

Design of a Measurement System for Surface Roughness using Speckle ImagesJ. Darani Priya¹, J. Mahashar Ali²¹ Department of Mechanical engineering, B. S. Abdur Rahman University² Department of Mechanical engineering, B. S. Abdur Rahman University

Abstract: The advances in fibre optics and the dawn of high speed wide-ranging computers and prevailing vision systems has made image analysis easy, fast and flexible. The illumination of the laser on the specimen prepared through the Electrical Discharge Machining process is captured using an online measurement system constructed with CCD camera and He-Ne laser. The images captured shows a speckle pattern which is further analysed to quantify the surface texture and is processed with the aid of advanced algorithms to have a comparative study with the results obtained from the stylus instrument. The online vision system has a lead over the stylus, having good penetration capacity and is non-contact. The novel methods employed in biometrics, Hamming distance and Euclidean distance is used as metrics for the image recognition process. A database is generated and the recognition process is analysed using MATLAB software.

Keywords - Surface roughness, Image processing, Electrical Discharge Machining (EDM), Euclidean distance, Hamming distance.

I. INTRODUCTION

The stylus instrument is the widely used mechanical measuring device for surface roughness measurements. The tip of the stylus instrument moves vertically up and down, along the surface profile generating the roughness parameters of the specimen under study. The stylus tip is prevalent with a disadvantage that it could not penetrate in valleys less than the tip diameter, thus gives an overall surface roughness by averaging. But this drawback is persistent in the surface measurements of fine parts and in non-linear deformations. Further when used on malleable surfaces, damage may be induced to the contact area or the tip of the stylus instrument and the setup time required is comparatively high, adding to its limitation which has increased the need for a measurement method that is reliable, prompt and non contact. The machining processes like milling, grinding, EDM induces a specific lay pattern. The lay pattern produced by machining process may be regular or irregular, with accordance to the tool used. The EDM machining being a process of erosion produces a random lay pattern. The EDM machined surface, when illuminated with a laser source, undergoes constructive or destructive interference by the surrounding particles inducing a speckle pattern. These speckle patterns are further analysed using advanced algorithms.

Researchers have come up with many techniques but none has proved to be reliable and pertinent for the shop floor relevance. Even the optical methods have failed for the robust technology. The technique implemented in this paper has been employed fruitfully in biometric recognition. An endeavour is taken to present the similar work for surface recognition of machined parts. The biometric recognition techniques, employed in this paper have been utilized efficiently proving their robustness and reliability. These methods have shown fine results in the surface analysis process and are under experimentation for the non contact methods. The Euclidean distance and Hamming distance are measured for all the images of the surfaces under study. The surface roughness of the specimen surfaces are measured using the stylus instrument and a set of database is prepared. The Euclidean distance and Hamming distance between the reference and the test specimen is calculated. The smaller the difference, the greater the matching of the reference surface images surface roughness with the test surface image. Thus, the average surface roughness (Ra), of that reference image can be ascribed to the test image.

Many researchers have performed experimental analysis with the machine vision system and have proved several results of the calculated parameters and with speckle correlation techniques. T. Jeyapoovan, et al.[1] carried out experiment with milled and ground specimens to analyse the statistical parameters such as mean, variance, etc using the pixel intensity of the surface image. It is proved to have positive correlation with average roughness values obtained using stylus profiler. Ma et al. [2] generated 1D intensity signals and observed its local sharp variation points to characterize the iris. M Nicklawy, et al.[3] proposed a simple method to characterize surface roughness for objects using digital fourier transformation of speckle pattern recorded on a CCD camera at different object locations. B. Dhanasekar, et al.[4] has presented an experimental approach for surface roughness measurement based on the coherent speckle scattering pattern caused by a laser beam in machined surfaces (milling and grinding). The Ra values obtained indicated successful implementation in practical use, as compared with stylus. Ersin Kayahan, et al.[5] introduced a technique SPBI (Statistical Properties Of Binary Images) which utilizes the combined effects of speckle and scattering phenomena. It was

found to have a strong relationship between the parameters. A.M. Hamed, et al.[6] has conducted experiments with different aluminium rough surfaces and obtained digital speckle images using a CCD camera. It was shown that the surface roughness of the examined surfaces is dependent upon the degree of agglomeration of the speckle images. Hatem El-Ghandoor, et al.[7] investigated the digital speckle images recorded for different rougher and smoother surfaces, using an optical imaging system in two and three dimensions with a high resolution CCD camera. The back projection technique and the interference microscope were used to reconstruct a 3-dimensional surface roughness profiles from multi-directional projection data. The experimental results verify the coincidence of the measured surface roughness. Persson .U [8] presented a paper on the measurement of surface roughness using angular speckle-correlation on machined surfaces. Surfaces of approximately $1.6 < Ra < 6.3\mu\text{m}$ have been measured. The surfaces were classified in the same manner as when using a stylus instrument.

II. EXPERIMENTAL PROCEDURE

The experimental procedure starts with the spark erosion, EDM machining process producing nine specimens with varying roughness values, induced by varying the current (I) and the T-on, T-off. Out of the nine specimens, six are considered as reference specimens to be stored in the database and three, as the test specimens with unknown surface roughness. The work piece selected is mild steel and the tool used is a cylindrical copper rod of diameter 12mm, giving an impression of 12mm.

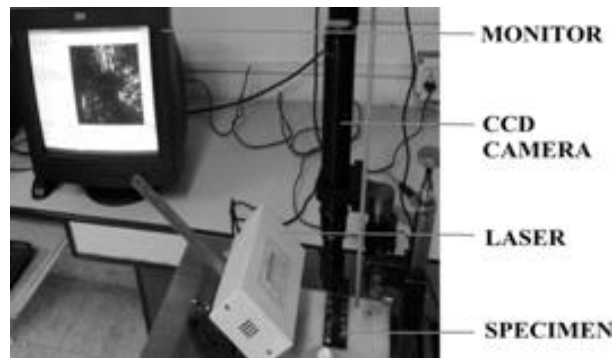


Fig.1. Experimental Setup

The surface roughness of the nine specimens were measured using Taylor and Hobson Talysurf stylus instrument, whose pick-up is a variable inductance type transducer, with a diamond stylus tip of radius $2\mu\text{m}$. The images with the calculated surface roughness values are stored in the database. The range of the surface roughness values measured from the specimens under study is of a range $6\mu\text{m}$ to $12\mu\text{m}$. R_a , the average surface roughness values have been obtained adopting an evaluation overall length, $L_s = 0.0025\mu\text{m}$ and a cut-off length, $L_c = 0.8\mu\text{m}$. Since the profilometer measurement is carried out along a line, the roughness value of each specimen has been obtained by averaging the measures. This same principle is implemented in the image acquisition process.

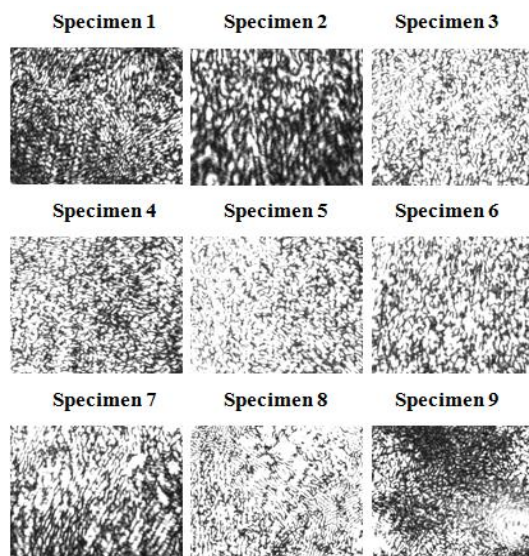


Fig.2. Speckle Images of the Specimens

The vision system consisted of a Basler PiA2400-12gm CCD camera with a Zoom 6000 lens with optical magnification up to 45.0X and a polarized He-Ne laser source of wavelength 632 nm. A table mounted with two adjustable arms was used to grasp the laser source and the camera at a required position. A protractor was used to fine-tune the angle of the laser source to 45 degree respectively and is made to be incident on the workpiece at 45 degree. Thus the set up is exemplified as shown in the fig.1, with the camera placed perpendicular and the laser inclined at 45 degree to the specimen under study. The images of all specimens were captured at a resolution of 2058 X 2456 and stored for future image processing. The images were obtained in 8-bit, grey scale with value varying between 0 and 255. The images obtained are shown in the Fig.2. These images are further analysed to form a comparative database using the Hamming and Euclidean distance.

III. METHODOLOGY USED

The experimental procedure is commenced with the capturing of speckle images of the specimens with known surface roughness, from the illumination of the laser source. The average surface roughness of EDM machined surfaces was measured using the Taylor and Hobson Talysurf stylus instrument. Consequently, the speckle images of the specimens with unknown surface roughness were captured. The images of the specimens were captured using a CCD camera and are pre-processed to eliminate the effects occurred due to improper lighting and noise.

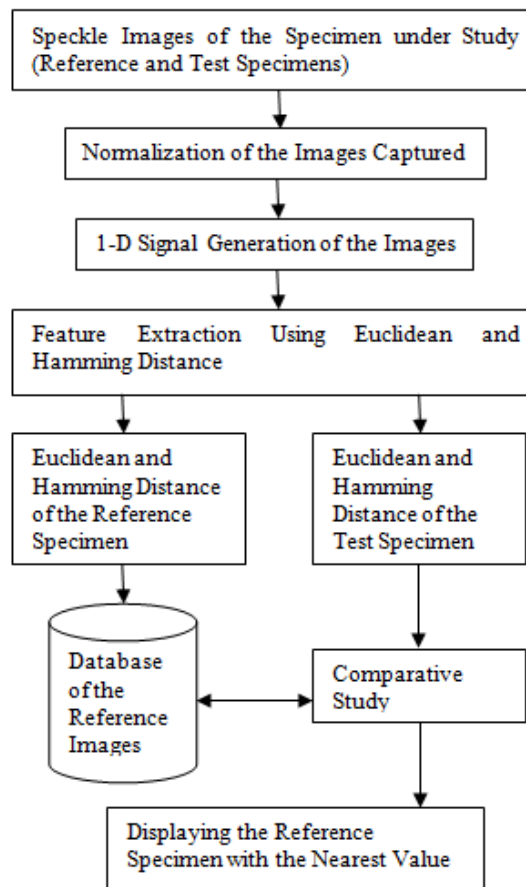


Fig.3. Steps Involved in the Proposed Method

Normalization process is used to eliminate the after image effects. The process is illustrated as explained in the Fig.3. The similarity/difference of surface of the test images were analysed using two different metrics, Hamming distance and the Euclidean distance with respect to the reference images and thus, the surface roughness of the specimens with unknown value has been estimated.

3.1. Image Normalization

The image is normalized to have uniformity in the pixel intensity distribution. The speckle images of the specimen under study so obtained from the above steps are normalized before the analysis. The normalization process is performed using the formulation,

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

Where the $g(x, y)$ is the normalized image intensity matrix, $f(x, y)$ is the image intensity matrix; $\min(f)$ is the minimum value in the image intensity matrix and $\max(f)$ is the maximum value in the image intensity matrix. The values obtained from the above step is multiplied with the maximum gray scale value of an 8-bit image, 255 to form a gray scale image with a pixel intensity ranging between 0 and 255. The speckle images were processed using MATLAB 2012.

3.2. 1-D Signal Generation

The diameter of the stylus tip used in the experiment is $2\mu\text{m}$, approximately the length of three pixels. The edges are removed to eliminate the effects caused due to the lightening effects. Hence, the images obtained with the resolution of 2058×2456 are cropped to 3×2000 pixels for evaluation. The averaging of the 3 rows to 2000 columns of the pixel resolution generates a 1-D image signal which is further processed using algorithms in the MATLAB software. The 1-D signal is generated using the coding produced in the software for the references specimen and the same course of action has been opted for the test specimen. Thus the speckle images so obtained are transformed to a 1-D signal.

3.3. Feature Vector Matching

The feature based comparison is used to analyse the similarity between the reference and the test specimens. It is performed using biometric metrics, the Euclidean distance and the hamming distance. These methods have shown successful results when used in iris recognition. Thus an attempt is taken to apply the sample principle in the surface roughness measurement by formulating a database of images of known roughness values.

3.3.1. Euclidean Distance

The Euclidean distance is the spatial distance between two feature vectors, i.e. the distance between the vectors of p ($p_1, p_2, p_3, \dots, p_n$) and q ($q_1, q_2, q_3, \dots, q_n$). The 'p' vector denotes the pixel values of the reference images and the 'q', that of the test images. The Euclidean distance thus gives the spatial distance as well as the dissimilarity between the vectors of the reference and the test specimen. The equation of the Euclidean distance can be computed as,

$$ED = \sqrt{\sum (p_i - q_i)^2} \quad (2)$$

A circular shift based matching procedure is used to overcome the possibility of translational variance in the matching process. The analysis process is set up with the vectors of the test specimen placed in a loop, where the difference or the Euclidean distance between the vector q_1 of the test specimen and p_1 of the reference specimen is found. The next step proceeds by analysing the difference or the Euclidean distance of the vector q_2 of the test specimen and the vector p_1 of the reference specimen. The procedure is continued for a whole circular shift and the minimum value or the smallest distance between the reference and the test specimen obtained from the above steps is considered.

Ra (μm)	Reference Specimen	Test Specimen 1 Ra = 6.8824	Test Specimen 2 Ra = 9.7311	Test Specimen 3 Ra = 10.6083
6.6198	1	2.4911e+03	6.7771e+03	7.8288e+03
7.0862	2	7.9036e+03	7.4072e+03	7.9810e+03
8.8569	3	5.3374e+03	6.1547e+03	5.1738e+03
9.6903	4	5.0659e+03	3.2009e+03	5.0042e+03
10.3044	5	5.9652e+03	6.2131e+03	2.7881e+03
11.8237	6	7.0345e+03	6.8111e+03	6.9310e+03

Fig.4. Euclidean Distance of the Specimens

The results obtained are tabulated as shown in the Fig.4. The least value of the Euclidean distance gives a perfect matching of the reference image with the test image.

3.3.2. Hamming Distance

The Hamming distance is the number of mismatches obtained by bitwise analysis. It can be computed as,

$$HD = \left(\frac{1}{N}\right) \times (\text{Dissimilarity Count}) \quad (3)$$

Assuming that the feature components follow a Gaussian distribution, the standard deviation of the images of the test specimen is found. The dissimilarity count between the reference and the test specimen is computed using the formula,

$$DC = \text{Count of } [(p_i - q_i) > s] \quad (4)$$

Where ‘ p_i ’ is the vectors of the reference images, ‘ q_i ’ the vectors of the test images, ‘ N ’ is the feature vector dimension and ‘ s ’, the standard deviation of the test specimen images. The circular shift based method was used to overcome the rotational inconsistency due to the shifting of the intensity values in the feature vector. The circular shift based method is employed as in the Euclidean distance and the minimum values of the Hamming distance between the reference and the test specimen is considered for the feature vector matching process. The reference specimen with which the test specimen shows the lowest mismatching value will be used to characterize that test specimen. The Hamming distances for the reference image signals and the test image signal obtained is tabulated as in Fig.5. The Hamming distance with the least value indicates the matching of that test image signal with the reference image signal. The efficiency of the method was analyzed by matching the same images to obtain the zero error clarification.

Ra (μm)	Reference Specimen	Test Specimen 1 Ra = 6.8824	Test Specimen 2 Ra = 9.7311	Test Specimen 3 Ra = 10.6083
6.6198	1	0.2015	0.7519	0.5326
7.0862	2	0.5573	0.5214	0.5578
8.8569	3	0.6027	0.6955	0.7847
9.6903	4	0.5663	0.2814	0.6527
10.3044	5	0.7552	0.5009	0.3270
11.8237	6	0.6806	0.6791	0.6616

Fig.5. Hamming Distance of the Specimens

IV. CONCLUSION

An attempt was made to develop a design, for the measurement of the surface roughness using the speckle images. The results obtained by using the Euclidean and the Hamming distance are quite promising and can be used in, in-process measurements. The Euclidean and the Hamming distance obtained were very low for the surfaces with the similar surface roughness values. The use of a larger database of reference images would provide results more efficient for an online measurement. There are many other biometric and wavelet methods used in the iris recognition that could be employed in the surface roughness measurement process.

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