Modifying Images for Color Blind Viewers

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***Abstract*—This paper explores different methods of adjusting images such that viewers suffering from dichromacy are able to better perceive image detail and color dynamics. In particular, we select deuteranopia, a type of dichromacy where the patient does not naturally develop "green", or medium wavelength, cones in his or her eyes. This comparison considers three algorithms for this type of image processing; they are LMS daltonization, color contrast enhancement, and LAB color adjustment. Two separate processing algorithms serve to evaluate the effectiveness of these adjustment techniques. First we simulate deuteranopia on both the original and processed images to see the algorithm's effects from the perspective of a color blind viewer. Second, we calculate the delta E value between the two images in order to assess how greatly the image changes from the perspective of a non-color blind viewer. Color contrast enhancement provides the greatest advantage to color blind viewers, but also changes the image most significantly for non-color blind viewers. LAB color adjustment has the least effect in both cases, and LMS daltonization falls in between the other two techniques.**

I. INTRODUCTION

Color blindness affects roughly ten percent of human males. It is possible for a woman to be color blind, however, because the main form of color blindness manifests as a defect in the X chromosome, most color blind individuals are men. Of those diagnosed with color blindness, over ninety-nine percent of them suffer from some sort of red-green deficiency, where they are unable to distinguish well between red and green.

Dichromacy is a general term for a person's lack of ability to perceive one of the three wavelength groups perceptible to non-color blind persons. The three types of receptor cones in the normal human eye are often referred to as red, green, and blue (RGB); it is more correct to describe them as receptors of long, medium, and short (LMS) wavelengths.

Three types of complete dichromacy exist. Protanopia is an absence of red cones, deuteranopia is an absence of green cones, and tritanopia is an absence of blue cones. This paper considers the case of deuteranopia, and explores methods of correcting images such that a person suffering from deuteranopia is able better perceive image detail and color dynamics. All simulation and calculation is performed in Matlab 2011b.

II. SIMULATING DEUTERANOPIA

In order assess the effectiveness of the algorithms in question, we first must develop a method of simulating an image through the eyes of a person suffering from deuteranopia.

[1] suggests a fairly simple conversion method. The image is first converted into the LMS color space. Since Matlab's imread function reads in images in the RGB color space, we must convert from RGB to LMS. Fortunately, this is a simple linear matrix multiplication operation.

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 17.8824 & 43.5161 & 4.11935 \\ 3.4565 & 27.1554 & 3.86714 \\ 0.02996 & 0.18431 & 1.46709 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

This operation, applied to every pixel of the image, yields a new set of pixels whose information is now defined for the LMS color space.

Now that the image exists in the LMS color space, we remove information associated with the M cone and replace it with information perceived by L and S cones. It can be seen below that the M information is removed, however the M component of the new pixel is not empty. It is filled with a proportion of information from the L and S cones because that M light is seen by the eye but perceived as being from the L and S wavelength bands instead. This requires another matrix multiplication operation.

$$\begin{bmatrix} L_{deut} \\ M_{deut} \\ S_{deut} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0.49421 & 0 & 1.24827 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} L \\ M \\ S \end{bmatrix} \quad (2)$$

Now that the medium wavelength information has been removed from the image and the new M pixel filled appropriately, deuteranopia has been simulated. In order to view the results, we simply convert back to the RGB color space by once again performing matrix multiplication on each LMS pixel. This time the matrix is the inverse of that found in Equation 1.

III. DELTA E

The second tool required for assessing the impact of color blindness compensation techniques is Delta E. Delta E is a popular metric for measuring color difference. We choose this metric in order to help determine the extent to which the algorithm in question changes the original image, i.e. negatively affecting the image as seen by viewers without color blindness.

The Delta E algorithm is another simple operation, calculated for each pixel of an image. This function takes in two images in order to evaluate the color difference between them. Both images are first converted from RGB to the LAB color space. Matlab has a built in function which allows the user to convert between these two color spaces; no such function exists for the prior RGB to LMS conversion.

LAB pixel values hold lightness, L, and color coordinates A and B, based on a compressed version of the standard XYZ color coordinate space. The actual Delta E value for each pixel is calculated as follows.

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (A_2 - A_1)^2 + (B_2 - B_1)^2} \qquad (3)$$

A recent study in [2] suggests that the Delta E value for a just noticeable difference is approximately 2.3. This will be worthy of consideration while assessing our results.

IV. The Compensation Algorithms

[1], [3], and [4] suggest algorithms to adjust images in such a way that color blind viewers are able to discern detail originally lost due to their color blindness. Many more methods exist besides these, however we choose to examine only these three in order to provide useful results while still maintaining a reasonably limited scope for the project. While they all ultimately strive to compensate for color blindness, each is performed in a different color space and thus provides some amount of theoretical diversity.

A. LMS Daltonization

LMS daltonization in [1] uses the information lost in the deuteranopia simulation in order to improve the original image. The lost information from the original simulation is converted from the LMS color space to RGB and then mapped to wavelengths perceptible to the viewer, in this case long and short wavelenghts, mostly red and blue. This lost information, now shifted to colors the viewer can see, is then added back to the image.

Section II of this report shows how to convert from LMS to RGB color spaces. The lost information, now as RGB pixels, is mapped using the following matrix multiplication.

$$\begin{bmatrix} R_{map} \\ G_{map} \\ B_{map} \end{bmatrix} = \begin{bmatrix} 1 & .7 & 0 \\ 0 & 0 & 0 \\ 0 & .7 & 1 \end{bmatrix} * \begin{bmatrix} R_{lost} \\ G_{lost} \\ B_{lost} \end{bmatrix}$$

It is clear that this operation does nothing to the lost red and blue information, but shifts the lost green partially into red and partially into blue. These new mapped RGB components are added to the original image. Finally, the image is checked and concatenated to ensure that no pixel value rises above one or below zero.

B. RGB Color Constrasting

Suggested by [3], this algorithm adjusts an image's RGB values in order to enhance contrast between red and green and, in general, make green pixels appear to be bluer. The process begins by halving every pixel in the original image in order to provide room for pixel values to be increased.

For each pixel, three operations occur. The first step is to increase the value of the pixel's red component relative to pure red. Reds further from pure red are increased significantly while reds already very close to pure red are only marginally increased. The green component of each pixel is manipulated next by applying exactly the same logic as that used on the red components. Finally, for pixels that are mostly red, the value of the blue component is reduced. For pixels that are mostly green, the blue component is increased.

Both this and the following algorithm lack a clear theoretical basis. The scaling values here are determined through experimental evidence found by [3] through trial and error with color blind subjects. The exact scaling values can be found at [3] or within this project's source code, available online.

C. LAB Color Correction

This algorithm, suggested in [4], endeavors to modify reds and greens of an image to increase color contrast and clarity for a color blind individual. What sets this process apart from RGB Color Contrasting is that it is performed in the LAB color space.

The algorithm generally operates as follows. The original image pixels are converted from RGB to LAB color space. The first operation is on each pixel's A component, where a positive A means it is closer to red and negative A means it is closer to green. Just as in RGB Color Contrasting, this A value is adjusted relative to its maximum, making positive values a bit more positive and negative values a bit more negative. Again, in each pixel the B component is adjusted relative to how green or red it is in order to bring out blue and yellow hues in the image. Finally, L, the brightness of the pixel, is also adjusted relative to the pixels A value. The image is converted back to the RGB color space and concatenated to ensure pixel values lie between zero and one.

As with RGB Color Contrasting, this algorithm lacks clear theoretical basis. It is also based upon experimental procedures relying mostly on trial and error in the presence of a color blind viewer. An implementation with these experimental values is found in [4].

V. Results

Images of the original, adjusted and simulated images, as well as plots of Delta E for each algorithm are available in the poster for this project, available online. The image used for testing was found in [5], and chosen at the discretion of the author. Though testing the effectiveness of color blindness correction algorithms might be best served by applying them to an Ishihara color blindness test, we have chosen to explore its effects on an image of the popular DC comic book hero team, the Justice League. Given our freedom to define this project, we decided that it would be more interesting to examine color blindness and its effects on an image meant not just as a binary test, but rather as something created to convey action, excitement and awe; we wanted an image designed to evoke an emotional response. We therefore made the unconventional choice of testing these algorithms on the Justice League.

The images on the poster show that the contrasting technique changes the image drastically for both color blind and non-color blind viewers. It's fair to say that any adjustment from the perspective of a non-color blind individual is a change from the original artistic vision and, therefore, bad. However, the changes for color blind individuals are both good and bad. The main negative observation is that all skin tone in the new image is distorted to an unsightly yellow. On the flipside, Green Lantern’s outfit goes from blending in with his skin to becoming its own distinct blue entity. This new clarity, that his shirt is a separate object from his skin, is crucial and available only after applying the RGB Color Contrasting algorithm.

LMS Daltonization affects the image only marginally for both viewers; the adjusted images require close inspection to notice differences. Finally, the color correction algorithm is even more benign, barely affecting the test image whatsoever.

This project gives us the opportunity to see the world through the eyes of someone suffering from colorblindness and explores the effectiveness of different attempts to improve their world. It is exciting and humbling to have this opportunity to learn from the perspective of others.

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