Generating Digital Image of Ukiyoe by Applying the Kubelka-Munk Theory

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Abstract
Ukiyoe is a kind of multicolored woodcut print made in Japan in about the 16th century. Those prints now existing have been discolored. The authors tried to print a digital image of Ukiyoe by using Kubelka-Munk theory. First, the image data were obtained by tracing outline of each colored region with a graphic software on the real Ukiyoe image scanned. Those data show the shapes of each plate on multicolored woodcut print. Next, the absorption coefficient and the scattering coefficient, *K* and *S*, of some colorants (watercolors, Japanese traditional pigments) were calculated. And then, the spectral reflectance of all the pixels of final digital image was calculated from *K* and *S* of paints, thickness of paints layer, roughness of the surface of the paper, and the image data holding shape of each plate. Then the reflectance was transformed into sRGB digital counts, and the digital image was printed with an inkjet printer. It was confirmed that the color with two or more layers, and the textures derived on the paper surface were more realistically reproduced.

Introduction
A kind of woodcut print called "Ukiyoe" was familiar in Japan in about the 16th century. Now, those prints existing have been discolored. And it was expected that those prints be shown as vividly as ones not discolored.

Some Ukiyoe prints were recreated with replicated plates. But, well-developed high skills are required to carve the plates, multicolored print and so on. There are few technicians who have those skills. And it involves an immense amount of time and efforts to make. Therefore, the Ukiyoe prints were created with computer graphic software as shown in Figure 1. However, it was difficult to express the color of mixed colorants, the color of overlapped colorant layer and the relationship between the color and the thickness of colorants.

Therefore, we tried to compute digital image of Ukiyoe based on the Kubelka-Munk theory. There are two or more layers of different colorant in multicolored woodcut print. Spectral reflectance was calculated based on the Kubelka-Munk theory by given different kinds of colorants, shapes of image in each plate and thickness of colorant layer on each plate. The sRGB digital counts were calculated from the reflectance[1].

Figure 1. The digital image of Ukiyoe created with a computer graphic software

The Kubelka-Munk theory
Kubelka and Munk showed the reflectance *R* of given colorant layer as;

$$R = \frac{1 - R_g (a - b \coth bSX)}{a - R_g + b \coth bSX}$$
$$a = 1 + K / S \tag{1}$$
$$b = \sqrt{a^2 - 1}$$

where R_g is the reflectance of substrate that painted the colorant on, *S* is scattering coefficient, *K* is absorption coefficient[2] and X is thickness of the colorant.

Moreover, the scattering coefficient and the absorption coefficient of the mixed colorant are the sum of the scattering coefficient and the absorption coefficient of each colorant. The absorption coefficient K and the scattering coefficient S of the colorant created by mixing given colorants i are[2],

$$K = \sum c_i K_i \quad S = \sum c_i S_i \tag{2}$$

where c_i is the concentration of the colorant i.

Calculation of scattering coefficient and absorption coefficient

A scattering coefficient and an absorption coefficient are determined by the measured spectral reflectance of a colorant layer.

The ratio of scattering coefficient and the absorption coefficient is calculated from R_∞, spectral reflectance of colorant layer painted so thick that it completely covered the substrate, by the following equation[2].

$$\frac{K}{S} = \frac{(1-R_\infty)^2}{2R_\infty} \tag{3}$$

Moreover, R defined as the spectral reflectance of the colorants painted with thickness X on the substrate with its reflectance being R_g, and R being the range $R_\infty > R > R_g$, S will be

$$S = \frac{1}{bX}(\operatorname{arccoth}\frac{a-R}{b} - \operatorname{arccoth}\frac{a-R_g}{b}) \quad a = \frac{1}{2}(\frac{1}{R_\infty} + R_\infty) \quad b = \frac{1}{2}(\frac{1}{R_\infty} - R_\infty) \tag{4}$$

However, some colorant does not satisfy the range $R_\infty > R > R_g$, so "reference method"[3] is used for such a case. Using the method, a scattering coefficient of pure colorant p, S_p, is calculated from the following equation based on equation (2),

$$S_p = S_w \times \frac{c_w}{c_p} \times \frac{(K/S)_{w+p} - (K/S)_w}{(K/S)_p - (K/S)_{w+p}} \tag{5}$$

First, S_w, the scattering coefficient of colorant w satisfying the range $R_\infty > R > R_g$ in all wavelength, such as white, is calculated with the equation (4). This colorant can be called "reference colorant."

And the ratio K/S of the reference colorant w, $(K/S)_w$, is calculated from R_∞ of reference colorant, which is already used in equation (4), by using equation (3).

Next, a given colorant p is painted on a substrate with an enough thickness to cover the color of substrate. $(K/S)_p$ is calculated from reflectance of the painted sample.

The colorant from mixing the reference colorant and the pure colorant at given ratio c_w:c_p, is painted with an enough thickness to cover the color of substrate. Then the reflectance of the sample painted with mixing colorant is measured, and $(K/S)_{w+p}$ is calculated from the reflectance.

As all values appeared in the right hand of equation (5) have been obtained, we can obtain the scattering coefficient S_p of the given colorant p. Finally, absorption coefficient of the colorant p, K_p, is obtained by

$$K_p = (K/S)_p \times S_p \tag{6}$$

Experiments

Calculating scattering coefficient and absorption coefficient

First, "Turner Poster Color White" as a reference colorant was painted on two sheets of black paper. One of them was painted with the thickness of 10.5 μm. Another one was painted thick enough not to be affected by the color of the substrate.

The spectral reflectances of the two samples were measured by GretagMacbeth Spectrolino in 36 wavelengths from 380nm to 730nm at intervals of 10nm, and R and R_∞ in equation (4) were obtained.

Next, Japanese traditional colorants used in Ukiyoe and watercolors being on the present market shown in Table 1 are painted on a sheet of Kent paper. Pure one and mixed one with reference colorant ratio of 1:1 by weight were painted on a sheet of Kent paper thick enough not to be affected the color of the substrates.

Thus, the scattering coefficient and absorption coefficient of each colorant were obtained. The coefficients of Tan were shown in Figure 2 as an example.

Producing the image holding shape of plate

The original Ukiyoe print used in this study is shown in Figure 3. Multicolored Ukiyoe print was created from two or more plates. An image data were produced with graphic software Adobe Illustrator by tracing outline of each colored region on the real Ukiyoe image scanned with a flatbed scanner. The digital count of this image data were correspondent to concentration of the colorant. We assumed a linear relationship; i.e. the concentration of the colorant is 0% when digital count is 0, the concentration of the colorant is 100% when digital count is 255.Thus, image data of four plates shown in Figure 4 was obtained.

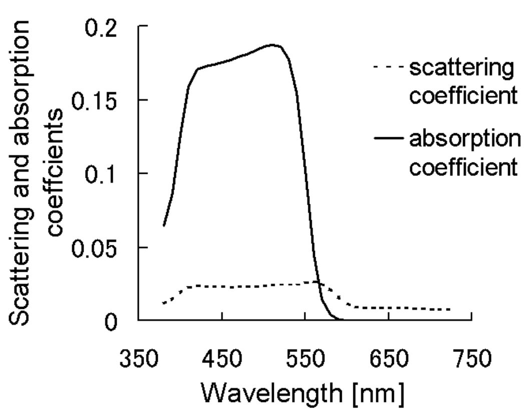
Measuring roughness of the paper surface

Being printed on the paper with roughness, the thickness of colorant was not flat as shown in Figure 5. Hence, the reflectance is not even for uniform area of plate.

Roughness on the surface of Japanese traditional paper “Hosyoshi” used for Ukiyoe was measured to express the uneven reflectance. Firstly, the transparent watercolor was painted on the paper. The transmittance of this paint was

Table 1. Names and colors of colorants used in this study

name	color
Japanese traditional colorants	
Sumi	black
Bengara	burned umber
Betsujyo hon-ai	navy
Tan	orange
Hon-shu	red
Toh-oh	yellow
Present watercolors	
Sakura Suisai viridian	green
Sakura Suisai Ao	blue



measured preliminarily. This painted paper was scanned by a flat bed scanner Epson GT-8200U. The input-output relationship between the reflectance and the digital count of this scanner was also measured preliminarily. As light scattering in the watercolor paint is small, the Lambert-Beer’s law can be applied to the paint. Therefore, from the digital count of each pixel, the thickness of colorant in the region was calculated by the following equation.

Figure 3. The original Ukiyoe print

Figure 4. The image data of the shape of the plates

$$X = \frac{\log R - \log R_g}{2\log T} \qquad (7)$$

where X is the thickness of colorant layer, R_g is the reflectance of substrate, T is the transmittance for unit thickness and R is reflectance of each pixel.

Thus, two-dimensional digital data corresponding the roughness of paper surface were measured.

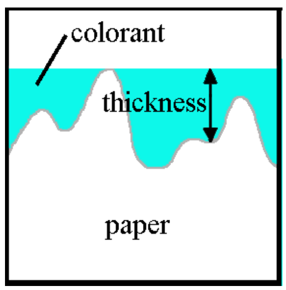


Figure 5. Thickness of colorant and roughness on the paper

Figure 6. The digital image of Ukiyoe

Printing digital image

The spectral reflectances of all the pixels on the digital image were calculated from the scattering coefficient of the colorants, the absorption coefficient of the colorants, the shape of plates and the thickness of the colorants. CIE tristimulus values, X, Y and Z, were calculated from the reflectance with standard illuminant D65. Then the digital counts of the sRGB color space were calculated. Finally, the obtained digital image shown in Figure 6 was printed with an inkjet printer.

Discussion

It was observed that uneven color derived from roughness on the paper surface and the color on the place where were overlapping two or more colorant were well expressed. The reason for it is that the relationship between the effects of the ray and the thickness of the colorant is well expressed.

Light is scattered a lot in the many of Japanese traditional colorants. Hence, there is a complex and nonlinear relationship between the thickness of colorants and reflectance. The reflectance of such colorants cannot be expressed by the weighted average of digital counts and the Lambert-Beer law. However reflectance calculated by the Kubelka-Munk theory include the effect of light scattering in the colorant layer. Thus, the Kubeka-Munk theory is well suited to obtain the color of Ukiyoe print.

Conclusion

It was confirmed that the Kubelka-Munk theory enables us reproducing and also creating digital image of Ukiyoe prints as vivid as ones soon after they were printed and more realistically.

References

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Author Biography

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