Three Dimensional Surface Roughness Evaluation of Machined Components in Computer Integrated Manufacturing

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Abstract -- **Surface roughness evaluation is very important for many fundamental problems such as friction, contact deformation, tightness of contact joints positional accuracy etc. Many techniques have been developed for measuring surface finish ranging from the simple touch comparator to sophisticated optical techniques. In recent years, the advent of high-speed general-purpose digital computers and vision systems has made image analysis easier and more flexible. Unlike the stylus instruments, computer vision systems have the advantages of being non-contact and are capable of measuring an area from the surface rather than a single line. A vision system is considered relatively cheap, fast and suitable for automation.**

The proposed method works on the principle of interferometry. In this method, a vision system is used. Vision system consists of a CCD camera, frame grabber, advanced image processing card and a high end computer. The surface images are grabbed using CCD camera and then transferred to the computer memory through frame grabber. An image processing algorithm is prepared using MATLAB. The surface roughness parameter values (3D) obtained by Vision system are then compared with those obtained by Optical method. Strong correlation is obtained between the vision roughness and optical roughness parameters. Hence the proposed method can be used in the assessment of 3D surface finish. The complete analysis of results is presented in this work.

Key Words: Vision System, CCD Camera, Frame Grabber, image processing.

I. INTRODUCTION

Surface roughness measurement is an important requirement in many engineering applications. Surface finish is specified as the component requirement for many produced parts and manufacturing operations in order to satisfy their desired functionality and aesthetics [1]. In manufacturing, the surface finish is adopted as finger print of the machining process [2] [3]. In many engineering applications maintaining some amount of roughness is very important concern to have adequate contact between mating components, hence surface roughness controls are mandatory to define the process and validate the quality of the machined parts [4].

Surface roughness measurement can be carried out in two ways, first one is Contact measurement technique, which includes Stylus instruments [3] and the second one is Non-contact measurement technique, which include Optical and Electro-Optical methods. As the name insists, the difference between these types of measurement is whether there exists contact between measuring instrument and work piece or not. The development of non-contact roughness measurement techniques for engineering surfaces has received much attention. However, stylus-based equipment is still dominating in industries. Stylus technique has great inherent limitations as they were originally intended to acquire 2D surface topography. Therefore, 3D surface roughness data can only be obtained from stylus equipment by executing multiple scans of the surface. However, this task is a very time consuming [2].

The proposed method for surface roughness measurement uses vision system and image processing technology. The proposed method helps in evaluating engineering surfaces for surface roughness.

In recent years, the advent of high-speed general purpose digital computer and vision systems has made image analysis easier and more flexible [2]. Computer vision technology has maintained tremendous vitality in many fields. Various investigations have been performed to inspect surface roughness based on computer vision technology [5]. This work presents a unique approach for surface roughness characterization using computer vision and image processing technique. A vision system has been introduced to capture images for surfaces to be characterised and software has been developed to analyse the captured images.

3D surface roughness parameters or 3D Amplitude parameters gives information about the statistical average properties. 3D surface roughness parameters such as S_a, S_q,

S_{sk}, S_{ku}, S_z, S_p and S_v are used to define the surface roughness.

The 3D surface roughness parameters as defined by M. B. Kiran [6] is as below,

1. The Roughness Average, S_a, is given as:

$$Sa = \frac{1}{MN}\sum_{K=0}^{M-1}[z(x_k - y_l)] \quad (1)$$

2. The Root Mean Square, (RMS) parameter S_q, is given as:

$$Sq = \sqrt{\frac{1}{MN}\sum_{K=0}^{M-1}\sum_{l=0}^{N-1}[z(x_k - y_l)]^2} \quad (2)$$

3. The Surface skewness, S_{sk} , describes the asymmetry of the height distribution histogram, and is given as:

$$Ssk = \frac{1}{MNSq^3}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} z(x_k - y_l)^3 \quad (3)$$

4. The Surface Kurtosis, S_{ku}, describes the "peakedness" of the surface topography, and is given as:

$$Sku = \frac{1}{MNSq^4}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} z(x_k - y_l)^4 \quad (4)$$

5. The Peak-Peak Height, are defined as the height difference between the highest and lowest pixel in image.

   Sz = Zmax – Zmin

   (5)

6. Maximum Valley Depth S_v: is defined as the largest valley depth value.
7. Maximum Peak Height S_p: is defined as the largest height value.

II. PHASE SHIFTING INTERFEROMETRY

Phase Shifting has been widely adopted in optical interferometry for extracting phase information encoded in the interference fringes on 3D surface geometry [8]. Interferometry is a technique of determining phase difference between multiple waves of same frequency moving along same direction. The technique functions primarily by acquiring a number of intensity images with phase increments between successive frames [9]. In this technique grating lines are projected onto the test surface by an optical projector which casts shadow of the grating onto the test surface. These grating shadows are called fringes [10]. These fringes contain the information of surface profile as they deform due to the surface irregularities.

Although only 3 images are required to solve for the three variables of t he Phase Shifting Interferometry (PSI) equation, in practice more than 3 images are often digitised for ease of computation, noise suppression and reduction in sensitivity to phase stepper errors. The large number of frames can be used to decrease the sensitivity to these errors. In the four position technique, the nominal phase-step is P/2, and the reference phase takes values of 0, P/2, P/4, and P/16. Where P is pitch of the beam.

In four step algorithm method, four steps are given as input and four interferograms (I_1, I_2, I_3 and I_4) are recorded. Phase shift is taken at 0, π/2, π and 3π/4. The corresponding intensity equation for these phase shifts can be written as,

$$I_1 = I_1(x, y) + I_2(x, y) \cos[\theta(x, y)] \quad (6)$$

$$I_2 = I_1(x, y) + I_2(x, y) \cos[\theta(x, y) + \pi/2] \quad (7)$$

$$I_3 = I_1(x, y) + I_2(x, y) \cos[\theta(x, y) + \pi] \quad (8)$$

$$I_4 = I_1(x, y) + I_2(x, y) \cos[\theta(x, y) + 3\pi/2] \quad (9)$$

These equations can be solved for phase θ(x, y) at every point on the interferogram and by using trigonometric identities equations (1), (2), (3) and (4) can be written as,

$$\tan[\theta(x, y)] = \frac{I_4 - I_2}{I_1 - I_3}$$

or

$$[\theta(x, y)] = tan^{-1}\frac{I_4 - I_2}{I_1 - I_3} \quad (10)$$

The Optical Path Difference (OPD) or depth values at every point can be obtained from the relation [13-15],

$$OPD = \frac{\lambda}{2\pi}\tan^{-1}\frac{I4 - I2}{I1 - I3}$$

(11)

III. SPECIMEN PREPARATION

Specimens of Aluminium (diameter 50mm and 8mm thickness) are prepared using machining process of Milling as shown in Fig, 1. Specimens are prepared by changing machining parameters such as speed, feed and depth of cut as shown in Table 1. Milling operation is performed in vertical machining centre (X- 600, Y-300 and Z-200) by using Carbide tool.

TABLE 1 MILLING SPECIMENS (ALUMINIUM)

Specimen No	Speed (rpm)	Depth of cut (mm)	Feed (mm/rev)
1	355	0.1	20
2	355	0.2	20
3	355	0.3	20
4	355	0.4	20
5	355	0.5	20

Fig, 1 Milling Operation

Some of the prepared specimens are shown in Fig, 2.

Fig, 2 Sample specimens used in the experiment

IV. MACHINE VISION SYSTEM and MATLAB

Machine vision is the technology to replace or complement manual inspections and measurements with digital cameras and image processing. This technology is in use in a variety of different industries to automate the production, increase production speed and yield, and to improve product quality [2].

The application of machine vision system offers better solution in on-line and real-time monitoring surface roughness. Machine vision involves the use of charge coupled device (CCD) camera, frame grabber, computer system and image processing software to acquire, analyses, monitor, and assess surface roughness parameters [2]-[12].

Machine vision systems play an important role in the monitoring and control of automated machining systems. It has generated a great deal of interest in the manufacturing industry [2]. Using machine vision, it is possible to characterize, evaluate, and analyse the area of the surfaces of machined components.

Machine vision in operation can be described by a four-step flow:

1. Image capturing.
2. Analysing the image to obtain a result.
3. Communicate the result to the system in control of the process.
4. Take action depending on the vision system's result.

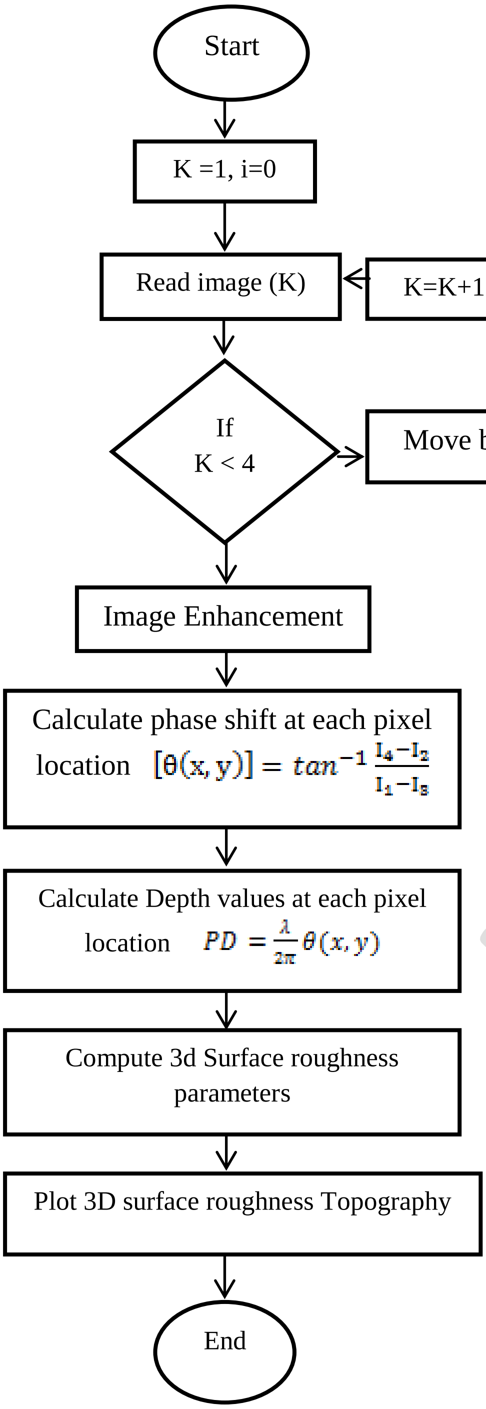
CCD camera is a combination of semiconductor device and image sensors. CCD camera captures the image of test specimen. CCD camera used in experimentation process is Pulnix camera with 512 × 480 resolution. Frame grabber convert original image into digital image and stores it into random-access memory of a computer with windows operating system which is interfaced with vision system. This computer contains image processing software to calculate the 3D surface roughness parameters.

MATLAB is the tool used for developing algorithm for computing 3D surface roughness parameters. Image processing tool in MATLAB is used to convert captured image of a machined surface to digital image. This digital image contains brightness values at each pixel in a matrix form. MATLAB takes image as input and calculates 3D surface roughness parameters using the developed algorithm which is shown in Fig, 4.

V. EXPERIMENTATION

The tests specimens are placed below the CCD camera on a table which is provided with length scale. The CCD camera captures the image of test surface and sends the image data to the computer. Computer is provided with the image processing software which calculates the 3D surface roughness parameters. This experimental process is explained in detail in following paragraphs.

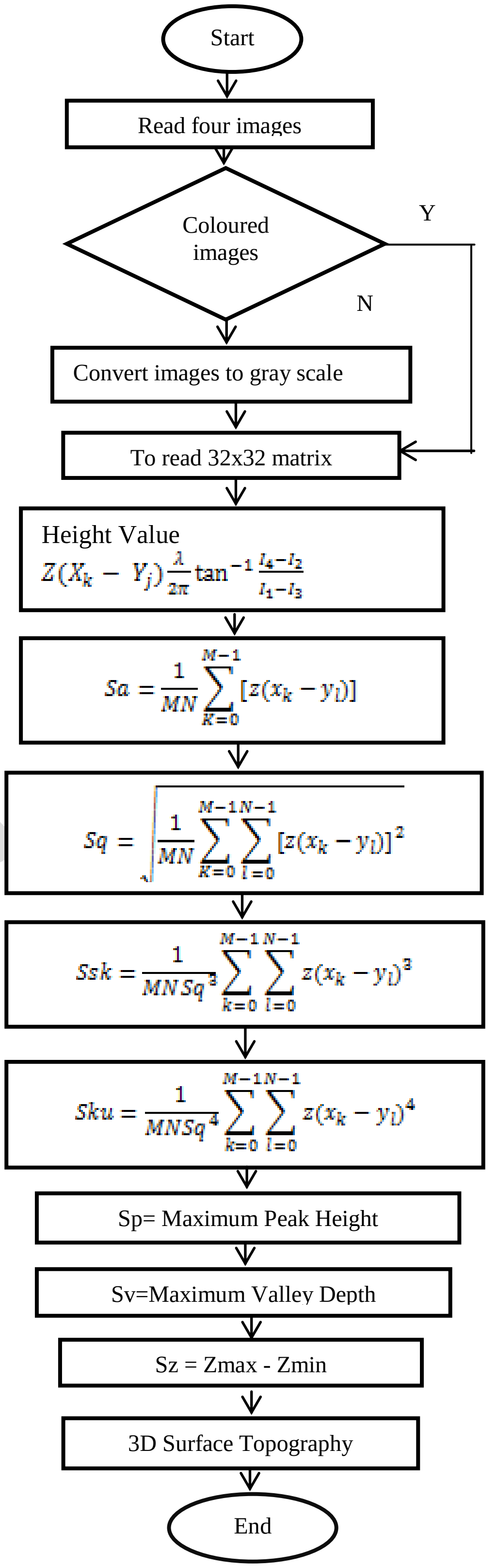
The proposed method employs phase shifting interferometry technique. In this method test specimens are illuminated using grating projector. Image of the test specimen along with projected grating is captured into 512 × 480 pixels of resolution. The test specimen is then moved, in increments of P, P/4, P/8 and P/16 (where, P is the pitch of the grating) and an image is captured after each movement. Image enhancement is done to remove noise. Phase shift calculation and depth value calculation is performed at each pixel location (32 × 32) and finally 3D surface roughness parameters are computed. 3D surface topography is plotted to visualise the test surface. The formula to calculate phase is given in equation 10 and for depth calculation given in equation 11. 3D surface roughness parameters obtained by Vision method is then compared with those obtained by Optical method. Fig, 3 shows the flowchart of the experimental procedure and Fig, 4 shows the flowchart for algorithm development. 3D Confocal Microscope (Olympus LEXT OLS4000) is used as Optical method for 3D surface roughness parameter measurement. Confocal scanning microscopy is a technique for obtaining high-resolution optical images.



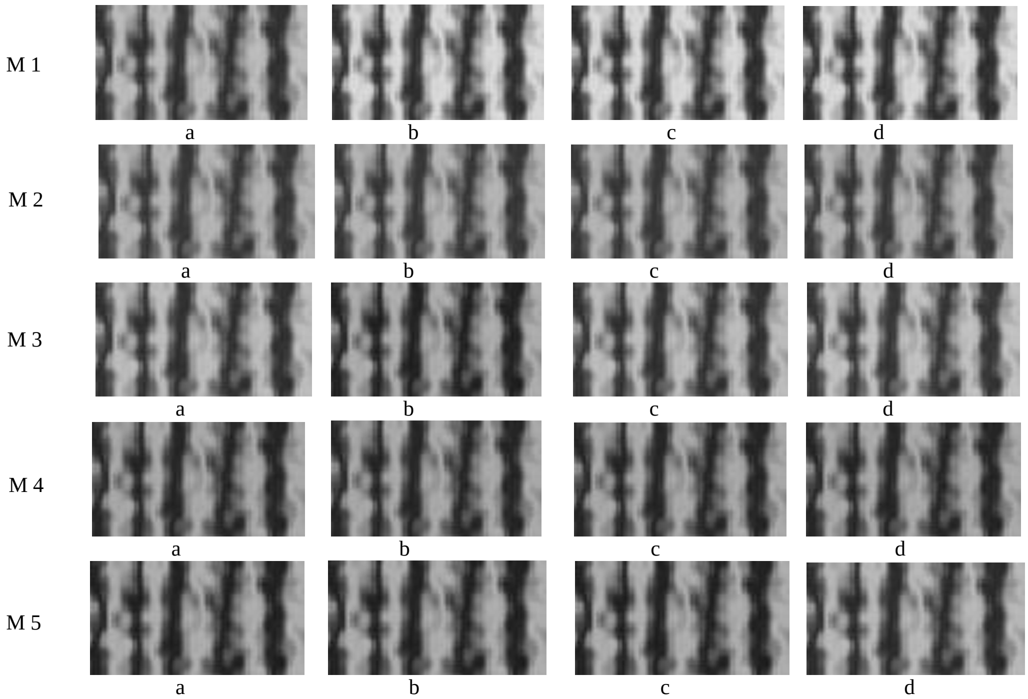
Fig, 3 Flow chart showing experimentation procedure

The Optical sectioning in confocal microscopy is a process of acquiring in-focus images from selected depths. The focused on the surface of test specimens is 2.5 x 2.5mm, pitch used is 2.75µ and objective lens used is of 20X. The images obtained by Vision method for Milled specimens are shown in Fig, 5.

These images are used as input images to calculate phase values.



Fig, 4 Flow chart for developed algorithm for 3D surface roughness parameter measurement

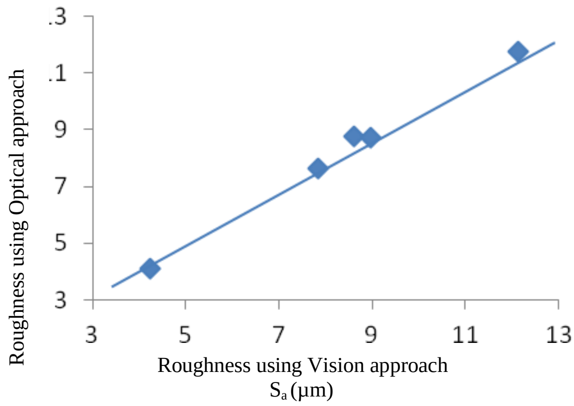


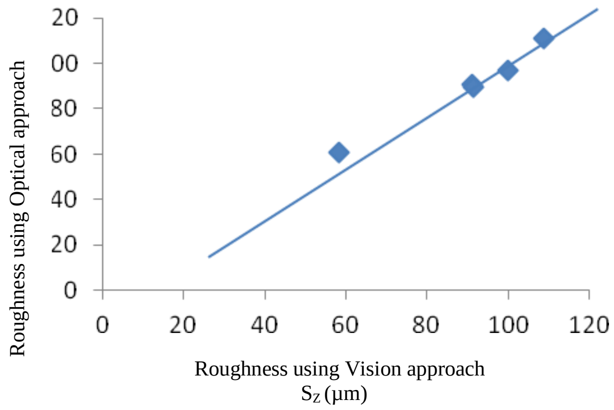
Fig, 5 Captured Images by Vision system

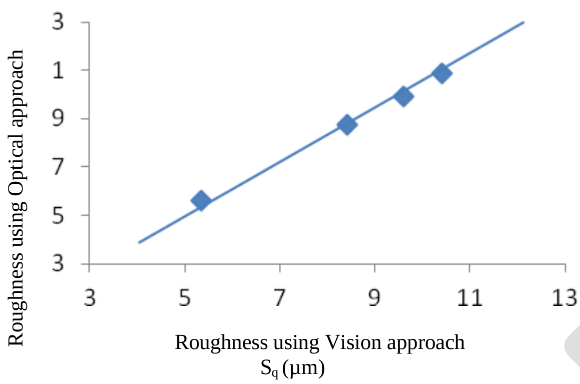
Using these depth values 3D surface roughness parameters are evaluated. The 3D surface roughness parameter values obtained by vision method and those obtained by Optical method are given in Table 2. In figure 5 a, b, c and d are the four captured images of single Milled component taken at increments of P, P/4, P/8 and P/16. Graphs have been plotted to compare 3D surface roughness parameters obtained by vision approach and Optical approach as shown in figure 6.

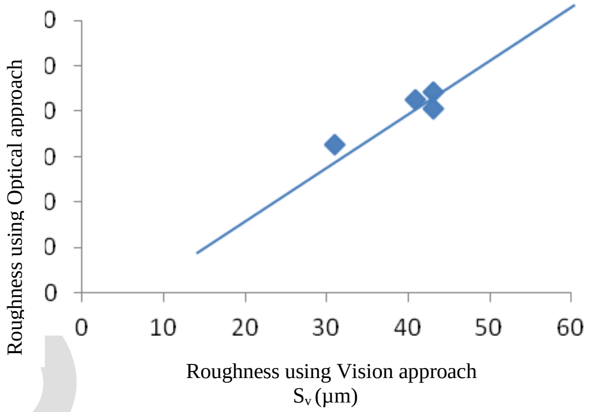
TABLE 2 3D SURFACE ROUGHNESS PARAMETERS VALUES by VISION METHOD and OPTICAL METHOD

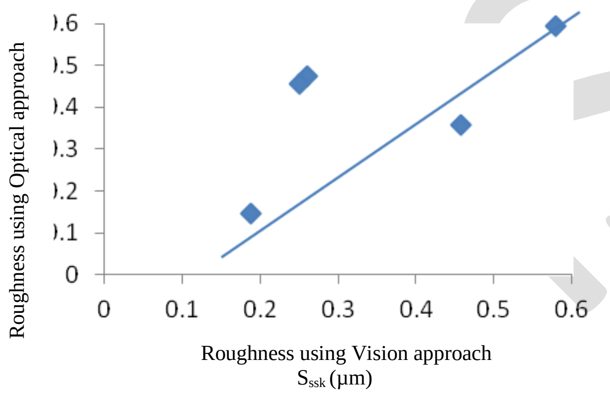
Specimen No	**Experimentation Method**	S_a	S_q	S_{sk}	S_{ku}	S_z	S_v	S_p
M 1	Vision Method	4.221	5.356	0.579	4.856	58.236	30.981	28.215
	Optical Method	4.127	5.630	0.595	4.918	60.598	32.777	27.821
	Error %	2.27	4.86	2.68	1.26	3.89	5.47	1.41
M 2	Vision Method	7.832	9.589	0.261	5.378	91.178	40.856	46.981
	Optical Method	7.623	9.920	0.474	3.771	90.637	42.595	48.041
	Error %	2.74	3.36	4.49	4.26	5.96	4.08	2.20
M 3	Vision Method	8.598	10.410	0.189	3.447	100.001	42.989	58.123
	Optical Method	8.782	10.892	0.146	3.043	97.061	40.457	56.604
	Error %	2.09	4.42	2.94	1.32	3.06	6.25	2.68
M 4	Vision Method	12.121	13.823	0.457	2.892	108.675	43.102	63.231
	Optical Method	11.747	14.285	0.357	2.771	110.899	44.353	66.546
	Error %	3.18	3.23	2.80	4.36	2.01	2.82	4.98
M 5	Vision Method	8.980	8.413	0.250	5.298	91.459	44.245	46.312
	Optical Method	8.744	8.012	0.455	4.935	89.667	45.908	43.760
	Error %	2.70	5.00	4.50	7.35	1.99	3.62	5.83

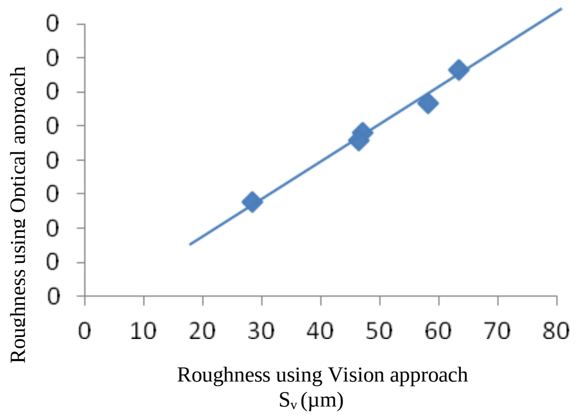


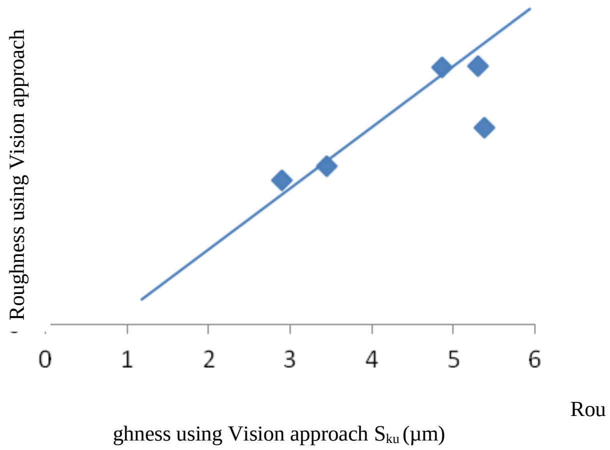












Fig, 6 Graphs comparng roughness values by Vision approach and Optical approach for 3D surface roughness parameters.

CONCLUSION

A non-contact method for 3D surface roughness parameter measurement by Vision system is introduced using phase shifting interferometric technique. The system captures the images of test surface and calculuates 3D surface roughness parameters from the algorithms developed by using MATLAB. These values obtained by Vision method are compared with those obtained by Optical method.

From Table 2, it can be found that the 3D surface roughness parameters values obtained by Vision method are in close aggrement with those obtained by Optical method. However it is observed that there may be s slight measurement error. The error in the measurement can be attributed to resolution of the CCD camera and shifting of grating.

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