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Vision based system for surface roughness characterisation of milled surfaces using speckle line images

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Abstract: In the recent years, many breakthroughs are made in the Image Processing Technology, particularly in areas like satellite imaging and biometrics. This paper presents an experimental approach of vision based surface roughness measuring system using speckle images produced by a line laser beam on milled surfaces. A CCD Camera, line laser source and white light were used for capture the images of milled surfaces. A signal vector was obtained from image pixel intensity and it was processed using MATLAB software. Mean and standard deviation are the two parameters used to characterise the image signal vector. The roughness of the specimens, particularly the Arithmetic mean slope (R_{da}) are computed using a stylus instrument. From the experiments, it is found that mean intensity of the signal vector of the speckle line images correlate well with R_{da} values of the surface roughness. Hence, the mean image intensity value of speckle line images has a strong potential for the online characterisation of surfaces.
Keywords: Surface roughness, milling, computer vision system, image processing, speckle images, statistical parameters.

1. INTRODUCTION

One of the prominent machining operations used for making flat surfaces is milling. The lay patterns produced in milling are important in deciding the finish of a milled surface. This surface finish is of great importance when dealing with issues like friction, lubrication, wear, fatigue and corrosion. The surface profile of machined surface has features like amplitude and wavelength. To measure this surface profile, a stylus instrument is widely used with high reliability. The stylus instrument has an up and down vertical movement depending on the surface profile for a desired horizontal travel. The major limitation of the stylus instrument is that the tip radius of the stylus cannot reach the fine depth of the valleys of the surface texture. [1, 2]. Moreover this type of stylus measurement is an offline process and consumes a lot of time. Other limitation is the damage on the surface due to the contact pressure of the stylus tip, which will become significant if the surface is soft. The objective of the present work is to develop a simple, reliable, robust non-contact surface roughness measurement system. Vision based surface roughness measurement has recently received much industry attention. Machine visions coupled with the application of computers are used in automation of surface characterisation. Considering the imaging techniques and components, the field of machine vision continues to expand.

Speckle metrology is one of the flourishing fields for surface evaluation with the use of vision techniques. Using the laser, high resolution CCD camera, high speed computers and frame grabbers, speckle interferometry is now a powerful measurement technique with many applications [3]. This work is aimed to explore a machine vision approach, for use in surface roughness measurement and characterisation using line speckle images.

The structure of the paper is as follows: Section 2 deals with surface roughness parameters, Section.3 deals with the computer vision systems, Section.4 describes about the image processing, Section 5 describes speckle images, Section 6 deals with the experiment setup and procedure used, Section.7 for Results and discussion and Section.8 for conclusion.

2. SURFACE ROUGHNESS PARAMETERS

Surface texture is the signature that a machining process would leave on the surface. In engineering industry, measurement and evaluation of surface texture is very much important for many functional problems [4]. The real surface texture is very much complex as the surface may combine different wavelengths produced by different machining processes. Characterisation of this surface texture is much significance in engineering. To characterise the surface structure a number of roughness parameters has to be studied. The commonly used surface roughness parameter is roughness average $R_{a,}$

$$R_a, RoughnessAverage = \sum_{I=1}^{N} \frac{|Yi|}{N} \qquad (1)$$

The Yi designate the up and down deviations from the average line. Since the surface topography is very much complicated to evaluate it with the finite number of parameters. To designate a surface two or more surface roughness parameters usually used to calculate the roughness in the two dimensional (2D) or in the three dimensional (3D) forms. Among the different types of parameters being used, there is a hybrid parameter R_{da} [5] is also being used the complex structure of the surface. It is defined as,

$$R_{da}, ArithmeticMeanSlope = \sum_{i=1}^{N} \frac{|\Delta_i|}{N} \qquad (2)$$

In hybrid parameters, R_{da} the arithmetic mean slope of surface profile which is termed as the mean absolute profile slope over the measurement length. Where, Δi is deviations in the slope. In tribological analysis, surface slope, surface curvature and developed interficial area are considered to be the important factors. Since the surface having peaks, valleys and slope, the image intensity variations will be the function of these slope parameter [6]. In the present work, an investigation is made to correlate the surface hybrid parameter R_{da} with the parameters derived from the images of the surfaces. Since the image characteristics are also influenced by slope distributions, an attempt is made to correlate R_{da} parameter derived from the images of the surfaces. Also this work explore a machine vision approach, for use in surface roughness measurement and characterisation using speckle line images.

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3. COMPUTER VISION SYSTEMS

In manufacturing automation, computer vision systems play a very important role. The purpose of computer vision system is to interpret the three dimensional details of the object from two dimensional images. For non-contact online inspection of machined surfaces concern a computer vision-based techniques are highly suitable. Rajneesh kumar et al. [7] evaluated the roughness of machined surfaces by regression analysis and using machine vision system. They have magnified the images by Cubic convolution interpolation technique and used a parameter called $G_a$to correlate the same from surface roughness. Kiran et al. [8] used a CCD camera and appropriate lighting and captured images of resolution 512 x 512 pixels to study the relation between the histogram of surface images and roughness based on the texture unit spectra. A texture unit was defined to contain a set of eight elements representing the intensity value of the neighbouring pixels. For all texture units a frequency distribution and the occurrence frequency was obtained. It was noted that the different texture spectra were obtained for different surfaces in terms of the height and the position of the principal peaks. The texture surface obtained was unique for particular machined surface. Priya et al. [9] investigated the influence of inclination of the component using vision system and image processing by knowingly maintaining the work pieces at different angles. They have compared the optical surface finish with the conventional stylus measured roughness values. Artificial neural network (ANN) was developed and trained to obtain surface roughness values using the digital images of the test surfaces as input. Optical roughness parameter and angle of inclination of the test surfaces were used as input parameters. A shadow removing algorithm was incorporated to enhance the image quality. Surface roughness thus estimated showed good correlation with the values of the stylus instrument. Tian et al. [10] reviews light scattering on vision systems. They have proposed two methods angular-resolved scatter and total integrated scatter for roughness measurement. Polarization of the incident light is used in ARS method and in TIS method, the scattered light goes in to a hemisphere setup from the investigated surface, finally the scattered light was collected and measured. From this an integrated method to measure roughness, waviness and form is proposed. Lee et al. [11] used a computer vision system for self organizing adaptive modelling method and a polynomial network to relate between the surface image features and the actual surface roughness using different machining conditions. Shahabi et al. [12] used a CCD camera to capture the nose area of a cutting tool image during the machining operations and to capture the machined edge profile of the specimen. The machine was switched off for capturing the images and a wiener filtering is used to remove the noise. A Response surface methodology (RSM) is used and the roughness average R_a is obtained as output of that model. The various cutting conditions are extracted from the simulated profile data of the RSM model and the real work pieces in real time machining operations is verified with this predicted models.

4. IMAGE PROCESSING

Image processing has shown reliable applications in several fields. The Iris recognition and fingerprints recognition are the well-established areas. Many commercial techniques are available in these image processing. Ma et al. [13] used key sharp variation points in the iris image signal for human identification. Iris images were captured and the one dimensional intensity signal of each image was generated. Lighting variations are overcome by normalization of the iris image. In this image processing, the important method is to capture the key sharp variations along the x direction. The representation of 5 rows to a one dimensional signal is obtained from averaging the intensity values of 5 rows. There are consecutive rows were used to obtain an image signal and 10 such signals were combined. Then a feature vector was obtained through a wavelet transform. Then iris image signal was decomposed with different scales. Two consecutive scales were used to characterize the iris image signals. In this iris recognition methodology, to calculate the similarity and matching the exclusive OR operation is used. Jeyapoovan et al. [14] adopted the same iris recognition methodology

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in their work for machined surface characterization using the Euclidean distance and Hamming distance as matrices. A CCD camera and white light source, for obtaining the machined surface images were used. MATLAB software is used for signal vector generation from image pixel intensity. A database of reference images with known surface roughness values were used to find the surface roughness values of the test surface by comparing them using the metrics.

5. SPECKLE IMAGES

Laser speckle image obtained using laser light was considered for surface roughness measurements. A grainy image is generated from the scattering of light on the surface when, a beam of collimated laser light is directed to that rough surface, and it is called as speckle images. Fig 1 shows a speckle image.

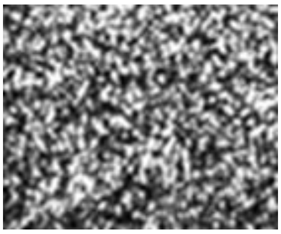

Figure 1. Speckle image.

Leonard et al. [15] used laser speckle contrast method for studying finished surfaces by demonstrating a linear relationship between contrast of the speckle image and the roughness. The angle of incidence of laser beam was set to 30° and 80°. It was observed that an increase in the measurement angle by a factor of 4 for finished surfaces, with a higher value of 0.4 µm, and by factor of 2 for polished surface with a surface roughness of 0.2 µm. Pearsson et al. [3] used angular speckle correlation technique for roughness measurements in the machined surfaces. A video camera was used to capture the speckle pattern by illuminating the surface using laser beam. By changing the illumination angle by 0.5° a yet another speckle pattern was recorded. The characterization is done by the correlation of two differently taken speckle images. This approach was found suitable for surfaces with average roughness, R_a, less than 1 µm. A monochromatic speckle correlation technique to evaluate surface roughness was proposed by Dhanasekar et al. [16]. To establish the relationship between surface roughness and speckle patterns, the speckle pixel intensities were used. Surface roughness measured using stylus instrument was used to correlate the results obtained based on the speckle pattern. Jeyapoovan et al. [17] used the speckle image pixel intensity parameters to evaluate the roughness of the surface. They used the statistical parameters skew, kurtosis, mean, standard deviation and variance, and to correlate the ground specimens and milled specimens. They found to have a positive correlation with the intensity parameters of captured images and the roughness values R_a obtained using Talysurf instrument. Also they found the correlation is showing good results for milled surfaces rather than ground surfaces.

6. EXPERIMENTAL SETUP AND PROCEDURE

In this Investigation, the experimental setup and procedures consists of the following steps

- Milled specimen preparation on EN8 plain carbon steel
- Contact type roughness measurement using stylus instrument
- Image acquisition using CCD Camera
- One Dimension image signal vector generation

In this experiment EN8 flat plain carbon steel was used as a work piece material. Seven different specimens were milled with different roughness values using dry milling. The cutter diameter used

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was 50 mm and cutting was performed by fly milling. Since, the significant process parameter that affects the surface roughness is feed, the feed value alone was varied, the depth of cut was kept constant at 0.1 mm and the cutting speed was kept at 290 m/min. The different feed rates used in the milling were 0.5405, 0.5676, 0.5946, 0.6216, 0.6486, 0.7567, 0.7838 mm / tooth. Fig. 2 shows the milled work pieces.

Figure 2. Milled work pieces.

The contact type stylus instrument was used for measuring the surface roughness. The Talysurf surface roughness tester used for roughness measurement is shown in figure 3. The tip radius of the stylus used was 2 µm. The cut-off length value of 0.8 mm is used for a surface data length of 6 mm. Approximately the central region of the specimen was chosen for roughness measurement. The talysurf instrument was connected to a computer to control the surface roughness measurement and process the measured surface data to compute the roughness parameters Ra, R_{da}, R_{dq} etc. Stylus diamond tip has to be vertically moved over the specimen using a computer controlled motor. This movement of the stylus across the surface generates the electrical signal, which undergoes amplification and an analog to digital conversion. The resulting digital profile stored in a computer and used for the analysis of roughness parameters. Using this data, the roughness values were computed. A representative surface profile measured along with the roughness parameter R_{da} is shown in Figure 4. Table 1 shows the various roughness values of the milled specimens.

Figure 3. The Taylor and Hobson surface roughness tester (Talysurf).

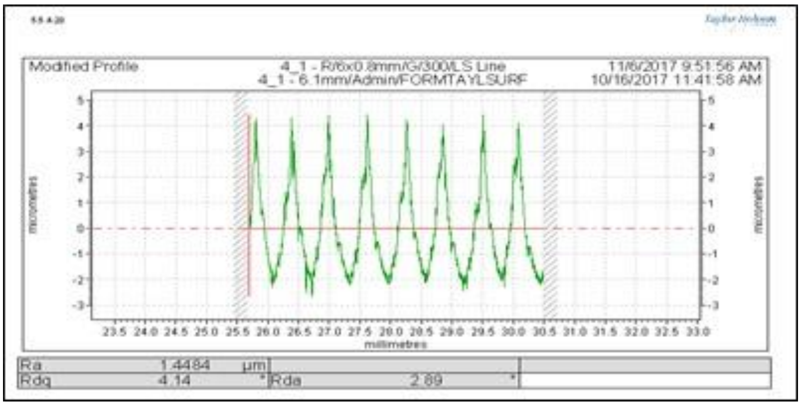

Figure 4. A Representative Surface roughness profile.

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Table 1. Various roughness values of the work pieces.

S. No	Feed mm/tooth	R_a µm	R_{da}
1	0.6216	1.4484	2.89
2	0.7838	1.9138	3.31
3	0.7567	1.8055	3.52
4	0.5676	1.3753	3.77
5	0.5405	1.2767	3.80
6	0.6486	1.5571	3.84
7	0.5946	1.4821	3.89

A high resolution CCD camera, fitted with an optical magnification zoom lens was used for image acquisition. The specification of CCD camera is given in table 2. The lighting system with line laser and white light was used to capture the speckle and white light images. The camera and the specimen were placed on an adjustable table and the camera set at an angle of 90° to the specimen surface. The same camera and lighting conditions were used for capturing the images of all surfaces. The coaxial white light is used with uniform illumination. A separate line laser source is used for speckle image acquisition. The line laser source with the separately designed camera table is shown in figure 5. Figure 6 (a & b) shows the images obtained for milling specimens before normalization using white light and line laser source. After the image acquisition normalization was carried out to overcome the lighting variations. The normalization of the pixel intensity of the image matrix was obtained using mathematical transformation given by equation [18].

$$h(p,q) = \left(\frac{k(p,q) - min(k)}{max(k) - min(k)}\right) \times 255 \qquad (3)$$

The h(p,q) is the normalized pixel intensity of the image matrix, k(p,q) is the pixel intensity of the image matrix, min(k) & max(k) are the minimum and maximum value of the pixel intensity of image matrix.

Table 2. The specification of the CCD camera.

Item	Specification
Sensor type	Siny ICX625ALA/AQA Progressive scan CCD
Sensor size	2058 x 2456
Pixel data format	Mono 8 bit
Data output type	Giga bit Ethernet (1000 Mbits/sec)
Max frame rate (at full resolution)	12 fps
Exposure control	Programmable via the camera API
Synchronisation	Via software
Power requirement	5.4 W @ 12V DC
Image dimension	2058 x 2456 Pixels
Camera Size (L x W x H)	98.5 x 44 x 29 mm (with adaptors & connectors)
Weight	220 g (approximately)

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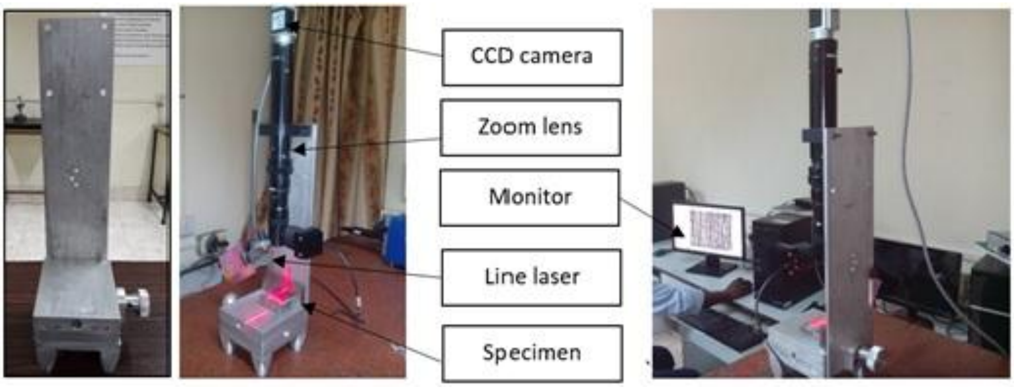

Figure 5. The Camera table and the experimental setup.

This normalization was done to eliminate the influence of unevenness is illumination. It was carried out on all the images. The normalized white light images and speckle images are shown in figure 7 (a & b). Finally, a single line signal vector was generated by averaging the respective 3 columns from the 3-pixel rows of the white light image and speckle image. This was done to the middle portion of the images taken. All these image processing was done by MATLAB 2014 by writing a separate program modules. The one dimensional image signal was generated for each surface image. The middle portion of the image was identified to derive the image signal for white light and speckle images by selecting three pixel rows of length 2000 pixels. The reason for selecting 3 rows was based on the width of the stylus tip. An image matrix of size 2058 x 2456 is shown in figure 8.

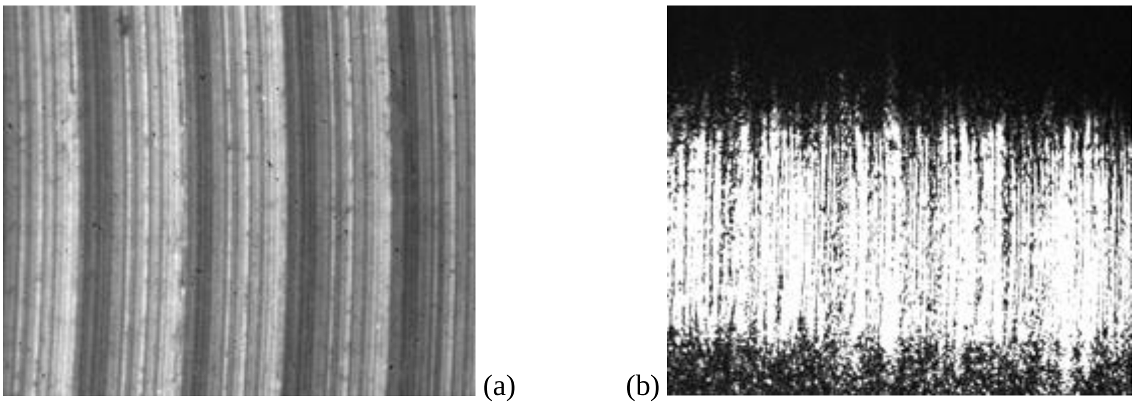
(a) (b)

Figure 6. (a & b) Images of the specimens taken by (a) White light (b) Line laser source.

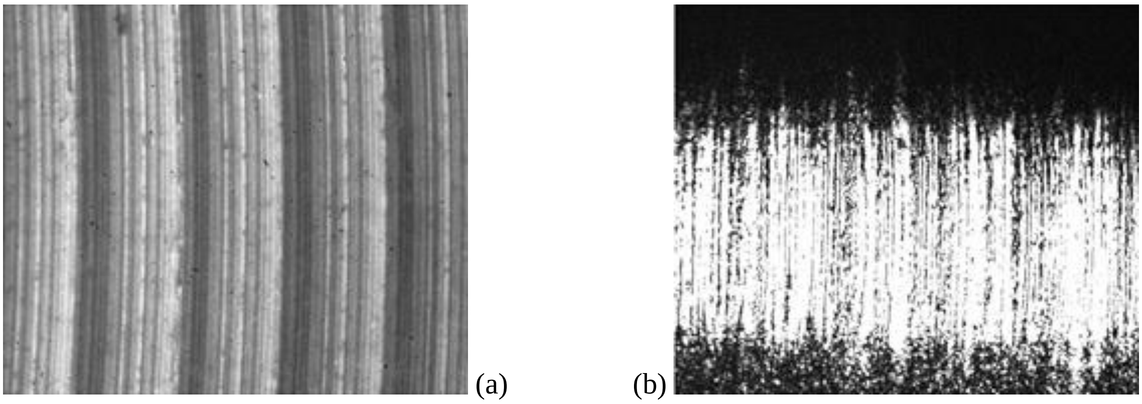

Figure 7. (a & b) Normalised Images of the specimens taken by (a) White light (b) Line laser source.

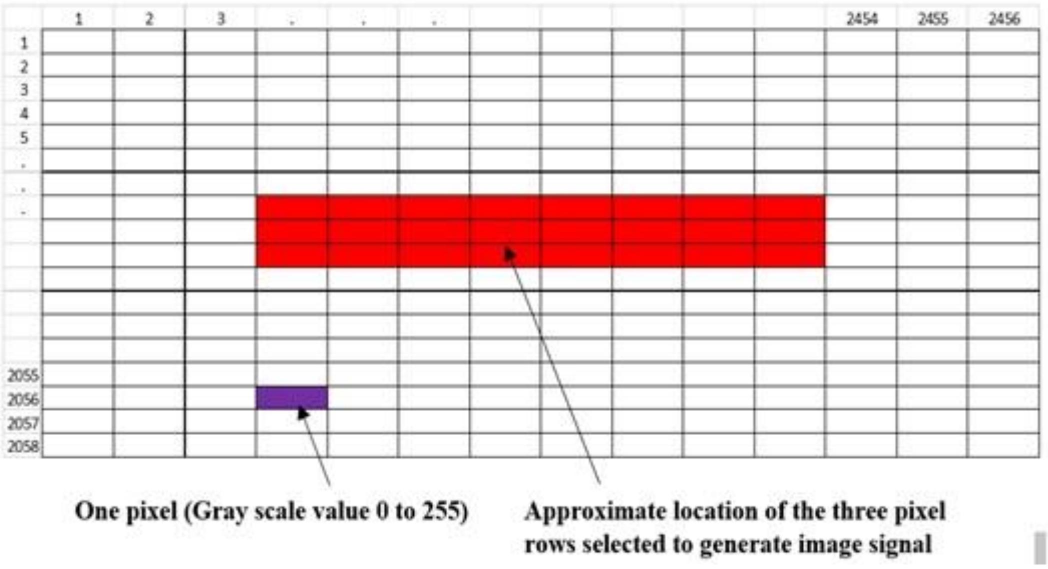

Figure 8. The representation of an image matrix.

7. RESULTS AND DISCUSSION

The mean and standard deviation of the image signal vector was obtained for each components speckle images as well as white light images. The statistical parameters of image pixel intensity is shown in Table 3. The correlation of the roughness from the image parameters of the test surface is obtained by comparing the parameters of image pixel intensity with the hybrid surface roughness parameter arithmetic mean slope R_{da}.

Table 3. The statistical parameters of image pixel intensity**.**

S.No	R_{da}	Image Pixel Intensity			
		Line Laser Light		White Light	
		Mean	Standard Deviation	Mean	Standard Deviation
1	2.890	122.752	45.188	128.847	33.755
2	3.310	198.401	79.581	122.752	45.188
3	3.520	202.015	78.336	125.362	55.918
4	3.770	219.948	67.763	152.240	46.174
5	3.800	210.455	73.851	139.422	38.190

6	3.840	207.060	76.198	145.448	41.757
7	3.890	230.556	56.733	160.837	36.155

The plot of mean of image pixel intensity with R_{da} for line speckle images is shown in figure 9. The plot of standard deviation of image pixel intensity with R_{da} for line speckle images is shown in figure 10. It can be observed from the trends that the mean value of the image intensity vector correlates better with roughness parameters R_{da} than the standard deviation for line speckle images. This is quite expected as the mean value of the image intensity is even though influenced by the effect of ambient lighting which was removed by normalization and this effect is less when the images are obtained on flat components.

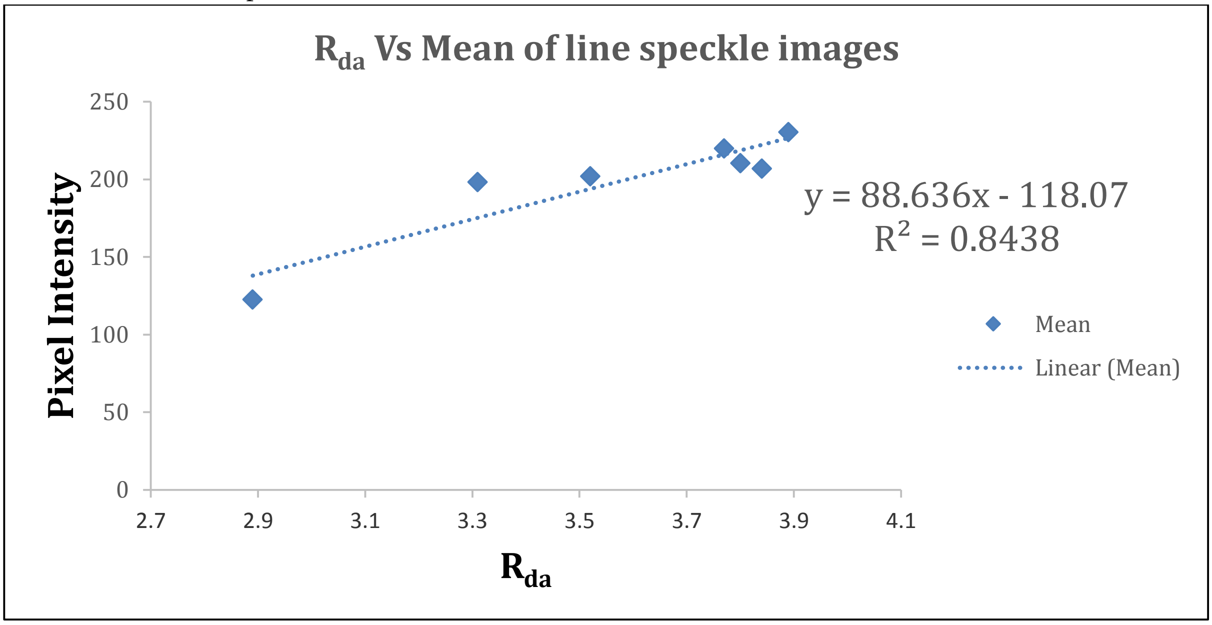

Figure 9. The correlation of mean of image intensity with R_{da} for line speckle images.

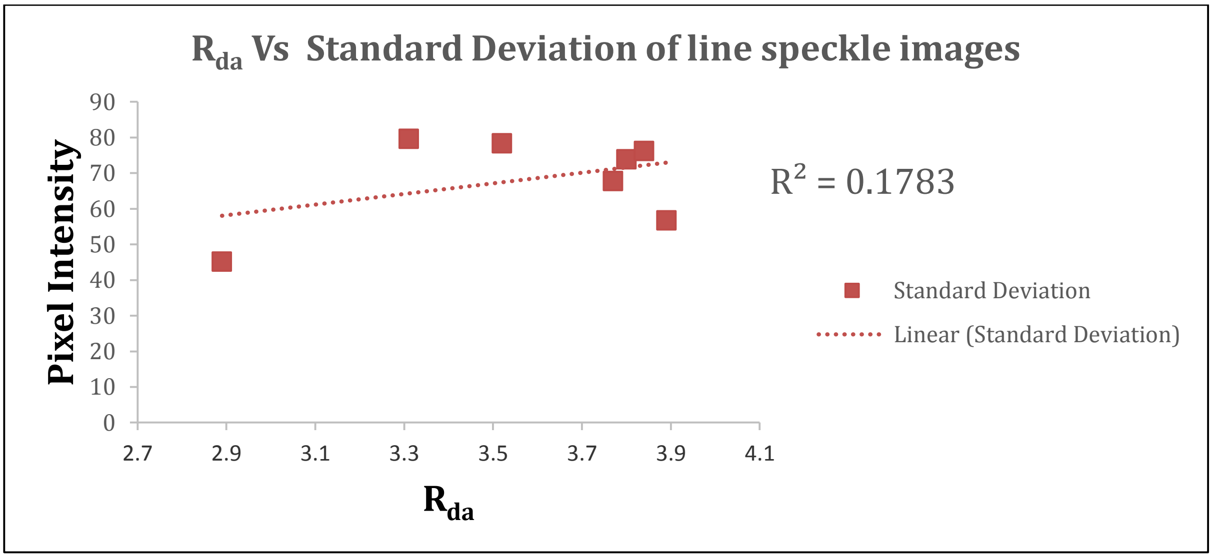

Figure 10. The correlation of standard deviation of image intensity with R_{da} for line speckle images.

The correlation of standard deviation of the image intensity vector with the surface roughness parameters is not good. This means, the level of dispersion of the image intensity value is not capable of measuring the roughness of the surface for line speckle images.

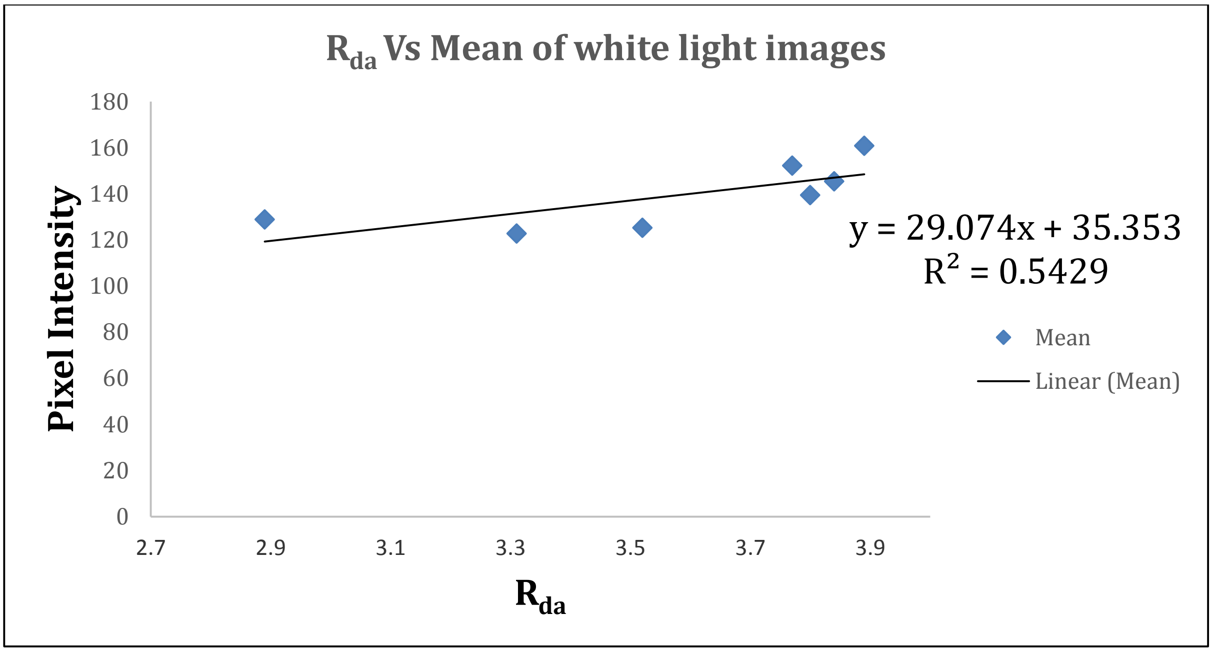

Figure 11. The correlation of mean of image intensity with R_{da} for white light images.

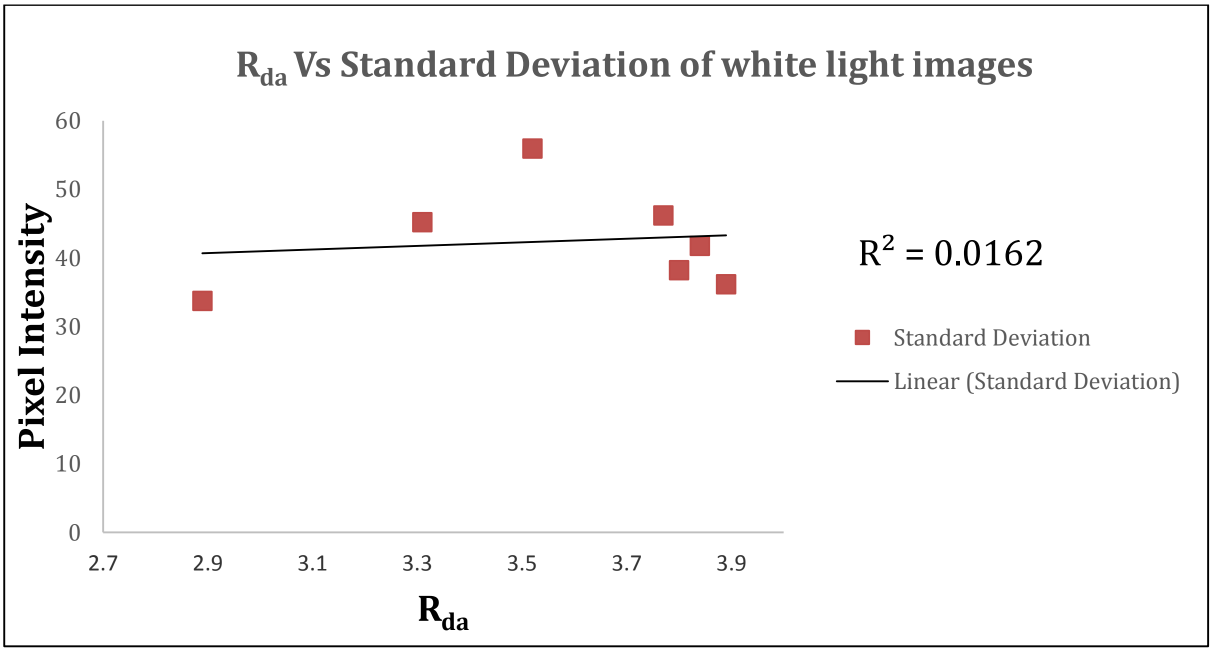

Figure 12. The correlation of standard deviation of image intensity with R_{da} for white light images.

The plot between the mean of image pixel intensity and R_{da} for white light images is shown in figure 11. The plot of standard deviation of image pixel intensity and R_{da} for white light images is shown in figure 12. It can be observed from the figures that the mean correlates better with roughness parameters R_{da} than the standard deviation for white light images also. But the correlation coefficient is less compared to correlation of line speckle images of the specimens.

The poor correlation in white light images is primarily because of the shadow effect caused by the peaks of the surfaces on the neighbouring areas. Depending on the angle of incidence of a light ray the peaks tend to alter the intensity values of the neighbouring regions. The use of coaxial white light source was to reduce this influence. But experiments demonstrate that this influence cannot be altogether eliminated.

The R^2 values, which shows the effectiveness of correlation, for mean and standard deviation of the line speckle images as (0.8438, 0.1783) and R^2 value for the mean and standard deviation of white light images as (0.5429, 0.0162). Since, the surface slope at each point of the surface influences the line speckle pattern, the surface roughness parameters Arithmetic mean slope (R_{da}) is used to characterize the milled surface by line speckle images in this work.

8. CONCLUSION

- A non-contact vision based image processing method for roughness evaluation of milled surfaces is attempted in this work. At first a set of 2-D speckle and white light images of milled surfaces were obtained. The mean and standard deviation of the image pixel intensity for line speckle and white light images were calculated from each surface image.

- With white light imaging the correlation between the image parameters and the stylus parameters were found to be very poor. This could probably be because of the influence of the angle of incidence of the light source on to the surface leading to the peaks causing shadows on the immediate vicinity.

- The mean speckle image intensity parameters correlate very well with the stylus parameters.

- The stylus hybrid parameter Arithmetic mean slope (R_{da}) was found to correlate well with the speckle line image parameters as the slopes at various points on the free surface are responsible for the reflection of light rays.

- The technique of using the mean of the speckle line images for noncontact evaluation of surface roughness is promising. The reliability of measurement can be established through experiments of bigger sample size.

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