Discrimination of Metallic and Colored Surface States by Optical Pattern Projection Method

T. Inari and N. Aoki
Kinki university, Japan

Abstract

In the optical pattern projection method called by the authors for surface roughness measurement, the roughness is detected from the qualities of the output image, such as contrast, formed by an imaging system including a target surface. We will report the relation between the roughness and contrasts for metallic surfaces and the colored plastics in the range of R_a of about 0.1 μm and below, using a video camera. For the colored plastic surfaces, the authors explain that the sensitivity for gloss depends on the contrast of the formed image under additional illumination by other light sources.

1. Introduction

The authors proposed and examined some optical methods for surface roughness measurement using reflection of laser light [1], and the other uses image formation and processing [2,3,4]. In this paper, we will treat the optical pattern projection method called by the authors for surface roughness measurement and trial application of this method to discriminate the human sensitivity for gloss of surfaces. In this method, the roughness is detected from the parameters corresponding to quality of the output image, such as contrast, formed by an imaging system including the target surface. In the imaging system used for this method, the light beams are passed through the input image such as a knife edge, and are projected by the lens on the observing plane. The target surface to be measured is placed in the way of the optical path of the imaging system.

In the previous works, the authors found the relation between the contrasts of the images and the arithmetic mean R_a of the surfaces could be expressed by an experimental equation in the range of R_a of about 0.1 μm and below [2]. The use of a video camera [3] is desirable for practical application of this method. However, the dynamic range of the video camera is limited, and the dark output gives the deviation of the contrast data from the theoretical relation between the roughness and contrast [4].

We will report the relation measured by use of a video camera between the roughness R_a and contrasts for metallic surfaces in the range of R_a of about 0.1 μm and below. And then, we explain the relations between roughness and contrasts, in the case of colored plastic surfaces, are almost the same as the cases of metallic surfaces, and are independent on the human gloss sensitivity. We will report, however, the gloss sensitivity depends on the contrast of the formed image under the illumination from an additional light source.

2. Measurement of Surface States and Gloss Sensitivity

2.1 Outline of the pattern projection method

Quality of the images formed by an imaging system including a target surface depend on the surface states of the target. Surface states, therefore, can be detected using this relation. We call this method the pattern projection method. The basic configuration of the method is shown in Fig.1. The light beams from the light source are illuminated the input pattern from behind of it, and are focused on the observing plane through the reflection off the target surface. The optical transfer function of the imaging system is dominated by the surface roughness of the target, then the quality of the output image relates with the surface states such as roughness. Therefore the roughness can be measured by detection of a parameter, such as the contrast, representing the quality of the image [2].

2.2 Characteristics of the method

In the previous works [2] the authors found that the correlation between the contrast C and the R_a is expressed by the equation,

$$C = \exp(-g), \tag{1}$$

where $g = (4\pi\sigma/\lambda)^2$, λ is wavelength of the light used and σ is the standard deviation of the amplitude of the surface profile of the target, and σ can be replaced by R_a. In this work, the authors used the mechanical scanning of a photo-diode to detect the light intensity distribution (brightness) of the pattern on the observing plane. The calculation of C is done in the case of $\lambda = 1$ in equation (1).

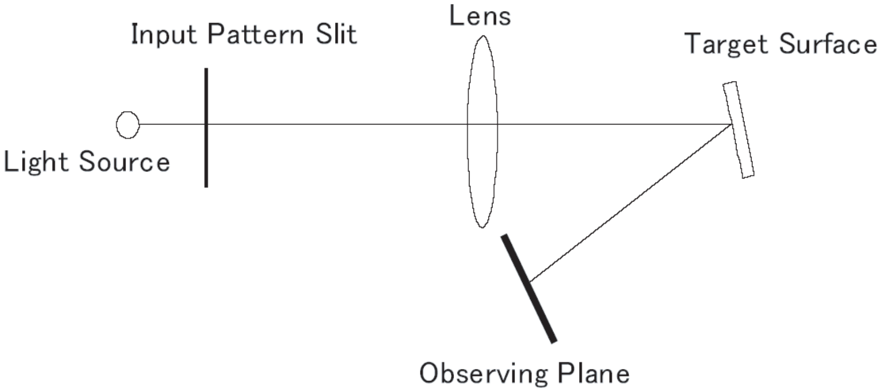

Figure 1: Basic configuration of the pattern projection method

In the experiment, the contrast was obtained using the equation as follows,

$$C = (I_{max} - I_{min})(I_{max} + I_{min}) \tag{2}$$

I_{max} and I_{min} are the maximum and minimum values of the brightness data respectively along one scanning line being across the edge line of the knife edge image. The positions of the maximum and the minimum are at constant distances from the edge line.

When a video camera is used to detect the intensity distribution of the image, the reduction or deviation of the contrast from the calculated results is appears. The authors proved this deviation was originated from the dark output of the video camera, and proposed the method of compensation for gray level of an image [4].

The compensation is done as follows. The range of the gray level of the image is enlarged into the full scale of the camera using the following equation,

$$br = \frac{MAX - MIN}{max - min}(f - min) + MIN \tag{3}$$

where max and min are the maximum and minimum of the original brightness data, MAX and MIN are the maximum and minimum of the brightness data enlarged. f is brightness data of the original image.

2.3 Application of the method to gloss sensitivity

Gloss is usually defined simply by a ratio of diffused component to the specular component of scattered light from a surface. This definition has little relation with human sensitivity for gloss. Human sensitivity correlates with appearance of an image formed on a surface. The pattern projection method, therefore, is expected to be applied to the measurement of gloss.

3. Experiments

3.1 Experimental method

The experimental system using a video camera is shown in Fig.2. The video camera detects the output image formed on the observing plane. Image data are processed, and the contrast is derived. A knife edge is used as the input pattern. The samples used are stainless steel plates about 50 × 50 mm in size. The range of R_a are from 0.016 to 0.090 μm. Colored plastic plates with the surface roughness R_a being from 0.036 to 0.042 μm are prepared. The colors of them are white, black, red, yellow, and transparent.

The contrasts are calculated from the brightness data along a scanning line of the video camera using equation (2). The final contrast data of a sample are deduced by average of the contrast data from 150 scanning lines. The contrast data are deduced from the images after gray level compensation by equation (3) from the original images. The contrasts from the original images without compensation are also shown in the figure.

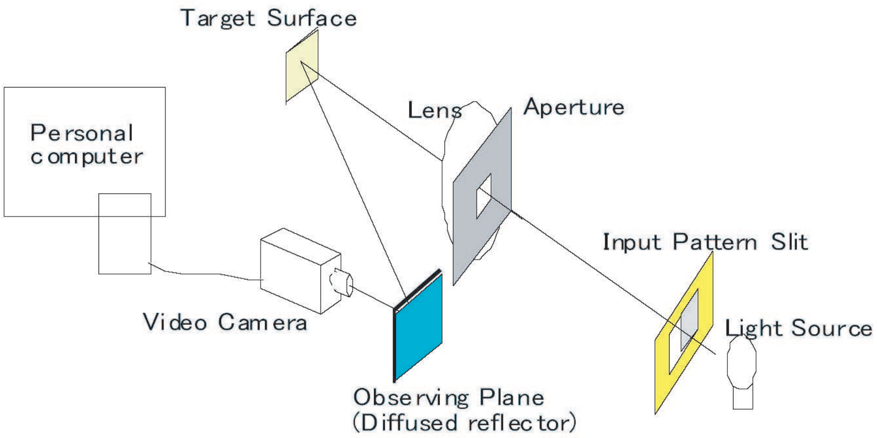

Figure 2: Configuration of the experimental system

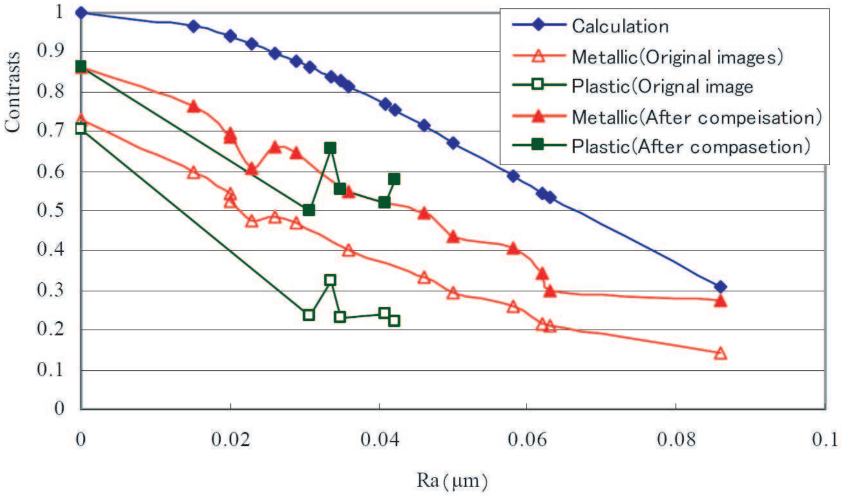

Figure 3: Relations between contrasts and roughness Ra for metallic and colored plastic surfaces, calculated results from the experimental equation are shown together. The results before and after the gray level compensation are shown

3.2 Experimental results

The contrast data from the metallic and the plastic surfaces, before and after the gray level compensation, are shown in Fig.3. The curve of calculated results from the equation (1) is shown together. The deviations of the contrast data from the calculated curve appear and the effect of the gray level compensation is clear. The correlation between the contrast and R_a in case of the plastic surfaces is the same with the case of the metallic surfaces.

4. Discussions

In the case of the plastic surfaces, the contrast data depend also only on the surface roughness R_a, though human sensitivities for gloss are different between the colored plastic surfaces. The contrast data described above is originated only from specular scattering on the upper layer of the surfaces.

Then, we propose a new pattern projection method using the illumination with an additional light source. The additional illumination gives the diffused reflection from the lower layer of the surface. The imaging system used in this new method is different from that shown in Fig.2. The image of the input image is detected directly with the video camera through reflection on the target surface. The direction of the additional illumination is inclined from the specular direction.

The detected images obtained by the method are shown in Fig.4. The used samples are white and black plastic plates. The images obtained with and without the additional light source are shown in the figure. The

(a) Black (without additional light) (c) White (without additional light)

(b) Black (with additional light) (d) White (with additional light)

Figure 4: Appearances of the images from the plastic plates of black ((a) and (b)), and white ((c) and (d)). The cases with additional lights are shown in (b) and (d)

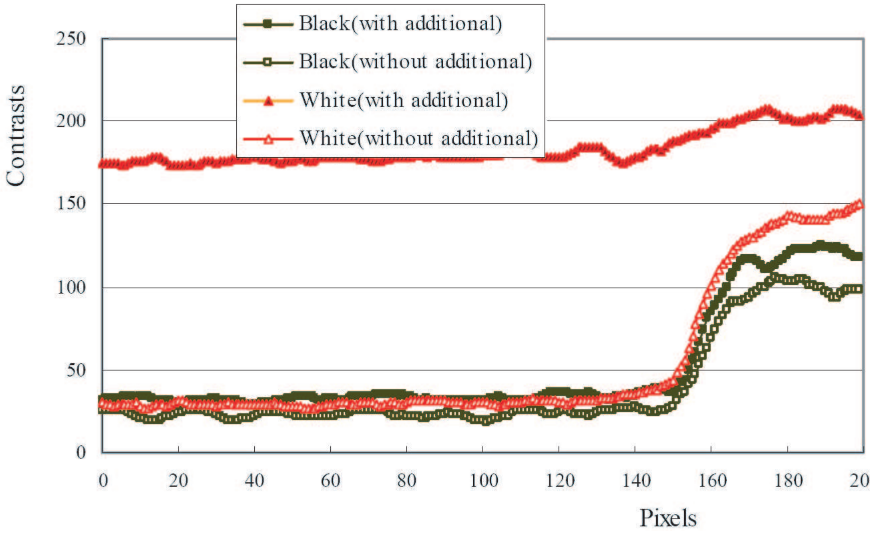

Figure 5: Brightness distributions along the scanning lines of the plastic plates of black and white surfaces, under with and without additional light sources.

differences of the appearances between the images of the white and the black plates are clear.

The brightness distributions along one scanning lines of the images in Fig.4 are shown in Fig.5. We find that the change of the contrast of the image of the white surface caused by the additional illumination is larger than that of the black case. This result corresponds to our sensitivity that a black surface is superiorly glossy than a white surface.

5. Conclusion

We proved the roughness R_a of about 0.1 μm and below can be measured by the pattern projection method, and the gray level compensation is useful in this method. This method gives the same results for the colored plastic surfaces with metallic surfaces, if R_a of them are same with each other.

The new method using additional light sources is proved to be useful in order to represent the human gloss sensitivity for white and black colored plastic surfaces. Therefore, farther development based on this result for gloss sensitivity measurement is expected in future.

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