Base Color Recognition by Tetragonal Regression for Overlapped Watercolors

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Abstract

In this paper we propose a base color recognition method for multicolor printing with watercolors including some areas overlapped each printed layer. Watercolors have an important feature that the observed colors are different by the printing order. The proposed method is based on a particle density model to express the features of watercolors. The approach of this method is to solve an inverse problem, that is, determining a printed area corresponding to a watercolor from an observed image. Our purpose in this study is to estimate woodblocks from a woodblock print. We focus on multicolor woodblock prints such as Ukiyo-e: Japanese traditional woodblock printing, artistic documents. The base colors forming the given image are derived by planar regression bounded by a tetragon in the CIE $L^*u^*v^*$ color space. The tetragon is determined by the color distribution of the given image. The results of the base color estimation will be utilized to preserve techniques and prints of Ukiyo-e. An Ukiyo-e print is created from several woodblocks with several watercolors, and has a mixing color expression similar to the effects of watercolor painting.

Keywords: Virtual Woodblock Printing, Virtual Ukiyo-e, Particle Density Model, Digital Archive, Watercolor

1. Introduction

In the field of digital archives of handwritten fine arts, a general method is to store as a two-dimensional image. However, oil painting, watercolor painting, pastel, *etc*. have different features (for example, shape of surface and color mixture on the painted surface) by painting process, techniques and equipments. Therefore, it is needed an archive method considering each art's properties. For example, Tominaga *et al.* [9] proposed a method to estimate various parameters for a reflection model from a single-colored image of an object and they applied the model to preserving and digital archiving of oil paintings.

The authors have studied on a method of virtual woodblock printing and its applications. *Ukiyo-e* is one of the fine arts in Japan and is produced by several woodblocks corresponding to several watercolors. Watercolors are used widely in fine arts, especially at watercolor painting and woodblock printing. In these techniques, color pigment covers a paper sheet and sometimes overlapped. However color mixture is often observed and analyzed based on additive mixture of color stimuli or subtractive mixture of color stimuli in general, those fundamentals are not simply applicable to watercolor because of layered structure of pigments of watercolors and these semi-transparency. The mixing color effect at overlapped watercolors depends on the overlapping order. The effect is often seen in *Ukiyo-e*. Color recognition of handwritten or hand-engraved *Ukiyo-e* prints is an important issue not only to preserve them as cultural heritages but also to extract handwritten characters in them. In this paper we propose a method to analyze the mixing color phenomena with watercolors to estimate printed area of each color. A particle density model and a color decomposition strategy using CIE $L^*u^*v^*$ distribution are discussed. The approach of this method is to solve an inverse problem which is to estimate print areas corresponding to watercolors from a multicolor print image. The effectiveness of the proposed method in case of two colors overlapped printing including some simple watercolor prints and *Ukiyo-e* prints are also demonstrated. This study is a part of *Ukiyo-e* preserving and digital archiving project[7].

2. *Ukiyo-e* preserving project and watercolors

Ukiyo-e is a Japanese traditional multicolor woodblock printing technique known world-widely. An *Ukiyo-e* print

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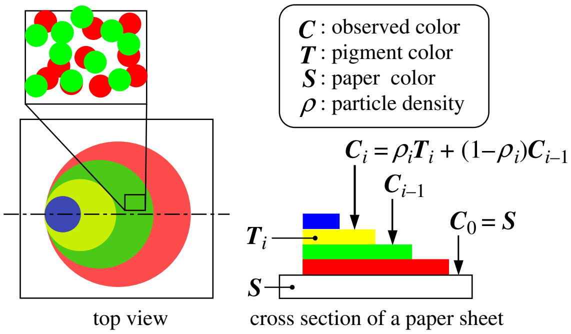

Figure 1. Particle density model

is produced by three processes, drawing by *E-shi*; a painter or a designer, woodblocks engraving by *Hori-shi*; an engraving technician and printing by *Suri-shi*; a printing technician. The authors have studied on a *Ukiyo-e* preserving project [7] which is one of important cultural heritages based on virtual woodblock printing [6]. The main feature of the project is to preserve not only a print image but also virtual woodblocks, so that it is an important issue to estimate woodblocks from existing *Ukiyo-e* prints. The virtual woodblock printing system has an intermediate description of color layers, virtual woodblocks. The virtual woodblock printing system accepts a color image to input and process each color layer[4][5]. If the color information of an existing *Ukiyo-e* print is provided, the system can re-produce copies of an *Ukiyo-e* print which have the printing properties. If real woodblocks are generated by an NC (numerical controlled)-machine, a real *Ukiyo-e* print can also be re-produced with them.

3. Color mixing by particle density model

For expressing color mixing effects, a color mixing model of watercolors called *particle density model* is introduced. Therefore the model is described by a linear approximate formula, it is easy to apply the model to analyze an image as an inverse problem. We propose the model for estimating each region of printed color for a watercolor from a color image of a watercolor print. As related studies, Curtis *et al.* [1] and Saito *et al.* [8] have proposed the methods of synthesizing a real watercolor paint image based on the Kubelka-Munk model[3], it depends on thickness of a paint layer. However, therefore the Kubelka-Munk model is nonlinear the model is very difficult to apply to solve an inverse problem.

As illustrated in Figure 1, we assume that a watercolor pigment is composed of opaque particles, and is distributed in a medium which is transparent and colorless. Therefore, the mixed color is observed as an average color mixture similar to pointillistic painting.

3.1. Particle density model

When watercolors have been printed in n times overlapping on a paper sheet (Figure 1), the observed color through from i-th layer $\boldsymbol{C}_i$ is described by the following formula:

$$\boldsymbol{C}_i = \begin{cases} \rho_i \boldsymbol{T}_i + (1-\rho_i)\boldsymbol{C}_{i-1} & (0 < i \leq n) \\ \boldsymbol{S} & (i = 0) \end{cases} \tag{1}$$

$\boldsymbol{C}_i$: observed color through i-th layer
$\boldsymbol{T}_i$: pigment color of i-th layer
ρ_i : particle density of i-th layer
$\boldsymbol{S}$: paper color

where $\boldsymbol{C}_i$, $\boldsymbol{T}_i$ and $\boldsymbol{S}$ are color vectors in the CIE $L^*u^*v^*$ color space.

3.2. Features of two watercolors overlapped

Figure 2(a) shows a situation of overlapped printing with two kinds of watercolors which are A (pigment color: $\boldsymbol{T}_{\mathrm{A}}$, particle density: ρ_{A}) and B (pigment color: $\boldsymbol{T}_{\mathrm{B}}$, particle density: ρ_{B}) on a paper sheet (color: $\boldsymbol{S}$). Its printed order is A $\rightarrow$ B meaning A first and B second. We can observe basically four colors; $\boldsymbol{C}_{\mathrm{A}}$, $\boldsymbol{C}_{\mathrm{B}}$, $\boldsymbol{S}$ and $\boldsymbol{C}_{\mathrm{BA}}$ in it.

Coplanar points in color space:

Based on the particle density model, the colors of the situation are described as:

$$\boldsymbol{C}_0 = \boldsymbol{S} \tag{2}$$
$$\boldsymbol{C}_{\mathrm{A}} = \rho_{\mathrm{A}}\boldsymbol{T}_{\mathrm{A}} + (1-\rho_{\mathrm{A}})\boldsymbol{S} = \rho_{\mathrm{A}}\boldsymbol{a} + \boldsymbol{S} \tag{3}$$
$$\boldsymbol{C}_{\mathrm{B}} = \rho_{\mathrm{B}}\boldsymbol{T}_{\mathrm{B}} + (1-\rho_{\mathrm{B}})\boldsymbol{S} = \rho_{\mathrm{B}}\boldsymbol{b} + \boldsymbol{S} \tag{4}$$
$$\begin{aligned} \boldsymbol{C}_{\mathrm{BA}} &= \rho_{\mathrm{B}}\boldsymbol{T}_{\mathrm{B}} + (1-\rho_{\mathrm{B}})\boldsymbol{C}_{\mathrm{A}} \\ &= \rho_{\mathrm{A}}(1-\rho_{\mathrm{B}})\boldsymbol{a} + \rho_{\mathrm{B}}\boldsymbol{b} + \boldsymbol{S}. \end{aligned} \tag{5}$$

where $\boldsymbol{a}$ and $\boldsymbol{b}$ are two vectors originated from $\boldsymbol{S}$; $\boldsymbol{T}_{\mathrm{A}} - \boldsymbol{S}$ and $\boldsymbol{T}_{\mathrm{B}} - \boldsymbol{S}$. A plane can be described by the equation:

$$\boldsymbol{n} \cdot \boldsymbol{x} - d = 0 \tag{6}$$

where, $\boldsymbol{n}, d$ and $\boldsymbol{x}$ are a normal vector, a constant and an arbitrary point on the plane, respectively. The normalized normal vector $\boldsymbol{n}$ is formed by the vector product of $\boldsymbol{a}$ and $\boldsymbol{b}$, and normalization:

$$\boldsymbol{n} = \frac{\boldsymbol{a} \times \boldsymbol{b}}{|\boldsymbol{a} \times \boldsymbol{b}|}. \tag{7}$$

d can be calculated by substituting $\boldsymbol{S}$ into equation (6) :

$$d = \boldsymbol{n} \cdot \boldsymbol{S} \tag{8}$$

Substituting the equations (7) and (8) into the equation (6), we get the plane equation,

$$\frac{\boldsymbol{a} \times \boldsymbol{b}}{|\boldsymbol{a} \times \boldsymbol{b}|} \cdot (\boldsymbol{x} - \boldsymbol{S}) = 0. \tag{9}$$

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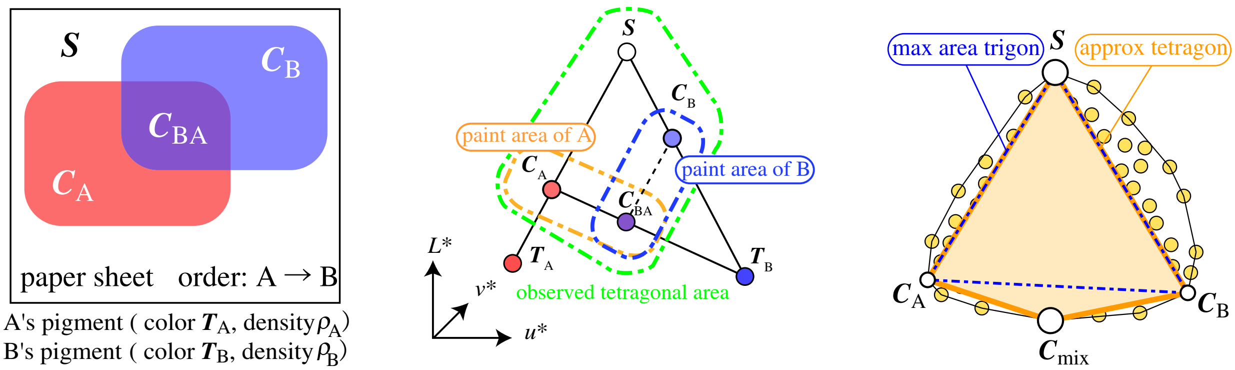

(a) Input image (b) $L^*u^*v^*$ color space (c) Estimation of tetragon

Figure 2. The features of two overlapped watercolors based on particle density model

Of course $\boldsymbol{C}_{\mathrm{A}}, \boldsymbol{C}_{\mathrm{B}}$ and $\boldsymbol{C}_{\mathrm{BA}}$ in equations (3), (4) and (5) satisfy (9), and $\boldsymbol{S}, \boldsymbol{T}_{\mathrm{A}}, \boldsymbol{T}_{\mathrm{B}}, \boldsymbol{C}_{\mathrm{A}}, \boldsymbol{C}_{\mathrm{B}}$ and $\boldsymbol{C}_{\mathrm{BA}}$ are coplanar points. These colors form a shape of tetragon in the CIE $L^*u^*v^*$ color space (Figure 2(b)).

An actual image which is two overlapped watercolors has threshold in the color space. Therefore, we estimate the tetragon using planar regression from the color distribution. Where, we map all pixels from a given image to CIE $L^*u^*v^*$ color space. A color corresponding to a pixel in a given image is described as the three-component vector:

$$\boldsymbol{x} = (L, u, v)^{\mathrm{t}} \tag{10}$$

where $\boldsymbol{x}$ is a column vector, and t means transposition.

A vector $\boldsymbol{m}$ which is the mean of $\boldsymbol{x}$ and a variance-covariance matrix $\boldsymbol{R}$ are described as follows:

$$\boldsymbol{m} = \mathrm{E}\left[\boldsymbol{x}\right] = \left(\overline{L}, \overline{u}, \overline{v}\right) \tag{11}$$

$$\boldsymbol{R} = \mathrm{E}\left[(\boldsymbol{x}-\boldsymbol{m})(\boldsymbol{x}-\boldsymbol{m})^{\mathrm{t}}\right] \tag{12}$$

$$= \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{pmatrix} \tag{13}$$

v is an explaining variable, L and u are dependent variables. Where, expressing the equation (6) as explicit form:

$$v = \alpha L + \beta u + \gamma. \tag{14}$$

Using equation (13), α and β are determined from simultaneous equation,

$$\begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} R_{13} \\ R_{23} \end{pmatrix} \tag{15}$$

and γ is determined as follows:

$$\gamma = \overline{v} - \alpha\overline{L} - \beta\overline{u}. \tag{16}$$

Thus, $\boldsymbol{n}$ and d in equation (6) is expressed as follows,

$$\boldsymbol{n} = (\alpha, \beta, -1) \tag{17}$$

$$d = -\gamma. \tag{18}$$

4. Procedure of color decomposition

The decomposition for a two-color problem is based on a tetragon approximation based on the particle density model. The procedure consists of the following two steps; (a) derivation of an approximate tetragon, and (b) estimation of each color layer from a given overlapped printing image.

4.1. Determination of an approximate tetragon

In order to determine an approximate tetragon in the CIE $L^*u^*v^*$ color space from an actual image, the following procedure is used:

(1) Estimation of a plane corresponding to equation (6) by multiple regression in a distribution of a given actual image.

(2) Projection of all of plotted points to the estimated plane.

(3) Determination of a two-dimensional convex hull on the estimated plane from all projected points.

(4) Determination of the point of paper color $\boldsymbol{S}$ as the most nearest point to the point $(L^*, u^*, v^*) = (100, 0, 0)$, *i.e.* white (Figure 2(c)).

(5) Determination of an inscribed and maximum area triangle which has a vertex of $\boldsymbol{S}$, included in the convex hull (Figure 2(c)).

(6) Determination of a mixed point of the maximum distance point $\boldsymbol{C}_{\mathrm{mix}}$ from a line which consists of two vertices which is not a vertex of paper color of the triangle and is included in the convex hull (Figure 2(c)).

(7) Adding the fourth vertex at the opposite side and forming a tetragon (Figure 2(c)).

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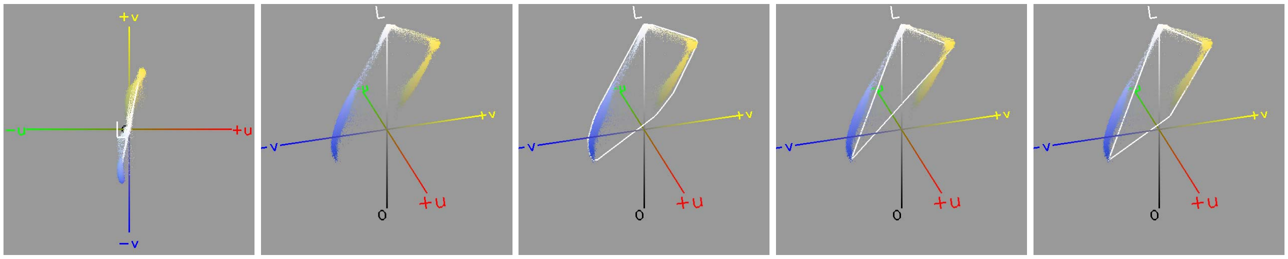


(a) Original (top) (b) Original (side) (c) Convex hull (d) Triangle (e) Tetragon

Figure 4. The results of deriving approximate tetragon from color distribution of a given image

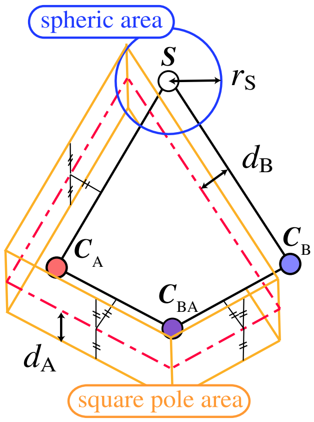
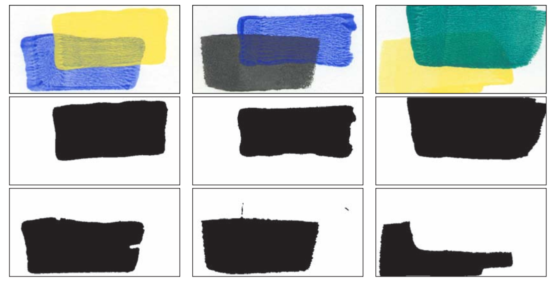
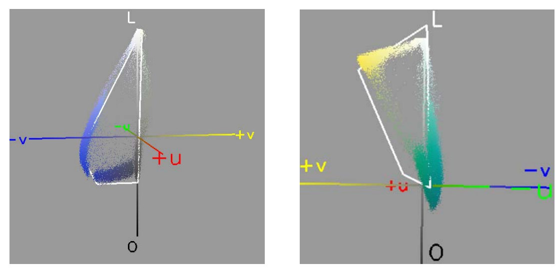


Figure 3. Extraction shape



(a) Succeeded result of B $\rightarrow$ Y (b) Succeeded result of K $\rightarrow$ B (b) Failure result of Y $\rightarrow$ G

Figure 5. Results of experiments



(a) Black $\rightarrow$ Blue (b) Green $\rightarrow$ Yellow

Figure 6. Tetragon estimation problem

4.2. Extraction of each printed area

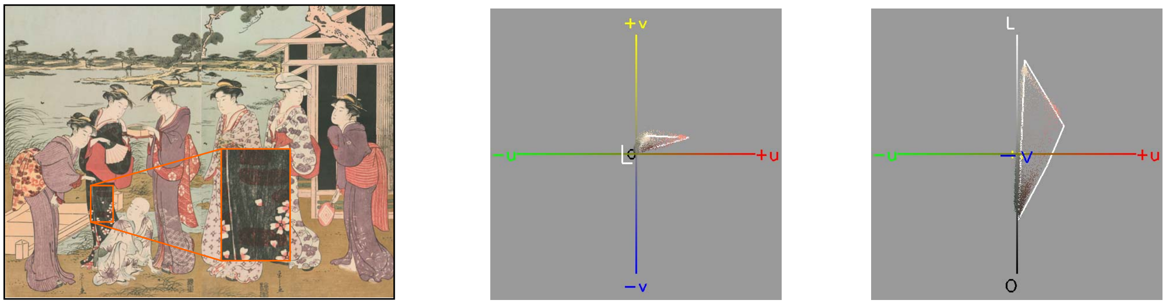
In order to estimate each mono-color printed area, we extract two kinds of three-dimensional area corresponding to each watercolor in CIE $L^*u^*v^*$ color space. Considering an actual printing density is not even, we extract the three-dimensional area by determining threshold of an approximate tetragon by the three parameters d_A, d_B, r_S in Figure 3. These parameters are defined as that r_A, d_B are related to an extracting area, r_S is related to not extracting area.

5. Experiment

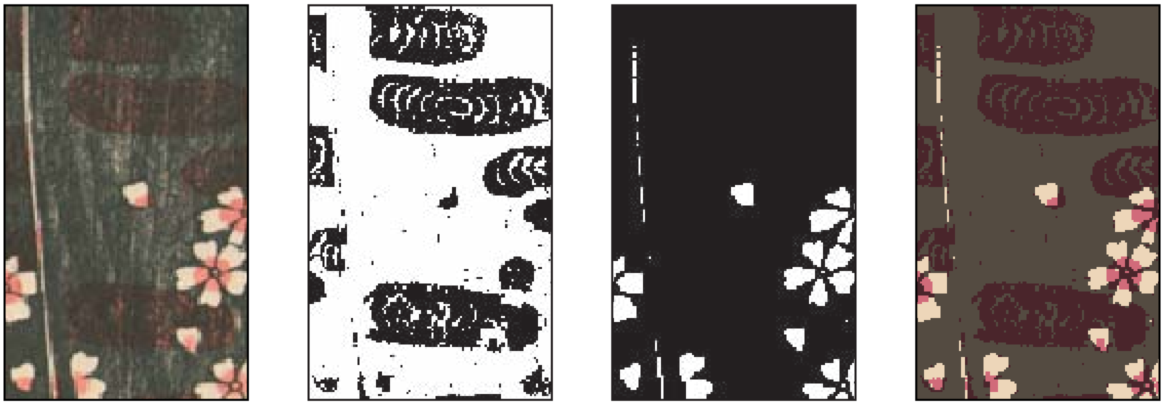
5.1. Two colors overlapped painting sample

As a simple experiment, we applied the method to actual sample images (512×265pixels) which are overlapped printing with two kinds of watercolors. Figure 5(a) shows the an actual image which is painted with a roller to make its printed layer thickness as even as possible. Figure 4(a) and (b) show its distribution that the color vectors for all pixels of the image is plotted. The shape of the distribution is similar to a tetragon based on our model. Therefore, in a two-color case, we can estimate each color layer from an actual image using the method. Figure 4(c), (d) and (e) show actual determining process views corresponding to steps (3), (5) and (7) in the tetragon determination process in section 4.1, respectively. The white line in these figure is the determined polygon. In this experiment, we select two out of five watercolors (Red, Yellow, Green, Blue and Black), and the number of total sample is $2 \cdot {}_5C_2 = 20$. The upper row of Figure 5 shows three sample images, the middle and lower rows show decomposed results which is rendered as mono-color. The portion of black is a kind of watercolor printing area. By these samples, two experiments are achieved:

(a) The parameters in Figure 3 are determined by maximizing success rate and fixed over the samples.



(a) The original *Ukiyo-e* (b) u^*v^*side view (c) L^*v^*side view



(d) ROI of the original image (e) Extracted area for *Enji*, red (f) Extracted area for *Sumi*, black (g) Re-produced image

Figure 7. An experimental result for an Ukiyo-e: “Firefly viewers” by CHOBUNSAI Eishi

(b) The parameters in the procedure are determined variably by providing a best result individually.

In the experiments (a) and (b), the success rates are $11/20$ and $19/20$, respectively.

In Figure 5, (a) and (b) are succeeded samples. The reasons for failure results as in (c) are that the vertices of a derived convex hull catch noises which are isolated points (Figure 6(a)), and it is a wrong strategy which is maximum area for calculating an inscribed triangle within a calculated convex hull (Figure 6(b)). Where these result images are reduced in noise by mathematical morphology operations.

5.2. *Ukiyo-e* sample

Figure 7 shows experiments of applying our method to a portion of *Ukiyo-e* (Figure 7(a)) “Firefly viewers”[2] by *CHOBUNSAI Eishi*. ROI of 119×193 pixels, approximate 300[dpi] for the experiment. Figure 7(d) indicates a portion of cloth of a lady which is overlapped by *Enji*, red and *Sumi*, black. Figure 7 (b) and (c) indicate its color distribution with the approximate tetragon in the CIE $L^*u^*v^*$ color space. Figure 7(e) and (f) are the results from the given image with *Enji* and *Sumi*, respectively. By these results, we can synthesize an *Ukiyo-e* image with the equation (1) by CG rendering as shown in Figure 7(g). However, we are not satisfied these results because of two reasons. One is that the proposed method is not enough, especially in deriving process in 4 and the utilized color space. The other is that the *Ukiyo-e* we utilized is from a book copy instead of real products. The first issue should be achieved as one of the future works. As another results, Figure 8 shows experiments of applying our method to a portion of *Ukiyo-e* (Figure8(a)) “Collection of Contemporary Popular Beauties”[10] by *KITAGAWA Utamaro*. ROI of 147×285 pixels, approximate 300[dpi]. Figure 8(d) indicates a portion of the title and the signature characters which is overlapped by *Yuou*, yellow and *Sumi*, black. The extracted results in Figure 7(e) and (f) indicate the proposed method is not satisfied in a case that one of overlapped color is black. A portion of extracted results for *Yuou*, yellow covered *Sumi*, black is failed.

6. Conclusion

In this paper we proposed a color decomposition method for watercolors using an approximate tetragon based on a

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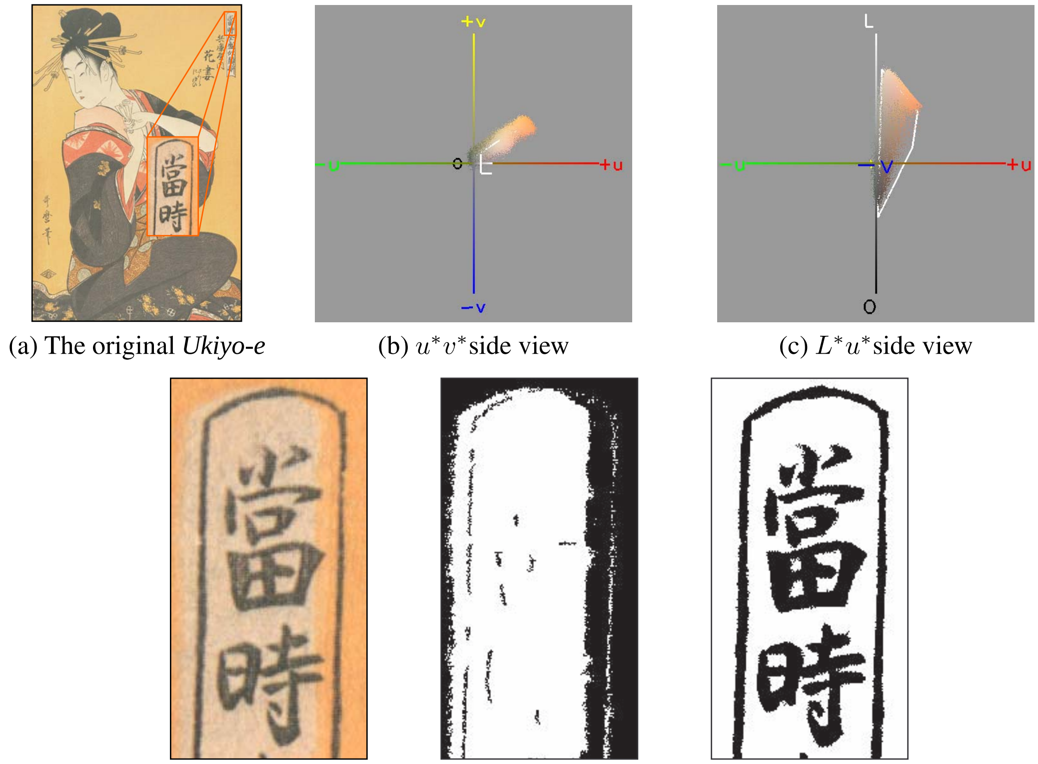

(a) The original *Ukiyo-e* (b) u^*v^*side view (c) L^*u^*side view

(d) ROI of the original image (e) Extracted area for *Yuou*, yellow (f) Extracted area for *Sumi*, black

Figure 8. An experimental result for an Ukiyo-e: 'Collection of Contemporary Popular Beauties' by KITAGAWA Utamaro

particle density model in CIE $L^*u^*v^*$ color space. Some experiments with simple materials and portions of *Ukiyo-e* suggests the proposed method can be utilized to recognize properties of watercolors.

As future works we have to advance accuracy of vertices determination which is included in an approximate tetragon, and enables the proposed method to decompose colors for overlapped printing with more than two watercolors. In multicolor woodblock printing, a printed order is important, therefore we have to consider it. How to determine automatically the parameters in the proposed method is also an important issue.

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