An Adaptative Fuzzy-Based System to Evaluate Color Blindness

Jinmi Lee
Escola Politécnica de Pernambuco
Universidade de Pernambuco
Recife, PE - Brazil
jinmilee@gmail.com

Wellington Pinheiro dos Santos
Escola Politécnica de Pernambuco
Universidade de Pernambuco
Recife, PE - Brazil
wellington.santos@ieee.org

Abstract—About 8% of men are affected by color blindness. That population is at disadvantage because an important portion of visual information cannot be viewed by them. This work presents three computational tools that we developed to help color blind people. The first one aims at testing color blindness and assesses its severity. The second tool is adaptive, based on Fuzzy Logic, and proposes a method for correction of digital images in order to improve visual quality for individuals with color vision disturbances. The third tool intends to simulate red and green color blindness. Finally, tests were conducted to evaluate the results.

Keywords- accessibility; correction of color visual deficiency; color blindness; simulation.

I. INTRODUCTION

Thousands of years of evolution have made the human visual system one of the most important sensory. However, about 8% of the male population has some kind of color vision disturbance, for example. This is characterized by reducing, partially or completely, the ability to distinguish some colors [1]. People with color blindness often live years without realizing that they have a color vision deficiency. The reason is that the disorder can appear in different intensities. The increasing user interaction with graphical interfaces has evidenced problems related to color discrimination, often restricting the use of some applications [1].

The evolution of computer technology, as well as digital image processing on the improvement of visual information for human interpretation, have enhanced the visual quality of digital images for people with some kind of disturbance in color perception. However, most applications that seek to lessen the color blindness effects do not take in account that such disorder can occur in many degrees, differing from person to person [2].

The purpose of this paper is to study the chromatic abnormalities of the human visual system and develop computational tools for adaptability of human-machine interfaces, providing the inclusion of individuals with color blindness and creating more accessible solutions.

We developed a simulation tool of color blindness from the application of linear transformation matrices that model the nonexistence or disability of the cone cells responsible for sensitivity to low, medium and high frequencies. We also developed a tool for testing color blindness and assessing the degree of color blindness, using an approach based on Fuzzy Logic. The last tool was developed to improve the visual quality of digital images for people with color blindness. This integrated solution includes since tests for the diagnosis of the color disturbance type to the image preview with the adjustments that aims to reduce the color blindness effects.

II. MATERIALS AND METHODS

In the eyes, specifically in the retina, is the zone where we find the sensory cells specialized in capturing the light stimuli: the photoreceptors known as rods and cones [3]. There are three different types of cones in the human eye, each containing one type of photosensitive pigment. One type detects red light, another detects green light and the third one detects blue light, and all those together allow color vision [3].

Statistical studies show that about 8% of males and 0.4% of females have some form of disability related to the perception of colors. Deficiencies for the colors are also called dyschromatopsias, or simply color blindness [4] [5].

Just to simplify notation and avoid transcribing the full name of the deficiencies of the chromatic visual system, throughout this article we adopt the terms *protan*, *deutan* and *tritan* to the deficiency of sensitivity to the frequencies of red, green and blue, respectively.

About twenty methods of diagnosis and classification of color disorders are most often used. Pseudoisochromatic plates are used in the discrimination tests and the Ishihara test is the most known and used worldwide. Although these tests do not provide a quantitative assessment of the problem, studies show that the Ishihara test remains the most effective test for rapid identification of congenital deficiencies in color vision [5].

One important part of visual information disappears when viewed by people with color blindness. Thus, it is possible to say that color blindness constitutes an obstacle to the effective use of the computer, which nowadays uses more and more graphics in its interface and its visual communication.

There is a growing commitment to create computational tools focused on the accessibility of people with color visual disturbances. The color blindness simulators are already quite common and avoid serious problems of accessibility, helping to understand the perceptual limitations of a color blind individual.

There are also applications that seek to improve the visual quality of images. However, in most applications, it is assumed that the user already knows his type of disorder and does not consider that the disorder may occur in varying degrees. The difference of using an adaptive filter is in the diagnosis and the use of an approach that considers the uncertainty associated with the problem, where Fuzzy logic appears as a natural candidate for solving the adaptation to the user according to his degree of color blindness.

It is quite common for people with color blindness not to realize that they have a visual disturbance, and many, when they discover the problem, do not know how to classify it. However, it is very important to improve efficiently the quality of life of those people, the knowledge of information as the type of color blindness and in what degree it is.

To fill this information gap, a test tool called DaltonTest was developed. The goal of this tool is to classify the color blindness, showing the degree of the disability and its possible forms of presentation.

In DaltonTest tool, the user is submitted to the Ishihara test, that has been customized through the use of weights. Different weights were assigned to the Ishihara test questions, so that the inaccurate responses received fewer points than the precise answers. Fig. 1 shows an example of the data structure adopted to describe and store a question of the Ishihara test used in the DaltonTest tool. This simple change makes it possible to evaluate approximately the degree of blindness of the user.

```xml
<?xml version="1.0" encoding="utf-8"?>
<images>
    <image image="ishihara16.gif" question="text...">
        <normal weigth="2" answer="26"/>
        <colorblind weigth="2">
            <protan weigth="2" answer="6"/>
            <protan weigth="1" answer="(2)6"/>
            <deutan weigth="2" answer="2"/>
            <deutan weigth="1" answer="2(6)"/>
        </colorblind>
    </image>
</images>
```

Figure 1. Example of XML code describing the data structure of the DaltonTest tool.

The test, when completed, presents an estimated diagnosis of the user color blindness, containing three factors: the degree of color blindness, the degree of protanomalia, and the degree of deuteranomaly. Such result is then used by the correction tool, providing a fuzzy character for the application.

The developed tool called DaltonSim allows the simulation of the most common cases of dichromatism: the protanopia and the deuteranopia.

The simulation algorithm of colorblindness is based on the color model LMS (*Longwave*, *Middlewave*, *Shortwave*), and the conversion of the RGB components into components of the LMS model is the first step of the algorithm. The conversion is achieved by the application of a matrix, and, therefore, a linear conversion [4]:

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = (RGB\_LMS) \begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = \begin{pmatrix} 17,8824 & 43,5161 & 4,11935 \\ 3,45565 & 27,1554 & 3,86714 \\ 0,0299566 & 0,184309 & 1,46709 \end{pmatrix} \begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} \quad (2)$$

The second step is to reduce the normal domain of colors to the domain of a color blind individual. The linear transformation for protanopia is expressed as follows:

$$\begin{pmatrix} L_p \\ M_p \\ S_p \end{pmatrix} = \begin{pmatrix} 0 & 2,02344 & -2,52581 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix}, \quad (3)$$

and for deuteranopia:

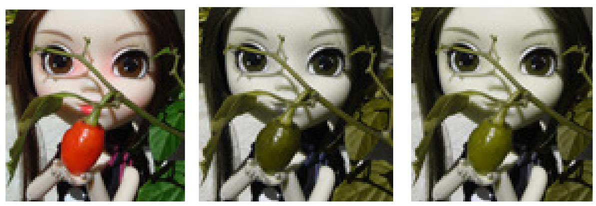
$$\begin{pmatrix} L_d \\ M_d \\ S_d \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0,494207 & 0 & 1,24827 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix}, \quad (4)$$

Finally, there must be a transformation of the LMS color model to RGB. This transformation is obtained using the inverse matrix of the first step matrix.

$$\begin{pmatrix} R_p \\ G_p \\ B_p \end{pmatrix} = (RGB\_LMS)^{-1} \begin{pmatrix} L_p \\ M_p \\ S_p \end{pmatrix} \quad (5)$$

$$\begin{pmatrix} R_p \\ G_p \\ B_p \end{pmatrix} = \begin{pmatrix} 0,080944 & -0,130504 & 0,116721 \\ -0,0102485 & 0,0540194 & -0,113615 \\ -0,000365294 & -0,00412163 & 0,693513 \end{pmatrix} \begin{pmatrix} L_p \\ M_p \\ S_p \end{pmatrix} \quad (6)$$

The DaltonSim has a very simple interface, and the result from the simulation is the visualization of the original images along with the changing images.



(a) (b) (c)

Figure 2. Result of dichromate simulation. (a) Original image, normal vision. (b) Image simulating protan type color blindness. (c) Image simulating type deutan color blindness.

The simulation has shown to be essential to understand the problems of accessibility of the color blind individuals. Fig. 2 shows some results from the simulation tool. Notice the presence of green color, since the absence of cones that detect green, in this case the type deutan color blindness, does not prevent the perception of this spectral range, as there is a compensation due to the presence of other cones, as evidenced in the mathematical model of the anomaly deutan [4]. However, there is no perception of the real green [4].

The correction tool called DaltonCor, using digital image processing, is intended to improve the visual quality of the color blind individuals, whereas its deficiency may be presented in different degrees.

The DaltonCor tool was divided into three modules: Filter, Fuzzy and Control. This last one, in addition to link the other two modules, communicates with the graphical interface and feeds it with information.

The solution developed in the filter module is based on color perception in cases of absolute color blindness.

The proposed correction seeks to compensate the lack of sensitivity to a particular color with new values for the normal color perception. The following equations represent the proposed correction for the protan type color blindness:

Consider $f=(f_r,f_g,f_b)$, the original image followed by its three bands of color r, g and b. Its correction occurs through two equations. The first one (7) is to assign new values to the bands not affected by color blindness. To protans, these bands of color are f_g and f_b.

$$f'=(f_r,f_g',f_b'),\quad \begin{cases} f_g'=\dfrac{1}{2}\left(f_r+f_g\right) \\ f_b'=\dfrac{1}{2}\left(f_r+f_b\right) \end{cases} \tag{7}$$

In order to increase the visual quality of the image, the second equation (8) is intended to improve the contrast, where the chosen technique was the histogram equalization. Consider γ the contrast optimizer.

$$f_p=(f_r,f_g'',f_b''),\quad \begin{cases} f_g''=\gamma(f_g') \\ f_b''=\gamma(f_b') \end{cases} \tag{8}$$

Note that the correction equations for deutans (9 and 10) are similar to those presented above:

$$f'=(f_r',f_g,f_b'),\quad \begin{cases} f_r'=\dfrac{1}{2}\left(f_r+f_g\right) \\ f_b'=\dfrac{1}{2}\left(f_g+f_b\right) \end{cases} \tag{9}$$

$$f_d=(f_r'',f_g,f_b''),\quad \begin{cases} f_r''=\gamma(f_r') \\ f_b''=\gamma(f_b') \end{cases} \tag{10}$$

The Filter Module returns two corrected images f_p and f_d. The Fuzzy Module is responsible for the filter customization and, based on the outcome from the test tool, assigns a fuzzy character of this correction. From an experimental approach, the following rules were proposed:

$$x_p'=\beta\wedge\alpha_p, \tag{11}$$

where x_p' is equal to the degree of color blindness β with conjunction the degree of protan α_p.

$$x_d'=\beta\wedge\alpha_d, \tag{12}$$

where x_d' is equal to the degree of color blindness β with conjunction the degree of deutan α_d.

$$x_n'=\alpha_n\wedge(\neg\beta), \tag{13}$$

where x_n' is equal to the degree of normality α_n and with conjunction not color blindness.

From the measurements obtained from the rules above, it is possible to make a fuzzification process on these magnitudes to obtain the weights expressed by the following equations:

$$x_p=\frac{x_p'}{x_p'+x_d'+x_n'}, \tag{14}$$

$$x_d=\frac{x_d'}{x_p'+x_d'+x_n'}, \tag{15}$$

$$x_n=\frac{x_n'}{x_p'+x_d'+x_n'} \tag{16}$$

The corrected image f_c is a weighted average of the corrected images for protan and deutan type color blindness, and the original image, as represented in the following expression:

$$f_c=x_p.f_p+x_d.f_d+x_n.f \tag{17}$$

III. Results

In order to analyze the results of the Correction Tool proposed, 10 images in bitmap-32bits format were used. The use of simulation tool was essential to understand how the corrections would be perceived by people with color blindness. We also analyzed all the correction variations in RGB, LMS, and with and without histogram equalization. In Fig. 3, it can be seen the correction result for an individual 100% color blind, 0% protan, 100% deutan and 0% normal.

Note that in Fig. 2.b the fruits shades appear nearly equal. However, in Fig. 2.d the shades of fruits are subtly different. Thus it is easy to see the gain of visual information after correcting the image.

Although the analysis done by the simulator display is satisfactory, a group of four people with color blindness volunteered to test the tool. The volunteers were evaluated with the customized Ishihara test using the test tool. Through the obtained results, the four combinations of correction were analyzed. The results are presented in Table 1.

TABLE I. RESULTS FROM THE ANALYSIS OF THE CORRECTION FILTERS.

	With equalization		Without equalization	
RGB	Much better	20%	Much better	0%
	Better	46%	Better	43%
	Indifferent	20%	Indifferent	43%
	Worse	14%	Worse	14%
	Much worse	0%	Much worse	0%
LMS	Much better	20%	Much better	7%
	Better	17%	Better	33%
	Indifferent	0%	Indifferent	3%
	Worse	7%	Worse	7%
	Much worse	36%	Much worse	50%

Each corrected image was subjectively evaluated and judged as *much better*, *better*, *indifferent, worse* or *much worse*. Distortion and greater ability to distinguish elements in relation to the original image were considered as evaluation criteria.

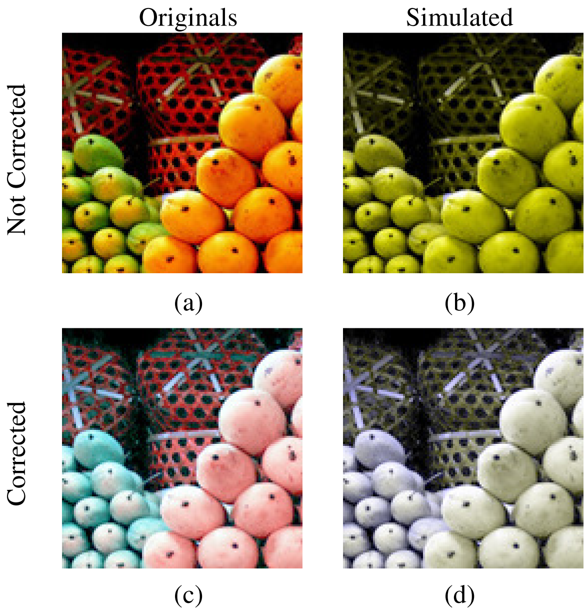


Figure 3. Results from image correction using the method in RGB. (a) Original image. (b) Simulation for the deutan type. (c) Corrected image with histogram equalization. (d) Simulated image corrected for deutan color blindness.

It was observed that, by the correction in RGB domain with histogram equalization, the images became more understandable, because elements that were perceived with the same color (due to color blindness) received different colors. Some images after the correction showed less saturation in their colors and some of these cases were considered worse. With the correction in RGB without histogram equalization there was not a big gain in the visual improvement of images, although this type of correction has been found to cause less negative impact on the distortion of the original colors.

The correction in LMS, in general, changed overmuch the original colors of the images, although it performed efficiently on images that purposely have hidden elements, like the images used in pseudoisochromatic Ishihara plates.

IV. DISCUSSION AND CONCLUSION

Despite the rapid technological developments and advancements in the area of digital image processing, it is not easy to find tools that reduce the effects of chromatic visual disturbances. So, this paper proposes the development of a set of computational tools to improve the accessibility and visual quality of life for color blind people. However, one of the greatest difficulties encountered in developing this work is the relative lack in the literature about other mathematical methods for adaptive compensation of color blindness as the proposed.

Tests were conducted with a group of people with color blindness. This experience was important to evaluate the results obtained from the correction filters, and to more accurately gauge the difficulties encountered by the volunteers. The results were very positive, confirming that the proposed correction is able to extract a higher amount of information from an image.

Moreover, all the tools proved to be intuitive and easy to use, providing a better user experience, and consequently their habitual use.

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