (2007)

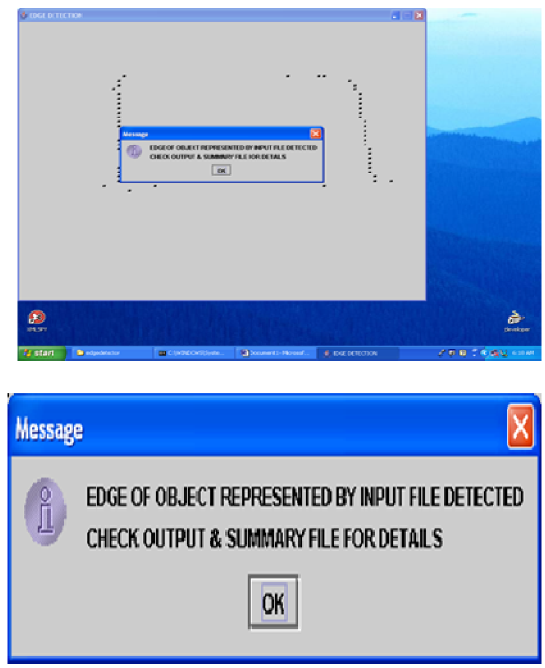

Fig. 8: Showing Wear Detection Output
Source: Developed by the Author (2007)

The following results were obtained from the image analysis and processing of the four images.

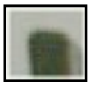

Fig. 9.1a

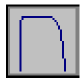

Fig. 9.1b

Fig. 9.1a and 9.1b represented the actual image analysis of the scanned image of the new parting-off tool.

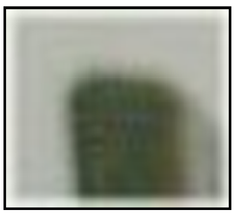

Fig. 9.1c

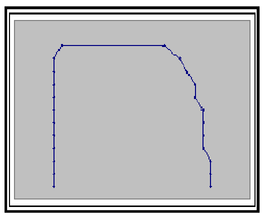

Fig. 9.1d

Fig. 9.1c and 9.1d represented the expanded image analysis of the scanned image of the new parting-off tool.

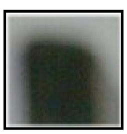

Fig. 9.2a

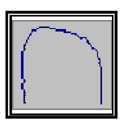

Fig. 9.2b

Fig. 9.2a and 9.2b represented the actual images analysis of the scanned images of the used parting-off tool.

Fig. 9.2c

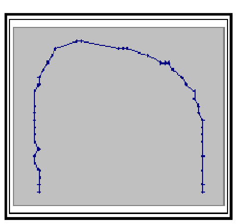

Fig. 9.2d

Fig. 9.2c and 9.2d represented the expanded images analysis of the scanned images of the used parting-off tool.

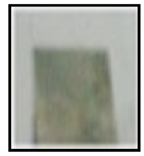

Fig. 9.3a

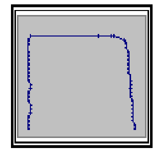

Fig. 9.3b

Fig. 9.3a and 9.3b represented actual image analysis of the scanned images of the new H.S.S Cutting tool.

Fig. 9.3c

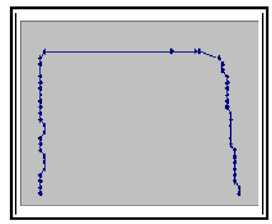

Fig. 9.3d

Fig. 9.3c and 9.3d represented expanded image analysis of the scanned images of the new

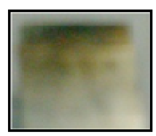

Fig. 9.4a

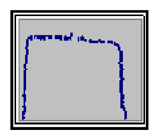

Fig. 9.4b

Fig. 9.4a and 9.4b represented actual images analysis for the scanned images of the used H.S.S Cutting tool.

Fig. 9.4c

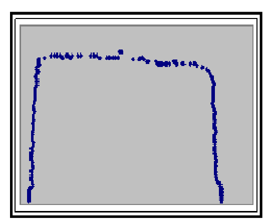

Fig. 9.4d

Fig. 9.4c and 9.4d represented expanded images analysis for the scanned images of the used H.S.S Cutting tool.

picture was taken initially. This is a photographic effect which resulted from the resolution of the camera used. A possible corrective measure of the background entails enhancement of the background by flood filling.

From the results obtained through image analysis, it shows the edges of the tool (whole and wear) with the associated noise. The noise was as a result of the enhancement of the images by flood filling due to wear. The effect of the noise is that it reduces the sharpness or brightness of the image. In order to remove the noise, a thinning algorithm which can be developed into a program can be written. However, the edges reflected the edges of the real image

CONCLUSIONS

From the results presented above it can be concluded that, despite the noises recorded on the edges of the images, all the edges are in conformity with the expected result. Therefore, the main objective of this study in automatically detecting tool wear has been achieved. The noise effect can be taken care of by the thinning algorithm which can be developed into a thinning program the algorithm could be used to develop an automatic tool wear detector or robotic arm control.

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