IIUC Journal of Science and Engineering
Vol.-1, Issue-1, December 2023, pp. 119-140
ISSN: 3005-5873

Image based color correction for dichromatic colorblind patients

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Article info

Keywords
Daltonization algorithm
Deuteranopia
Dichromatic
Protanopia
Tritanopia

Abstract

Color correction for color blindness to understand the vision defect images is an active research area in the field of computer vision and image processing. The problem occurs due to the lack of human cone cells. For that, defective people cannot recognize specific wavelengths and colors. To mitigate this problem, we focus on fixing the color of images for dichromatic patients in this work. In this regard, the Ishihara test distinguishes the dichromatic patient. After that, the second Ishihara test is used to specifically categorize the patient, i.e., protanopia, deuteranopia, or tritanopia. These processes are used to reduce the processing time. Afterwards, the evaluation method is applied to create the image that the colourblind people originally saw. Finally, the daltonization algorithm is utilized to correct the color. The proposed method shows better results with respect to the other method and real-time images.

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1. Introduction

In current decays, color correction for color blindness is an important and active research area in the field of image processing. To make this situation more traditional and polite, it would be advantageous to correct color of some images so that the color blind person can understand those images, which is the one of the most complex research areas in the field of image processing, which has been working on colorblind persons to get them a better view. The patients of the color blind are usually neglected the issue because of this community is less amount, however, we cannot even ignore them, because they are also human being, who needs proper attention like normal people. Many pieces of research utilized various types of color blind persons from schools and other institutions, so we have to improve the existing system's performance for the color blind peoples.

In our daily lives, we go through many things that Normal people usually do not think about, but colour affects a lot in our day-to-day life to get a smooth, happy and healthy life. For example, we can only cross the road if we see the signal light; we cannot drive ourselves to our destination if we do not see the signs on the road. Moreover, we will only be unable to get all the jobs because we will have numerous problems. Even if we cannot enjoy our lives, we will see the colourless gardens, nature, and, in fact, the whole world.

Color vision deficiency (CVD) is a vision problem; more specifically, it is a lack of human cone cells, which causes the inability to observe specific colours in different situations. CVD is mainly observed in men rather than women, as because of this problem, it occurs for the X sex chromosome. The present color defect problem in the Europe population is shown in Figure 1 (Aydin, Mantiuk, Myszkowski, & Seidel, 2008; Ribeiro & Gomes, 2019). In Figure 1, a map is shown where we can see the difference in the colourblind enhancement ratio in Europe in 2006. Though the percentage of this problem is still less among the world's population, it must be addressed. We must take steps to overcome the problem and allow the patients to be viewed as normal. Currently, there are lens and therapies that are so costly that everybody cannot afford them. So to get the patients to understand the view of deficit colors, we will take a fixed number of images and correct color for them through the vision system. As a result, the problem can be solved through the vision system, as the other treatments could be more successful. Moreover, for dysfunction, there is no complete treatment or absolute cure.

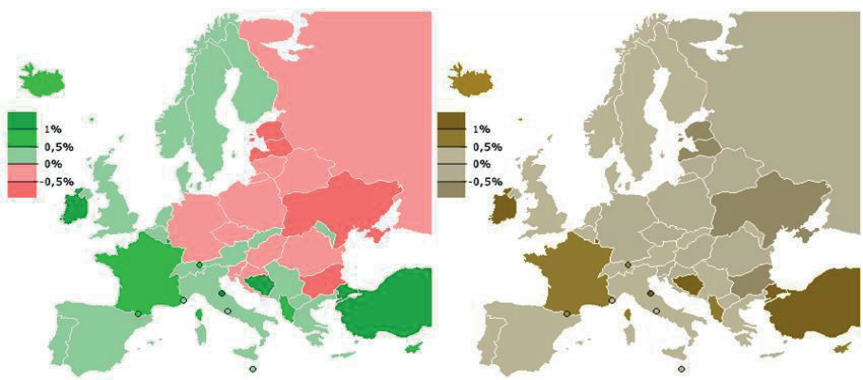


Figure 1
Left image is the map of Europe population growth shown in colorful contrast, and the right side image is the defected view of population growth (Aydin, Mantiuk, Myszkowski, & Seidel, 2008).

One can cope with the world through augmented reality, having this disease. Another solution is to use the lens, which is costly; everybody needs help to afford it. On the other hand, numerous therapies are available to eliminate this disease at the primary level. However, this is even more costly than the lens. By implementing the vision system, we can solve the problem by correcting the image by applying some methods so that the affected person gets a look-alike view. CVD problem impacts daily life, both personal and professional. Among the three types of colour blindness, i.e., Monochromacy, Dichromacy, and Trichromacy, Dichromacy is the most common CVD problem among the other two. So, in this work, we chose this type of problem to correct as the percentage was not so up to date in previous work.

Human color vision depends on three light-sensitive pigments in three dimensions (Alpern & Wake, 1977; Berendschot, Van de Kraats, & Van Norren, 1996). Three types of cone cells on the retina—L-cones, M-cones, and S-cones—determine the correctness of deficiency. Normal human vision requires some activities, such as the activities of some cone cells. They are, respectively, L, M, and S cone cells; lacking these cone cells cause colour blindness. Moreover, these cone cells are mainly wavelength, L for long wavelength, which absence causes red color deficiency. M is for medium wavelength, whose absence causes green colour deficiency, and S is for small wavelength, whose absence causes green colour deficiency. The Dichromacy rate in percentage between men and women is presented in Table I (Ribeiro & Gomes, 2019; Cicerone & Nerger, 1989; DeMarco, Pokorny, & Smith, 1992).

Table I

Dichromacy rate in percentage of men and women (Ribeiro & Gomes, 2019)

	Normal Vision	L-cone defect	M-cone defect	S-cone defect
Men	**91.4%**	**2.45%**	**6.1%**	**0.011%**
Women	**99.6%**	**0.04%**	**0.36%**	**0.04%**
Overall	**95.5%**	**1.25%**	**3.24%**	**0.025%**

In this work, we will focus on one type of colour blindness: Dichromacy, which has three subtypes shown in Figure 3 (Wong, 2011). The subtypes of Dichromacy are Protanopia, Deuteranopia, and Tritanopia (Wong, 2011). The whole overview of every kind of vision deficiency is presented in Figure 4. Protanophic patients have an absence of L cone cells, so they do not see the red colour at all. Deuteranopic patients have no M cone cells, so they do not see a green colour. Tritanophic patients have no S cone cells, so they do not see a blue colour. In our thesis, we will take some images and correct their

colour for dichromatic patients. Thus, they will be able to see those images correctly.

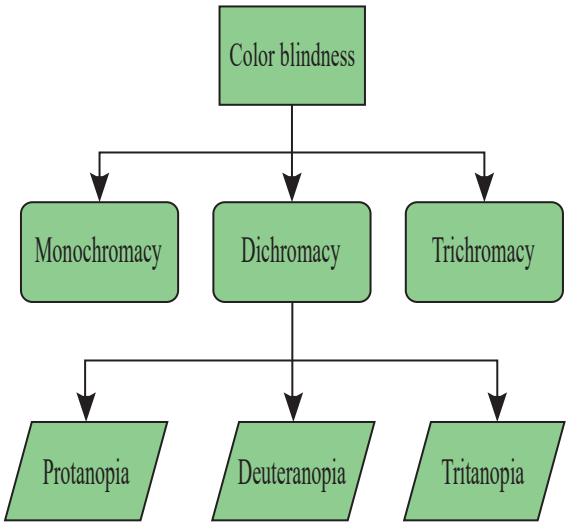


Figure 3
Color blindness variation with sub types of Dichromacy.

Color blind type	Cause	Effect
Monochromacy	No cones exist. or only one cone type exist.	Inability to see any color, they see the world in black and white or grey shade.
Dichromacy	One cone type is missing- They are three types: 1. Protanopia: L cone is missing 2. Deuteranopia: M cone is missing 3. Tritanopia: S cone is missing	Inability to see the color corresponding to the missed cone type. Inability to see RED color. (RED colorblind) Inability to see GREEN color. (GREEN colorblind) Inability to see BLUE color. (BLUE colorblind)
Trichromacy	All cone types do exist, but they are not aligned. They are also three types: 1. Protanomaly: L cones are not aligned 2. Deuteranomaly: M cones are not aligned 3. Tritanomaly: S cones are not aligned	Reduction in the sensitivity to a particular color. Less sensitivity to RED color. (RED weak) Less sensitivity to GREEN color. (GREEN weak) Less sensitivity to BLUE color. (BLUE weak)

Figure 4
Color blindness causes according to LMS cone cells (Bergman, Rogowitz, & Treinish, 1995).

In the past decades, many researchers have utilized many methods on small and fixed datasets to eliminate the defects of colour blindness. However, the

authors did not get better results for the Dichromatic patients. In this regard, in this work, we focus on Dichromatic patients to correct the colour of such objects, whose deficiency will be detected by the colourblind human eye.

The further sections are discussed as follows. Section 2 discusses related works to the topic, section 3 explains the proposed methods, section 4 shows the experimental outputs of the method, and section 5 consists of the paper's conclusion.

2. Related work

In the past decades, many researchers have researched and proposed up-to-date colour correction techniques for dichromacy colour-blind patients. These techniques differ regarding the assisted Dichromacy types and the relevant algorithms used. Almost all the researchers utilized the three algorithms: LMS daltonization, LAB colour adjustment, and colour contrast enhancement. The LMS daltonization algorithm, the referred color correction algorithm, can be operated for each type of Dichromacy color blindness. Consequently, applied algorithms are recommended for a specific type of color blindness.

2.1. Simulation techniques

Aside from the importance of understanding how people with color blindness retain color, very little is being done to mimic their point of view of common trichromats. There are no previous methods that control undesirable Trichromacy or Dichromacy during the simulation process evaluated in that concept. The simulation evaluation could be more consistent: generally, it is impossible to mimic the general concept of trichromatic colour in people with colour vision deficiency due to the decline in the colour scheme. The first strategies for matching the perception of people with color vision deficiency were developed based on a combined dichromatic population report (Hurvich, 1972). According to their report, achromatic and other colors are equally visible in both eyes. The authors drew this gamut in the color space of XYZ.

They also counted these lines of confusion in the area of colour, showing indications that there was no colour variety according to the dichromats' perception. By expressing colors in confusing lines in a reduced gamut, they describe the exact process of imitating Dichromacy. Finally, similar operations were performed (Viénot, Brettel, & Mollon, 1999). The procedure proposed by Brettelet, Viénot, & Mollon (1997). It is the most targeted imitation. The researchers limit the direction of misleading lines to fit the axis index of color L, M, or S, depending on the type of Dichromacy

by protanopia, deuteranopia, or tritanopia, respectively. It is the processing of colouring in flying aircraft. These methods produce good results in cases of dichromacy but cannot be performed in cases of undesirable Trichromacy, which accounts for approximately 71% of colour vision deficiency cases (Kondo, 1990). Some authors have tried to mimic the view of undesirable trichromats. A model was proposed to mimic the point of view of people with undesirable Trichromacy based on the dichromatic concept, given the similarities between the ideas of dichromat and people with undesirable Trichromacy (Kondo, 1990).

The method proposed by Grundland and Dodgson (2007) mimicking the perception of people with undesirable Trichromacy has the process of changing the color from the RGB color space, about the normal output of the CRT track, to the color space of the LMS, according to L, M, and S (Grundland & Dodgson, 2007). With such modifications, mimics are removed from view of undesirable clusters. The authors discuss their simulation approach by converting color from RGB to an unpopular LMS and restoring color from standard LMS to RGB. The program does not comply with opponents' analysis of the human visual system because it limits statistical calculation to the photoreceptor level. As a result, mimics are often of a different color than what people see with color vision deficiency. Strong protanomaly and deuteranomaly are shown in the last column, which should be similar to the view of protanopes and deuteranopes, respectively. The results were obtained by simulation process (Brettel, Viénot, & Mollon, 1997). Protanopia and deuteranopia differ from the results of the Trichromacy of of severe disease (Huang, Sherman, Zheng, Yang, Imamichi, Stephens, & Lempicki, 2009).

2.2. Recoloring techniques

A number of researchers have investigated the problem of retrieving a picture of people with color vision deficiency. The existing strategies can be widely categorized as user assisted and operational based approaches.

2.2.1. User-Assisted Techniques

There is another technique which needs assistance; without the assistance of one, it cannot be operated. Six parameters were used to convert the actual colors of the input image (Shrestha, 2020). Daltonize (Culp, 2012) uses three parameters to define the regeneration process (protanopes and deuteranopes). These parameters specify how the red-green channel should be extended, shown to the light channel and the yellow-blue channel. Huang, Sherman, Zheng, Yang, Imamichi, Stephens, and Lempicki (2009) authors enhance colour brightness by replacing Hue components in the HSV colour

space, which aims to provide a wide range of dynamic distances of very complex colours. This method uses a control parameter to determine the level of development.

2.2.2. Optimization based techniques

Lin, Chen, and Wang (2019) authors propose an improved version of the method. Here, the authors utilized an improved version of the method to correct the colour deficiency of colour-blind people. A technique was operated without user interference, consisting of procedure after optimization (Wakita & Shimamura, 2005). It uses a genetic algorithm to recall web pages of undesirable trichromats. Subsequently, the authors expanded their work of recalling images. They introduced the process of retrieving dichromats. That approach had some objectives, which were: (i) preservation of colour enhancement, (ii) enforcement of colour contrast at its' maximum, and (iii) colour preservation to get a more natural image. These functions were measured in user-defined parameters and enhanced by the resulting annealing. They reported that producing more than ten color manuscripts can take just a few seconds. Jefferson and Harvey (2006) authors use four-purpose functions to store light, color brightness, color in available magnetic fields, and color environment. Their strategies develop the functions of integrated objectives using gradients with specific characteristics. The authors reported several minute editing times in a 25-color set. Rasche, Geist, and Westall (2005) authors introduced the process of recalling a picture of dichromats containing performance that attempts to maintain a distinct difference between all color couples of dichromats using a variant. Though variations, the color was not captured by this transformation. The variations were in different directions. Also, it could not guarantee that the colors are mapped in the correct position. Jefferson and Harvey (2006) authors addressed these limitations using the restricted process of multivariate efficiency in a compressed set of calculated colours. A well-designed set of emerging colours enhances the whole set of colors. Rasche, Geist and Westall (2005) authors introduced a process to improve the colour brightness of dichromats that preserve the environment regarding spring efficiency, which can be optimized for GPUs. Similar to the procedure by Rasche, Geist and Westall (2005), pre-production is done in a multi-colour set, which is used to add all colours. Their process is three times faster than the previous method. This method is speedy, so it can be used in real-time operation. One cannot maintain a temporary contact on that plane. This does not reserve the original set but gives better results in real-time photos. Also, it maintains temporary integration. Huang, Sherman, Zheng, Yang,

Imamichi, Stephens and Lempicki (2005) authors also introduced a performance-based approach to image retrieval. This means operating in the CIE L * a * b * colour space. The faster the system, the faster the output is. For example, if one has good RAM and the microprocessor speed is relatively fast, no matter the resolution of the pictures, the result can be obtained way faster than others. Note how recycling techniques can detect color differences. Note that the results of Kuhnet. It preserves the environment by blocking colors similar to dichromats and common trichromats.

2.3. Color-to-gray scale mappings

Reducing dimension is a problem to re-colour images for dichromats. It is like a minimal problem of making a colour map grey. The traditional methods commonly used in commercial systems make this map simply by taking the amount of colour light embedded in a particular colour field. A most wanted printing feature is achromatic colors. Though no necessary steps are taken to account, these methods calculate all the bright colors in the same shade of gray, although there are differences in their perception. Many methods are proposed to highlight the limits. Authors use a quadratic calibration procedure called the pixel number in a picture. Though this method produces good results, it is also costly to afford, so to collaborate with the application, cost prevents it. Authors evaluated to find the measurement. The PCA was failed to detect and convert colorful images with numerous directions, and to combine principal components as optimization is needed. As the original picture processing has limitations, for that reason, the simulated images were used in Rasche, Geist, and Westall (2005) and Grundland and Dodgson, (2007) to make a gray color map by inserting the first luminous value of Yi for pixel pi, a certain number of Ki attempts to compensate, and it occurs because of the loss of contrast. To calculate Ki while avoiding quadratic costs the researcher introduced a new strategy called Gaussia pairing. Contain a selection with each pixel pi, pixel pjin a circular area around the pi. The choice of pj is based on Gaussia's job opportunity distribution opportunity. Area size is calculated based on image size. France provided in pairs (pi, pj), the related comparative losses are calculated as:

$$l\,(pi, pj) = 1 - (Yi - Yj) \,/\, (pi - pj, RGB)$$

Where Yi and Yj are light values of pixels pi and pj, respectively, and pi− pj RGBis length vector of color vij = pi - pj marked in the RGB color space. Note that the distance included in the lower value does not have a comprehensive definition. To quantify the value of Ki, the authors drew real RGB colors in place of their opposing color (YPQ), which, too, differed in

understanding. In the YPQ color space, they measured the dmcl indicator for a high loss of comparison. Measuring high data distribution is an important component to analyse using the total vector weight. The result is different than Eigen vector problem. This caused the solution is also different from Eigen vector rather than PCA.

3. Proposed method

In this section, we will describe the details of the process to correct the colour of an image for Dichromacy colour-blind patients. The problem occurs due to the lack of some cone cells in the human eye, which causes vision deficiency. There are three sub-types of dichromacy; each sub-type has a different lack.

To improve the method's performance, we perform the second Ishihara (Ishihara, 1990) test to get the deficiency more specifically. The test can be explained as the following way. If one is unable to see the rad color, the patient is missing the L cone cell. The patient is treated as a Protanopia patient. Secondly, if a person cannot see the green colour, the patient has missed the M cone cell. In this case, the patient is treated as a Deuteranopia patient. Lastly, if the person cannot see the blue colour, then the patient has missed the S cone cell; in this case, the patient is treated as a Tritanopia patient.

To determine the colour correctness of colour-blind people, we have performed the Daltonization method in this work. The method is presented in Figure 4. The Daltonization method is performed in seven basic steps. The steps are: 1) taking an RGB image to enhance its' color contrast, 2) Color contrast enhancement occurs because of the color space conversion of RGB to LMS, 3) then the viewer lost information and missing cone cells will be calculated, 4) the lost information will be shifted to color visible to patient, 5) the original image, shifted lost information will be added, 6) the missing of cone cells will be received by the viewers through this process, and 7) the color is corrected for the patient and he will observe the lookalike view. The workflow diagram of this work is presented in Figure 5.

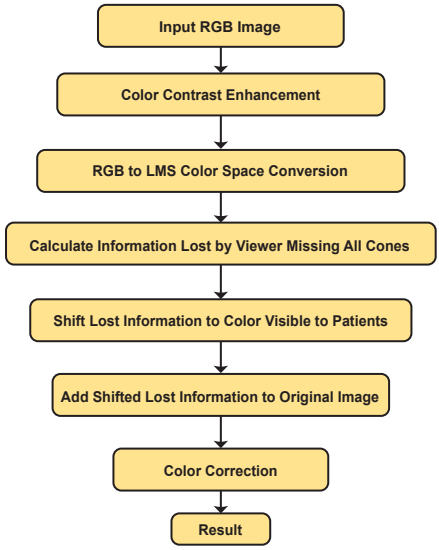


Figure 4
Daltonization method process step by step.

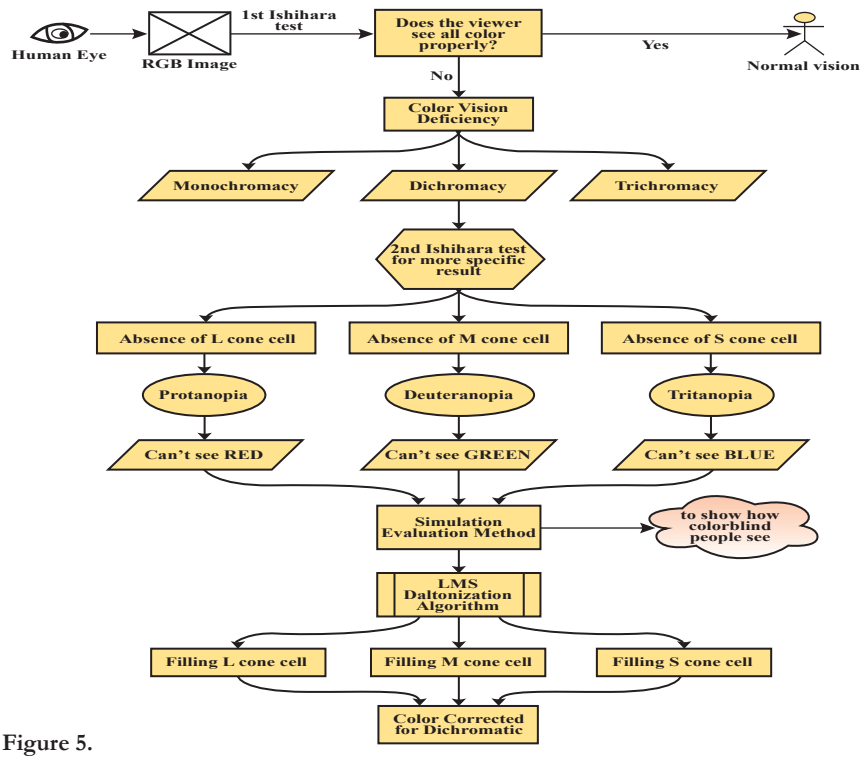


Figure 5.
Workflow diagram of our research method.

3.1. Daltonization algorithm

Three types of cone cells obtain color vision: L, M and S cone cells. Lacking and absence of them cause vision deficiency. These L, M, and S wavelengths are long, medium, and short, respectively. Three types of Dichromacy occur each if cone cells are missing. If L, M, and S cones are missing, these cause protanopia, deuteranopia and tritanopia, respectively. In our algorithm, we will fix them and correct the colors of some images (Brainard & Vision, 1997).

The first and foremost task of our algorithm is by using conversion matrix, finding the LMS values from the red, green, and blue (RGB) images. The LMS value is calculated in respect to retina. On the other hand, RBG value is calculated by a cathode ray tube screen, so the colors can be matched. Thus, the digital image is defined. Then a conversion is made to delete the lost information of the cone types to get the LMS values as L' M' S'. Then to get the R' G' B' values, we did a reverse transformation of L' M' S' values. Because R' G' B' value represent how a color-blind person observe an image. This criterion is followed for all the pixels, and then the method is complete (Davis, 2019).

From Figure 6, we can see the spectrum of 8 colours, which are segmented into three dimensions: L, M, and S. We achieved it through matrix multiplication. We converted the RGB values by generating a matrix in each pixel. Then, we used RGB to LMS matrix to transform it to LMS space. After converting to LMS space, the critical part comes. We must find out the lost information corresponding to the deleted cone cell and fulfil the requirement. In Figure 6, K indicates black, R for red, Y for yellow, G for green, W for white, C for cyan, M for magenta and B for blue.

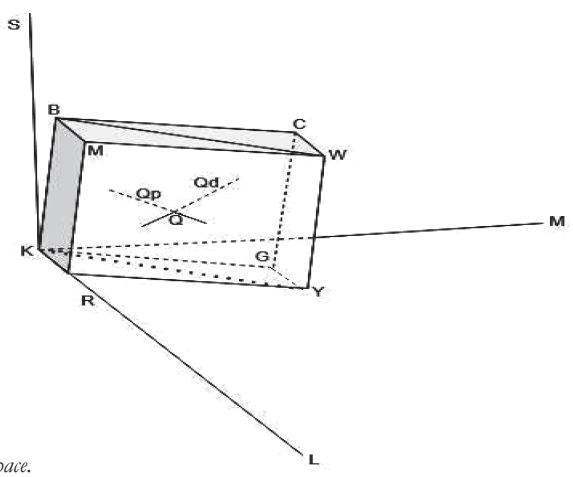


Figure 6
The LMS color space.

An average person can observe all eight colours, which means they have the presence of KRYGWCMB. However, those colours on the QpQ line will appear the same for the protanope, which is the KYWB plane. Similarly, the colours on the QdQ line will show a similar KYWB. For that reason, similar properties are missing for both deuteranopia and protanopia, which means that outside properties of KYWB are not. So, the equation should be similar to Eq. (1).

$$\alpha L + \beta M + \gamma S = 0 \quad (1)$$

That are passes to the points of (LW, MW, SW), (LB, MB, SB) as well as (0, 0, 0). The value of α, β, γ are solved using the Eq. (2), (3) and (4).

$$\alpha = MWSB - MBSW \quad (2)$$

$$\beta = SWLB - SBLW \quad (3)$$

$$\gamma = LWMB - LBMW \quad (4)$$

After evaluating these values the value of Lp and Md are evaluated through the Eq. (5) and (6) protanopia and deuteranopia respectively.

$$Lp = -(\beta M+\gamma S)/\alpha \quad (5)$$

$$Md = -(\alpha L+\gamma S)/\beta \quad (6)$$

The L cone responds to protanope, and the M cone responds to deuteranopia. The S cone response to protanope. So, this code was finally converted to an RGB image. The basic idea behind this lactonization algorithm can be briefly explained. Firstly, we will take an RGB image to enhance its colour contrast. Colour contrast enhancement occurs because of the colour space conversion of RGB to LMS. Then, the viewer loses information, and missing cone cells will be calculated. Then, the lost information will be shifted to a color visible to the patient. In the original image, shifted lost information will be added. The viewers will receive the missing cone cells through this process. Then, the color is corrected for the patient, and he will observe the lookalike view.

4. Experimental results

In this work, we have used three types of self-made datasets. We have collected several images from the internet and real-time images from different environmental conditions during the daytime and night. Each dataset contains ten images, and as there are three dichromacy types, the total number of images taken is 90. The sample dataset images are shown in Figure 7.

We have used Python Programming language libraries: Daltonize, colour contrast, and some necessary basic libraries. Daltonize is an ultimate image processing-based framework implemented from the Daltonization

algorithm, making it easy to fix and travel. As it is written in Python, it has high-level features that make it simple and natural to use. The system is implemented in Google Colaboratory, which is a free cloud service and a research tool for data science.



Figure 7
Sample dataset.

4.1. Implementation

This section describes the detailed process to implement the color correction process. For that, firstly, to find out whether the person is color blind or not. To solve this issue, we will go through the Ishihara test, and for that, we have to choose some specific numbering pictures to categorize colourblind types. Hence, the total amount of patients becomes less. The pictures of the first Ishihara test are shown in Figure 8.

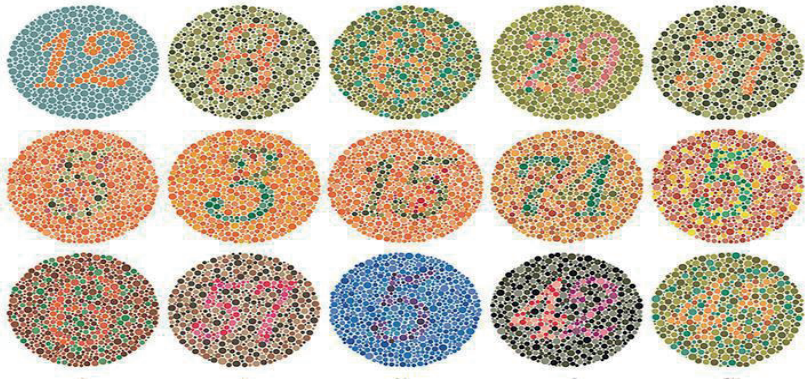


Figure 8
Ishihara testing plates for detecting color blindness.

According to the Ishihara test, specific color-blind people are recognized. From Figure 8, if any person cannot recognize a specific type of number, then a specific type of colour blindness will be found. If the person cannot see the red, green and blue type numbers, then the person will be a Dichromatic patient. On the other hand, if the person sees in the little shade, then the patient will be a Trichromatic patient. If the person sees every picture in the grey shade, then the person will be a Monochromatic patient.

After testing the Ishihara test, we have our specific type of patient and can separate dichromatic-type patients from the other two types. So, the processing time will be reduced. As we know, there are subtypes of every kind of colour blindness, so we will go for the second Ishihara test to find a more specific sub-type. Moreover, the testing picture of the second Ishihara test is shown in Figure 9.

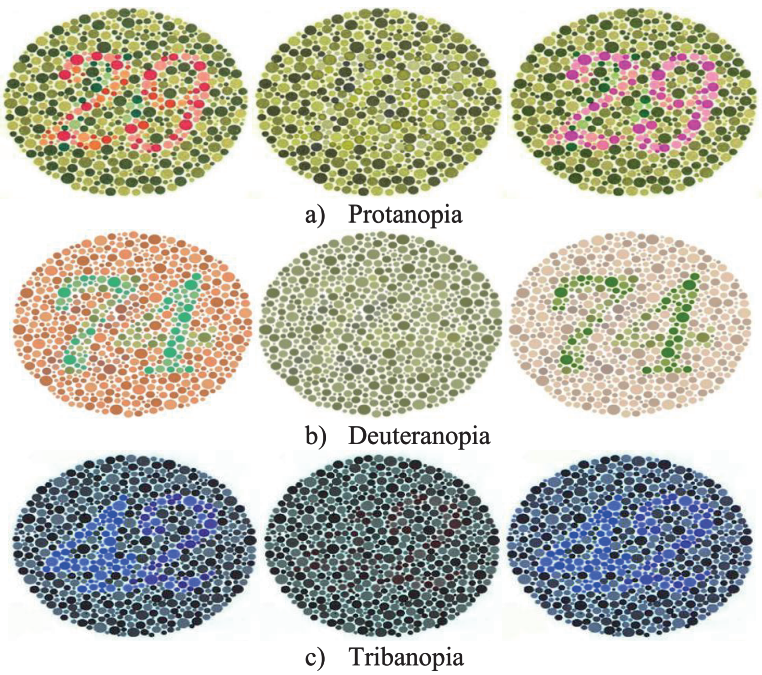


Figure 9
Second Ishihara testing plate for more accurately categorization.

According to the second Ishihara test, the specific sub-types of color blind people are recognized. According to Figure 9, if any person does not see the number 29 in Figure 9(a), then the person is treated as a protanopia patient. On the other hand, the person who does not see the number 71 in Figure 9(b) is treated as a deuteranopia patient. Finally, the person who does not see

the 42 from Figure 9(c) is treated as a tritanopia patient.

As we have found our required patients, we can show them the pictures to observe those colours, which they cannot usually see. Thus, to get the problem's solution, ordinary people have to see how colourblind people observe an image; we will apply the simulation evaluation method (Colblindor, 2021). The simulation evaluation method lets the ordinary person see the pictures that the color-blind people initially saw. After that, the LMS Daltonization algorithm is applied to correct the wavelengths, LMS- L for long wavelength, M for medium wavelength and S for short wavelength; if we correct the specific wavelength for a specific type of deficiency, then the person will get the image correctly and will understand the proper scenario.

4.2. Experimental results for Protanopia

This section shows some experimental results for the patients of protanopia. This category of patients does not see the red color due to the absence of the L cone cell. The Figure 10 shows the processing example of the experiments. Here, Figure 10(a), 10(b) and 10(c) are the original images, simulated images and colour-corrected images, respectively. The simulated image is the image version of the blind people is seen. A color-corrected image is an image that is corrected through the Daltonization algorithm. In these experiments, we tested the algorithm through the images that were captured during the daytime and nighttime and the images that were captured in real-time.



Figure 10

Processing example of protanopia patients for day light, night time and real time images: a) original image, b) simulated image, and c) color corrected image.

4.3. Experimental results for Deuteranopia

The deuteranopia patients do not see the green colour because of the lack of M cone cells. The deuteranopia patients processing example is shown in Figure 11. Here, Figure 11(a), 11(b) and 11(c) are the original images, simulated images and colour-corrected images, respectively. The simulated image is the image of how colourblind people observe an image. A color-corrected image is an image that is corrected through the Daltonization algorithm. In these experiments, we tested the algorithm through the images that were captured during the daytime and nighttime and the images that were captured in real-time.

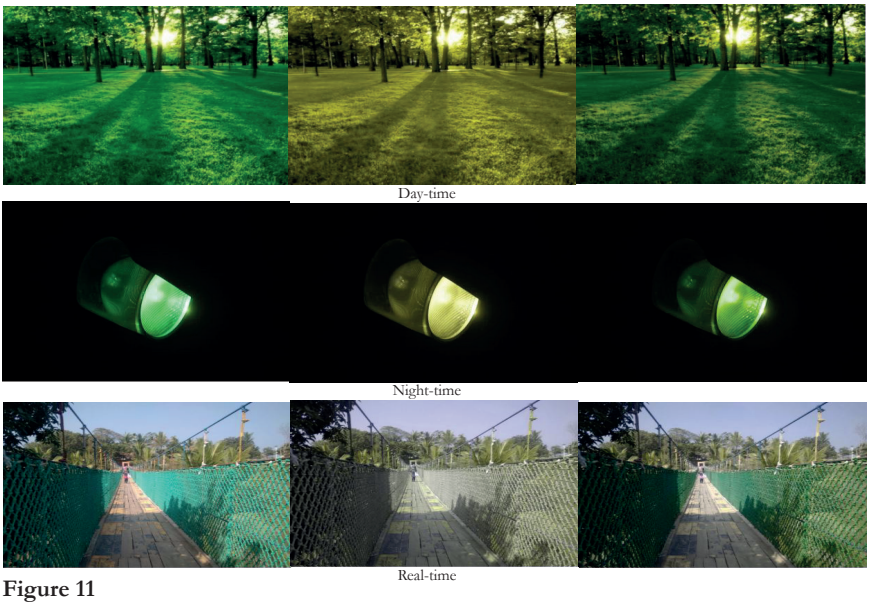


Figure 11

Processing example of deuteranopia patients for day light, night time and real time images: a) original image, b) simulated image, and c) color corrected image.

4.4. Experimental results for Tritanopia

Tritanopia patients are the people who do not see the blue color because of the lack of S cone cells. The deuteranopia patients processing example is shown in Figure 12. Here, Figure 12(a), 12(b) and 12(c) are the original images, simulated images and colour-corrected images, respectively. The simulated image is the image of how colourblind people observe an image. A colour-corrected image is an image that is corrected through the Daltonization algorithm. In these experiments, we tested the algorithm through the images captured during daytime and nighttime and the images captured in real-time.

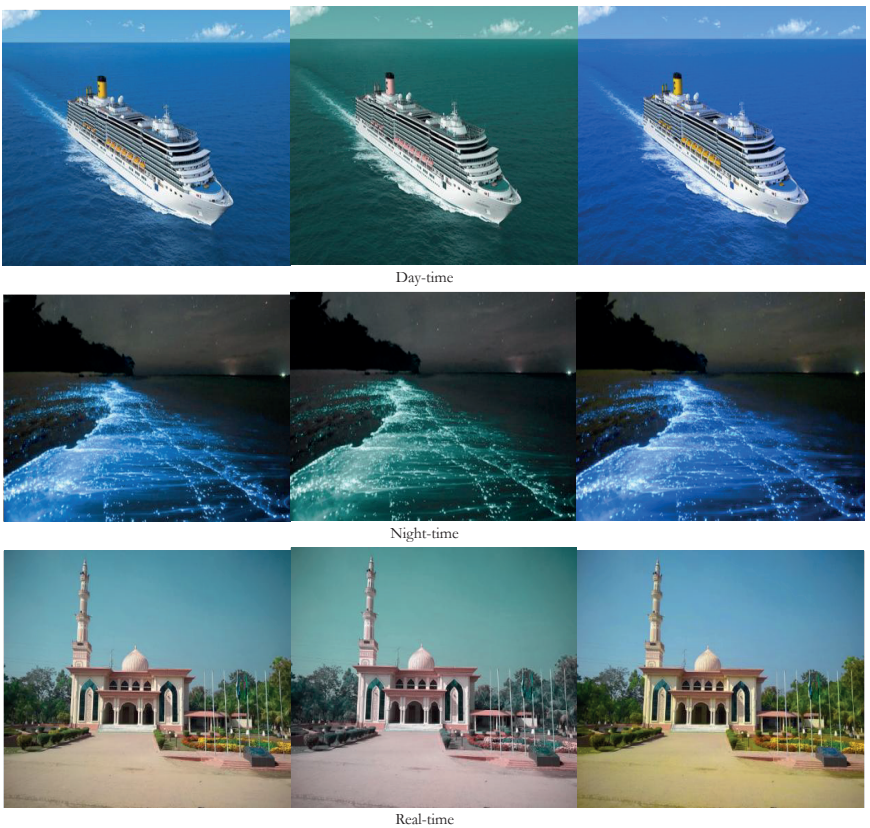


Figure 12
Processing example of tritanopia patients for day light, night time and real time images: a) original image, b) simulated image, and c) color corrected image.

4.5. Comparative analysis

We compared our research with the vischeck algorithm to get the accuracy difference. In Figure 13, we can see three images, where Figure 13(a) is the original image, Figure 13(b) is the simulated view, and Figure 13(c) is a fixed view for deuteranope.

On the other hand, in Figure 14, we can see the result after applying the vischeck algorithm on the Figure 13 image, where in Figure 14, Figure 14(a) is the simulated view and Figure 14(b) is a fixed view for deuteranopia. So, one can easily see the difference in which one looks better. In the vischeck algorithm (Tasnim & Hasan, 2017; Vischeck, 2021)), the author could not fix the loss information of the cone cell and thus could not shift the loss information into an RGB image for the defected person.

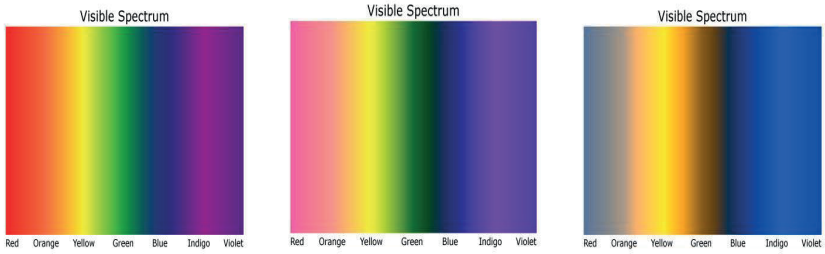


Figure 13

Firstly, original spectrum, secondly daltonized dpectrum with error transform algorithm, and thirdly daltonized spectrum perceived by the deuteranope.

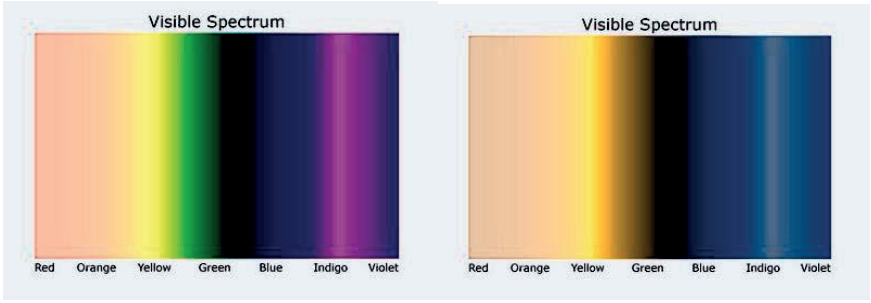
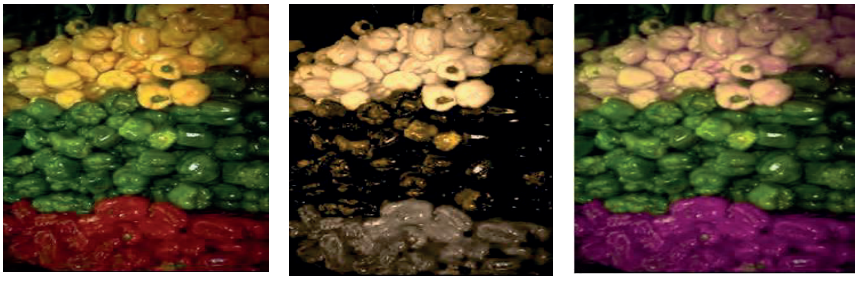


Figure 14

Daltonize Spectrum with vischeck Algorithm (left), and Daltonized Spectrum Perceived by a Protanopia (right).

In Figure 15, we took a picture of beans and compared it with the vischeck algorithm. The first is the original image, the second is the result from the vischeck algorithm, and the third is the result after applying our LMS daltonization algorithm.



(a) (b) (c)

Figure 15

Firstly, original image, secondly daltonization with the vischeck algorithm, thirdly daltonization with our algorithm.

Again, in Figure 16, we shown the original image first and the deuteranope view in second.

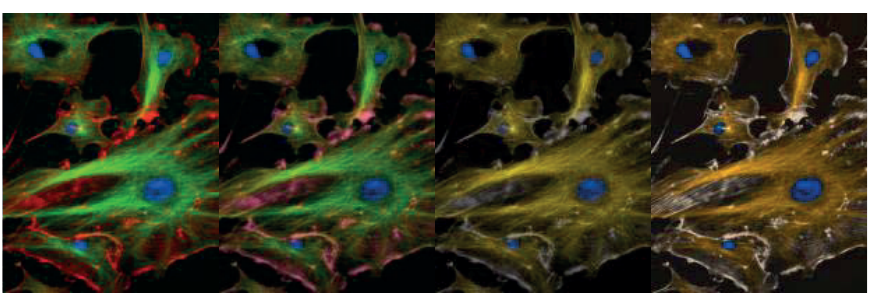


(a) (b)

Figure 16

Firstly, original picture, secondly daltonized picture perceived by a deuteranope

In Figure 17, Figure 17(a) is the original image; Figure 17(b) is the daltonized image after applying daltonization. Figure 17(c) results from a vischeck observed by a protanopia, and Figure 17(d) applies our algorithm perceived by a protanopia.



(a) (b) (c) (d)

Figure 17

Firstly, original, secondly daltonized by our error-transform algorithm, thirdly picture second perceived by a protanopia, fourthly original image daltonized by vischeck, and perceived by a protanopia

5. Conclusion

The lack of color vision affects the professional life of an estimated 200 million people worldwide. Therefore, it is essential to have a deeper understanding of this situation and to provide solutions, as it is badly needed. So, to make people understand one has a deficiency, we made a dataset, and the differences will help them to know about this disease. Moreover, in this work, the Daltonization algorithm is used to overcome the vision defect of the Dichromate patients. The Ishihara and second Ishihara tests are used in this work to reduce the processing time and categorise the specific patient.

This work uses the simulation evaluation method to show the images that the vision defect patient views. By the proposed method, different environmental images can be color-corrected. Moreover, patients can observe such a view of some natural beauty. In this work, nighttime images for dichromate patients are used and show effective performance than other methods.

Dichromate image regeneration techniques are derived from the feedback obtained from the dichromat comprehension techniques. However, recollection of dichromats has been proven to produce effective results and may lead to better solutions for these individuals. With the proposed model, it is possible to mimic the view of other dichromacy. Therefore, the potential for future work is to restore the image. As we have worked on some collected photos and real-time images, in future, there will be a concept of working on videos, not just still pictures and also applying this technique on Android devices and computers so that blind people can have a better life like ordinary people.

References

Alpern, M., & Wake, T. (1977). Cone pigments in human deutan colour vision defects. *The Journal of Physiology, 266*(3), 595-612. https://doi.org/10.1113/jphysiol.1977.sp011778

Aydin, T. O., Mantiuk, R., Myszkowski, K., & Seidel, H. P. (2008). Dynamic range independent image quality assessment. *ACM Transactions on Graphics (TOG), 27*(3), 1-10. https://doi.org/10.1145/1360612.1360669

Berendschot, T. T., Van de Kraats, J., & Van Norren, D. (1996). Foveal cone mosaic and visual pigment density in dichromats. *The Journal of Physiology, 492*(1), 307-314. https://doi.org/10.1113/jphysiol.1996.sp021303

Bergman, L. D., Rogowitz, B. E., & Treinish, L. A. (1995, October). A rule-based tool for assisting colormap selection. *In Proceedings Visualization'95* (pp. 118-125). IEEE. https://doi.org/10.1109/VISUAL.1995.480803

Brainard, D. H., & Vision, S. (1997). The psychophysics toolbox. *Spatial Vision, 10*(4), 433-436. https://doi.org/10.1163/156856897X00357

Brettel, H., Viénot, F., & Mollon, J. D. (1997). Computerized simulation of color appearance for dichromats. *JOSA A, 14*(10), 2647-2655. https://doi.org/10.1364/JOSAA.14.002647

Cicerone, C. M., & Nerger, J. L. (1989). The density of cones in the fovea centralis of the human dichromat. *Vision Research, 29*(11), 1587-1595. https://doi.org/10.1016/0042-6989(89)90031-0

Colblindor (2021). Color BLIndness Simulator. Retrieved from: https://www.color-blindness.com/category/tools/

Culp, G. M. (2012). Increasing accessibility for map readers with acquired and inherited colour vision deficiencies: a re-colouring algorithm for maps. *The Cartographic Journal, 49*(4), 302-311. https://doi.org/10.1179/1743277412Y.0000000023

Davis, H. (2019). Creative Black and White: *Digital Photography Tips and Techniques*. Rocky Nook, Inc.

DeMarco, P., Pokorny, J., & Smith, V. C. (1992). Full-spectrum cone sensitivity functions for X-chromosome-linked anomalous trichromats. *JOSA A, 9*(9), 1465-1476. https://doi.org/10.1364/JOSAA.9.001465

Grundland, M., & Dodgson, N. A. (2007). Decolorize: Fast, contrast enhancing, color to grayscale conversion. *Pattern Recognition, 40*(11), 2891-2896. https://doi.org/10.1016/j.patcog.2007.03.019

Huang, D. W., Sherman, B. T., Zheng, X., Yang, J., Imamichi, T., Stephens, R., & Lempicki, R. A. (2009). Extracting biological meaning from large gene lists with DAVID. *Current Protocols in Bioinformatics, 27*(1), 13-11. https://doi.org/10.1002/0471250953.bi1301s27

Hurvich, L. M. (1972). Color vision deficiencies. In *Visual psychophysics* (pp. 582-624). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-96188-4_17

Ishihara, S. (1990). *Ishihara's Tests for Color-Blindness,* (38th ed.). Kanehara, Shuppan: Tokyo, Japan.

Jefferson, L., & Harvey, R. (2006). Accommodating color blind computer users. In *Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility* (pp. 40-47). https://doi.org/10.1145/1168987.1168997

Kondo, D. K. (1990). *Crafting selves: Power, gender, and discourses of identity in a Japanese workplace*. University of Chicago Press.

Lin, H. Y., Chen, L. Q., & Wang, M. L. (2019). Improving discrimination in color vision deficiency by image re-coloring. *Sensors, 19*(10), 2250. https://doi.org/10.3390/s19102250

Rasche, K., Geist, R., & Westall, J. (2005). Detail preserving reproduction of color images for monochromats and dichromats. *IEEE Computer Graphics and Applications, 25*(3), 22-30. https://doi.org/10.1109/MCG.2005.62

Ribeiro, M., & Gomes, A. J. (2019). Recoloring algorithms for colorblind people: A survey. *ACM Computing Surveys (CSUR), 52*(4), 1-37. https://doi.org/10.1145/3347717

Shrestha, R. (2020). A framework and methodology for spectral color vision deficiency imaging. In *Proceedings of the International Colour Association (AIC) Conference*. International Colour Association.

Tasnim, A., & Hasan, M. S. (2017). An improved dynamic daltonization for color-blinds. In *2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)* (pp. 798-801). IEEE. https://doi.org/10.1109/R10-HTC.2017.8289043

Viénot, F., Brettel, H., & Mollon, J. D. (1999). Digital video colourmaps for checking the legibility of displays by dichromats. *Color Research & Application, 24*(4), 243-252. https://doi.org/10.1002/(SICI)1520-6378(199908)24:4<243::AID-COL7>3.0.CO;2-9

Vischeck (2021). Colorblind Image Correction. Retrieved June 27, 2022, from https://www.vischeck.com/daltonize/

Wakita, K., & Shimamura, K. (2005). Smartcolor: disambiguation framework for the colorblind. In *Proceedings of the 7th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 158-165). https://doi.org/10.1145/1090785.1090812

Wong, B. (2011). Color blindness. *Nature Methods, 8*(6), 441. https://doi.org/10.1038/nmeth.1618