Spectrum Shifting: A Effective Technique for Colour Differentiation for Colour Blind Users

Abstract

Colour Vision Deficiency (CVD) also known as colour blindness affects many people in their day-to-day lives, reducing their ability to distinguish certain colours. The predominant types of CVD are red-green CVD and blue-yellow CVD. We introduce colour spectrum shifting to aid CVD users in enhancing their colour differentiation by taking advantage of the existing range of colours they can perceive. Spectrum shifting has been implemented within ASTER, an iOS phone app applying real-time image processing to the live camera feed. Using ASTER, CVD users can now correctly identify all numbers in a standardised Ishihara test and they also report it effective in everyday use.

Keywords: colour vision deficency, colour spectrum shift, app development, real-time image processing

1 Introduction

We introduce colour spectrum shifting, a novel technique that allows people with CVD to distinguish different colours by taking advantage of the existing colours they can perceive. It is accomplished by eliminating the indiscernible colours in the colour spectrum and using colour interpolation to fill in the gaps. This technique is demonstrated in an iOS app, allowing users to utilise colour spectrum shifting on both a real-time camera feed and pre-existing images.

Approximately 300 million individuals globally experience colour blindness [1], a condition characterised by an altered perception of colours compared to the typical colour perception of the general population. Colour blindness is formally termed Colour Vision Deficiency (CVD), the most prevalent types of CVD are red-green (protan and deutan) and blue-yellow (tritan) [2]. Those with protan and deutan CVD will have difficulty distinguishing or viewing red and green respectively. Similarly, those with tritan CVD will have difficulty distinguishing between blue and green and between yellow and red. A standard way to assess whether an individual has red-green CVD is the Ishihara test, shown in Figure 1. Ishihara tests consist of circular plates with dots of different sizes, there is no discernible pattern or figure that can be inferred due to the placement of irregularly sized dots [3]. Figures and patterns can be created only by applying different colours to the dots, the test assesses whether the user can distinguish between different hues to identify the figure in the test.

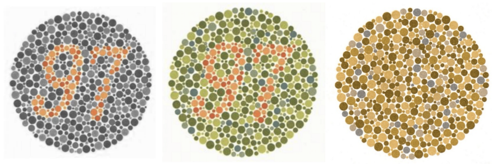


Fig. 1 Number 97 in Ishihara test adjusted for all viewers (left), the original Ishihara test (middle) and the test in the perspective of an individual with Protanopia (right)

Colour spectrum shifting does not enable people with CVD to view any new colours. However, it allows them to perceive much more distinct differences between colours which were previously indistinguishable, making best use of their remaining colour sight capabilities.

This paper is intended to be read in colour and assumes the reader's full-colour vision. Those who are colour blind may have difficulty interpreting some figures as intended but the differences should be apparent.

2 Related Work

Currently, several technologies can aid those with CVD and minimise the effects of CVD on their lives. Some existing solutions are colour blindness correcting glasses, colour-detecting pens and mobile apps.

EnChroma glasses filter light to enhance the contrast between red and green light [4]. However, they are only suitable for red-green CVD users, meaning there is no alternative for individuals with blue-green CVD. They aren't designed for those with Dichromacy (only two cones are functioning), therefore, this solution is only suitable for those with mild CVD [4]. A study also showed that the glasses will not allow the user to view colours they previously were unable to perceive. Instead, they enable the user to view the same colours differently [5].

"Colorino Colour Identifier and Light Detector" is a product used to help users identify colour. It is a small device that can be conveniently carried around. It announces the colour of an object when pointing the device to the object and pressing a button. It can announce up to 150 shades and detect the proximity and intensity of light [6]. There are several mobile app alternatives currently, one of them is "Color Name AR" [7], it can identify colours in real time and shows users the name of the colour along with other metadata such as RGB codes.

"Color Blind Pal" is another mobile app that has useful features to help those with CVD. It has features such as a pixel colour indicator, stripe overlay on reddish colours and filtering specific colours [8]. These features are useful for people with different types of colour blindness, for example, an individual can filter out the colour green, to differentiate between shades of green and red on the map when looking for landmarks.

In this work, "CVSimulator" [9] was used when observing the effects of the colour spectrum shift from the perspective of a person with CVD. Since a person with full-colour vision cannot otherwise perceive the benefit of colour shifting for CVD users, by simulating the effects of CVD, CVSimulator highlights the usefulness of the colour shift technique. CVSimulator also serves to educate those with normal colour vision about the struggles of those with CVD.

3 Method and Implementation

Spectrum shifting is implemented by creating colour transfer functions for each different type of CVD. The task is to determine the required spectral translation for each colour that the user cannot distinguish to another that they can, while best preserving existing colour perception. These spectrums are constructed by observing the range of colours viewed by those with CVD and identifying sections which look the same or don't have distinct differences. The new spectrum is created by interpolating the removed hues to leave a complete and continuous range of colours that the user is able to see.

The leftmost spectrum of Figure 2 shows the shifted spectrum catered for people with Protantopia, it removes the red section of the spectrum by using the purple hue which comes after the blue hue and stretching it to the end of the spectrum. The pink/fuchsia hue is shifted to the start of the spectrum to fill in the gaps left by removing the red section. The yellow, green and blue sections are kept the same as this results in a more natural shift in colours.

The middle spectrum of Figure 2 presents the shifted spectrum tailored for people with Deuteranopia. This spectrum was derived from the spectrum for Protanopia, when testing the Protanopia filter using a Deuteranopia simulator, it was noted that distinguishing between the pink/fuchsia hue and the green hue was slightly more difficult. Therefore, the spectrum is modified to enhance the differentiation between the colours.

The rightmost spectrum of Figure 2 is the shifted spectrum created for people with Tritanopia. The red and yellow hues have been stretched to encompass half of the green hue. The green hue is then used to stretch across the blue. This can eliminate the majority of the blue section by translating the blue hue to cyan or green hue.

To stretch the spectrum, colour interpolation [10] is used to fill in the gaps between two values, representing the colours. RGB interpolation is preferable for this application, as interpolation is used when certain hues are removed. If hue interpolation were used, it would reproduce the removed hue, rendering the interpolation ineffective.

A transfer function between each pair of colour spectrums (Figure 2) is implemented as a lookup table of 1000 elements, representing the RGB space. It serves as a mapping between the original colour spectrum to the shifted colour spectrum. It was chosen due to its efficiency. Each RGB value is converted into HSV to obtain the hue, which is then used to index the colour spectrum arrays. The same index is used to retrieve the corresponding shifted hue in the shifted colour spectrum array. Subsequently, the hue of the original HSV value is replaced with the retrieved hue from the shifted colour spectrum. The saturation and value of the HSV value are kept constant

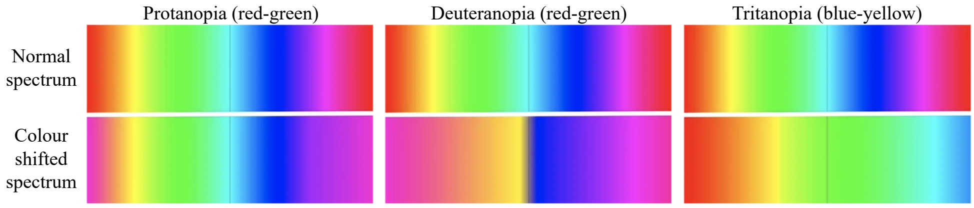


Fig. 2 Shifted Colour Spectrum for Protanopia (left), Shifted Colour Spectrum for Deuteranopia (middle), Shifted Colour Spectrum for Tritanopia (right)

to ensure the camera feed still looks natural. The lookup table can be represented as a filter, the filter will alter the hue of all the colours within an image according to the lookup table and output the image which has been colour shifted.

4 Effect of Colour Spectrum Shifting

Figure 3 shows a sample image (1), how a person with Protanopia (simulated) sees it directly (2), the spectral transform (3) and how this appears to a CVD user (4). Note that the vibrant reds and greens of the toy (1) both appear as brown in the simulator (2). The blue of the stapler and yellows are largely unaffected. When transformed (3) and viewed through the simulator (4) the reds and greens are now clearly distinct, greens remain brown but the reds become distinctly "cyan". The dark blue and yellows (and cyan) remain quite similar but somewhat altered to make space in the transformed spectrum. In practice, the 1000 transformed hues available allow quite subtle differences in colour shading to be discerned. Since a colour shifted image does not deliver an accurate colour representation a method of colour identification is also desirable, allowing CVD users to view the true colour name at any place on that image.

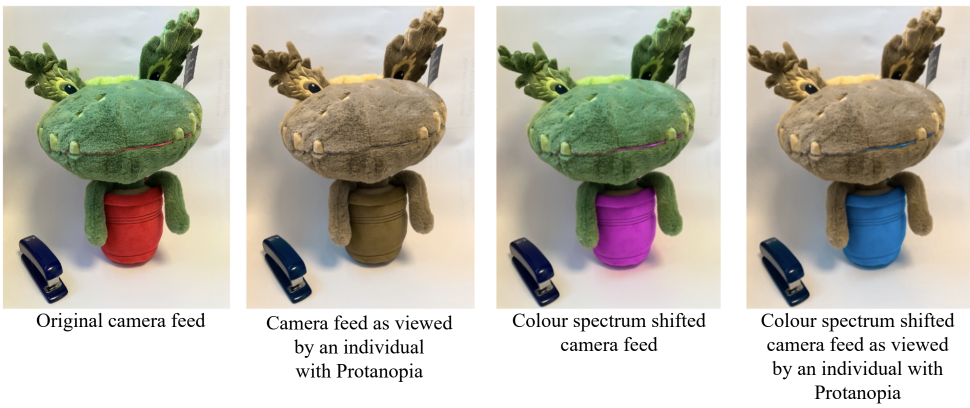


Fig. 3 Colour Spectrum Shifting Effects with Intermediate Steps

Figure 4 presents three representative Ishihara plates in the first column. In the second and fourth columns, a Protanopia and Deuteranopia simulator respectively have been applied to all the plates. The third and fifth columns show the effect of using the colour shift feature on the original plates, the corresponding CVD filter is applied back onto the plate to simulate the CVD condition.

As seen in Figure 4, there is a distinct difference between the Ishihara plates without the app and with the app from the perspective of CVD users. This demonstrates the effectiveness of colour spectrum shifting for individuals with CVD when completing the Ishihara test.

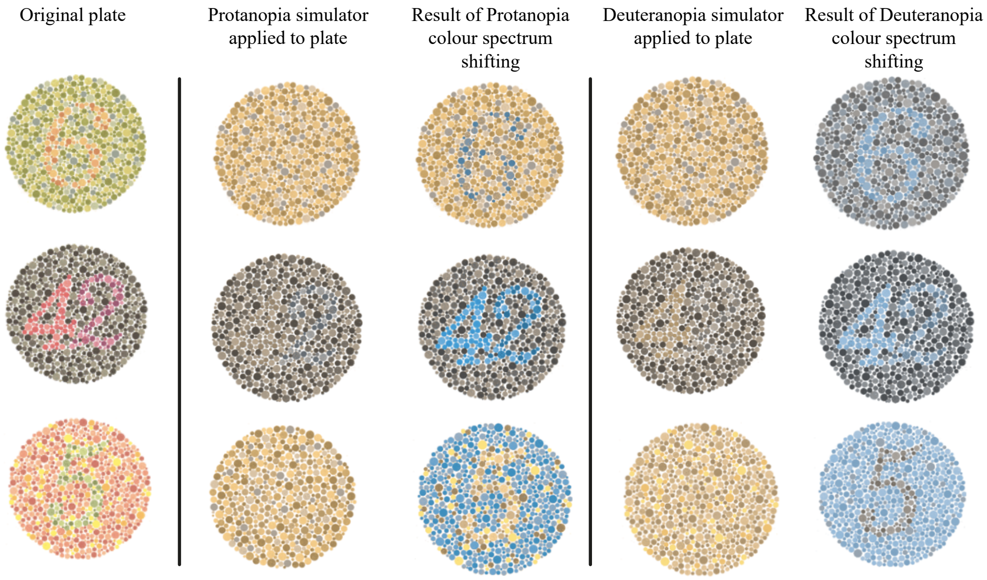


Fig. 4 Effect of Colour Spectrum Shifting on 3 Different Ishihara Plates

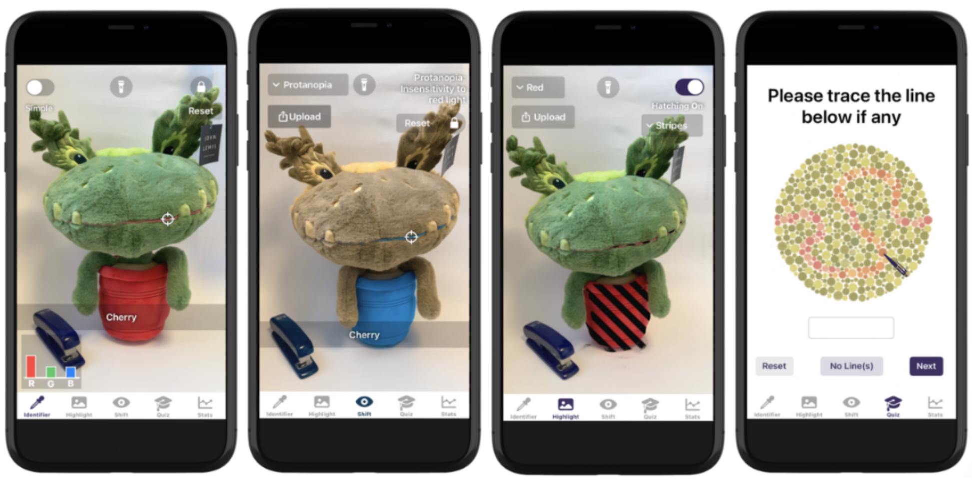
5 Delivery - The ASTER iPhone app

An iOS app called ASTER (Advanced Spectrum Transformation and Enhanced Recognition) has been developed to incorporate colour recognition features along with colour spectrum shifting. This is implemented within the app with an integrated colour identifier. Users can select from the different spectrum shifts available for different types of CVD. The colour identifier includes a movable pointer to allow users to select any pixel to find its colour before the colour spectrum shifting is applied.

ASTER has three main features, colour identification, colour highlighting and colour spectrum shifting. Figure 5 shows the interface for different features in ASTER. Colour identification identifies colours by displaying the colour name of the RGB code of a pixel. In the simple mode for this feature, the Euclidean distance between the pixel's RGB codes and a set list of RGB codes determines the pixel's colour name. The advanced mode for this feature fetches from an Application Programming Interface (API) to display a more extensive list of detailed colour names.

Colour highlighting will emphasise a specified colour by either desaturating all other colours (desaturation mode) or applying patterns and adding textures to the specified colour (hatching mode). A filter is created for each colour to extract the coloured pixels, in this case four colours (red, green, blue and yellow). For instance, if the selected colour is red, applying the red filter displays all red objects in the camera feed against a black background, as all other pixels have become transparent. After extracting the colours, it is overlaid back onto a black and white or colour camera feed for desaturation mode and hatching mode respectively.

ASTER also has an integrated CVD test to indicate whether a user has a form of red-green CVD. Along with the traditional number Ishihara plates, it also includes line tracing Ishihara plates. Users can use a pen to trace the line in the plate to determine whether they may have a type of red-green colour blindness and choose the correct colour shift for their individual needs.



Colour identification (Similar to 'Color Name AR') | Colour spectrum shifting with colour identification | Colour highlighting (similar to 'Color Blind Pal') | Integrated CVD test

Fig. 5 Colour Identification (first), Colour Spectrum Shifting (second), Colour Highlighting in Hatching Mode (third), Integrated Colour Blindness Test (fourth)

6 Evaluation

To evaluate the effectiveness of colour spectrum shifting as a tool for those with CVD to more easily distinguish colours, a user study was performed. 15 participants aged between 18 and 34 with CVD (M: 14, F: 1) were recruited along with a further five participants with the same age and gender balance. The study received a favourable ethical opinion from [Anonymised].

In the evaluation, participants were asked to take an Ishihara test both without and then with the aid of the colour shifting tool. Participants then answered a questionnaire about their experience of using the ASTER app and the colour spectrum shifting aid.

Users were asked to rank the difficulties of completing the Ishihara tests with and without the app (0-Very Easy, 10-Very Difficult). A Shapiro Wilk test found that responses to this test were not normally distributed.

A Wilcoxon Signed-Rank test indicated that the users found the difficulty of the Ishihara test to be statistically very significantly lower when using the app than without the app ($W = 0.00$, $p = 0.001$). The median score on a 10-point Likert scale was 0 with the app compared with 8 without the app. Where 0 indicates that the task was very easy and 10 indicates that the task was very difficult. All users were able to correctly report all of the numbers presented in the Ishihara test.

67% of participants with CVD reported that they did not find the shifted colours distracting or unnatural on first use. 80% of participants also found the feature 'easy to use' and were able to identify the filter suitable for their type of CVD. A user commented that using the colour spectrum shifting "for the Ishihara tests felt like magic" and another user mentioned that even though they could view the number using another filter, using the filter tailored to their type of CVD was much clearer.

The ASTER app was also evaluated in an informal, week-long evaluation. ASTER was found to be useful. A user gave this assessment: "The colour blind app [ASTER] has greatly improved various aspects of my daily life, from identifying colours to observing them more accurately. It's thrilling to finally be able to see the numbers in the Ishihara test, which I couldn't see before. This app has truly enhanced my ability to experience with colours".

7 Summary and Conclusions

Colour spectrum shifting is an effective way to help CVD users distinguish different colours, however, it is unable to help the users identify colours. Some users may require some extra features to be able to recognise the colour of an object as spectrum shifting alters the appearance of an object, meaning it does not represent the accurate colour of the object. ASTER conveniently incorporates features useful for distinguishing and identifying colours into a single app.

Colour spectrum shifting is an innovative method to allow people with different types of CVD to be able to distinguish different colours. By keeping some sections of the colour spectrum constant, the colour spectrum shifting was able to provide a more natural view. Using the CVDSimulator [9], engineering tests were conducted to assess the effectiveness of the colour spectrum shifting from the perspective of an individual with CVD. The app was also shared with individuals with CVD to evaluate its effectiveness and gain feedback for improvements. Two of users were unsure which filter to use for their type of CVD and suggested a configuration in the app to help them select a suitable filter for their type of CVD. Future plans include using a user's cone sensitivities and CVD type to further customise the shifted colour spectrums and provide a more tailor-made experience for all users. Potential future uses include include integrating the colour spectrum shifting into a camera's viewfinder to increase its accessibility and also into rear view cameras of cars to reduce the ambiguity of colours on the road.

In conclusion, when users used the app it was clear that they were able to more clearly distinguish the colours of different objects. ASTER represents a step change in support for CVD users. Formal tests were able to further confirm that users were able to clearly and correctly recognise all the figures in the Ishihara tests with the help of ASTER. Real-world evaluations also indicated a high satisfaction for ASTER with positive feedback after one week of use.

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