Reverce Engeneering of Wood-block Printing

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1 Introduction

Ukiyo-e is a multi-woodblock color print and an important historical and cultural heritage from the Edo period in Japan. An Ukiyo-e print is produced with three processes: drawing by an E-shi, a painter or a designer; woodblocks engraving by a Hori-shi, an engraving technician; and printing by a Suri-shi, a printing technician. The produced prints from the same woodblocks are not exactly the same between each other, and they have own characteristics. Although 200 to 300 sheets were printed from the same woodblocks, few prints exist today in Japan because of overseas outflows and war fires. Furthermore, it is very difficult to re-utilize the existing woodblocks because of their cracking, wearing and warping. Therefore, preserving Ukiyo-e is a very important mission.

The authors have worked an Ukiyo-e preserving project [1] based on a woodblock printing technique. The main objective of the project is to preserve not only a virtual printing image but also the process of printing with virtual woodblocks. Virtual woodblocks, made from information of a real Ukiyo-e print, are used for creating virtual Ukiyo-e prints with a virtual woodblock printing system [2]. Therefore, it is important to estimate information of real woodblocks from a real Ukiyo-e print. In this paper we propose a method for estimating the information by using multiple regression analysis.

This paper is organized as follows. In Sec. 2 the outline of the Ukiyo-e preserving project and its elemental technologies are introduced. In Sec. 3 the process for estimating the information of real woodblocks is illustrated. Finally, the experimental results show the effectiveness of the proposed method to generate virtual woodblocks automatically from a real Ukiyo-e which has overlap-printed region and reproduce the virtual Ukiyo-e.

2 Ukiyo-e Preserving Project

An archiving method [1] proposed by the authors is to preserve real woodblocks as the virtual woodblocks by digital coding using the virtual woodblock printing system [2]. The main feature of the project is to preserve Ukiyo-e techniques as historical and cultural heritage, instead of preserving only the prints in a digital image format. The archiving method is based on intelligent coding as the important feature. The outline of the project is shown in Fig. 1.

2.1 Virtual woodblock printing system

The system accepts a color image as input and generate each woodblock [3, 4] by simulating the woodblock print creating method. At the first step (a), the digitized image of a real Ukiyo-e print is analyzed to decompose its color with image processing techniques. Virtual woodblocks, made from information of a real Ukiyo-e print, are used for creating virtual Ukiyo-e prints with a virtual woodblock printing system [2]. Therefore, it is important to estimate information of real woodblocks from a real Ukiyo-e print. In this paper we propose a method for estimating the information by using multiple regression analysis.

In the case of that the color information of a real Ukiyo-e print is provided, the system can reproduce copies of an Ukiyo-e print which have the printing properties. When real woodblocks are generated with an numerical controlled (NC) machine at the step (e), a real Ukiyo-e print can also be reproduced by a real Suri-shi with them at the step (f).

You can notice that the virtual drafts are very important as input for the system. Some region of a Ukiyo-e are printed by two or more woodblocks and different watercolors are overlapped there. Therefore, the color decomposition method based on par-
article density model is used to create the drafts from a real Ukiyo-e and estimate the order of use of woodblocks.

2.2 Particle density model

For expressing an effect of overlapped watercolors, a mixing color model of watercolors called particle density model is introduced. The model is described with a linear approximate formula. It is easy to apply the model to an analysis of the effect as an inverse problem of overlapping. We use the model to estimate colors of a Ukiyo-e image at each region. As related studies, Curtis et al. [7] and Saito et al. [8] have proposed methods for synthesizing a real watercolor paint image based on the Kubelka Munk model [9], and they depend on the thickness of each layer of paint. However, the model is not linear, and it is very difficult to apply it to solve the inverse problem.

As illustrated in Fig. 2, we assume that a watercolor pigment is composed of opaque particles, and distributed in a transparent medium. Therefore, the mixing color is observed as an average color mixture that is similar to pointillistic paint.

When watercolors have been printed in $n$ times overlapping on a paper, the $i$-th observed color $C_i$ is described as follows:

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

(1)

$C_i$: observed color through $i$-th layer

$T_i$: $i$-th printed pigment color

$\rho_i$: particle density of $i$-th printed

$S$: paper color

where $C_i$, $T_i$ and $S$ are color vectors in a CIE XYZ color space.

2.3 Color space distribution

In this paper, we limit to an overlapped region to printed by two pigment colors. The observed mixing color is described in the linear interpolation of the two pigment colors and the paper color. In the case of two-color overlapping of pigment colors $T_A$ and $T_B$ in a circular shape, mainly four colors are observed on the paper, that is, the color of paper $S$, $C_A$ and $C_B$ in single painted areas, and mixing color $C_X$ can be observed as a two-variable Venn diagram as shown Fig3(a). When all pixel values of the print are mapped in a CIE XYZ color space, four points $S$, $C_A$, $C_B$ and $C_X$ form a tetragon on a plane defined with $T_A$, $T_B$, and $S$ as shown in Fig.3(b). The tetragon ideally forms a trapezoid. When the first printed color is $T_A$ and the next is $T_B$, the line $SC_A$ is parallel to the line $C_B C_X$. It is possible to estimate the order of printing at overlapped region. On a real print, each color of sample points are mapped in the XYZ color space and $S$, $C_A$, $C_B$ and $C_X$ are decided by estimating these points. The order of overlapped printing is estimated by calculating the parallelism of pairs of sides a tetragon $SC_A C_B C_X$.

3 Presumed Method of Printing Information

The decomposition for a two-color problem is based on a tetragon approximation on the particle density model. The method consists of the following two steps: (a) derivation of an approximate tetragon, and (b) estimation of each color layer of the input image.

3.1 Tetragon

In our method, sample points of an input image are mapped in the XYZ color space, and a tetragon with vertices $S$, $C_A$, $C_B$ and $C_X$ is decided by using all of the sample points. In the previous method, the tetragon was decided based on its area, and the accuracy of estimating printed order was not so good. We propose a new method to decide the tetragon based on the number of sample points. All vertices in the multiple regression tetragon can be decided by the following procedure.

1. All pixels of the input image are utilized as sampling points in the color space.

2. Deciding a multiple regression plane by using all sample points.

3. All sampling points are orthographically projected on the multiple regression plane.

4. Deciding a 2D convex hull of all projected points.
5. The nearest projected point from the point of white color is decided as the paper color $S$.

6. Assuming that paper color point $S$, vertices of the convex hull, the radius $R$, and a parameter $E$.

7. Considering a circle whose center $S$ and radius is $R$, and remove projected points inside the circle.

8. The point $C_A$ and $C_B$ are selected from vertices of the convex hull. $C_A$ and $C_B$ meet condition that a line $SC_A$ and a line $SC_B$ divide the number of the projected sample points at an $E : (1 - E)$ ratio and a $(1 - E) : E$ ratio, respectively.

9. Deciding the compound color point $C_X$ which maximizes the value $|C_A - C_X| + |C_B - C_X|$.

### 3.2 Printing area, order and pigment color estimation

For estimating printing areas corresponding to two pigments, two discriminant volumes are used as illustrated in Fig. 5. The discriminant volume for pigment $A$ is determined by the half space $H_A$, and the spheric area $P$, and the volume is defined as $P \cap H_A$ which includes $C_A$ and $C_X$. The half space $H_A$ is defined by a plane $S_A$ with $S$, $C_B$ and a parameter $r_S$. The discriminant volume for pigment $B$ is defined similarly by changing the index $A$ with $B$ as $P \cap H_B$ including $C_B$ and $C_X$. The discriminant volumes are half-infinite for two-color analysis and these should be closed volumes for multicolor analysis.

For estimating the order of printing by watercolors $A$ and $B$, we utilize parallelism of edges of the tetragon since the tetragon is a trapezoid ideally under the particle density model as discussed in Chapter 2. Since $l$ and $m$ indicate the tendency of the parallelism between $SC_A$ and $C_BC_X$, and $SC_B$ and $C_AC_X$ in estimated tetragon illustrated in Fig. 4, those are expressed by Eqs. (2) and (3) by scholar products.

\[
l = \frac{|C_A - S|}{|C_A - S|} \cdot \frac{|C_X - C_B|}{|C_X - C_B|} \tag{2}
\]

\[
m = \frac{|C_B - S|}{|C_B - S|} \cdot \frac{|C_X - C_A|}{|C_X - C_A|} \tag{3}
\]
The process to estimate the printing order and determine $C_X$ is shown below.

**procedure** Print-Order($l$, $m$)

determine threshold $t$

if $l > m$ then

if $l > t$ then

printing order is $A \rightarrow B$ and $C_X$ is $C_{BA}$

else

printing order can not be determined

end if

else

if $m > t$ then

printing order is $B \rightarrow A$ and $C_X$ is $C_{AB}$

else

printing order can not be determined

end if

end if

end procedure

We decided the parameter $t = 0$ experimentally.

For estimating the two pigment colors $T_A$ and $T_B$, that cannot be determined using only the estimated tetragon, the method, based on the particle density model, consists of following two strategies: One is based on the estimated tetragon, and the other is based on the color distribution by assuming that the distribution includes the pigment color. When the overlapping order is estimated as $A \rightarrow B$, the pigment color $T_B$ is determined as the intersection point of two lines respectively passing $S$, $C_B$, and $C_A$, $C_{BA}$. The pigment color $T_A$ is determined as the farthest to $S$ in the spheric boundary defined by the radius $|SC_A|/2$ and the center $C_A$, conveniently. When the overlapping order is $B \rightarrow A$, this method is applied similarly by changing the index $A$ with $B$.

As a simple experiment, we applied the proposed method to actual sample images ($512 \times 265$[pixel], $200$[dpi]) indicated in Fig. 6. They have overlapped printing created by a roller to make its printed layer thickness as even as possible. The number of samples is $2 \cdot 5 \cdot 2 = 20$ for all combinations of five watercolors (Red, Yellow, Green, Blue and Black). Using these sample images, we made an experiment is achieved for the parameters $d_A$, $d_B$ and $r_S$ introduced in Sec. 3. And, by fixing the radius $R = 30$ and changing $E$, we have obtained 70% for the maximum success rate of printing order estimation (shows in Fig. 7). On the other hand, because we choose the vertices of the multiple regression tetragon from the vertices of the convex hull, there are no chances to increase the success rate.
4.2 Experiment on a real *Ukiyo-e*

Fig. 8 to Fig. 15 shows experimental results of applying our method to a portion of *Ukiyo-e* “Firefly viewers” [10] by Eishi CHOBUNSAI. We decided a ROI in the *Ukiyo-e* whose size is 119×193[pixel] and it is approximately 300[dpi]. In the ROI, *Enji*-red and *Sumi*-black is overlap-printed. The printing order is unknown. Fig. 10 shows its color distribution with the approximate triangle and tetragon as white lines in *XYZ* color spaces, respectively. Figs. 11 and 12 are the decomposed images from the given original image by the proposed method. In this experiment, overlapped regions were decomposed and printed regions by both pigments are extracted correctly. Our method estimated the order of printing *Sumi* → *Enji*.

By utilizing these results in *XYZ*, we can generate virtual woodblocks for the two watercolors rendered by 3D-CG in Fig. 13 and Fig. 14 and synthesize *Ukiyo-e* images with the particle density model in Eq. (1). The reproduced image in Fig. 15 used estimated two pigment colors *Enji* (48.2, 35.7, 20.3) and *Sumi* (3.45, 3.61, 3.10). Using the decomposed images, we can generate virtual woodblocks for the two watercolors automatically, and reproduce a virtual *Ukiyo-e*. Fig. 15 is a virtual *Ukiyo-e* which used estimating pigment colors. The estimated pigment colors would be affected by discoloring. Fig. 16 is a virtual *Ukiyo-e* which used colors of Japanese traditional pigments. This image corresponds to a *Ukiyo-e* just after printed.

5 Conclusion

The success rate of printing order estimation with the former method [6] was 55% and it is raised to 70% with the proposed method in the first experiment. The main reason of success in the proposed method is that the shape of the multiple regression tetragon by the proposed method becomes suitable in contrast to the previous method. In the second experiment, using an actual *Ukiyo-e* print, we confirmed that suitable woodblocks were reproduced. The proposed method also succeeded printing order estimation for the *Ukiyo-e* print. The experimental results show that the proposed method is not satisfied for the author’s purpose. However, availability of the basic strategy of the proposed method is well-suggested by the experiments. As future works, to make our method responsive to more than two watercolors overlapped printing should be studied. How to determine automatically the parameters in the proposed method is also an important issue. Finally, to apply the method to an entire *Ukiyo-e* print.

References

Fig. 9: ROI of the original image

Fig. 10: CIE XYZ plane

Fig. 11: Enji Area

Fig. 12: Sumi Area

Fig. 13: Enji Hangi

Fig. 14: Sumi Area

Fig. 15: Reproduction A

Fig. 16: Reproduction B


