Image Processing for Colour Blindness Correction

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Abstract— **Colour blindness is a genetic mutation that alters the colour vision of the subjects by decreasing the sensitivity to certain colour wavelengths, depending on the defect. There are many forms of colour blindness ranging from monochromacy (black-white) to the most common form, the "red-green" variation where reds or greens are weakened, the vibrant shades are easily seen and the dull shades are difficult to perceive. A filter was designed based on the Ishihara colour tests in order to correct the colour blind deficiencies. This was successful for seeing the hidden objects within the test plates but did not translate well for real world images. The filter was modified, removing the dullest/lightest shades and shifting all the shades to the darker vibrant shades. The original image was shown to colour blind and normal vision subjects with results varying among all the subjects. After the modified filter was applied to a natural image, the colour blind and normal vision subjects were all able to correctly identify the test colours.**

Keywords-component; Colour blind, image processing, Ishihara, Red-green, colour correction, filter design

I. INTRODUCTION

Colour blindness is a colour vision deficiency that naturally occurs within the population. Images with similar colours and shades can prove to be difficult to view. Object recognition within images can also be hindered. Therefore a processing system to aid in this natural mutation would be beneficial. Colour blind individuals often have difficulties in modern society with traffic lights, paint samples and digital images. Our focus is on the later: filtering digital images in order to correct the colour vision deficiency. There exists little to no help for most colour blind individuals. Normally this is not life threatening and most colour blind people live normally. Some people may not even know they are affected without testing. Modern societies have even started to aid the colour blind with traffic signals; blue hues are added to the green traffic light, while orange hues are added to the red light to further distinguish the three colours from each other. However, with modern image processing technology, it may be possible to design an aid to enhance the colour blind's perception of colour in everyday situations.

II. BACKGROUND

A. Trichromatic Vision

The human eye contains two types of image receptors: rods and cones [2]. The rod receptors are sensitive to low light levels but do not differentiate colours. Cones, on the other hand, are only sensitive to brighter light levels but enable us to see different colours. Colour perception is due to presence of three types of cones: long, medium and short wavelength cones. They each correspond to a specific light wavelength that represents the three basic colours red (long wavelength), green (medium) and blue (short) as shown in figure 1. Vision that uses three receptors for colour perception is referred to as trichromatic vision.
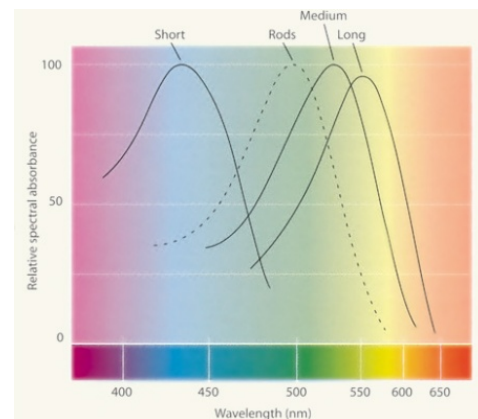

Figure 1. The wavelength of the cone systems [2]

B. Colour Blindness

There are three degrees of colour blindness: monochromacy, dichromacy and anomalous trichromacy [2]. Monochromacy is very rare and vision is limited to the 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 wavelength. Anomalous trichromacy is the most common form of colour blindness and simply is the defect in one of the three cone systems. The middle/green and long/red wavelength sensitive cones are more likely affected resulting in difficulties discriminating reds, yellows and greens. This is commonly called "red-green" colour blindness. Along with the colour difficulties, duller shades of colours are also harder to distinguish, whereas vibrant colours are easier to see. The medical names are

protanomaly for red defect and deutranomaly for the green defect. The less common form of trichromacy, tritanomaly, is the blue cone defect and results in trouble discerning blues and yellows.

There are two causes of colour blindness. It can occur in an accident after birth causing eye, brain or nerve damage. Most commonly colour blindness is inherited genetically from mutations on the X-chromosome. Since men have only a single X-chromosome, men are much more susceptible to colour blindness: if the single X-chromosome is affected, the male will be colour blind. If only one of a woman's X-chromosomes is affected, she may not present any colour blindness as the other chromosome could make up for the defect. Therefore, both X-chromosomes must be affected in order for a woman to be colour blind. As a result, less than 1% of women are colour blind whereas 7-10% of males are, [4]. 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 colour blind, depending on if they receive mother's X-chromosome or father's X-chromosome. Figure 2 illustrates the inheritance rules for colour blindness.
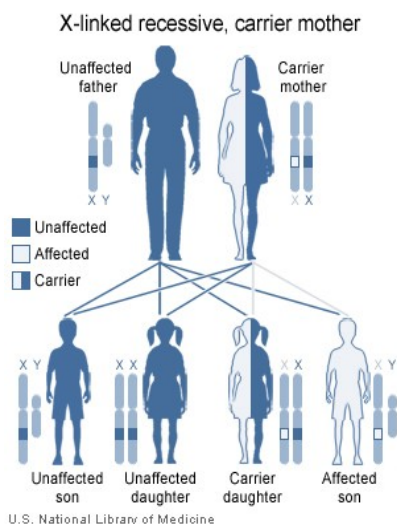

Figure 2. Inheritance rules for colour blindness [3]

C. Tests for Colour Blindness

Over the years, a number of different tests for colour blindness have been developed.

1) Ishihara colour test

The Ishihara colour test, [6] is a standard way to test for "red-green" colour blindness. It was named after its creator Dr. Shinobu Ishihara in 1917 at the University of Tokyo. The test has a variety of coloured plates with a circle of dots of randomized size and colour. In this dot pattern is a number or object that should be visible to those with normal vision but invisible to those with the defect. Figure 3 shows six examples of Ishihara colour plates.
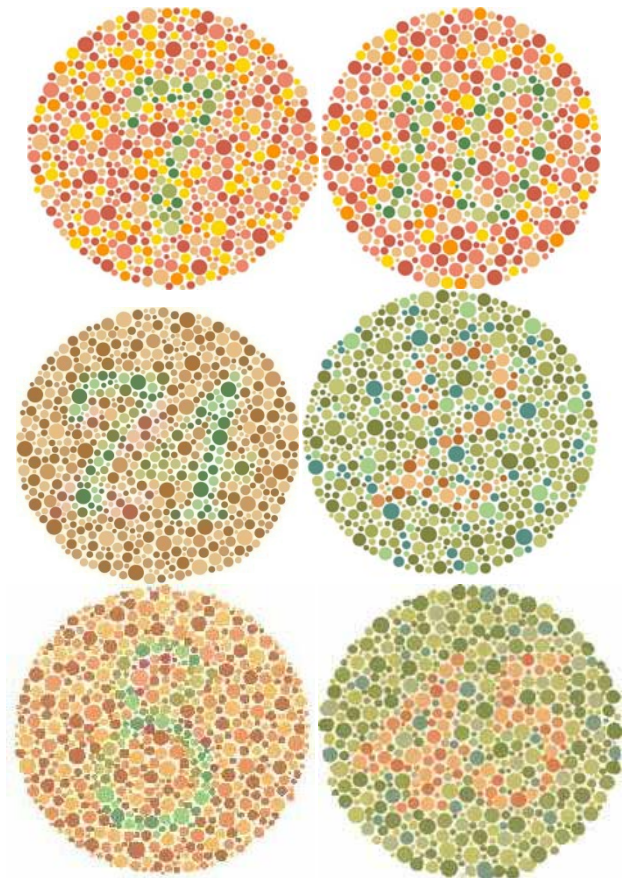

Figure 3. Ishihara plates. From top left: 7, 10, 4, 2, 8, 45

2) Colour Difference Vectors

A quantitative scoring technique for panel tests of color vision, [5], presents a complex scoring scheme with Color Difference Vectors (CDV) to determine the type of colour blind defect, the degree of the defect and the amount of randomness in the sample.

Figure 4. Circle test for CDV analysis

The circles must be arranged from left-to-right matching the colour most like the colour directly to the left. Figure 4 shows the test at starting. Figure 5(a) shows the sorted circles by a normal vision subject compared to 5(b) for a colour blind subject. The patterns within the arrangement of the coloured circles reveal the estimation of the colour blind qualities.

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Figure 5. (a) Normal subject results, (b) Colour blind subject results

The arrangement of the coloured circles generates CDVs that are used to create the moment of inertia. The moment of inertia is yields three important factors: confusion angle (A), selectivity index (E) and confusion index (F). The confusion angle can be used to identify the type of colour defect. The selectivity index (major radius/minor radius) tells the amount of polarity of the subject: the larger the value the more severe the degree of the vision deficiency. The confusion index is the comparison of the normal (perfect) vision arrangement to the erroneous arrangement and quantifies the colour difference. The research in [5] presented a chart for comparison of these values. A large panel of 53 normal and 66 colour deficient subjects were used to calibrate the data and the scoring results of this testing is shown in Table 1.

TABLE I.   CALIBRATION OF SCORING RESULTS

Type of Colour Vision	Angle (A)	Major Radius (B)	Minor Radius (C)	Total Error (D)	S-Index (E)	C-Index (F)
Normal	62.0	9.2	6.7	11.4	1.38	1.00
Minor Error	-12.1	9.8	9.2	13.4	1.07	1.06
Protanomaly	28.3	18.0	8.2	20.4	1.97	1.95
Protanope	8.8	38.8	6.6	39.4	6.16	4.20
Deuteranomaly	-5.8	25.4	9.6	27.5	2.99	2.75
Deuteranope	-7.4	37.9	6.3	38.4	6.19	4.10
Tritanomal	-80.8	16.3	6.4	17.5	2.57	1.77
Tritanope	-82.8	24.0	6.4	24.9	3.94	2.60

D. Previous Work

Little work has been done investigating the use of image processing filters to assist colour perception for the colour blind. Some work has been done in order to attempt to filter real-world with physical devices. A colour sensing system to aid the colour blind was presented in [4]. The author designed a simple system with two colour sensors that detect the colours and sends an analog voltage to a microcontroller. The signal is then conditioned and related to a colour. The colour detected is output on a display screen where it can be read by the colour blind. The system was effective in performing this basic operation. The wavelengths of each colour were detected and the theory behind the anomalous trichromacy deficiencies was graphed. It was found that the red/green (common) defects result in the medium (green) and long (red) curves being shifted to the left. This results in the lack of detection of these specific wavelengths.

III. METHODS

A. Test Subjects

First, the CDV method proposed in [5] was used with eight test subjects: four colour blind males and four individuals with normal vision (two men & two women). The quantitative testing proved to be accurate as the test subjects with normal vision (NM_1, NM_2, NF_1 NF_2) all scored the same (perfect, see Table 2) where the test subjects that were colour blind (CB_1, CB_2, CB_3, CB_4) all scored unique results with varied output (Table 3).

TABLE II.   NORMAL VISION RESULTS

	Results (NM_1)	Results (NM_2)	Results (NF_1)	Results (NF_2)
A	61.98	61.98	61.98	61.98
B	8.85	8.85	8.85	8.85
C	7.21	7.21	7.21	7.21
D	11.42	11.42	11.42	11.42
E	1.23	1.23	1.23	1.23
F	0.96	0.96	0.96	0.96

TABLE III.   COLOUR BLIND VISION RESULTS

	Results (CB_1)	Results (CB_2)	Results (CB_3)	Results (CB_4)
A	11.41	18.73	17.58	13.32
B	22.32	14.03	16.38	18.39
C	8.97	8.61	8.58	8.45
D	24.06	16.46	18.49	20.24
E	2.49	1.63	1.91	2.18
F	2.42	1.52	1.77	1.99

All four test subjects tested within the same range of colour blindness according the study: protanomalous. Test subject CB_1 is shown to have the most colour defect while CB_2 has the least defect. The results show that all test subjects were within the protanomaly level which is the red weakness colour defect, long wavelength.

It is therefore hypothesized that the red portion of the image should be altered in order to aid the colour blind test subjects. Every colour blind individual's vision is unique and therefore the level of correction may need to be optimized in order to achieve accurate results. The Ishihara colour plates will first be examined and processed in order to determine if colour correction can aid in the visibility of the numbers in the plates. Once this analysis is complete, real world digital images will be filtered to determine if colour correction can then be implemented. The processing will be performed in MATLAB.

IV. RESULTS AND DISCUSSION

A. Preliminary Ishihara Analysis

The Ishihara plates were shown to both sets of test subjects. The numbers inside the plates (7, 10, 4, 2, 8 and 45) are not visible to any of the four red-green colour blind subjects

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whereas all four normal vision subjects could correctly identify all six values. The designing and testing of various filters and image enhancement techniques were used on the images. As a simple approach, the images were processed to remove the green and blue components leaving only the red component. This can be easily implemented in MATLAB using the imadjust command:

```
A=imadjust(IM,[0 0 0; 1 1 1],[0 0 0; 1 1 1],[1 0 0])
```
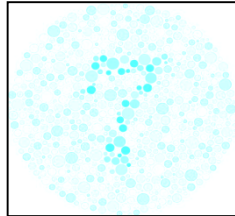

Figure 6.   Ishihara Plate: Red component only.

By filtering out these two colour components only the "weak" red component remained. An example Ishihara image is shown in Figure 6. The image is very bright and the object ("7") within the plate was visible to the protanomalous test subjects and normal vision subjects.

The next filter is built on the same idea of removing the unaffected colour wavelengths (green/blue) and focus on the weakened red. The same function was used with the gamma weight towards the darker (higher) pixels to decrease the image brightness. In MATLAB, this was accomplished as:

```
A=imadjust(IM,[0 0 0; 1 1 1],[0 0 0; 1 1 1],[2 0 0])
```
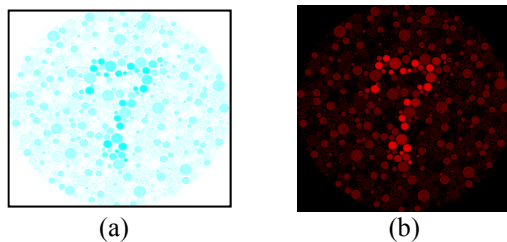

Figure 7.   (a) Gamma weighted towards dark side, (b) Final filter result

As expected the image is slightly darker as seen in Figure 7(a). The objects within the Ishihara images again are visible to all subjects. The final improvement on the filter was to negate the image while double the red component and removing the green and blue components. This is displayed in Figure 7(b). The light red/white values are all flipped to the reverse end of the spectrum resulting in a clear bright object being displayed. The function used is:

```
A=imadjust(IM,[0 0 0; 1 1 1],[1 1 1; 0 0 0],[2 0 0])
```

The final generated filtered image was added to the original Ishihara test plate image. The hidden number within the plate became practically invisible to the normal vision subjects whereas some of the colour blind subjects could in fact see the hidden value in the new image, see Figure 8 (a, b).
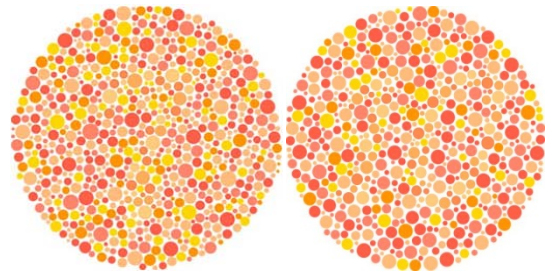

Figure 8.   Hidden values with the colour blind filter

More research was to be done around this idea as perhaps adding in these values helped the colour blind subjects. The next stage is to apply this approach to real images.

B. Digital Image Analysis

Now, it is known that focusing on the red component itself is beneficial in colour blind image processing, whereas overall image attributes like contrast and brightness do not play a large role. Figure 9 illustrates the difference in sensitivity of the red cone receptor. Figure 9(a) shows the normal vision subject cone sensitivity charts and Figure 9(b) shows the protanomalous subject chart. The sensitivity of the read cone is clearly weakened. The sensitivity of the red cone is reduced for all brightness along the curve.
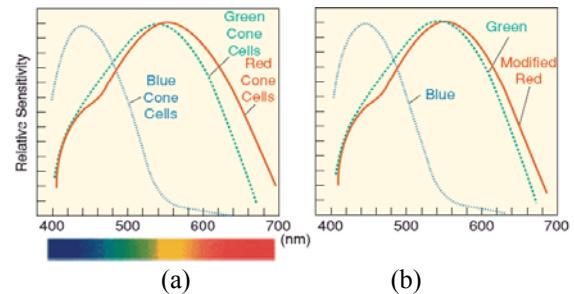

Figure 9.   (a) Normal vision wavelengths, (b) Protanomaly colour blind wavelengths [4]

First, we select a test image for enhancement. An image with lots of colour variety was used as shown in figure 10. The same technique that was attempted on the Ishihara plates was used on the detailed "flower" image with the results displayed in figure 11. The image filtered with the preliminarily designed filter adds far too much red to the detailed image. The concentration of the amount of red had to be reduced. The red component added to the original image is weighted towards the darker red shades. This results in the dark red shades remaining the same and the brighter values becoming darker. This is does not exactly correspond to the shift in sensitivity according to figure 9 as the red wavelength must be completely shifted not just the bright values. We now proceed with this modified filter.

Figure 10. Detailed image processing sample with desired colours labeled

Figure 11. Ishihara filter applied to "flower" image

The histogram of the red component of the original flower image was graphed as shown in figure 12(a). The values of the red component were increased by a tested variable amount. This shifted the values of the histogram to the left, as shown in figure 12(b), darkening the red pixels and effectively removing the lightest 50 shades.
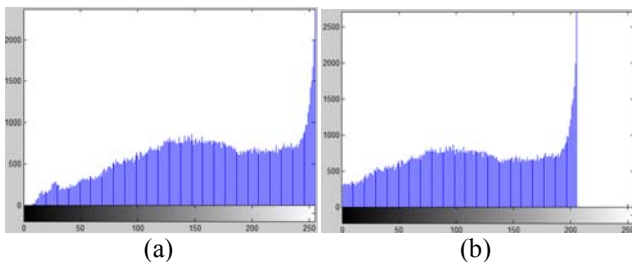

Figure 12. (a) Original "flower" image histogram, (b) Modified red component of the "flower" image

The colour blind subjects had difficulties with the weak or lighter red values. For this reason increasing the darkness of all the red values will theoretically compensate for the genetic

weakness and remove these troublesome shades. Once this was performed the green and blue components of the original image were re-introduced back into the image resulting in figure 13. Labels are placed on six test colours of interest (A-F). The order of the labels (A-F) in the original image and the filtered image were varied to reduce the chance the colour blind subject would remember the order of the colours.

Figure 13. Corrected/Filtered "flower" image

The values of all the red components were increased by 19.5%, (50 of 256 total levels). This value was estimated with the scoring scheme values obtained in the design results. From the histograms in figure 12; we see that the brightest/dullest red pixels are all removed (darkened). Removing the lighter shades of red, which are harder to distinguish, helps the vision correction process as the darker more vibrant shades remain. The original image was shown to five test subjects yielding the results in Table 4:

TABLE IV.   ORIGINAL "FLOWER" IMAGE RESULTS

	NM_1	NF_1	CB_1	CB_2	CB_3
A	Purple	Pink-Purple	Blue	Pink-Purple	Blue-Purple
B	Red	Red	Red	Orange-Red	Red
C	Blue	Blue-Purple	Blue	Blue	Blue
D	Pink	Pink	Pink	Pink	Pink
E	Green	Green	Green	Green	Green
F	Yellow	Yellow	Yellow	Yellow	Orange

The results varied quite a bit. The average colour responses were incorrect 1/6 or 16.67%. The colour blind subjects had trouble with the A & B flowers. The filtered image was also shown to the same four individuals at a different time as shown in table 5:

TABLE V.   FILTERED "FLOWER" IMAGE RESULTS

	NM_1	NF_1	CB_1	CB_2	CB_3
A	Purple	Purple	Purple	Purple	Purple
B	Yellow	Yellow	Yellow	Yellow	Yellow
C	Blue	Blue	Blue	Blue	Blue
D	Green	Green	Green	Green	Green
E	Pink	Pink	Pink	Pink	Pink
F	Red	Red	Red	Red	Red

All five subjects identified the same colours of all six flowers. The colour blind subjects were able to correctly identify the previously incorrect colours because of the correction of the red component. Referring to Table IV for flower labels; the correction has removed the blue/pink distortions that are seen by the colour blind subjects in flower A, the orange distortion seen in flowers B/F and the purple distortion seen in flower C. The image now appears more vibrant, by removing the weaker shades, and it is much easiest now for the colour blind subjects to distinguish the different colours.

V. Conclusions

Many people are affected by colour blindness, yet little has been done to investigate image processing methods to aid the colour blind. This paper has proposed a method to aid the colour blind using digital image processing. In the most common type of colour blindness, a genetic mutation alters the colour vision of the subjects by decreasing the sensitivity to certain colour wavelengths, depending on the defect. Most commonly the "red-green" variation is seen where reds or greens are weakened resulting in vibrant shades being easily seen and the dull shades not. A filter was designed based on the Ishihara colour tests in order to correct the colour blind deficiencies. This was successful for the test plates but did not translate well for real image since there was too much colour compensation. The filter was modified, removing the dullest/lightest shades and shifting all the red shades to the darker vibrant shades. This resulted in an image where colour blind subjects were able to identify the colours in the image correctly, while still having the image appear naturally to those with normal vision. Future research is required to generalize the results in a larger study and to investigate the implementation of such processing in a portable aid for the colour blind.

References

[1] Blanchet Gerald. Charbit, Maurice. *Digital Signal and Image Processing using MATLAB*, Hermes Science Europe. 2001.

[2] Livingstone, M. *Vision and art: the biology of seeing*. Harry N. Abrams, May 2002

[3] U.S. National Library of Medicine "X-linked recessive (carrier mother)" http://www.nlm.nih.gov/. Retrieved, March 2009

[4] McDowell, Jason. "Design of a color sensing system to aid the color blind." *IEEE Potentials*, pp 34-39, v 27, no 4, July-Aug 2008.

[5] Vingrys, A.J. and King-Smith, P.E. "A quantitative scoring technique for panel tests of a color vision" *Investigative Ophthalmology and Visual Science*, v 29, pp 50-63, 1988.

[6] Ishihara, S. "Tests for colour-blindness" Handaya, Tokyo, Hongo Harukicho, 1917.

[7] Gonzalez, Rafael. Woods, Richard. Eddins, Steven. *Digital Image Processing Using Matlab*. Prentice Hall, 2003.