Image Filter for a Color Deficient Person

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Problem Statement

A color deficient person cannot distinguish the difference between some colors. Such deficiency is known as color blindness. Such condition is caused by the absence of some color-sensitive pigment in the retina's cone cells. Out of all the persons diagnosed by color blindness, 90% of them will be suffering from some kind of red-green deficiency in which they cannot distinguish red and green color. Figure-1 given below shows an example of the vision of a color blind person.

Figure-1 [1]

Aim of the project is to develop a filter for a color blind person so that they can perceive the image details and color dynamics in much better way and try to explore the effectiveness of different method to do the same in order to improve the vision of a color blind person.

Following are some of the statements from the people suffering from color blindness. [1]
- "If I get an email with words highlighted in red, I can't see them."
- "I couldn't spot an orange laying in my lawn."

One of the misconception is that people suffering from color blindness will only see in shades of gray color. Rather, some of the common color blindness is basically the inability to perceive the differences between some colors. One of the most common type of color blindness leads to difficulties discriminating between red and green hues of the color. The above figure on the right demonstrates what a person with red-green color blindness will see when looking at the rainbow stripes on the left. Total color blindness is much rarer. [1]

Since we have increased the use of colors in all the multimedia contents and used them to convey different visual information, it is really important to perceive the colors for proper and accurate information interpretation. Roughly there are around 5% to 8% of men and 0.8% of women that have some kind of color deficiency or color blindness around the world. Hence the multimedia contents with rich colors information, which a person with normal color vision can be well discriminated, may cause misunderstanding to people with anomalous color vision. [2]

Images that have such colors and shades can be difficult to view. Also recognizing object within that images can also be hindered. Thus a processing system to compensate this natural mutation would be beneficial to the community. Color blind individuals generally have difficulties in modern society with traffic lights, paint samples, digital images and many more. Our focus is on filtering the digital images in order to correct the color vision deficiency. Normally this is not life threat and most color blind people live normally. Some people may not even know they are affected without performing testing. [3]

Considering the above mentioned problems here in this project we are proposing two different ways to filter an image so that the color deficient person can distinguish between the colors that he/she is not able to see and interpret the information presented by the image. Basically we will start with the simulation of the vision of a color deficient person that will help us in understand how they see the world. Once the simulation is done we will use the data of information lost to improve the image. Here we will discuss two approaches. First approach will try to clip the lost information and adjust the image according to it. Here we will decrease the intensity of the color that a color blind person cannot see and try to compensate that color lost with the colors that he/she is able to distinguish between. The second approach will increase the intensity of the colors that a color blind person cannot distinguish between along with the adjustment of other colors in the image. This will basically increase the color intensity of the image overall letting the color deficient person to distinguish between different colors and capture the information presented by the image.

Literature Survey and previous work

Human color vision works on the responses to the photons in three different types of photoreceptors, which are also called “cones” and are present in the retina of the human eyes [4]. The sensitivities of these cones lie in the Long (L), Medium (M), and Short (S) wavelength regions of the light spectrum. Color deficiency is frequently characterized by some shifts of one or more cone types that makes the pigments in one type of cone, not sufficiently distinct from the pigments in others. Lack of L-cones, M-cones and S-cones is referred to as Protanopia, Deuteranopia and Tritanopia respectively. Among these three types of color deficiency, Protanopia and Deuteranopia have difficulty in distinguishing red from green which is commonly detected, while tritanopia has difficulty in discriminating blue from yellow which is a rare deficiency. There many research works conducted on simulating and correcting color-deficient vision [5]–[8].

There are three different types of color blindness: Monochromacy, Dichromacy and Trichromacy [9]. Monochromacy is very rare and vision of the person is almost equivalent of a black-and-white movie. Dichromacy is also rare and is the absence of one of the three cones which causes the total loss of vision of that one particular wavelength while Trichromacy is the most common form of color blindness and simply is the defect in one of the three cone systems. The Long/red and Medium/green wavelength sensitive cones are more likely affected resulting in difficulties discriminating reds and greens. This is commonly called “red-green” color blindness. Along with the color difficulties, duller shades of colors are also difficult to distinguish between. [3]

There are basically two causes of color blindness, it can occur in an accident causing eye, brain or nerve damage or is inherited genetically from mutations on the X-chromosome. Since men have only a single X-chromosome, men are much more likely to suffer from color blindness as if the single X-chromosome is affected, the male will be color blind on the other hand women have two X-chromosome, if only one of a woman’s X-chromosomes is affected, she may or may not suffer from any kind of color blindness as the other chromosome could make up for that defect but if both the X-chromosomes are affected then woman will probably suffer from color blindness. As a result, less than 1% of women are color blind whereas 7-10% of males are. [10] If the woman has a defective chromosome then she will be a colorblindness carrier. An affected male's daughters will typically be a carrier. A carrier's male children will most likely be color blind, depending on if they receive father's X-chromosome or mother's X-chromosome. Figure below illustrates the inheritance rules for color blindness. [3]

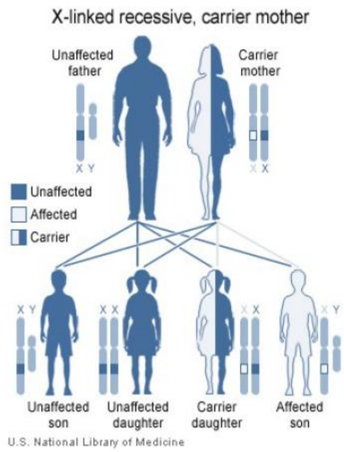


Figure-2 [11]

There are some simple tests available to check if any individual is suffering from color blindness of not. One of the test is The Ishihara color test, [12] which is considered a standard method to test the "red-green" color blindness. It is named after its creator Dr. Shinobu Ishihara in 1917 at the University of Tokyo. This test includes number of colored plates with dots of randomized size and colors. In this dot pattern there is a number or object that should be visible to the individual with normal vision but will be invisible to those with the defects. Figure below shows five examples plates of Ishihara color test.

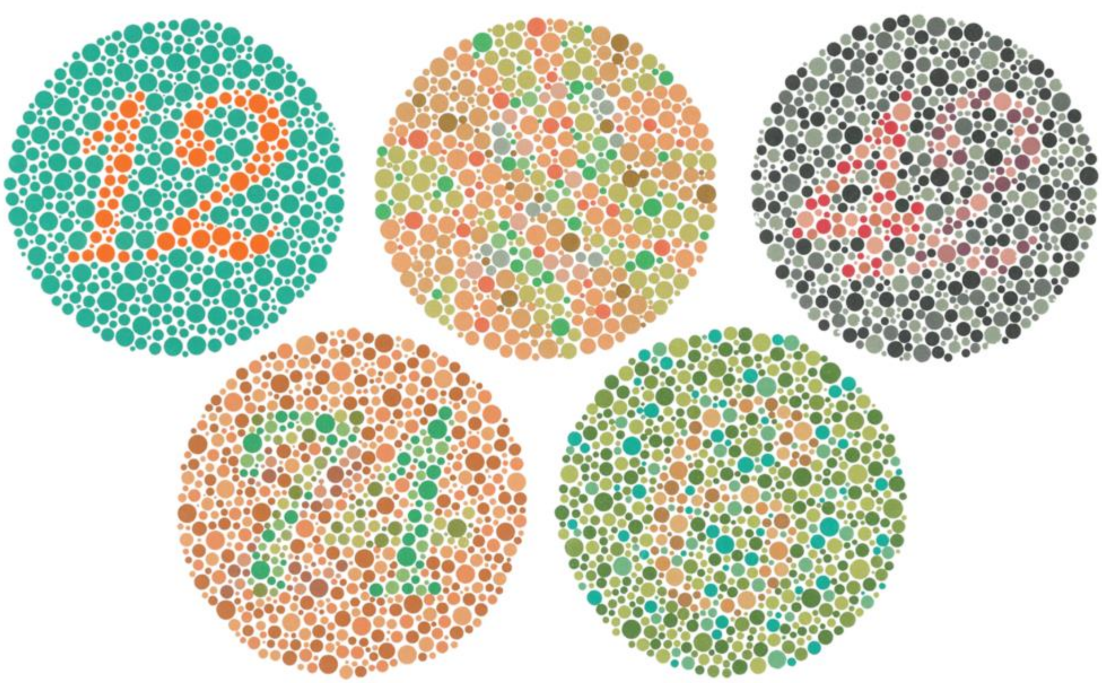


Figure – 3 [12]

The person with normal color vision will be able to see the number 12, 2, 42, 74 and 6 in the above plates but the person suffering from color blindness (specifically "red-green") will not be able to see them.

Technical Description of Methods

The first part of the project is to simulate the vision of a color blind person. Here for this project I have implemented two different simulation of Deuteranopia (less sensitive to green color) and Protanopia (less sensitive to red color) i.e. difficulty in distinguishing red-green color.

- Deuteranopia Simulation

Following is the algorithm to simulate the Deuteranopia [13]:

- Read any input image.
- Convert the RGB image to LMS image using the following matrix:

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

- Further multiply the each LMS pixel value to the matrix give below that will remove the information associated with the M cone and replace it with information perceived by L and S cones. We can see that the M information is removed, however the M component of the new pixel is not completely 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.

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

- Now once again the LMS image will be converted to RGB by simple multiplication of LMS pixel value to the inverse of the matrix mentioned in the first step.
- The output image will be the simulated vision image of a person suffering from Deuteranopia.

- Protanopia Simulation

Following is the algorithm to simulate the Protanopia [14].

- Read any input image.
- Convert the RGB image to LMS image using the following matrix:

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

- Further multiply the each LMS pixel value to the matrix give below that will remove the information associated with the L cone and replace it with information perceived by M and S cones. We can see that the L information is removed, however the L component of the new pixel is not completely empty.

It is filled with a proportion of information from the M and S cones because that L light is seen by the eye but perceived as being from the L and S wavelength bands instead.

$$\begin{bmatrix} L_p \\ M_p \\ S_p \end{bmatrix} = \begin{bmatrix} 0 & 2.02344 & -2.52581 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}$$

- Now once again the LMS image will be converted to RGB by simple multiplication of LMS pixel value to the inverse of the matrix mentioned in the first step.
- The output image will be the simulated vision image of a person suffering from Protanopia.

Deuteranopia being the most commonly found disorder in human beings, in this project I have implemented two different algorithm that can modify the normal colored image to a color blind friendly form through which the person suffering from this disorder can infer the data and visualize the information properly. The two methods namely LMS Daltonization and LAB Color Correction are implemented here.

- LMS Daltonization

This algorithm uses the information that is lost when we are simulating the normal image to the image seen by a person suffering from Deuteranopia. Following is the algorithm of the LMS Daltonization [13]:

- First step is to simulate the Deuteranopia using the method mentioned above.
- Collect the information lost matrix from the image after the simulation is completed by subtracting the output simulated image from the original input image.
- Now multiply the correction matrix mentioned below to the pixel matrix of the information lost matrix:

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

  This operation is nothing but the mapping of the lost information to wavelengths visible to the viewer, which is Long (Red) and Short (Blue) wavelengths.
- Further this shifted matrix of lost information is added back to the original image generating a colorblind friendly image.

Now once the input image is filtered I have once again simulated the filtered image to the colorblind person in order to see if the filter was able to preserve the information shown by the image or not.

- LAB Color Correction

This algorithm works with the LAB color space and increase the color contrast of the image. Following is the algorithm of the LAB Color Correction [13]:

- Read the input image.
- Convert the RGB of the image to LAB color space.
- Decide the parameters i.e. up to what extent we want to enhance the contrast of the image.

- First of all the A component of the LAB color space will be checked for the value. If it is positive or negative. If the A component has positive value, that means the pixel is closer to red color and if the A value is negative that means it is closer to green color.
- We are supposed to alter this A value making positive value more positive and negative value more negative, enhancing the red and green color contrast.
- Once the A component is altered the B component of LAB color space will be shifted according to the red and green color intensity so that we can bring out the blue and yellow shade of the image pixels.
- And in the end the L component i.e. the brightness of the image will be increased relative to the A's value.
- In the end the final output of LAB is converted back to RGB form.

Now once the input image is filtered I have once again simulated the filtered image to the colorblind person in order to see if the filter was able to preserve the information shown by the image or not.

Implementation & Experimental Setup

For the implementation of the project I have used the Image Processing tool box of MATLAB. For each and every implementation I have created separate programs that will take an input of the image and will process them to give out the filtered image. Following is the list of the program I have implemented.

1. SimulationDeuteranopia.m
   - Simulates the Deuteranopia vision.
   - Expects an input image (place the image in same folder and give the image name in the program) to process and displays the simulated vision of the person suffering from Deuteranopia.
2. SimulationProtanopia.m
   - Simulates the Protanopia vision.
   - Expects an input image (place the image in same folder and give the image name in the program) to process and displays the simulated vision of the person suffering from Protanopia.
3. LMSDaltonization.m
   - Implements the LMS Daltonization filter.
   - Expects an input image (place the image in same folder and give the image name in the program) to process and displays the filtered image and final simulated image (of filtered image).
4. LABColorCorrection.m
   - Implements the LAB Color Contrast filter.
   - Expects an input image (place the image in same folder and give the image name in the program) to process and displays the filtered image and final simulated image (of filtered image).

- Input Data

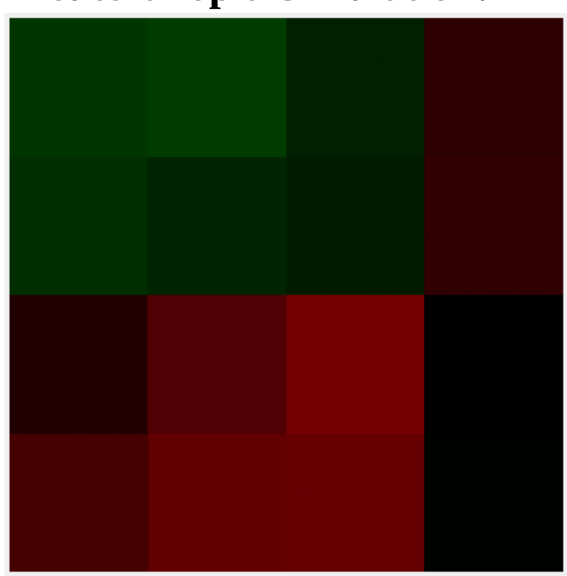
In form of input we can use any suitable colored images.

Results

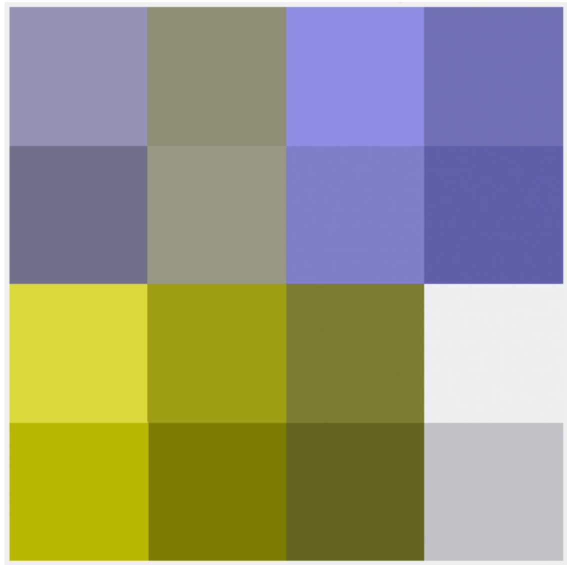
Following are the out puts of the implementation mentioned above. For the sake of simplicity I have used one single image as input so that we can compare the results with each other.

Input Image:

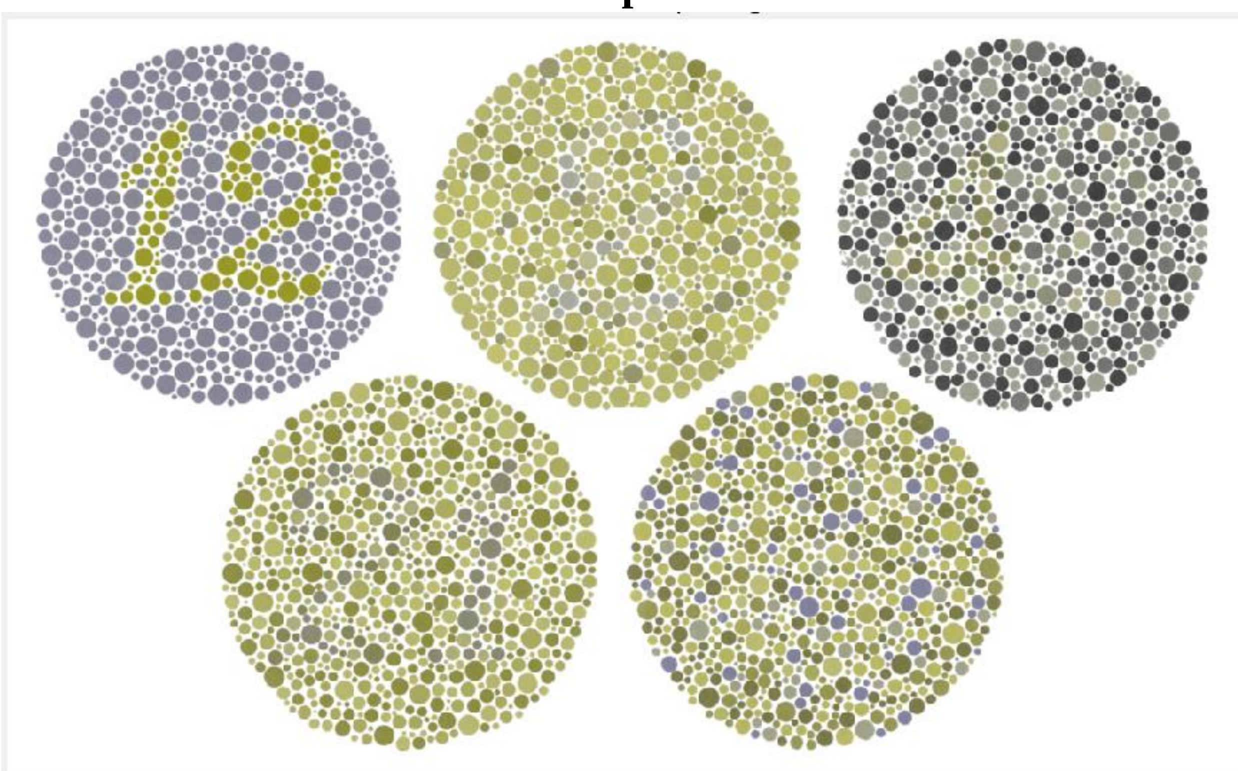
Information lost in Deuteranopia Simulation:



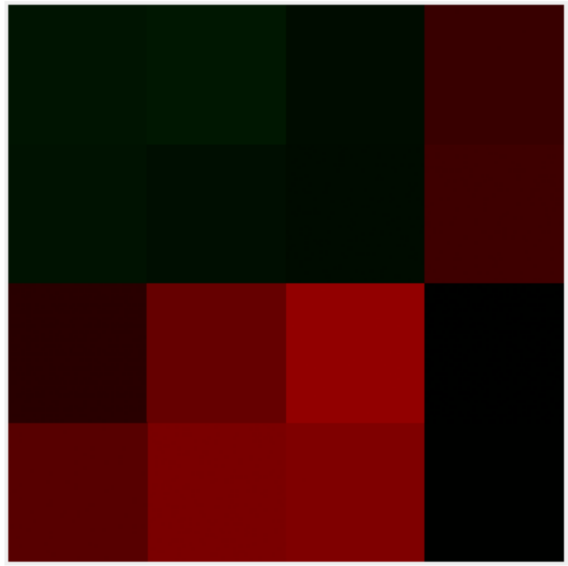
Deuteranopia Simulation:



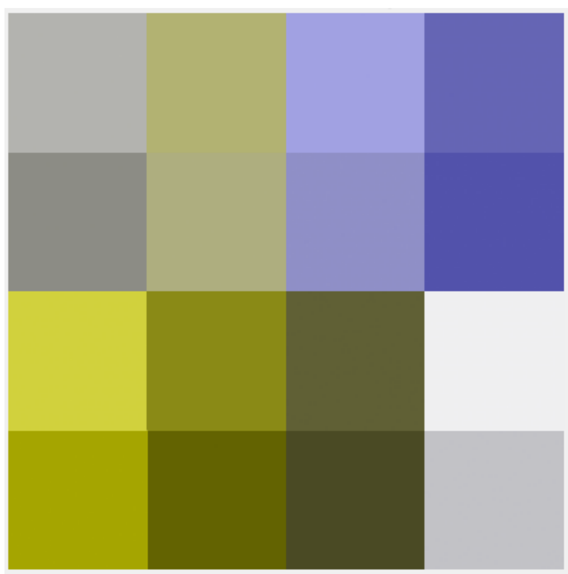
Color Plate Simulation Deuteranopia:



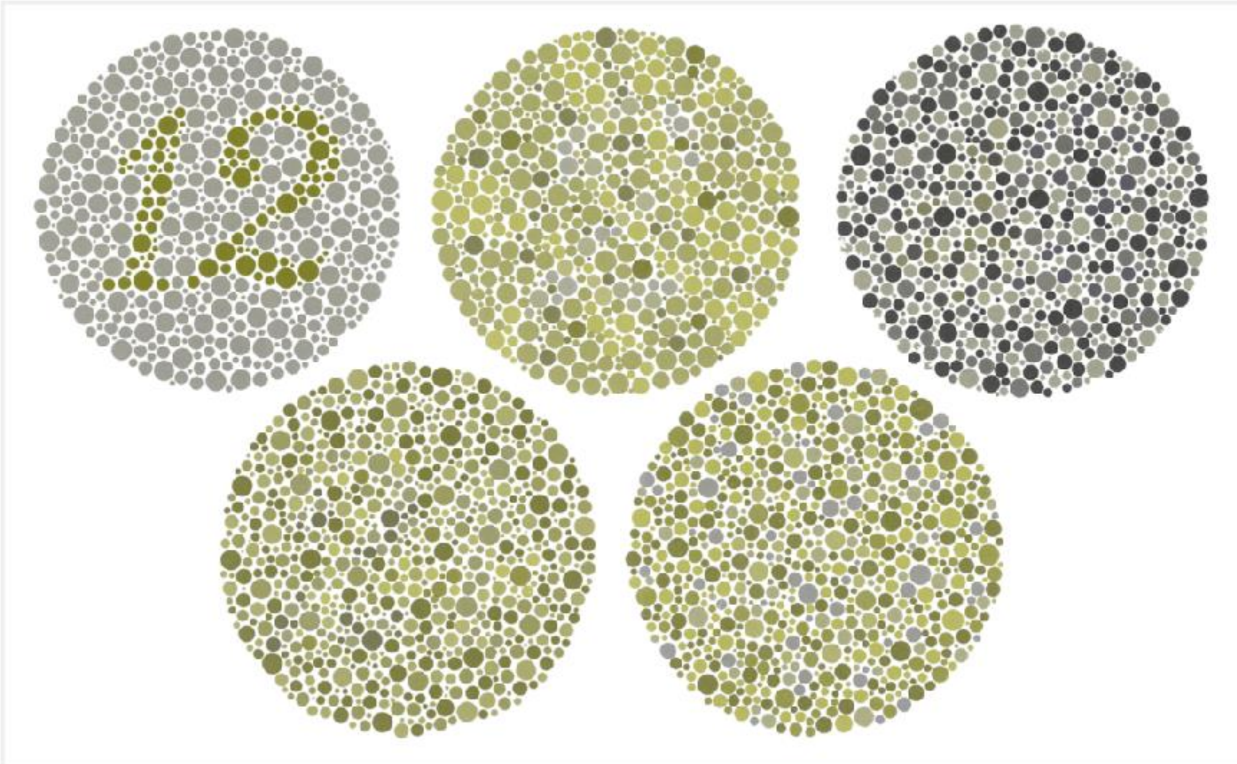
Information lost in Protanopia Simulation:



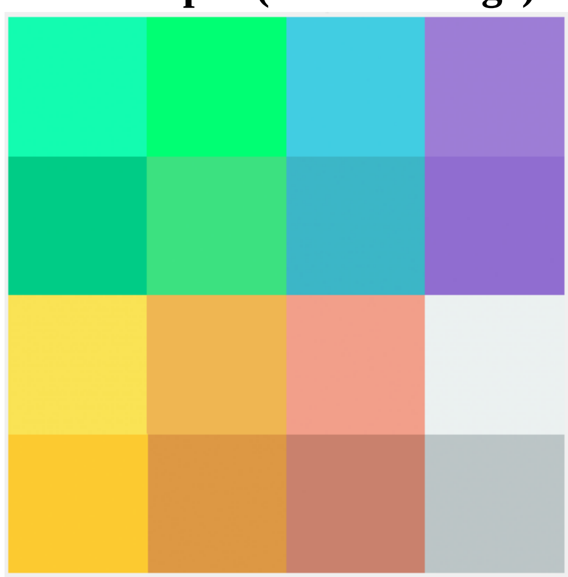
Protanopia Simulation:



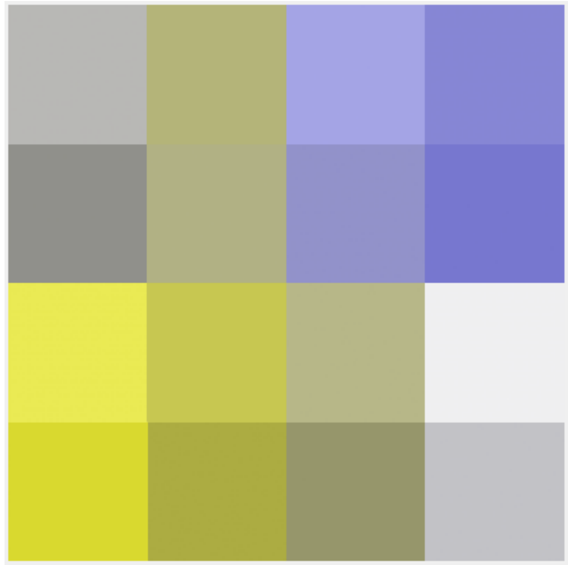
Color Plate Simulation for Protanopia:



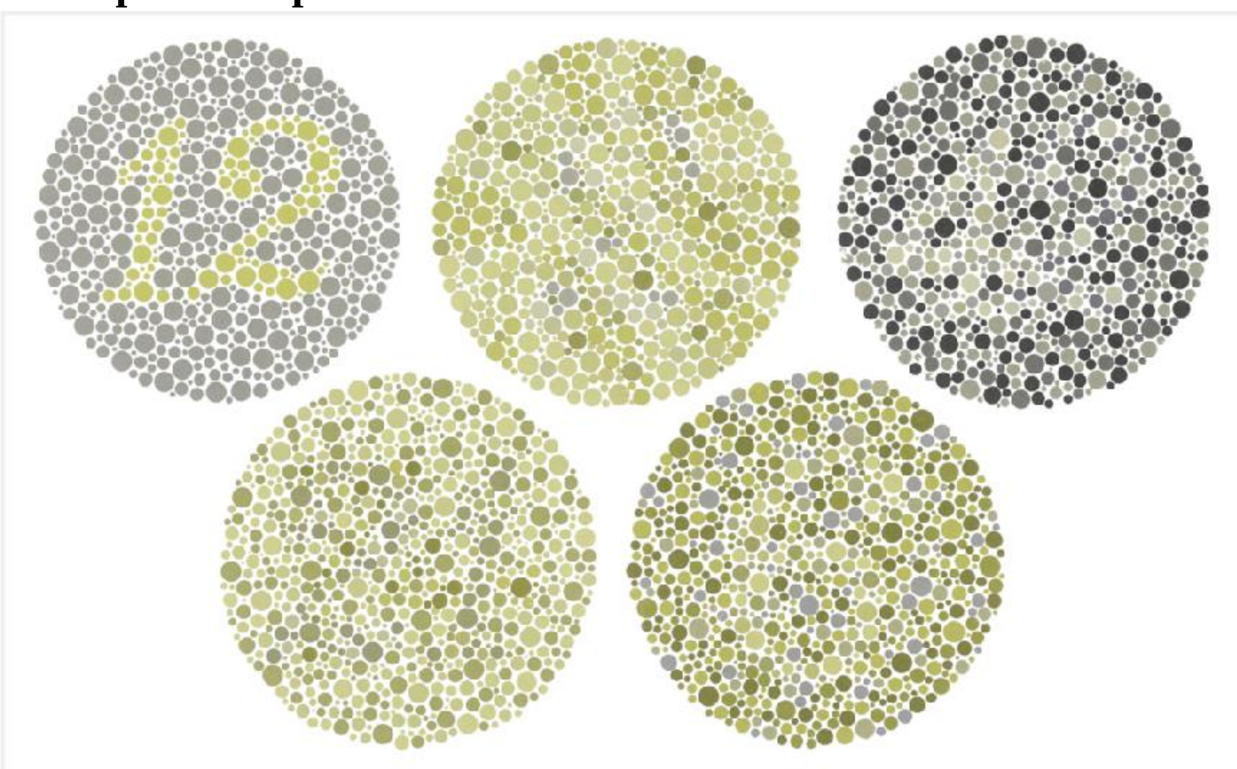
LMS Daltonization filter output (filtered image):



Deuteranopia Simulation of LMS Daltonization filtered image:

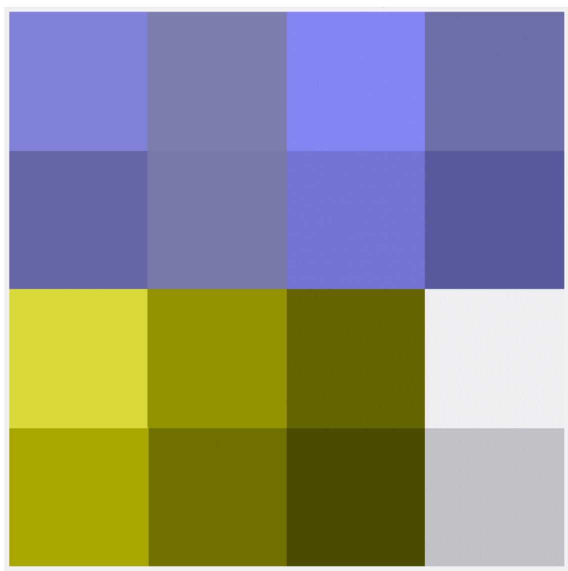


Color plates output of LMS Daltonization filter:

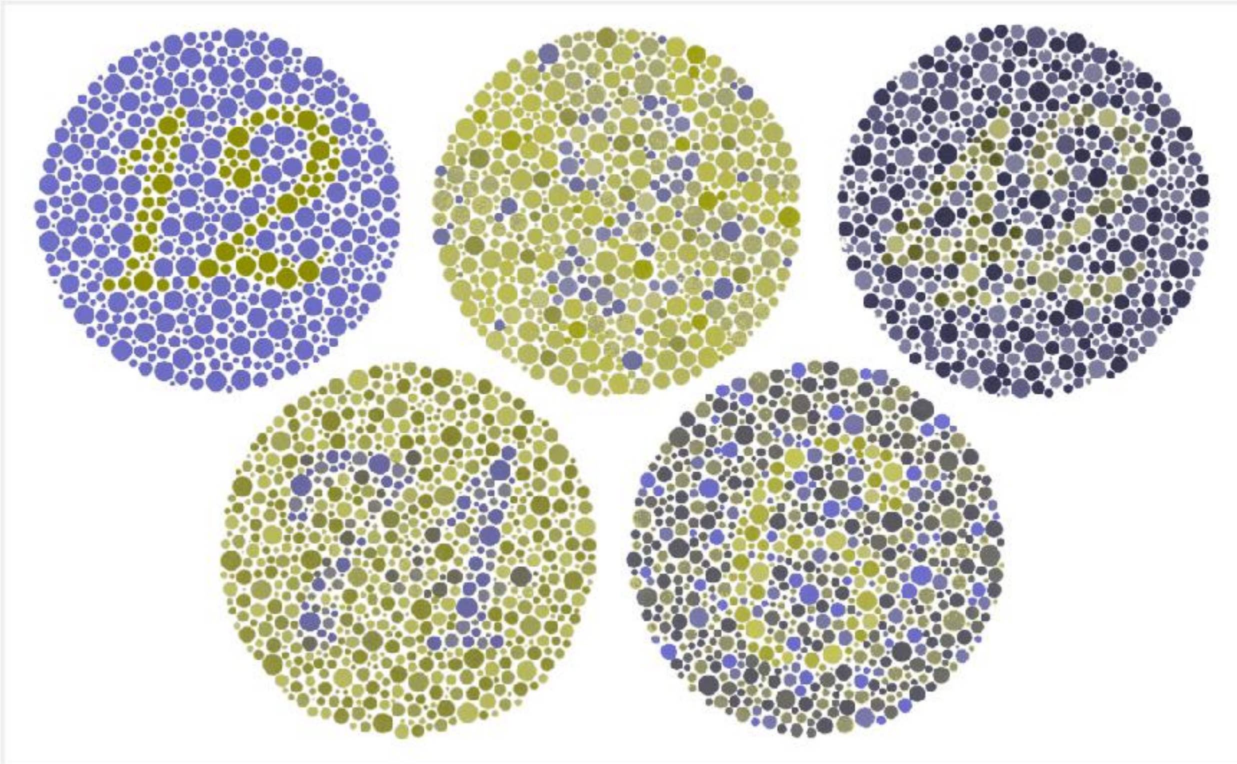


LAB Color Correction filter output (filtered image):

Deuteranopia Simulation of LAB Color Correction filtered image:



Color plates output of LMS Daltonization filter:



Conclusions

Many people around the world are affected by color blindness, but very little has been done to investigate image processing methods that helps in getting over the color blindness. Throughout this project we have simulated the vision of the color blind person and demonstrated two of the methods that can help in removing this deficiency using digital image processing. Most commonly the “red-green” type of color blind ness is seen and to be precise the green colored deficiency is seen the most.
Also the simulations were tested on the color plates as well which demonstrates the problems faced by any person suffering from color blindness as he /she will lose significate amount of details from the image i.e. they are not able to identify the digit in the plates. Also the filter algorithms does demonstrates quite impressive results in improving the quality of the image for the color blind person. We can easily identify the digits in the plates after implementing the filter which was not possible in the simulation image outputs.

Future Work

In the future we can use this implementation of the filters and convert them into more compact and handy form i.e. implement them in to a mobile or tablet application that can be easily accessed by the patients. Further this approach can be extended to altering and filtering the user interface of the websites, mobile devices, and laptop computers as well. This a sincere attempt to make the world a better place for color blind people.

References

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[14] https://ssodelta.wordpress.com/tag/rgb-to-lms/
[15] http://www.mathworks.com/help/matlab/learn_matlab/matrices-and-arrays.html?refresh=true
[16] http://www.mathworks.com/help/images/ref/makecform.html

Read Me:

- All the simulation and filters are implemented using MATLAB as it provides much easy and simpler interface for image processing.
- For all the tasks to be performed, I have created different MATLAB functions.
- All the functions were tested on different color images.
- Following is the list of files:
  - SimulationDeuteranopia.m (For Deuteranopia simulation)
  - SimulationProtanopia.m (For Protanopia simulation)
  - LMSDaltonization.m (For LMS Daltonization filter)
  - LABColorCorrection.m (LAB Color Correction filter)
- Also for all the function the images should be placed in the same folder of the function.