'93 KACC (1993. 10. 20~22)

A Study of In-process Optical Measurement of Surface Roughness

Atsuhiko Noda and Hiroshi Harada
Faculty of Engineering, Kumamoto University, 2-39-1 Kurokami,
Kumamoto, 860, JAPAN

Abstract: This paper attempts to propose new procedures to evaluate roughness of ground metallic surface in the range of $1 \sim 10\mu m$ from data gained by an optical, in-process measurement of the surfaces. Studies are made to process the data of reflected lights pointed at the surface to be measured. Results obtained are compared with those of measurement by stylus roughness meter.

Correlations between the two types of roughness measurement are well. The proposed method can be used as a sensor for a polishing robot.
Key words: roughness of surface, in-process measurement, optical measurement, polishing robot

1. Introduction

In this paper, a new optical measurement is proposed for evaluation of polished surface roughness. In-process measurement of roughness of surfaces is an important factor in automatic polishing or grinding. One of the authors has proposed a contact-type in-process measurement of grinding depth on surfaces , thus achieved a real time control of grinding robot on the basis of the measured data[1]. The roughness of ground metallic surfaces can be measured exactly by a stylus roughness meter. However, by reason of vibration arising during grinding or by a long time necessary for the measurement, the stylus meter is not applicable to in-process measurement. Optical, non-contact measurement is preferable.

This paper deals with the patterns of beam of light reflected from the surface to be measured. By proper processing of the patterns, the obtained criteria correlate well with the results of measurements by stylus roughness meter.

System configuration used for the measurement of surface roughness is shown in section 2. In section 3, three procedures are proposed to evaluate surface roughness and measures are derived from these procedures. In order to show that surface roughness can be evaluated by these criteria, several experiments have been carried out. Results of the experiments are shown in section 4. In section 5, conclusions drawn are described.

2. System configuration

Fig. 1 shows schematic configuration of the system for measurement of surface roughness. The light source is a halogen lamp. When surface roughness is measured by an optical method, it is usual to use a laser as a light source [2)~5)]. There are two reasons why a halogen lamp is used instead of laser. The first reason is that we want to evaluate surface roughness in an area of some square millimeters. The halogen light can illuminate a wider range of the surface. The second reason is the easiness of handling.

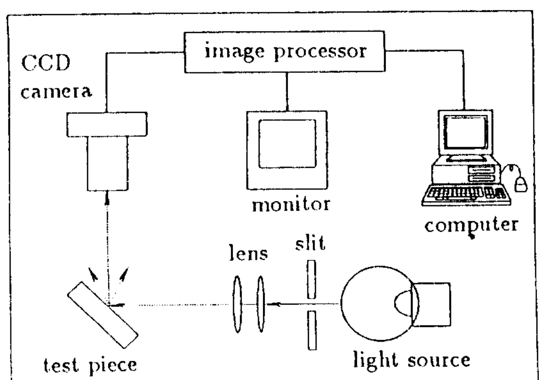
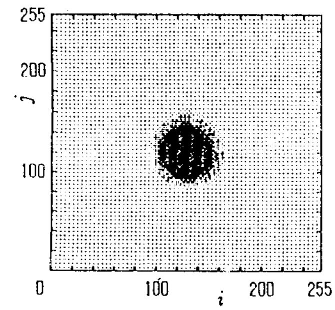


Fig. 1 Schematic configuration of the measurement system

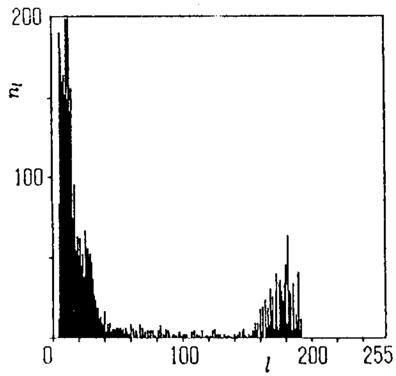
By use of a slit and lens, beam of light is focused at an angle on the surface to be measured. The reflected beam of lights is caught and transduced to digital data by a CCD camera with 256 × 256 pixels, and with 256 light intensity levels. The digital data are transferred to a computer in order to get measures of surface roughness. Procedures for evaluation of surface roughness are carried out in a reasonable time for in-process measurement.

3. Evaluation of surface roughness

Fig. 2 (a) is an example of pattern of reflected lights obtained from the CCD camera and Fig. 2 (b) is a histogram of the intensity of the light.



(a) image of reflected light



(b) histogram of intensity

Fig. 2 An example of pattern of reflected light

From Fig. 2 (a), it is shown that central part of the pattern shows high intensity levels, while boundary part becomes dark. This is due to the surface roughness. So, it is considered that the surface roughness can be evaluated by use of the intensity levels of the reflected lights.

Let $f(i,j)$ be the intensity level of i,j-th pixel.

$$0 \leq f(i,j) \leq 255 \qquad (0 \leq i,j \leq 255)$$

Then n_l represents number of pixels satisfying next equation.

$$f(i,j) = l \qquad (0 \leq l \leq 255)$$

The output $f(i,j)$ of the CCD camera is processed in a personal computer to get measures of surface roughness. In this paper, following three procedures have beeen selected. Each of them aims to represent the roughness of the lighted surface.

3.1 measure Gr

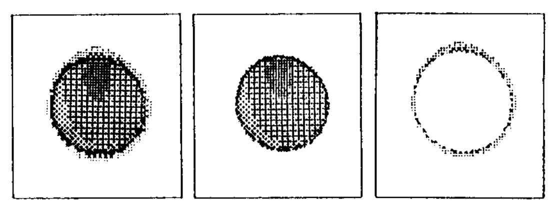
The first measure Gr is introduced by use of distribution of the intensity of the reflected lights. When the surface becomes more smooth, the light reflects more regularly and less scatters [6]. Then, the numbers of pixels with higher intensity levels increase. The measure Gr is defined by next equation.

$$Gr \equiv \frac{\sum_{l=f_t}^{f_{max}} l \cdot n_l}{\sum_{l=f_t}^{f_{max}} n_l} \qquad (1)$$

Here, f_t is the threshold level for dividing image of the reflected light from background and f_{max} is the maximum intensity level of the image. Thus the measure Gr is derived from the portion of numbers of pixels with higher intensity. So, the measure Gr represents the smoothness of the lighted surface.

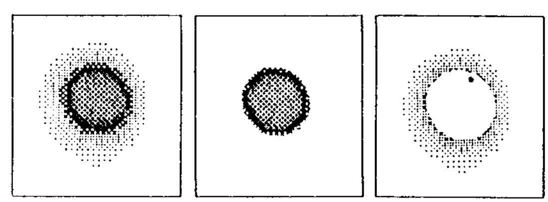
3.2 measure Gb

The second measure Gb proposed in this paper is to evaluate contrast of brightness at the boundary of the beam. If the polished surface is smooth, the intensity of the light will change sharply at the boundary of the beam. Oppositely, contrast of bright/dark becomes dull if the surface is rough. Fig. 3 (a) is an example of image when the surface is smooth. The bright and dark region are shown in Fig. 3 (b) and (c), respectively. Fig. 4 corresponds to an image of rougher surface.



(a) original image (b) bright region (c) dark region

Fig. 3 An example of image when the surface is smooth



(a) original image (b) bright region (c) dark region

Fig. 4 An example of image when the surface is rough

Comparing these figures, when the surface is smooth, the area of the dark region becomes small. So, the surface roughness can be evaluated by the ratio of the area of bright region to that of dark region.

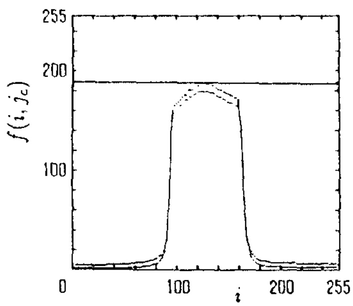
The measure Gb is given by next equation.

$$Gb \equiv \frac{\sum_{l=f_b+1}^{f_{max}} n_l}{\sum_{l=f_t}^{f_b} n_l} \qquad (2)$$

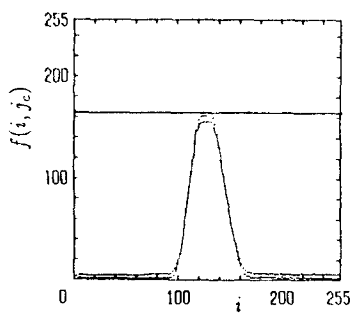
Here, f_b is the threshold level which is used to discriminate between bright region of the reflected light and the dark region. In this paper, the threshold level f_b is determined by Ohtsu's method [7]. From eqn. (2), the contrast at the boundary of the beam can be evaluated by the measure Gb.

3.3 measure Gs

From the examples shown in Fig. 3 and 4, the surface roughness influences the intensity level at the boudary of beam. So, another measure is derived by use of the intensity level at the cross-section of the image. Let (i_c, j_c) be the co-ordinate of the center of the beam. Then, $f(i, j_c)$ $(0 \leq i \leq 255)$ means the intensity level at the central line. Examples of the intensity level $f(i, j_c)$ $(0 \leq i \leq 255)$ are shown in Fig. 5.



(a) when surface is smooth



(b) when surface is rough

Fig. 5 Intensity level at the central line

From Fig. 5, it is shown that when the surface becomes smoother, the slope of the intensity level becomes steeper. Therefore, it is considered that the surface roughness can be measured by use of steepness of the intensity level.

Let i_1 and i_2 $(i_1 > i_2)$ be co-ordinates satisfying

$$f(i_1, j_c) = f(i_2, j_c) = (f_{max} - f_l)/2$$

Then, the third measure Gs is defined by next equation.

$$Gs \equiv f_{max}/(i_1 - i_2) \quad (3)$$

When the surface is smooth, the slope of the intensity level is steep and $i_1 - i_2$ is almost equal to the diameter of the image of the reflected light. While, the surface becomes rough, the slope becomes dull and the measure Gs becomes small. So, by use of eqn. (3), the surface roughness can be evaluated.

4. Results of experiment

In order to investigate that roughness of polished metallic surface can be evaluated by use of the proposed three measures, experiments have been done. The proposed measures, Gr, Gb and Gs are calculated using several test pieces made by brass of different surface roughness. After optical measurement, test pieces have been are measured by a stylus type roughness meter and the results of two measurements are compared.

The relation between the surface roughness R_{max}, which are measured by the stylus roughness meter and the measure Gr calculated by eqn. (1) are shown in Fig. 6.

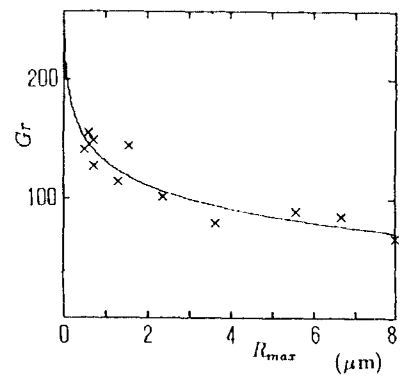


Fig. 6 Surface roughness R_{max} vs. measure Gr

From Fig. 6 , it is shown that when the surface becomes smooth, Gr takes large value. In this case, the relation between the surface roughness R_{max} and the proposed measure Gr can be calculated by next equation.

$$R_{max} = 162.5 \times \exp(-0.03658 \times Gr) - 0.1329$$

In Fig. 7, the relation between the surface roughness R_{max} and the measure Gb is revealed.

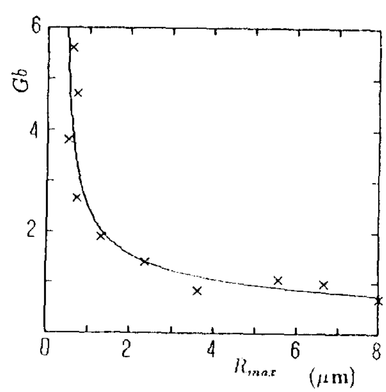


Fig. 7 Surface roughness R_{max} vs. measure Gb

The two values R_{max} and Gb are connected by next equation.

$$R_{max} = 4.064 \times Gb^{-2.084} + 0.3953$$

When the surface roughness R_{max} is evaluated by the measure Gs, the results are shown in Fig. 8.

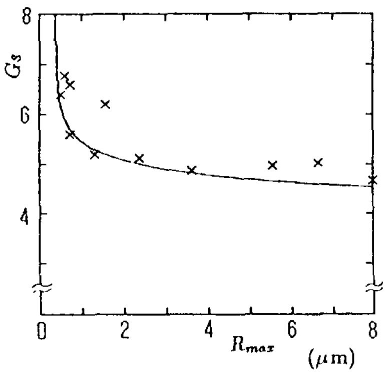


Fig. 8 Surface roughness R_{max} vs. measure Gs

The relation between R_{max} and Gs is given by

$$R_{max} = 4.434 \times 10^9 \times Gs^{-13.36} + 0.3953$$

From these figures, the measure Gb is most suitable for evaluation of the surface roughness.

5. Conclusion

A new simple optical measurement for evaluation of surface roughness of ground metallic surfaces has been proposed. In this paper, three measures are defined using the patterns of beam of light reflected from the surface to be measured. The results of experiments show that these measures correlate quite well with the results of measurements by stylus roughness meter. This fact suggests that the proposed measures can be applied to in-process measurement of surface roughness during grinding processes.

6. References

1. A.Noda et al. :Development of Sensor Controlled Robot for Deburring, Proc. 15th Int. Symp. Industrial Robots, 207/214, (1985)
2. E.G.Thwaite : The Direct Measurement of the Power Spectrum of Rough Surfaces by Optical Fourier Transformation, Wear **57**, 71/80 (1979)
3. K.Mitsui: In-process Sensors for Surface Roughness and their Application, Predision Engineering, **8-4**, 212/220, (1986)
4. R.Brodmann: Roughness Form and Waviness Measurement by Means of Light-scattering, Precision Engineering, **8**-4, 221/226, (1986)
5. M.Shiraishi: A Consideration of Surface Roughness Measurement by Optical Method, Trans. of ASME, J. of Engineering for Industry, **109**, 100/105, (1987)
6. H.E.Bennett and J.O.Porteus : Relation Between Surface Roughness and Specular Reflectance at Normal Incidence, J. Opt. Soc. Am., **51**-2, 123/129, (1961)
7. N.Ohtsu : An Automatic Threshold Selection Method Based on Discriminant and Least Squares Criteria, Trans. of IECE of Japan, **J63-D**-4, 349/356 (1980) (in Japanese)