Evaluation of Surface Roughness of Machined Components using Machine Vision Technique

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***Abstract*—The machined components produced by different machining process have different surface roughness characteristics. Surface roughness evaluation is very important for many fundamental problems such as contact deformation, tightness of contact joints and positional accuracy etc. Contact stylus roughness measurement is widely used for measuring surface roughness which may lead to scratches on machined surfaces and more time-consuming inspection process. Machine vision is the one of the noncontact surface roughness measuring technique which is being noncontact, reliable and accurate with low cost. This technique provides imaging based automatic inspection, process control and robot guidance in manufacturing industries. In this work the analysis and measurement of surface roughness of Aluminium-6061-T6 specimens which are prepared on EDM, CNC milling and surface grinding machines by varying input parameters are carried out. The effect of machining parameters on surface roughness of EDM, CNC milling and grinding machined specimens are analyzed by evaluating their surface roughness using contact stylus method. The low-cost noncontact Machine Vision technology was investigated as alternate method for evaluation of surface roughness. The digital images of machined surfaces were captured using suitable lighting and camera. The images are processed to enhance their quality and analyzed to determine image optical parameters such as Standard Deviation, Root Mean Square and Mean to evaluate surface roughness using MATLAB software. The image optical parameters determined to evaluate surface roughness shows good correlation with surface roughness parameter "Ra", which is determined by contact stylus method. Machine Vision technique can be used as automated inspection method to evaluate surface roughness of machined components either online/offline.**

***Keywords*—EDM, CNC milling, Surface grinding, MATLAB, Machine Vision, Noncontact, surface roughness, Image processing.**

I. INTRODUCTION

Surface roughness is irregular geometry shape characteristic(error) which includes peaks and valleys on the machined surfaces. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well the cost of production. The assessment of surface roughness can be carried out in many number of ways. The most common used stylus method to calculate surface roughness has limitations being contact with machined surfaces. Machine vision technology has maintained tremendous vitality during a ton of fields. New applications still are found and existing applications to expand. Many investigations are done to examine surface roughness of the manufacturing components. Though it's been shown that the surface roughness of a work piece is strongly characterize by the surface image, sensible surface roughness instruments supported machine vision technology are still tough [03].

Rammoorthy et al [01] stated that there were basically three possible approaches for characterizing the textural features from the digitized images: statistical, structural and spectral. He used statistical methods that are grey level histogram (first order) and co-occurrence matrices (second order) to characterize some of the features of texture pattern of the processed digital images of the different machined components. F. Luk et al [04] used the grey level histogram of the surface image to characterize surface roughness. He derived the "Optical roughness parameter (R) = S.D./RMS, from the grey level intensity histogram. Lee et al [03] a polynomial network with self-organized adaptive learning ability is adopted in his study to process the surface images to obtain the surface roughness of the work pieces. He shown that the polynomial network can linearly correlate the input variables with the output variable, of the work piece. B.M. Kumar et al [13] they used commercial digital single-lens-reflex camera with high shutter speed and backlight was used to capture image of the rotating work piece profile. The roughness profile was extracted at sub-pixel accuracy from the captured images using the moment invariant method of edge detection. G Dilli Babu et al [11] developed model equations in terms of the machining parameters, image parameters using response surface methodology(RSM) based on experimental results and he checked the effectiveness of the machine vision based results, a wide range of surface roughness were generated on CNC milling centre using Design of Experiments (DoE) technique. Srinagalakshmi Nammi et al [9] used a vision system with coaxial lighting arrangement at different angular orientations of the work pieces of milled components. The noises in the captured images were removed by applying Gaussian filter as per ISO 4288. Shivanna D.M et al [12]; B Danasekar et al [7]; N. Nithyanantham [5] et al calculated optical surface roughness using optical surface parameter 'Ga'. They applied geometric search approach to the gray scale images to enhance the surface characteristic features. They acquired machined surface images using the CCD camera and further preprocessed to eliminate the effects due to improper illumination and noise. Median low pass filter was applied to the captured images to avoid the salt and pepper effect [5].

There are many approaches are introduced to evaluate the surface roughness of the machined components, each approach has its own advantages and disadvantages in terms of easiness, accuracy etc. But from the literature research it is cleared that Machine Vision is one of the easiest, low cost and high accurate surface roughness measurement technique.

II. EXPERIMENTAL PROCEDURE

The experiment was mainly focused on the low cost and high accurate, being noncontact surface roughness measurement technique alternate to most commonly used stylus measurement technique. From the research Machine Vision was found an alternate surface roughness measurement technique. The experiment methodology is given in the below Fig1.

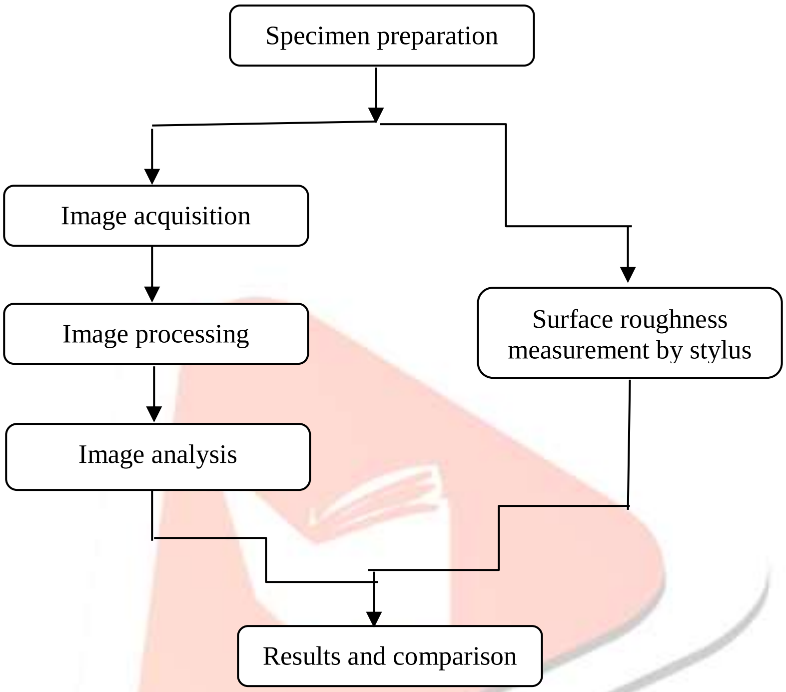


Figure1 Methodology of the experiment

Specimen preparation: The specimens of Aluminium-6061-T6 were prepared on EDM, CNC milling and surface grinding machines by varying the machining parameters. The surface characteristics of the specimens are different for different specimens produced by the different machining processes. Parameters considered for preparing specimens are:

EDM: peak current, pulse on time and gap voltage

CNC milling: speed, feed and depth of cut

Surface grinding: wheel speed and depth of cut

Measurement of surface roughness by stylus instrument: Measured average surface roughness (Ra) of the surfaces of the specimens for further analysis by widely accepted contact stylus (Mitutoyo Surf Test SJ-500) method.

Image acquisition: The analysis of the surfaces requires good quality of images, so to capture good quality of images we should select good camera and suitable lighting arrangement. Lighting is one of the important part of the image acquisition to get good quality of images and different material have different reflectivity therefore lighting position is very important to acquire good quality of images.

The images of the machined surfaces were captured using canon EOS 1200D camera with diffuse, white light arrangement shown in the Fig.2.The focal length and lighting position was same for all the specimens.

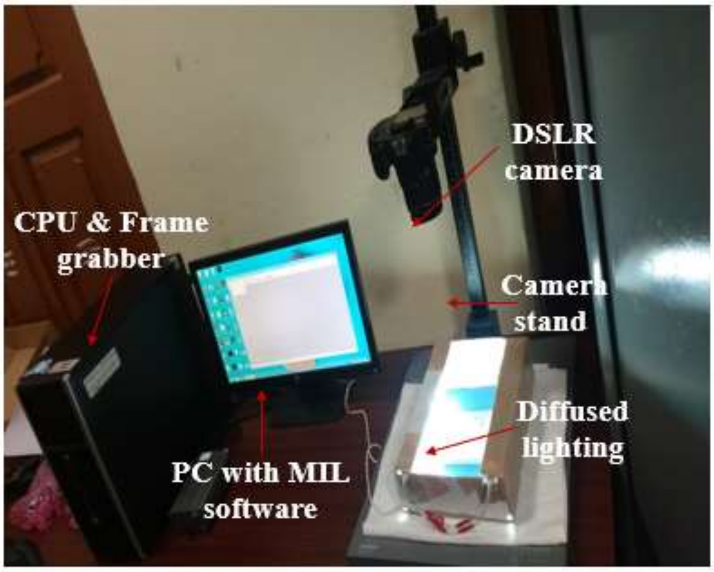


Figure 2. Image acquisition using Machine Vision set up

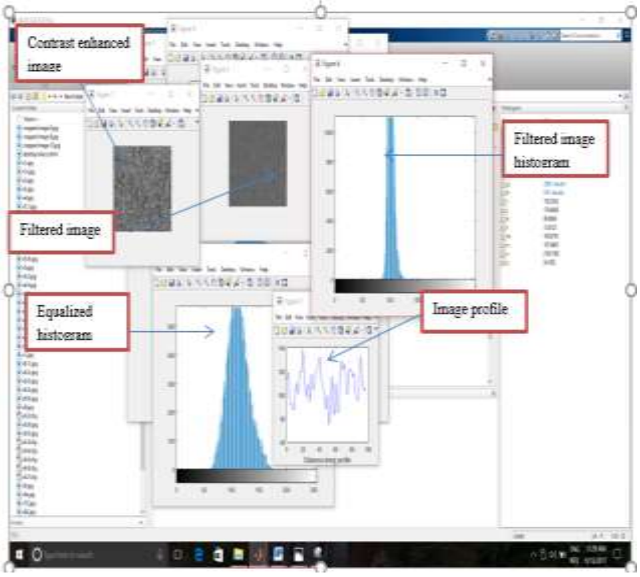


Figure 3. Image processing and analysis in MATLAB

Image processing: It is the technique in which it enhances the image quality to extract the useful information from the images. The images of the machined surfaces were processed in MATLAB to evaluate surface roughness of the images grabbed.

The steps were carried out in image processing are:

- The conversion of color images into gray images to easily extract the useful information for surface roughness evaluation of the machined surfaces.
- The noises were removed from the acquired images using median filtering technique. The noises exist in the images due to the dust or impurities on the machined surfaces while image acquisition. These noises may lead to loss of information of the images.
- The contrast of the filtered images was enhanced using histogram equalization technique to extract all the useful information mainly the edges of the irregularities present on the machined surfaces.

Image processing was done for the images of the specimen of the EDM, CNC milled and surface grounded. The resulting images and their histograms are shown in the Table1.

Table 1. Image processing steps and respective images of the EDM, CNC milled, surface grounded specimens

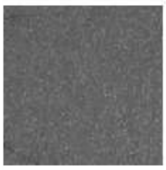
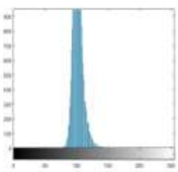
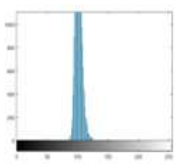
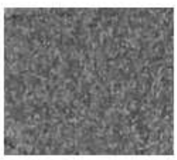
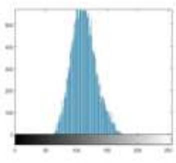
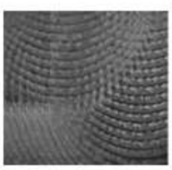
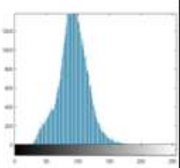
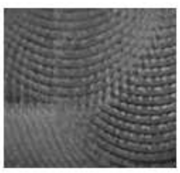
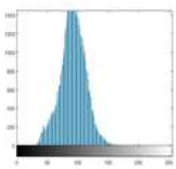
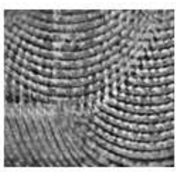
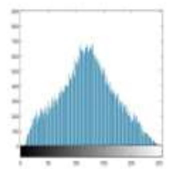
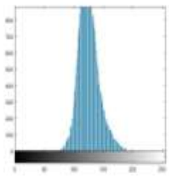
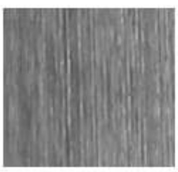
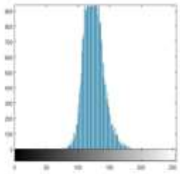
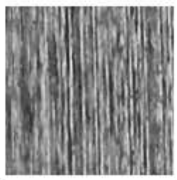
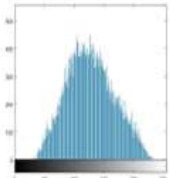
Speci mens	Cropped original color images	Gray images	Histograms of gray images	Filtered images	Histograms of filtered images	Contrast enhanced images	Histograms of enhanced images
EDM							
CNC milled							
Groun ded							

Image analysis: To analyze the surfaces of the machined surfaces here we have extracted the numerical parameters called as optical parameters from the processed images. These optical parameters are based on the pixel intensity distribution along the lines selected on the ROI of images. Those are given below

The Mean Value of the pixel intensity distribution is the mean of the light intensity values along the line profile. It was calculated as:

$$\text{Mean} = \frac{1}{N}\sum_{i=0}^{255} F_i X_i$$

N= total number of pixels in the distribution
Fi = intensity value of pixel Xi
Xi = pixels along the line (i =0, 1, 2 . . ., 100)

The Standard Deviation of the pixel intensity distribution (SD) provides the variation in the light intensity value along the line profile and was computed using:

$$S.D = \sqrt{\sum_{i=0}^{255} \frac{F_i (X_i - X)^2}{N-1}}$$

X = Mean value of the pixel intensity distribution
X= Xi /N

The RMS of the pixel intensity distribution is the root mean square height of the pixel intensity distribution and was computed using:

$$RMS = \sqrt{\sum_{I=0}^{255} \frac{{F_i}^2}{N}}$$

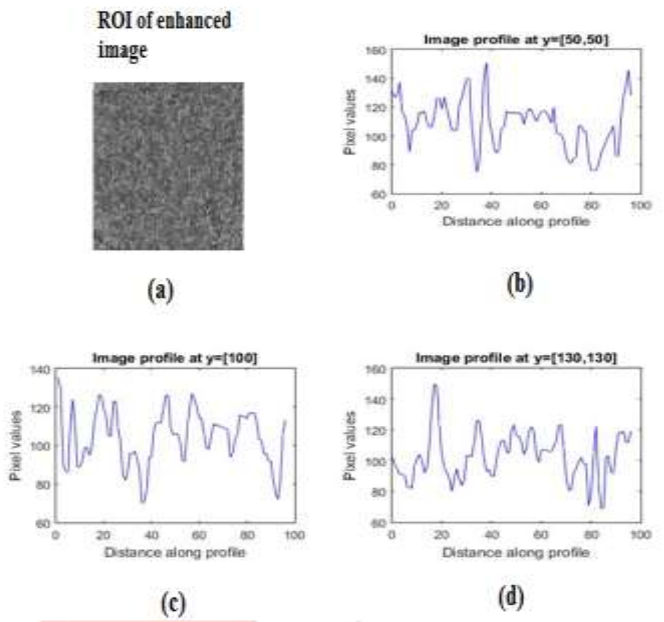
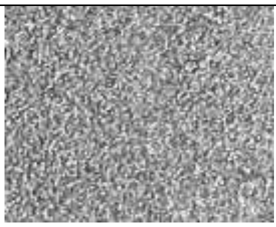
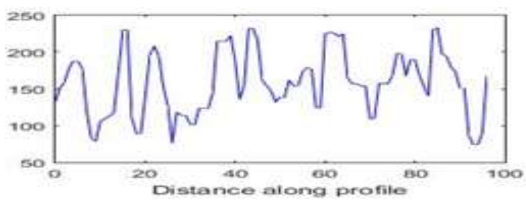
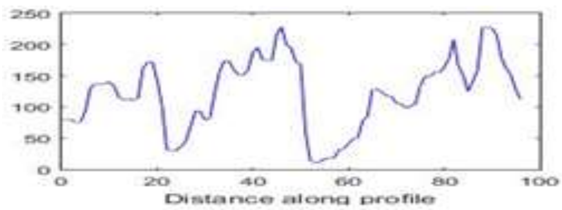
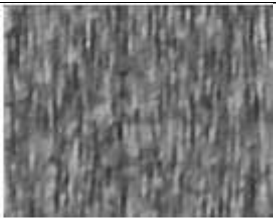
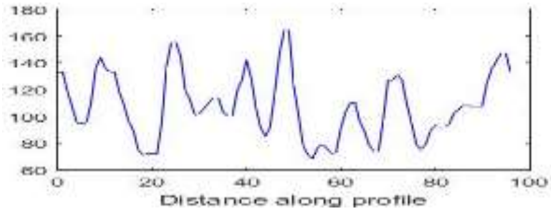


Figure 4. a) ROI (region of interest) of the machined surface image. b) c) d) Image profiles along lines on the ROI

These are the optical parameters derived from the image profile of lines on the ROI of processed image to measure surface roughness. we conducted and selected different lines on the ROI to evaluate accurate optical parameters results from the images. Calibrated the technique to evaluate the surface roughness. The obtained results of the EDM, CNC mill and surface grounded specimen are shown in the Table 2.

Table 2. ROI, image profiles and optical parameters of the images of EDM, CNC milled, surface grounded specimen

Specimens	**Selected ROI of size 150×150 pixels**	**Image profile along lines on the ROI**	**Optical parameters extracted from images.**
EDM			SD=43.6329 RMS=163.53 Mean=157.71

CNC milled			SD=56.6 RMS=134.39 Mean=121.98
Grounded			SD=25.63 RMS=111.21 Mean =109.68

Results and Comparison: The measured Ra values by stylus method and optical parameters standard deviation, root mean square and mean values are tabulated in Table 3 (for EDM specimens), Table 4 (for CNC milled specimens) Table 5 (for Surface grounded specimens) with varied parameters.

The regression analysis was done to calculate correlation between the optical parameters and stylus measured surface roughness values. The correlation graphs were plotted for stylus measured and optical parameters derived that are shown in the Fig.5, Fig.6, Fig.7

Table 3 Correlation Values between Optical Parameters and Average Surface Roughness of EDM specimens

Peak current (IP) in (A)		Pulse-ON (TON) in (µs)	Gap voltage (Vg) in V	Surface roughness by stylus (Ra) in (μm)	Optical Standard Deviation	Optical Root Mean square	Optical Mean
2A	**E1**		45	1.012	7.4381	103.8849	103.64
	E2	15	50	1.219	11.53	146.73	146.28
	E3	20	55	1.1	8.1943	112.799	111.38
	Correlation coefficients				**0.965665**	**0.9716**	**0.965665**
4A	**E4**	10	45	2.372	7.0017	96.56	94.36
	E5	15	50	2.786	18.84	108.3	105.97
	E6	20	55	2.474	9.4572	98.44	95
	Correlation coefficients				**0.999163**	**0.996035**	**0.98207**
6A	**E7**	10	45	2.574	16.06	105.9484	104.76
	E8	15	50	2.914	43.6329	163.5324	157.711
	E9	20	55	2.692	32.282	145.5324	141.6082
	Correlation coefficients				**0.962032**	**0.925698**	**0.922127**

Table 4 Correlation Values between Optical Parameters and Average Surface Roughness of CNC milled specimens

Constant speed (950RPM)	Feed (mm\rev)	Depth of cut(mm)	Surface roughness by stylus (Ra) in (μm)	Optical Standard Deviation	Optical Root Mean square	Optical Mean
M1	200	0.5	0.617	10.577	88.67	88.35
M2	500	0.5	0.7438	24.415	118.5	112.6
M3	650	0.5	1.018	30.62	120.28	117.4

M4	800	0.5	1.5755	49.52	145.9	137.226
Correlation coefficients				**0.971945**	**0.9108**	**0.971945**
Constant feed (400 mm/rev)	**Speed (RPM)**	**Depth of cut (mm)**	**Surface roughness by stylus (Ra) in (μm)**	**Optical Standard Deviation**	**Optical Root Mean Square**	**Optical Mean**
M5	650	1.5	1.594	56.6	134.39	121.98
M6	800	1.5	1.374	34.81	118.95	113.29
M7	950	1.5	1.165	30.72	116.47	112.95
M8	1100	1.5	1.08	29.32	103.18	98.96
Correlation coefficients				**0.927459**	**0.94659**	**0.879148**

Table 5 Correlation Values between Optical Parameters and Average Surface Roughness of Grounded specimens

Specimens	**Speed(rpm)**	**Depth of cut (μm)**	**Surface roughness by stylus (Ra) in (μm)**	**Optical Standard Deviation**	**Optical Root Mean Square**	**Optical Mean**
G1	2500	10	0.406	25.63	111.2198	109.68
G2	2500	20	0.485	30.8893	115.6069	111.64
G3	2500	30	0.52	34.5063	117.55	112.43
G4	2500	40	0.564	36.1739	129.61	119.68
G5	2500	50	0.635	40	133.59	132.05
G6	2500	60	1.037	48.26	139.09	133.98
G7	2500	70	1.088	62.02	151	138.8
Correlation coefficients				**0.9514**	**0.9256**	**0.9009**

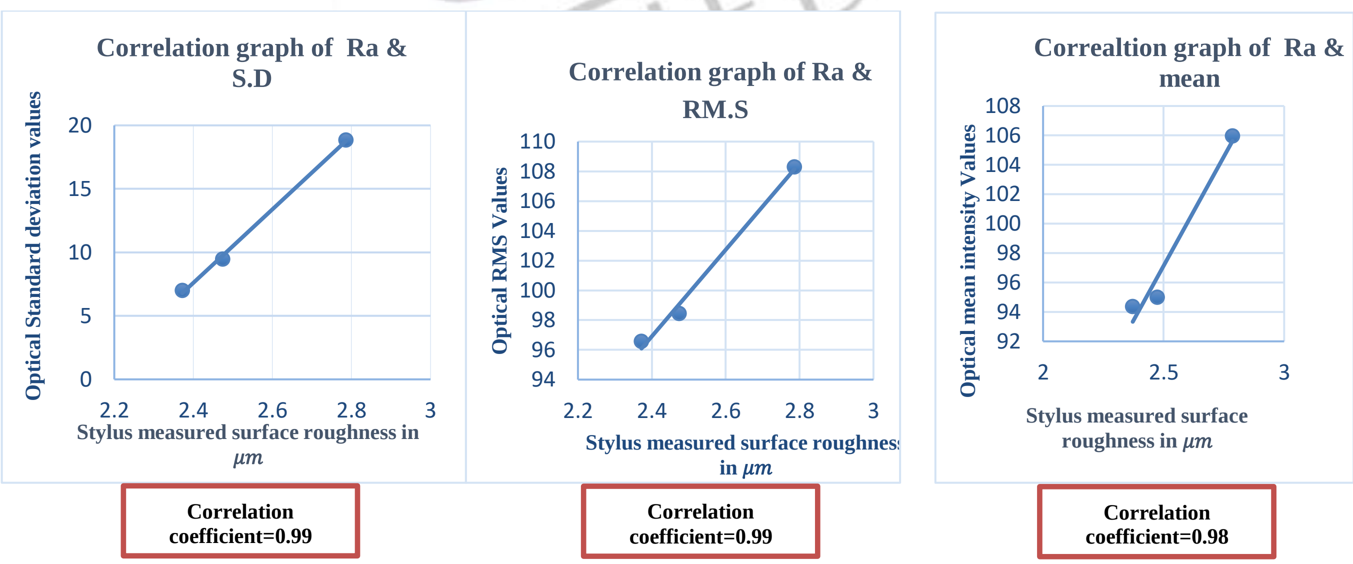


Figure 5 Correlation graphs of EDM specimens (peak current 4A)

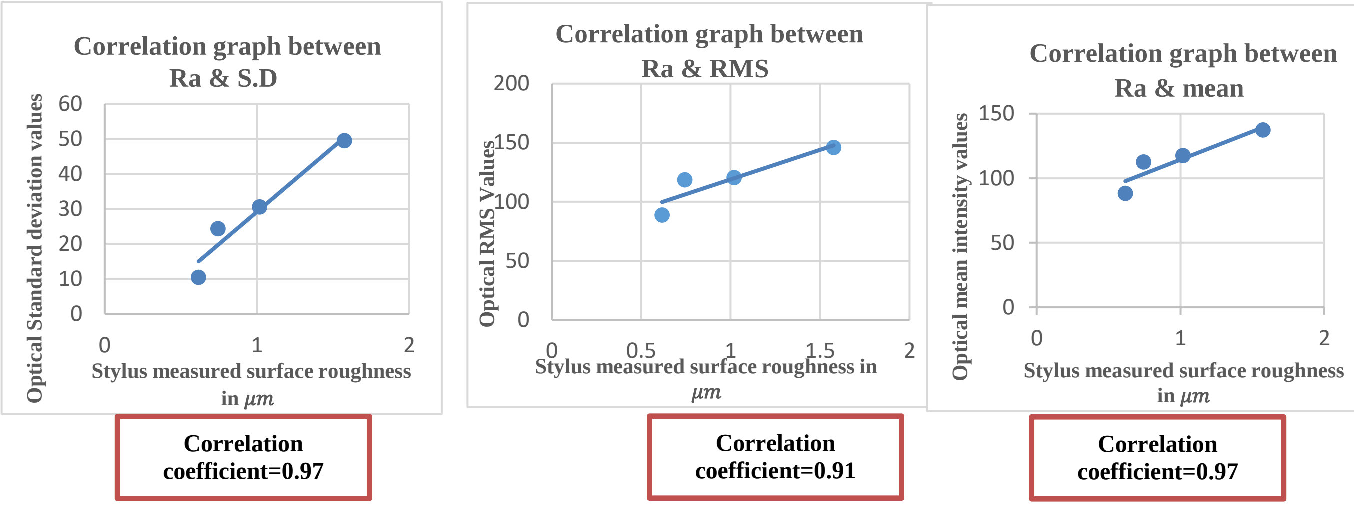


Figure 6 Correlation graphs of CNC milled specimens (constant speed)

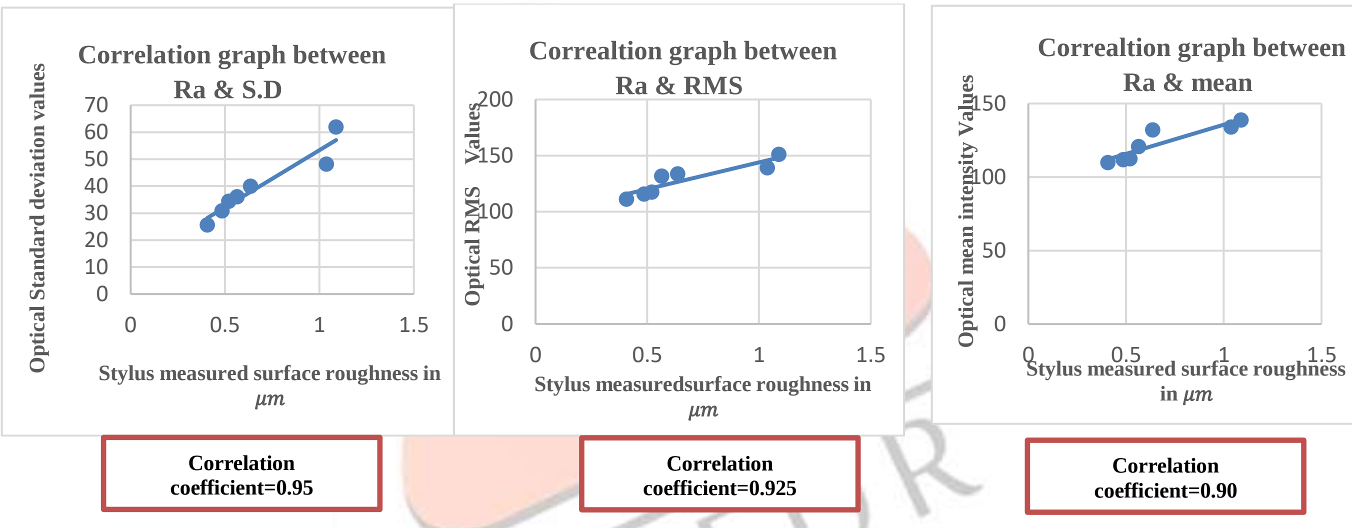


Figure 7 Correlation graphs of surface grounded specimens

III. DISCUSSION OF RESULTS

Surface roughness measurements were performed on Aluminum 6061 alloy specimens machined by milling, grinding and electrical discharge machining processes with varying the parameters and their values are presented in the Table 3, 4and 5. After preprocessing the optical parameters defined standard deviation, mean and root mean square values are calculated along the lines selected on the region of interest and the obtained optical parameters are plotted against the stylus measured average surface roughness values and calculated correlation values from the graphs plotted. Those values are presented in the Table 3,4 and 5.

It was observed that optical parameters have good correlation with the stylus measured average surface roughness (Ra) values. Standard deviation has better correlation with the average surface roughness values compare to mean and root mean square values.so standard deviation can be used for surface roughness evaluation.

IV. CONCLUSIONS

This work clearly indicates that the Machine Vision technique can be used to evaluate the surface roughness of the machined components and it is cleared from the results that stylus measured Ra values and optical parameters values have good linear relationship. Among all the optical parameters defined, standard deviation has good correlation with Ra values measured by the conventional and widely accepted stylus instrument of the machined surfaces prepared by the machining processes that are electrical discharge machining, milling and grinding processes. The optical parameters evaluation procedure is same as stylus surface roughness measurement procedure. It is indicating that Machine Vision technique can be used effectively with low cost set up and it yields reliable and high accuracy results.

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