Study on Influence of Filter Design Parameter on Printing Image Reproduction Quality in Spatial Color Gamut Mapping

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Abstract

Image filter is one of the primary influencing factors for image processing and reproduction in spatial gamut mapping. The primary target of filter is to decompose the image into several bands and then to use different gamut mapping methods to get high quality reproduction in the spatial gamut mapping framework. Gaussian filter, mean filter and bilateral filter etc. are often used in spatial gamut mapping. For the same filter, the scale parameter plays a critical role in improving the image processing and reproduction quality. In this paper, Gaussian filter and bilateral filter were used to process the digital original images based on the theory of printing image processing in spatial gamut mapping. Various filter scale parameters were selected to decompose the originals into low band images and high band images in color gamut mapping and to study on the relations between the scale parameter and filtered image. The results indicated that the appropriate filter parameters contribute to influence the properties of different band images then to influence the gamut mapping quality. And it helps to improve the spatial gamut mapping algorithms and improve the gamut mapping quality.

Introduction

Color gamut mapping technique is one of the core techniques in color management and image reproducing workflow. It is one of the most interested topics in color science now. Generally speaking, color gamut mapping is studied and performed based on color properties and the relations between image and device. We classify the gamut mapping algorithms into two types, device-to-device gamut mapping algorithm and image-to-device gamut mapping algorithm [1-3]. In the device-to-device gamut mapping framework, the mapping function is developed according to the relations between input device and output device, in which there was no direct relation to the image itself. In the other framework, image-to-device framework, the mapping function is developed based on the statistics analysis of the image colors and contents and the characteristics of the originals. Morovic J etc. have done detailed studies and discussions in this area [2]. With the development of gamut mapping techniques, a new type of gamut mapping algorithm, spatial gamut mapping algorithm, is developed. This new algorithm not only takes the image color characteristics into account but also takes the spatial relations between different pixels, i.e., it can perform good reproductions according to image contents and image color characteristics. Bonnier etc. studied the spatial gamut mapping algorithms and gave new spatial gamut mapping framework in his doctorial paper [1-4].

Spatial filtering of image is to do spatial conversion for pixels directly and it is a neighborhood operation. Every pixel value of converted image is performed by processing the neighborhood pixels of original images according to the specified methods. In spatial color gamut mapping framework, the main function of filter is to decompose the image into several bands which are processed by different algorithms and then to get high quality reproduction. Gaussian filter, mean filter and bilateral filter are common used in spatial gamut mapping framework [3, 8-11]. For the same filter, scale parameters play a key role in image processing and improving the reproduction quality. Gaussian filter and bilateral filter were used to process digital original images for digital printing according to printing image processing theory in this paper. Several scale parameters of filter were chosen to study the relations between the parameters and the reproduction quality. The results indicated that the appropriate scale parameters help to improve gamut mapping quality and to improve the reproduction quality.

Introduction to several spatial filters

Digital image plays more and more important role in people's daily life and industrial production with the development of digital techniques, e.g. medical image analysis technique, astro observation technique, digital image reproduction technique, cross media transform technique and digital printing technique. However, there are many noises embedded in image data sampled from imaging sensor. In such noises, some can be perceived by people while some can't be perceived for they are influenced by the neighborhood pixels. The perceived noises usually are filtered by image noise reduction technology before reproducing the image. The unperceived noises and the relations to the neighborhood pixels have great influence on the image color reproduction especially in color gamut mapping, though they have no impact on vision results [4,9-10]. Bonnier makes a lot of research on spatial gamut mapping algorithms and develops a new mathematical framework for adaptive spatial gamut mapping which is based on multiscale image decomposition technique [1]. In the framework, firstly, it decreases noises of original image, i.e., to use specific spatial filter to decompose the original image into low-band image and high-band image. Then the corresponding gamut mapping algorithms are used for the different band images. And we get the final input image by fusing the filtered images. Gamut mapping quality and color reproduction quality are improved by using the framework. Gaussian filter, mean filter and bilateral filter are often used in the preceded image decomposition algorithms and spatial gamut algorithms [1]. So we chose the Gaussian filter and bilateral filter as the image decomposition tools and studied the influence of scale parameters on different-band images.

Gaussian Filter

Gaussian filter is a common filter used in spatial gamut mapping framework. Gaussian filter is a low-band filter that has the smoothness in frequency domain. It can be done by doing product in frequency domain. Gaussian smoothing filter is useful to restrain the noise of the normal distribution. Its width is determined by scale parameter σ, where the bigger σ is, the wider the band is so that the better the result of smoothing image is. The equation to indicate Gaussian filter can be showed as follows:

$$g(x^i, x^j) = e^{-\frac{1}{2}\left(\frac{\|x^i - x^j\|}{\sigma}\right)^2} \quad (1)$$

where, σ is scale parameter. In many spatial gamut mapping algorithms [5], original image is decomposed into high-band and low-band. The decomposition expression can be showed as follows:

$$\begin{cases} L^{*i}_{low} = \sum_{j \in I_{in}} w^j_{img} L^j_{img} \\ a^{*i}_{low} = \sum_{j \in I_{in}} w^j_{img} a^j_{img} \\ b^{*i}_{low} = \sum_{j \in I_{in}} w^j_{img} b^j_{img} \end{cases} \quad (2)$$

where, $w^j_{img}(x^i, x^j) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{\|x^i - x^j\|}{\sigma}\right)^2}$,

L^* is psychological lightness, a^* and b^* are psychological chromaticity, I_{in} is original image, σ is scale parameter, w^j_{img} is gaussian function of spatial Euclidean distance between the arguments of the location x^i of pixel i and x^j of pixel j of a nearby pixel j.

Bilateral Filter

In spatial image noise reduction process, mean filter is the simplest. However, some image details are filtered when mean filter filters the noises, which smoothes the discontinuous step change into slow change and blurs the original image. Tomasi C etc. proposed bilateral filtering to compensate the mean filter [6]. Bilateral filtering can self-adapt to the mean weight coefficient of local shape adjustment of image. Bilateral filtering can be showed as follows:

$$\hat{x}(i) = \frac{1}{C(i)} \sum_{k \in \Omega_i} y(k) e^{-\frac{|k-i|^2}{\rho^2}} e^{-\frac{|y(k) - y(i)|^2}{h^2}} \quad (3)$$

where, $C(i) = \sum_{k \in \Omega_i} e^{-\frac{|k-i|^2}{\rho^2}} e^{-\frac{|y(k) - y(i)|^2}{h^2}}$, serves as normalization, ρ and h are scale parameters. From the above equation, we can see that if the difference between the specific pixel value and the central pixel value is bigger, the corresponding weight is smaller, and the nearer from the pixel to the central pixel, the bigger the weight is, and the far from the pixel to the central pixel, the smaller the weight is.

Buades A etc. proposed nonlocal filtering method that is a modified mean filter method and it can be showed as follows:

$$\hat{x}(i) = \sum_{j \in I} w(j) y(j) \quad (4)$$

where $w(j)$ is the weight, and if $w(j)$ falls within the scope of 0 and 1, $\sum_{j \in I} w(j) = 1$. Nonlocal filtering method computes the average pixel value not in local neighborhood window but in the whole image. $w(j)$ is dependent on the similarity of the vectors, $y(N_i)$ and $y(N_j)$ which are composed of gray value. N_k is the local neighborhood whose center is pixel k. The similarity of the two vectors is measured by Euclidean distance, $\|y(N_i) - y(N_j)\|^2$. The weight is computed as follows:

$$w(j) = \frac{1}{C(i)} e^{-\frac{\|y(N_j) - y(N_i)\|^2}{h^2}} \quad (5)$$

where, $C(i)$ serves as normalization, $\frac{1}{C(i)} = \sum_{j \in I} e^{-\frac{\|y(N_j) - y(N_i)\|^2}{h^2}}$.

Bonnier etc. proposed 5D Bilateral filtering in CIE1976L*a*b* space used to reproduce printing image [1,7,12]. It can be showed as follows:

$$\begin{cases} L^{*i}_{BF} = \sum w^j_{BF} L^{*j} \\ a^{*i}_{BF} = \sum w^j_{BF} a^{*j} \\ b^{*i}_{BF} = \sum w^j_{BF} b^{*j} \end{cases} \quad (6)$$

In Eq. (6), $w^j_{BF} = \frac{d(x^i, x^j) r(p^i, p^j)}{\sum_{j \in I_{in}} d(x^i, x^j) r(p^i, p^j)}$ $d(x^i, x^j) = e^{-\frac{1}{2}\left(\frac{\|x^i - x^j\|}{\delta_d}\right)^2}$, $r(p^i, p^j) = e^{-\frac{1}{2}\left(\frac{\Delta E_{ab}(p^i, p^j)}{\delta_r}\right)^2}$ where, I_{in} is original image, $d(x^i,x^j)$ is the geometric closeness between the locations x^i of pixel i and x^j of a nearby pixel j. $r(p^i,p^j)$ is the colorimetric similarity between the colors (L^{*i}, a^{*i}, b^{*i}) and (L^{*i}, a^{*i}, b^{*i}) of pixel i and j [1].

Experiment and Discussion

In spatial gamut mapping algorithm framework, Bonnier etc. proposed one basic framework as follows [1]:

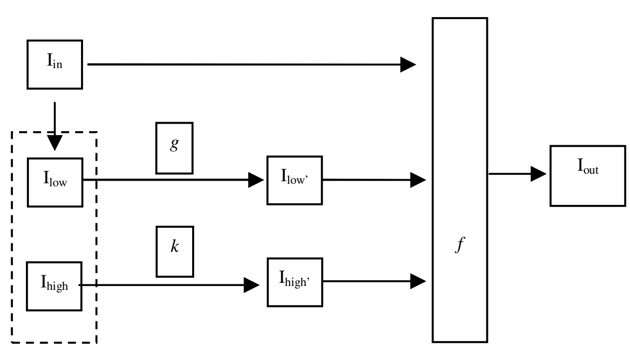
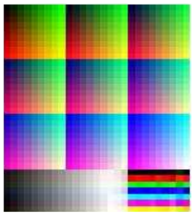


Figure 1 Framework for spatial and color adaptive gamut mapping algorithms, f, g, k are the adaptive mapping functions

Two original images, TC9.18RGB color test chart and memory color image (Fig.2), are decomposed into low-pass image and high-pass image by Gaussian filter and bilateral filter.



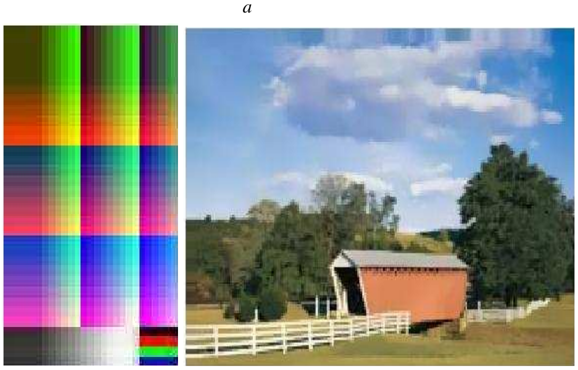
a

b

Figure 2 Original images, a is TC9.18RGB color test chart and b is memory color image

We used Gaussian filter and bilateral fitler to decompose the two above original images into high-band image and low-band image. In Gaussian filter, the scale parameter, σ, is 5, while in bilateral filter, the scale parameters, σ_d and σ_r, are 5 and 5 ΔE_{ab}. The size of both templates for the two filters, *N*, is 5 (Fig. 3).

a



b

Figure 3 Two filtered images, a is filtered by Gaussian filter and b is filtered by bilateral filter.

Different templates and scale parameters have great influences on the filtered image, i.e. low-band image. We find that the blur level of low-band image becomes less blurry with the increase of template *N* and becomes more blurry with the increase of scale parameter on condition of the fixed template in the process of filtering image using Gaussian filter. While in the process of filtering image using bilateral filter, there are three parameters to decide low-band image, i.e. template size, *N*, scale parameter σ_d and σ_r. When *N* changes from small to large, there will be mosaic phenomenon in the image edge (Fig. 4).

When *N* is fixed, the blur level of filtered image becomes more blurry with the increase of σ_r and becomes less blurry with the increase of σ_d. We find that the characteristics of the final fused image are determined by different band image when low-band image and high-band image are mapped respectively according to the framework in Fig. 1. And then the characteristics of the final input image are determined, which has influence on the reproduction quality. However, the filtered images were researched and the low-band images and high-band images were not mapped respectively in this paper. And we will pay more attention to study the influence on the final reproduction quality further.

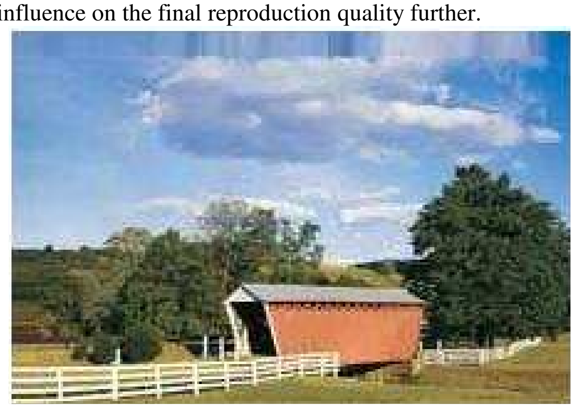


Figure 4 Low-band image when N = 11

Summary

In this paper, digital original images were processed by Gaussian filter and bilateral filter in spatial gamut mapping for digital printing according to printing image processing theory. Different scale parameters of filters were chosen to study on the relations between scale parameters and reproduction image, especially its influence on low-band image. The results showed that in spatial gamut mapping framework different scale parameters and the template size of the same filter have great influence on the low-band and high-band images. The appropriate filter parameters contribute to influence the properties of different band images then to influence the gamut mapping quality. And it helps to improve the spatial gamut mapping algorithms and improve the gamut mapping quality.

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