A Color Decomposition Method for Preserving Ukiyo-e Woodblocks

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Abstract

In this paper we propose a color decomposition method for multicolor printing of watercolors including areas overlapping each print layer. Watercolors have an important feature that the observed colors are different on the printing order. The proposed method is based on a particle density model for expressing the effects 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. The authors have already proposed a non-photorealistic rendering method to produce virtual woodblock prints. This approach can be utilized to 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. The color decomposition method can be applied to produce virtual woodblocks in the virtual woodblock printing. The results of woodblock estimation will be utilized to preserve the techniques and prints of Ukiyo-e.

1. Introduction

Non-photorealistic rendering (NPR) techniques can provide computer-generated fine arts. Many techniques for the purpose in NPR are proposed especially for oil paintings, pencil drawings, etc. The authors have proposed a virtual multicolor woodblock printing method [MOT99] and its applications to *Ukiyo-e*, a traditional multicolor woodblock printing technique in Japan. One of the main purpose of the project is to preserve the *Ukiyo-e* technique, instead of preserving only the prints in a digital image format. Printing techniques including woodblock and copperplate produce many prints from original printing blocks. The produced prints are not quite same each other and they have own values and identities. The authors have also studied on a project [OMT01] to preserve *Ukiyo-e* as one of important cultural heritages based on the virtual woodblock printing method[MOT99]. Since preserving not only a print image but also virtual woodblocks is a main feature in this preserving project, 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 be input and processes each color layer. If the color informa-

tion of an existing *Ukiyo-e* print is provided, the system can re-produce copies of a *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.

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 semitransparency. The mixing color effect at overlapped watercolors depends on the overlapping order. The effect as two-color mixing is often observed in *Ukiyo-e*. In the field of computer vision, color information of a given image is necessary to estimate physical properties of the image, and color analysis of a target image is an important issue to understand its properties. For example, Tominaga *et al.* proposed a method [TT00] for estimating various parameters for a reflection model from a single color image of an object and they applied the model for preserving and digital archiving
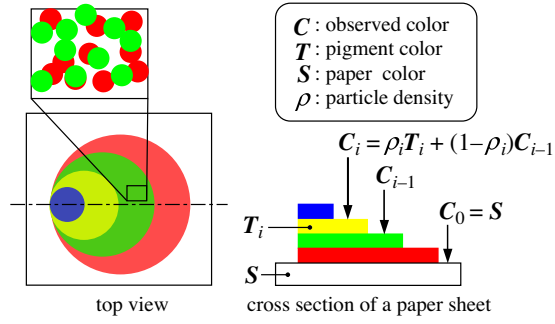
C : observed color
T : pigment color
S : paper color
ρ : particle density

$$C_i = \rho_i T_i + (1-\rho_i) C_{i-1}$$
$$C_{i-1}$$
$$C_0 = S$$

T_i

S

top view   cross section of a paper sheet

Figure 1: *Particle density model.*

of oil paintings.

In this paper we propose a method to estimate printed area of each watercolor. A particle density model and a color decomposition strategy using CIE $L^*u^*v^*$ distribution is 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 an *Ukiyo-e* print is also demonstrated.

2. Particle density model

For expressing the effects in overlapped watercolors, a mixing color 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 analysis of 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.* [CAS*97] and Saito *et al.* [SN99] have proposed the method of synthesizing a real watercolor paint image based on Kubelka Munk model[KM31], it depends on thickness of a paint layer. However, Kubelka Munk model is not linear, therefore 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 transparent medium. Therefore the mixed color is observed as an average color mixture similar to pointillistic painting.

2.1. Model formula of the particle density model

When watercolors have been printed in n times overlapping on a paper sheet, the i-th observed color C_i is described by the following formula:

$$C_i = \begin{cases} \rho_i T_i + (1-\rho_i) C_{i-1} & (0 < i \leq n) \\ S & (i = 0) \end{cases} \quad (1)$$

where C_i, T_i, ρ_i and S are observed color through i-th layer, pigment color i-th printed, particle density of i-th printed, and paper color, respectively. C_i, T_i and S are color vectors in a CIE $L^*u^*v^*$ color space.

2.2. Distribution in a color space

Figure 2(a) shows a situation of overlapped printing with two kind of watercolors which are A (pigment color: T_A, particle density: ρ_A) and B (pigment color: T_B, particle density: ρ_B) on a paper sheet (color: S), its printed order is A → B meaning A first and B second. We can observe four colors; C_A, C_B, S and C_{BA}. If the observation is based on the particle density model, colors are distributed as a quadrangular shape in CIE $L^*u^*v^*$ color space (Figure 2(b)). Figure 4(a) shows an actual image with overlapped printing of two watercolors and Figure 3(a) and (b) show its distribution that the color vectors for all pixels of the image is plotted. In the result of an actual image, its shape of distribution should be similar to a quadrangle based on our model.

3. Procedure of color decomposition

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

3.1. Derivation of an approximate quadrangle

In order to derive an approximate quadrangle from an actual image, following procedure is used:

1. Derivation of a plane by multiple regression in a distribution of a given actual image.
2. Projection of all of plotted points to the plane.
3. Calculation of a two-dimensional convex hull from all projected points (Figure 3(b)).
4. Calculation of an inscribed and maximum area triangle included in the convex hull (Figure 3(c)).
5. Calculation of the maximum distance point 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. Where, the color of the paper is determined as the nearest point to the point whose components of L^* is maximum and u^*, v^* are zero.
6. Calculation of a quadrangle which consists of the triangle and the point which is calculated in step 5. (Figure 3(d)).
7. Adding the fourth vertex at the opposite side and forming a quadrangle (Figure 3(e)).

3.2. Estimation of each mono-color printed area

In order to estimate each mono-color paint area, we extract a three-dimensional area in the color space. Considering an actual printing density is not even, we extract the three-dimensional area by determining threshold of an approximate quadrangle (Figure 2(c)). We determine three parameters d_A, d_B, r_S . These parameters are defined as r_A is related to an extracting area, d_B, r_S are not extracting area.
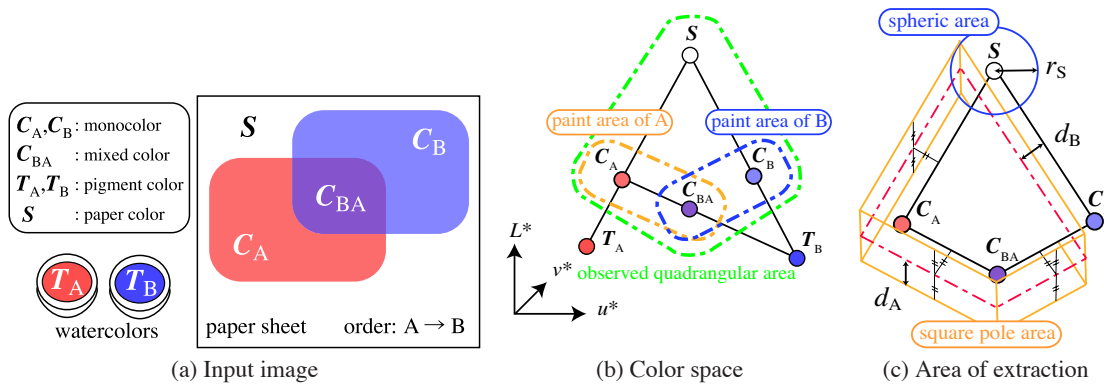
(a) Input image   (b) Color space   (c) Area of extraction

Figure 2: *Example of distribution based on our model in a color space.*

(a) Original (top)   (b) Original (side)   (c) Convex hull   (d) Triangle   (e) Quadrangle
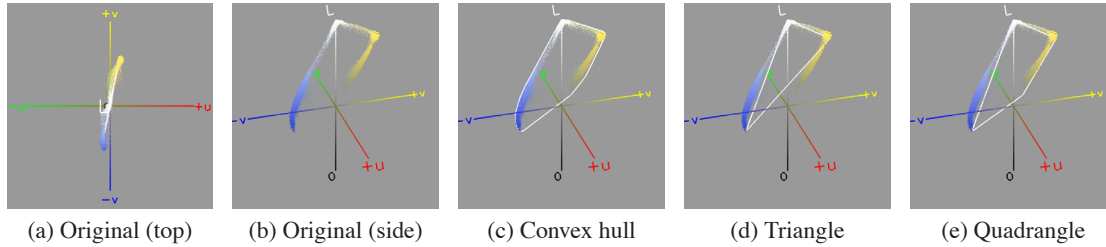
Figure 3: *The process of deriving approximate quadrangle from color distribution of a given image.*

(a) Succeeded result of B → Y	(b) Succeeded result of K → B	(b) Failure result of Y → G

Figure 4: *Results of experiments.*

(a) Black → Blue   (b) Green → Yellow
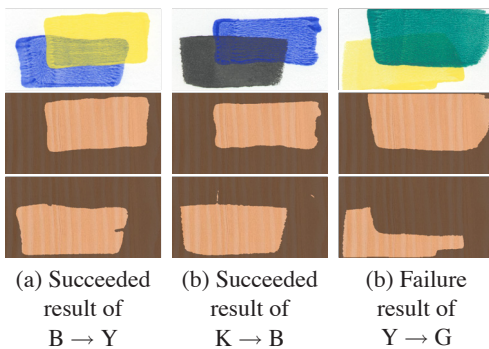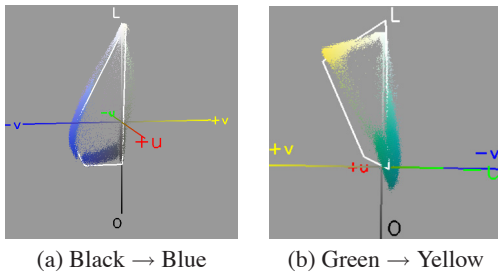
Figure 5: *Quadrangle approximation problem.*

4. Experiments and results

As a simple experiment, we applied the method to actual sample images (512×265pixel) which are overlapped printing by two of five watercolors (Red, Yellow, Green, Blue and Black) with a roller to make its printed layer thickness as even as possible, and the number of total sample is $2 \cdot {}_5C_2 = 20$. The upper row of Figure 4 shows some sample images in them. The middle and lower rows show decomposed results rendered as woodblocks. The highlighted portions are area to print. By these samples, two experiments are achieved:

(a) The parameters in Figure 2(c) are determined by maximizing success rate and fixed over the samples.
(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 4, (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 5(a)), and it is a wrong strategy which is maximum area for calculating an inscribed triangle within a calculated convex hull (Figure 5(b)). Where these result images are reduced in noise by mathematical morphology operations.

Figure 6 shows experiments of applying our method to a portion of *Ukiyo-e* (Figure 6(a)) "Firefly viewers"[Kik77] by *CHOBUNSAI Eishi*. ROI of 2057×1541 pixels, approximate 300[dpi] for the experiment in (d) is a portion of cloth of a lady which is overlapped by *Enji*, red and *Sumi*, black. Figure 6 (b) and (c) indicate its color distribution with the approximate quadrangle in CIE $L^*u^*v^*$ color space. Figure 6 (e) and (f) are the rendered woodblocks by decomposed im-
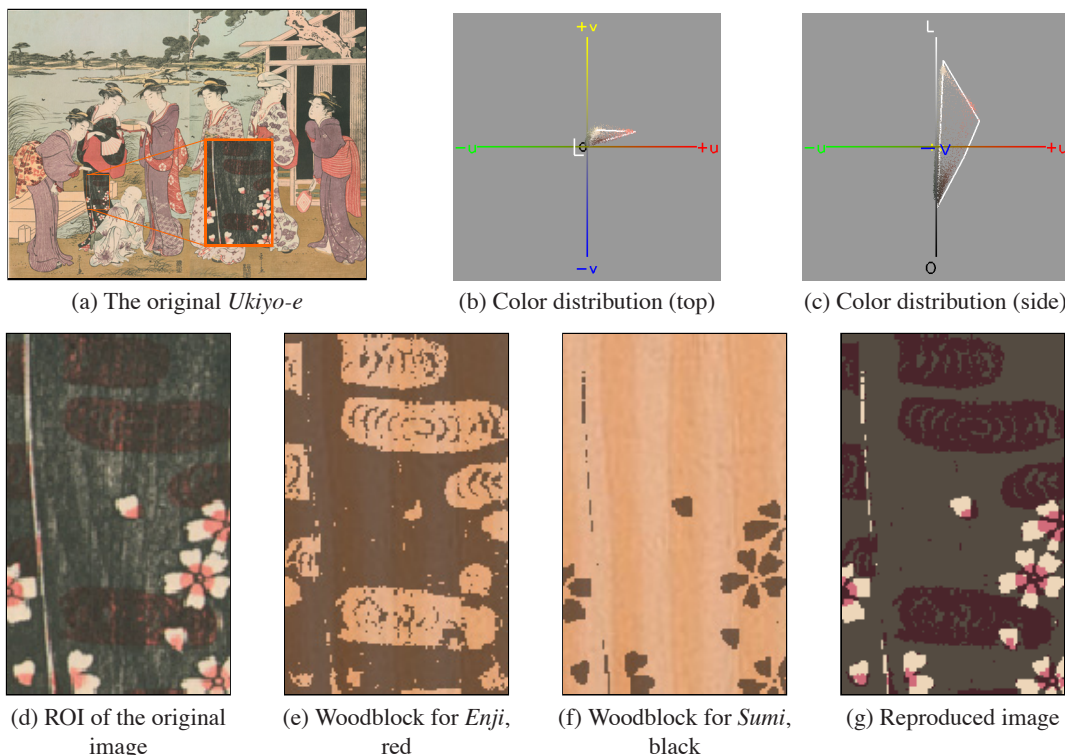
(a) The original *Ukiyo-e*   (b) Color distribution (top)   (c) Color distribution (side)

(d) ROI of the original image   (e) Woodblock for *Enji*, red   (f) Woodblock for *Sumi*, black   (g) Reproduced image

Figure 6: *The results of color decomposition for a portion of an Ukiyo-e*

age from the given image with *Enji* and *Sumi*, respectively. By these results, we can synthesize an *Ukiyo-e* image with equation (1) by CG rendering as shown in Figure 6 (g). However, we are not satisfied with these results because of two reasons. One is that the proposed method is not enough, especially in deriving process in 3.1 and 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.

5. Conclusion

In this paper we proposed a color decomposition method for watercolors using an approximate quadrangle based on a particle density model in CIE $L^*u^*v^*$ color space. As two-color problems of this study, some experiments with simple materials and a portion of *Ukiyo-e* suggested that the proposed method can be applicable to obtain virtual woodblocks from prints. The experiments in this study suggested that the proposed method provides good results when the parameters are not fixed.

As future works we have to advance accuracy of vertices estimation which is included in an approximate quadrangle and enables the proposed method to decompose color for more than two watercolors overlapped printing. How to determine automatically the parameters in the proposed method is also an important issue.

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