Image enhancement for dichromats using image pyramid based on saturation

Daisuke Miyazaki Hodaka Tanida
Hiroshima City University, Hiroshima 731-3194, Japan
Corresponding author: miyazaki@hiroshima-cu.ac.jp

Abstract

Dichromats recognize colors using two out of three cone cells; L, M, and S. For example, red-green color blinds cannot distinguish the color between red, yellow, and green. To extend the ability of dichromats to recognize the color difference, we propose a method to expand the color difference when observed by dichromats. We analyze the color between the neighboring pixels in chromaticity space. In addition, we employ multiresolution analysis to form the Poisson equation. Our multiresolution analysis is non-linear depending on the saturation of each pixel's color. Solving the multiresolution Poisson equation results in the color enhanced image.

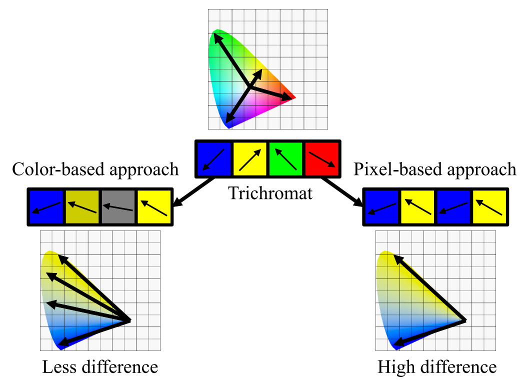

Figure 1. Schematic explanation of color-based approach and pixel-based approach.

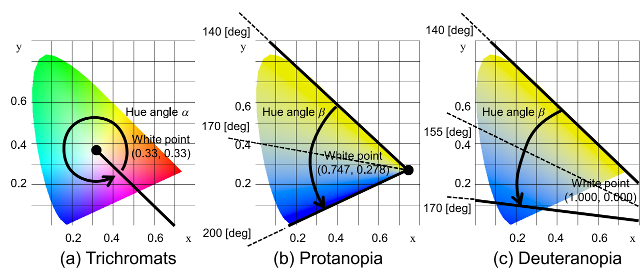

Figure 2. Definition of hue of (a) trichromats, (b) protanopia, and (c) deuteranopia.

1. Introduction

Enhancing the visibility of color image for dichromats is an important research field [1–11]. Most methods first map all pixel colors in color space such as RGB, HSV, XYZ, LMS, L*a*b*, etc., and next, they deform the color space or deform the clusters of mapped points so that it satisfies the required condition. On the other hand, our method analyzes the color difference between neighboring pixels. Namely, our method analyzes not in color space but in image space (*i.e.*, pixel coordinates). We formulate the Poisson equation so that the relative color difference between neighboring pixels will be preserved.

Some methods [13–15] also solve the Poisson equation to enhance the visibility of dichromats. These methods [13, 15] form the Poisson equation in RGB intensity space, while our method forms in xy-chromaticity space. As a result, our method exaggerates the color difference between neighboring pixels. Existing methods [14] also forms the Poisson equation in xy-choromaticity space. The method based on Poisson equation is sensitive to the close neighboring pixels. On the other hand, our method can consider far pixels due to the non-linear multiresolution analysis. The contribution of this paper is illustrated in Fig. 1.

2. Color enhancement for dichromat

In xy-diagram calcualted from CIE-XYZ value, the white color is placed in $(x, y) = (0.33, 0.33)$ for trichromats. First, the hue α of trichromats is defined as an angle defined in xy-plane (Fig. 2 (a)). The trichromatic hue α is defined as an angle around the white point $(x, y) = (0.33, 0.33)$.

The white point (the center of color confusion) of protanopia is $(x, y) = (0.747, 0.253)$ and that of deuteranopia is $(x, y) = (1.000, 0.000)$ [16]. The hue β is defined as the angle around these white points [6].

The vector $\mathbf{a}$ from the white point $(1/3, 1/3)$ of xy chromaticity to the chromaticity of image pixel is represented as Eq. (1).

$$\mathbf{a}(u,v) = \begin{pmatrix} \tilde{x}(u,v) - 0.33 \\ \tilde{y}(u,v) - 0.33 \\ 0 \end{pmatrix} . \tag{1}$$

Here, we use (u, v) for representing the x and y components of pixel position represented in Euclidean coordinates with x and y axes.

We deonte the 4-neighbor pixel position as $(u+\Delta v, u+\Delta v)$, where the integer values Δu and Δv obey $|\Delta u| + |\Delta v| = 1$. The color vectors of neighboring pixels are also calculated as Eq. (2).

$$\tilde{\mathbf{a}}(u+\Delta u, v+\Delta v) = \begin{pmatrix} \tilde{x}(u+\Delta u, v+\Delta v) - 0.33 \\ \tilde{y}(u+\Delta u, v+\Delta v) - 0.33 \\ 0 \end{pmatrix} . \tag{2}$$

We normalize these vectors and denote them as $\hat{\mathbf{a}}(u,v)$ and $\hat{\mathbf{a}}(u+\Delta u, v+\Delta v)$. We denote the cross product of these two vectors as $\mathbf{a}$.

$$\mathbf{a}(u+\Delta u, v+\Delta v) = \hat{\mathbf{a}}(u+\Delta u, v+\Delta v) \times \hat{\mathbf{a}}(u,v) . \tag{3}$$

Calculating the arcsine of $\mathbf{a}$ results in the signed angle between $\hat{\mathbf{a}}(u+\Delta u, v+\Delta v)$ and $\hat{\mathbf{a}}(u,v)$. We denote this angle as $\Delta\alpha(u+\Delta u, v+\Delta v)$.

$$\Delta\alpha(u+\Delta u, v+\Delta v) = \sin^{-1}(\mathbf{a}(u+\Delta u, v+\Delta v)) . \tag{4}$$

The difference of hue angle $\tilde{\beta}$ between neighboring pixels should be proportional to the difference of hue angle α between neighboring pixels. Namely, the Laplacian of $\tilde{\beta}$ should be the same as the Laplacian of α, scaled with a certain constant value.

$$\triangle\tilde{\beta}(u,v) = \triangle\alpha(u,v) . \tag{5}$$

The discretized representation of Eq. (5) is represented as follows.

$$\begin{aligned} &\tilde{\beta}(u,v) - \frac{1}{4}\tilde{\beta}(u-1,v) - \frac{1}{4}\tilde{\beta}(u+1,v) \\ &-\frac{1}{4}\tilde{\beta}(u,v-1) - \frac{1}{4}\tilde{\beta}(u,v+1) = \\ &\frac{1}{4}\Delta\tilde{\alpha}(u-1,v) + \frac{1}{4}\Delta\tilde{\alpha}(u+1,v) \\ &+\frac{1}{4}\Delta\tilde{\alpha}(u,v-1) + \frac{1}{4}\Delta\tilde{\alpha}(u,v+1) . \end{aligned} \tag{6}$$

The saturation a in this paper is defined as the length of the vector from the white point $(1/3, 1/3)$ to the pixel's chromaticity.

$$a(u,v) = \sqrt{(\tilde{x}(u,v) - 0.33)^2 + (\tilde{y}(u,v) - 0.33)^2} . \tag{7}$$

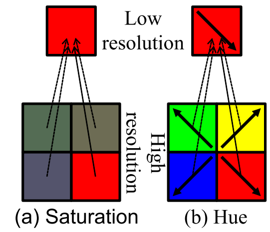

Figure 3. Choosing the pixel of maximum saturation.

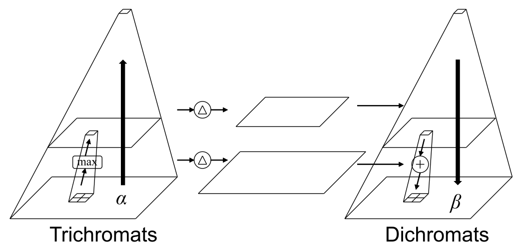

Figure 4. Hue/saturation pyramid.

The image size 512×512 is downsized to 256×256 by choosing the maximum saturation of each 2×2 block (Fig. 3). For the lower resolution image, in addition to the saturation, we also preserve the hue vector. We repeat this process until the image size becomes 1×1 (Fig. 4). Eq. (10) shows the equation to make 256×256 image from 512×512 image.

$$a_{256}(u,v) = a_{512}(\tilde{u},\tilde{v}) , \tag{8}$$

$$\mathbf{a}_{256}(u,v) = \mathbf{a}_{512}(\tilde{u},\tilde{v}) . \tag{9}$$

$$\begin{aligned} &(\tilde{u},\tilde{v}) = \underset{(\tilde{u},\tilde{v})}{\operatorname{argmax}} \, \alpha_{512}(\tilde{u},\tilde{v}) , \\ &(\tilde{u},\tilde{v}) \in \{(2u, 2v), (2u+1, 2v), \\ &(2u, 2v+1), (2u+1, 2v+1)\} . \end{aligned} \tag{10}$$

Here, a represents the saturation (Eq. (7)), $\mathbf{a}$ represents the hue vector (Eq. (1)), and $(\tilde{u},\tilde{v})$ represents the selected pixel position. Note that the "argmax" in Eq. (10) sieves the chromatic pixel. For example, if we uset the "average" instead of "argmax," the final result of downsampling and upsampling coincides with the input image that results in a meaningless process.

We denote the hue angle of the enhanced image as β. First of all, we set $\beta(u,v) = 0$ for 1×1 image. Next, we copy the hue of 1×1 pixel to 2×2 pixels (Eq. (11)).

$$\begin{aligned} &\tilde{\beta}_2(2u, 2v) = \tilde{\beta}_2(2u+1, 2v) = \tilde{\beta}_2(2u, 2v+1) \\ &= \tilde{\beta}_2(2u+1, 2v+1) = \beta_1(u,v) . \end{aligned} \tag{11}$$

The color difference $\Delta\tilde{\alpha}(u+\Delta u, v+\Delta v)$ between

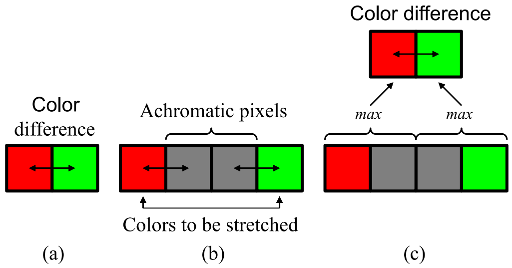

Figure 5. Specific example: (a) The color difference between 2 pixels, (b) the chromatic pixels separated by achromatic pixels, and (c) the chromatic pixels chosen from 4 pixels.

neighboring pixels is calculated as Eq. (4). The discretized Poisson equation is shown in Eq. (6). After copying β, we add the color difference between neighboring pixels, which forms Poisson equation as follows.

$$\beta_i(u,v) = \frac{1}{4}\tilde{\beta}_i(u-1,v) + \frac{1}{4}\Delta\tilde{\alpha}(u-1,v) + \frac{1}{4}\tilde{\beta}_i(u,v-1) + \frac{1}{4}\Delta\tilde{\alpha}(u,v-1) + \frac{1}{4}\tilde{\beta}_i(u,v+1) + \frac{1}{4}\Delta\tilde{\alpha}(u,v+1) + \frac{1}{4}\tilde{\beta}_i(u+1,v) + \frac{1}{4}\Delta\tilde{\alpha}(u+1,v)\,. \tag{12}$$

We repeat these processes until the image size becomes 512×512 (Fig. 4).

Here, we explain the contribution of our method. Existing methods exaggerates the color difference between neighboring pixels (Fig. 5 (a)). However, the achromatic pixel between the chromatic pixels interfere the color exaggeration (Fig. 5 (b)). Therefore, we choose chromatic pixels to calculate the low resolution image (Fig. 5 (c)). As a result, we can increase the color difference of neighboring pixels since the neighboring pixel of low resolution image is chromatic, not achromatic.

3. Experiment

We first deformed the input image to 512×512 and applied our method, and finally deformed the result to its original size.

Fig. 6 (a) shows the input image of two chromatic area separated with less chromatic area. Similar to the appearance of the dichromats (Fig. 6 (b)), the result of existing method [14] (Fig. 6 (c)) are also yellowish for both patches, which shows the color difference of these patches are insufficiently enhanced. Our result (Fig. 6 (d)) changes these

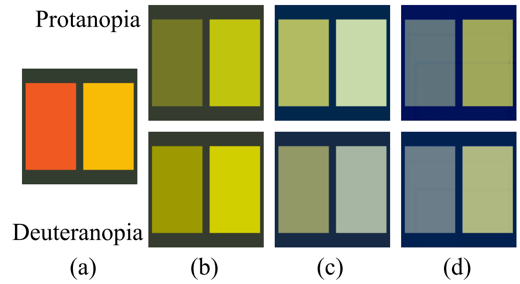

Figure 6. Result [Patch]: (a) Input image, (b) appearance of dichromats, (c) result of existing method, and (d) result of proposed method.

Table 1. Color difference of xy-chromaticity: (a) Input image, (b) appearance of dichromats, (c) result of existing method, and (d) result of proposed method.

(a)	(b)	(c)	(d)
0.144	0.021	0.077	0.177
	0.000	0.072	0.129

patches to blue and yellow, which proves the high performance of enhancing the color difference even if there is an achromatic area in the image. Table 1 shows that the color difference of our method is larger than that of existing method.

Input image is shown in Fig. 7 (a), the dichromats' appearance is shown in Fig. 7 (b), the result is shown in Fig. 7 (d), and the comparison to previous method [14] is shown in Fig. 7 (c).

Our results have higher color difference than existing method's results. Our method has high performance to exaggerate the color difference locally, and the result has sharp features, or badly speaking, has noisy artifacts. Our method has high performance to exaggerate the color difference globally, however, the whole image becomes unnatural.

4. Conclusion

In this paper, we have proposed a method that enhances the visibility of dichromats. Our method converts the color of an image so that the image will be clear for dichromats. We have formulated the color difference of trichromat as a Poisson equation and solved it to preserve the color differ-

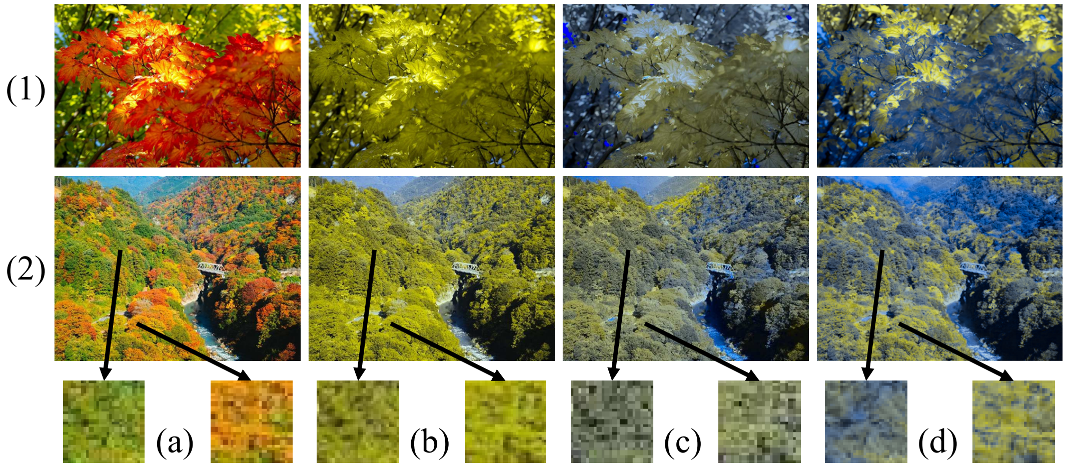

Figure 7. Result [Leaves]: (a) Input image, (b) appearance of dichromats, (c) result of existing method, and (d) result of proposed method.

ence which can also be perceived by dichromats. The Poisson equation formulated in chromaticity space exaggerates the color difference of neighboring pixels, and at the same time, it preserves the chromaticity difference of trichromats. Our multiresolution approach can exaggerate the color difference between chromatic pixels even if there is an achromatic pixel between chromatic pixel.

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