Comparison between 3D Digital and Optical Microscopes for the Surface Measurement using Image Processing Techniques

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Abstract:

Surface Engineering has been a scientific discipline studying various procedures for the improvement of surface properties since 1980. The surface roughness of manufactured parts is commonly measured by the tactile methods. The stylus profilometer is one of the standard techniques assessing surfaces. This is a worthy method for looking at small areas but the major disadvantage of using a stylus profilometer is that it requires direct physical contact limiting the measuring speed. In contrast to contact measurement systems, optical technique, which is a non-destructive and non-contact method, appears to be a proper alternative for performing measurement of surface quality including surface roughness. The optical measurement instruments were used for the experiments. One of them was based on the “Focus Variation” technology and the other one was the confocal laser scanning microscope. In this study, 3D digital microscope in addition to the optical microscopes was used. The aim of this study is to compare each technique with others.

In this study, the surface roughness were evaluated by employing the image processing methods such as line scanning, speckle and fast fourier transform (FFT) with three different samples machined via different manufacturing processes. The surface roughness results from processed images were obtained using flexible image analysis techniques such as Dark-light technique developed by the authors. The values calculated with the proposed method were compared with the roughness values obtained from 3D digital and optical microscopes.

Keywords: 3D digital microscope, Optical microscope, Image processing

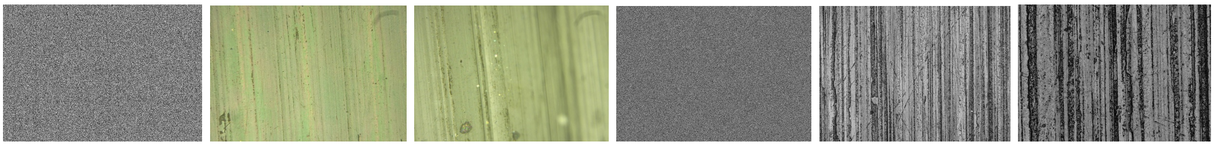
Introduction

Surface roughness is one of the most significant features in evaluating the materials quality such as a lens, key component in digital cameras. R_a, average of centre line profile and R_z, average maximum height of roughness profile are the most preferred parameters generally measured by a stylus profilometer [1–3] in surface roughness evaluation. As a complementary of stylus method, the optical measurement techniques make a great contribution to the development of the field of dimensional measurement [4].

Experimental Procedure

Machining of the Workpieces

The experiments were performed by preparing specimens manufactured by different machining processes, surface grinding, front milling and face turning. The images for three different roughness values of (R_a) 0.0362, 1.0590 and 2.384μm from the surfaces are given in Fig. 1. The above values of R_a were averaged values taken from the infinite focus and confocal laser scanning type microscopes as optical microscopes and digital microscope.



(b) (c) (d) (e) (f)

Fig. 1: The images taken from the workpieces (digital images) a) Fine-Ground surface (R_a=0.03 μm), b) Front Milled surface (R_a=0.09 μm) and c) Face Turned surface (R_a=2.3 μm) (optical images) a) Fine-Ground surface (R_a=0.05 μm), b) Front Milled surface (R_a=1.2 μm) and c) Face Turned surface (R_a=2.5 μm)

Measurement of the Workpieces

A confocal laser scanning microscope and an infinite focus microscope as optical microscopes, and a digital microscope were used in roughness measurements of this study.

The scanning type confocal laser microscope provides the operation at 408 nm by minimizing the aberrations associated with short wavelength illumination and maximizing the 408 nm light source performance. In this study, patterns of the machined metal surfaces (Fine-Ground, Front Milled and Face Turned) were captured using a collimated laser beam with 408 nm laser diode (LD) laser and white light emitting diode (LED) illumination [5].

The operating principle of the infinite focus microscope (IFM) combines the small depth of focus of an optical system with vertical scanning in order to provide topographical and colour information from the variation of focus [6].

The Keyence VHX-600 digital microscope is a high resolution CCD camera based system with a high intensity halogen lamp and image processing capabilities that integrates observation, recording, and measurement functions.

In this study, patterns of the machined metal surfaces (Fine-Ground, Front Milled and Face Turned) were also captured using a high power white coaxial LED. The size of workpieces was 5x5 mm. The field view of instruments was 21x21 μm. Each measurement is the average of six scans [7]. 11 roughness parameters like R_a, R_q, R_z etc. were obtained during each measurement and R_a values were used in this study.

Image acquisition and processing

Some research works have been accomplished to inspect surface roughness of a sample by using image processing techniques. The standard image acquisition and processing employs the following steps (Fig. 2).

Fig. 2: Image processing flow for surface roughness measurement

The captured images were processed and analysed using Matlab image processing toolbox. Three image processing techniques were carried out. These techniques were Line scanning, Speckle and Fast Fourier Transform.

Line Scanning

In this study, the true color images were binarised. The size of images was 1024 by 1024. DN (Digital number) values of binarised images were collected from the selected lines using line scanning technique. Figure 3 illustrates how information is picked up from the image for further analysis by line scanning [8].

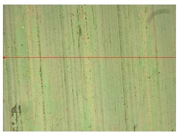


Fig. 3: Line Scanning Representation

Speckle

The spatial properties of the speckle pattern can be related to the surface characteristics. For example, surface roughness could be extracted from the information provided by speckle pattern [9]. This technique adds multiplicative noise to the image. The variance of the added random noise was 0.05 in this study.

Fast Fourier Transform

The Fourier Transform is used if the geometric characteristics of a spatial domain image are desired. Because the image in the Fourier domain is decomposed into its sinusoidal components, it is easy to process certain frequencies of the image. The 2D FFT function in Matlab software transforms the spatial-domain image into the frequency domain image to identify the major influencing factors.

Results

Line Scanning

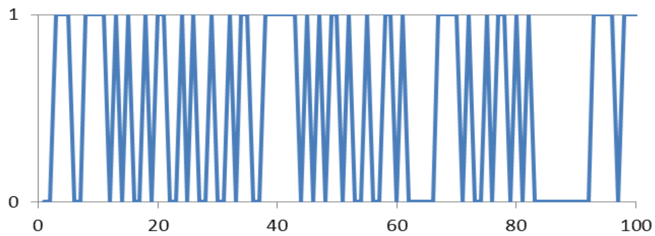


Fig. 4: The signal taken from the workpiece digital image manufactured by surface grinding (Ra=0.03 µm)

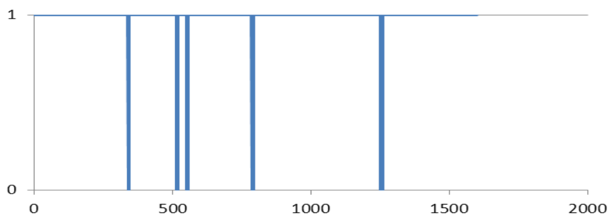


Fig. 5: The signal taken from the workpiece digital image manufactured by front milling (R_a=0.09 µm)

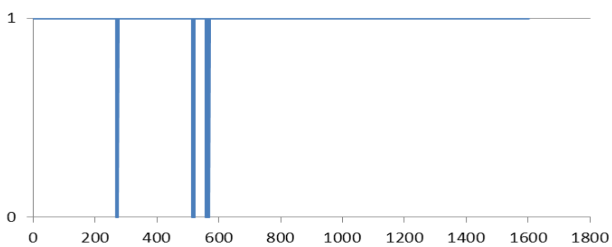


Fig. 6: The signal taken from the workpiece digital image manufactured by face turning (Ra=2.3 µm)

The results of line scanning as an image processing techniques from Figs 4, 5 and 6 clearly indicates that pulse numbers are different for each surface. The number of pulses is 486, 5 and 3 respectively for ground, front milled and face turned surfaces.

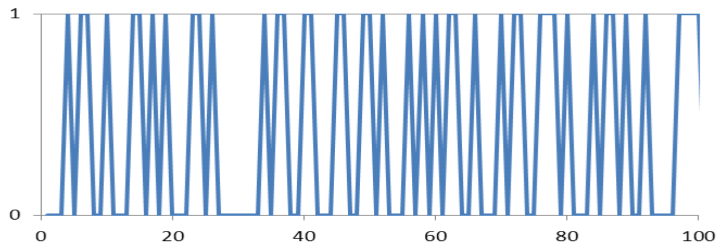


Fig. 7: The signal taken from the workpiece optical image manufactured by surface grinding (R_a=0.05 µm)

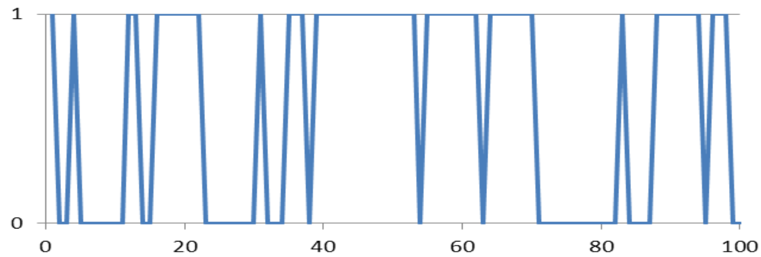


Fig. 8: The signal taken from the workpiece optical image manufactured by front milling (R_a=1.2 µm)

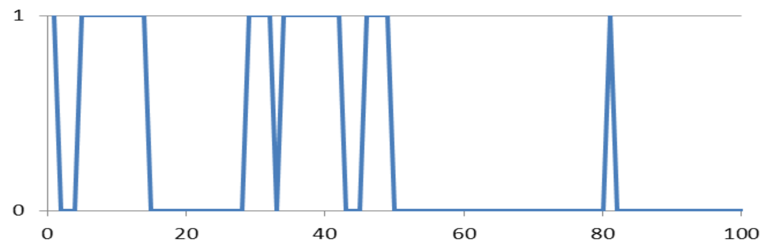


Fig. 9: The signal taken from the workpiece optical image manufactured by face turning (R_a=2.5 µm)

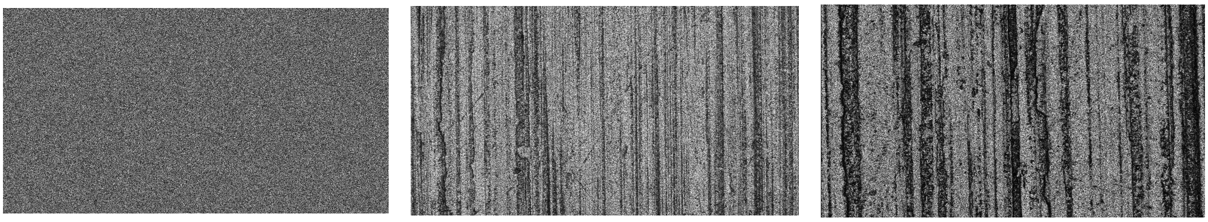
The results of line scanning as an image processing techniques for optical images from Figs 7, 8 and 9 clearly indicates that pulse numbers are different for each surface. The number of pulses is 504, 12 and 6 respectively for ground, front milled and face turned surfaces.

Speckle

Speckle analyses results are shown in Figures 10 and 11 for digital and optical images. Figs 10a, 10b, 10c, 11a, 11b, 11c clearly indicate that as the roughness increases the sharpness and colour distinctions increase. Also, surface texture becomes more recognized.

(a) (b) (c)

Fig. 10: The Speckle images taken from the images of workpieces (digital images) a) Fine-Ground surface (R_a= 0.03 µm), b) Front Milled surface (R_a= 0.09 µm) and c) Face Turned surface (R_a= 2.3 µm)

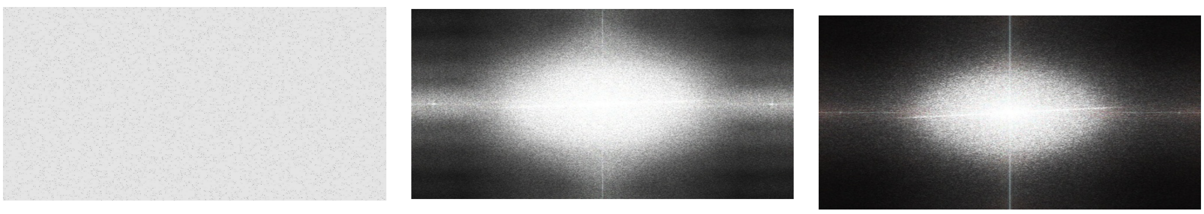


(a) (b) (c)

Fig. 11: The Speckle images taken from the images of workpieces (optical images) a) Fine Ground surface (R_a= 0.05 µm), b) Front Milled surface (R_a= 1.2 µm) and c) Face Turned surface (R_a= 2.5 µm)

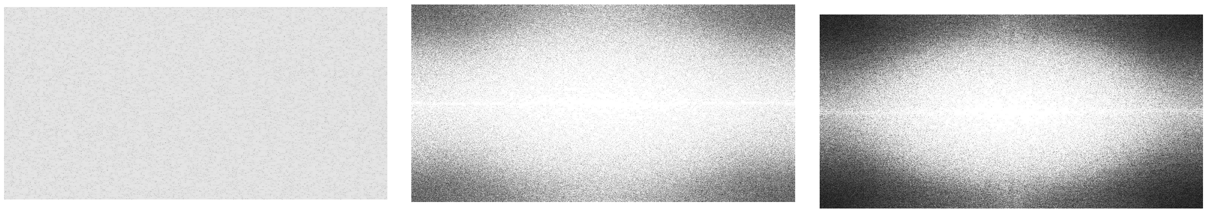
Fast Fourier Transform

Figure 12 and 13 illustrate the results of 2D Fast Fourier Transform analyses. Figs 12a, 12b and 12c clearly indicate that as the roughness increases the diameter of white pixels blob decreases. Additionally, the number of black pixels increases as the roughness of surface increases.



(a) (b) (c)

Fig. 12: The FFT images taken from images of workpieces (digital images) a) Fine Ground surface (R_a=0.03 µm), b) Front Milled surface (R_a=0.09 µm) and c) Face Turned surface (R_a=2.3 µm)



(a) (b) (c)

Fig. 13: The FFT images taken from images of workpieces (optical images) a) Fine-Ground surface (R_a=0.05 µm), b) Front Milled surface (R_a=1.2 µm) and c) Face Turned surface (R_a=2.5 µm)

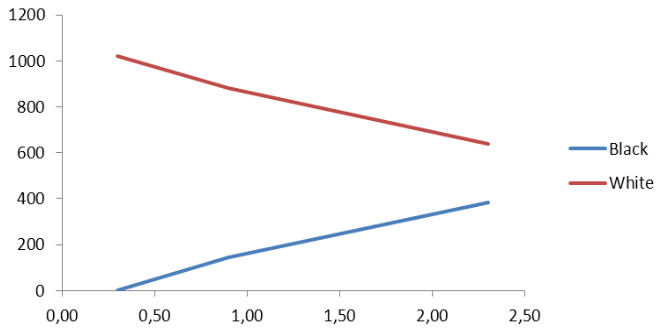


Fig. 14: The number of Black (Dark) and White (Bright) pixels from FFT images taken from images of workpieces (digital images a) Fine-Ground surface (R_a= 0.03 µm), b) Front Milled surface (R_a= 0.09 µm) and c) Face Turned surface (R_a= 2.3 µm)

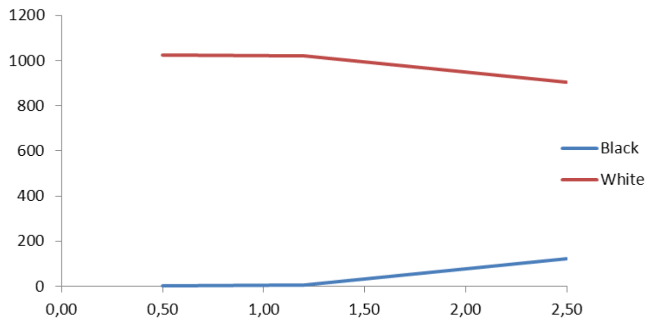


Fig. 15: The number of Black (Dark) and White (Bright) pixels from FFT images taken from mages of workpieces (optical images a) Fine-Ground surface (R_a= 0.05 µm), b) Front Milled surface (R_a= 1.2 µm) and c) Face Turned surface (R_a= 2.5 µm)

Figs. 14 and 15 respectively show the relationship between the number of black and white pixels and surface roughness. The number of black pixels in the image increases with increase in surface roughness (Fig.14). The regression equation and the coefficient of determination for the relationship between black pixels and surface roughness are given below.

$y = 188,2x - 42896 \quad R^2 = 0,99$ (digital)

$y = 64,223x - 47246 \quad R^2 = 0,89$ (optical)

where;

y is the number of black pixels; x is surface roughness

Also, as the surface roughness increases, the number of white pixels in the image decreases. Therefore, the decrease in the number of white pixels (Figs.14 and 15) agrees with the results from Figs. 12 and 13. The regression equation and the coefficient of determination for the relationship between white pixels and surface roughness are given below.

$y = -188,2x + 1066,9 \quad R^2 = 0,99$ (digital)

$y = -64,223x + 1071,2 \quad R^2 = 0,89$ (optical)

where;

y is the number of white pixels; x is surface roughness

Conclusions and Recommendations

Line Scanning, Speckle and 2D FFT image processing and analyses results explicitly imply that three techniques are useful in the determination of surface roughness. The most useful technique is found to be FFT image processing for determining surface roughness.

Acknowledgement

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