Inkjet Printing System for Textile Using Hi-fi Colors

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Abstract

We have developed a textile inkjet printing system having a large gamut and smooth gradations. In textile printing, some particular colors are more important than the others. We use orange, red and violet hi-fi color inks in addition to conventional cyan, magenta, yellow and black in order to fulfill the request. These colors are processed based on the minimum hi-fi method and the maximum black method. The printer can reproduce large color gamut in red and blue regions with a high precision of average ΔE^*_{ab}=2.05. In order to ensure smooth gradations, we have developed a new smoothing technique and a new interpolation technique for color transformation. The both convert tonal curve to be linear scale in the processing. As a result, the printer can produce smooth gradations throughout the entire color gamut composed by CMYK and hi-fi colors.

Introduction

The contemporary market requires the textile industry the following points:

- Non mass production
- Short return time
- Communication capability through network
- Environment friendly

One of the solutions to these requirements is the use of inkjet printer for textile printings. Especially, a high-speed inkjet printer with on-demand type heads realizes the above requirements simultaneously.

Thus, we developed an inkjet printing system for texitile with eight inks of dark and light C, M, Y and K colors[1]. This has been successfully used in full color printings of photo-like natural scenes since light colors assures low dot noise caused by halftoning. On the other hand, highly saturate colors are desired to reproduce major colors used in conventional textile printings. For example, red is often used for national flags as well as in sporting wears. Blue is another important color frequently used in clothing.

In order to achieve these highly saturated colors with inkjet printing system, we employ hi-fi color reproduction using orange, red, and violet in addition to regular CMYK colors.

One of requirements in practice for high image quality is smooth transition along any direction of color gradation. The use of hi-fi colors will cause more chances of pseudo contours in smooth gradations.

In this paper, we describe newly developed color image processing techniques to solve this problem. Firstly, we introduce the specification of the printer. Secondly, we quantitize the color gamut. Thirdly, we state problems found in the development, and lastly, we introduce our solutions and results.

Printing System

The developed printer named Nassenger KS-1600 II (Figure1) can choose a set of ink from disperse type (for synthetic fabrics) and reactive type (for natural fabrics). In this paper, we focus on the former case.

The following ink sets for synthetic fabrics are prepared:
[Ink set 1] Dark and light cyans, magentas, yellows, and blacks.
[Ink set 2] Dark cyan, dark magenta, dark yellow, dark and light blacks, orange, red, and violet.

Ink set 1 is used for printing with lower noise level as possible as used in its predecessor. Ink set 2 is a new color set, and is used to reproduce highly saturated colors.

This system has three types of color reproduction modes: namely paint, sRGB, and LAB. The paint mode gives saturated colors, the sRGB mode gives smooth gradation compatible with the sRGB standard[2], and the LAB mode gives absolute colors according to $L^*a^*b^*$ color image data in TIFF.

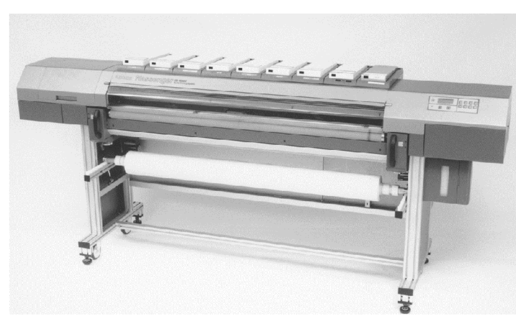

Figure 1. Textile inkjet printer Nassenger KS-1600 II

When Ink set 2 is chosen. the signal flow of the color image data is illustrated in Figure 2. The processing is performed in a personal computer. Colors are converted into seven colors by tetrahedral interpolation with a 33 × 33 × 33 device-link LUT. The converted colors are processed by error diffusion with tonal curves adjusted to a visually equal step in order to minimize quantization errors.

Table 1 summarizes the major specifications of the printing system.

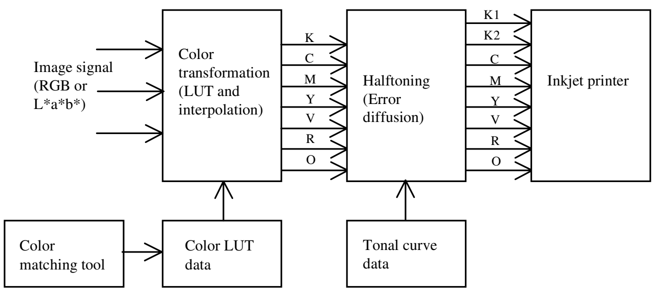

Figure 2. Signal flow of hi-fi printing

Table 1 Specifications of Nassenger KS-1600II

Printing method	On-demand Inkjet printing
Printing head	300 dpi, 8 printing heads
Ink type	Disperse ink for synthetic fabrics (polyester) Reactive ink for natural fabrics (cotton and silk)
Maximum cloth width	1600mm
Printing speed	Dark and light: 10m2/h (6.7m/h), Hifi-color: 7.5m2/h (5m/h)
Color mode	Paint, sRGB, and LAB

Hi-fi Color Reproduction

General Approach to Hifi Printing

Based on the methodology for hi-fi color reproduction presented by one of the authors, [3] we have chosen a combination of the minimum hi-fi method and the maximum black method.

The minimum hi-fi method uses hi-fi color inks as less as possible to reproduce a specified color without losing color gamut. This method reduces the impact of dot noise to human eyes because hi-fi colors used in this printer are darker than C, M and Y inks. Also it can avoid using costly hi-fi inks.

Likewise, the maximum black method uses black ink as much as possible. This method minimizes ink consumption by its nature without loosing color gamut. Also, since the printer has light black ink, a better noisiness is achieved for gray compared with the same gray reproduced by dark C, M, and Y inks. This approach reduces the effect of the illuminant metamerism as well.

Color Gamut Formation

Hi-fi colors are characterized by four sub color gamuts: CMYK, CMVK, OMRK, and YMOK. We choose this combination for a better connectivity and a larger color gamut different from the original proposal[3]. Although red does not effectively expand the color gamut, it is used because of a strong request from the market. This causes to a gradation problem described later.

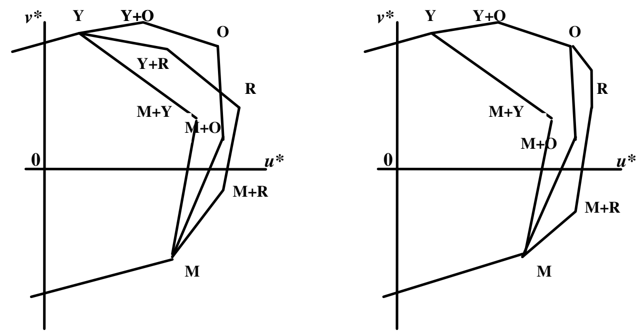

Figure 3. Schematic diagram of sub color gamuts for red region (left: original formation, right: new formation)

Color Gamut

Based on the above color gamut formation, color gamut boundaries at equal L^* planes are calculated. The equal L^* planes are obtained using a wire frame gamut model for the four sub color gamuts. By searching crossing points between surface triangles and the line at a certain lightness and hue angle, the final boundary of the entire color gamut is obtained[4]

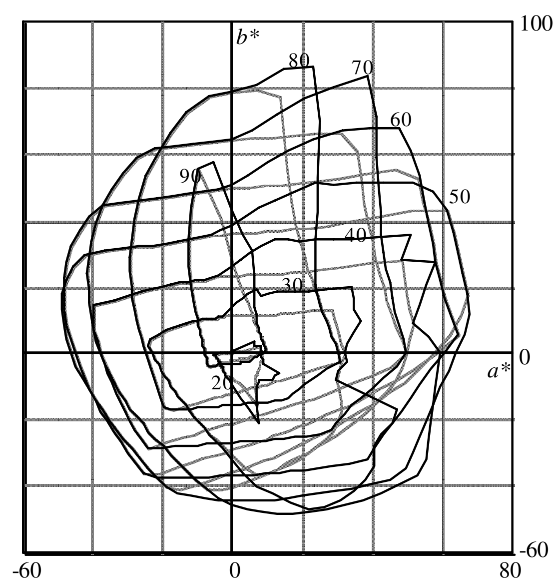

Figure 4. Color gamut of hi-fi color and CMYK color at each L (solid line: hi-fi color gamut, shaded line: CMYK color gamut. Numbers indicate L* level).*

Figure 4 indicates the difference of CMYK gamut and hi-fi gamut. Here, Illuminant D65 and 10-degree color matching functions are used. These colors effectively expand the color gamut in orange-red and blue-purple regions.

Smooth Gradation

In order to achieve a photo-grade quality, smooth gradations throughout the entire color gamut is essential. Since the use of hi-fi colors gives more connecting boundaries between sub color gamuts, it tends to cause pseudo contours.

Moreover, due to the measurement error and a potential overlap among the sub color gamuts, extremely different amounts of colorant combinations are likely to be chosen at neighboring colors. In such case, along a color gradation, the color amounts drastically changes. It leads color interpolation error - it is apparently observed in a whitish color.

This phenomenon happened in the red region because two hi-fi colors are located close by. Figure 5 shows ink amount change along a blue gradation (from black to blue) and a red gradation (from black to red) in the sRGB mode, respectively. While the blue gradation has a simpler change than the red gradation, the red gradation shows drastic changes at LUT grid 16 and 24. These cause pseudo contours.

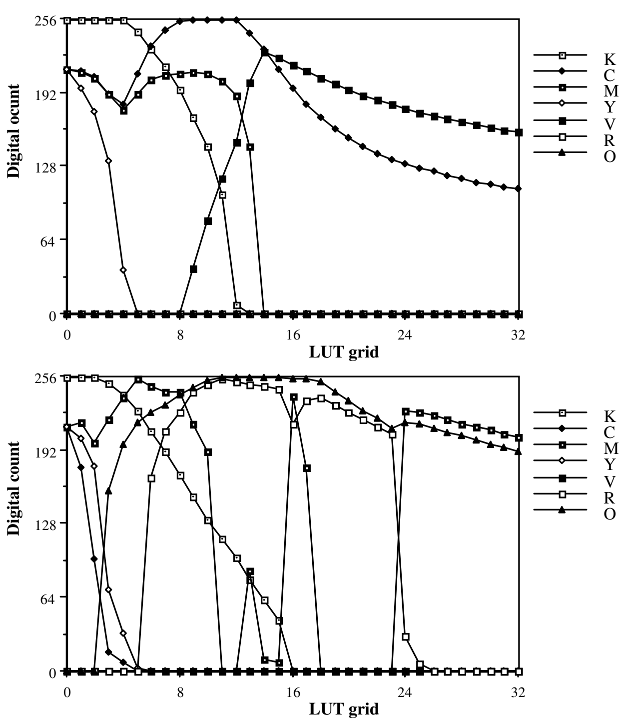

Figure 5. Colorant changes in blue (upper) and red (lower) regions.

The phenomenon may be explained as follows: The interpolation is performed approximately in a color space proportional to the third root of intensity although halftoning is performed in a intensity-linear color space. Therefore the interpolation gives the error.

It is thought that there are two approaches to solve the problem:

- Modify the sub color gamuts so that these sub gamuts are clearly segmented (as in the blue region).
- Modify color transformation not to be sensitive to these changes.

As the first approach is considered, it would not be universally used when a different set of hi-fi colorants is employed. Thus we chose the second approach.

First, we applied linearization for smoothing of LUT. The original simple smoothing for 3D-LUT is described as follows:

$$LUT'(k,j,i,col) = \frac{1}{27}\sum_{kk=-1}^{1}\sum_{jj=-1}^{1}\sum_{ii=-1}^{1} LUT(k+kk, j+jj, i+ii, col) \tag{1}$$

where, LUT is an output value of Color *col* at Grid (k, j, *i*), and LUT' means smoothed data.

We apply a gamma conversion in *order to* *ake* the smoothing calculation in the linear scale as follows:

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$$LUT'(k,j,i,col) = \left[\frac{1}{27}\sum_{kk=-1}^{1}\sum_{jj=-1}^{1}\sum_{ii=-1}^{1}\{LUT(k+kk, j+jj, i+ii, col)\}^{\gamma}\right]^{1/\gamma} \tag{2}$$

where, γ is a value for linearization.

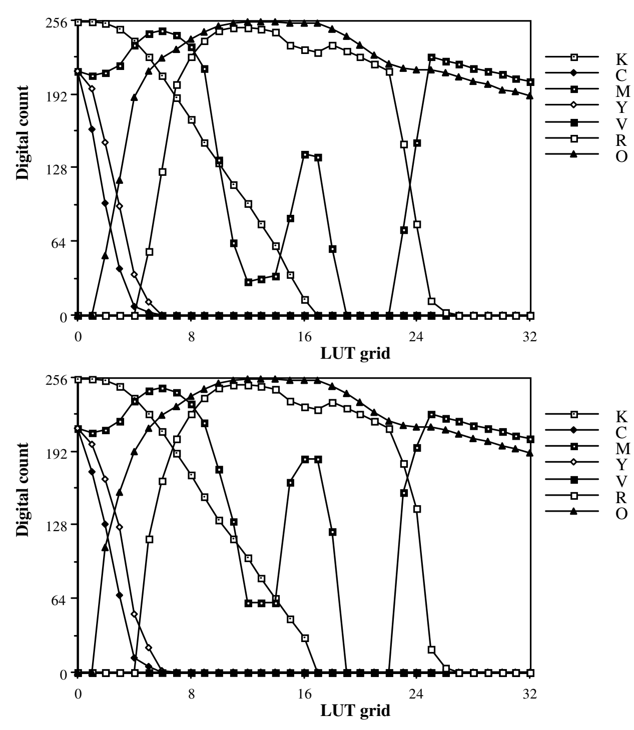

Figure 6. Colorant changes in red gradation with simple smoothing and modified smooting

Figure 6 illustrates the effect of the gamma conversion in the smoothing for the red region. Figure 7 shows the pictures of actual gradation samples, and Figure 8 illustrated lightness changes of these gradations. By this technique, the pseudo contour (indicated by an arrow) becomes invisible.

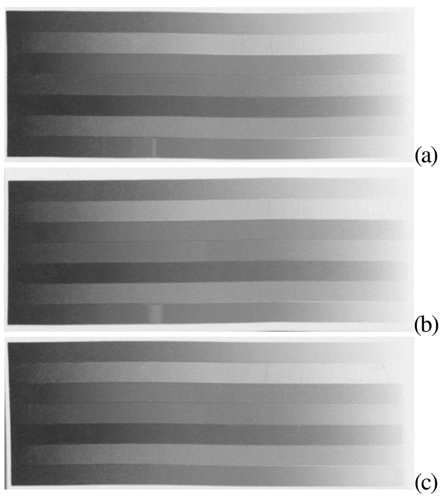

Figure 7. Smoothing effect in gradations: (a): original, (b): simple smoothing, (c): smoothing with gamma conversion. From top, gradations are gray, yellow, magenta, cyan, blue, green, and red.

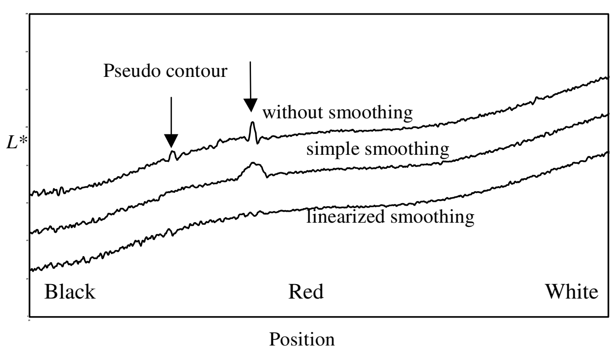

Figure 8. Lightness change of gradations (Each curve is shifted by 20 for illustration)

Likewise, we applied the same modification for the color transformation, or color interpolation. Since the color interpolation needs to perform a large amount of image data, an optimization of the interpolation calculation in speed is essential.

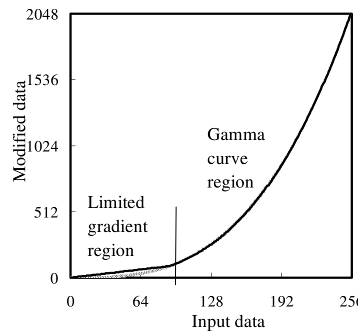

Figure 9. Gamma curve with a gradient limitation (For explanation, 11-bit case is illustrated here).

In order to minimize the tetrahedral interpolation algorithm, a parallel calculation is used[5]. Two output colors are simultaneously interpolated by utilizing a 32-bit width of CPU. Since this algorithm has a redundancy of five bits for each color, we use them to minimize quantization error in the gamma conversion. However, since the 13-bit width is not enough to keep the bit precision when $\gamma = 3$ is used, we use a gradient-limited curve as shown in Figure 9.

Color Reproduction Error

In the LAB mode, we measured printed color samples for an $L^*a^*b^*$ grid with an increment of 10 within the printer color gamut. The average error was ΔE^*_{ab}=2.05 for 421 color points. The maximum error was ΔE^*_{ab}=6.6.

When no gamma conversion is used for color transformation, the worst error reached to ΔE^*_{ab}=16.5 in orange region.

Summary

We have developed a textile printing system using hifi colors. In order to ensure smooth gradations, we proposed tone-corrected smoothing and interpolation techniques. Consequently, the printer has smooth gradations throughout the entire color gamut.

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5. Japanese patent disclosure: H07-209772.

Biography

Po-Chieh Hung received his BS and MS degrees in electronic engineering from Waseda University, Tokyo, Japan, and his Ph.D. in imaging science from Chiba University, Chiba, Japan; in 1999. He is a Chief Research Associate at Konica Corporation's Central Research Laboratory, and is engaged in digital imaging.

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