ANNALS OF FACULTY ENGINEERING HUNEDOARA
- INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Fascicule 3. (ISSN 1584 - 2673)

1. Anayet U. PATWARI, 2. M. D. ARIF, 3. N. A. CHOWDHURY, 4. S. I. CHOWDHURY

3-D CONTOUR GENERATION AND DETERMINATION OF SURFACE ROUGHNESS OF SHAPED AND HORIZONTALLY MILLED PLATES USING DIGITAL IMAGE PROCESSING

1-4. DEPARTMENT OF MECHANICAL AND CHEMICAL ENGINEERING, ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT), BOARD BAZAR, GAZIPUR, DHAKA: 1704, BANGLADESH

ABSTRACT: Surface roughness is usually a detrimental by-product of all machining processes. This research work applied digital image processing capabilities of MATLAB to measure and generate 3-D contour plots of surface roughness, from digital pictures of two common types of machined surfaces (horizontally milled and shaped surfaces). Initially, calibrated plates of known R_a were used. The acquired images were converted to resized grey-scale images. The asperities and troughs of the surface roughness manifested as bright and dark regions. MATLAB was then used to determine the average pixel intensity and generate profile and 3-D contour plots. The average pixel intensity and R_a values were subsequently used to generate calibration curves for the two machining processes. Error compensation was performed and the calibration curves were tested with additional machined plates of known R_a. The technique showed good accuracy and reliability. Consequently, this novel technique could be used as an economical, precise, and reliable way to measure and visualize surface roughness.

KEYWORDS: Surface Roughness, Digital Image Processing, Surface Prolife, and 3-D Contour Generation

❖ INTRODUCTION

Machining processes, such as shaping and horizontal milling, inevitably produce surface roughness. Surface roughness generally has negative effects on the performance of a machined part, especially where relative motion between parts is present. It leads to dry friction, wear, excess heat and noise generation, efficiency reduction, susceptibility to corrosion, and lubrication requirements; Kalpakjian et al. [1]. These increase production and maintenance costs. Therefore, the measurement and reduction of roughness is very important in manufacturing. Surface Roughness, R_a, measurements are usually carried out using two basic types of measurement tools, i.e. contact and non-contact systems. The most common tactile roughness measurement tool is the surface profilometer. The typical ones usually have a diamond stylus, Yoo S. M. [2]. Alam et al. [3] used a precision surface profiler, Mitutoyo, Surftest SV-500, Japan, for determining the resultant R_a of Ti-6AL-4V machined using a Mitsubishi flat end mill and 2 mm solid carbide tool. However, the Surftest SV 500 equipment is an expensive tool whose resolution depends upon the diameter of the probe and is used to measure and record the surface roughness and topography profile of only a small part of the sample, called the cut-off. Thus, the entire surface profile or the 3-D surface contour of the sample is not obtained using this apparatus. Surface topography is also be determined using non-contact interferometry, which uses dual coherent laser beams, split by a partially transmitting mirror, in order to observe the interference fringe patterns produced in an interferogram [4]. This process is suitable for inspecting near mirror finish surfaces but the setup is expensive. Campana et al. [5] developed a non-contact roughness measurement system based on the principle of laser light scattering and diffusion. They used a modified laser surface roughness probe and a measurement system. The advantage of their technique was that it could be used to measure roughness irrespective of work-piece orientation [5]. The major limitations of the measurement system were the narrow measurable R_a range and the significant costs involved. Smooth surfaces' roughness can also be measured using optical, scanning-electron, or atomic-force microscopes. Of these, atomic force microscopy (AFM) can even distinguish atoms on atomically smooth surfaces. However, AFM is very expensive and is used to scan very minute portions, less than 100 μm square, of the machined sample [1]. Constantin et al. [6] used AFM for performing statistical analysis of surface corrugations of small ball bearings. From their results they were able to determine roughness parameters down to a sub-micrometer scale, which were more accurate than the AFBMA standard. Gadelmawla [7] used a novel computer vision and image processing technique in order to typify surface roughness using the grey level co-occurrence matrix (GLCM). The maximum incidence, occurrence position, and standard deviation of the matrix were calculated from the GLCMs and compared with the average roughness, R_a, in order to establish correlation. Arif et al. [8] also used standard deviation of machined plates' images, to develop a regression model for measuring R_a. As a guideline for their work, Arif et al. [8] referred to the original work of Md. Anayet U. Patwari et al. [9]. The latter had previously used digital image processing techniques on grey scale sample profile pictures. These were done to study chatter formation. Visual Basic was used to classify the primary and secondary serrated teeth of machined chips, which was utilized to correlate chip serration frequency to the chattering. The authors of this paper did more extensive research on the techniques developed by Md. Anayet U. Patwari et al. [9] and Arif et al. [8] in order to generate 3-D contours from the 2-D digital visages of sample machined plates. The 3-D contours and their grey scale matrices were then used for determination of R_a.

❖ EQUIPMENTS

A standard environment conducive to image acquisition was maintained (figure 1).

i) Canon PowerShot SD 750 Camera with 7.1 mega pixels resolution and 3X optical zoom
ii) Blackened-interior 12 inch hollow Perspex cube with fixturing mechanism on the bottom inner face
iii) Rubert & Co. Ltd. (Cheshire, England) plates with common machined surfaces' roughness values, R_a

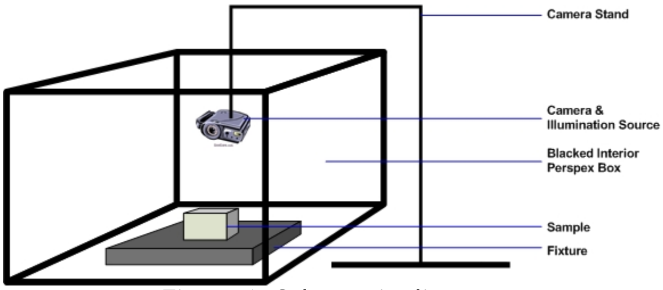

Figure 1: Schematic diagram of the image acquisition setup

The flow diagram of the entire process is shown in Figure-2.

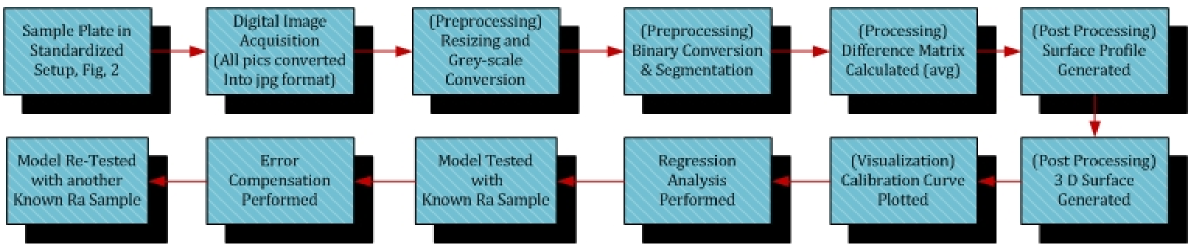

Figure 2: Flowchart of the process sequence

❖ DIGITAL IMAGE PROCESSING AND ALGORITHM USED

Digital image processing involves the application of computer logic and algorithm to analyze images. For the analysis, MATLAB 2008a [10] image processing toolbox was utilized, which can efficiently process the samples' images represented as *n* by *m* 2-D matrix form. The mathematical definition of average surface roughness, R_a, was utilized. R_a is equivalent to half of the mean difference in heights between the asperities and troughs of a rough surface. The equation is as follows:

$$R_a = \frac{y_a + y_b + \dots + y_n}{n} = \frac{1}{n}\sum_{i=1}^{n} y_i = \frac{1}{l}\int_0^l |y|\, dx$$

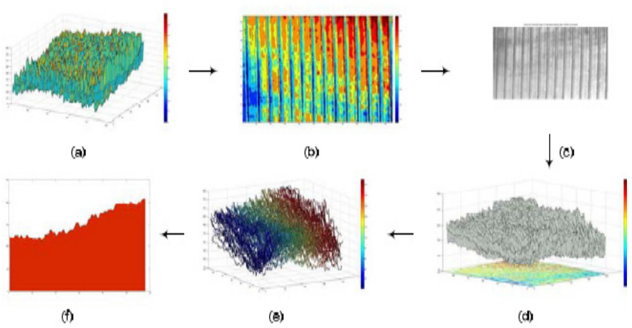

Figure 3: Graphs for Shaped plate (R_a = 25 μm) (a) 3-D contours, (b) 2-D contours, (c) Grey scale resized image, (d) 3-D surface superimposed on 2-D contour map, (e) Entire profile plot, (f) Single profile view

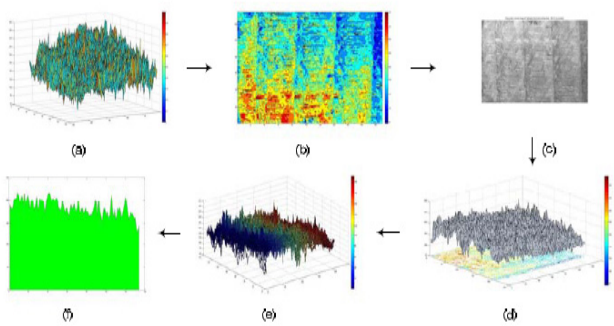

Figure 4: Graphs for Horizontally milled plate (R_a = 25 μm) (a) 3-D contours, (b) 2-D contours, (c) Grey scale image, (d) 3-D surface superimposed on 2-D contour map, (e) Entire profile plot, (f) Single profile view

The acquired RGB images were resized, keeping their aspect ratios intact, to standardize the comparison. Grey scale and binary conversions were performed. The peaks and valleys of the surface roughness showed up as bright and dark regions in the grey scale images. MATLAB stored each resized image as a 2-D matrix, where each column corresponded to a 'strip' of the image and contained pixel intensity values. The matrices were then manipulated using standard MATLAB commands: 'max,' 'min,' and 'trimmean' respectively. The outputs were termed 'Difference Matrix Average' or 'avg_a.' Each avg_a corresponded to the R_a value of a specific machined plate. The matrices were then used to plot surface roughness profiles, surface contour maps, and 3-D contour surfaces. Figure 3 and 4 illustrate the results for Shaped and Horizontally milled plates, respectively.

Shaper machines are used in high volume production industries for making keyways, slots, and intricate internal cavities [11]. Shaped plates of known R_a were used for plotting a calibration curve and a positive power series regression model (figure5). Error compensation was then performed and tabulated as displayed in table 1. Two other plates of R_a 25 and 6.3 µm were used to test the calibration curve.

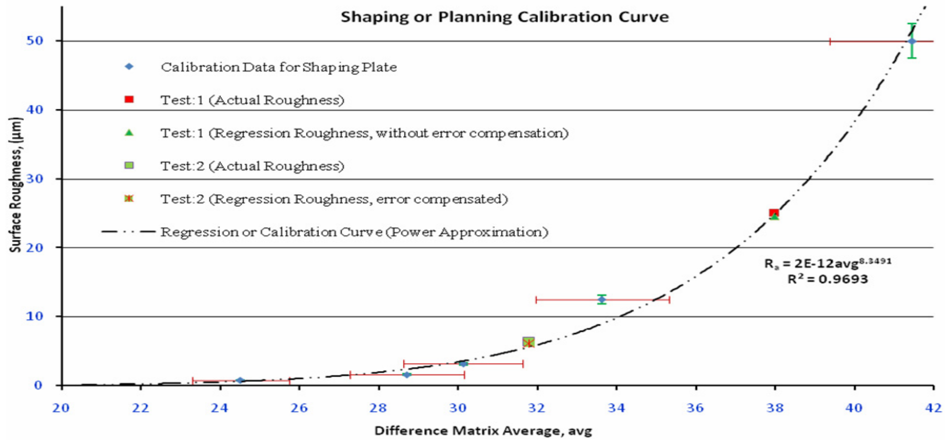

Figure 5: Shaping calibration curve with 5% error bars and test results

Table 1: Calibration and test results for shaped or planed plates

Calibration Results				Test: 1 (no error compensation)			
Sl. No.	Avg Diff. Matrix	Ra_a (µm) Calibrated	Error Comp. Amount, E_{sh}	Avg Diff. Matrix	Ra_a (µm) Actual	R_{aR} (µm) Regression	Error %
1	41.4667	50.0	0.0489	37.9989	25		5.79
2	33.6381	12.5		37.9989		23.55	
3	30.1381	3.2		Test: 2 (error compensated)			
4	28.7190	1.6		31.8112	6.3		1.98
5	24.5142	0.8		31.8112		6.1753	

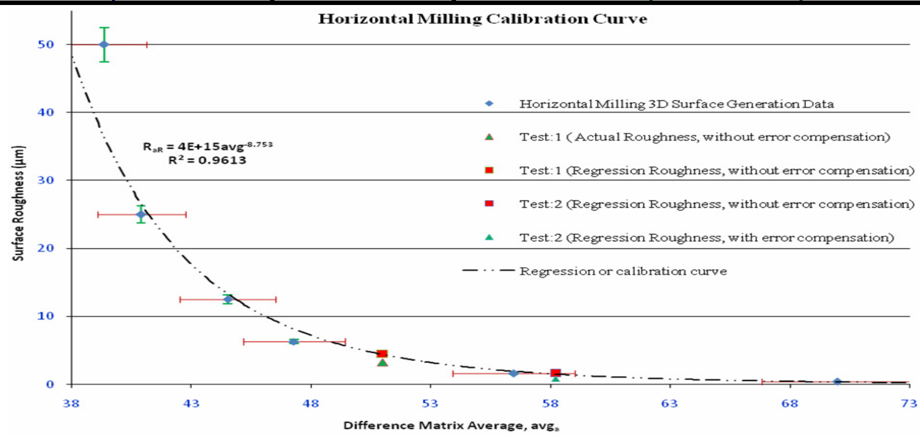

Figure 6: Horizontal milling calibration curve with 5% error bars and test results

Table 2: Calibration and test results for horizontally milled plates

Calibration Results			Error Comp. Amount, E_{hm}	Test: 1 (no error compensation)			
Sl. No.	Avg Diff. Matrix	Ra_a (µm) Calibrated		Avg Diff. Matrix	Ra_a (µm) Actual	R_{aR} (µm) Regression	Error %
1	39.3567	50.0	-0.7736	50.9881	3.2		-6.57
2	40.8997	25.0		50.9881		3.4102	
3	44.5143	12.5					
4	47.2857	6.3		Test: 2 (error compensated)			
5	56.4630	1.6		58.2000	0.8		-1.74
6	69.9619	0.4		58.2000		0.8139	

Horizontal milling is used widely to machine gear teeth in helical and worm gears, making dovetail recesses and guides, and for machining slabs, profiles, and gangs in peripheral milling operations [12]. Horizontally milled plates of known R_a were used to generate the negative power series calibration curve (figure 6). Error compensation and test results were tabulated in table 2. Two additional horizontally milled plates, R_a 3.2 and 0.8 μm, were used to test the calibration curve thus obtained.

❖ RESULTS

The shaped plates' data was best represented by a positive power regression model with $R_a = 2E\text{-}12avg^{8.3491}$, $R^2 = 0.9693$, and maximum error less than 2%. A negative power series regression model ($R_a = 4E{+}15avg^{-8.753}$, $R^2 = 0.9613$, and maximum error < 2%) was optimum for horizontally milled plates. Also, the resultant 3 and 2-D graphs aided the authors to effectively visualize the surface roughness in both cases.

It is to be noted that Webster et al. [13] had previously used a computer-automated method to create 3-D maps of curved raceways of bearings and utilized it for subsequent calculations concerning topological features. However, their results were based on the hypothesis of elastic deformation. The authors' results, discussed above, were concerned with machined plates which underwent plastic and shear deformations.

❖ CONCLUSIONS

Various metrology related researches have led to a manifold of surface roughness measurement methods. Nevertheless, most of these techniques are either expensive, sample only a small portion of the machined surface, require complex software, or involve tactile measurement. The novelty and uniqueness of the authors' technique is that it addresses all these shortcomings. The technique is simple, sensitive, reliable, area sampling, non-contact, non-destructive, and economical. A computer, a digital camera, and MATLAB are all that are needed to implement this method. These three elements are readily available in most industries, machine shops, universities, and research facilities. Also, the 3-D surface generation ability will help engineers and technicians to visualize the machined surfaces they photograph. The technique is being advanced further and certain enhancements, such as the use of coherent and monochromatic light, an optical microscope, and a more complex model based on wavelet analysis, will undoubtedly make it more reliable and accurate. Jiang et al. [14] discussed the modern applications of wavelet analysis in surface metrology. The authors plan on exploiting this proven method, discussed above, to advance their research and measurement technique.

❖ REFERENCES

[1.] Kalpakjian, S., and Schmid, S. R., Manufacturing Processes for Engineering Materials, 5th Edition, U.S.A.: Pearson Education, inc. (2008).

[2.] Yoo, S. M., Dornfield, D. A., and Lemaster, R. L., "Analysis and modelling of laser measurement system performance for wood surface," Journal of Engineering for Industry, Vol. 112, pp. 69-76 (1990).

[3.] Alam, S., Amin, A. K. M. N., Patwari, A. U., and Konneh, M., "Prediction and investigation of surface response in high speed end milling of TI-6AL-4V and optimization by genetic algorithm," Journal of Advances Materials Research (AMR), advances in materials processing vols 83-86 (2010), pp 1009-1015, Trans Tech publication Switzerland

[4.] Bennet, M. M., "Measurement of the RMS roughness," Applied Optics, Vol. 15, No. 11, pp. 2705-2707 (1976).

[5.] Campana, C., Derynioski, B., and Moslehpour, S., "Non contact surface roughness measurement instrumentation," American Society for Engineering Education (Annual Conference Proceedings), AC 2007-2557 (2007).

[6.] Constantin, R., Christoph, R., Béguin, J., Boving, H., and Hintermann, H. E., "Use of atomic force microscopy for surface roughness determination of ball bearings," Surface and Coatings Technology, Vol. 62, Issues 1-3, pp. 517-522 (1993).

[7.] Gadelmawla, E. S., "A vision system for surface roughness characterization using the grey level co-occurrence matrix," NDT & E International, Vol. 37, Issue 7, pp. 577-588 (2004).

[8.] Arif, M. D., Patwari, A. U., and Chowdhury, N. A., "Surface roughness characterization using digital image processing technique," Proceedings of the 13th Annual Paper Meet, Mechanical Engineering Department, Institution of Engineers, Bangladesh.

[9.] Md. Anayet U. Patwari, A. K. M. Nurul Amin, and Faris, W., "Identification of instabilities of chip formation by image processing techniques," Proceedings of ICME 2009, 26th to 28th December, Dhaka, Bangladesh (2009).

[10.] Math Works Incorporation, MATLAB User Manual, version 7.0 R14, Natick, MA (2006).

[11.] Roe, J. W., English and American Tool Builders, U.S.A.: Yale University Press (1916).

[12.] Juneja, B. L., Sekhon, G. S., and Seth, N., Fundamentals of Metal Cutting and Machine Tools, 2nd Edition, India: New Age International (P) Limited (2005).

[13.] Webster, M. N., West, M. A., and Sayles, R. S., "A method of three-dimensional topography measurement and analysis on arcuate surfaces," Wear, Vol. 109, Issues 1-4, pp. 385-399 (1986).

[14.] Jiang, X., Scott, P., and Whitehouse, D., "Wavelets and their applications for surface metrology," CIRP Annals – Manufacturing Technology, Vol. 57, Issue 1, pp. 555-558 (2008).