# Surface roughness assessment of machined metal surfaces using image processing techniques

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*Surface roughness is usually a technical prerequisite for engineering products and one of the most used significant technical index of product quality. The assessments of a mechanical part are of great importance to achieve the desired surface quality for functional performance in practice. On the other hand, the mechanism behind the formation of surface roughness is very complicated and process dependent, therefore it is very difficult to calculate its value through analytical formula simply since surface roughness is affected by many factors like feed, cutting speed and tool geometry, etc.*

*In this study, three workpieces were produced by conventional machining techniques. These techniques were face turning, front milling and grinding. The measurements were carried out using both the infinite focus microscope and the confocal laser scanning type microscope. The images captured by optical measurement techniques for measuring surface roughness were analysed by using three image processing techniques. These were line scanning, speckle and fast fourier transform (FFT). Then the obtained results from images for determining roughness were compared with those obtained results from both the infinite focus microscope and the confocal laser scanning type microscope. The results from image analysis indicated that FFT analysis represented the surface roughness variation with high correlation ($R^2$ = 0,91).*

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**NOMENCLATURE**

FFT = Fast Fourier Transform
GPS = Geometrical Product Specification and Verification
$R_a$= Average roughness of the profile
$R_z$ = Average maximum height of roughness profile
ISO = International Organization for Standardization
3D = Three – Dimensional
RMS = Root Mean Square

## 1. Introduction

Advances in software and hardware technology have produced major structural alterations in digital image processing, which is the use of computer algorithms to perform image processing on digital images. Surface roughness is one of the most significant features in assessing the quality of materials such as a lens, key component in digital cameras.

Surface roughness affects the surface quality and dimensional accuracy of machined components, thus its monitoring is a fundamental factor in planning of manufacturing processes.

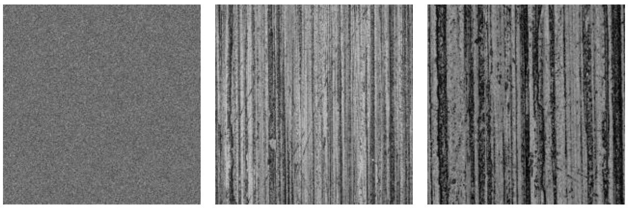
$R_a$, average of centre line profile and $R_z$, average maximum height of roughness profile are the most preferred parameters in assessment of surface roughness. These parameters are commonly measured by a stylus-based measurement system [1–3]. The conventional approach utilizing a stylus gauge has some drawbacks, although it is still widely used surface topography technique. There are some critical factors taken into consideration to obtain good measurement data, while measuring by the stylus profilometer. These are stylus tip dimensions, and 'scan parameters' such as length, speed, the rate of scanning, and the force to be applied on the sample surface. As a complementary of stylus-based measurement method, the non-contact, non-destructive optical measurement techniques making a noteworthy contribution to the development of the field of dimensional measurement [4] are commonly used for measuring these roughness parameters.

Previous researchers have conducted several studies for surface texture evaluation using image processing techniques in the literature. Al-Kindi et al. [5] utilized a roughness parameter based on both the spacing between grey level peaks and the number of grey level peaks per unit length of a scanned line in the grey level image to estimate the surface roughness. Kayahan et al. [6] expressed statistical properties of binary images (SPBI) for surface roughness measurement and binary digitized speckle images can be related with average roughness ($R_a$). Dhanasekar et al. [7] performed an experimental investigation to study the improved implementation of the laser speckle technique for measuring surface roughness. Pre-processing of images of speckle pattern was carried out to improve the quantification of roughness parameters.

## 2. Experimental Procedure

### 2.1 Machining of the Workpieces

The experiments were carried out by preparing specimens manufactured by different machining processes. These machining processes were surface grinding, front milling and face turning. The images for three different roughness values of ($R_a$) 0.498, 2.382 and 3.984μm from the surfaces are given in Fig. 1. The above values of $R_a$ were averaged values taken from the infinite focus microscope and the confocal laser scanning type microscope.



(a) (b) (c)

Fig. 1 The images taken from the workpieces a) Ground surface ($R_a$=0.498μm), b) Front Milled surface ($R_a$=2.382μm) and c) Face Turned surface ($R_a$= 3.984μm)

### 2.2 Measurements of Roughness Parameters

A scanning type confocal laser microscope and an infinite focus microscope are commonly used instruments in the field of precision nanometrology. The measuring principles used in optical surface metrology include optical focusing profilers, confocal point measuring and areal measuring sensors as well as interferometrical principles such as white light interferometry and speckle techniques.

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. Current confocal laser instruments have the light source with 405 nm wavelength. In this study, patterns of the machined metal surfaces (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 [8].

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 color information from the variation of focus [9]. In this study, patterns of the machined metal surfaces (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 [10]. 11 roughness parameters were obtained during each measurement and $R_a$ values were used in this study.

### 2.3 Image processing and analysis

Several investigations have been performed to inspect surface roughness of a workpiece by using image processing techniques. The standard image acquisition and processing employs the following steps (Fig. 2).

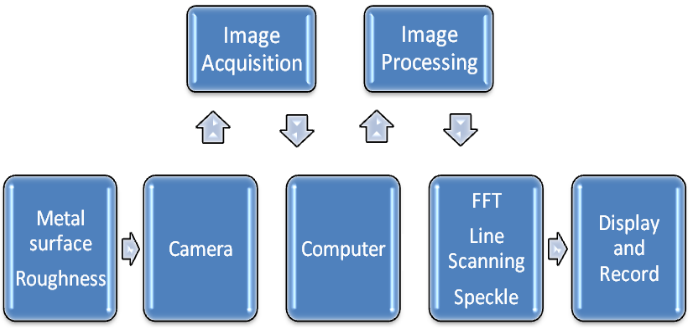



Fig. 2 Image processing flow for surface roughness measurement

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.

#### 2.3.1 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 [11].

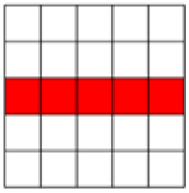


Fig. 3 Line Scanning Representation [11]

#### 2.3.2 Speckle

Speckle is the random pattern of bright (white pixels) and dark (black pixels) regions that is observed when a surface is illuminated with a highly coherent light beam. When the illuminating beam is reflected from a surface, the optical path difference between various wavelets with different wavelength would result in interference showing up as a granular pattern of intensity termed as speckle. The properties of this speckle pattern are used for estimation/quantification of roughness parameters. The spatial properties of the speckle pattern can be related to the surface characteristics. For example, surface roughness may be extracted from the information provided by speckle pattern [7].

This technique adds multiplicative noise to the image. The variance of the added random noise was 0.05 in this study.

#### 2.3.3 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 examine or process certain frequencies of the image, thus influencing the geometric structure in the spatial domain. The 2D Fast Fourier Transformation (FFT) function in Matlab software transforms the spatial-domain image into the frequency domain image to identify the major influencing factors.

## 3. Results

### 3.1 Line Scanning

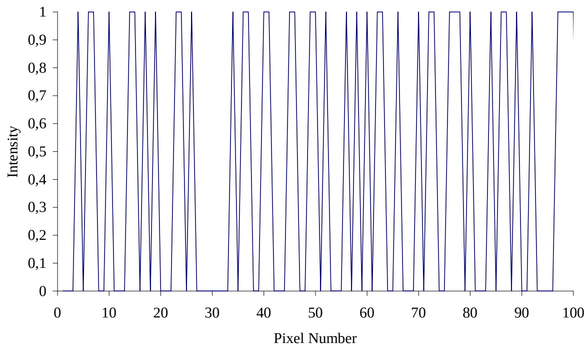



Fig. 4 The signal taken from the image of workpiece manufactured by Grinding ($R_a$=0.498 μm)

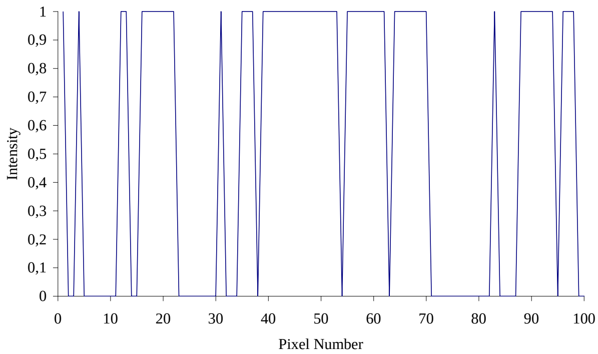



Fig. 5 The signal taken from the image of workpiece manufactured by Front Milling ($R_a$=2.382 μm)

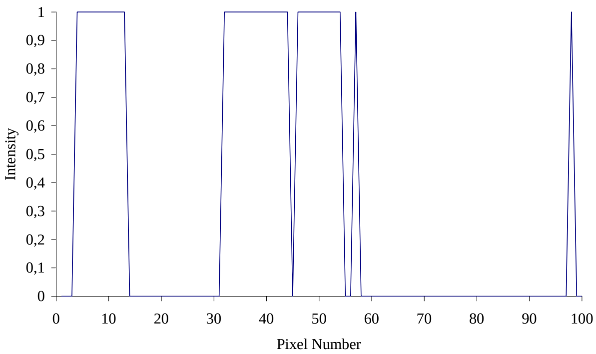
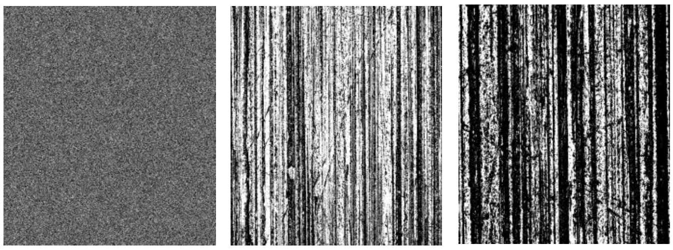



Fig.6 The signal taken from the image of workpiece manufactured by Face Turning ($R_a$= 3.984 μm)

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 28, 11 and 5 respectively for ground, front milled and face turned surfaces. Also Pulse width of signals (Figs 4, 5 and 6) confirm that pulse width increase with increase in surface roughness.

### 3.2 Speckle

Speckle analyses results are shown in Figure 7. Figs 7a, 7b and 7c clearly indicate that as the roughness increases the sharpness and color distinctions increase. Also, surface texture becomes more recognized.

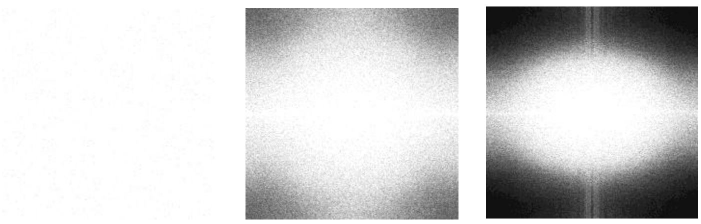


(a) (b) (c)

Fig. 7 The Speckle images taken from the binarised images of workpieces a) Ground surface ($R_a$=0.498μm), b) Front Milled surface ($R_a$=2.382μm) and c) Face Turned surface ($R_a$= 3.984μm)

### 3.3 Fast Fourier Transform

Figure 8 illustrates the results of 2D Fast Fourier Transform analyses. Figs 8a, 8b and 8c 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. 8 The FFT images taken from images of workpieces a) Ground surface ($R_a$=0.498μm), b) Front Milled surface ($R_a$=2.382μm) and c) Face Turned surface ($R_a$= 3.984μm)

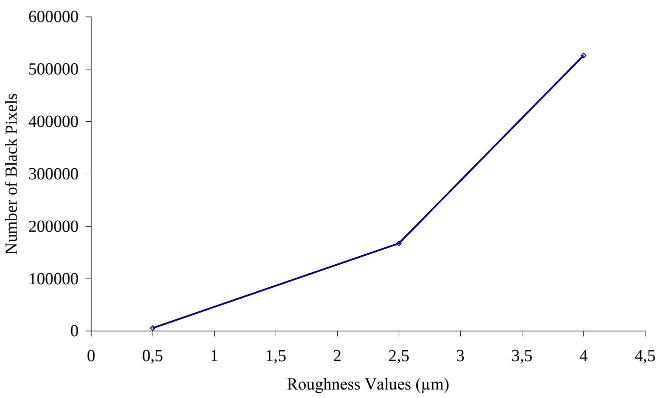



Fig. 9 The number of Black (Dark) pixels from FFT images taken from images of workpieces a) Ground surface ($R_a$=0.498μm), b) Front Milled surface ($R_a$=2.382μm) and c) Face Turned surface ($R_a$= 3.984μm)

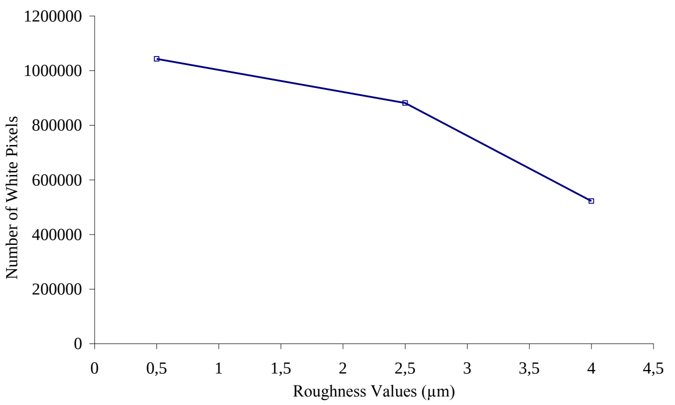



Fig. 10 The number of White (Bright) pixels from FFT images taken from images of workpieces a) Ground surface ($R_a$=0.498µm), b) Front Milled surface ($R_a$=2.382µm) and c) Face Turned surface ($R_a$= 3.984µm)

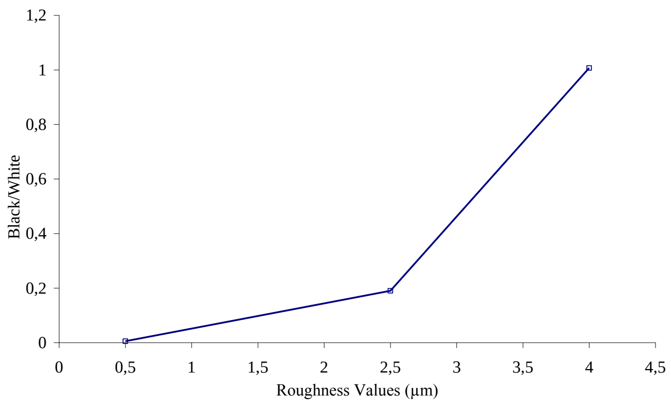



Fig. 11 The ratio of Black (Dark) pixels to White (Bright) pixels from FFT images taken from images of workpieces a) Ground surface ($R_a$=0.498µm), b) Front Milled surface ($R_a$=2.382µm) and c) Face Turned surface ($R_a$= 3.984µm)

Figures 9, 10 and 11 respectively shows the relationship between the number of black, white and the ratio of black-white pixels and surface roughness. The number of black pixels in the image increases with increase in surface roughness (Fig.9). The regression equation and the coefficient of determination for the relationship between black pixels and surface roughness are given below.

$y = 145061x - 105427$ ($R^2 = 0{,}91$)

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 (Fig.10) agrees with the results from Fig. 9. The regression equation and the coefficient of determination for the relationship between white pixels and surface roughness are given below.

$y = -145061x + 1E^{+06}$ ($R^2 = 0{,}91$)

where;

y is the number of white pixels

x is surface roughness

## 4. Conclusions and Recommendations

This study showed that computer vision has a great potential in the determination of the surface roughness parameters as the noncontact measurement. Line Scanning, Speckle and 2D FFT image processing and analyses results explicitly imply that three techniques are useful in the determination of surface roughness. Further investigations were suggested to be conducted with high quality imaging systems (high resolution, high digitization, and high CCD sensitivity etc.), imaging techniques (light source, tilt angle, and lens quality etc.) and image processing techniques.

## ACKNOWLEDGEMENT

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