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Re-coloring approach with information preserving for color defective vision and vision correction

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Abstract

Several computer users suffer varying degree of visual impairment and hence human computer interaction is greatly affected. The vision correction method based on image pre-compensation largely outweighs the existing vision correction methods(spectacles, contact lens, LASIK etc). The blurring caused by visual is counteracted through the pre-compensation performed on images displayed on the computer screen. The visual aberration of the human eye forms the basis of the pre-compensation model, which can be measured by a wavefront analyser. However the aberration measure depends on one's specific pupil size and hence the pre-compensation model should be adjusted with varying pupil size to sustain the appropriate performance. The adjustment of the wavefront function used for pre-compensation is implemented to match the viewing pupil size. Results indicate that the images perceived and recorded by the patients were significantly improved. Also a fast re-coloring method utilises a new color transform that can enhance the perceptibility for the color blind while maintaining the recolored image as natural as possible for the normal viewer. Experimental results also verified the same.

Keywords:*pre-compensation,wavefront analyser,image vision,biometrics*

1. Introduction

Visual perception is the ability to interpret the surrounding environment by processing information that is contained in visible light,and by sensing the intensity and color of light.Human eye may have many a visual aberration.Color vision deficiency is the inability to perceive color differences under normal lighting conditions.This is due to the fault in the development of one or more sets of retinal cones that perceive color in the light.Due to this deficiency the color blind find it difficult to discriminate some color combinations. This leads to misunderstanding or missing significant information.Therefore it is required to enhance the color perceptibility of people with CVD.

2. Proposed Method:

In the proposed method, an improved CBU color detection method and a novel color transformation is introduced. In addition, by estimating an amount of change of each color, this method can be efficiently performed within the reduced number of iterations. In the following sub-sections, the overall process of the proposed method is first explained. The proposed color transformation is explained in the later sub-section.

2.1 Recoloring Algorithm

The re-coloring of image can be done using Color transformation method.This can be achieved as follows:

2.1.1 Overall Process of Proposed Re-coloring Method

Fig. 1 illustrates a block diagram of the proposed recoloring method which is performed as follows:

1. For the CBU color detection, classify all colors instead of clusters in an input image into two subsets, $O_1$and its complement set $O_2 = \overline{O_1}$. The each CBU color, X_k, of O_1 to be re-colored is obtained by an improved color detection method as follows:

$$O_1 = \{X_k | \varphi(X_k{}^o, X_k{}^d, \psi_1) = 0 \; and \; \gamma(X_k{}^o) = 1\} \quad (1)$$

where γ (.) is the proposed reddish color extraction function which is defined as

$$\gamma(X_k{}^o) = \begin{cases} 1, if\ R^o > G^o\ and\ R^o > B^o \\ 0, otherwise \end{cases} \quad (2)$$

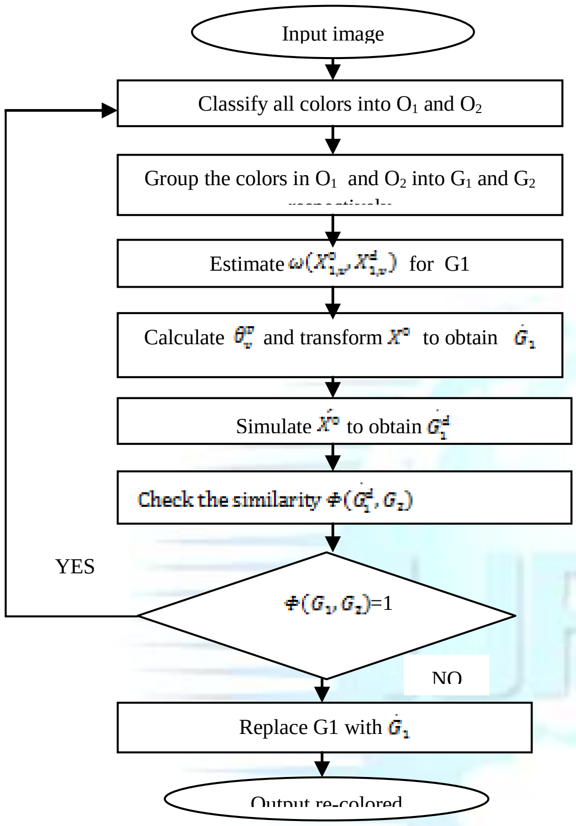


Fig. 1 Overall architecture of the proposed method.

2. Group the colors with similar intensities in O_1 and O_2 into $G_1 = \{g_{1,1}, g_{1,2}, \dots, g_{1,N_1}\}$ and $G_2 = \{g_{2,1}, g_{2,2}, \dots, g_{2,N_2}\}$ respectively, using the Fuzzy-C-means algorithm. Each cluster, $g_{u,v}$, has a representative color $X_{u,v}$ which is an RGB color obtained by the center value of the cluster.

3. To reduce the number of iterations, an extent of change, $\omega(X^0_{1,v}, X^d_{1,v})$ for each color in G_1 is approximately estimated by summing the absolute difference of each RGB component between $X^0_{1,v}$ and $X^d_{1,v}$ as follows:

$$\omega(X^0_{1,v}, X^d_{1,v}) = |R^0_{1,v} - R^d_{1,v}| + |G^0_{1,v} - G^d_{1,v}| + |B^0_{1,v} - B^d_{1,v}| \quad (3)$$

A larger $\omega(X^0_{1,v}, X^d_{1,v})$ indicates that $X^0_{1,v}$ tends to be confused with other neighboring colors. Thus, it is required to be changed more. Since $\omega(X^0_{1,v}, X^d_{1,v})$ is proportional to an amount of change, we calculate the θ^p_v that is an angle employed to a color transform matrix as follows:

$$\theta^p_v = \lfloor \alpha * \left(\omega(X^0_{1,v}, X^d_{1,v}) + \beta\right) * \theta^r_v \rfloor \quad (4)$$

where α and β are the pre-defined parameters, and $\lfloor \cdot \rfloor$ is a truncation operation to make integer angle. θ^r_v is an angle between $\pi/2$ and θ^0_v that is an angle of $X^0_{1,v}$ obtained by

$$\theta^0_v = \tan^{-1}\left(\frac{B_{1,v}}{\sqrt{R^2_{1,v} + G^2_{1,v}}}\right) \quad (5)$$

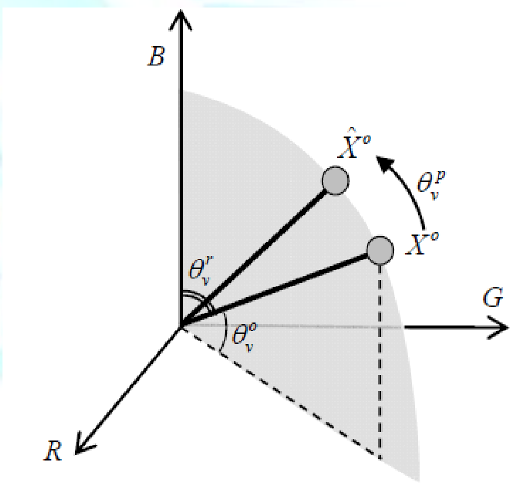


Fig. 2 Color transform that rotate the color component.

The angles θ^r_v, θ^0_v and θ^p_v are illustrated in Fig 2.

4. To enhance the perceptibility, we can obtain new color set $\acute{G}_1$ by directly multiplying RGB colors in G_1 to the proposed color rotation matrix P where only one parameter θ^p_v exists, i.e. $X^{0'} = P.X^0$. The proposed color rotation matrix, P, will be explained in detail in next sub-section.

5. In order to simulate the converted colors for the CB, obtain $\acute{G}^d_1$.

6. Check whether any $\acute{X}^d_{1,v}$ of $\acute{G}^d_1$ is discriminative to all the representative colors, $X_{2,v}$'s, of G_2 or not as follows:

$$\Phi\left(\acute{G}_1^d, G_2\right) = \begin{cases} 1, if\ \exists X_{1,v_2}^{\acute{d}}\ \epsilon\ \acute{G}_1^d, X_{2,v_2}\ \epsilon\ G_2 \mid \Phi\left(X_{1,v_1}, X_{2,v_2}, \Psi_2\right) = 1 \\ 0, otherwise \end{cases} \quad (6)$$

If $\Phi\left(\acute{G}_1^d, G_2\right) = 1$, i.e. at least, any color in $\acute{G}_1^d$ is similar to one of colors in G_2 , Steps 1-5 are iteratively repeated using the proposed color conversion matrix *P* with re-estimated and re-clustered sets, O_1 and O_2 defined by (1) until the $\Phi(G_1, G_2)$=0.Otherwise, the procedure is terminated and the re-colored image is generated by replacing the colors in G_1 with colors in $\acute{G}_1^o$. In our simulations, the process is terminated after the first iteration for most cases.

2.1.2 Proposed Color Transformation

In the conventional method, the re-colored image sometimes looks unnatural for both normal people and the CB because the unperceivable color difference, $\left|R_k^o - R_k^d\right|$, is subtracted from reddish colors and compensated to the greenish and bluish colors, iteratively. Consequently, the ratio of reddish to greenish colors is not preserved.We propose a new color transform which rotates the indistinguishable colors in the direction of perceivable color to make the re-colored image natural for normal viewer as well as perceptible for the CB. In Fig. 2, an example of color rotation is depicted. In order to formulate the rotation operation, we utilize the unit quaternion which is related to the spatial rotations in three dimensions. With the quaternion, the color conversion matrix is calculated by

$$P = \begin{bmatrix} 1-2(q_2^2+q_3^2) & 2(q_1q_2-q_0q_3) & 2(q_0q_2+ \\ 2(q_1q_2+q_0q_3) & 1-2(q_1^2+q_3^2) & 2(q_2q_3- \\ 2(q_1q_3-q_0q_2) & 2(q_0q_1+q_2q_3) & 1-2(q_1^2 \end{bmatrix}$$

where q_i's are quadruple data forming a quaternion. When an rotation θ and a RGB color value,$X^0 = (R^0, G^0, B^0)$, are given, each is calculated as follows:

$$q_0 = \cos(\theta/2)$$
$$q_1 = \sin(\theta/2)\cos(R^0)$$
$$q_2 = \sin(\theta/2)\cos(G^0)$$
$$q_3 = \sin(\theta/2)\cos(B^0)$$

2.2 Pre-Compensation algorithm

The purpose of pre-compensating the images to be displayed on the screen is to counteract the blurring and degradation caused by visual aberrations of computer users. Our method achieves this pre-compensation through deconvolution.

2.2.1 Deconvolution

Deconvolution is commonly used to restore the original image from a degraded image with a known degradation model. However, instead of applying deconvolution to a degraded image, deconvolution here is to be implemented at the source of the image.In the context of our vision correction for computer users, Human eye can be described as a linear shift invariant (LSI) system, by its impulse response called PSF.Therefore, we can describe imaging in the human eye by convolution of PSF with displayed image on the screen. Thus, the convolution result of PSF,h(x,y), with the input image, displayed on the monitor,I(x,y) , forms the retinal image,R(x,y):

$$R(x,y) = I(x,y) * h(x,y) \quad (7)$$

where * denotes convolution. Fig.1 can depict this process clearly. Before viewing a digital image it can be manipulated in advance,PC(x,y).

$$PC(x,y) = R(x,y) * h^{-1}(x,y) \quad (8)$$

where *PC(x,y)* is pre-compensated image. This process, equation 2, is called deconvolution, which would perceived undistorted viewing with patient PSF,RI(x,y).

$$RI(x,y) = \{ R(x,y) * h^{-1}(x,y) \} * h(x,y) \quad (9)$$

where *RI(x,y)* is patient's retinal image.

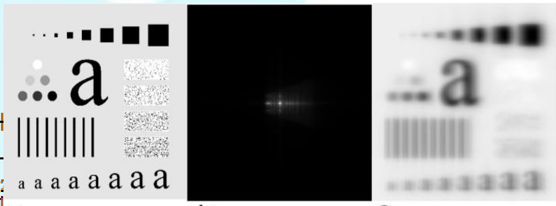

(a) (b) (C)

Fig. 3 Image formation as a convolution (a)displayed image, (b) patient PSF (c)perceived image.

2.2.1.1 PSF of the human eye

The PSF of the target eye should identify to perform the pre-compensation method. Wavefront analyzers based on Hartmann-Shack principle could measure the wavefront aberration of the human eye. The PSF of any optical system, as well as human eye, could be found indirectly through wavefront aberration function, W(x,y). The pupil function, P(x,y) , combines all the information about optical imaging properties of system and is defined as

$$P(x,y) = A(x,y)e^{-j2\pi\omega t.w(x,y)/\lambda} \tag{10}$$

where A(x,y) is the amplitude attenuation at the pupil plane, usually given a value equal to one, n is index of refraction, λ is wavelength of light in vacuum, and the PSF is calculated as:

$$OTF(fx,fy) = P(x,y) * P'(-x,-y) \tag{11}$$

$$PSF\ (x,y) = F^{-1}\{\ OTF\ (fx,fy)\ \} \tag{12}$$

where OTF is optical transfer function, P'(-x,-y) is complex conjugate of pupil function and F^{-1} { } denotes inverse Fourier transform. Therefore,OTF is autocorrelation of pupil function .

2.2.1.2 Zernike polynomials

Zernike polynomials are two-dimensional orthogonal functions defined over the unit circle. This defines the optical properties of systems with circular apertures. They have been used in optical engineering for almost 70 years . Usually the Zernike polynomials have been used to describe the aberration function of the human eye . Wavefront analyzers could calculate coefficients for any Zernike polynomials terms. Having the wavefront aberration function,W(x,y) , the PSFcould be computed from equations (4), (5) and (6); thus, making it possible to employ PSF in the deconvolution process.

$$PC(x,y)=F^{-1}\{\frac{F\{R(x,y)\}}{F\{h(x,y)\}}\} \tag{13}$$

This is inverse filtering in frequency domain, and is equivalent to two-dimensional deconvolution in spatial domain. It should be mentioned that according to equation (6), the denominator of equation (7) is the OTF of the patient eye. However utilizing this inverse filtering has a lot of limitations, e.g. where any pixels in the OTF has a value equal or near zero, the whole fraction will rise to a great value, affected by noise. Therefore, as a common approach to solve this problem minimum mean square error (MMSE) filtering is used .

$$PC(fx,fy) = \left[\left(OTF(fx,fy)\right)^{-1}.\frac{|(OTF(fx,fy))^2|}{|(OTF(fx,fy))^2|+K}\right].I(fx,fy) \tag{14}$$

where *Pc(fx,fy)*, is the Fourier transform of the precompensated image, K is usually a constant value to regulate the noise effect and *I(fx,fy)* is the Fourier transform of initially input image. Equation (8) also known as Wiener filter, and this process is called Wiener deconvolution, if we calculate the inverse Fourier transform of the *PC(fx,fy)* , which gives *PC(x,y)* .

2.2.2 Pupil Size of Computer Users

When the aberration of the human eye, represented as a set of Zernike coefficients, is calculated, the pupil size in which the Zernike coefficients and functions are defined must be specified. Therefore, the pre-compensation introduced above is strictly associated with a particular pupil size. However, in practice the pupil size of the human eye is quite sensitive to illumination. Once the ambient illumination increases, the pupil may quickly constrict. It has been reported that the mean pupil size of 250 volunteers under room light was 3.86mm and in near-total darkness was 6.41mm.

2.2.3 Readjustment of Pre-compensation

If the user's pupil size at the time of viewing the images is the same as the pupil size during the measurement by the wavefront analyzer, the pre-compensation model can maintain its performance without readjustment. Otherwise the pre-compensation model should be adjusted. In this paper, the transformation method proposed by Campbell is used to recalculate the Zernike coefficients and rebuild the pre-compensation model from the original one to the new one corresponding to the current (viewing) pupil size. The basic idea in Campbell's method is that the same area of a surface will be described by different sets of Zernike coefficients if a different aperture radius is used to find the coefficients. With the information available only in the form of a set of Zernike coefficients related to a given aperture radius, Campbell developed a conversion matrix [C], that will properly convert the vector of one Zernike coefficient set |c| corresponding to an original aperture radius to the vector of another Zernike coefficient set |c'| corresponding to a new aperture radius as:

$$|c'| = [c]|c| \tag{15}$$

The conversion matrix [c] is derived as :

$$[c] = [P]^T[N]^{-1}[R]^{-1}[\eta][R][N][P] \tag{16}$$

where the "*T* " and " -1 " superscripts mean matrix transposition and inversion respectively. Besides,[P] represents the permutation matrix, [N] indicates the normalization matrix,[R] indicates the weighting coefficient matrix and[η] indicates the powers of ratio matrix .It must be noted that attempting to reshape the aberration at a pupil size that is larger than the measured one is not feasible since the aberration information outside the measured pupil area is unknown. In our context, this is not a problem as the aberration measurement is always conducted under dark illumination while computer users usually view the screen under regular room light.

3.Experimental Results

In this section, various simulation results are illustrated to verify the usefulness of the proposed method. Since it is difficult to gather various types of the color-vision impaired,the computerized simulation of CB vision is utilized to evaluate the re-colored images generated by the re-coloring method. Both quantitative and qualitative measurements are evaluated in our experiments. For the objective evaluation, we measure the naturalness, E_{nat} , and the perceptibility, E_{per} , of the re-colored images as follows:

$$E_{nat} = \sum_i ||X_i^o - \acute{X}_i^o||^2$$

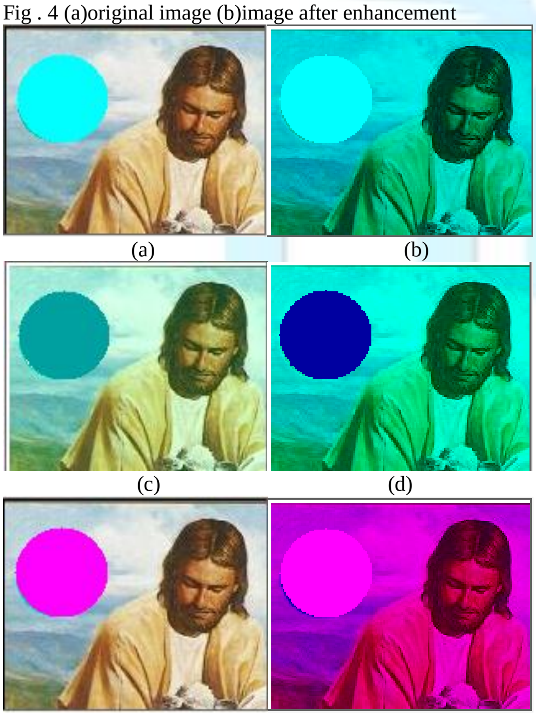
$$E_{per} = \sum_i \sum_j (||X_i^o - X_j^o|| - ||\acute{X}_i^d - \acute{X}_j^d||)^2$$

In this sub-section, we demonstrate some experimental results to present the excellence of the proposed color detection method.

This section also shows the image enhancement by applying suitable threshold.This is explained in Fig.4.This is done by means of pre-compensation of images.

(a) (b)

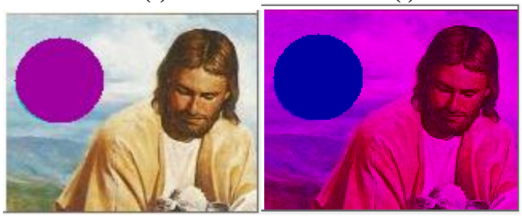
Fig . 4 (a)original image (b)image after enhancement



(a) (b)

(c) (d)

(e) (f)



(g) (h)

Fig.5 Re-colored image for protanopes and deuteranopes.(a),(e) original image (b),(f)image as perceived by the color blind (c),(g)image as perceived by the normal user after recoloring (d),(h)image as perceived by the color blind after recoloring

4.Performance Analysis

It is shown form Fig. 6 that the quantitative quality of the recolored image is evaluated according to the color detection methods in terms of the perceptibility and the naturalness. The smaller cost indicates the higher performance. As illustrated in Fig. 6, our proposed color detection method produces better quality of the re-colored images than the conventional one regardless of any re-coloring method. As a result, visually appealing re-colored images are generated for both the color blind and normal vision people, respectively.

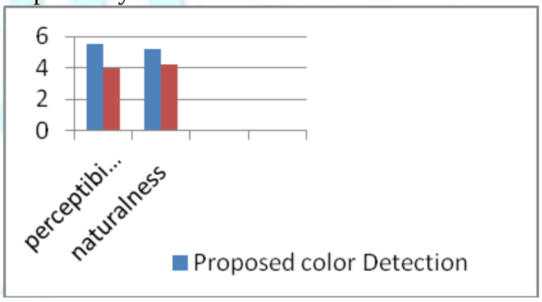


Fig.6 Quantitative performance comparison of the color detection methods.

5. Conclusion

In this paper, we proposed the computationally efficient recoloring method based on a novel color transform for the CB who cannot distinguish some color differences. In the proposed method, the CBU colors are first accurately estimated by employing an improved color detection method, and an amount of change for each color is estimated to reduce the number of iterations in the re-coloring process. With an extent of the color change information, re coloring is performed by rotating the CBU colors in the direction of CB perceivable colors. Since the color transform was designed to maintain the ratio of reddish colors to greenish colors, it preserves the naturalness of the original images and enhances the color perceptibility. Experimental results showed that the proposed re-coloring method outperforms the conventional methods both subjectively and objectively with reduced computational load. In order to improve the visual perception of computer users with visual aberrations, this paper proposes a correction method based on image pre-compensation.

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