Tool Wear Monitoring using Image Processing Techniques

By

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NIRMA UNIVERSITY

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Tool Wear Monitoring using Image Processing Techniques

Major Project Report

Submitted in partial fulfilment of the requirements for semester-IV of

Master of Technology in Mechanical Engineering

(CAD / CAM)

By

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Undertaking for Originality of the Work

I, Kavan Patel, Roll No.18MMCC16, give undertaking that the Major Project entitled **"Tool Wear Monitoring using Image Processing Techniques"** submitted by me, towards the partial fulfilment of the requirements for the degree of Master of Technology in Mechanical Engineering (CAD/CAM Engineering) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that

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CERTIFICATE

This is to certify that the Major Project entitled "**Tool Wear Monitoring using Image Processing Techniques**" submitted by Mr. Kavan Patel (18MMCC16) towards the partial fulfilment of the requirements for the degree of Master of Technology in Mechanical Engineering (CAD/CAM Engineering) of Nirma University, Ahmedabad has the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Monitoring tool wear is very important in machining industry as it may result in loss of dimensional accuracy and quality of finished product. Generally there are two techniques follow in the industry to decide the finish of tool life and replace it. In one case, where the cost of a workpiece is higher than the tool is replaced prematurely before its useful life has finished. This saves the costly workpiece from getting damaged. In other cases, where the cost of the part is not worthy, the tool is used till the finish of the useful life. Once the tool reaches the finsh of tool life and part quality affected, the tool is changed and the workpiece is either replaced or rework is carried out. Generally, the industry utilizes past data to determine the useful life of the tool. There are two ways to know the tool wear: Direct and Indirect. Generally, tool wear is measured directly using an optical microscope which is an offline and time-consuming technique. In the indirect technique, the parameter that is affected by tool wear is measured. Many researchers have selected the parameter like the current, force, surface finish, temperature etc. and correlated it with tool wear and tool life.

After carryout literature review, it has been observed that image processing methods has a lot of scope measurement of tool wear. Digital image processing methods automate the task of measurement and monitoring of tool wear. This work is focused on implementing digital image processing methods to automate the task of two dimensional flank wear measurement.

Keywords: - Image processing, tool wear, global threshold algorithm

1 Introduction

1.1 Tool Wear and Tool Life

Tool wear sudden failure of cutting tools due to regular machining operation. One of the important criteria in machining is tool life. Tools which wear or otherwise fail slowly comparatively long service live, resulting in reduced production rate and surface finish capability. Tools that fail gradually as compared to sudden failure, have longer tool life. So to study tool life, study of different types of failure of tool is required to be carried out. Tool fails due to fracture, wear or plastic deformation. [1]. Tool wear is categorized based on place on the tool where wear is occurred or physical phenomenon by which it has occurred.

A primary goal of tool wear research has develop methods of predicting tool life from tool failure mechanisms. It has been observed that many researchers [1, 7, 13, 15, 20, 28, and 29] studied on developing the techniques by which tool life can be predicted. Predicting rate of tool wear is possible based on the past data or an experimentation, but it is difficult to correlate this information to tool life. This is because tool life is dependent on the part requirements. Tools are discarded when they no longer produce the part which are of acceptable requirements like surface roughness, dimensional accuracy, etc.

1.2 Types of Tool Wear

Tool wear classification region of the tool where affect by operation. Major tool wear occur on the relief and rack surfaces [1]. The wear which occur on the relief surface is called flank wear and wear that occurs on the rake surface is called crater wear.

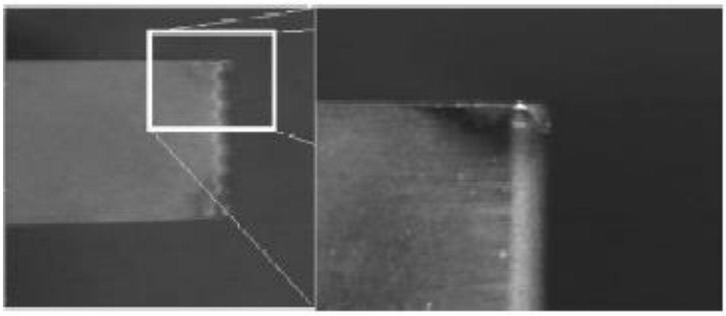

Fig. 1: Flank wear with approx. 100 µm [4]

Flank wear is a gradual wear which occur due to abrasion of cutting edge. As shown in Fig. 1. Progression of flank wear is most related with time as shown in Fig. 2. At the start of the wear, rounding of the cutting edge occurs, then it progresses gradually at a steady rate until it reaches the maximum width of the wear land. Tool is then discarded. The wear of flank is measured by the high value flank width, VB_{max} and an average width of flank, VB.

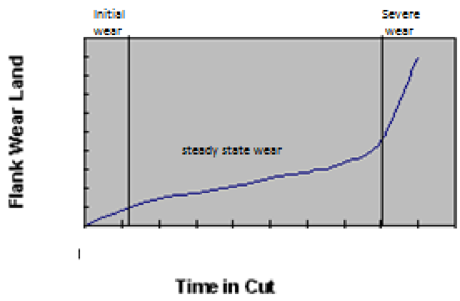

Fig. 2: Variation of flank wear with cutting time. [1]

Flank wear is often monitored by observing the tool wear directly, part quality or some physical parameter like change in cutting forces, temperature, vibration, etc. [3]. The first method is direct method but time consuming since the tool is required to be removed and checked under a microscope for wear measurement. The other method of checking the part quality or change in physical parameter is often studied by researchers or implemented in the industry. Flank wear can decrease by maximize the deformation material of tool and using of hard coatings top of the tool.

Another type of tool wear is crater wear developed on the tool rake surface. Some amount of crater wear does not decrease tool life but instead it increases rake angle and reduces the cutting forces. But high value of crater wear makes the tool fail and the tool may fail due to breakage or deformation. Crater wear is generally measured by crater depth KT.

Notch wear develop when tool used in rough turning and radius of nose wear produce on the corner of the tool. Other types of wear are usually thermal cracking, deformation of gross plastic, edge chip, chip hammering. Out of all these wear, flank wear and crater wear are most common wear and are usually studied to estimate the tool life [3]. Flank wear is a gradual wear, predictable and is often selected as optimization criteria for machining processes.

1.3 Summary

It is proposed to develop image processing techniques to measure flank wear. The rationale of considering flank wear as critical parameter is that, the wear is gradual and in research [3], it is generally taken as criteria to correlate tool life. Measurement of flank wear requires two dimensional image processing techniques. It is proposed to measure flank wear using image processing techniques and to compare the same with flank wear as measured using microscope.

2 Literature Review

The demand for high quality product at reduced cost is increasing. Due to advancement in hardware and computing techniques, image processing for automatic monitoring of tool condition is gaining importance. Damaged tool or dull tool can seriously effect part quality and productivity of machine. By appropriate tool condition monitoring techniques, tools can be used to their maximum level without affecting quality of the part.

2.1 Introduction

Image processing techniques are the set of mathematical operations performed on an image to enhance or obtain some useful information in an image. Image is treated as a two dimensional matrix of elements wherein each element represents intensity of a corresponding pixel in an image. There are many application areas of image processing like medical imaging, satellite images, automatic number plate identification, industrial process monitoring and quality monitoring system, etc. One of the application area is to monitor the tool wear using image processing techniques.

Tool wear used image processing is increasing with the helping in software and computer vision methods. In their research, Dutta *et al.* [3] introduced in paper, inclusive suggestion of various methods measurement of tool wear using digital image processing methods. Principally, two groups one of direct techniques and second of indirect techniques divided tool condition monitoring process. In one of direct techniques measured like wear of flank, depth of crater, and area of crater. Tool maker's microscope, scanning electron microscope or optical microscope, 3D surface profiler, and online methods using CCD or CMOS camera and vision systems all this methods include off line methods to monitor tool wear used direct method. In second of In-direct method measures signals like acoustic emission, force, temperature, finish of surface etc. to predict the angle of tool wear. TCM methods used texture of surface study of machined objects are depend on analysis of texture. Set of pixels is a connected primitive in texture, characterized by a set of attributes (coarseness and directionality). For example, in case of turned surface, a repetitive feed marks can be obtained as texture primitives. Methods like transforms of fast fourier can be used for analysis of texture and gain useful information about tool wear.

2.2 Generic Image Processing Methods

First step in image processing is image acquisition of wear region. In this process, CCD or CMOS camera is used and capture pictures of cutting tool or work object surface. CCD camera comprised capture of image which is matrix of generated absorbed signals to collect electricals charges. Two types of information are stored in an image matrix: One of size of matrix, which gives size of image and second value of each element of matrix which is intensity of a pixel in an image. CMOS camera has higher rate of capturing the image frames as compared to CCD camera. Analog form of a light source from a scene is converted to digital form by camera using technique of sampling and quantization [17]. As shown in Fig. 3, digitizing of coordinate value is related to sampling. Similarly sampling of intensity value is called quantization as shown in Fig. 4.

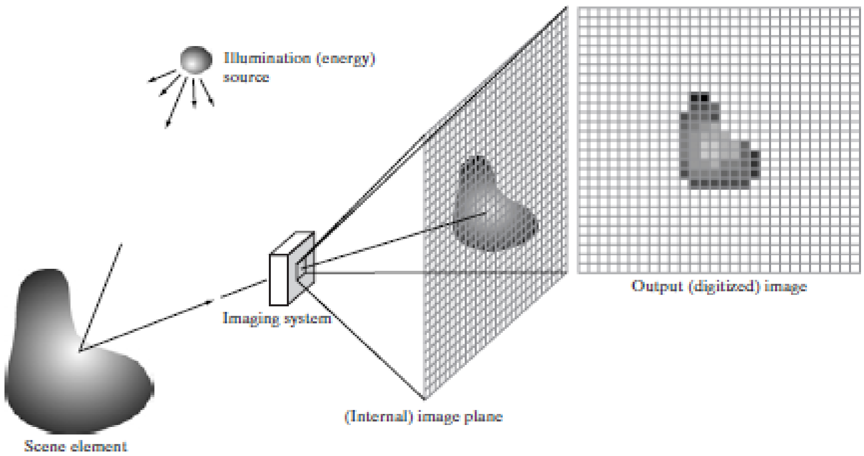

Fig. 3: Image sampling [17]

Next step is image pre-processing tasks, improvement of image enlargement, contrast enhancement as shown in Fig. 5, noise reduction, histogram processing, etc. An image enlargement increases the size of an image by the techniques like linear or cubic interpolation. Contrast of an image can be enhanced by techniques like histogram equalization and contrast stretching.

Noise reduction in an image can be carried out by filtering technique. Low pass filtering used in image smoothing in both frequency domain and spatial domain. In spatial domain, low pass filtering noise reduce is carried out by convolving an image with mask and median filter is used reduce dust in image. Gaussian low pass filter is used in frequency domain to reduce noise. To sharpen the image, high pass filtering techniques are used.

Noise reduction and image enhancement techniques are applied to identify the wear by removing effect of noise like coolant, dust, etc. Similarly wear edges can be enhanced by high pass filtering.

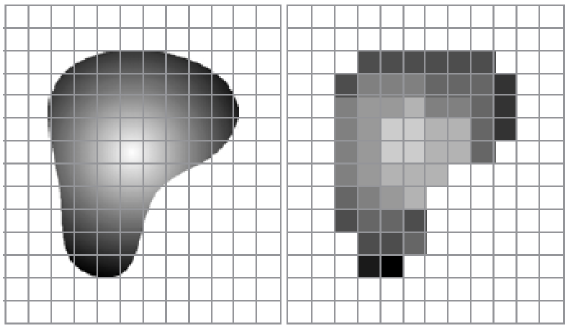

Fig. 4: Image Sampling and Quantization [17]

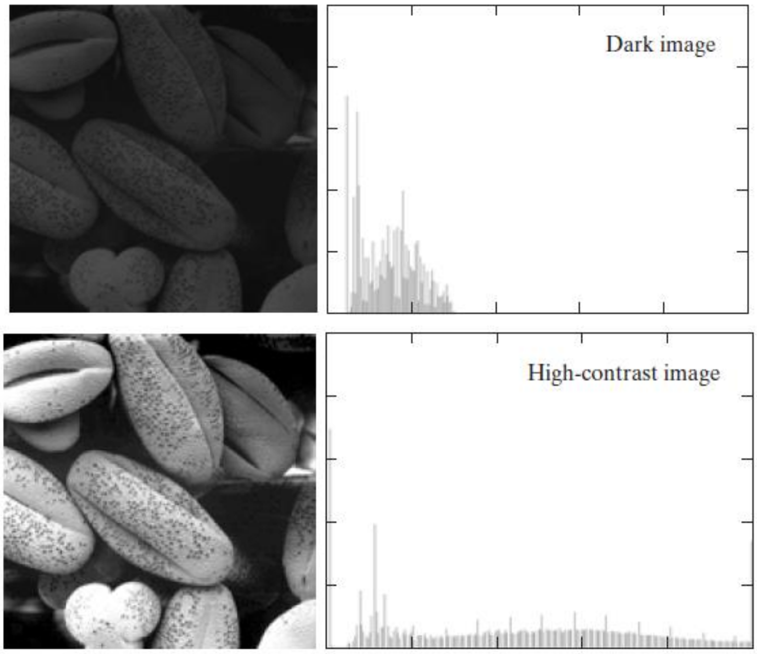

Fig. 5: Histogram equalization [17]

Next step in image processing is to differentiate wear region from background and to highlight the edges of the wear area. An image segmentation includes texture based image classification. The pixel value of image region are clubbed together using some threshold value. The region growing method is one of the texture based technique of segmenting the image.

The wear edges on the tool can be identified by edge detection algorithms. One of the algorithms to detect edges in tool wear is Canny algorithm as shown in Fig 6 and 10. The morphological operations are used which help in closing the broken edge detected as shown in Fig. 7.

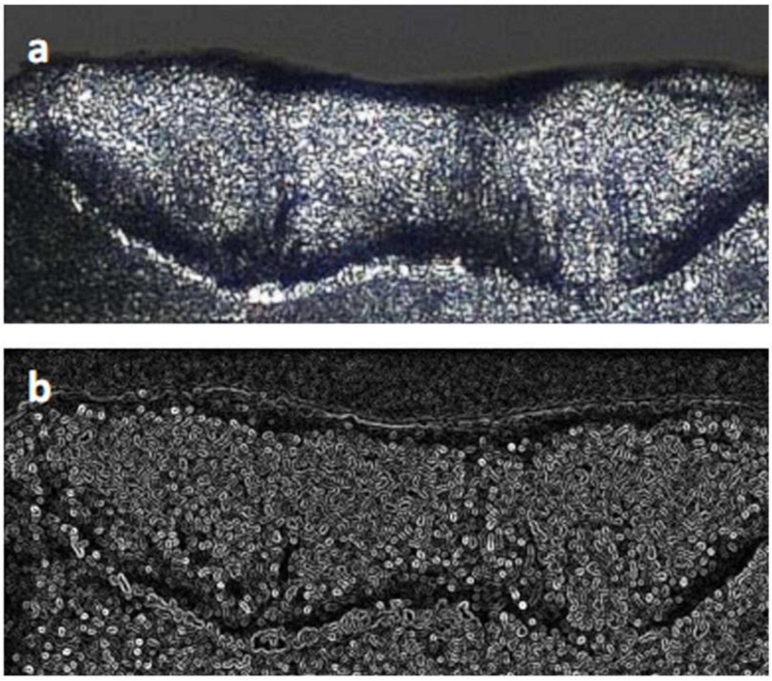

Fig. 6: a) tool wear image and b) Canny edge detector [3]

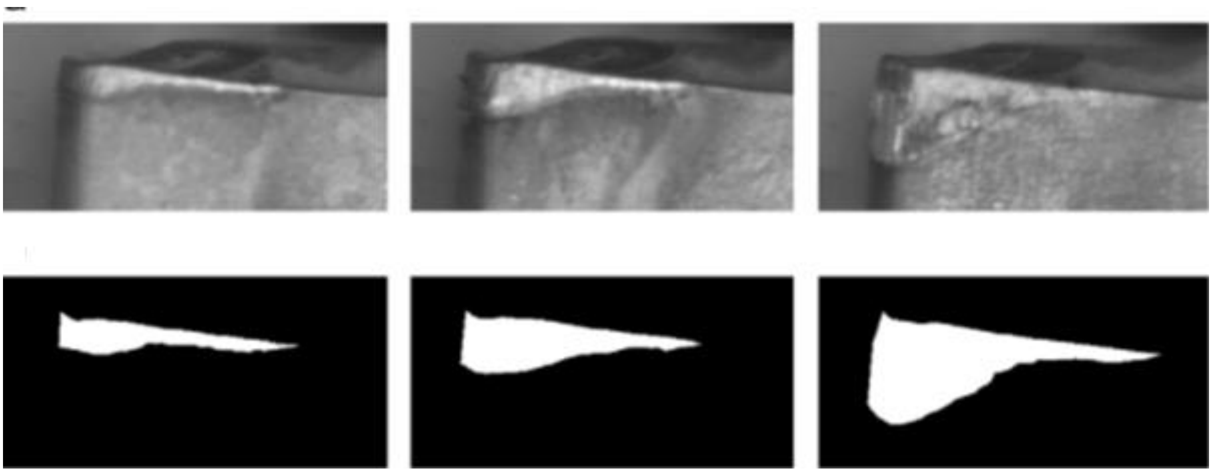

Fig. 7: Flank wear images and their corresponding segmented images [13]

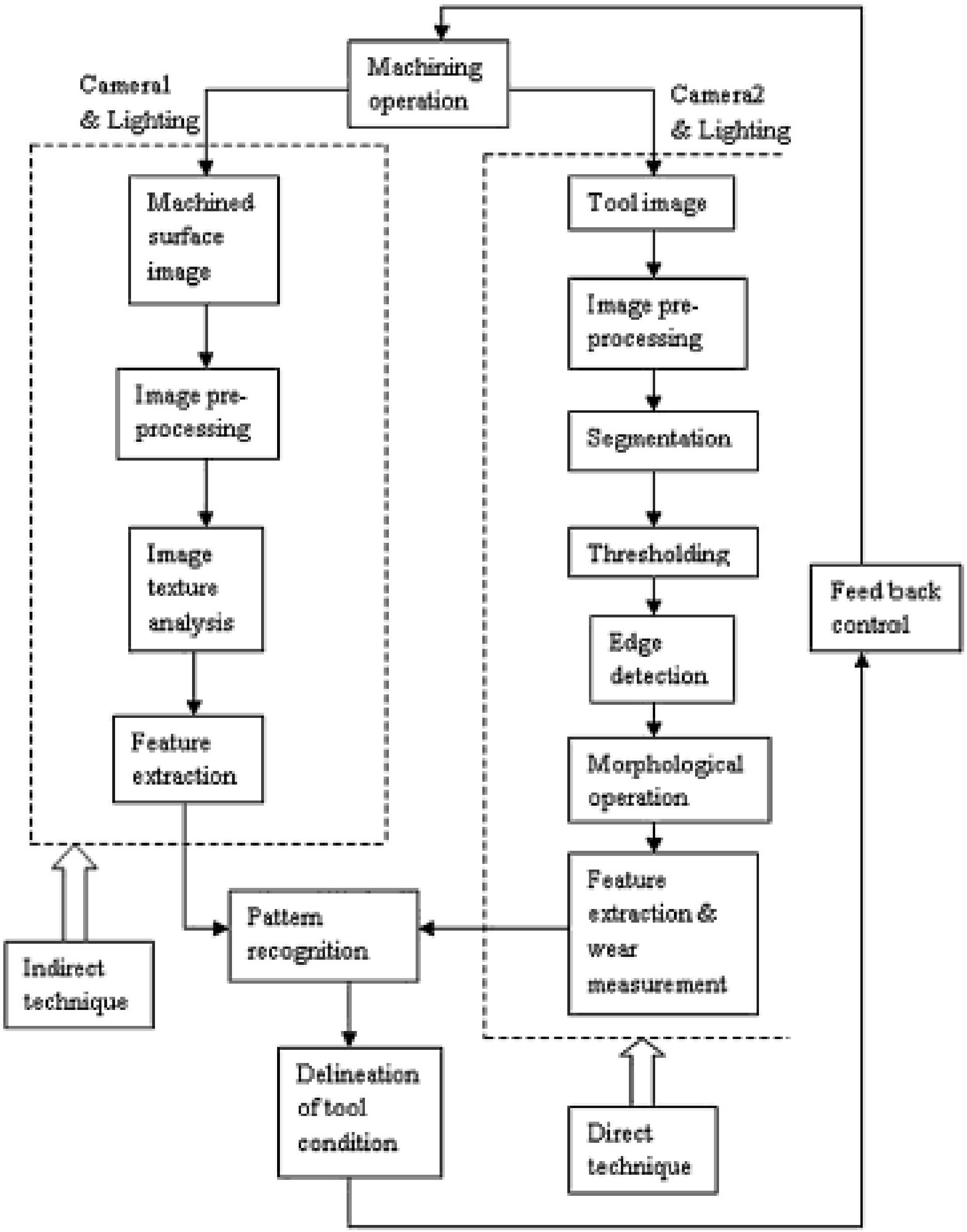

Fig. 8: Flow diagram of image processing for tool wear [3]

Fig. 9: Image illumination to detect flank wear [4]

Fig. 8 shows general steps of image processing techniques for measuring tool wear. The proper illumination of the wear region before capturing the image helps in identifying the wear region correctly without much error as shown in Fig. 9. Various lighting systems like LED, fibre–optic, diode flash, etc. are used to enhance the illumination of the object. The high power lighting like Halogen light is also used for an identification of flank wear. The directed light with high value of illumination is required for an image capturing and processing.

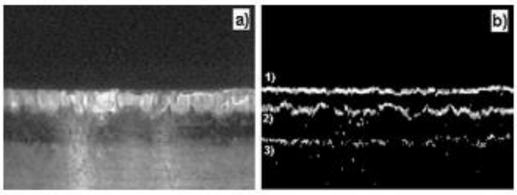

Fig. 10: a) Image of tool wear b) edge detection [6]

Flank wear measurement can be carried out by two dimensional techniques whereas crater wear required three dimensional measurement techniques. Flank wear occurs gradually and is pre-dominant factor in predicting tool life. As shown in Fig. 11, the proposed work will focus on automating the task of measurement of flank wear.

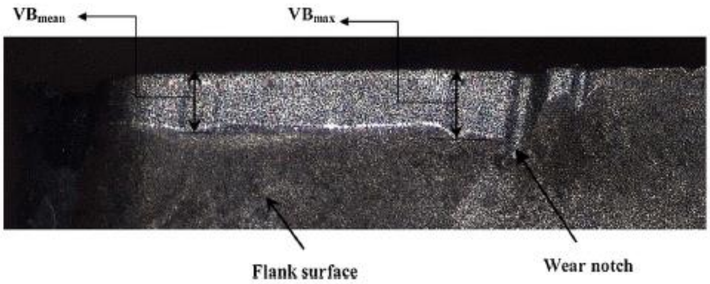

Fig. 11: Image of tool wear [3]

2.3 Merits and Demerits of Image Processing Techniques for Tool Wear Measurement

Image processing techniques are having many advantages over other methods of tool wear measurements. Some of the merits are listed below:

1. The image processing technique is in-process application and no contact is required to be made.

2. No load is applied to take measurement or sense signals.
3. The system once installed can run continuously without human interference.
4. There is less effect of environmental conditions like noise, vibrations etc. on accuracy of measurement.
5. This system can be applied to all types of tool wear or tool failure unlike other system of measurements [3]. For example, breaking of tool can be measured by accelerometers or vibration sensing devices, but gradual tool wear like flank wear cannot be measured by this sensor. So multiple sensors are required to measure different types of tool wear or tool failures.
6. Two dimensional information like job dimension, waviness of surface and roughness of surface from image captured by camera can further be processed to obtain useful information and can be used to correlate tool wear and machining parameters. This information is not possible to be obtained from one dimension surface profiler.
7. Now a days, industrial camera with CCD or CMOS technology is available, so image capturing and processing in harsh industrial environment is possible.
8. Techniques like stereo vision can be applied to obtain three dimensional tool wear measurement, like crater wear on-line, which is not possible by any other matter.

There are some limitations image processing techniques which are listed below:

1. Proper lighting system is required for algorithm of image processing to highlight and identify the features from the image.
2. Effect of coolant, chips, dirt, dust and other environmental factors make image capturing task difficult.
3. Inaccessible areas like deep holes drilling make image capturing and processing task difficult.

2.4 Direct Techniques for Tool Condition Monitoring

Tool wear can be measured directly using tool maker's microscope. But this technique is very time consuming and is not preferred in industries. Tool wear can also be measured directly by taking images of the wear region and carrying out further analysis on these images to measure the tool wear.

Following sections describes the work carried out by researchers in area of monitoring tool wear directly using image processing techniques.

Castego et al. [13] proposed machine vision framework to evaluate cutting inserts of tool wear. Their examination concentrated on wear of flank properties of turning tool inserts by means of computer vision methods together with divided methods depend on geometric sugesstion as shown in Fig 12. The flank wear was depicted by nine geometrical descriptors. Levels of three wear were found using a model depend on analysis of cluster. The wear evolution was monitored by means of the evolution followed by each insert along the machining and provided by the discriminant analysis.

Fig. 12: Experimental setup [13]

This development speaks to the represents of having a place with each class at the present wear map area. In this way, this estimation finds the wear level of the insert and, thus, gives a tool substitution basis so as to protect part tolerances. The results show an improvement in the tool life.

Saeidi et al., proposed the tool wear checking of solidified carbide bits utilized in boring work in mining. Noise impacts were minimized, and picture of the bit was taken by CCD camera. The foundation was deducted from the image to minimize noise impacts. 14 number of bits were utilized to set up bit wear estimation utilizing image processing. Results acquired were contrasted and real measurement utilizing micrometer and tool weight. Utilizing methods of image processing, wear on a tool bits is recognized and give data to the administrator to timing of the bit change.

In their paper, Zhang and Zhang, inspected the framework for measurement of tool wear utilizing computer vision methods. Tip purpose of the tool was resolved and wear discovery region were segmented in the tool pictures taken by CCD camera.

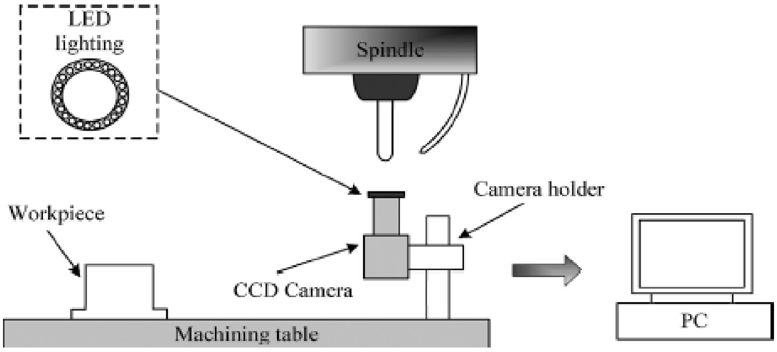

Fig. 13: Tool wear measurement setup on milling machine [21]

The change in grey level intensity of array near corner point is maximum and this useful in edge detection for tool wear measurement as per Fig. 13 and 14.

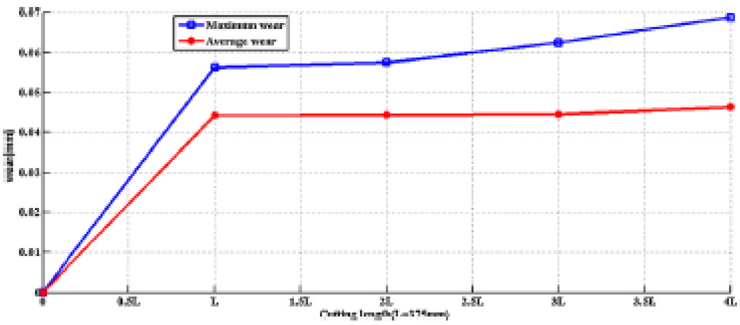

Fig. 14: Tool wear versus cutting time [21]

The results obtained by image processing were compared with the results as measured by microscope and were found to be comparable.

D'Addona and Teti [19] recommended a technique to forecast tool life by recognizing tool wear utilizing methods from the pictures of cutting tool. Artificial neural systems were utilized for discovering tool life dependent on measurement of crater wear from image. Image pre-processing was done to recognize wear and tool life was anticipated from data got from image processing. Images were changed over to gray scale, from values 0 to 255. Histogram equalization was utilized for differentiate extending.

Many researcher [4 – 8, 10, 11 13, 16] talked about threshold method to recognize wear after histogram pre-processing of picture. However, complex tool wear design, makes the undertaking of threshold value difficult. Xiong et al. [15] recommended powerful strategy for choice of threshold utilizing dynamic shape for segmentation of picture. The outcomes acquired were contrasted and actual measurement with the help of microscope. The outcomes were close with most extreme variety of 1%.

Wang *et al.* [12] developed automated system to capture image of moving inserts and measure flank wear of tool. There developed method dependent threshold method, in this method depended to threshold value but this method is not useful for coated carbide material. Median filtering was utilized as pre-preparing step to minimize noise while keeping the necessary data in a picture. For improving complexity and to isolate normal value of intensity of pixel of wear zone from back ground pixels, histogram equalization was utilized. Sobel administrator was applied for edge recognition. Morphological activities were performed to reduce noise and join broken edges. The proposed technique had great precision of measurement, but accuracy is reliant on calculation of reference line which may not act naturally accurate.

In their paper, Su et al. [11] examined measurement of flank wear naturally for smaller scale machining utilizing image processing. Picture was isolated into 2 sections, wear region and background region. Two dimensional recognition of edge is done. Wear measurement is completed by adjusting edge to reference line. So precision of measurement is reliant on recognizable proof of reference base edge of wear. In their paper, Liang et al. [8] proposed image enrollment strategy to measure wear. The two images are compared and the wear was measured.

Sortino [6] proposed a technique in which joined low and high pass filtering and statistical filtering was utilized. Image close to wear region isn't homogeneous and thus a single algorithm, as sobel, Pivett and so forth., for edge detection is not sufficient.

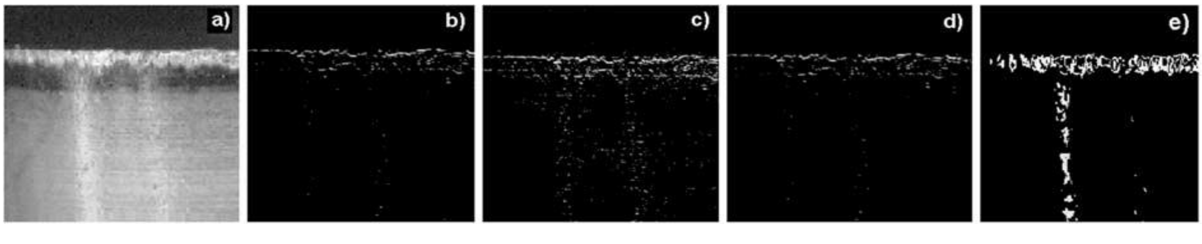

Fig. 15: Comparison of edge detection a) original b) smoothen c) Sobel d) laplace e) Previtt [6]

The variation in the result obtained was approximately 10% with the proposed method as shown in Fig 15.

In their paper, Kim et at. [5] examined an arrangement of measuring wear utilizing CCD camera and advanced the machining parameter utilizing Taguchi technique. Wear detection technique was done physically by moving the machine to adjust the wear edge with reference line in computer. One parameter Taguchi strategy was utilized to optimize illumination intensity.

Kurada and Bradley [2] proved that textural and inclination administrators can be utilized to quantify tool wear in a picture taken by CCD camera. Instead of standard thresholding strategies, textural method was utilized. Image was improved before sectioning it by median filter to hold edge data. Group of pixels that structure a area with a specific power values were identified and wear area was measured. Be that as it may, the impact of noise makes grouping of pixels and recognizing wear a difficult task.

Author/s	Contributions
Jurkovic et al. [10]	• Authors utilized halogen lamp and manual estimation utilizing image processing programming to appraise flank wear and twisting of laser light example on rake face. • Depth of crater wear was not found.
Pfeifer and Wiegers [22]	• Authors showed that image processing methods can be viable in measure wear. • Be that as it may, they did not check their methods for various wear conditions.
Wang et al. [23]	• Authors proposed a system based on successive image analysis for periodic measurement of flank wear in milling. • Method developed was regarding removing noise but was dependent on threshold value
Castejon et al. [24]	• Authors derived a method to estimate the wear level (high, medium and low). • 99.88% discrimination was achieved. • Wear prediction was not performed
Kim et al. [5]	• Authors developed magnetic jig fixing lighting system and camera for milling tool. • Waves to noise ratio of estimatate were

	compared using camera and manual measurement using microscope. • This work focused, instead of image processing technique, more prone to the measuring system.
Kurada and Bradley [2]	• Authors examined vision system to monitor flank wear turning using texture based segmentation. • The method was done offline using video zoom microscope.
Liang et al [8]	• Nose radius changed by image registration method. • The two images are compared and the wear was measured. • Their technique is difficult for the estimation of crater and flank wear
Sortino [6]	• Authors developed method for measuring flank wear by using edge detection method in colour image. • As the resolution of the developed system was 10 µm, the accuracy wass limited
Pfeifer and Wiegers [4]	• Images of tool inserts were caught with a ring light in various points of incidence. • Then they compared those caught images and decrease inhomogeneous enlightenment issue for even difficult cutting edges. • However, they did not check their systems for various wear conditions.
Mikołajczyk et. al. [25]	• Authors proposed image processing techniques using artificial neural network to estimate tool wear. • Using the proposed algorithm, authors made in Visual Basic the special Neural Wear software for analysis of the worn part of the cutting edge was done.
Dai and Zhu [28]	• Tele-centric lens was used to minimize the errors in imaging. • The control system drives a three dimensional motion platform carrying the imaging device to probe and grab in-focus image at the

	predetermined time interval of machining.
Szydłowski at. El. [33]	• Authors proposed tool wear measurement of micro-milling using machine vision system. • Variable light intensity was used in image capturing to detect regions of different reflective properties.

2.5 Indirect Techniques for Tool Condition Monitoring

Indirect techniques correlates the some physical parameter of a machine like vibration, current drawn, acoustic emissions, images of surface textures of work-piece, etc. to predict amount of tool wear. Dutta et al. [14] observed that tool wear can be monitored by processing the image of machined surface of the part. Image transforms and Voronoi tessellation techniques were used to extract information from the image as shown in Fig.16. Due to change in roughness and feed marks, tool wear can be correlated.

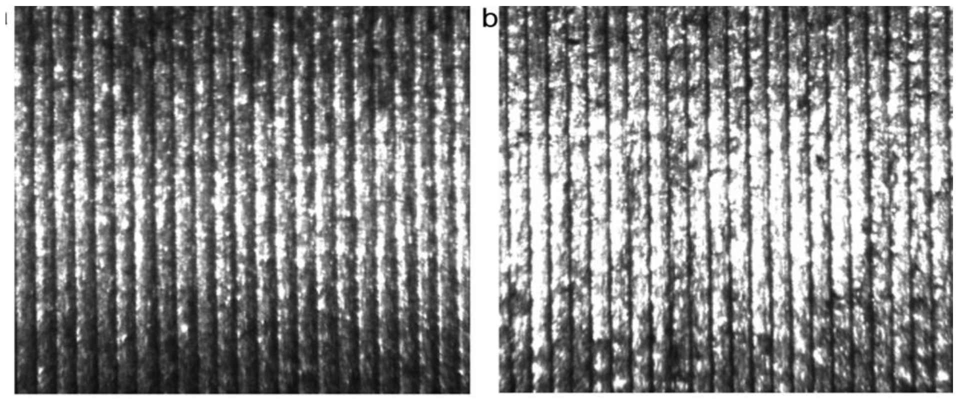

Fig. 16: Images of a) fresh tool and b) worn out tool (VB_{mean} = 0.362 mm) [14]

Author/s	Contribution
Lim [24]	• Author found that at various cutting speeds, the vibration amplitudes consistently produce two peaks throughout the life of the tool. • Correlation between the acceleration amplitude of vibration and the tool flank wear and is established to predict tool failure
Bhattacharyya et al. [27]	• Combination of signal processing to estimate tool wear was proposed in milling operations by capturing cutting force. • Sensor fusion at feature level was used in search of an improved and robust tool wear model in their studies.
Chen and Li [29]	• Tool wear discovered model for measurement flank wear in machining nickel-based alloys was proposed by authors • Different in cutting force measured was related to online tool wear monitoring system

2.6 Summary of Literature Review

By carrying out literature review, it was observed that image processing techniques are set of mathematical tools which can be applied for monitoring the tool wear.

Following points are summarized from literature review

- Although a many authors is done on the tool wear observing dependent on machine vision and an incredible progress has been made, a few issues are should have been concentrated further about comfort, versatility and robustness for on-line tool wear monitoring.
- The relations between tool wear development and the properties parameters must be prepared preliminarily in various cutting conditions and which need suitable tool monitoring equipment.
- Evidently, these problematic circumstance would make an implementation of these techniques complex and are not extremely helpful for the tool wear estimation.

- The precision of tool wear measurement obtained while using indirect methods is not as good as the wear measurement precision obtained using direct techniques. It is due to noise signal observed in it. Contradict with previous statement, it was suggested by many authors that the digital image processing methods are very useful for fast and easier automatic detection of different types of tool wear.
- Number of researchers have proposed threshold technique to identify wear after histogram pre-handling of image. But complex tool wear design, makes the assignment of choice of threshold value complex.
- Image pre-processing, image thresholding, edge detection and morphological operations can be used for getting the faster outputs.
- Robust Illumination model are an important parameter in image processing.

3 Problem Definition and Methodology

The proposed research work is focused on the development of system of tool condition monitoring by measuring wear on cutting tool using image processing techniques with a aim to automate the process of production and improve the quality of part manufactured.

3.1 Rationale for taking up the project

In today's competitive world and customer driven market, demand for high quality product at reduced cost is increasing day by day. To fulfill these demands, industry is striving to produce the goods with high quality and lower cost. The quality of the product manufactured can be improved by automation of the process of monitoring the parameters affecting part quality.

Automation is the need of today's manufacturing sector. Products can be manufactured with improved quality and reduced costs with the help of automation of production systems. The industry is aiming for automation in production processes and need unsupervised or unmanned machining is increasing. These has driven researchers to propose automation of cutting tool condition monitoring. Condition of the cutting tool directly affects quality of the part being manufactured. Traditionally, the task is carried out manually. One of the promising technology for online of monitoring of cutting tool is computer vision systems developed with the advances in digital image processing techniques. After studying research papers in the area of tool wear measurement techniques, it is found that there is lot of scope in developing a commercially viable system for effectively automating the task of tool condition monitoring.

3.2 Objectives

- To develop a robust illumination model for tool condition monitoring using computer vision techniques
- To develop a tool wear measurement system using image processing techniques
- To work on an improvement of the wear detection techniques using fusion of direct and indirect wear measurement techniques

- To develop a tool wear prediction technique for computing remaining useful life of machine measurements.

3.3 Methodology

Initially, illumination model along with hardware components to correctly identifying tool wear region will be proposed. Then development of algorithms for direct measurements of tool wear using image processing techniques will be done. Experiments of machining will be carried out for measuring tool wear using image processing techniques and validating the results with manual wear measurements using microscope will be carried out. Then further algorithms of image processing using fusion of direct and indirect techniques (using machined work-piece surface) will be developed. The developed algorithms will be validated using experimentation work with an aim to increase robustness of tool wear measurement algorithms. Predicting remaining useful life of tool using statistical estimation, Artificial Neural Network (ANN), Fuzzy Logic and other available data classification techniques will then be proposed and validated using experimentation work.

3.4 Experimentation Work to measure Flank Wear Using Image Processing Techniques

The aim of initial experimentation to measure flank wear was to gain insights of the hardware and software integration requirements for measuring tool wear accurately and to find the sources of error in wear measurement using image processing techniques.

3.4.1 Image Acquisition

A DSLR camera was used to capture the images of tool. The camera was mounted on the CNC lathe machine. The light mounted to surrounded lens of camera. The images were taken once the tool is dis-engaged from the job and is positioned in front of camera at a fixed point on the CNC lathe machine. This position was included in part programme, so that exact position can be maintained each time the image is taken. The wear region to be measured by analyzing the images of tool taken is of very small width ranging from 50 microns to 2000 microns. So micro camera photography was used.

The flank wear was required to be measured in SI units (microns). So it was required to convert the distance measured in terms of number of pixels to microns. For this, two parallel lines on the tool itself were identified and distance between them was measured using optical microscope. This known distance can be used to calibrate the pixel distance.

3.4.2 Image Thresholding

Image consists of various entities and background. So first task is to divide the image into foreground and background pixels. The image is then converted into binary image. This step is performed to identify the Region of Interest (ROI). The tool position in CNC lathe machine as shown in Fig. 17 will remain same each time, the image is taken.

Fig. 17: Experimental setup

The thresholding algorithm converts image into binary image.

$$f(x, y) = 0 \quad \text{if, } f(x, y) > T$$
$$= 255 \quad \text{otherwise}$$

Here T is the thresolding value selected to segement the image. The pixel value will be selected for thresholding the image and converting it into binary image as shown in Fig. 18.

(a) Original image (b) Binary image

Fig. 18: Conversion of an image into binary image

3.4.3 Finding Region of Interest

Once the image is converted to binary form, it has only two values of pixel that is either 0, for black portion identified as objects in image or 255, for white portion identified as background of image. The next step performed is finding the Region of Interest (ROI). Here an algorithm specifically finds the flank wear on the tool mounted on CNC lathe. The image is captured, while the tool is on the turret, placed inclined and positioned in front of the camera. This is achieved by taking image of tool while tool is placed in turret head and by writing codes in part programming of CNC lathe machine. Now the tip of the tool is located by scanning the image in downward and leftward direction starting from top right corner of the image. The top right corner of the image is assumed to be background having pixel value of 255. To achieve this condition, the background can be kept as white while capturing the tool image. The tool tip will be recognized by the scanning the pixel values Tool tip is identified when pixel value of 0 is located during scanning as shown in Fig. 19.

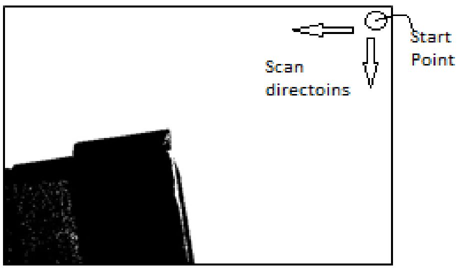

Fig. 19: Finding the tip of the tool in the binary image

A window around the point located on the tool tip is identified and the original image is cropped of the size of window as shown in Fig. 20.

Fig. 20: Cropped image

3.4.4 Converting image to gray level

The cropped image is converted to gray scale image with the 8 bit intensity levels. The range of intensity values of pixel varies from 0 to 255. The histogram of the gray scale image is shown in Fig. 21.

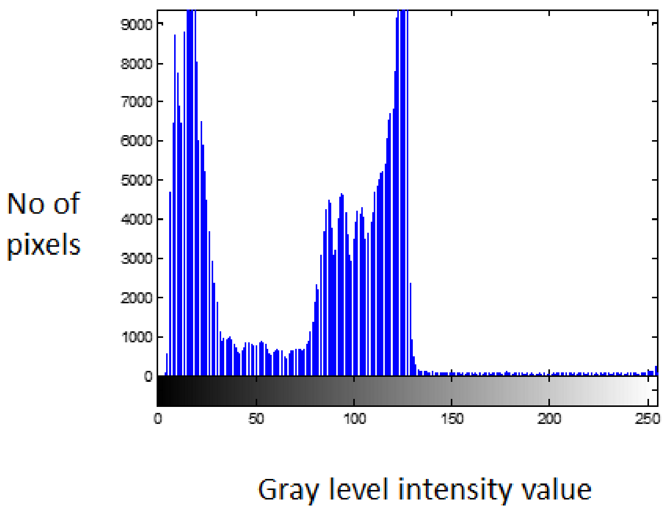

Fig. 21: Histogram of a gray scale image

3.4.5 Finding edges in the image

The next step is detection of 2 – D edges of the wear region. The image contains wear region where there is significant transition in the image. There is steep change in intensity value at the border of the wear region as shown in Fig. 22.

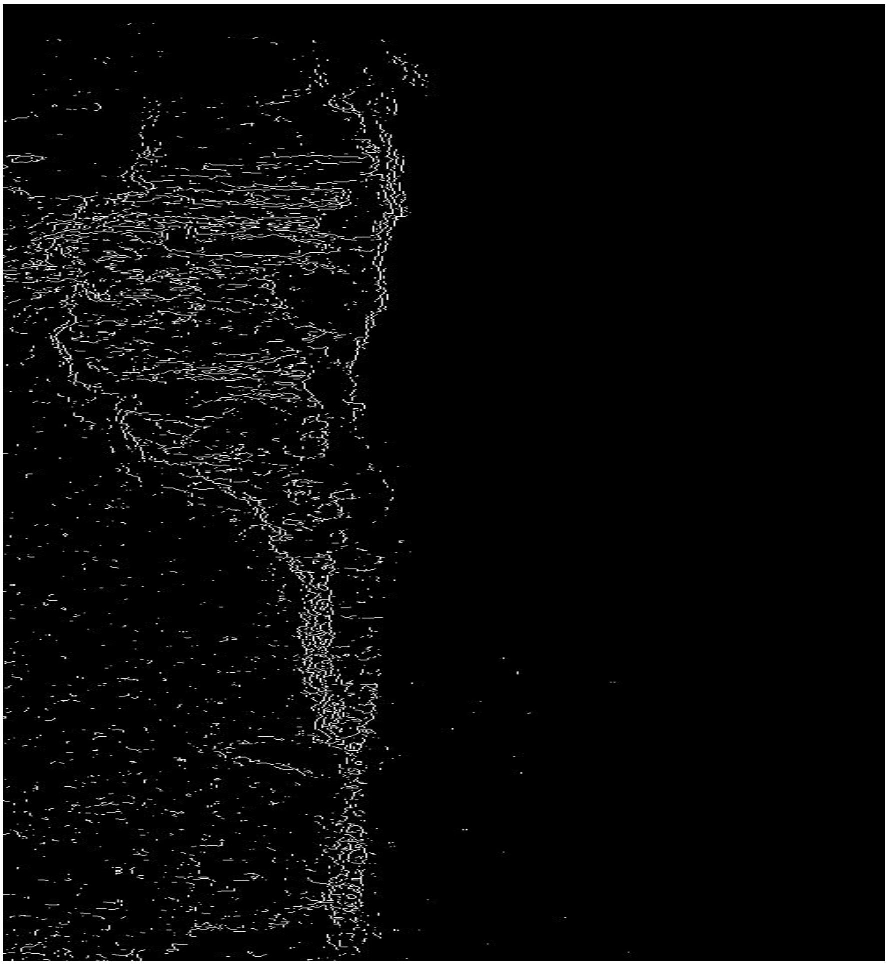

Fig. 22: Edge detection using Sobel operator

In tool wear detection, there is lot of noise present due to marks on the tool surfaces, chips, etc. So, this conditions are to be considered for accurate detection of edge.

3.4.6 Removing noise in the image

The tool image contains salt and paper noise as shown in Fig. 23. This noise is required to be removed before processing further. The noise is generally removed by blurring the image using some mask filter

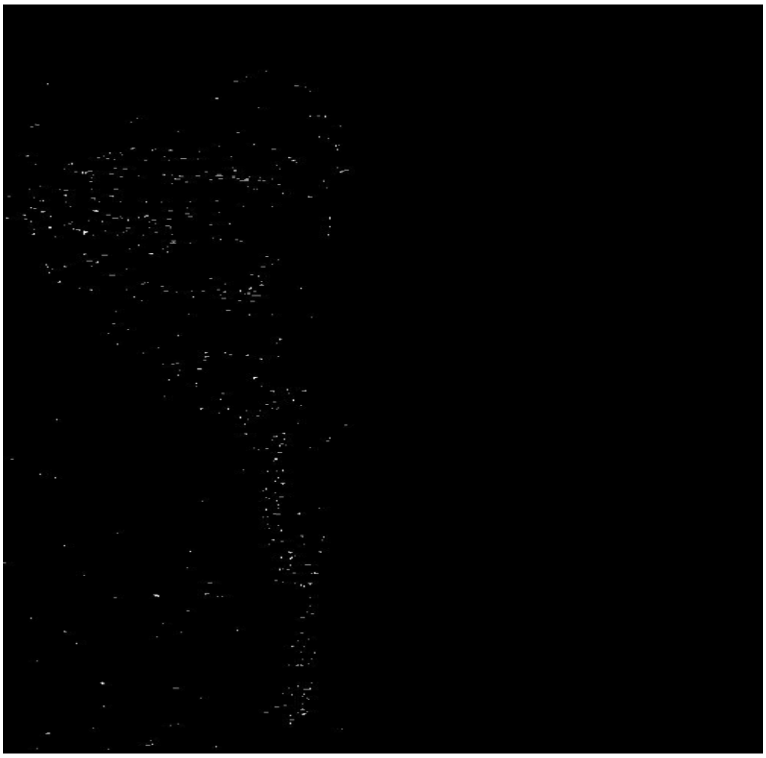

Fig. 23: Salt and pepper noise

The filter utilizes neighborhood operation to carry out filtering. A 3 X 3 filter can be chosen to perform the filtering operation as shown in Fig. 24.

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighbourhood pixel values:
115 119 120 123 124 125 126 127 150

Median value: 124

Fig. 24: Finding the median value of pixel using filter size of 3 X 3

3.4.7 Morphological operation

The basic idea to apply morphological operation to the image is to complete the profile of the wear region. This helps carrying out geometric descriptors of the wear region to measure flank wear.

An operation of dilation have been performed to complete the wear region. The dilation operation expands the object in the image as shown in Fig. 25. So this helps in filling the holes and connecting the disjoint objects in the wear area.

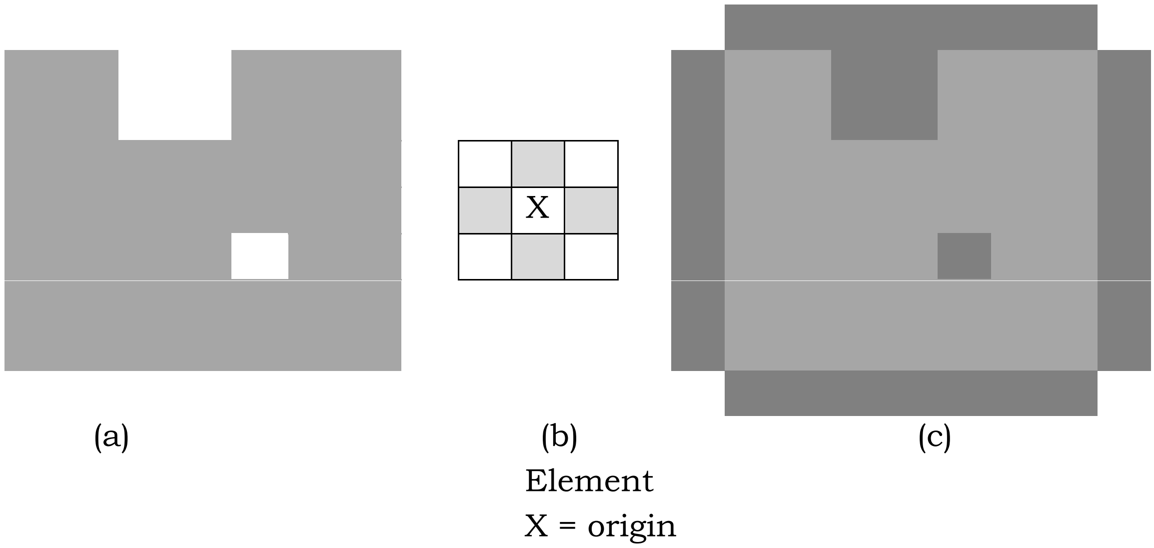

Fig. 25: Dilation process (a) Original Image (b) structuring (c) dilated image

In dilation operation a structuring element is applied to the input image and at the output, dilated image is obtained. This involves process of convoluting the tool image with structuring element. Structuring element is a binary element or mask of 64 X 64 pixels in size. The value of each element in the structuring matrix is either zero or one. The origin of the structuring element is selected as centre of the structuring element.

Structuring element performs the same operation on image similar to median filter used earlier. The structuring element is placed over the image. Each pixel in the image is convoluted with the structuring element. Now comparison of the structuring element with the input image and at the origin point is done. If the neighbourhood pixels of the origin of the structuring element is overlapping, than the origin of the structuring element corresponding to the input image is turned on. This process is repeated for all element and output image is obtained as shown in Fig. 26.

Fig. 26: Dilated wear region in image of the tool

3.4.8 Post processing

One of the steps performed in post processing is filling the holes in the connected components in the image, so that object properties can be defined. This is achieved by flood filling algorithm as shown in Fig. 27.

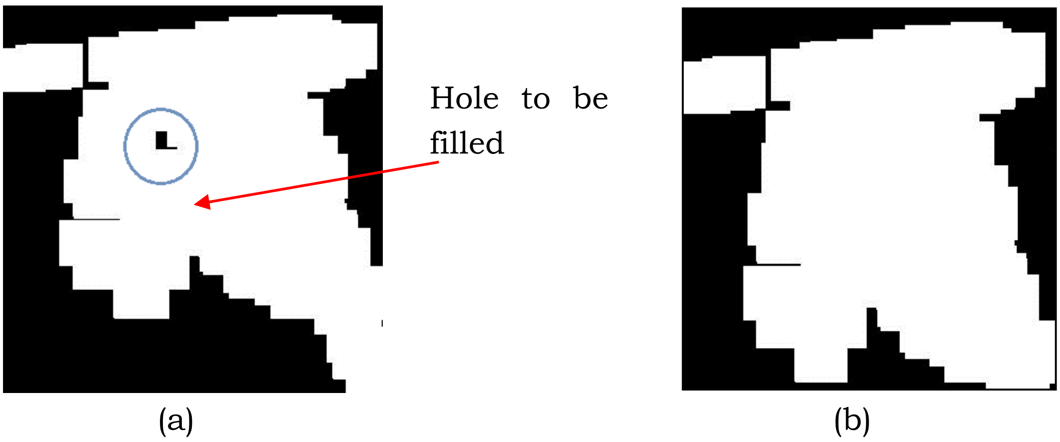

Fig. 27: (a) Image with holes to be filled (b) image with filled holes

3.4.9 Measurement of Wear

The tool wear region is continuously connected by group of pixels. This region will be the largest region in the binary image obtained from previous step. In finding this connected pixels of wear region, different numbers are assigned to pixels belonging to different objects in the image. To find connected component in the image, each pixel is visited iteratively from top to bottom and left to right. If there are no neighbour, new number is assigned to the pixel. Otherwise a new neighbor is found with the smallest label and it is assigned to the current pixel. This process is repeated for all pixels in the image.

Fig. 28: Identified maximum flank wear region in the tool

Once the connected components are determined, than MATLAB® image processing toolbox has been used to find size of an ellipse circumferencing the object in the image as shown in Fig. 28. The minor axis length of maximum size will be the maximum flank wear measurement in pixels, which is then converted in units of microns with the help of calibrated value.

3.4.10 Results and discussion

The tool wear measurement algorithm is able to measure the maximum flank wear on CNC lathe machine. The image of the tool was captured keeping tool position and orientation fixed. This made the process of finding the ROI simpler. The edge detection and noise removal was carried out and the pixels were dilated to obtain connected components. The properties of connected components were found out to obtain the wear measurement. The calibration of the image was done to obtain the flank wear measurement in microns.
The flank wear was measured manually by microscope to compare it with the measurement obtained by software. The results of comparison is shown in table 1 and Fig. 34.

TABLE 1: Comparison of manual measurement and measurement by proposed method

Sample No.	Maximum wear V_b Measured by software in microns	Manual measurement by microscope in microns	Difference in microns	Percentage difference
1	297	290	7	2.41%
2	190	192	2	1.04%
3	430	438	8	2.60%
4	316	328	12	3.65%
5	515	527	13	2.47 %
6	215	223	8	3.58%
7	730	718	12	1.67%
8	295	281	14	4.98%
9	260	278	18	6.47%
10	327	341	14	4.10%

From the table it can be observed that the maximum flank wear as measured by algorithm are almost similar to the measurement as done manually. The maximum variation in the result of wear measurement manually and by software is 6.47%. The conditions for image capturing like distance between tool and camera and tool orientation was fixed. The proposed method of wear measurement can be applied to measure maximum flank wear in CNC turning centre. The operator on the machine can measure wear and it helps in optimum use of tool.

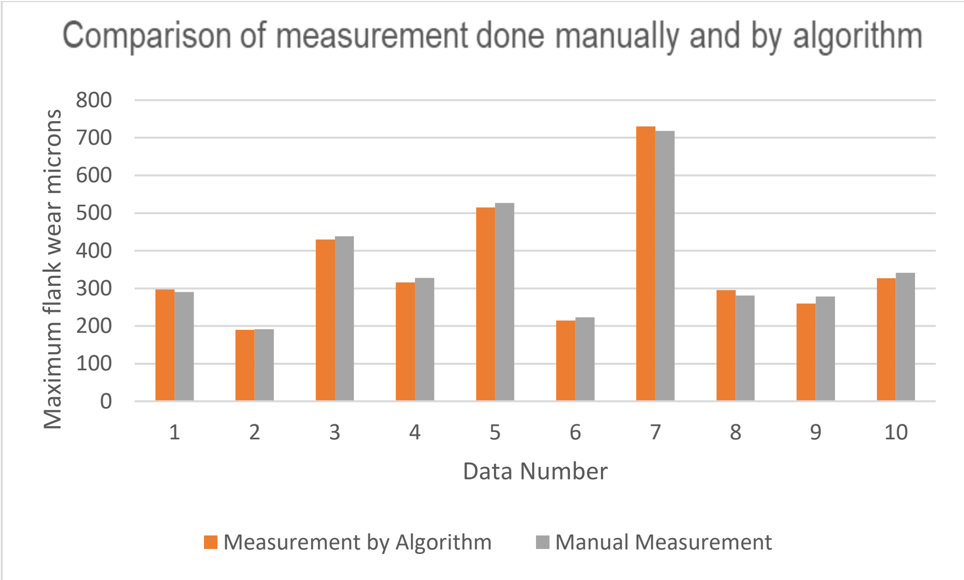

Fig. 29: Comparison of tool wear measurement done manually and by algorithm

The proposed method investigated the method of determining maximum flank wear measurement on CNC lathe machine. One of important factors in image processing for tool wear measurement is to develop robust illumination model. Reasons for this is, firstly the tool surface itself has lot of noise in form of uneven surface. Secondly the wear region to be identified is also uneven. So proper illumination plays important role in development of robust algorithm and identification of wear area.

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