

Improvement of the printing model in multi-colored and multi-woodblock virtual printing

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Abstract

In this paper, we propose a physically based model for the printing process in the virtual woodblock printing for improvement of printing quality. Virtual printing is a simulation of real printing using “woodblocks”, “a paper sheet”, “a baren (Japanese squeegee)”, and “inks” in a virtual 3D space. A print is synthesized by an interaction among them, and it is very important to study physical properties and behaviors of the virtual items. We focus on the property and the behavior of ink and study a variety of effects due to the degree of moisture of the ink.

1. Introduction

Synthesizing non-photorealistic images such as a painting created by computers has recently attracted much attention in the field of computer graphics (CG). Many techniques of non-photorealistic images are studied in the recent years ^{1,2,3,4}. There are two basic strategies to synthesize non-photorealistic images with computer graphics: appearance based rendering and physically based rendering. The former is not a matter of the way of rendering if the product looks like an image created in the real world. The latter aims to simulate the physical actions of drawing in the real world. As a result, the rendered image looks like a hand-drawn product.

As a way of synthesizing non-photorealistic images with CG, the authors have developed a designing system using virtual sculpting and virtual printing ^{5,6}. In the virtual printing, a monochrome print is synthesized by using “a woodblock”, “a paper sheet”, and “a Japanese squeegee: baren” in virtual space similar to real printing (Figure 1). This is a kind of physically based rendering. We extended this system to synthesize a multicolor print using different virtual woodblocks. The new virtual item “ink” is introduced ⁷.

Our system is based on the process of real woodblock printing; that is carving woodblocks, spreading inks on woodblocks, putting a paper sheet on each of woodblocks, and printing with a “baren”. The system has been appreciated because the user can create a quality print in the virtual world as they do in the real world without special knowl-

edge of CG. In our system, we believe it is very important to follow the actual printing process with some interactions because of entertainment of the printing and the physical fidelity.

However, we have not conducted enough study of the physical background of the printing process. The system simulated the process only based on the appearance of a real print. A better printing model can make virtual prints of higher quality.

In this paper, we study a physically based model of the printing process to improve the quality of our virtual printing. Especially we reconstruct a new model for mixing the ink in overlapped printing.

2. Outline of the virtual woodblock printing

A virtual woodblock print is created from printing woodblocks, a paper sheet, a “baren” (used like a squeegee in printing a silk screen) and ink prepared in virtual 3D space.

A virtual woodblock is generated by an interactive operation of a virtual sculpting system ^{5,6}. In this system, to create a virtual woodblock, the user carves a virtual board with virtual chisels. The shapes of the chisels are ellipsoidal, cubic or cylindrical. The surface of the virtual woodblock is similar to a real woodblock. The virtual ink is spread on the woodblock.

A virtual paper sheet is expressed as a set of 2D lattice

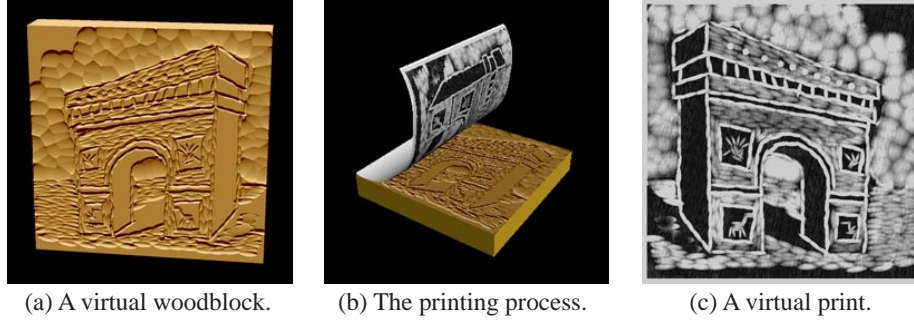


Figure 1: The virtual printing.

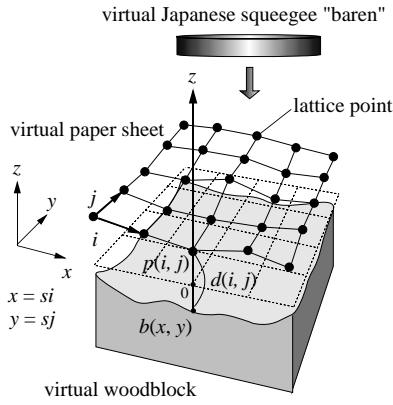


Figure 2: A virtual paper sheet on a virtual woodblock.

points and it is put on the virtual woodblock (Figure 2). Each lattice point can move only in the direction of perpendicular line of the woodblock, under a few constraints in the angle of the paper sheet surface at the point. The movement amount is controlled by the user with a virtual “baren”.

A synthesized woodblock print is a digital image. An image is printed at each point based on a distance from the paper sheet to the woodblock and virtual ink. The distance expresses the pressure of the virtual “baren”. The more, the user operates the “baren”, the nearer the paper sheet approaches the woodblock and the image becomes thicker.

3. A physically based model in the virtual printing

3.1. Multicolored virtual printing

Multicolored virtual printing uses several virtual woodblocks with virtual inks of different colors like real multicolored printing (Figure 3). It is also possible to change the ink in a virtual woodblock.

In multicolored printing, images from other woodblocks sometimes overlap each other. The former image is seen

through the image printed after. It gives a special effect often seen in Japanese traditional prints “Ukiyo-e”.

In the virtual printing, this effect is realized by definition of transparency of an image and it depends on the wetness of the ink. The transparency is decided by the distance from a virtual paper sheet to a virtual woodblock at each point and the degree of moisture in the virtual ink.

A pixel value of each color f_{col} at each lattice point is computed with the following expression:

$$f_{col} = kI_{col} + (1 - k)p_{col}, \quad (1)$$

$col = \{c, m, y\}$ (colors),

k : the degree of transparency ($0 \leq k \leq 1$),

I_{col} : the color of the printing ink,

p_{col} : the former color of each point of the paper sheet.

3.2. The previous printing model

Formerly, we calculated the degree of transparency k with the following function in virtual multicolored printing ⁷.

$$k(w, d) = \begin{cases} 1 - \left(1 - \sqrt{1 - \frac{d^2}{t_d^2}}\right)w & : 0 \leq d \leq t_d, \\ 0 & : t_d < d, \end{cases} \quad (2)$$

w : the degree of moisture of the ink ($0 \leq w \leq 1$),

d : the distance between a paper sheet and a printing woodblock at each point,

t_d : the distance of the woodblock beginning to print the paper sheet.

We decided Equation (2) only to meet the conditions that the color of a print is deeper when the distance from the paper sheet to the woodblock is small, or thick ink with a low moisture degree is used. Overlapped printing is also realized with this function. However, the wetness of the ink becomes maximum even if thin ink with a high degree of moisture is used (Figure 4 (a)), and it is difficult to decide suitable transparency.

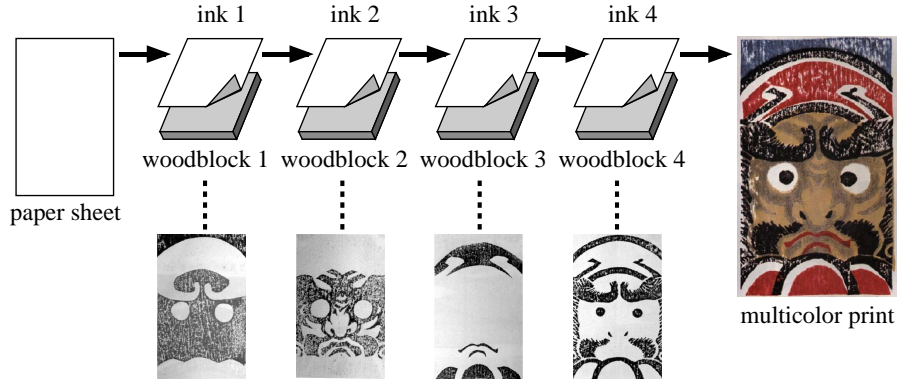


Figure 3: The process of multicolored virtual printing.

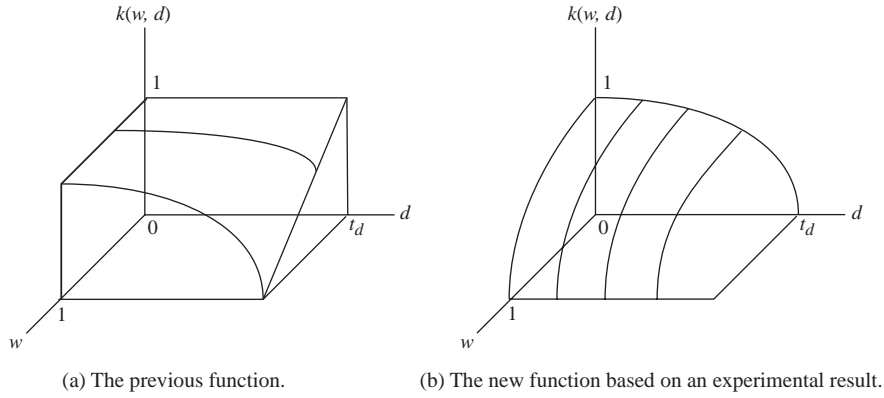


Figure 4: Graphs of functions to calculate the degree of transparency.

3.3. A new printing model

We propose a new printing model to solve the problem mentioned in the former section. The following are observed at an experiment on real printing.

1. An increase in the wetness of the ink is proportional to a decrease in the moisture degree of the ink.
2. A decrease in the wetness of the ink is proportional to an increase in the distance between a paper sheet and a printing woodblock.

On the basis of these experimental results, the following simultaneous partial differential equations are obtained below:

$$\frac{\partial k(w, d)}{\partial w} = -k_1(d)w, \quad (3)$$

$$\frac{\partial k(w, d)}{\partial d} = -k_2(w)d, \quad (4)$$

where, $k(w, d)$, w and d are same as in Equation (2). k_1 and

k_2 are functions of variables d and w . A general solution of Equation (3) and (4) is as follows.

$$k(w, d) = -\frac{w^2}{2} \left(\frac{c_1 d^2}{2} + e_1 \right) + \frac{c_2 d^2}{2} + e_2. \quad (5)$$

The following boundary conditions were obtained experimentally.

$$\begin{aligned} k(0, 0) &= 1, \\ k(0, t_d) &= 0, \\ k(1, 0) &= 0, \\ k(1, t_d) &= 0. \end{aligned}$$

Using these conditions, coefficients and constants of Equation (5) are solved as follows.

$$k(w, d) = w^2 \left[\left(\frac{d}{t_d} \right)^2 - 1 \right] - \left(\frac{d}{t_d} \right)^2 + 1. \quad (6)$$

This is a new function to calculate the degree of transparency of the printed image at each point. A printed color is calculated by Equation (1) where the value of k is substituted by Equation (6). The new printing model with Equation (6) differs from the previous model with Equation (2) that the printing degree never gets to the maximum when the moisture degree is not zero, and the ink of 100% degree of moisture is completely transparent and never prints a paper (Figure 4 (b)).

4. Experiment

We implemented a virtual printing system with the physically based model mentioned above, and compared it to the previous method.

Figure 5 shows the results of virtual printing. An image is printed by a virtual woodblock [2] on an image printed by a woodblock [1]. Figure 5 (d), (e), (f) and (g) are in the previous method and (h), (i) and (j) are in the new method. In the previous method, even a high moisture degree of ink becomes opaque when the user operates a Japanese squeegee “baren” too hard. It is different from real printing, and it is unsuitable for multicolored printing. On the other hand, the new method keeps the suitable level of transparency. The user can create a virtual multicolor print the same as in real printing.

Figure 6 shows an attempt to make a reproduction of a Japanese traditional multicolor print “Ukiyo-e” (Figure 6 (k))⁸ with virtual printing. Figure 6 (a), (b), (c) and (d) are virtual woodblocks. They were generated with the computer aided carving of virtual woodblocks^{7,9} by using an “Ukiyo-e” (Figure 6 (k)) as a draft image, thus they are not necessarily the same at all with real woodblocks for the draft print. With the new printing model we propose in this paper, it is possible to generate gradations of transparency by changing the degree of moisture of the virtual ink (Figure 6 (f), (g), (h) and (i)), that is difficult with the previous printing model. The reproduced image looks like the original image, and it is said that the virtual printing can apply to the creation of Japanese traditional multicolor prints.

5. Conclusion

In this paper, we studied a physically based new function to calculate a mixture of color for virtual multicolored printing. The new function is based on an experimental result from real printing, and it is important to consolidate the foundation of the virtual printing. It improves the printed image when using a thin virtual ink and the operation of virtual printing is closer to the real one. Thus, the user can create a virtual print more intuitively as if printing it in the real world.

In the future we are going to express a variety of printing according to the quality of the materials such as the woodblock and the paper sheet by modeling them in virtual space. Furthermore, we are going to preserve woodblocks of Japanese “Ukiyo-e” in a virtual space with the electronic technique founded on the virtual printing.

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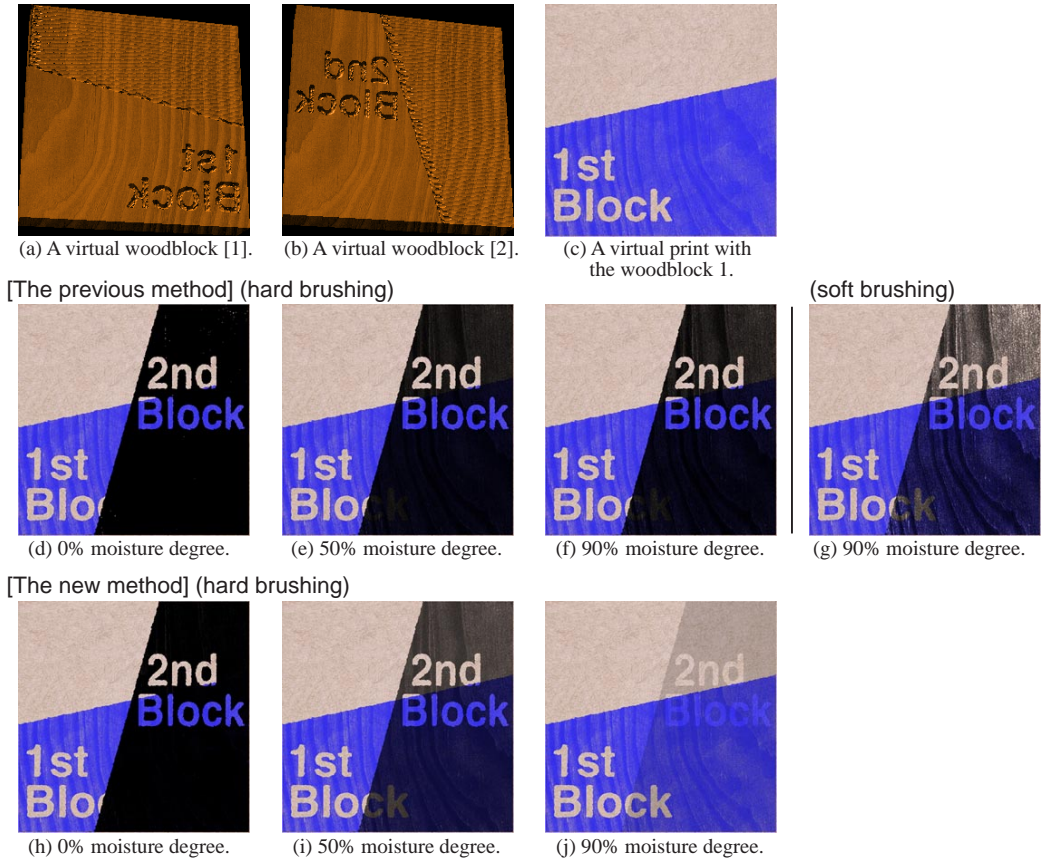


Figure 5: Printing examinations.

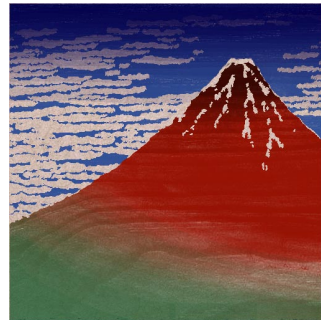
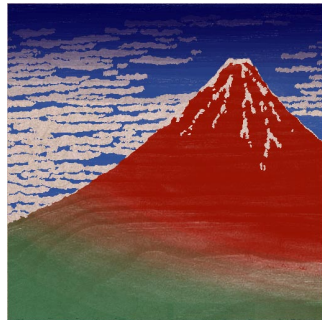
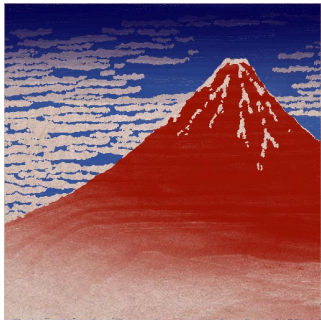
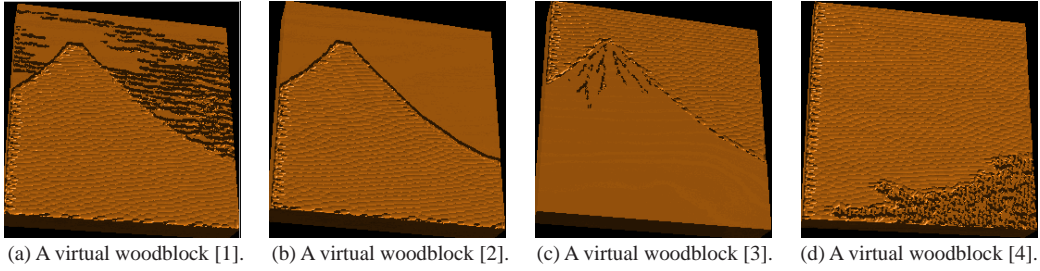


Figure 6: A reproduction of a Japanese traditional multicolor print "Ukiyo-e".