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Color Inspection by Spectral Imaging for Coated Surface

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Abstract Multispectral imaging technique has attracted attention in the machine vision field to enhance measurement and inspection systems. In this paper, we present an on-line color inspection system of the surface color of building materials using an imaging spectrograph. The color inspection of building materials has a problem of the three-dimensional unevenness, while the detection of a delicate tone of color is requested. We show a method which makes it possible to detect differences in color stably using shading compensation which cancels the three-dimensional curvature in the colorimetric system CIEL*a*b*.

1 Introduction

Measuring technology using an optical spectrum has been applied widely to various fields, such as colorimetry, various chemical analyses and remote sensing.

The need for the spectroscopic technology is increasing also in industrial fields: color inspection for printing, coating and building materials, quality evaluation, the sorting and contaminant inspection of products, and it is now also increasing from the viewpoint of research on users' tastes for products and the improvement of human-machine interfaces [1][2].

Then, High-speed multispectral imaging technology using an imaging spectrograph is now expected. The following methods have prevailed up to now: spectrophotometers, multiband cameras and RGB color camera. However, there are many cases in which the required specifications cannot be satisfied, because each method has a weak point in its measurement time, spatial or spectral resolution [3][4].

In this paper, an on-line color inspection system of the surface color of building materials using an imaging spectrograph has been presented. The color inspection of building materials has a problem of the three-dimensional unevenness, while the detection of a delicate tone of color is requested. We show a method which makes it possible to detect differences in color stably using shading compensation which cancels the three-dimensional curvature in the colorimetric system CIEL*a*b* used widely as color information.

2 Outline of Imaging Spectrograph

The imaging spectrograph is of the type of straight-axis spectrograph which has a C-mount installed between the lens and a monochrome CCD camera as shown in Figure 1.

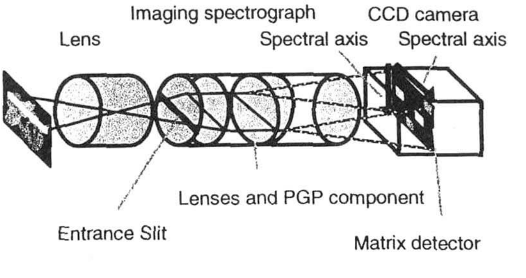


Fig. 1: Construction of an imaging spectrograph.

The optical structure is based on a prism-grating-prism -construction (PGP element) and transmission optics. Both the vertical axis and horizontal axis of the CCD-chip become either the spectral axis or the spatial axis and the spectral components are obtained as the intensity of each pixel. A single image contains the spectral distribution of points in a one-dimensional line of the object.

Such standard color information as RGB, L*a*b* and HVS can be reconstructed by obtaining the spectral distribution of each point. It makes also possible to obtain spectral information of a spatial two-dimensional plane on a moved object on an on-line inspection system, and to construct a multispectral image by scanning a slit in the vertical direction to the spatial axis of an object.

3 Model of a coated surface

Building materials such as tiles and ciding boards are composed of the inside basic layer and the surface coating layer. The surface coating layer plays an important part not only in the coloring but also in the protection against the weather. The aim of this color inspection is to judge the amount/thickness of the paint forming the coating layer.

Figure 2 shows the relationship between the amount of the paint and the color of the coated surface. Here we use the color values in the colorimetric system CIEL*a*b* widely known as color information are adopted. In this graph, each color value changes with a local maximum/minimum, which is regarded that the color of the coated surface is determined by the ratio of 2 kinds of material element in surface area shown in figure 3.

4 Color inspection of building materials

We present here an on-line color inspection system of the surface color of building materials using an imaging spectrograph has been presented.

The color inspection of building materials has a problem of the three-dimensional unevenness, while the detection of a delicate tone of color is requested. We show a method which makes it possible to detect differences in color stably using shading compensation which cancels the three-dimensional curvature in the color space CIEL*a*b*.

4.1 Method of shading compensation of L*a*b* value

Regarding the object color, the L*a*b* value, we first find tristimulus values X, Y, Z from the following expressions:

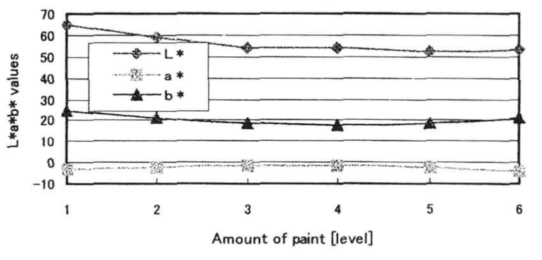


Fig. 2: Relationship between amount of paint and color

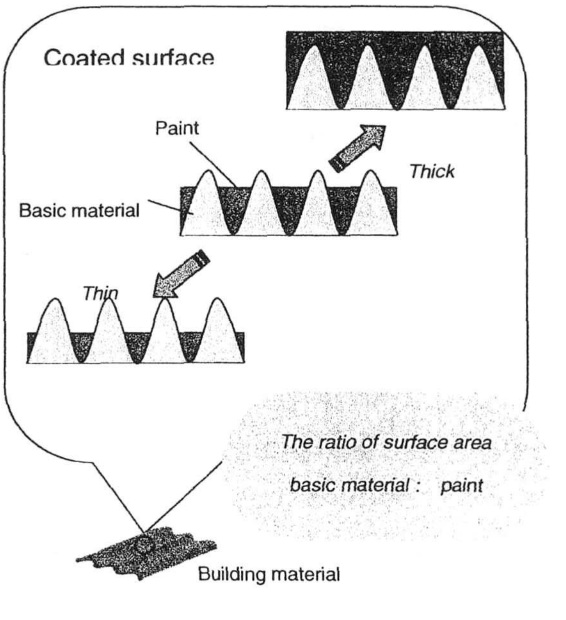


Fig. 3: Model of coated surface.

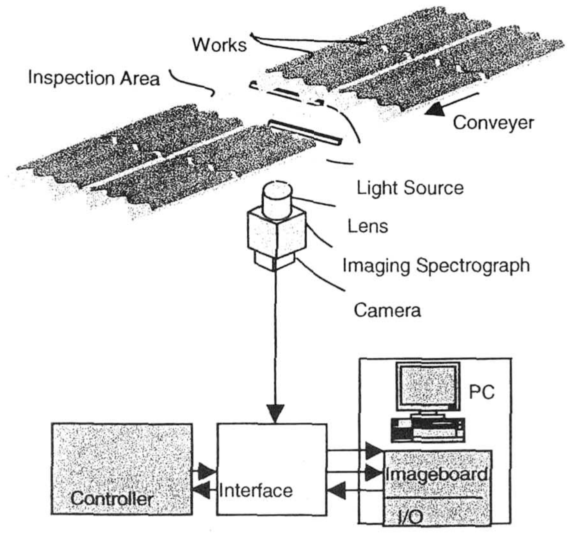


Fig. 4: Configuration of the color inspection system..

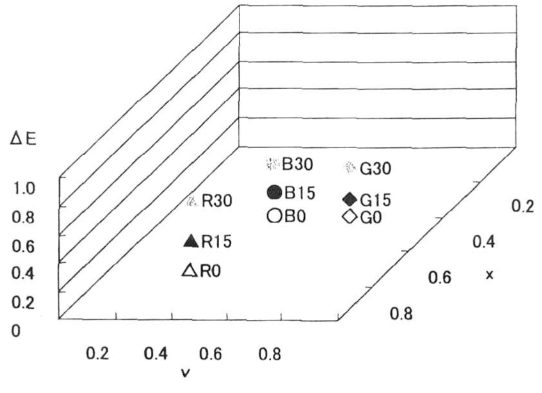


Fig. 5: Comparison of ΔE.

$$X = k\Sigma R(\lambda)P(\lambda)x(\lambda)$$

$$Y = k\Sigma R(\lambda)P(\lambda)y(\lambda) \quad \cdots(1)$$

$$Z = k\Sigma R(\lambda)P(\lambda)z(\lambda)$$

provided $R(\lambda)$ is the spectral reflection distribution of an illuminant; $P(\lambda)$ is the spectral distribution of the object; and $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ are color matching functions;

$$k = 100/(\Sigma R(\lambda)y(\lambda)) \quad \cdots(2)$$

Secondly, we transform the XYZ color space into the color space CIEL*A*B* using the following expressions:

$$L^* = 116(Y/Yn)^{1/3} - 16$$

$$a^* = 500\{(X/Xn)^{1/3} - (Y/Yn)^{1/3}\} \cdots(3)$$

$$b^* = 500\{(Y/Yn)^{1/3} - (Z/Zn)^{1/3}\}$$

Shading caused by three-dimensional unevenness can be supposed to be independent of the wavelength components, because the light is a component of diffused reflection, that is to say, it means a decrease of the reflected light depending on the incident angle of the light source, and not on the visual angle. Therefore, in a surface with the spectral reflection distribution $P(\lambda)$, the spectral reflection distribution $P_u(\lambda)$ of a point receiving the shading due to an undulation can be expressed as follows:

$$P_u(\lambda) = eP(\lambda) \quad \cdots(4)$$

where e is a shading coefficient.

Since the XYZ of the shaded point, Xn, Yn and Zn, are similarly equal to eX, eY and eZ respectively, the true value L^*_c, a^*_c, b^*_c of the shaded point can be stated by compensating the measured value L^*_u, a^*_u, b^*_u with e as follows:

$$L^*_c = e^{-1/3}(L^*_u + 16) - 16$$

$$a^*_c = e^{-1/3}a^*_u \quad \cdots(5)$$

$$b^*_c = e^{-1/3}b^*_u$$

4.2 Experiment

Figure 4 shows the configuration of the color inspection system. As shown in the figure, oblique light at an angle of 45 degrees in a line is cast onto the reverse side of an object flowing on a conveyor from under a conveyor. The object is imaged by the imaging spectrograph and CCD camera mounted right below the object and processed by a personal computer through the image board.

4.2.1 Confirmation of basic performance

First, when the object is at a standstill, the compensation process is confirmed by using color chips as the object by receiving the reflected light when 3 kinds of chip, red, green and blue were inclined at angles of 0 (horizontal), 15 and 30 degrees respectively.

Previously, *e* was calculated in advance from the reflected light when a white reference plate was inclined at the same angles, 0, 15 and 30 degrees and the shading coefficients *e* 15 and *e* 30 obtained at each angle from the expression (4). Then L*a*b* is calculated while compensating according to these coefficients and the color difference ΔE from L*a*b* at an angle of 0 degrees is found.

Figure 5 shows the values of ΔE plotted on the *xy* chromaticity diagram. For example, R15 means the ΔE of the red chip at angle of 15 degrees. R0, G0 and B0 indicate their original x, y values on the *xy* plane and of course their ΔE=0. It shows a low color resolution of the Z area in this system where the compensated value of the color chip, red, takes a relatively poor value. However, it was confirmed that all values satisfied ΔE < 0.59 and the basic performance was satisfactory.

4.2.2 On-line inspection of building materials

Next, experiments were conducted using building materials flowing on a conveyor. The spatial resolution was 3 mm/pixel and the shading coefficient measured previously became 0.8 < *em* < 1.0.

Figure 6 shows an example of spectral image and figure 7 show an example of shading compensation. When the inspection data was compensated like this, an area having a different color, of with 1 pixel width, could be found by a threshold of ΔE<5. Processing, from image input to the final process, the L*a*b* calculation of each point and the total judgment, is carried out in about 0.2 seconds. Increasing the speed of processing will realize a real-time spectroscopic inspection system.

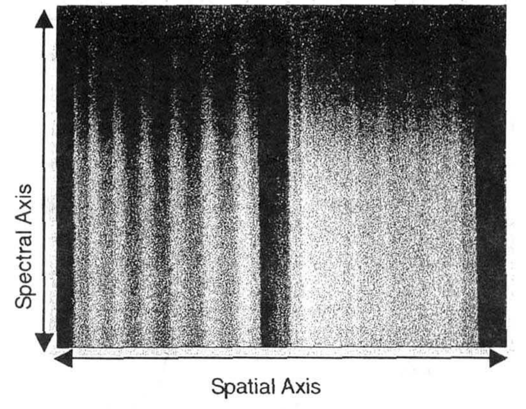


Fig. 6: An example of spectral Image.

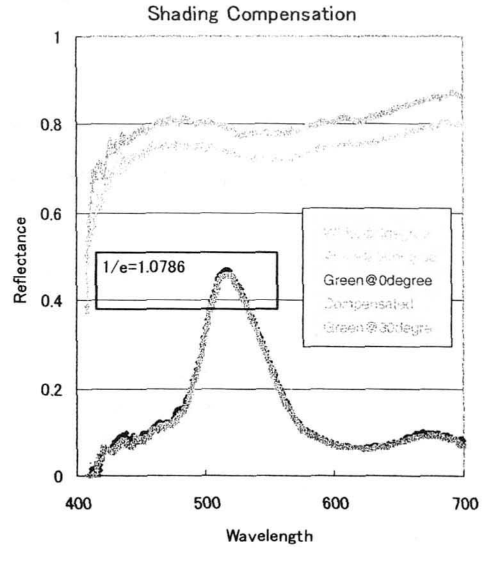
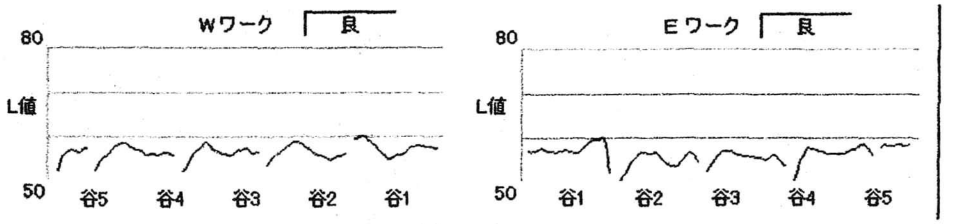


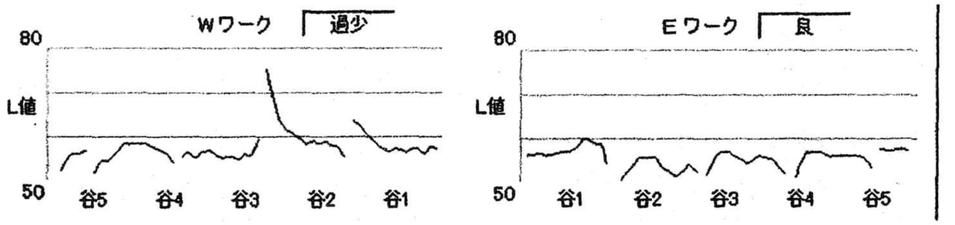
Fig. 7: An example of shading compensation.

5 Conclusion

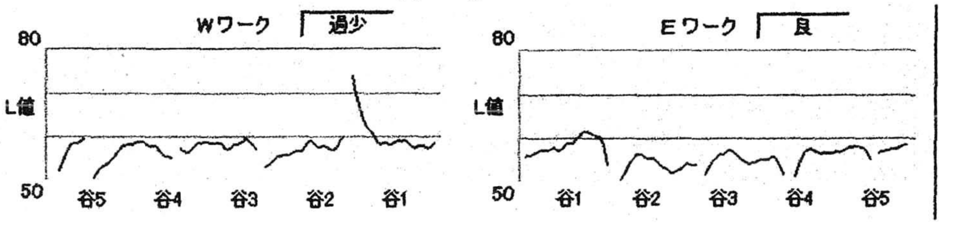
The on-line color inspection system of the surface color of building materials using an imaging spectrograph has been described. In this color inspection system, it was shown that the shading compensation given to an L*a*b* value could make the on-line inspection of color tones possible, while eliminating the influence of 3-D shapes. It is our desire to realize a more highly accurate measurement of color tone in future.



(a) good.



(b) No good.



(c) No good.

Fig. 8: Inspection results (L* values).

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