Perceptual Dependencies in Fabric Appearance between Texture and Color

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Abstract

In this paper, for producing realistic color fabric images, we investigate perceptual dependencies in fabric appearance between texture and color. Color fabric images are synthesized using combinations of textures and color patterns. Texture patterns are extracted from fabric surface images, whereas color patterns are obtained done from colored pattern images. Color patterns are transferred onto texture patterns in the YIQ color space through our proposed algorithm. For validating the algorithm, we conducted two subjective evaluation experiments. The first experiment was conducted for evaluating the unnaturalness of synthesized color fabric images. Experimental results indicated that the unnaturalness depended on the relationship of the frequency between texture and color patterns. Then, we conducted a second experiment to evaluate our proposed technique for reducing unnaturalness. For reducing the unnaturalness of synthesized color fabric images, we applied the Gaussian filter to inputted colored pattern images. The results of the second experiment showed that the unnaturalness can be reduced by applying appropriate standard deviations of the Gaussian filter. Finally, we developed a model to estimate the standard deviations from input color and fabric images. We also showed that the model has sufficient estimation accuracy.

Introduction

Studies on surface texture appearance have immense significance in the fields of vision science, color imaging, and computer graphics. For instance, Dana et al. surveyed the reflectance and texture of real-world surfaces and investigated their applications to computer vision and computer graphics [1]. Tsin et al. proposed a method for replacing textures (re-texturing) in natural images [2]. Fabrics, in particular, are one of the most important materials when studying texture. Numerous types of fabrics exist in our daily life such as those used in interior living spaces and clothing wear. Therefore, owing to its considerable relevance in our day to day life, fabric textures have been widely investigated and analyzed. Ngan et al. proposed a method for acquiring and reconstructing the appearance of materials [3]. Their method properly reproduced fabrics and knit wears. Wang et al. presented computer vision techniques to measure the texture of fabrics [4]. Their technique enables us to measure the weave repeat and surface roughness of fabrics. Ravandi et al. presented a method to analyze plain weave fabric appearance using Fourier transform [5].

Recently, Giesel et al. published interesting results from their study on fabric texture appearance. In their study, they analyzed the relationship between fabric texture and its frequency features [6]. They proposed a technique that controls fabric texture appearance from the viewpoint of "undulation," "thickness," and "roughness." The appearance of each material is controlled by manipulating the corresponding frequency band. However, they performed fabric appearance control for only monochrome images. Color information is very important when studying surface appearance; it is essential to control color fabric appearance.

In this paper, we propose a method to synthesize realistic color fabric images by combining texture patterns and color patterns. In our precondition, fabric texture appearance can be controlled using the technique of Giesel et al. Then, we focus on how to transfer color information onto the fabric texture. Our color transfer algorithm is implemented in the YIQ color space. The IQ components of the colored pattern image are transferred to the Y components of the fabric texture patterns (see the next section and Fig. 1). For validating the color transferring algorithm, we conduct two subjective evaluation experiments. The first experiment is conducted for evaluating the unnaturalness of the synthesized color fabric images. The second experiment is performed to evaluate our proposed technique for reducing unnaturalness of the synthesized images. In particular, we investigate and analyze the relationship between appearance and image frequency.

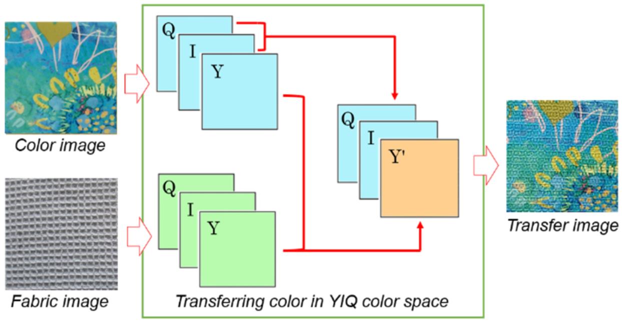


Figure 1. Schematic diagram of the proposed color transfer algorithm. Our algorithm utilizes two input images to synthesize a color transfer image. One of the input images is a texture image of fabric surface, and the other is a colored pattern image. The synthesized images have the texture of the fabric image and color information of the colored pattern image. The Y component is processed based on the summation of the deviation of a fabric image and the intensity of the color image. The IQ components are not processed.

Color Transfer on Fabric Texture Image

To synthesize a color fabric image, we use two images. One is a color image that has color information. The other is a fabric image that has fabric texture. As described in the Introduction, we focus on how to transfer color information to the fabric texture. A synthesized color transfer image has the color information of an input colored pattern image and the texture information of an input fabric image. Figure 1 shows the color transfer algorithm. This processing is carried out in the YIQ color space. The IQ component of an input colored pattern image is used for synthesizing a color transfer image without any processing. On the other hand, the Y component of an input fabric image is processed before the color transfer as follows.

$$Y' = (Y_f(x,y) - \overline{Y_f}) + Y_c(x,y) \qquad (1)$$

where (x,y) is the image coordinate, Y_f is the Y component of an input fabric image, $\overline{Y_f}$ is the average of the Y component of an input fabric image, and Y_c is the Y component of an input fabric image. We assumed that the texture appearance is derived from the deviation of the Y component in fabric images. Then, for calculating the Y components of a color transfer image, the deviation of the Y components of an input fabric images are added

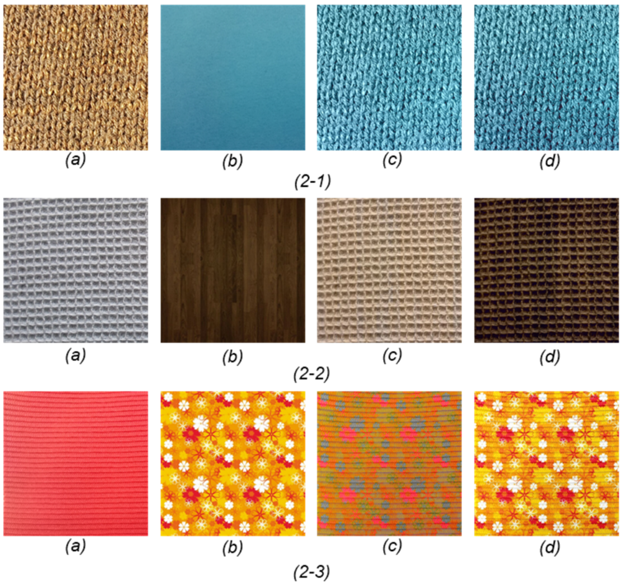


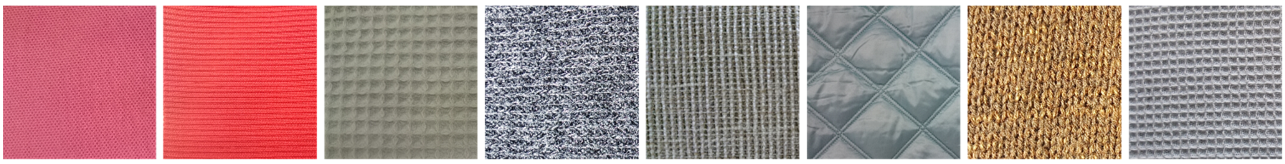
Figure 2. Synthesized images using the color transfer algorithm. (a) Fabric image prepared for the synthesis. (b) Colored pattern image prepared for the synthesis. (c) The synthesized image, which consists of the Y component of the fabric image and the IQ components of the color image without processing. (d) The synthesized image using our proposed algorithm. The color of the blue paper is transferred to fabric of the sweater (2-1). In Fig.2-1, the differences between the intensities of the blue paper and that of the sweater are small. Therefore, there is little difference between the two synthesized images. However, Fig.2-2(c) and 2-3(c) do not preserve color information of color images well. These color mismatches are caused by the differences between the intensities of the fabric images. On the other hand, the proposed algorithm can well manipulate color information of Fig.2-2(d) and 2-3(d).

to the Y components of an input colored pattern image. The deviation of the Y components in a fabric image is defined by subtracting the average of the Y components from the Y component of each pixel. Figure 2 shows a comparison between images subject and not subject to the algorithm for the Y components. We can prevent any loss of color information in synthesized color transfer images.

Subjective evaluation experiment for unnaturalness using color transfer

We conducted a subjective experiment to evaluate the unnaturalness of color transfer images synthesized using our algorithm. Figure 3 shows the images prepared for the subjective experiment. The pixel size of each image is 512 × 512. Participants observed both the original texture and the color images. Then, they answered whether or not they felt the synthesized color transfer images were unnatural through observed. Unnatural implies an unreal appearance after combining fabric textures to colored pattern images.

The details of the experimental procedure are as follows. First, a fabric image and a color image on the monitor were presented to participants. Then, the participants guessed an image that consists of the texture of the fabric image and color information of the color image. Next, a color transfer image with the Y component processing was presented to the participants. Then, the participants evaluated the unnaturalness level of the color transfer image. If a participant felt no unnaturalness, he/she evaluated the image with a score of "0." The acceptable limit of the evaluation score was "50." An upper limit of the evaluation score was not provided. We presented 20 color transfer images. In addition, for investigating repeatability, each image was evaluated twice with changing display orders. Ten participants evaluated the color transfer images. Figure 3 shows images that were used in the experiments. Display size of each image is 9.5 × 9.5 cm. EIZO ColorEdge CS 230 was used as a monitor. The distance between a participant and the monitor was 40 cm.



(a) Fabric image

(b) Colored pattern image

Figure 3. Images prepared for subjective evaluation experiments. (a) Fabric images. (b) Colored pattern. Fabric image have various frequency feature. Colored pattern images consist of photos and digital pictures.

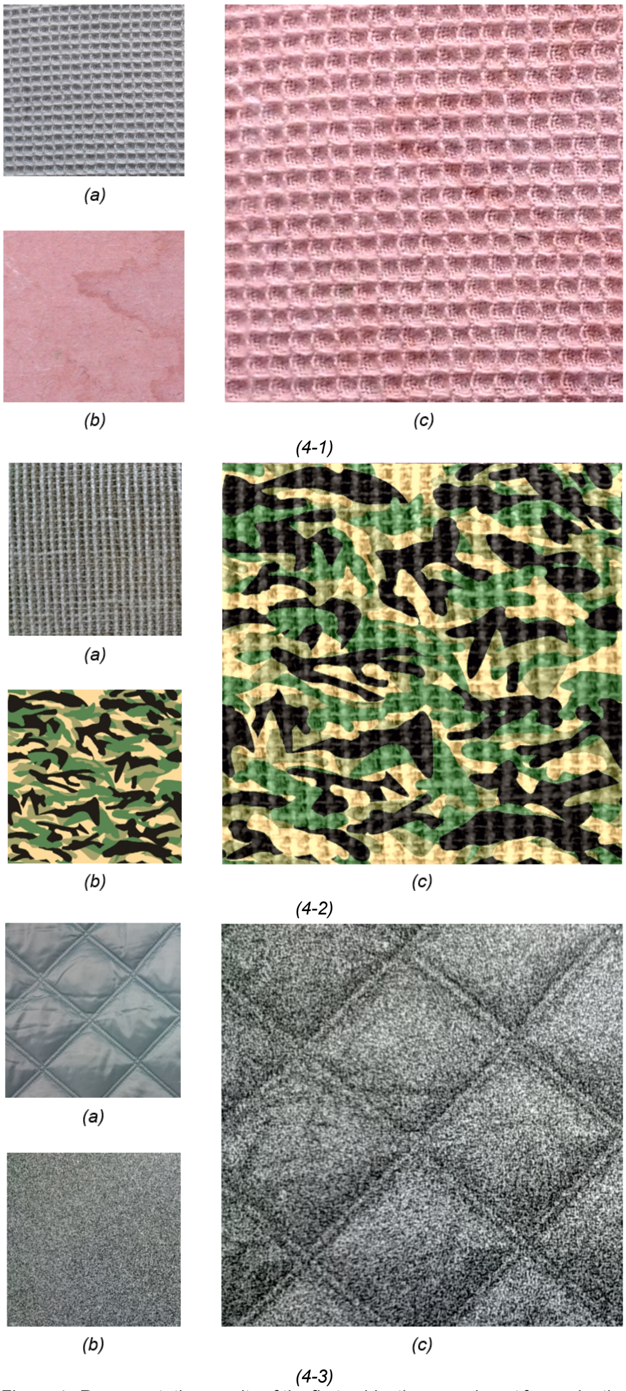


Figure 4. Representative results of the first subjective experiment for evaluating "unnaturalness" of color transfer images. (a) Input fabric images. (b). Input color images. (c) Synthesized color transfer images based on the two input images. (4-1) low "unnaturalness" score: 16. These do not have the features that color image has high edge intensity and color image has high frequency that fabric image does not have. (4-2) and (4-3) were evaluated as high "unnaturalness": 71 and 67. (4-2) of color image has high edge intensity. The "unnaturalness" is caused by this feature. In the case of (4-3), color image has higher spatial frequency than that of the fabric image. This feature causes "unnaturalness" in the synthesized color transfer image.

Figure 4 shows representative examples of input and color transfer images. From the experimental results, we found that color transfer images with high "unnaturalness" scores are mainly caused by two image features: high edge intensity (see Fig. 4-2), and higher spatial frequency of colored pattern image compared to that of a fabric image (see Fig. 4-3).

Subjective evaluation experiment for reducing unnaturalness in color transfer images

To reduce the unnaturalness in color transfer images, we applied the Gaussian filter to colored pattern images in the RGB color space. We assumed that the Gaussian filter can inhibit the two factors of unnaturalness, i.e., the high spatial frequency of colored pattern images can be reduced, and the edge intensity of the colored pattern images can be lowered. After applying the Gaussian filter in the RGB color space, we transferred the color information to the fabric texture in the YIQ color space.

To validate the effects of the Gaussian filters, we conducted subjective evaluation experiments. Participants evaluated images with an unnaturalness score of over 50 in the previous experiment. The color transfer images with the Gaussian filters are displayed in orderly. First, participants evaluated a color transfer image with $\sigma = 0$ (σ: standard deviation of the Gaussian filter). Then, participants increased σ until they felt that the "unnaturalness" was acceptable (evaluation score = 50 in the previous experiment). The σ was prepared in [0.5, 5.0] with an interval of 0.5 for the scale of pixel size. Figure 5 shows color transfer images applied the Gaussian filter. Other viewing conditions are the same as the previous experiments.

Original color transfer images without the Gaussian filter were evaluated as "unnatural" by participants. However, from the experimental results, all the color transfer images with the Gaussian filter were evaluated under the score of acceptable "naturalness." In other words, applying the Gaussian filter to colored pattern images is effective in reducing unnaturalness. Figure 6 shows the relationship between average "unnaturalness" score for original color transfer images, $\mathrm{U}_{\mathrm{ave}}$, and average of necessary standard deviation for synthesizing natural color transfer images, σ_{ave}. Correlation coefficient between $\mathrm{U}_{\mathrm{ave}}$ and σ_{ave} is 0.89. There is a very strong correlation. As shown in this figure, inhibition of unnaturalness linearly depends on the standard deviation of the Gaussian filters.

Estimation of the standard deviation

Here, we develop a model to estimate optimal standard deviations for reducing unnaturalness by using input image features. As described above, optimal standard deviations are determined based on the subjective "unnaturalness" score which is attributed by two kinds of input image features. One of the image features is edge intensity of an input colored pattern image. The other feature is high frequency components of an input color image. We estimate optimal standard deviations by quantifying these feature values. Model formula to estimate standard deviations is obtained by regression analysis between these features and subjective scores of "unnaturalness."

F_E is the height of edge intensity of an input colored pattern image. It is based on the assumption that high edge intensity of colored pattern image induces unnaturalness. F_E is quantified by applying a differential filter to color images in RGB color space. F_E is defined as the maximum values among all pixels in the filtered colored pattern image. When edge intensity of a color image

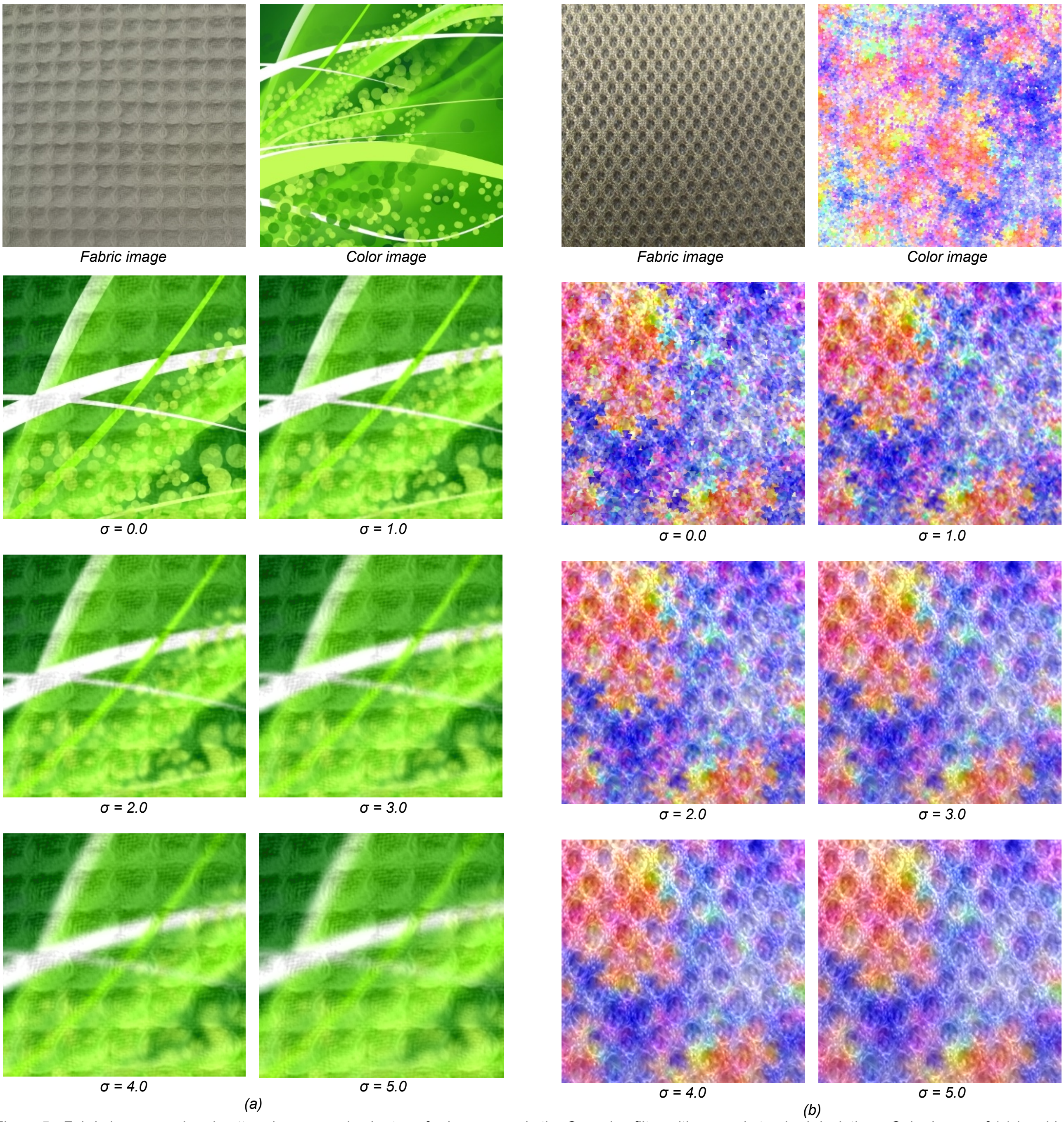


Figure 5. Fabric images, colored pattern images and color transfer images apply the Gaussian filter with several standard deviations. Color image of (a) has high edge intensity and color image of (b) has higher spatial frequency than that of fabric image. The color transfer images with "σ = 0" is equal to an original transfer image described in the previous experiment. The Gaussian filters with too high standard deviations prevent proper color transfer because color information of colored pattern images is not preserved. In the left side of the figures, (a), the green color image has circle pattern. However, the circle pattern of image applied the Gaussian filter with σ=5.0 in (a) is reduced. In the right side of the figures, (b), color image has minute pattern. Synthesized image applied the Gaussian filter with σ=5.0 in (b) has no detail of color pattern. Therefore, optimal standard deviation to reduce unnaturalness is needed.

is high, F_E becomes high. We apply the Sobel filter as a differential filter.

F_D is the differences of high frequency components between input fabric and color images. It is based on the assumption that unnaturalness appearance induces in the case that a colored pattern image has high frequency that a fabric image does not have. F_D is given by the following equations.

$$F_D = \int_{min}^{max} \frac{g}{g_{c(x,y)}} dx, \tag{2}$$

$$g = \begin{cases} g_{c(x,y)} - g_{f(x,y)} & (g_{c(x,y)} > g_{f(x,y)}) \\ 0 & otherwise, \end{cases} \quad (3)$$

where x and y are the image coordinates in the frequency domain, g is the power spectra, *max* is the end of the image, and *min* is 150 (cpi: cycle per image) which is decided to account for high frequency components of a colored pattern image. F_D represents the amount of frequency of a colored pattern image except the frequency of a fabric image. High F_D value means that an input colored pattern image has higher spatial frequency than that of a fabric image.

We performed a regression analysis to derive the model formula to estimate the standard deviation. F_D and F_E are independent variables, dependent variable is σ_{ave}. According to the regression result, F_D and F_E are significant as predictable features ($p < 0.05$). Following equations are the model formula to estimate standard deviations given by the regression analysis.

$$\hat{\sigma} = 0.0159\, F_D + 0.0013\, F_E \quad (4)$$

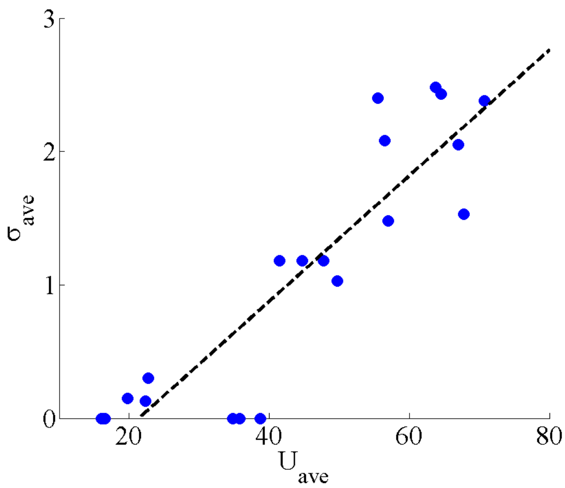


Figure 6. Relationship between U_{ave} and σ_{ave}. There is a strong correlation between average of "unnaturalness" score and average of necessary standard deviation.

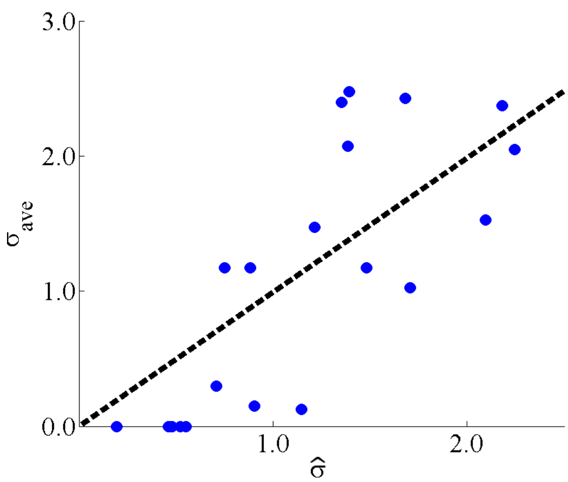


Figure 7. Relationship between $\hat{\sigma}$ and σ_{ave}. There is high correlation coefficient, 0.80. The estimation accuracy is sufficient for our algorithm.

where $\hat{\sigma}$ is the estimated standard deviation. Figure 7 shows the relationship between evaluated standard deviation and estimated standard deviation given by Eq.(4). The correlation coefficient between σ_{ave} and $\hat{\sigma}$ is 0.80. We could achieve accurate estimation results. Figure 8 shows the synthesized images using the proposed algorithm.

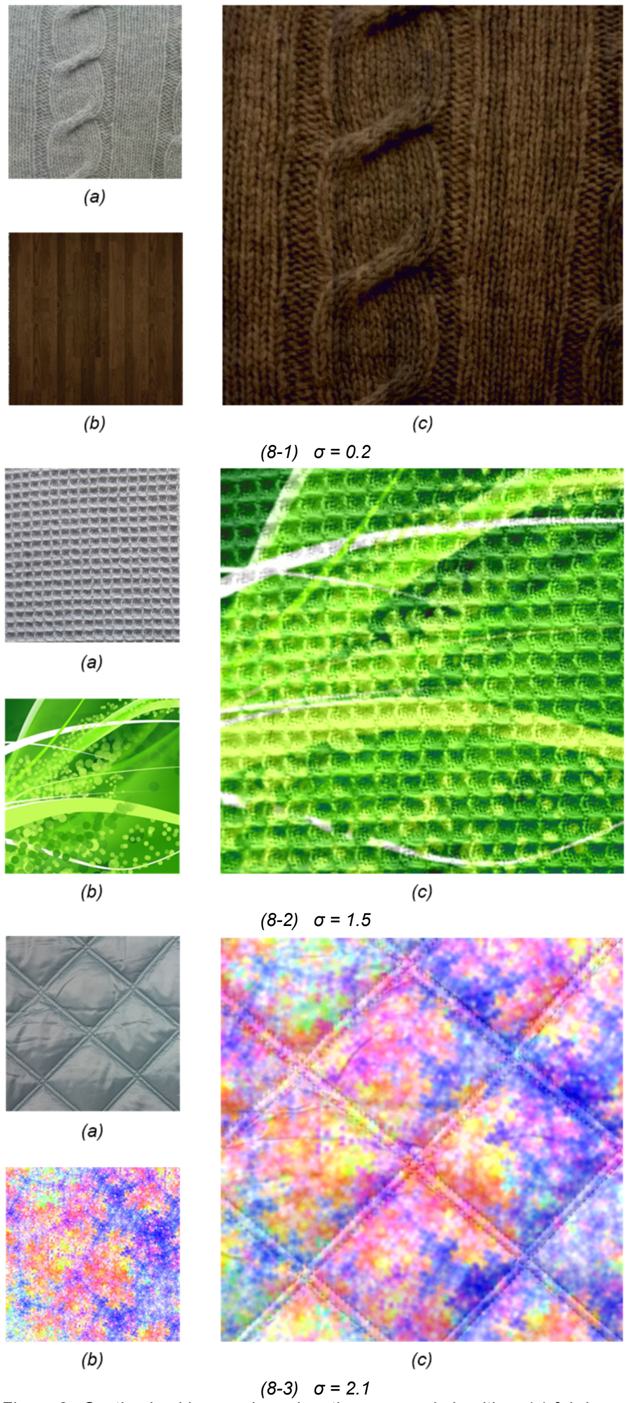


Figure 8. Synthesized images based on the proposed algorithm. (a) fabric images. (b) colored pattern image. (c) synthesized images. Standard deviations of The Gaussian filter is shown at the bottom of each figure.

Instead of the Sobel filter, we also apply the Laplacian filter to quantify the edge intensities of input colored pattern images. Correlation between F_E by Sobel filter and F_E by Laplacian filter is 0.88. We obtain almost the same estimate accuracy by applying the Laplacian filter.

Conclusion

In this paper, for synthesizing realistic color fabric image, we investigated color fabric image appearance. We conducted the experiments to clarify the relationship between texture and color. At first, we proposed a color transfer algorithm to synthesize images that consist of texture information of a fabric image and color information of a colored pattern image. The algorithm is implemented in the YIQ color space. In particular, we modified the Y component for natural color transfer. For validating the color transfer algorithm, we conducted subjective experiments for evaluating the unnaturalness of color transfer images. The results show that the unnaturalness appearance is caused by two factors: (1) edge intensity of colored pattern image, and (2) relationship of spatial frequency between texture and color. Then we apply the Gaussian filters for reducing unnaturalness. For validating the effect of the Gaussian filter, we conducted a second subjective experiment for evaluating color transfer images to which the Gaussian filters were applied with various standard deviations. The results show that the Gaussian filter can reduce the unnaturalness of the synthesized color transfer images. In particular, inhibition of unnaturalness linearly depends on the standard deviation of the Gaussian filters. The model to estimate standard deviations of the Gaussian filter is derived based on the regression analysis between image features and subjective scores. The model allows us to estimate them with high accuracy. Based on the proposed algorithm, it is possible to reproduce color fabric images with natural appearance from any combinations of texture and color images. This study will contribute to develop technology related to fabric appearance.

Reference

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Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 15H05926 (Grant-in-Aid for Scientific Research on Innovative Areas "Innovative SHITSUKSAN Science and Technology").

Author Biography

Takafumi Katsunuma received the B.E. degree from Chiba University in 2015. He is currently a master course student in Chiba University. He is interested in texture analysis and rendering, material perception, color and SHITSUKAN engineering, and interactive imaging system.