Non-contact surface roughness measurement using laser speckle technique

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Abstract. This paper deals with selected contact type stylus method and non-contact type machine vision method using laser speckle for components prepared by grinding of AISI 1040 steel with a variety of wheels and varied depth of cut. In this interactive study, Optical method based on statistical properties of binary images is proposed for machined surfaces. Grounded metal surfaces are used to develop a binary digitized speckle pattern by a beam of He-Ne laser light source. High end camera is used to capture the image of a speckle pattern. White to black pixels ratios is computed from the binary images using image processing toolbox in Matlab. The correlation is developed between white to black pixels ratio and measured two-dimensional surface roughness parameter. Two-dimensional surface roughness parameters are recorded using a contact-type surface profilometer. The results which opted, clearly supports that these parameters have a relationship with a degree of surface roughness. A linear relationship is observed between parameter obtained from proposed technique and measured value of surface roughness using surface profilometer. The statistical analysis represents the performance of maximum relative error in prediction of surface roughness is 9%.

1. Introduction
Surface quality has been one of the most prominent measures for machined metal surfaces, in which surface roughness (Ra) is one of the crucial indices of measure. The surface’s durability and manifestation viz. properties of various tribological surface, friction at the surface, wear and tear resistance against its varied applications and fatigue or rupture on the surface (notice in [1,2]), essentially depends on the properties of Surface roughness. Generally, mechanical stylus instrument is implemented in the measurement of surface roughness [3], but it induces some adverse impact by taking more duration for measurement and eventually vandalizing the surface itself [4]. Recently, non-contact measuring methods largely, optical techniques are buoyant in its application for measuring surface roughness [5]. On the other hand, these methods are gruelling due to its measuring complexity and colossal data. On bombarding the machined surface with a coherent light source, at an instance scattering occurs, causing a maze of fine defragmented spotted structure known as, speckle pattern, detect as dark and bright region [6]. This obtained pattern of dark and bright region carries crucial information regarding the surface texture. The gathered speckle pattern properties apprehends in determining the parameter of surface roughness (Ra). Non-contact type surface assessment using machine vision system includes both identification of machined texture [7] and evaluation of surface roughness [8]. Determination of surface roughness of machined surfaces by means of indirect imaging
type optical methods such as interferometry, specular reflection, speckle and light scattering are reported through several studies in the literature [9–16]. S I Mohamed et al. used milled surfaces to check reliability of method of surface roughness prediction using speckle technique. In order to develop the relationship, image intensity parameters mean and standard deviation were selected. Experimental results revealed the good correlation with mean of pixel intensity while standard deviation didn’t fit well [17]. Good correlation were found between surface roughness parameter and 4th level decomposed signals variance using wavelet transform of speckle images captured by complementary metal-oxide semiconductor (CMOS) camera. Signal vectors were formed using speckle images generated through illuminating laser light on the surface produced by electro discharge machining [18]. Scattering effect is prominent for coarse surface. Digitized image having white and black pixels is generated using scattering of the emerging beam reflection which forms a elicit image [15]. Experimentally, when a coarser machined surface is illuminated with laser light, occurrence of scattering effect decreases the intensity of laser beam. This variation in reflected light intensity is captured through CCD camera which is varied with change in surface roughness. The roughness measurement is based on this relationship of parameters in the procured image. The objective of the reported experimental study is to find the correlation between surface roughness parameter measured with surface profilometer and white pixel count, black pixel count and white to black pixel count ratio in order to develop the linear relationship based on correlation value which leads to prepare prediction model for average surface roughness measurement of grounded components using laser speckle technique.

2. Experimental details

2.1. Experimental set-up
Nine identical specimens were prepared using a grinding machine. A square bar made up of AISI 1040 steel was cut into nine equal sizes of 40*40 size and 17 mm length. The specimens were prepared from a square bar with 204 mm length and 40*40 mm size AISI 1040 steel which was normalized to 900 °C and hardened to 35 HRC. As shown in Table 1 different type of grinding wheel and depth of cut were selected. Later on a total, nine experimental runs have been performed with full factorial design and Handysurf 35A/B is utilized for surface roughness measurement of prepared specimens.

| Specimen No. | Grade of Wheel | Depth of Cut (mm) |
|--------------|----------------|------------------|
| 1            | Finish         | 0.1              |
| 2            | Semi Finish    | 0.1              |
| 3            | Rough          | 0.1              |
| 4            | Finish         | 1.5              |
| 5            | Semi Finish    | 1.5              |
| 6            | Rough          | 1.5              |
| 7            | Finish         | 2                |
| 8            | Semi Finish    | 2                |
| 9            | Rough          | 2                |

2.2. Surface roughness measurement using surface profilometer
A portable surface profilometer (Handysurf E 35A) with stylus contact method is used for measuring surface roughness parameters. In industry, contact type surface profilometer is being considered as a standard instrument in order to determine the numerous parameters of surface roughness. Measured
values of amplitude parameter will be considered as point of reference to ensure the accuracy and precision of predicted measurement. Figure 1 demonstrates the setup of contact type surface profilometer. Single line scan preferred for present study. Diamond stylus is used with the radius of 5 µm at the speed of 0.6 mm/sec. Measuring conditions of surface profilometer are given in Table 2.

![Figure 1. Surface Profilometer (Handysurf 35B).](image)

| Table 2. Measuring condition. |
|-------------------------------|
| **Measurement type** | **Roughness** |
| Calculation standard | ISO'97/JIS'01/DIN |
| Measuring range | 160 µm |
| Evaluation length | 8 mm |
| Measuring speed | 0.6 mm/s |
| Cut-off value | 0.8 mm |
| Type of filter | Gaussian |
| Form remove | Straight |
| Material of stylus | Diamond |
| Radius of stylus | 5 µm |
| Number of line scans | Single |

2.3. Set-up of a machine vision system

As shown in Figure 2 machine vision system consist of the CCD camera with a high-end resolution, frame grabber, High-end industrial central processor unit is utilized for putting away and handling of the machined surfaces. The CCD camera (PULNIX) with a resolution of 1024 X 1360 is used to record scattered light. Distance between CCD camera and machined surface is kept at 130 mm. To prevent from any edge effects, 450 X 400 pixels size images were extracted from the captured images mainly from central part. The electronic noise is removed from the extracted image using noise removal algorithm written in Matlab version.

Grounded metal surface is used to develop binary digitized speckle pattern by a beam of He-Ne laser. Figure 3 shows the speckle pattern image of grounded component captured using a CCD camera. Figure 4 demonstrates that pixels in binary image with a value of 1 are displayed as white while value of 0 as black. Binary images are used for computation of parameters such as W (white pixels count) and B (black pixels count) and W/B pixels ratios.
3. Result and discussion
Surface roughness is measured using contact-type surface profilometer to validate the results obtained after predicting surface roughness through developing relationship between ratio of white and black pixels. The relative error between measured and predicted roughness values are shown in Table 3.
Table 3. Relative error between measured and predicted roughness value.

| Measured Ra (µm) | White/Black Pixel Ratio | Predicted Ra (µm) | Absolute Error | Relative Error (%) |
|------------------|--------------------------|-------------------|----------------|-------------------|
| 0.300            | 6.989                    | 0.297             | 0.003          | 1%                |
| 0.310            | 7.591                    | 0.337             | -0.027         | -9%               |
| 0.425            | 8.783                    | 0.417             | 0.008          | 2%                |
| 0.515            | 9.780                    | 0.484             | 0.031          | 6%                |
| 0.585            | 10.663                   | 0.543             | 0.042          | 7%                |
| 0.600            | 11.862                   | 0.623             | -0.023         | -4%               |
| 0.670            | 12.823                   | 0.688             | -0.018         | -3%               |
| 0.715            | 13.612                   | 0.741             | -0.026         | -4%               |
| 0.810            | 14.503                   | 0.800             | 0.010          | 1%                |

Furthermore, a relative error has been calculated to check the measurement ability of proposed method which turns out into higher accuracy rate with maximum 9% of relative error. Experimental results show the performance level of proposed technique on grounded surface prepared under different grinding parameters, which is used to prepare good surface finished components. A good correlation has been found between measured Ra and white to black pixels ratio which is 98.97%. As shown in Figure 5 linear relationship has been developed between measured Ra (µm) and white/black pixel ratio. While developing relationship, 97.98% coefficient of determination was recorded, this provides the less relative error during prediction of surface roughness.

Figure 5. Linear relation between measured Ra(µm) and white/black pixel ratio.

4. Conclusion
In this study, white pixel count, black pixel count and white to black pixel ratios were computed from binary image of grounded components. Speckle pattern were created using He-Ne laser light source on machined surfaces. Linear relationship was found between image parameters and measured roughness values. The mathematical relationship is developed between white/black pixel ratio of pre-processed captured images and arithmetic mean deviation (Ra) measured through contact-type surface profilometer. The statistical analysis identifies that performance of maximum relative error in
prediction of surface roughness is 9%, which showed better performance characteristics of presented linear detection model. Due to the simplicity of the method and required optical system one can conclude that it has great potential for automation and it can be utilized for in-process measurement.

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