Enhanced Re-coloring Method with an Information Preserving Property for Color-Blind Person

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***Abstract*--Various image re-coloring methods have been developed to enhance the perceptibility of the image for the color-blind. Recently, some methods have been proposed to produce the re-colored images that are not only visually perceptible for color deficient viewers but also look natural for normal observer. However, the methods are impractical to apply to the consumer devices due to its high complexity. Therefore, in this paper, an efficient re-coloring method that utilizes color clustering is proposed. The proposed method detects visually important region to further enhance perceptibility of re-colored images. Experimental results show that the proposed method can provide more comprehensible images for the color-blind person while maintaining the original color information.**

I. INTRODUCTION

With the explosive growth of the multimedia contents, delivering higher quality of experience (QoE) to the users becomes significantly competitive advantage in the marketplace. Since color is one of the most important factors for QoE, it becomes more crucial to provide the color information precisely. However, in contrast to people with normal color vision, color does not provide the entire information for the color-blind who experiences difficulty to distinguish between some colors.

Many works have been devoted to enhancing color perceptibility for the color-blind based on the computational model that simulates normal observers' perception of the image for the people with color vision deficiency (CVD) [1]-[3]. Although the existing methods can enhance the accessibility of an image for the color deficient viewers, the re-colored image may look unnatural for normal users. To solve this problem, Huang et al. [4] proposed an image re-coloring algorithm that considers both the naturalness and the increased perceptibility of details in the re-colored images.

However, since the aforementioned method is based on the optimization process that requires large computations, it is not applicable to consumer devices. Moreover, this method does not consider the spatial information where people perceive more important. In this paper, we propose an improved re-coloring method that adopts color clustering to speed up the optimization process and utilizes visual saliency information to enhance the re-colored image more visually perceptible.

This paper is organized as follows: In Section II, we introduce the proposed re-coloring method. Section III provides experimental results followed by the conclusion.

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II. PROPOSED ALGORITHM

A. Re-coloring Framework: Color Rotation

The CIELAB color space is adopted as a working domain in the proposed method. According to the Brettel's simulation [1], the values of each *L* and *b* between the original colors and the simulated ones for the color-blind are strongly correlated while the values of *a* are weakly correlated. In other words, the simulated color information in *a* is deteriorated significantly while the ones in *L* and *b* are retained.

To enhance the visual accessibility, it is a reasonable way to transform the color information from *a* to *b.* We calculate the transformed color by rotating the original one along with *a-b* plane given by

$$\begin{bmatrix} L' \\ a' \\ b' \end{bmatrix} = M\left(\begin{bmatrix} L \\ a \\ b \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi(\theta)) & -\sin(\phi(\theta)) \\ 0 & \sin(\phi(\theta)) & \cos(\phi(\theta)) \end{bmatrix}\begin{bmatrix} L \\ a \\ b \end{bmatrix}, \tag{1}$$

where (*L',a',b'*) and (*L,a,b*) are, respectively, the CIELAB values of the mapped color and the original color. $\phi(\theta)$ is a degree of rotation by an included angle, θ, of the original color in *a-b* plane. Such rotation based color mapping maintains both luminance and saturation after operation [3]. $\phi(\theta)$ is supposed to be the monotonically decreasing function so as to prevent the color reversal. For $\phi(\theta)$, the proposed method utilizes the formulation defined as in [3] as follows:

$$\phi(\theta) = \phi_{\max}\left[1 - \left(\frac{|\theta|}{\pi/2}\right)^{\gamma}\right]. \tag{2}$$

Our goal is to find the optimal parameters, $\phi_{\max}$ and γ, used for color mapping function (2) such that not only the visual awareness of color-blind's perception is enhanced but also the color information is preserved by minimizing the objective cost function. Following two sub-sections will present how the objective function is derived to satisfy these two properties.

B. Color Clustering and Weight Map Generation

In the optimization process which finds the optimal solution, it is too complex to use all distinct color samples contained in the original image. To reduce the number of distinct colors, the proposed method uses the octree based color quantization algorithm [5]. However, each clustered representative value is not equally important because each image pixel has different meaning in terms of not only the visually salient information but also the color distortion in the perception. To solve this problem, we adopt the weight consisting of two factors as

$$w(x_i) = w_s(x_i) + w_d(x_i)\ , \tag{3}$$

where x_i denotes the *i-th* representative color vector. w_s and w_d are the weight values related to the saliency information and the color distortion, respectively. w_s and w_d are calculated as

$$w_s(x_i) = \sum_j (SM(c_{i,j}))^2\ , \tag{4}$$

$$w_d(x_i) = \sum_j (|\, c_{i,j} - S(c_{i,j})\,|)^2\ , \tag{5}$$

where *S(·)* and *SM(·)* denote, respectively, the perceived image using the Brettel's simulation [1] and the saliency weight map proposed in [6] as a function of a color vector $c_{i,j}$. $c_{i,j}$ is the *j-th* color vectors in the *i-th* cluster with a representative value x_i.

C. Objective Cost Function for the Optimal Solution

In proposed method, two error functions such as $E_{awareness}$ and $E_{distortion}$ are introduced to get an objective cost function. The first one maximizes the visual awareness to make the color-blind's perception as comprehensible as the normal viewer's perception, which is given by

$$E_{awareness} = \sum_i \sum_j w(x_i) \cdot E_{detail}(i, j)\ , \tag{6}$$

$$E_{detail}(m, n) = (|\,(x_m) - (x_n)\,| - |\,S(M(x_m)) - S(M(x_n))\,|)^2\ , \tag{7}$$

where *M(·)* denotes the color mapping function in (1). The second one is defined for the color information preserving property so as to make the normal viewers and the color-blinds feel natural given by

$$E_{distortion} = \sum_i w(x_i) \cdot (x_i - M(x_i))^2\ . \tag{8}$$

Both error functions are normalized and combined together into an objective cost function such as

$$E = N(E_{awareness}) + \lambda \cdot N(E_{distortion})\ , \tag{9}$$

where λ denotes the user parameter and *N(·)* is normalizing function which normalizes the argument from 0 to 1. A larger λ makes the output have more reliable information preserving property and smaller λ makes the output be more comprehensible to color-blind's perception. In the experiments, we set λ to 0.2 and used conjugate-gradient method to find out the optimal solution.

III. Experimental Result and Conclusion

To evaluate the performance of the proposed method, we compared our re-coloring method with the conventional one proposed in [4]. In Fig. 1, the resultant re-colored images (RI) and its perceived images by the deuteranopic deficiency (PID) are depicted. For the PID, we used the Brettel's simulation [1]. As can be seen from Fig. 1(b), red and green colors seem to be similar. This disturbs deuteranopia from distinguishing players' uniforms.

Fig. 1. Experimental result of conventional method and proposed method

Figs. 1(d) and (f) show the RIs that are converted by the conventional method and the proposed method, respectively. Although both images are more perceptible than Fig. 1(b), Fig. 1(f) is more perceptible than Fig. 1(d) especially in the region of green uniform. This is because the region is detected as visually important region by (3) so that the contrast of that color is more enhanced than the other regions.

The proposed method also has advantage in computational cost. The proposed method requires only processing time of 2.876 seconds per image with size 500×300. This is much faster than the conventional method. Therefore, the proposed method has better performance and computational efficiency.

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