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Specular Reflection based On-Machine Surface Roughness Rating of Machined Surface

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With the recent advancement in scientific foundations and technological implementation, optical metrology has become versatile problem-solving backbone in various applications especially in high precision application. Machine vision system has been widely applied to various industrial inspection applications, however, there is not only limited application for on-site inspection but many of them use complicated learning process. This study mainly concerns the surface inspection of machined metal surface using specular reflection. Machining shows a narrow but very bright specular highlight due to constant fine irregularities. As these irregularities changes in terms of surface roughness the intensity of reflected light changes. We use optical simulations to measure the irradiance as it provides fast and robust modeling of reflective and refractive freeform optics in both single-surface and segmented configurations. Machine vision was adopted and grayscale values were used to get the statistical data of images from the experiments to validate the simulation results. The highest resolution of 20nm was obtained with coincidence greater than 96% when compared to conventionally used inspection method. The proposed method is shown to be useful not only for long standoff distance and real time inspection, but also is very fast inspecting 8400mm2 area in just 3.2 seconds and robust to apply at industrial sites for real time surface inspection.

1. Introduction

Optical metrology using machine vision has become versatile problem solving backbone in various applications [1]. In the recent years, metrology and machine vision have been frequently considered together due to the versatility of artificial vision to solve industrial inspection problems. As described in the literature [2] the purpose of visual inspection is to identify specific attributes of the component and to determine whether an object deviate from a given set of specifications.

The flexibility and complexity of modern manufacturing process results in the challenges for the assurance of speed of manufacturing and quality of product due to high production demand [3]. The fundamental properties of light can be utilized as information carrier of a measurement, enabling a wide range of optical metrology tool that allow the measurement of a wide range of objects.

Although many of the methods are available in literature [3-5], the use of these techniques is limited at industrial sites. We recently proposed the use of specular white light reflection [5] for the field surface roughness levelling of lapping meal surface and extracted the texture features using gray level co-occurrence matrix. This study is a preliminary attempt of on –machine surface roughness rating of machined metal surface using optical simulations adopting image processing technique. The results were then compared with the experimental data from our previous work.

2. Optical Simulation

We introduce a predictive, optical based simulation model for surface roughness rating of machined metal surface. The main purpose was to track the intensity of reflected light concerning height change in the roughness which is synonymous to the tool mark residuals. An enhanced technique of measuring the radiant flux in terms of irradiance was used in our method. LightTools illumination software was used for this purpose, as it provides fast and robust modeling of reflective and refractive freeform optics in both single-surface and segmented configurations.

The simulation setup consisted of a LED light source, a specimen to be inspected and sensor/camera for image acquisition as shown in figure 1. We used four different CAD models with height ranging from 30μn to 0μn with the decrement of 10μn, and 0μn being the mirror finished surface. Figure 2 shows the CAD model with decrease in the tool mark height as finishing process proceeds.

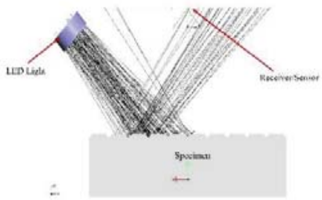

Fig. 1 Optical simulation setup in LightTools software

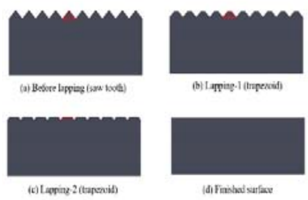

Fig. 2 Decrease in tool mark height as finishing proceeds

3. Experimentation

Similar to simulation, experimental setup consists of camera, lightening device and specimen to be inspected (figure 3).

Reflection is a representative of how light interacts with the surface, it depends upon optical constants and surface morphology. In this case, being same material of the specimen reflective index and absorption coefficient is constant, thus, the intensity of reflected light depends only on surface rugosity. If there are more irregularities on the surface, the reflected light will be scattered, resulting in the decreased pixel intensity. On the contrary, if the surface is defect free, it will reflect all light in the same direction as a concentrated bundle, giving specular highlight. Machine vision was adopted and grayscale values were used to get the statistical data of the image. Figure 4 shows the specular reflection and the which in turn used for the surface roughness rating.

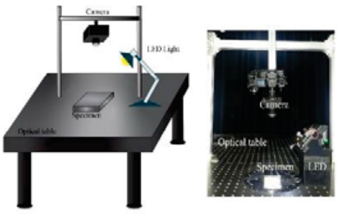

Fig. 3 Experimental architecture

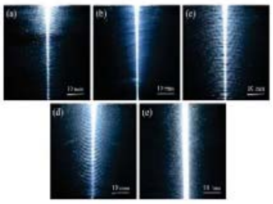

Fig. 4 Machined metal surface: (a-d) Face milling, (e) Lapping

4. Results

For the simulation, irradiance value for different surfaces was calculated. The results of the simulation showed the exponential change in irradiance with roughness values as in figure 5(a). The maximum value of 0.7watt/mm^2 was obtained for the mirror finish surface with theoretical 0μm tool marks height and the minimum value of 0.03 watt/mm^2 was for maximum tool marks height of of 30 μm. In experiment, from the smooth finished surface, we got high grayscale values. Consequently, as the roughness decreases from a-e the width of the reflected light becomes wider. Mean grayscale intensity value was calculated and graph was plotted in figure 5(b) showing the change in grayscale intensity values corresponding to the surface roughness for each of the five specimens. This result complies with the exponential change in irradiance with respect to roughness. Results were then compared to the conventionally used stylus type method in table 1.

(a) (b)

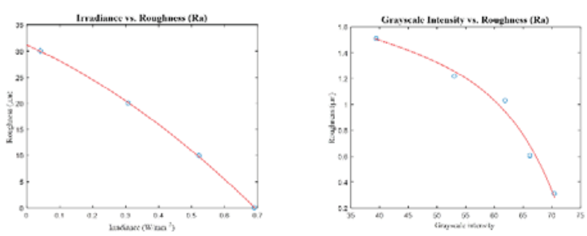

Fig. 5 (a) Simulation result, (b) Experiment result

Table 1. Comparison of conventional and proposed method

Specimen	Stylus type (μm)	Proposed method (μm)	Coincidence (%)
Milling ϕ80	0.584	0.561	96.06
Milling ϕ100	1.114	1.072	96.23
Milling ϕ125	0.460	0.443	96.30

5. Conclusion

Images captured with digital camera were analysed statistically in terms of light intensity using optical simulation and machine vision. Simulation results showed the corresponding change in irradiance with roughness values.

- In experiment, grayscale values change exponentially with surface roughness.
- Both the irradiance and grayscale value decreases as the finishing process proceeds due to the decrease in tool marks residuals.
- A fast yet simple and accurate method was presented for surface levelling, with coincidence more than 96% and a time of 3.2 seconds for 8400 mm^2 area.

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