Detection of defects on the paint panel surface of a car body using laser scattering method

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Summary

This paper reports a new method for detecting defects on the paint panel surface of a car body, which is light scattering method based on optical Fourier transform theory. In this paper, an incident laser beam emitted from He-Ne laser is illuminated onto the test surface. Light reflected from the test surface is directed to a CCD camera through the Fourier transform lens. Then, the scattered light intensity distribution is characterized by the defect size of the test paint surface. The defect size ranges of 5-50 µm in height and 500-2000 µm in width are measurable by computing the intensity ratio of diffuse reflection to specular reflection of panel surfaces. The experiment results show that the proposed method using the laser light is available for detecting defects on the paint panel surface of a car body.

Keywords: Defect detection, Laser scattering, Paint panel surface, Fourier optics

1. Introduction

Paint appearance of a car is becoming the important factor with a user's individualization and diversification of needs in recent years. There are many kinds of defects at different places on the paint panel surface of a car body. A human visual inspection is still in practical use. The visual inspection depends on expert workers, however an oversight and incorrect inspection of defects are never avoided. Furthermore, the defects induce user's complaint. Therefore, development of the paint panel surface inspection technology is required to attain the automation and laborsaving in car industry. Many inspection technologies have been developed as far, however, contact technique has several drawbacks, namely:(a) it takes long time to perform the measurement, (b) it is very sensitive to environment noise and vibration, (c) the stylus may scratch the surface, (d) the working distance is too short. Optical measurement technologies have several advantages due to non-contact method using conventional laser light. Especially, light scattering method based on optical Fourier transform theory with a lens system is effective method, which is applied to detect the different kinds of surface defects such as micro-scratches, pinhole, particular contaminations, at high speed as well as with high resolution.

In this paper, we proposed a new optical method, which enables to detect the panel surface defects by computing the intensity ratio of diffuse reflection to specular reflection of panel surface. Fundamental experiments are carried out for the various test pieces with different colors. From the experimental results, it is found that the proposed inspection method is effective for the defects detection of paint panel surface.

2. Principle of Measurement

Fraunhofer diffraction is a kind of diffraction phenomena obtained by optical Fourier transform with a lens system. The imaging geometry for obtaining Fraunhofer diffraction pattern of the reflecting surface is shown in Fig.1. When the object surface is illuminated by parallel laser light, the reflected light produces an intensity pattern, which is called the Fraunhofer diffraction pattern on image plane located at the principal focus of the Fourier transform lens. This intensity pattern gives us some optical information about the different shapes and sizes of defects on the paint panel surface.

In this paper, the basic principle of light scattering technology is based on the fact that the different micro-structures of a test surface may cause changes in the scattering pattern.
characteristic of the reflected light. Fig.2 shows the principle of measurement for obtaining the defect sizes as well as existence of the defect on the panel surface. In our experiment, intensity of specular reflection is denoted as $I_s$ and intensity of diffused reflection is denoted as $I_d$. We introduce a parameter $P$ that is directly related to the size of defect. Thus,

$$P = \frac{I_s - I_d}{I_s + I_d}$$  \hspace{1cm} (1)

If there is no defect on the test surface, the diffraction intensity pattern on CCD camera is a circle and the value of $P$ is may be higher than 0.90. (If the test surface is a reflective mirror, the value of $P$ is 1.0). On the other hand, if there is a defect on the test surface, the diffraction intensity pattern on CCD camera is irregular and the value of $P$ is estimated to be less than 0.60. The smaller the size of defect is, the larger the value of $P$ is. Therefore existence discernment of a defect can be performed from the form of intensity pattern and the size of defects can be evaluated by the value of parameter $P$.

![Image](Fig.2 Distribution of reflection on painted surface)

The feature of this technique is as follows: (1) it is realizable to be high-speed measurement due to non-contacting technique using laser light, (2) it is hard to be influenced by disturbance, such as vibration since a Fourier transform optical system is used, (3) it is possible to obtain the detailed information of the defects because of detecting the diffraction intensity patterns.

3. Experimental method

The experimental setup is shown in Fig.3. Light beam from a 4 mw He-Ne laser is illuminated through attenuator onto the test surface mounted on the three-axis translation stage. The reflected light from the test surface is passing through the Fourier transform lens and then is accepted by CCD camera. The intensity distribution detected by the CCD camera is converted to 8 bit digital image data and stored in the image memory. These data are deal with a personal computer.

In our experiment, 4 different color panels are used for test surface. There are Green, Blue, Red and Gold. Fig.4 shows the typical defect sizes which are 4-23 μm in height and 1400-2800 μm in width on the test surfaces.

4. Experimental results and discussions

4.1 Boundary of $I_s$ and $I_d$'s domain

In order to obtain the intensity ratio $P$ from $I_s$ and $I_d$, the boundary of $I_s$ and $I_d$ in the intensity distribution detected by CCD camera is required. As shown in Fig.7, when there is no defect on the test surface, the intensity...
distribution becomes a circle sharp as a beam spot. The radius of circle (r) and the center co-ordinate value (X₀, Y₀) as shown in Fig.5 are obtained by counting the number of pixels (M) in which the intensity is larger than a threshold value. Since the area of circle is expressed as
\[ S = \pi \times r^2 = M \times a^2 \]  \hspace{1cm} (2)
Where \( a \) is the CCD camera's pixel size (11*11 \( \mu \text{m/pixel} \)), the radius of circle (r) is easily given by
\[ r = a \sqrt{\frac{M}{\pi}} \]  \hspace{1cm} (3)

Similarly, from the positions (Xi, Yi) of pixels indicating which the intensity is larger than a threshold value, then the center co-ordinate value of the circle is obtained as
\[ X₀ = \frac{1}{n} \sum_{i=0}^{n-1} X_i, \quad Y₀ = \frac{1}{n} \sum_{i=0}^{n-1} Y_i \]  \hspace{1cm} (4)

The inside intensity of boundary circle is considered the specular reflection (Iₐ), while the outside intensity is the diffused reflection (Iₐ).

4.2 Threshold for boundary
A histogram means the frequency of pixels of the intensity values. For example, the histogram of test surface without defect is shown in Fig.6. The number of pixels increase rapidly at 5 and has a peak at 8, after that, it decrease nearly equal to 0 at 11. In order to avoid the influence of noise, the threshold should be selected a little larger value than the background value of 8. Then the value of threshold is determined as 11 in this case.

4.3 Characteristics of scattered light intensity distribution
The color paint panels with different defects sizes are used as the test surfaces. When there does not exist any defect on the illuminated surfaces as shown in Fig.7, the intensity pattern is circular shape as a beam spot and its distribution is similar to normal one. Table.1 shows the value of P for 4 different color panels. The value of P is higher than 0.9 regardless of color.

![Intensity pattern without defect on the test surfaces](image)

Table.1. Values of P for different color test surfaces without defect

<table>
<thead>
<tr>
<th>Test specimen</th>
<th>Green</th>
<th>Blue</th>
<th>Red</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of P</td>
<td>0.98</td>
<td>0.97</td>
<td>0.90</td>
<td>0.91</td>
</tr>
</tbody>
</table>

On the other hand, Fig.8 (a), (b), (c), (d) show the intensity pattern scattered from the defects on the 4 different color panels of Green, Blue, Red and Gold. In the case of (a) and (b), these patterns are widely distributed and not uniform, however, the patterns of (c) and (d) are concentrated around the center and are seem to be uniform distribution. The pattern features seem to be characterized by the shapes as well as the sizes of the defects. Table.2 shows the defect sizes (height, width) and the values of P for 4 different color panels. The value of P is less than 0.5 in each defect pattern. Furthermore, The value of P has a tendency to be larger as the width becomes smaller, for example, P is 0.44 for 900 \( \mu \text{m} \) in width and 0.10 for 2800 \( \mu \text{m} \). Fig.9 shows the relation between the value of P and the value of volume multiplied height by width of the
defect size. The smaller the volume of defect is, the larger the value of \( P \) is. This fact suggests that the value of \( P \) gives us the defect sizes as well as the existence of defect on the color paint panel surface.

![Intensity patterns with defects on the different color test surfaces](image)

![Relation between \( P \) and volume](image)

Table 2: Values of \( P \) for the defects on different color test surfaces

<table>
<thead>
<tr>
<th>Test specimen</th>
<th>Green</th>
<th>Blue</th>
<th>Red</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of defects (( \mu m ))</td>
<td>22.97</td>
<td>22.27</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Width of defects (( \mu m ))</td>
<td>1600</td>
<td>2800</td>
<td>900</td>
<td>1400</td>
</tr>
<tr>
<td>Values of ( P )</td>
<td>0.21</td>
<td>0.10</td>
<td>0.44</td>
<td>0.19</td>
</tr>
</tbody>
</table>

5. Conclusions

In this paper, the methods of light scattering and light intensity parameter \( P \) are described for the measurement of the size of defects on the paint panel surface of a car body. Existence discernment of the defect on the surface can be performed from intensity pattern. The existence of a defect and the judgment of size can be performed on the light intensity parameter \( P \). (1) When there is no defect, the value of \( P \) is between 0.9–1.0. (2) When there is a defect, the value of \( P \) is -1–0.6, and the smaller the size of defect is, the larger the value of \( P \) is. Experimental results show that this technique is suitable for detect size on the paint panel surface of a car body. In addition, the present setup and procedures are relatively simple and have requirements for environmental stability.

Acknowledgements

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References