Applying Color Schemes to Color Images with Unilateral Filter

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Abstract: We propose a method for applying a color scheme to a color image with a unilateral filter (UF) which outputs at each pixel of an image the weighted average of neighboring colors in RGB color space. The proposed UF is a generalization of range filter which is a special case of bilateral filter. Experimental results show that the proposed method can change the colors of given images into other colors specified by given color schemes. The effectiveness of the proposed color scheme application is objectively evaluated for some color images. We also apply UF to color image enhancement such as saturation and contrast enhancement.

Keywords: Color scheme, RGB color space, Unilateral filter, Bilateral filter, Color image enhancement

1. Introduction
Color transfer [1] is one of the most important tasks in color image processing. In 2001, Reinhard et al. [1] have presented their pioneer work on color transfer, which is a method for altering the color of an image into that of another. After that, Welsh et al. [2] extended Reinhard’s color transfer method to colorization of grayscale images. Levin et al. [3] formulated the task of colorization of grayscale images as an optimization problem that can be solved efficiently using standard techniques. Tai et al. [4] proposed a modified expectation-maximization method for regional color transfer between two natural images. Hwang et al. [5] applied moving least squares method to the color transfer problem.

The above color transfer methods basically needs two images: source and target images [6]. In this paper, we propose a method for changing the color of a source image into the other color on the basis of a user-specified color scheme, which is the choice of colors used in design for a range of media [7]. That is, the proposed method requires a source image to be color-changed and a color scheme to which the colors of the source image will be changed. We formulate the procedure of color scheme application as a filter operating in a color space (RGB color space is used in this paper). We derive the proposed filter from bilateral filter (BF) [8][9], and call it unilateral filter (UF) because the weights of UF are calculated in range domain only without space domain, i.e., UF is a generalization of range filter [8] which is a special case of BF.

Recently, we have proposed an extended BF (EBF) for saturation-enhancing smoothing [10]. We formulated EBF as an intermediate filter between BF and UF, and derived UF from EBF. In this paper, we introduce the function of ad-

justment of the gamut of pixel values to that of given color schemes into UF. Experimental results show that the proposed UF can change the colors of given images into user-specified color schemes such as pastel, vivid and web216 colors.

The rest of this paper is organized as follows. Section 2 describes the proposed UF. Section 3 proposes a method for applying color schemes to color images with UF by introducing a gamut adjustment method. Section 4 shows experimental results, and discusses the applications of UF to color image enhancement. Finally, Section 5 concludes this paper.

2. Unilateral Filter
In this section, we derive a unilateral filter (UF) from bilateral filter (BF) [8][9]. Let I be an input color image whose pixel value at the position \( p \) is denoted by \( I_p \). Then BF is defined by

\[
\text{BF}(I)_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_r}(\|p - q\|) G_{\sigma_s}(\|I_p - I_q\|) I_q, \tag{1}
\]

where \( \text{BF}(I)_p \) denotes the pixel value at the position \( p \) of the output image BF, \( \| \cdot \| \) denotes the Euclidean norm, and \( W_p \) is a normalization factor:

\[
W_p = \sum_{q \in S} G_{\sigma_r}(\|p - q\|) G_{\sigma_s}(\|I_p - I_q\|), \tag{2}
\]

where \( S \) denotes the space domain, which is the set of pixel positions in an image, and \( G_{\sigma_r}(x) \) denotes the one-dimensional Gaussian kernel

\[
G_{\sigma}(x) = \frac{1}{2\pi\sigma^2} \exp \left( -\frac{x^2}{2\sigma^2} \right) \tag{3}
\]

with a standard deviation \( \sigma \). In (2), \( \sigma_r \) and \( \sigma_s \) denote standard deviations in space and range domains, respectively.
When $\sigma_r$ approaches to infinity or $\sigma_r \to \infty$, BF becomes a range filter (RF) [8] as follows:

$$RF(I_p) = \frac{1}{W_p'} \sum_{q \in S} G_{\sigma_r}(\|I_p - I_q\|) I_q.$$  \hfill (4)

where $W_p'$ is a normalization factor. Moreover, RF can be written without $q \in S$ as follows.

Let $I = \{I_k\}_{k=1}^K$ be a set of colors in $I$, i.e., $I_q \in I$ for all $q \in S$. Let $h_k$ be the frequency of $I_k$ or the number of pixels in $I$ with the $k$th color in $I$. Then we can express the pixel position-free expression of RF in (5) for applying an arbitrary user-specified color scheme to a given color image.

$$RF(I_p) = \frac{1}{W_p'} \sum_{k=1}^K h_k G_{\sigma_r}(\|I_p - I_k\|) I_k,$$  \hfill (5)

where $q \in S$ is replaced with $k$. In this paper, we generalize this pixel position-free expression of RF in (5) for applying an arbitrary user-specified color scheme to a given color image.

Let $C = \{C_i\}_{i=1}^L$ be a set of user-specified colors or a color scheme such as pastel, vivid and web216 colors. Then we propose the generalized RF as follows:

$$UF(I_p) = \frac{1}{W_p'} \sum_{i=1}^L v_i G_{\sigma_r}(\|I_p - C_i\|) C_i,$$  \hfill (6)

and denote it as unilateral filter, where $W_p'$ is a normalization factor, and $v_i$ is a weight for the $i$th color in $C$ and will be utilized for color image enhancement in Sec. 4.2. In (6), $I_p$ is an element-wise scaled and shifted version of $I_p$. Detailed descriptions of $I_p$ will be given in the next section.

3. Gamut Adjustment

Since the above filters contain the Euclidean distances between two colors, uniform color scales such as cube-root color coordinate system [11] and CIELab color space will be preferable for human perception. However, a number of color schemes are defined in RGB color space, e.g., color schemes are given in hexachromatic RGB values at colorodic.org [12]. Therefore, to be complete in RGB color space, we use RGB color space without any color space conversions.

Let $r_p$ be the R value of $I_p$, and let $r'_p$ be that of $C_i$, and let $r'_{\min} = \max_{p \in S} r_p$, $r'_{\max} = \min_{p \in S} r_p$, $r'_C = \max_{i=1}^L |r'_{C_i}|$ and $r'_{C} = \min_{i=1}^L |r'_{C_i}|$. Then the interval $[r'_{\min}, r'_{\max}]$ may be different from $[r'_C, r'_C]$. To adjust the former to the latter, we calculate the R value of $I_p$ as follows:

$$\tilde{r}_p = \frac{r'_{\max} - r'_C}{r'_{\max} - r'_{\min}} (r_p - r'_{\min}) + r'_{C}.$$  \hfill (7)

Then the resultant interval $[\tilde{r}_{\min}, \tilde{r}_{\max}]$, where $\tilde{r}_{\max} = \max_{p \in S} |\tilde{r}_p|$ and $\tilde{r}_{\min} = \min_{p \in S} |\tilde{r}_p|$, coincides with $[r'_C, r'_C]$. We also calculate the remaining G and B values of $I_p$ in the similar manner, i.e., $\tilde{g}_p$ and $\tilde{b}_p$ are obtained by replacing r’s in (7) with g’s and b’s, respectively. That is, $\tilde{I}_p = [\tilde{r}_p, \tilde{g}_p, \tilde{b}_p]$. Then, $\tilde{I}_p$ is expressed as a transformed version of $I_p$:

$$\tilde{I}_p = A \circ I_p + B,$$  \hfill (8)

where $\circ$ denotes the Hadamard or element-wise product, and

$$A = \left[ \begin{array}{c} r'_{\max} - r'_C \\ \rho_{\max} - r'_C \\ \rho_{\max} - r'_C \\ \rho_{\max} - r'_C \end{array} \right], \quad B = \left[ \begin{array}{c} r'_{C} \\ \rho_{\min} \\ \rho_{\min} \end{array} \right].$$  \hfill (9)

With the obtained $\tilde{I}_p$ by (8), we can calculate (6) to change the colors of $I$ into the specified colors $C$.

4. Experimental Results

In this section, we show experimental results of Color Scheme Application (CSA) to natural images by the proposed method. We used three color schemes provided by colorodic.org [12]: pastel, vivid and web216 colors. We also show an application of UF to color image enhancement by modifying weights in UF for desired tasks, and evaluate the effectiveness of the proposed CSA objectively.

4.1 Color Scheme Application

Figure 1 shows 300 pastel colors, of which the distribution in RGB color space is shown in Fig. 2, where we can see that the pastel colors are biased toward white color $[r'_{C}, g'_{C}, b'_{C}] = [255, 255, 255]^T$, and contain no dark colors. In that case, the interval adjustment in (7) is effective. Figure 3 shows the results of the pastel CSA. The left side shows the original images of Fish, Bird and Mountain, and the corresponding CSA images are shown in the right. The colors in the left column are changed into light colors in the right. We set parameters of UF as follows: $\sigma_r = 20$, $\nu_1 = 1$ for $l = 1, \ldots, L$ and $L = 300$.

Next, Fig. 4 shows 300 vivid colors, of which the distribution in RGB color space is shown in Fig. 5, where we can see that the vivid colors do not contain whitish and blackish colors. Therefore, it is difficult to express achromatic colors by using the vivid colors only. To alleviate this limitation on the vivid colors, we added white and black to the vivid colors. Figure 6 shows the results of the vivid CSA. The left column shows the original images of Flowers, Businessman and Snow, and the corresponding CSA images are shown in...
the right. The colors in the left column are changed into vivid colors or black or white in the right.

Figure 7 shows web216 colors, of which the distribution in RGB color space is shown in Fig. 8, where we can see that the web216 colors are uniformly sampled ones in RGB color space (note that $216 = 6^3$ and $L = 216$). Figure 9 shows the results of the web216 CSA. The left column shows the original images of Woman, Building and Dog, and the corresponding web216 CSA images are shown in the right. In Fig. 9, the difference between the original and the resultant images is not conspicuous because the web216 colors cover the gamut of RGB color space, but the latter are not strictly identical to the former. For example, we can see false contours on the cheek of a woman in Fig. 9(b), and not in Fig. 9(a).

4.2 Color Image Enhancement Next, we apply the web216 color transform to saturation/contrast enhancement. Let $r_{C_l}^c$, $g_{C_l}^c$ and $b_{C_l}^c$ be the RGB values of a color $C_l$ in the web216 colors. Then the saturation [13] of $C_l$ is defined by

$$s(C_l) = \sqrt{\frac{(r_{C_l}^c - g_{C_l}^c)^2 + (g_{C_l}^c - b_{C_l}^c)^2 + (b_{C_l}^c - r_{C_l}^c)^2}{3}}.$$  \hspace{1cm} (10)

To enhance the saturation, we propose to set the weight $v_l$ of $C_l$ as follows:

$$v_l = [s(C_l)]^\alpha,$$  \hspace{1cm} (11)

where $\alpha$ is a parameter for controlling the strength of the saturation enhancement. Figures 10(a), (c) and (e) show the results of Saturation-Enhanced (SE) web216 CSA from Fig. 9(a), (c) and (e), respectively. We set $\alpha$ as follows: $\alpha = 1$, 2 and 3 for Figs. 10(a), (c) and (e), respectively. The obtained images are more colorful than Figs. 9(b), (d) and (f) computed with uniform weight $v_l = 1$ for all $l = 1, \ldots, L$.

For contrast enhancement, we define the weights $v_l$ as follows:

$$v_l = \left| r_{C_l}^c + g_{C_l}^c + b_{C_l}^c \right| - \frac{I_{\text{max}}}{2} \frac{\beta}{\alpha},$$  \hspace{1cm} (12)
where $I_{\text{max}}$ is the maximum intensity, e.g., $I_{\text{max}} = 255$ for true (24-bit) color, and $\beta$ is a parameter. Figures 10(b), (d) and (f) show the results of Contrast-Enhanced (CE) web216 CSA, where we set $\beta = 4$. For example, we can see the effect of the contrast enhancement at the background and whiskers of the dog in Fig. 10(f). Figures 11(a)-(d) show the zoomed parts of Dog images in Figs. 9(e), (f), Figs. 10(e) and (f), respectively. The web216 CSA one in Fig. 11(b) is similar to the original in Fig. 11(a). On the other hand, SE one in Fig. 11(c) is more colorful than Figs. 11(a) and (b), and CE one in Fig. 11(d) shows the details more clearly than the others.

In such a way as to define suitable weights $v_l$ for an intended image processing task such as saturation and contrast enhancements, we can implement it by the proposed UF with the suitable weights.

### 4.3 Objective Evaluation

To evaluate the effectiveness of the proposed CSA objectively, we define a similarity measure between an image $I = \{I_p\}$ and a color scheme $C = \{C_l\}$ as follows:

$$\text{Sim}(I, C) = \frac{1}{|S|L} \sum_{p \in S} \sum_{l=1}^{L} G_{ss}(\|I_p - C_l\|).$$

(13)

where $|S|$ denotes the number of pixels in $I$. The larger $\text{Sim}(I, C)$ value means that $I$ and $C$ are closer in color.

Figures 12(a)-(c) show the similarity values for the original and CSA images in Figs. 3, 6 and 9, respectively. In each graph, the vertical axis denotes the similarity value, and the horizontal axis denotes the names of images such as Fish, Bird and Mountain. The white bars denote the original images, and the red bars denote the CSA images. For pastel and vivid CSA in Figs. 12(a) and (b), the similarity values are improved by the proposed CSA method. On the other hand, for web216 color scheme in Fig. 12(c), the similarity values are not improved, and the difference between the white and red bars is very small (note that the scale of the vertical axis in Fig. 12(c) is smaller than that of Figs. 12(a)
and (b)). The reason for this result is that the web216 color scheme is a uniform re-sampling of RGB color space.

5. Conclusion

In this paper, we proposed a unilateral filter (UF) for applying color schemes to color images, where the colors in an input image are changed into another colors based on a user-specified color scheme. We conducted experiments using three color schemes: pastel, vivid and web216. Experimental results show that the proposed method can change the colors of test images into designated colors given by color schemes. We further demonstrated the utility of UF for color image enhancement such as saturation and contrast enhancement. We also evaluated the effectiveness of the proposed color scheme application objectively on the basis of a similarity measure between an image and a color scheme.

Future work will include the applications of UF to non-photorealistic rendering such as image abstraction and stylization including character figure-like image generations.

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References


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Figure 12: Similarity to color schemes.

(a) Pastel

(b) Vivid

(c) Web216

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