# PERCEPTUALLY-ADAPTIVE COLOR ENHANCEMENT OF STILL IMAGES FOR INDIVIDUALS WITH DICHROMACY

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## ABSTRACT

Dichromacy is a medical condition in which a person is unable to distinguish all colors of the spectrum accurately due to the absence of one cone type within the retina of the eye. No known cure exists for dichromacy so techniques have been created to help improve color perception among affected individuals. This paper investigates a novel perceptually-adaptive technique for enhancing details within still images for persons suffering from dichromacy. A non-linear hue remapping is adaptively applied to the still images to improve color differentiation while preserving the aesthetics of the images. Simulations show that the enhanced images preserve visual detail and maintain the aesthetics of the original image.

***Index Terms***— dichromacy, perceptually-adaptive, color enhancement

Statistics show that color vision deficiencies affect 8.7% of the male population and 0.4% of the female population [5]. Dichromacy is a form of color vision deficiency that severely affects an individual's ability to differentiate hues. Dichromacy has no known cure. Previous research and development has focused on ways to help individuals cope with the medical condition. For example, software tools exist to remap colors in images to improve color differentiation [8, 9]. Such tools allow individuals with severe color vision deficiencies to view color-corrected images. Also, tools and techniques exist to simulate the effects of dichromacy on images and websites for individuals who do not suffer from color vision deficiences [7, 6, 1, 2]. Such tools and techniques allow individuals to verify the accessibility of images and webpages. One problem with current color correction techniques is that they do not adapt to the underlying color characteristics of the image. This fixed approach to color correction often results in images that do provide reasonable color differentiation but does not preserve the aesthetics of the original color image. Therefore, we propose a perceptually-adaptive approach to color enhancement for dichromats that utilizes the underlying hue characteristics to improve both color differentiation and preserve image aesthetics.

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## 1. COLOR VISION DEFICIENCIES

In the discussion of color vision deficiencies, it is important to first understand the biological characteristics of the human eye. The human retina normally consists of two types of photoreceptors cells: i) rods, and ii) cones. While the rods within the retina respond to dim light, the cones respond to bright light and are responsible for color vision. As such, the cones are crucial to the way color images are produced in the human vision system. In the normal human retina, there are three types of cones which are particularly sensitive to different light spectra. The three types of cones can be classified as L, M, and S cones, which are maximally sensitive to long, medium, and short wavelengths. It is through the combined activation of these cones at different levels that allow for the recognition of different colors within the visible spectrum.

A typical color vision deficiency is dichromacy, where one of the three types of cones are either malfunctioning or absent. In such a case, color is reduced to a two-dimensional representation as opposed to the normal three-dimensional representation. There are three types of dichromacy deficiencies: i) protanopia, ii) deuteranopia, and iii) tritanopia. Protanopia is a color deficiency where the L cones are absent or defective. Individuals suffering from protanopia see red hues appear dark and have great difficulty discriminating between red and green hues. Deuteranopia is a color deficiency where the M cones are absent or defective. Individuals suffering from deuteranopia have difficulty discriminating between red and green hues. Therefore, protanopia and deuteranopia are often referred to as red-green color blindness. Finally, tritanopia is a rare color deficiency where the S cones are absent or defective. Individuals suffering from tritanopia have difficulty discriminating between blue and yellow hues. Therefore, tritanopia is often referred to as blue-yellow color blindness. The three types of dichromacy deficiencies are illustrated in Fig. 1.

## 2. MODELLING OF COLOR VISION DEFICIENCIES

To visualize the effect of color vision deficiencies such as dichromacy deficiencies on image formulation in the human vision system, it is necessary to simulate how images would

**Fig. 1**. Dichromacy deficiencies; Top-Left: Colors of the rainbow, Top-Right: Simulation of colors viewed by a protanope, Bottom-Left: Simulation of colors viewed by deuteranope, Bottom-Right: Simulation of colors viewed by tritanope

appear to those suffering from such deficiencies. One commonly used approach to simulating color vision deficiencies is based on the LMS cone space [1, 3]. The LMS cone space is a three-dimensional space based on the biological characteristics of the photoreceptors in the human retina and represents color relative to the excitation of the L (long), M (medium), and S (short) cones. To convert a standard RGB (red-green-blue) image into the LMS cone space, it is first converted to the XYZ tristimulus color space and then converted to the LMS cone space. Since both conversions can be represented by linear transformation matrices, they can be combined to yield a single matrix that converts an image from the RGB colorspace to the LMS cone space. The RGB-to-LMS transformation can be expressed as follows [4]:

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} RL & GL & BL \\ RM & GM & BM \\ RS & GS & BS \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

Once in the LMS cone space, the information pertaining to the different types of cones can be altered to simulate the cone responses of individuals with dichromacy deficiencies. For example, the L, M, and S dimensions are altered individually to simulate the color information loss incurred by protanopes, deuteranopes, and tritanopes respectively. The altered image is finally converted from the LMS cone space back to the RGB color space. The resulting image simulates how the RGB image is perceived by those suffering from dichromacy.

## 3. COLOR-SPACE TRANSFORMATION

With a clearer understanding on the biological characteristics of the human eye and the cause of dichromacy deficiencies, it is possible to formulate methods for enhancing the perceptual quality of an image. The focus of the proposed method is to enhance an image such that details are accentuated for better perception by those suffering from dichromacy, as well as improving the aesthetic appeal of an image.

The main difficulty encountered by those suffering from dichromacy is the inability to differentiate between certain hues. Therefore, an effective approach to color enhancement is to alter the hue distribution of an image in such a way that hue discrimination is improved and details within an image become more perceivable by those suffering from dichromacy. To preserve the aesthetic properties of the original image, it is also desired that other characteristics of the image such as illumination and saturation are left unchanged. To accomplish this goal, the image is converted from the RGB colorspace to the HSV colorspace. An visualization of the HSV color space is illustrated in Fig. 2.

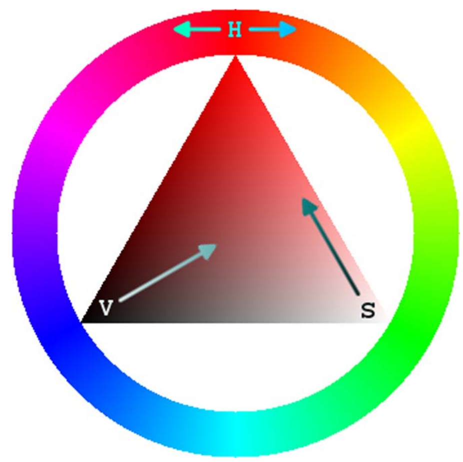


**Fig. 2**. HSV color space

By converting the image from the RGB colorspace to the HSV colorspace, the hue of the colors in the image can be altered without affecting the saturation and brightness of the image. The advantage of this approach is that the aesthetic properties of the original image is preserved while the hue distribution can be enhanced to accentuate the details within the image.

## 4. ADAPTIVE NON-LINEAR HUE REMAPPING

Once the hue space can be isolated, the goal of the proposed algorithm is to remap the hue distribution in such a way that the details that are easily perceived by individuals with trichromatic vision can also be easily perceived by individuals with dichromatic vision. A visualization of the hue space is illustrated in Fig. 3. It can be observed that the hue space wraps around in a circular fashion.

Depending on the type of dichromacy suffered by an individual, it is very difficult for an individual to distinguish between certain hues as the range of perceivable hues is decreased when compared to those with trichromatic vision. For


**Fig. 3**. Hue space

example, those suffering from deuteranopia are unable to distinguish between the green-yellow-red range of the spectrum.

One simple method of improving hue discrimination within this indistinguishable hue range is to perform a circular hue shift such that hues that can be easily discriminated are used to represent this hue range. One of the major disadvantages of this technique is that such a uniform hue shift results in highly unnatural images. The reason for this is that most of the hues that are actually correctly recognized by those suffering from dichromacy are now misrepresented by the hue shift. Therefore, while details may be accentuated using a simple hue shift, the original aesthetic feel of the image is not well preserved. Similarly, linear hue compression can improve the hue discrimination in indistinguishable hue ranges but the uniform nature of such transforms result in significant loss of dynamic range in the distinguishable portions as well as unnatural color remappings given the fixed redistribution. Therefore, a different approach where colors are re-distributed different depending on the hue ranges is desired.

In the proposed method, a number of steps were performed to enhance hue discrimination in the indistinguishable hue ranges while preserving the aesthetic feel of the original image as viewed by an individual with trichromatic vision. First, the hue space was rotated such that the two hues that were indistinguishable are at the front of the spectrum while the third hue is at the end. For example, in the case of protanopia and deuteranopia, the hue range containing the red and green hue components are rotated to the front of the spectrum while the blue hue range is at the end. A non-linear hue remapping is then performed on the rotated hue space in the form of a power transformation function:

$$f(h) = h^{\phi} \tag{2}$$

where $\phi$ is the control parameter for the nonlinear hue remapping. What this effectively does is a number of things. First, the range of hues that are indistinguishable (e.g., red-yellow-green range) are stretched over a wider dynamic range, thereby increasing the hue discrimination for that range of hues. Secondly, the range of the hue that is distinguishable from the rest of the spectrum (e.g., blue) is compressed, thereby having part of its dynamic range being redistributed to the indistinguishable range. By using a nonlinear remapping function, the range re-distribution is varied over the spectrum and therefore allows for greater flexibility in maintaining the aesthetic feel of the original image. For example, in the case of protanopia and deuteranopia, the red-yellow-green hue range is stretched such that the resulting green hue range consists of a smooth transition from yellow to blue when viewed by an individual suffering from these color deficiencies, making it easy to distinguish between these hues. However, the yellow hues that are correctly viewed by those with such color deficiencies are well-maintained to provide a similar aesthetic feel. Furthermore, the nonlinear transformation allows the range of blue hues to be compressed but still maintain a distinguishable dynamic range. After the nonlinear hue remapping, the hue space is rotated back to its original position. As such, no hue shift is performed and the aesthetical feel of the original image is better preserved.

It is important to note that the nonlinear hue remapping scheme presented above has a parameter $\phi$ that needs to be set. The parameter $\phi$ controls the curvature of the power function. In the aforementioned nonlinear hue remapping function, the value $\phi$ must be less than one such that the indistinguishable hue range is stretched while the remaining hue range is compressed in a nonuniform manner. A simple approach is to set the control parameter at a fixed value. However, the main problem to this approach is that hue distribution varies greatly from one image to another. For example, an image may consists of only blue hues. Therefore, a fixed value of $\phi$ will compress the blue hue range and stretch the other hue ranges without any perceptual benefit. This leads to an overall loss in perceptual quality. As such, it is necessary to dynamically adjust the value of $\phi$ based on the underlying image content to achieve enhanced perceptual quality.

An effective approach to determining a suitable value of $\phi$ is to analyse the hue distribution of the image. If the hue distribution resides mostly in the indistinguishable range, then the value of $\phi$ should be increased to stretch this range to improve hue discrimination and attenuate image details. However, if the hue distribution resides mostly outside this range, then the value of $\phi$ should be decreased to preserve the original hue distribution. In the proposed method, the control parameter $\phi$ is dynamically adjusted based on the contribution of the hues within the distinguishable hue range to the overall image, as expressed by:

$$\phi = \phi_{\min} + (\phi_{\max} - \phi_{\min})(n_d/(n_i + n_d)) \tag{3}$$

where $\phi_{\min}$ and $\phi_{\max}$ are the minimum and maximum values of $\phi$, and $n_d$ and $n_i$ are the number of pixels that fall within the distinguishable and indistinguishable hue ranges respectively. For example, in the case of protanopia and deuteranopia, $n_i$ is the number of pixels that fall within the hue range consisting of red and green hue components and $n_d$ is the number of pixels that fall within the hue range consisting of blue hue components. The presence of $\phi_{\min}$ and $\phi_{\max}$ adds an additional control factor to prevent over-stretching and under-stretching of the hue ranges respectively.

## 5. TESTING METHODS

To test the effectiveness of the proposed method, three different test images were processed using the proposed color enhancement algorithm as tuned for those suffering from deuteranopia. Both the original images and the enhanced images were then processed using the color deficiency model presented in Section 2 to simulate how the images would be perceived by an individual suffering from deuteranopia. Therefore, in the case of deuteranopia, the image data in the M space is altered to reflect color information loss by the M cones in the human retina.

## 6. EXPERIMENTAL RESULTS

The enhanced images produced by the proposed method as viewed by a simulated deuteranope is shown in Figure 4, Figure 5, and Figure 6. It is evident that the enhanced image show less perceptual information loss than the original image when viewed by an individual suffering from deuteranopia. For example, it is noticeably easier to recognize the berries from its surroundings within the enhanced image in test 3 and the roses from its surroundings in test 2 than in the original image as viewed by a deuteranope. Furthermore, it can be observed that the aesthetic appeal of the original image as viewed by an individual with trichromatic vision is mostly preserved in the enhanced image. This is most evident in test 1 and test 2, where the original image when viewed by a deuteranope appears dull while the enhanced image preserves the vibrancy of the original image when viewed by an individual with proper color vision. Therefore, the improved perceptual detail and aesthetic preservation in the enhanced images demonstrate the effectiveness of the proposed method.

## 7. CONCLUSIONS

This paper introduced a novel perceptually-adaptive approach for color enhancement of still images for persons suffering from dichromacy. By utilizing the hue characteristics of the underlying image content, the hue component of the image was adaptively remapped in a non-linear fashion to improve color differentiation while preserving the aesthetics of the image. Simulations demonstrate the effectiveness of the proposed color enhancement method in producing enhanced images that preserve visual detail and maintain the aesthetics of the original image.

## 8. ACKNOWLEDGMENT

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**Fig. 4**. Test 1; Left: original, Middle: simulated deuteranope view, Right: simulated deuteranope view after enhancement

**Fig. 5**. Test 2; Left: original, Middle: simulated deuteranope view, Right: simulated deuteranope view after enhancement

**Fig. 6**. Test 3; Left: original, Middle: simulated deuteranope view, Right: simulated deuteranope view after enhancement

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