Reliable Image processing method for non-contact evaluation of surface roughness - an in-vitro speckle image study in EDM

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***Abstract* — In order to understand the tribology and wear characteristics of manufactured products, surface roughness is a crucial parameter. A desirable criterion that affects productivity and the functioning of mechanical parts is surface finish. The majority of surface roughness measurements in a traditional process are obtained in an offline manner using the arithmetic average of absolute values (Ra). The primary goal of this work is to propose a robust image processing methodology for the evaluation of the EDM machined surface speckle pictures, together with an optical system intended for surface roughness measurement in an online mode of assessment. To facilitate further analysis and association with the stylus parameter Ra, the surface speckle pictures in this inquiry are cropped using MATLAB's image processing tools to an analogous stylus tip radius of 2 µm (5 x 2048 pixels). Rather than processing the image metrics of the entire 2058 x 2456-pixel image, this image processing approach provides a consistent, high correlation with image metrics in the range of 0.96.**

Keywords— EDM: Surface roughness: Image Processing: Image metrics: Linear Correlation

I. Introduction

The majority of industrial settings use either non-contact or contact stylus-type measurement techniques for surface finish inspection and evaluation. In order to measure contact, the item must typically be taken out of the machine, cleaned, and tested using an offline surface finish measuring device. Then, the machine must be adjusted as needed. In non-contact measurement using interference principle or light scattering methods the measurement is achieved. The primary drawback of taking these kinds of measurements with a stylus tool is that it necessitates direct physical contact, which slows down the measuring process. Furthermore, the instrument values are derived from a small number of line samplings, which might not accurately reflect the surface's true properties. This kind of variation, particularly when the surface profile is periodic, could lead to significant mistakes in the evaluation of surface quality. Contact type instruments are not appropriate for high-speed automated inspection due to these disadvantages.

A. Speckle pattern

A scatter light from a laser source illuminates the surface particles that are being studied. The surrounding particles then cause either constructive or destructive interference with this scattered light. A speckle pattern is produced by the combination of these constructive and destructive interferences. An intensity pattern created by a group of wavefronts mutually interfering is called a speckle pattern. Scientists have studied this phenomenon since Newton's time, but since the development of the laser, speckles have gained attention and are currently used in many other fields. The figure 1 shows a typical speckle image of a machined surface.

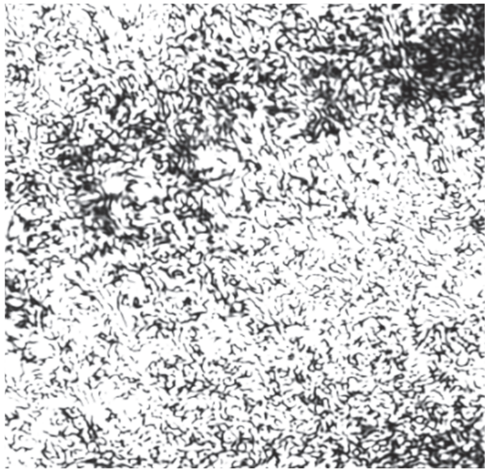

Figure 1 Speckle Image

B. Surface roughness parameters

Determining the statistical characteristics of rough surfaces and measuring surface roughness are crucial in many scientific and engineering domains. Surface roughness can be characterized using a wide range of factors. Different rough surfaces can be distinguished from one another using surface roughness metrics. The most commonly utilized statistical parameters are the average surface roughness (Ra) and the root mean square surface roughness (Rrms, Rq). Ra is the preferred component in mechanical engineering, whereas Rq is employed in optics due to its great precision.

II. LITERATURE SURVEY

Prior studies have assessed surface texture using machine vision techniques, covering a number of computed parameters and measuring average roughness (area) on the same surface using a stylus profilometer. Many papers have been presented in speckle correlation techniques. Using the pixel intensity of the surface picture, Jeyapoovan et al. [1] conducted an experiment with milled and ground specimens to analyze statistical parameters like mean, variance, etc. It has been demonstrated to correlate positively with the average roughness values that stylus profilers yield. Nicklawy et al. [2] presented a straightforward technique that uses the digital Fourier transformation of speckle patterns captured on a CCD camera at various object positions to measure surface roughness for objects. The SPBI (Statistical Properties of Binary Images) technique was introduced by Ersin Kayahan et al. [3]. This technique makes use of the combined effects of speckle and scattering processes. A substantial correlation was discovered between these characteristics. An experimental technique for measuring surface roughness based on the coherent speckle scattering pattern produced by a laser beam on machined surfaces (milling and grinding) has been reported by B. Dhanasekar et al. [4]. When compared to a stylus, the Ra values showed that the implementation was successfully used in practice. Roughness parameter estimation and quantification are done using this method. The spatial average technique (SAM), as it is often known, is a method that Xuezeng Zhao et al. [5] introduced. It is based on the spatial average analysis of the objective speckle pattern in the specular direction. It can measure surfaces with a small amount of roughness and perform online measurements, which removes the effects of diffuse light. Using a laser speckle pattern analysis created from lapped, ground, and milled surfaces, Motochika et al. [6] have provided a method for measuring the roughness and periodicity of surface structure.

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The surface texture is described by this approach across a broad range of Ra<1000nm, Rc<500nm, and RSm<600µm. Using a CCD camera, A.M. Hamed et al. [7] have experimented with various metal rough surfaces and acquired digital speckle images. The MATLAB software is used to examine and assess the digital binary images. It is demonstrated that the level of aggregation of the speckle images determines the surface roughness of the surfaces under examination. A dynamic speckle method (DSM) was proposed by Zhao Gao et al. [8] to predict the granularity of weak-scattering surfaces in motion, they examined the dynamic speckle intensity's statistical properties that the rough surface produced. Theoretical derivations and computer simulations demonstrate that the new approach is robust to machine tool vibration, insensitive to surface correlation length, and simple in terms of measuring principle. This indicates that in-process applications could benefit from the DSM.

Hatem El-Ghandoor et al. [9] used an optical imaging system in two and three dimensions with a high-resolution CCD camera to study the digital speckle pictures captured for various rougher and smoother surfaces. Reconstructing three-dimensional surface roughness profiles from multi-directional projection data was done using the interference microscope and the back projection method. The experimental findings confirm that the surface roughness measurements are coincident. Experimental research on the statistical characteristics of dichromatic speckle patterns was conducted by Hitoshi Fuji et al. [10]. The RMS difference in two normalized intensity fluctuations in a dichromatic speckle pattern generated in the far field of the object surface is used to calculate the RMS surface roughness of both glass and metal rough surfaces. Persson et al. [11] gave a study on angular speckle-correlation surface roughness measuring on machined surfaces. They have tested surfaces with a roughness of 1.6 < Ra < 6.3µm, classifying the surfaces in the same way as using a stylus tool. This method makes it possible to measure the surface roughness of machined surfaces while they are being produced. The efficacy of the machine vision system in analyzing the surface roughness of machined surfaces has been tested by Dhanasekar et al. [12]. They came to the conclusion that this method is most appropriate for online surface roughness measurement after using the geometric search strategy for photos of machined parts with different surface roughness that were produced through shaping, milling, and grinding. The metallic surface roughness of specimens manufactured by spark erosion procedure, with roughness ranging from 0.4 to 12.5µm, was measured by S. L. Toh et al. [13] using a whole-field speckle approach. The integrated autocorrelation coefficients of the speckle gram and a logarithmic relationship between the surface roughness and intensities were obtained and examined using point-wise filtering. The trial produced encouraging outcomes.

III. METHODOLOGY

In this experimentation, the following steps are used for non-contact evaluation of the surface roughness. They are (i) Specimen preparation by machining in EDM (ii) Contact surface roughness measurement using a stylus instrument (iii) Speckle image acquisition using a CCD camera (iv) Mining out the 1D signal vector from surface speckle images (v) linear correlation between stylus parameter and speckle image parameters.

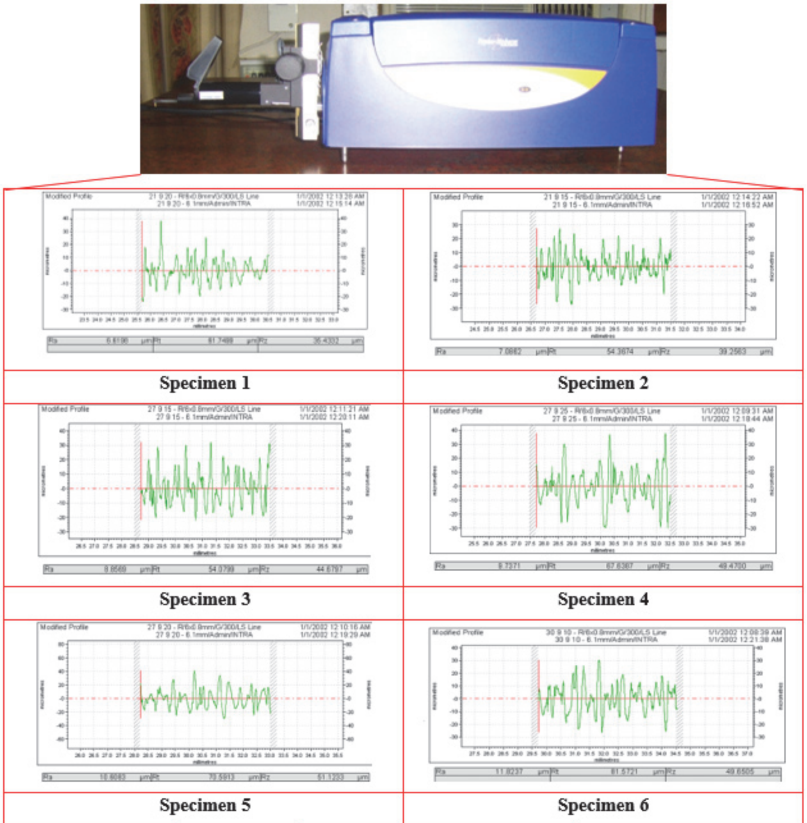
A. Specimen preparation by machining in EDM

The spark erosion and EDM machining process is the first step in the experimental technique, yielding fifteen specimens with different levels of roughness, from that the six specimens with distinct differences in the surface roughness Ra were considered for further investigation. The varying surface roughness is obtained by varying the current (I) and the Time-on, Time-off. The work piece selected is mild steel and the tool used is a cylindrical copper rod of diameter 12mm, giving an impression of 12mm. The Electrical Discharge Machine employed and the obtained specimen image is shown in the figure 2. The specifications of the Electrical Discharge Machine 500 x 300 mm Electronica are, travel of X x Y x Z of 280 x 200 x 250 mm, work tank dimension of 725 x 415 x 315 mm, dielectric capacity of 50 liters, DC Servo with speed-up function and ergonomically designed control panel.

Figure 2: EDM 500 x 300 Electronica with machined component

B. *Contact surface roughness measurement using stylus instrument*

Using a Taylor and Hobson Talysurf stylus instrument with a variable inductance type transducer as the pick-up and a diamond stylus tip with a radius of 2µm that imposes a force of 4 mN and a maximum traveling length of 50 mm, the surface roughness of the fifteen specimens was measured. The specimens under investigation had surface roughness values Ra ranging from 6µm to 12µm. Six unique specimens with a Ra value out of fifteen are taken into consideration. Since the profilometer measurement is made along a line, an average of the measurements was used to determine each specimen's roughness value. The image of the talysurf along with six various profiles and corresponding roughness values are shown in figure 3.



Specimen No	T On	T Off	I Current	Stylus Parameter Ra (µm)
1	21	9	20	6.6198
2	21	9	15	7.0862
3	27	9	15	8.8569
4	27	9	25	9.7311
5	27	9	20	10.6083
6	30	9	25	11.8237

Figure 3 Taylor and Hobson Talysurf Stylus Instrument with surface profiles

C. *Speckle image acquisition using CCD camera*

A polarized He-Ne laser source with a wavelength of 632 nm and a Basler PiA2400-12gm CCD camera with a Zoom 6000 lens that allowed for optical magnification up to 45.0X made up the vision system. Two movable arms installed on a table were utilized to hold the camera and laser source in the desired location. The laser source's angle was adjusted with a protractor to 45 degrees, making it incident on the work piece at that angle. with the laser angled 45 degrees toward the specimen being studied and the camera positioned perpendicular to the specimen. At a resolution of 2058 X 2456, speckle pictures of every item were taken and saved for later image processing. The eight-bit, greyscale speckle pictures had values ranging from 0 to 255. The image acquisition setup and the speckle images obtained are shown in the Figure.4. These speckle images are further image processed using the MATLAB.

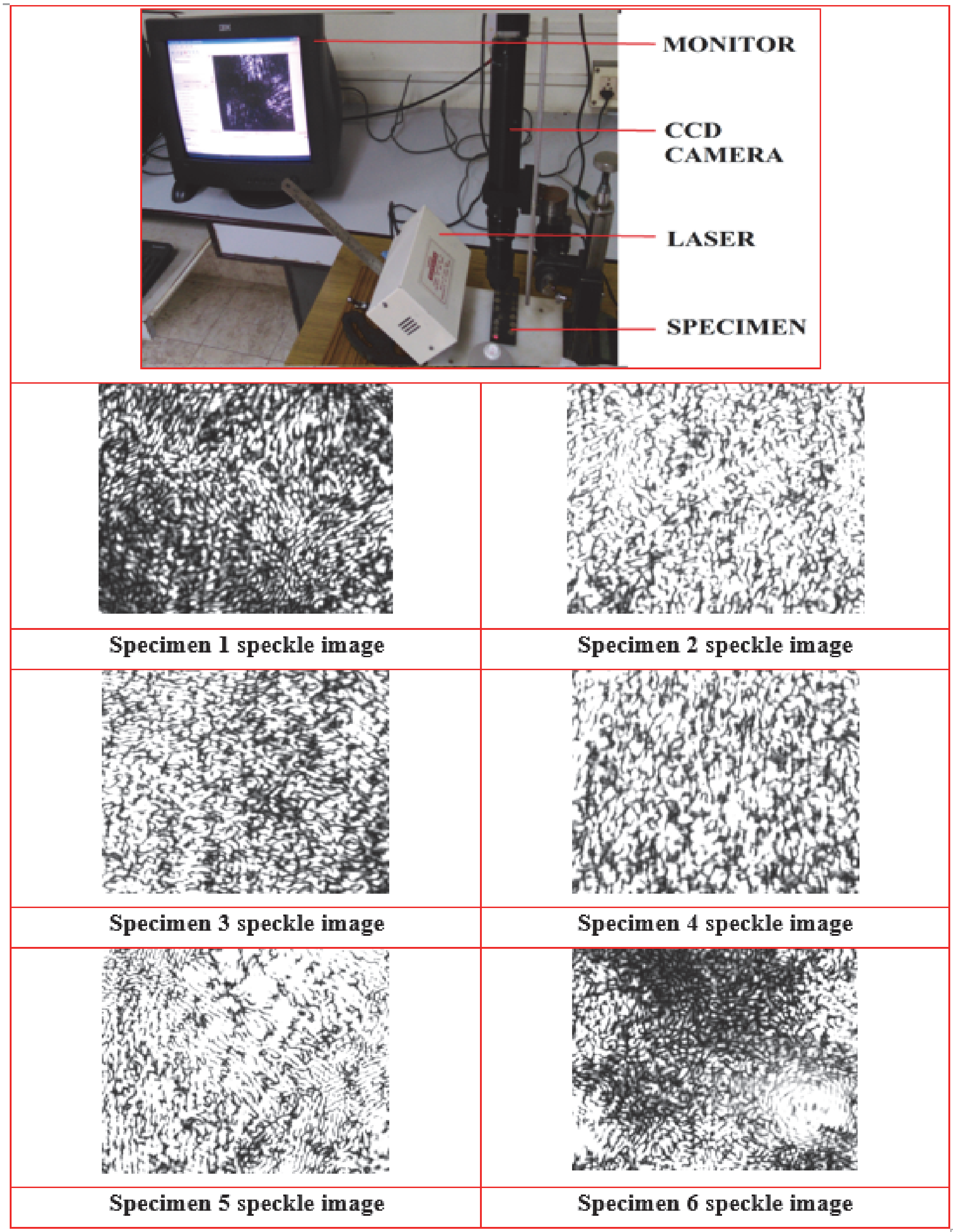


Figure 4 Image acquisition setup and the speckle images

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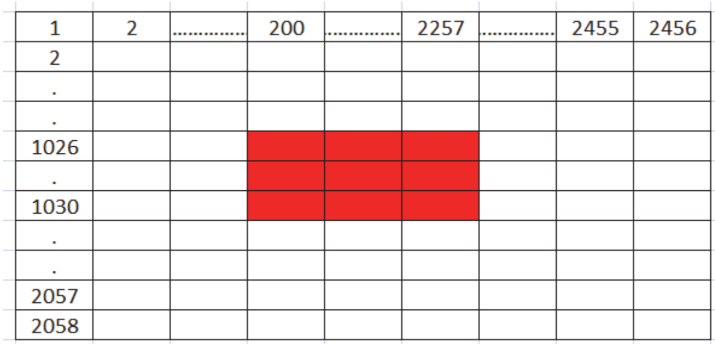


Figure 5 Image Signal Generation

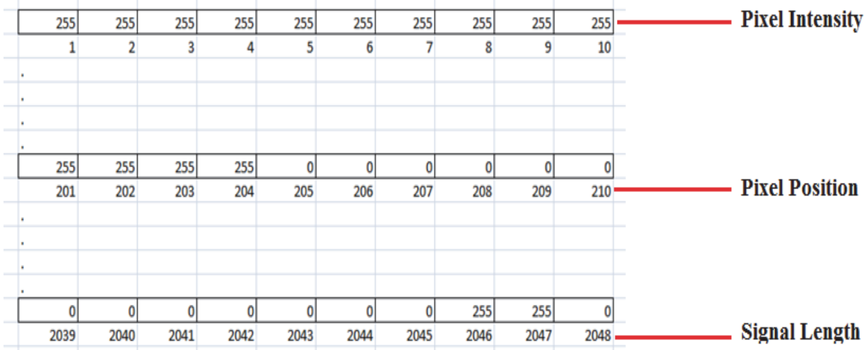


Figure 6 A typical image signal vector

D. Image Normalization

To ensure homogeneity in the distribution of pixel intensities, the image is normalized. Prior to analysis, the speckle pictures of the specimen under research that were produced using the aforementioned procedures are normalized. The formulation is used to carry out the normalizing process is,

$$g(x,y) = \frac{[f(x,y) - \min(f)]}{\max(f)} \times 255 \qquad (1)$$

The image intensity matrix is denoted as f(x, y), where g(x, y) is the normalized image intensity matrix and min (f) and max (f) are the minimum and maximum values, respectively, in the image intensity matrix. An 8-bit image's maximum grayscale value,255, is multiplied by the values from the previous step to create a grayscale image with pixel intensities ranging from 0 to 255. MATLAB was used for processing the speckle images.

E. Mining out the 1D signal vector from surface speckle images

The diameter of the stylus tip used in the experiment is 2µm, approximately the length of three-pixel rows. The speckle images obtained do not contain a pattern and are randomly positioned. The images are a random spot of minimum and maximum value. Hence five pixels in the Y-axis are taken to get an approximate result. This method is to give an extra portion and this removes the error which would take place due to the random process.

To get rid of the impacts brought on by the lightning effects, the edges are erased. As a result, for assessment, the 2058 x 2456 resolution photos are cropped to 5 X 2048 pixels. The Stylus Instrumentation works on the methodology of averaging. However, averaging is a statistical parameter used when a systematic procedure is followed. The speckle images obtained lack an order and hence averaging cannot be applied.

The normalized image is cropped to 5 x 2048 pixels, i.e. it contains five rows with 2048 columns. The method appreciates averaging the five rows as a single row to obtain 1–D signals. This is processed using algorithms in the MATLAB software. The image is cropped as shown in the figure. 5. A typical image signal vector is shown in figure 6.

F. Linear correlation between stylus parameter and speckle image parameters:

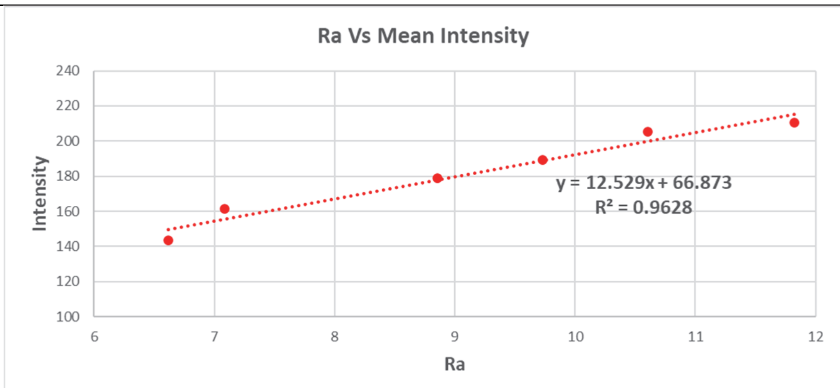
The correlation curves are plotted between the stylus measured parameters Ra with the image parameters (mean & standard deviation) of speckle image intensity of the cropped image equivalent to the stylus tip area and the speckle image intensity (mean & standard deviation) of the whole speckle image area.

IV RESULTS AND DISCUSSION

The image parameters arrived from the image pixel intensity from MATLAB software for the cropped stylus size area and the whole image area is noted and tabulated. Table 1 shows the image parameters and the stylus parameters for the six specimens. For the tabulated values of six specimens the correlation curves were plotted and shown in the figure 7 for the speckle image intensity of the cropped image equal to the stylus tip area.

From the curve it is found that the mean of the image parameter shows a good correlation with a correlation coefficient of 0.96 with an error of 4%, which is because of the lighting variations in the speckle image formation even though the normalization of the images was done on images. The mean intensity curve with Ra values is shows a positive correlation with the increase in mean intensity the Ra values are increasing. The curve can be used as a calibration curve for EDM surfaces in which we can find out the unknown roughness of any sample surfaces without using the stylus instrument.

The standard deviation of the image parameter shows a moderate correlation with stylus parameters with a correlation coefficient of 0.72, it is because of the more dispersion is intensity values due to the laser light interference in the speckle image formation.



(a)

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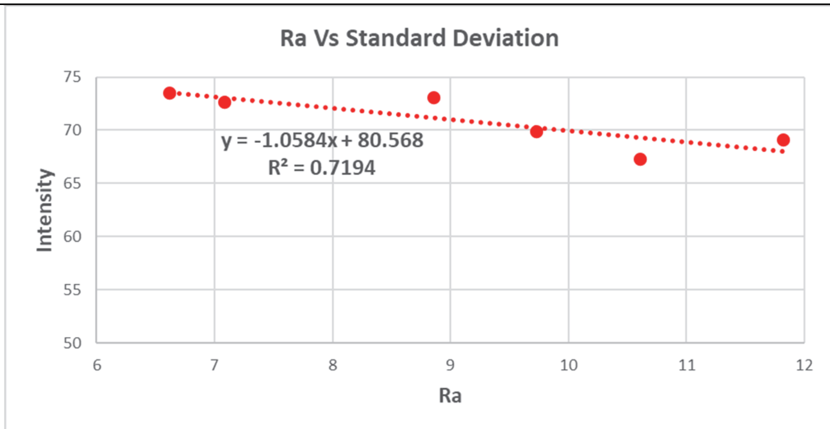


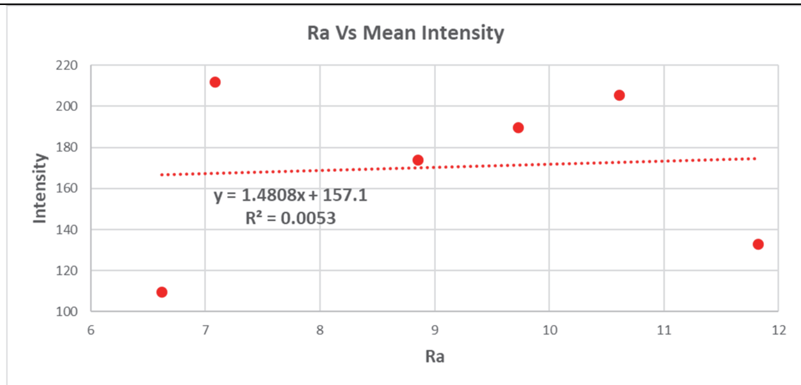
(b)

Figure 7 Plots of speckle image intensity of the cropped image equal to the stylus tip area.

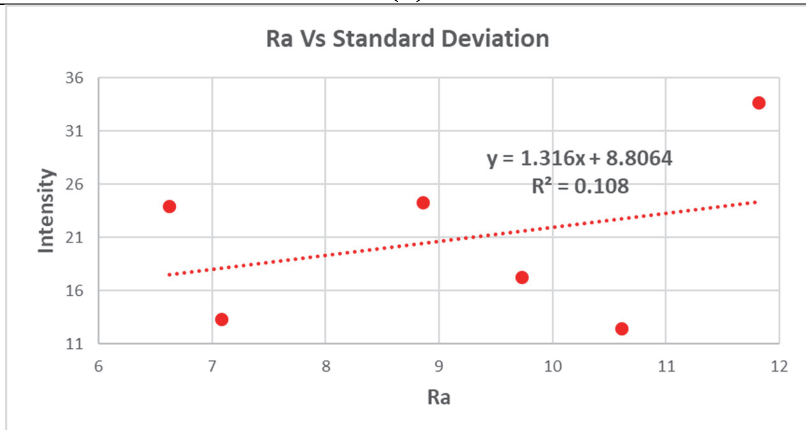
TABLE 1 THE IMAGE PARAMETERS AND THE STYLUS PARAMETERS FOR THE SIX SPECIMENS

Specimen No	T On	T Off	I Current	Stylus Parameter	Image Parameters			
				Ra	Speckle Image Intensity (stylus tip area)		Speckle Image Intensity (whole area)	
				(µm)	Mean	Std	Mean	Std
1	21	9	20	6.6198	143.198	73.5129	109.513	23.9194
2	21	9	15	7.0862	160.95	72.6451	211.876	13.2764
3	27	9	15	8.8569	178.765	73.0401	173.88	24.2628
4	27	9	25	9.7311	188.946	69.9056	189.766	17.3015
5	27	9	20	10.6083	204.951	67.3062	205.541	12.4251
6	30	9	25	11.8237	210.088	69.0717	133.062	33.6703

However, the plots of the speckle image intensity of the whole image show a very poor correlation which is shown in the figure 8. From the plots, it is seen that the intensity values are very scattered and the correlation curve is almost flat so extracting the unknown surface values is difficult.



(a)



(b)

Figure 8 Plots of speckle image intensity of the uncropped image of the whole area

V. CONCLUSION:

In order to develop a dependable image processing technique for the non-contact assessment of surface roughness in EDM machined surfaces, six specimens with surface roughness ranging from 6 to 11 µm are exposed to laser light. A CCD camera with 2058 x 2456 pixel size is used to acquire a speckle image. MATLAB software was used to handle the acquired images in order to do additional analysis and draw the following conclusions:

- The central region of the collected speckle pictures, which is roughly comparable to three-pixel rows and equal to the stylus tip diameter of 2 µm, was clipped and subjected to additional processing to determine the single row signal vector's mean and standard deviation.

- The stylus parameter Ra was correlated with the mean and standard deviation of the picture parameters, yielding correlation coefficients of 0.96 and 0.72, respectively.

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- More dispersion in intensity values owing to laser light interference in the generation of the speckle image leads to a moderate connection with stylus parameters, with a correlation coefficient of 0.72.

- The intensity values are very scattered and the correlation curve is almost flat for the correlation of the whole speckle image area with stylus parameter Ra from that extracting the unknown surface values is found difficult.

- The process could be more efficient for a wide range of surface roughness values.

- The same methodology can be applied with the aid of wavelet transformation. A future study can take place proving its effectiveness in characterizing surface roughness of machined EDM surfaces.

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