3-10-2021

Live Video and Image Recolouring for Colour Vision Deficient Patients

Sami Ali Hussain Ali Choudhry
University of Windsor

LIVE VIDEO AND IMAGE RECOLOURING FOR COLOUR VISION DEFICIENT PATIENTS

By

SAMI ALI HUSSAIN ALI CHOUDHRY

A Thesis
Submitted to the Faculty of Graduate Studies
through the School of Computer Science
in Partial Fulfillment of the Requirements for
the Degree of Master of Science
at the University of Windsor

Windsor, Ontario, Canada

2021

LIVE VIDEO AND IMAGE RECOLOURING FOR COLOUR VISION DEFICIENT PATIENTS

by

Sami Ali Hussain Ali Choudhry

APPROVED BY:

M. Hlynka
Department of Mathematics & Statistics

B. Boufama
School of Computer Science

I. Ahmad, Advisor

School of Computer Science

January 14th, 2021

DECLARATION OF ORIGINALITY

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication.

I certify that, to the best of my knowledge, my thesis does not infringe upon anyone's copyright nor violate any proprietary rights. Any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices. Furthermore, to the extent that I have included copyrighted material that surpasses the bounds of fair dealing within the meaning of the Canada Copyright Act, I certify that I have obtained a written permission from the copyright owner(s) to include such material(s) in my thesis and have included copies of such copyright clearances to my appendix.

I declare that this is a true copy of my thesis, including any final revisions, as approved by my thesis committee and the Graduate Studies office and that this thesis has not been submitted for a higher degree to any other University or Institution.

ABSTRACT

Colour Vision Deficiency (CVD) is an important issue for a significant population across the globe. There are several types of CVD's, such as monochromacy, dichromacy, trichromacy, and anomalous trichromacy. Each of these categories contain specific other subtypes. The aim of this research is to device a scheme to address CVD by using variations in pixel plotting of colours to capture colour disparities and perform colour compensation. The proposed scheme recolours the video and images by colour contrast variation of each colour for CVD patients, and depending on the type of deficiency, it is able to provide live results. Different types of CVD's can be identified and cured by changing the particular colour related to it and based upon the type of diseases, it performs RGB (Red, Green, and Blue) to LMS (Long, Medium, and Short) transformation. This helps in colour identification and also adjustments of colour contrasts. The processing and rendering of recoloured video and images, allows the affected patients with CVD to see perfect shades in the recoloured frames of video or images and other modes of files. In this thesis, we propose an efficient recolouring algorithm with a strong focus on real-time applications that is capable of providing different recoloured outputs based on specific types of CVD.

DEDICATION

To my family, friends, my sister Mahek and my love…

ACKNOWLEDGMENTS

I am very thankful to my supervisor Dr. Ahmad for the vision and foresight that motivated me to conceive of the thesis. His ideas and support have helped me become more creative towards my research topic. I would like to show my profound thankfulness to my thesis committee, Dr. Boubakeur Boufama, and Dr. Myron Hlynka, for providing me with great technical and personal guidance that has helped me to learn a lot about expertise of research.

I want to thank my parents, whose love and support, whatever I seek, is with me. In the pursuit of this study, nobody has been more valuable to me than my family members & colleagues. The true role models and the root of my inspiration are them. With all due respect throughout my course work at the University of Windsor, I would like to thank all of the School of Computer Science faculty and staff and my friends who have given constant encouragement and inspiration.

TABLE OF CONTENTS.

LIST OF TABLES

LIST OF ABBREVIATIONS/SYMBOLS

CVD	Colour Vision Deficiency
IP	Image Processing
RGB	Red, Green and Blue
LMS	Long, Medium, and Short
AR	Augmented Reality
CV	Computer Vision
UI	User Interface
IE	Image Enhancement
HSV	Hue, Saturation, and Value
HSB	Hue, Saturation, and Brightness
M	Monochromacy
D	Dichromacy
PP	Protanopia
DP	Deuteranopia
TP	Tritanopia
AT	Anomalous Trichromacy
P	Protanomaly
D	Deuteranomaly
T	Tritanamoly
GMM	Gaussian Mixture Model
PCA	Principal Component Analysis
DM	Daltonization Method
GM	Gradient Map Method
IPD	Inaccessible Points Detection

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Overview

It is important to perceive colours for effective visual communication. Globally, around 200 million people are affected with colour vision deficiency (CVD) [23], impacting their personal as well as professional lives. The human eye has three different types of photoreceptor: rods, cones, and intrinsically photosensitive retinal ganglion cells. The cones absorb photons to provide normal colour vision, and the rods provide scotopic vision (vision under low-level lights). Thus, rods detect low light levels, and cones usually perceive high light intensity levels. These three classes of photoreceptor cells are mainly differentiated by their spectral sensitivities, with peak responses lying in the long- (L), middle- (M), and short- (S) wavelength regions of the spectrum [22]. Photoreceptor cells perceive different light due to their characteristic from blue to green to red. When the light enters the eye, it stimulates the cone cells and produces an electrical impulse from the occipital lobe. The brain then interprets the signals from the cone cells and forms an object visible with its colours. The three classes of cone cells, red, green, and blue, work together, allowing them to see the entire spectrum of colours. For example, a particular simulation of the red and blue cones generates a purple colour, which one might be able to see. Colour vision impairment, or colour vision deficiency, results from partial or complete loss/damage of function of one or more types of cone cells. There are three major types of CVD: monochromacy, dichromacy, and anomalous trichromacy [22].

This research primarily focuses on the process of live application of video recolouring and images considering deuteranomaly and tritanomaly as being the most common type of CVD. Impairment related to deuteranomaly and tritanomaly is a significant concern for colour-blind patients because a majority of CVD patients suffer from these two conditions. Colour blindness is the individual's inability to differentiate between objects with colours between a specific range of wavelengths. So, any deformity for one particular type of CVD for example deuteranomaly, all of them will have the same type of deformity in cone structure. Thus, a similar solution is possible for each type of CVD. An overview of previous research and important techniques to help colour-blind individuals are discussed and can be found in [41].

The primary focus of this thesis is to design a scheme for live applications to benefit CVD patients. The proposed technique uses variations in RGB pixel values of objects in a video and further processes it to obtain the desired results. Depending on the detected type of CVD, it produces the output with variations in the colours for that specific CVD patient type. The emphasis of this thesis is on the most common and prevalent types of CVD as will be discussed in detail in chapter 2. When integrated into visualization systems, the proposed approach can provide visualization with immediate feedback. As such, both for people with normal and impaired visual colour systems, it can be a powerful tool for the creation of important visualizations. Our proposed system allows colour-blind users to access the system and stream the video directly with changes in the necessary spectral colours. A captured video is stored as an output file without any frame loss.

In order to identify an individual as CVD, a user must go through the Ishihara test (the visual test to determine colour blindness). If CVD is identified, then as instructed by the Ishihara plates test, the user is guided to the respective form of CVD. To allow feature differentiation in images, two algorithms, Daltonize and RGB-HSV, are used and compared based on speed, accuracy, and performance. RGB to LMS conversion is used in the daltonization algorithm to recolour images. For colour space conversion, the proposed scheme utilizes a matrix of RGB to LMS colour space conversion and vice versa. RGB-HSV is a non-linear algorithm, but reversible conversion is possible. It uses pixel transformation to transform colour space and the proposed algorithm allows us to recolour images and/or video in nearly real time. The video processing involves considering individual frames and, recolouring each frame according to the specific type of CVD with the proposed system, to get the recoloured video as the final results.

The main aim is to get a video through the proposed system, considering time in terms of live application, and quality of the result. The proposed system is developed in python and uses OpenCV for video processing by using RGB values and revising them for specific types of CVD individuals as per their needs.

1.2 Thesis motivation

Colour blindness (colour vision deficiency, or CVD) affects approximately 1 in 12 men (8%) and 1 in 200 women in the world [23]. For such people simple tasks, such as selecting ripe fruit, choosing to clothe, and understanding traffic lights can be quite challenging. Despite tremendous medical advancements, there is virtually no development for colour blind patients other than recolouring glasses or heavy hardware devices that are neither convenient nor practical for use in daily life. CVD makes daily tasks for patients very difficult in terms of professional as well as personal life. Colour blindness may also make some educational activities challenging and difficult. Typically, color-deficient people are thought to have trouble matching their own clothes, but the study shows that deficiency in colour vision affects both choices made and the patient’s ability to appreciate his or her pastimes. Some researchers have discovered a link between what a person eats compared to that person’s colour vision. They found that the colours of certain foods alert the brain to what type of food is being eaten. Since the colours of food impact what is being eaten, colour deficiency may create an unbalanced diet depending on the colours that a subject perceives [13]. In this thesis we propose a system that can eliminate many of the vision problems faced by CVD affected people. The proposed system is an attempt to make colour blind patients independent.

1.3 Thesis objectives and contributions

The main objective of the research is to design a system that can provide live video and image recolouring capabilities for colour vision deficient patients. Previous systems were based on adhoc design and implementation and were not developed for live applications and there was no consideration for video recolouring. The proposed research helps us provide live results without any loss of data in terms of missing frames.

The final goal is to achieve high performance with live applications and to mitigate all types of colour vision deficiency. Arguments such as size of the frame, orientation during live application and values of pixels are used as a skeleton to operate on, through which we can get fast results. Algorithms including daltonization, HSV and other Open CV libraries are used in order to achieve the results for a specific type of CVD patients.

A major feature of our proposed system is the inclusion of all major types of CVDs according to their prevalence and their processing in both videos as well as images for live application. The proposed system is a flexible system that can work with different types of colour spaces and can modify the underlying colour space based on its requirements. This system is developed in python with a combination of fast daltonization and video enhancement techniques such as video blurring and blending. Previously proposed algorithms required multiple passes on each frame for processing. This resulted in slower overall processing which fell short of expectations of live applications. However, the proposed system computes and processes the video using a single pass and, as a result, the output is produced in nearly real time. The video quality enhancement techniques also use minimal computational resources. The majority of techniques use greyscale conversion to lower the contrast, but the proposed system is independent of it. The system is software-based and can eliminate the need to use specialized hardware such as specialized glasses or other such equipment that may be inconvenient to use and can also be quite expensive.

1.4 Thesis organization

The rest of this thesis is structured as follows: In Chapter 2, we introduce and review several types of colour vision deficiency along with some of the previously proposed related models. In Chapter 3, we provide details about the proposed system and implementation. Chapter 4 provides experimental details and evaluation and analysis of our proposed methods and comparative studies. Finally, we present our conclusions and possible future work in Chapter 5

CHAPTER 2
RELATED WORKS

This chapter provides a brief overview of some of previously proposed techniques to provide a color vision deficient system solution. We study different types of colour vision deficient patients in section 2.1. Some of the previous work and methods that are applied in section 2.2. After that, we provide a background study in terms of the Literature Review.

TYPES OF COLOUR BLINDNESS:

Colour blindness is broadly divided as follows:

Type	Name	Cause of defect	prevalence
Anomalous trichromacy	Protanomaly Deuteranomaly Tritanomaly	L-cone defect M-cone defect S-cone defect	1.3% 4.9% 0.01%
Dichromacy	Protanopia - Deuteranopia Tritanopia	L -cone absent M-cone absent S-cone absent	1% 1.1% 0.02%
Monochromacy	Rod Monochromacy	no functioning cones	Very rare

Table 1: Types of Colour Vision Deficiencies [4]

The RGB colour model is a simple means of colour representation, but it is not based explicitly on the types of cones in the human eye. Therefore, CVD individuals find it difficult to differentiate between different colours. Colour is an integral part of human life, but some people are deprived of this beautiful experience. Deficiency in colour vision may affect the success at an early age in school or on the field of sports and affect their motivation. Getting CVD in adults can impact which occupations one can follow and can often be a daunting disorder. We want to enable people suffering from a lack of colour vision to differentiate between various coloured objects. This scheme will allow individuals with CVD to help them distinguish various colours.

Major types of CVD are Monochromacy, Dichromacy, Anomalous trichromacy, which is summarized as follows:

1. **Monochromacy**

Individuals with monochromacy either have no cones in their retina or have only one type of cone present. Vision of such people is limited to only black and white world. This type of colour deficiency is termed as achromatopsia and see the world as black, white, and different shades of grey. However, it is essential to note that the number of people with such a condition is limited to only 1% of the world population [23].

2. **Dichromacy**

These people have only two types of cones to perceive colours. In other words, in such people, one of the three types of cones is missing altogether. They cannot perceive particular portion of the light spectrum. This condition can further be described as follows [23]:

- Protanopia:

  Conditions in which individuals are unable to perceive red colour.
- Deuteranopia:

  Conditions in which individuals are unable to perceive green colour.
- Tritanopia:

  Conditions in which individuals are unable to perceive blue colour.

3. Anomalous Trichromacy

In people suffering from Anomalous Trichromacy, all three cones are present, but one of these cones is slightly out of alignment which means one of the cones in the retina is not functioning as well as the rest of the cones. However, the majority of the population suffers from this type of visual impairment. This condition is further divided as follows [23]:

- Protanomaly:

  L cones are defective and their sensitivity to red colour is low.

- Deuteranomaly:

  M cones are defective and their sensitivity to distinguish red and green colour is low.

- Tritanomaly:

  S cones are defective and their sensitivity to distinguish blue and yellow colour is low.

In some cases, some disease or injury can also affect the optic nerve, or the retina which can also result in a loss of colour perception. Some of the diseases that can cause colour deficits are [21]:

- Parkinson's disease
- Alzheimer's disease
- Multiple sclerosis
- Chronic alcoholism
- Leukemia
- Sickle cell anemia
- Diabetes
- Glaucoma
- Macular degeneration.

2.1 Previous Work

Existing methodologies to treat CVD patients can be generally classified into two broad types: techniques that require hardware support and self-regulating techniques. The first type focuses on aiding developers to alter enigmatic groups of colours to user interfaces. As images contain moderate colour differences or many different colours, these techniques are difficult to use. Therefore, to conquer all the problems, automated procedures are developed. Wakita and Shimamura [14] offered three similar reasons in this approach to briefly define the most fundamental colour effects and use assumed more rigid algorithms to discover re-coloured responses. Nevertheless, the approach suggested would not always lead to an optimized solution on a global network, as the complexity of mathematics appears to be more exorbitant.

The visibility of saving peculiarities for individuals affected by dichromacy was checked in the study performed by Jefferson and Harvey [15]. The task of adequately assessing this optimization problem is compounded by several variables in terms of their appropriate methods.

In order to convert or re-colour images for individuals affected by dichromacy, Rasche et al. [16] developed a simple and appropriate approach to convert colour components into grey component notions. After the re-colouring and remapping process, Kuhn et al. [17] developed a mass-spring device technique to preserve the accurate original colours and maintain the colour contrast. In order to manage critical colours correctly, an allocation technique or process is built to accurately model key colours. The middle point of each allotment category is regarded as a significant colour of the main component. From these component colours, the mapping of colour methods has its origins and produces a multi-derived nonlinear problem that is difficult to solve efficiently. When finding images for visually impaired people or self-regulating to detect anomalous regions in an image that are not perceived by CVD impaired individuals in a normal established image, these re-colouring techniques may be used to detect the regions which are not clear to CVD.

A self-regulating recolouration of images with GPU technique in Machado and Oliveira coeval [17] to improvise colour contrasts for people affected by dichromatic vision. They have developed a 3-D graphic-based approach and model for the preservation of original image using their proposed methodology and also discusses, that their technique is also relevant for re-colouring a video. However, in their research paper, no generalized method of re-colouring video responses is shown for all the types of CVD. They also used the vector space method to maintain the continuity of colour during a live image and video simulation session. Also, an assumption is made that the neighboring or upcoming frame contains identical objects and the current frame of the recolour vector space is thus used for the adjacent or upcoming frame. But because of the fundamental definition of moving entities or object movements, as we know, the neighboring or adjacent frames do not contain the same entities as that of the previous frame.

We then looked through the paper called “Study of re-colouring algorithms for colour deficient viewers” [41], which overviewed different working algorithms.

Completely compliant standards based on (ITS and BSI) Colour Limits: None of the algorithms surveyed included ITS or BSI colour information. Empirically derived thresholds have been used in all of the current studies. The colour space that is used is not precise for the definition of the colour threshold in many of the algorithms.

Detection of damaged, non-standard, or improperly mounted HVS lights: most of the algorithms focused on ideal scenarios where only circular (or arrow) lights were taken into account. In fact, due to lens darkening when using incandescent light bulbs, LED fading, and failure, there are several variations in the light form. Also, the greyscale and skin tone problem corrections are not taken into the account

No pre-driving requirement: Some of the tested algorithms demanded that the driving course be "pre-driven" and manually calculated the traffic signal position information.

No prerequisite for a GPS system: A majority of the algorithms surveyed were unable to use the image sensor alone to detect traffic light signals in a robust way. These systems were based on GPS and map data for awareness of potential traffic signals intersections. GPS dependency significantly decreases the system's generality and makes it vulnerable to infrastructure alteration failure.

Tracking of traffic lights: The robustness of the proposed system is significantly improved by adding temporal information on the status of the traffic lights by tracking the traffic signal lights detected.

Context-aware detection and next-state prediction: The current algorithm keeps track of the traffic signal light status. The device warns the user if there are sudden or abrupt adjustments and advises them to proceed with caution.

Results: Video of over 50 hours of intersections (over 2000 intersections) was checked with this device comprising intersections of one to all four traffic lights, monitoring various traffic lanes with 97.5 percent solid light detection accuracy. The suggested device is able to detect defective arrow and HVS lights, unlike other systems.

For the next work, we refer to a paper called “Colour contrast enhancement in visual media for anomalous trichromats” [26]. This paper proposes a recolouring algorithm that, when applied to images, re-colours them so that users with impaired colour vision can see things that they have not previously been able to see.

A distinctive image would be the output image. Based on these points, inaccessible regions are detected and indicated through a regularization framework. The approach is straightforward but effective, and it is capable of processing an image in less than 40 milliseconds. Experiments were performed on a variety of poster pictures, and the findings revealed their corresponding protanopic and deuteranopic pictures. The method first defines a collection of points around which, due to the lack of colour information, the patches are not prominent for colour blind viewers. Information loss happens, and it is a tedious job to measure the distance based on it. On the other hand, the gradient map method is also applied to OpenCV pictures, but for the reasons stated below, no recolouring is performed. The technique of colour contrasting provided the best results yet observed. By considering the key parameters that were addressed in the results, all the methods were considered.

Daltonization algorithm:

This method is used to recolour images by merely multiplying the pixel's RGB vector by a 3x3 matrix which denotes nothing but the spectral sensitivity values of the cones. For protanomaly, the spectral sensitivity values for L cones are shifted, M cones for deuteranomaly and S cones for tritanomaly. The process is depicted below [24].

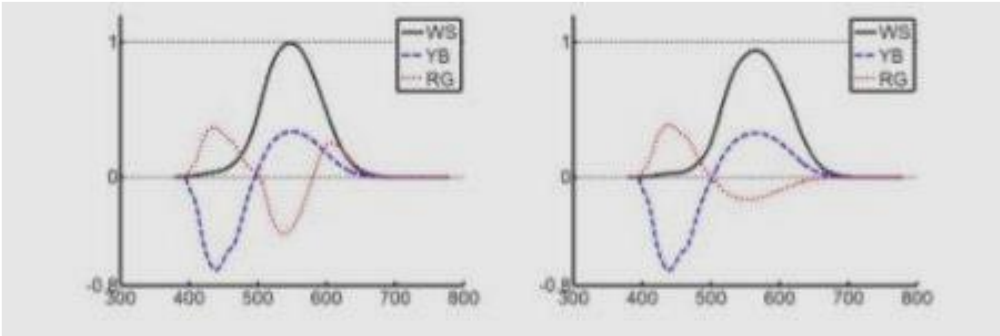

Figure 1: Spectral sensitivity shift for LMS

The above shifts are obtained by plotting the graphs of all the spectral sensitivities corresponding to various wavelengths which can be calculated as,

$$L_\alpha(\lambda) = L\,(\lambda + \Delta\lambda_L),$$

$$M_\alpha(\lambda) = M\,(\lambda + \Delta\lambda_M),$$

$$S_\alpha(\lambda) = S\,(\lambda + \Delta\lambda_S)$$

The areas under the curves of L, M, and S sensitivities are recorded, and the shifts are determined by using the following equation,

$$L_\alpha(\lambda) = \alpha L(\lambda) + (1\text{-}\alpha)0.96\,\frac{\text{AreaL}}{\text{AreaM}}\,M(\lambda)$$

$$M_\alpha(\lambda) = \alpha M(\lambda) + (1\text{-}\alpha)\frac{1}{0.96}\,\frac{\text{AreaM}}{\text{AreaS}}\,L(\lambda)$$

$$S_\alpha(\lambda) = S\,(\lambda + \Delta\lambda_S)$$

The total areas under the curves are calculated as,

$$\text{Area}_L = \int L(\lambda)d\lambda\ ,$$

$$\text{Area}_M = \int M(\lambda)d\lambda$$

Therefore, let LMS-N denote the matrix of spectral sensitivities for normal colour vision, with the columns denoting values for red, green, and blue wavelengths and rows depicting values for L, M and S cones. If LMS-A denotes the matrix for defective colour vision, then simulation of colour-blind vision on visual media can be done using our methodology with fast daltonization [26].

2.2 Literature Review

Several authors have proposed system for color vision deficient patients. Tomoyuki et al.'s, colour compensation vision system [1] for colour-blind people. This is to compensate image colour for colour-blind people, the image in RGB colour space is converted to HLS colour space which enables the defective colour range to be easily avoided. The proposed methodology is validated by the developed camera and display colour compensation system. According to statistics on types of colour blindness, the main types are red defective and green defective. One approach to assist colour-blind people is an eyeglass colour conversion display system to enhance colour difference, for which we developed a colour compensation algorithm.

- Major Problem-focused: - To recognize traffic lights as colour blind people may not be able to recognize the colour difference.
- Proposed Method: - A wearable eyeglass device which converts the RGB colour space to HLS colour visible area for a normal person with no CVD (colour vision deficiency), then to a defective area in HLS colour space by using the following formula

$$H' = H\ /\ 360\ \times\ 270\ +\ 45$$

Figure 2: HLS colour space formula

Also, conversion from normal HLS to defective can be represented diagrammatically as follows

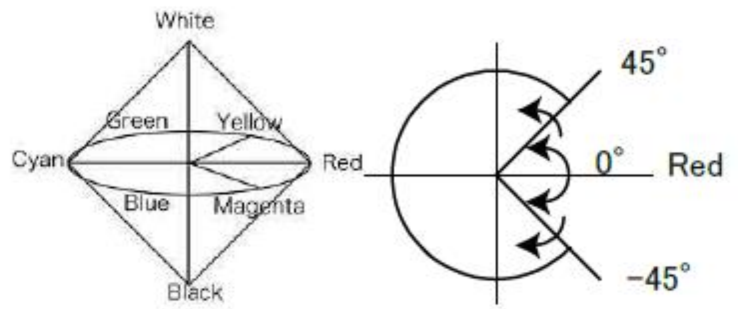

Figure 3: Normal HSL to defective HSL conversion.

- Evaluation of average and CVD person: - It uses Variantor to simulate the view and SD (standard differential method) to draw the result between normal and colour vision deficient patient, on using the proposed colour vision assist system and representing it on SD profile the results are almost the same without variantor confirming the validity of the system.

Jacek Ruminski et al [2] proposed an Image processing system with three image processing techniques to enhance image recognition and understanding by persons with dichromacy were proposed. A colour difference image is introduced to represent colour perception dissimilarity.

-Proposed Methods: -

- **Image simulation**

  Normal colour vision can be modeled using cone fundamentals. The energy received by a particular L, M, and S cone can be represented as: -

  $$[L, M, S] = \int E(\lambda)[\bar{l}, \bar{m}, \bar{s}]d\lambda,$$

  Where, *E*(l*)* is the light power spectral density and *l, m, s* are fundamental spectral sensitivity functions for cones.

  Also, it involves the steps of simulation procedure as follows: -

1. Gamma Correction.
2. Scaling of the colours
3. The transformation from RGB to XYZ to LMS.
4. The transformation from 3D LMS to 2D spaces, this involves two majorly focused types of CVD by this paper which are:
    (i) Protanopes.
    (ii) Deuteranopes.
5. Inverse gamma correction.

- **Colour transformation – colour difference**
  It uses colour difference method to compare the original and the simulated image; also, this colour difference greyscale image can be used by dichromats to calculate the contrast loss in the perceived image with reference to the normal observer.
- **Colour transformation – colour difference scaling**
  This method uses linear scaling for red/green elements of the colour in proportion to different colour values. For dichromats in this proposed method, the weight of the red component is increased, and green is decreased. Similarly, colour transformation – red/green scaling is also one of the methods which are introduced

-Results: -

- Two methods validate the results of the image simulation methods
    1. Ishihara Test: - It is one of the standard tests which is used where the simulated images were compared with expected results. With the above-proposed method, all nine tests gave positive results.
    2. Expert Opinion: - For this case, we consider two observers who are diagnosed with dichromacy compared to the original and simulated images and show differences for this case none have been found.
- The testing of performance was done on the following criteria using the set of images
    1. The same number of colours, but different image resolution.

2. The same image resolution, but different number of colours.

- A sample example of a market image is taken, and different image processing methods are used to get different results. The sample consists of the original image, the next results of simulation of a deuteranope's view for the Rashe method, Kuhn method, Vischeck method, our method 2, and our method 1.

Jason McDowell et al. [3], proposed a Colour sensing system, in which a device is implemented using two different colour sensors, a microcontroller and a display. Nine different colours of tissue paper were measured with the colour sensors. The performance of the sensors was evaluated by converting the red, green, blue (RGB) values they produced back into colours on a computer and then comparing these colours with the coloured tissue paper. An inexpensive commercial colour sensor produced a very accurate colour for all nine colour samples while the homemade sensor produced recognizable but washed-out looking colour for most of the colours. Also, future improvements can be made by replacing the red segment display with the white segment display due to difficulty for CVD patients to see the colours. Larger hardware of EEPROM, which has enough space to use and to specify the colour correction method to a particular type of CVD patient that is if the patient cannot see the red colour the system should only correct the red and correction of green and blue will become a waste of resource. The physical size of the device also plays an essential factor in the production level, which must be reduced.

P.K. Nigam et al. [4], proposed a colour correction system that describes how rods and cones in the eyes are responsible for colour detection and how colour blindness is transmitted by means of genetic mutation and different types of CVD (colour vision deficiency). Thus, correcting a dichromacy with a new filter on images is developed by image processing based on the Ishihara test.

- Tests for CVD patients: -
    1. Ishihara Plates for colour blindness test
    2. Farnsworth Dichotomous Test
    3. City University Colour Vision Test.
    4. Colour Vision Test at Biyee.net.
    5. Multiple Choice Colour Vision Test.

The colour blindness of a person can easily be detected using Ishihara plates. Four examples of Ishihara plates are given with normal person reading numbers 74, 6, 29, and no number respectively from each plate. However, a person with colour-blindness either reads the number wrong or cannot read it at all according to the deficiency he is suffering from. After applying the new filter, all plates look alike by which the colour deficient person can read it easily. For designing, the colour filtered code is developed in MATLAB, in which image adjusting function, contrast stretching, and the last one is that Negative functions are used.

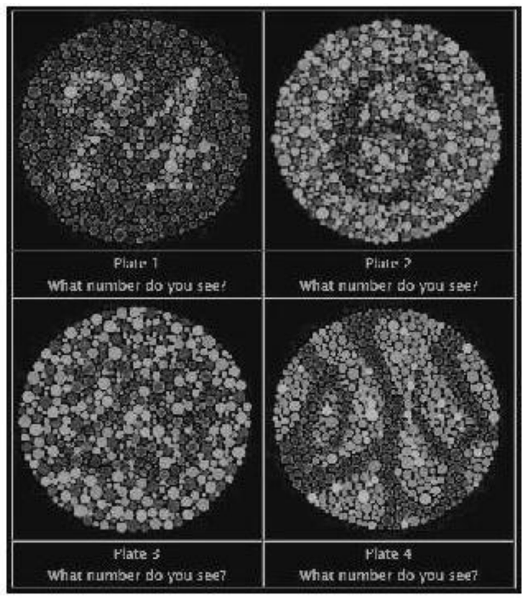

Figure 4: Results of proposed algorithm

The above figure shows the result of the applied image processing system with three functionalities applied, and CVD patients can easily see it

Akhil Khare [5] proposed a colour transformation system where numerous calculations had been recommended for the change of Images, so partially blind people will see picture detail plainly. This has been examined in detail. Other than these, numerous more procedures are accessible, yet we focus on the following three as they give some measure of hypothetical differing qualities.

1) LMS Daltonization: The procedure of LMS lactonization utilizes the data lost in the deuteranopia reenactment to enhance the first picture.

2) RGB Colour Contrasting: It adjusts the values of the image's RGB to enhance the contrast between red and green. It finely results in making green pixels appear to be bluer.

3) LAB Colour Correction: The thought process of this calculation is to adjust the reds and greens of a picture to expand colour difference and clearness for a visually challenged individual.

-Methodology: -

- Input image in RGB colour space.
- Read and analyze the pixel values.
- Obtain pixel values to be modified.
- Transfer pixel colours to colours that are visible to patients.
- Adding values to the original image.
- Output image.

Ananto et al. [6], proposed a colour transformation system based on colour-blind compensation and augmented reality. It focuses on people with colour blindness, providing solutions to help this problem by building a solution in terms of image processing techniques and applying augmented reality technologies. This paper focuses on designing the user interface of colour-blind aid system and colour blindness test system for Windows Phone7 device, and also developing colour transformation system for mobile and embedded device, design of colour-blind aid system user interfaces for Windows Phone 7 is implemented using Microsoft Expression Blend based on the barrier-free principle.

The implementation of this involves the following

- Designing of UI: - To use barrier-free principles to design a suitable user interface that involves designing and planning phases based upon the goal and to improve the overall efficiency of the product. It involves 480 x 768-pixel display size and that of windows phone 7.
- The colour blindness test system

1. Ishihara method: - With 21 test plates in this case, with a new feature of tolerance value in case the person has a normal vision, which is set to 4.

- Dalton's theory application to transform colours using a C# programming language with EmguCV library on an embedded device and then colour transformation on a mobile device of windows phone 7. This does not involve the image processing in real-time entirely as it involves colour space conversion from RGB to HSL and then colour channel shifting. Thus, hue and lightness are the two important parameters which are taken into account for processing.
- Analysis result: -
    1. Analysis for UI: - It shows how well the group of users has liked the interactive UI for the designed system.
    2. Clarity level of image: - 95% of the users were able to see the image clearly out of 10 individuals, and 2 respondents were partial colour blind.
    3. Accuracy level: - Comparison over 21 Ishihara images are shown in the figure which can be summarized as follows

Parameters	Without Colour Transformation	Using colour transformation
Not visible	7%	0%
Hardly visible	7%	0%
Visible	7%	3%
Clearly Visible	16%	23%
Very clearly visible	63%	74%

Table 2: Comparison table using Colour Transformation.

J. Huang et al. [7], proposed a colour reproduction algorithm. It focuses on the recolourization in this paper; it proposes a new re-colouring algorithm to enhance the accessibility for the colour vision deficient (or colour-blind). Compared to people with normal colour vision, certain combinations thereby become difficult for CVD, I.e., colour vision deficient patients to bifurcate between. This may cause a problem in visual coordination due to the increasing use of colours in few years. To provide a solution, recolouring of the image to preserve visual detail when perceived by people with CVD. At first, representing colour is extracted in the image. Then find the optimal mapping to maintain the contrast between each pair of these representing colours. The proposed algorithm is image content dependent and completely automatic. Experimental results on natural images are illustrated to demonstrate the effectiveness of the proposed re-colouring algorithm.

-Proposed Colour Reproduction Algorithm: -

It majorly involves four fundamental steps for image recolouring

1. Extract the L*a*b value in the CIEL*a*b* colour space for each pixel as the colour feature
2. Group these colour features into clusters by modeling the distribution using the GMM-EM approach
3. Relocate the mean vector of every Gaussian component for a specific type of CVD through an optimization procedure.
4. Perform Gaussian mapping for interpolation.

- Image representation via Gaussian Mixture Modelling: - Extraction of CIEL*a*b* for each pixel is performed, and the perceptual difference is calculated using Euclidean distance and K Gaussian in applied for the underlying distribution. Thus, it is initialized by using the K means algorithm, and then the E-M algorithm is applied for GMM estimation.
- Optimization: - The aim is to use symmetric KL divergence between each pair of Gaussians, and after mathematical calculations, colours which have similar or near values will be given small weights which means it need not be corrected, and thus using this process it focuses more on colours which have a more significant difference when perceived by people with CVD.
- Interpolation: - It uses LCH colour space, which is lightness, chroma, and hue, and thus hue shift is calculated for each Gaussian and corresponding mapping function to ensure smoothening after the recolouring process.
- Results: -

1. The time complexity for the proposed algorithm in this system for colour extraction using the GMM technique is *O(KN)*, where *K* represents the number of Gaussian in the mixture, and *N* is the number of pixels in the image.
2. The time complexity for the proposed algorithm in this system for optimization is $O\ (K^2)$, where *K* represents the number of Gaussian in the mixture.
3. The time complexity for the proposed algorithm in this system for interpolation is *O(KN)*, where *K* represents the number of Gaussian in the mixture, and *N* is the number of pixels in the image.
4. Recolouring process using the proposed algorithm of 300 x 300-pixel size image taken less than 5 seconds of computation, which is an improvement.

B.R. Navada et al. [8], proposed a colour detection system. It is used for detection of colour and distinguish between different patterns in a similar colour and work different trials are made for designing a prototype in aid for colour blind people in detecting colour and edges of a given image which are of similar colours. The major motivation included in this work is to try and reduce such deficiency using technology. Important techniques which are used are Image processing in proposed work to develop a setup for identifying the colours in an image and indicating the edges in case of different images with similar colours. Image processing involves two parts

1. Colour detection.

2. Edge detection.

These are carried out on a LabVIEW platform. A wireless camera is used to obtain the images in the field of view of a colour-blind person who is unable to identify or judge the colours. It is then processed using LabVIEW, colour, and the edge of the image is displayed on the LabVIEW front panel, and other review papers covered the functionality of the algorithm.

S. Poret et al. [9], proposed image processing techniques that focuses on the colour-blind correction. Colour blindness alters the subjects' color vision by decreasing the sensitivity to specific colour wavelengths, depending on the defect. It covers 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. It involves designing a filter based on the Ishihara colour tests in order to correct the colour-blind deficiencies. Being successful in 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 colourblind and normal vision subjects were all able to correctly identify the test colours.

There are different tests for colour blindness

1. Ishihara Colour Test.
2. Colour Difference Vectors.

-Experiments and Results: -

- Preliminary Ishihara Analysis: - There are numbers inside the plates, which are not visible to our red-green colour-blind patients; there are four such patients on which the test is conducted and also another set of 4 patients, which could correctly identify all six values in the plate. Initially, green and blue components are removed, leaving only the red component, which is implemented in MATLAB. Now only the bright part of the image is left. For the next step, the same function with gamma weight towards the darker pixels to decrease the image brightness. Finally, the red component is doubled, and blue and green components are further filtered. Moreover, this can be tested upon the real-life images.
- Digital Image Analysis: - A test image with lots of colour variation is selected, and Ishihara test analysis is applied to this, and results are seen in fig 4. Thus, from fig 4, we can see that there is too much of red component and hence the concentration of red component is reduced so initially red component is weighted compared to other darker red shades. So the modified filter comes into the picture. First, lightest

50 shades are removed as CVD patients had difficulties with weak or lighter red values once this is done green and blue components of the original image is restored and a filtered and correct image is seen in fig 5.

Figure 5: Test image

Figure 6: Result image (Red)

Figure 7: Result image (Green, Blue)

- Future Scope: - To generalize the result for larger study areas and to search more about the implementation of this process and optimize the given system for colour blind people.

L.Zhang et al. [10], provides a colour to grey system that mainly focusses upon conversion of images from colour to grey for CVD, it also describes the implementation using Gooch's algorithm, and for their own methodology, certain modifications are made in Gooch's algorithm to improve two major limitations of Gooch's which are

- Speed up computation, using region growing method and colour differences, are then calculated between arbitrary segmented region pairs rather than pixel pairs.
- To improve the different models to increase the contrast of greyscale images by simultaneously taking into account the luminance and chrominance difference.

-Experiments and Analysis.

Conclusions are evaluated based upon three parameters, which are subjective quality, objective quality, execution speed.

- Subjective Quality: - Because of the region growth method, the proposed algorithm helps in providing better results without loss of information and is represented in the result tables with bold values showing the best results (different K values).

- Objective Quality: - This is calculated using E-score and colour contrast fidelity ratio (CCFR). Thus, the higher the value better will be the result.
- Execution Speed: - Execution speeds of different algorithms are shown, but the main focus is that of the proposed algorithm, which depends on the number of segmented areas and has better time complexity, which is discussed further in the results section.

-Limitations: -

- This proposed algorithm is still not suitable for real-time application
- High processing power is needed for this algorithm as it involves complex computations

-Results: -

Greyscale images will have lower contrast, but due to the colour difference model used in the proposed algorithm by calculating the luminance and chrominance differences, it will help preserve certain contrast and minimize the loss of information.

- The time complexity for the Gooch algorithm is $o((m \times n)^2)$.
- Thus, the proposed algorithm reduces the time complexity to $O(m \times n) + O(k^2)$, which is similar to $O(k^2)$, where k is regions specified by the algorithm.

S. Angchekar et al. [11], provides an overview of techniques on recolouring and wavelength adjustment algorithms. It firstly gives an idea as to how colour deficiency is transferred biologically. Secondly, it describes different types of CVD's which are

- Trichromacy: - People with normal colour vision
- Anomalous Trichromacy: - Out of three cone cells one of the cone cells is out of alignment, and it is further divided into three categories
    1. Protanomaly: Reduced sensitivity to red light.
    2. Deuteranomaly: Reduced sensitivity to green light.
    3. Tritanamoly: Reduced sensitivity to blue light.

- Dichromacy: - Absence of one of the cones which are able to perceive colour, which means only two types of cone cells are present.
- Monochromacy: - They cannot see any colour at all, and they can see the only black and white world with a range of grey from minimum to maximum.

Also, it displays different algorithms that are available in order to recolour a particular image to an extent where the colour vision deficient might get a hint that actual colour and the visible colour is quite different and a process to lessen the separation of colour hues between the actual image and visible image for a person suffering from Colour Vision Deficiency. The following are the algorithms that help a colour-blind person cite the colour distinctly of the above-mentioned paper's actual image.

1. Daltonization Algorithm
2. Gradient Map Method
3. RGB Primary Colour Cluster
4. Algorithm using LabVIEW IMAQ tools

X. Zhang et al. [12], proposed a methodology by GAN-based architecture to improve the identification of colour by CVD patients. It makes use of BicycleGAN. This paper majorly uses three significant steps in order to show complete methodology.

- A CVD simulation model is integrated into BicycleGAN.
- Colour to a gray module is used in order to eliminate the distortion.
- Gaussian Mixture Model **GMM** and Kullback - Lelbler **KL** divergence calculation model for training purposes.
- The dataset consists of 1463 pairs of the training set and 790 pairs of the testing set.

-Generative Models: -

The aim is to use the pixel-level image for image conversion. Thus, the paper focuses on the following methodologies, as shown above in the summary table. The BicycleGAN involves two types of GAN techniques

- cVAE-GAN (Conditional Variational Autoencoder): - Encodes the ground truth images into the latent space, uses noise to simulate the correlation between input images and ground truth images, and provides a random latent vector taken from the noise to the input image to form the output image.
- cLR-GAN (Conditional Latent Regressor): - Now, the input and the random noise are fed to the generator of cLR-GAN, but it gives a distorted result, so they are encoded to recover the latent vector previously entered.

-The Computational model of CVD

This model can be used for protanopia and deuteranopia because the paper focuses on these two CVD, and thus, we take into account protanopia and construct a model.

- Step1: - Convert RGB colour space to LMS colour space
- Step2: - Convert LMS to protanopic LMS [L_p, M_p, S_p] domain.
- Step3: - Convert LMS [L_p, M_p, S_p] domain to RGB to simulate the image.

-Image to Gray Module

It uses a convolution network to convert images to grayscale images. The equation below shows the conversion from image to grayscale.

$$Gray = 0.299 * R + 0.587 * G + 0.114 * B$$

Figure 8: Image to gray scale

-Condition Model

It takes place in three steps: -

1. Clustering of the original image into K types by GMM
2. KL divergence is calculated between every two distributions, which shows the distance of each two-colour.
3. Recolouring is a constraint by comparing the distances of two KL divergence between input and generated image.

-Implementation

1. Input and the output images are resized to 256*256, and various parameters are set according to the formula for simulation and other GAN's processing.
2. One image is trained at a time; according to the algorithm for GMM training, iterations are set to 1000, and the number of clusters (k) is set to 6.
3. The mean matrix is [3*6], and variance is [1*3*6]
4. After feeding the output to BicycleGAN. Parameters of latent dimensions are set Z=18 for all experiments.
5. cVAE-GAN uses random noise obeying the Gaussian distribution as input during the test and helps in achieving the expected effect.

-Limitations: -

Due to the uncertainty of GMM clustering, the error of recolouring may occur. It can be improved by providing better data or pre-processing of the dataset.

In summary, there are vast numbers of CVD aid research modules that have often sought to strengthen existing software models and techniques. However, till the present time none of the existing system provides live recolouring of the videos and images for a particular type of CVD. Also, many of the hardware systems are implemented in the form of heavy devices or eyeglasses, but no software as such provides the live recolouring of videos and images. However, our system can provide results of recoloured videos and images without any loss of data and also in a very efficient way. Our system also helps in the visualization of results based on the type of CVD patient is suffering. Also, it can make use of different colour spaces as per the convenience of the user, and the parameters used for the computations are based on basic mathematical operators, which helps in getting the optimized results.

CHAPTER 3

PROPOSED METHODOLOGY

In Section 2.2, we discussed some of previous work and their foundations to the topic. Every system has benefits and drawbacks. Moreover, previous techniques are covered in detail. However, to explain the system that we are designing, we need to consider the existing techniques and algorithms. Thus, we implement a few recolouring techniques from every previous system into our video and image recolouring system.

3.1 Techniques for CVD

In the following sections, a brief description of some of the techniques used in the existing systems as well as those which are used in the proposed system. A lot of study and implementation work has been done in the past on Colour Vision Impairment, but it has not yielded perennial results. Nevertheless, these techniques could lead to new image processing technologies for people with vision impairment in the future. Some of the important computation techniques used in this research work, and some of the other relevant works are described below.

3.1.1 Image Enhancement using PSOs

In image processing, PSO is used to transfer one type of image to another type image, this type of image enhancement is most effective in enhancing the understanding of human viewers. Image enhancement is an optimization problem that is solved by particle swarm optimization (PSO). This technique sometimes leads to the problem of gamut because of very few pixels present in the targeted area. In the PSO, a single solution is calculated that is called a particle. PSO is an optimization tool that provides a population-based search procedure with the particles, that have changed the position with time in the particular operating area. The swarm in PSO's is initialized with a group of the particles in anyone, and it searches for optima by updating through iterations. Each particle update has two values: - Best position and Best position tracked by particle. One of this approach's key restrictions is that the contrast enhancement of the colour images cannot be performed [25].

3.1.2 Daltonization method

Daltonization method is used for colour adaption in an image to improve the colour perception for mainly colour-blind viewers. This algorithm primarily focuses on protanopes who cannot differentiate between red and green colour. In this method the protanope-unperceptible (Pu) colours are identified in the image then transferred into the new protanope -perceptible (pp) by a fast daltonization method. That is, it utilizes the colour clustering to measure the colour similarities rapidly. Daltonization method makes use of RGB to LMS transfer matrix which is used in the proposed methodology. When the recolouring process is done for colour transformation by using simple matrix method it then delivers different type of colours iteratively until the modified colours are not confusing with the (pu) and (pp). This process cannot decide whether more iterative recolouring needed or not [27]. However, this algorithm is discussed in detain in chapter 2. The daltonization method explained here is with respect to [27].

3.1.3 Gradient map method

The Gradient map method is an approach that can show the regions in an image that face the problem of accessibility for colourblind viewers, regions that contain details that colourblinds do not interpret well. This method can be used in different systems, such as testing the accessibility of built images for pixel modification, and helping designers escape the problem of accessibility (regions which cannot be detected) by making adjustments to the problem. Two key steps are inaccessible point detection and inaccessible positioning of the field. [11].

3.1.3.1 Inaccessible points detection

Inaccessible points are identified as, the points around which due to the lack of colour data, the patches are not detectable by colour blind people. For this data loss calculation, the difference in gradient maps of the original image is calculated, and its protanopic or deuteranopic views are calculated. We can obtain many points that colourblind viewers can still identify even if there is substantial information loss [11]. Therefore, we also compute the full gradient maps of the colourblind views of the image, which is the sum of the gradient maps of channels, and its inaccessible point detection is accomplished.

3.1.3.2 Inaccessible region location

It is the region that covers inaccessible points [40].

3.1.4 Shot Change Detection via Local Key point Matching

An approach focused on video frames for local key point matching. Without modeling various types of transitions, this method aims to identify both sudden and incremental transitions between shots. The findings of the experiments reveal that the proposed algorithm is efficient for most forms of shot modifications.

In reality, it takes a lot of processing time and memory space to take into account all the pixel values of the video volume. A bottom-up strategy is taken into consideration by taking advantage of the video structure to reduce memory redundancy. In order to define the consistency of frames, we first break a video into shots and then applied the principle of invariant local descriptors, comparison context histogram (CCH). If the same objects or backgrounds appear in adjacent frames, we will generally consider that there is no difference in the picture. To classify if two adjacent frames belong to the same shot, CCH is used. In addition, we can minimize the effect of both artifacts and camera movements by counting the number of matched CCH features, which can easily be misclassified as shot transitions and effectively detect both sudden and incremental transitions [28].

Five phases include processing:

1) Shot Detection
2) Shot primary extraction of colour
3) Colour extraction of video key
4) Colour reproduction of video main
5) Interpolation of Frame Colour [28].

3.1.5 Cluster and Colour Distance

The device produces three simple clusters (Red Cluster, Green Cluster and Blue Cluster) after all the testing is completed. Cluster Meaning of the clusters produced would clarify the ability of the eye to discern colours. The eye can hardly recognize the change in colour in the same cluster. The subject can see almost the same colour in the same cluster since the cluster boundary is created when the subject can discern the information from the test (number).

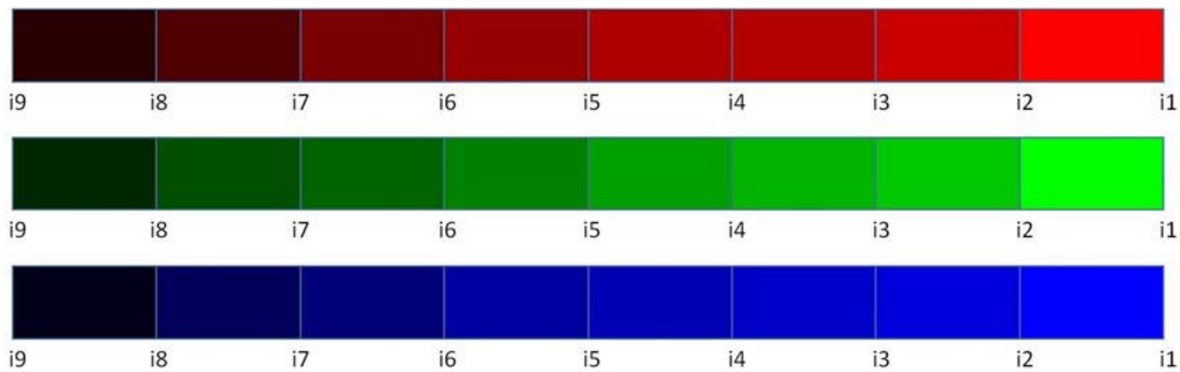

Figure 9: Colour cluster

The cluster will show us the capacity of the cone cells to discern colour. A greater number of colour cluster boundaries means a greater capacity of cone cells. Less colour cluster boundaries mean the worst capacity for cone cells. We can tell from the clusters what colour can be seen and what colour the subject can not see.

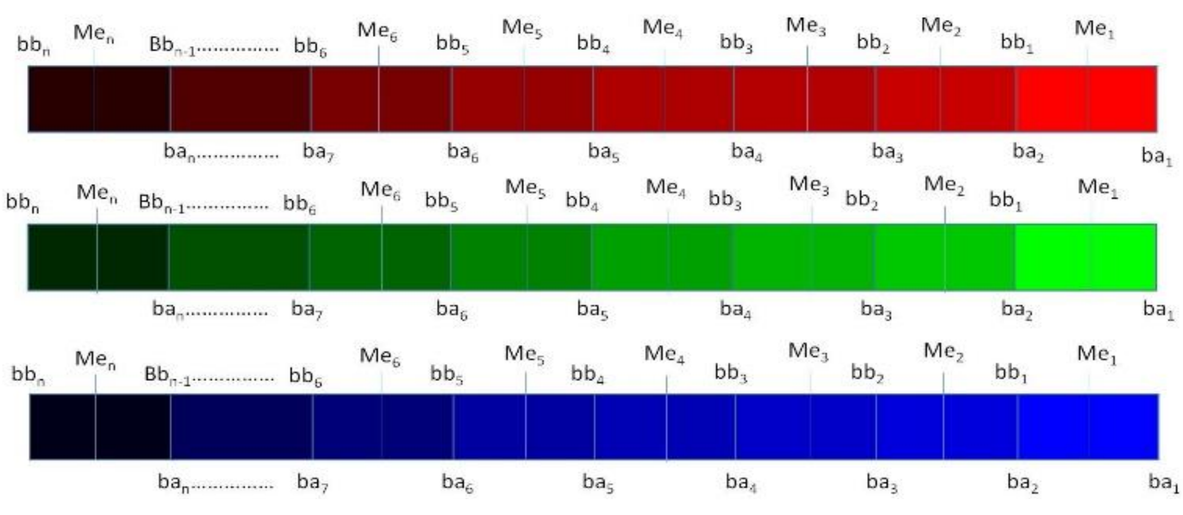

Figure 10: Details of clusters formed

The result gives us some knowledge that 96 percent of colour-blind people have fewer than 7 clusters for one or more primary colours, 100 percent of subjects can distinguish 2 colours with a distance greater than 100 percent, 100 percent of subjects can not distinguish 2 colours with a distance less than 50 percent and the last is 96 percent of subjects can distinguish 2 colours with doubt and colour distance between 50-100% [29].

3.2 Implementation of Algorithm.

This thesis focuses majorly upon the live recolouring of the videos and image simulation. The proposed system addresses CVD's problem by using variation in pixel plotting and capturing the colours. It initially uses the daltonization algorithm, which takes advantage of individual frames of video and performs RGB to LMS on each frame. The new LMS matrix will then be modified based on the type of CVD, and pixel variations are done, this is also called as fast daltonization method. Now the frames are converted again into the original RGB format and video quality improvement is performed on this. Thus, optimized and live application can be done by blending and removing distortion to get accurate results. The methods which are used to perform these techniques are Gaussian blurring and alpha blending with the background.

Algorithm 1: Live video recoloring for CVD

Input: Live video;

Output: Recoloured video;

Statement 1: - Capture video using *OpenCV()*;

while *True for video* **do**

Statement 2: - For each frame get RGB values;

Statement 3: - Convert RGB to LMS colour space;

Statement 4: - Using predefined value for each type add them to LMS matrix;

Statement 5: - Convert LMS_{cvd} to RGB. New RGB is the product of (statement 4) x inverse of (statement 2)

$$RGB_{new} = LMS_{cvd} \times inverse\ (RGB2LMS);$$

Statement 6: - Calculate the error value by subtracting the RGB and RGB_{new};

Statement 7: - Modify error to find the affected parts;

Statement 8: - Apply error value to original RGB to correct the pixel regions;

Statement 9: - Removal of noise;

Statement 10: - Smoothening of the video;

Statement 11; - Combine frames and display results.

end

returns: recoloured video

Algorithm: 1: Pseudo code for video recoloring

Statement 1: The video will be translated into individual frames. There are a variety of frames in the video clip. It can range from 100 frames to a thousand frames. We can function all the frames at once in a video. We therefore need to work on the basis of a single frame. Moreover, to process them, we turn the video into individual frames.

Statement 2: Extract a frame's RGB colour space. There are different attributes associated with each frame. Attributes such as the frame's size and orientation during live application as they may change depending on how the user holds the device, and values of the pixels for computation. The frame has RGB colour space by default. We then capture it in order to process it and change the colours.

$$RGB2LMS = \begin{bmatrix} 0.4306 & 0.8752 & 0.3659 \\ 0.2123 & 0.4587 & 0.4252 \\ 0.8108 & 0.5698 & 0.9156 \end{bmatrix}$$

Figure 11: RGB to LMS matrix

Statement 3: Convert the RGB to colour space to LMS. Colour blindness is related to the cones in our eyes. The cones are affected, such as the long medium or short. Thus, there is a correlation for graphical analysis between RGB and LMS, making LMS workspace suitable for easy computation. Thus, we transform the colour space from RGB to LMS.

Statement 4: Transform to LMS colourblind values.

$$\text{LMS to LMS}_{cvd} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ -0.1108 & 0.3698 & 0 \end{bmatrix}$$

Figure 12: LMS to CVD LMS

Thus, depending on the type of CVD being treated the matrix is modified. If the CVD has L cones missing, then the matrix is converted to the LMS matrix of a particular CVD. For example, if L cones are missing, we add values (add or subtract) in the matrix to get the desired colour. The resultant matrix will be used for further computation.

Statement 5: The new LMS values are converted back to RGB values. We have to re-convert the frame from LMS space to RGB space after processing.

$$NEWRGB = LMS_{cvd} * (RGB\ to\ LMS)^{-1}$$

Statement 6: Calculate the original RGB and new RGB. We now have new RGB values that are used to measure an error. The error is determined when the new RGB value is subtracted from the old RGB value.

Statement 7: We modify the error according to the type of CVD which is to be treated.

$$\text{Error to modify} = \begin{bmatrix} 0 & 0 & 0 \\ 8 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

Figure 13: Error matrix

We now know which sections cannot be seen by the affected individuals after the error is measured. These errors are altered to allow individuals with a definite type of CVD to discern colours easily.

Statement 8: Compute the value of error along with original RGB values. Now apply the values to the original image with the corrected mistake. This will retain the same original picture and change the colours that previous individuals with CVD could not discern earlier. This completes the fast daltonization algorithm.

Statement 9: As explained in the subsection apply methods to improve the quality of the video and images. This process is done in two parts first, we apply Gaussian Blurring and then Alpha blending. It uses a Gaussian kernel. It is done with the cv.GaussianBlur(). Gaussian blurring is extremely efficient for removing Gaussian noise from an image.

Statement 10: Apply alpha blending. Pixels are merged by using this. This is used to foreground the transparency with the background such that only necessary pixels are highlighted and helps in merging the modified colours with the original ones.

Statement 11: To finally render the new video and provide the results. Once all the frames have been separately processed, we combine them to get the production. The stored output will be of the stated extension in the code.

3.3 Implementation Strategy:

3.3.1 Python

Python is a high-level, general-purpose, interpreted, dynamic programming language which is commonly used. Its design philosophy emphasizes the readability of code, and its syntax enables programmers in languages such as C++ or Java to express concepts in fewer lines of code than would be possible. The language offers frameworks designed to allow both small and large-scale, transparent programs.

Several programming paradigms are supported by Python, including object-oriented, imperative, and functional programming or procedural types. It features a dynamic form framework and has a vast and extensive standard library and automated memory management [19].

3.3.2 OpenCV:

OpenCV is available under a BSD license (Open-Source Computer Vision Library) for both academic and commercial use and is therefore free. It supports Windows, Linux, Mac OS, iOS, and Android and has C++, Python, and Java interfaces. OpenCV was developed for computational efficiency and for real-time applications with a strong emphasis.

Written in optimized C / C++, library will take advantage of multicore processing. With OpenCL allowed, the hardware acceleration of the underlying heterogeneous computing platform can be taken advantage of. The usage ranges from digital painting, an inspection of mines, online stitching maps or advanced robotics [20].

3.4 Packages Used:

3.4.1 Cv2.imread() .

Use the function cv2.imread() to read an image. The image should be in the working directory or a full path of image should be given [30].

Second argument is a flag which specifies the way image should be read.

- cv2.IMREAD_COLOUR: Loads a colour image. Any transparency of image will be neglected. It is the default flag.
- cv2.IMREAD_GRAYSCALE: Loads image in grayscale mode.
- cv2.IMREAD_UNCHANGED: Loads image as such including alpha channelgoogle==1.9.3: Python bindings to the Google search engine [30].

3.4.2 imageio==2.1.2:

Library for reading and writing a wide range of image, video, scientific, and volumetric data formats. Imageio is a Python library which provides a wide range of image data, including animated images, volumetric data, and scientific formats, with an easy interface to read and write. It is cross-platform, runs on the 2.x and 3.x versions of Python, and is quick to install.

3.4.3 Open video file

A capturing device or an IP video stream for video capturing with API reference. This, is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

Parameters can be: -

1) Filename: -

- name of video file (e.g., video.avi)

- or image sequence (e.g., img_%02d.jpg, which will read samples like img_00.jpg, img_01.jpg, img_02.jpg).
- URL of video stream (e.g., protocol://host:port/script_name?script_params|auth). Note that each video stream or IP camera feed has its own URL scheme. Please refer to the documentation of the source stream to know the right URL.

2) apiPreference: -

- Preferred Capture API backends to use. It can be used to enforce a specific reader implementation if multiple are available: e.g. cv::CAP_FFMPEG or cv::CAP_IMAGES or cv::CAP_DSHOW [31].

3.4.4 matplotlib==2.1.1:

Python plotting package matplotlib strives to produce publication quality 2D graphics for interactive graphing, scientific publishing, user interface development and web application servers targeting multiple user interfaces and hardcopy output formats. There is a 'pylab' mode which emulates matlab graphics.

3.4.5 moviepy:

Video editing with Python. A Python library for video editing MoviePyis used for cutting, concatenations, title insertions, video composition (also known as non-linear editing), video processing and custom effect creation. For some examples of its use, see the gallery. With Python 2.7 + and Python 3. MoviePy can read and write any of the most common audio and video formats and also GIFs and runs on Windows / Mac / Linux. [32].

3.4.6 NumPy:

Processing of arrays for numbers, strings, records, and objects. NumPy is an array-processing package for general purposes designed to manipulate large multidimensional arrays of arbitrary records efficiently without losing too much speed for tiny multidimensional arrays. NumPy is based on the Numeric code base and introduces numeric and expanded C-API functionality and the ability to build arbitrary form arrays that also render NumPy ideal for general-purpose interfacing database applications. There are also basic facilities for discrete fourier transform basic linear algebra and random number generation [33].

All numpy wheels distributed from pypi are BSD licensed. In a multiple regression problem, we seek a function that can map input data points to outcome values. Each data point is a *feature vector* (x_1, x_2, …, x_m) composed of two or more data values that capture various features of the input. To represent all of the input data along with the vector of output values we set up an input matrix X and an output vector **y**: [34]

$$X = \begin{bmatrix} 1 & x_{1,1} & x_{1,2} & \cdots & x_{1,m} \\ 1 & x_{2,1} & x_{2,2} & \cdots & x_{2,m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n,1} & x_{n,2} & \cdots & x_{n,m} \end{bmatrix}$$

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

Figure 144: Numpy matrix

In a simple least-squares linear regression model we seek a vector **β** such that the product $X\boldsymbol{\beta}$ most closely approximates the outcome vector **y**.

Once we have constructed the **β** vector we can use it to map input data to a predicted outcome. Given an input vector in the form

$$\mathbf{x} = \begin{bmatrix} 1 & x_1 & x_2 & \cdots & x_m \end{bmatrix}$$

we can compute a predicted outcome value

$$\hat{y} = \mathbf{x} \cdot \boldsymbol{\beta} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m$$

The formula to compute the β vector is

$$\boldsymbol{\beta} = (X^T X)^{-1} X^T \mathbf{y} \text{ [34].}$$

3.4.7 OpenCV-python==3.7:

Wrapper package for OpenCV python bindings. This kit only includes the core modules of OpenCV without the optional contribution modules. Install OpenCV-contrib-python instead if one might look for a version that includes OpenCV contributors. The packages include binary OpenCV pre-compiled with Python bindings. This allows for super quick OpenCV installation for Python (usually < 10 seconds). No separate OpenCV installation is needed when but only need OpenCV Python bindings. The purpose of this repository is to provide the means to bundle the most used Python versions and platforms for each new OpenCV update. Also, with any Python version, it allows anyone to build a custom version of OpenCV: just fork this repo and change the build files and scripts to suit the needs [35].

3.4.8 Pandas:

Effective data structures for data analysis, time series operations for unsupervised learning, and statistics analysis. Pandas is a Python package that offers quick, versatile, and expressive data structures designed to make it both simple and intuitive to work with structured (tabular, multidimensional, potentially heterogeneous) and time-series data. It aims to be the simple high-level building block for Python to perform realistic, real-world data analysis. It also has the broader objective of being the most effective and scalable open-source data analysis/manipulation platform accessible in any language. It is well on its way toward this target already. For several different types of data, pandas are well suited: tabular data with heterogeneously typed columns, such as ordered and unordered (not necessarily fixed frequency) time series data in a SQL table or Excel spreadsheet. Arbitrary matrix data (homogeneously typed or heterogeneous) with some other kind of observational/statistical data sets for row and column labels. In fact, the data need not be labeled at all in order to be put in a data structure for pandas. The two primary panda data structures, Series (1-dimensional) and DataFrame (2-dimensional), deal with the vast majority of traditional cases of use in economics, mathematics, social science, and many engineering fields. DataFrame contains all that R 's data frame offers and much more for R users. Pandas is designed on top of NumPy and is intended to integrate well with many other third-party libraries within a scientific computing context [36].

3.4.9 pip-autoremove==0.9.0:

Remove a package and its unused dependencies First, install pip-autoremove:

$ pip install pip-autoremove

Install a package which has dependencies, e.g., Flask:

$ pip install Flask
...
Successfully installed Flask Werkzeug Jinja2 itsdangerous
markupsafe Cleaning up...
Uninstall it and all its unused dependencies:

$ pip-autoremove Flask -y
Flask 0.10.1 (/tmp/pip-autoremove/. venv/lib/python2.7/site-packages)
Werkzeug 0.9.6 (/tmp/pip-autoremove/. venv/lib/python2.7/site-packages)
Jinja2 2.7.3 (/tmp/pip-autoremove/.venv/lib/python2.7/site-packages) MarkupSafe 0.23 (/tmp/pip-autoremove/.venv/lib/python2.7/site-packages) itsdangerous 0.24 (/tmp/pip-autoremove/.venv/lib/python2.7/site-packages)
Uninstalling MarkupSafe:
Successfully uninstalled
MarkupSafe Uninstalling Jinja2:

Successfully uninstalled
Jinja2 Uninstalling
itsdangerous:
Successfully uninstalled
itsdangerous Uninstalling
Werkzeug:
Successfully uninstalled
Werkzeug Uninstalling Flask:
Successfully uninstalled Flask [37].

3.4.10 scikit-learn:

A collection of Machine Learning and Data Mining python modules. Scikit-learn is a machine learning Python module constructed on top of SciPy and distributed under the 3Clause BSD license. The project was launched in 2007 as a Google Summer of Code project by David Cournapeau, and many volunteers have contributed since then. Complete list of contributors is mentioned in the list of documentation. AUTHORS.rst file. CBLAS, the C interface for the Simple Linear Algebra Subprograms library, is also used by Scikit-learn. Scikitlearn comes with a reference implementation, but the construction system can detect the CBLAS system and use it if it is present. In several implementations, CBLAS does exist [38].

3.4.11 scipy:

Scientific Library for Python. For mathematics, science, and engineering, SciPy (pronounced 'Sigh Pie') is open-source software. The SciPy library depends on NumPy, which provides convenient and fast manipulation of the N-dimensional array. The SciPy library is designed to work with NumPy arrays and offers many numerical routines that are user-friendly and powerful, such as numerical integration and optimization routines. They work on all standard operating systems together, are easy to install, and are free of charge. NumPy and SciPy are simple to use, but strong enough for some of the world's leading scientists and engineers to rely on them. SciPy can be used to manipulate numbers on a machine and display or publish the data [39].

CHAPTER 4

RESULTS

In this chapter, we discuss various processing results related to different types of CVD obtained using the aforementioned system, which consists of the original image and recoloured image for each case of CVD. Also, the graphical results for the original image and the recoloured image with variation in red, green, and blue (i.e., RGB) are shown in the line graphs in section 4.2. Results for the videos are also present in section 4.1, which illustrates the result of live video recolouring. Moreover, frame number, resolution, format in which the video type is stored, and the processing information of frames per second and total number of frames are essential information mentioned in this section.

4.1 Experimental Evaluation and Technologies

For experimental evaluation of the proposed technique, we ran a series of experiments using live video with different parameters. Following subsections, provide details of some of these experiments. The technologies which are used for implementation include the following:

- Hardware Specification**:**
    1. Devices such as Laptop, Desktop, Tablet or PC.
- Software Specification**:**
    1. Operating System: Windows 7 or above, Android Jellybean and Ios .
    2. Recommended: Windows 8, Windows 10, Android Lollypop or above.
    3. Front End: Web application or mobile application.
    4. Back End: Python.
    5. Installed Multi-Media Application on System.
    6. Laptop / PC: VLC Media Player, Windows Media Player, ACG Player and all.

4.1.1 Example 1

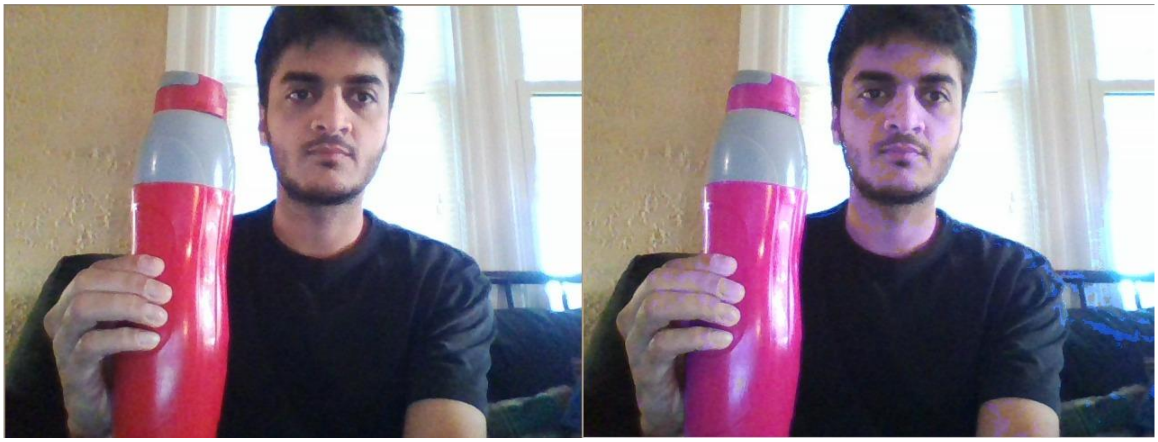

Figure 15: Recolouring of video with red object

For experimental evaluation, we tested the proposed system on various video of different resolution and length. The above figure shows the live video recolouring results, consisting of the first and last frames of a complete video. The video shows a person holding a red bottle which is recoloured specifically through the proposed system and particular colours are changed with respect to red anomaly of colour vision deficient patients. However, other components of the colours remain intact, and the video runs smoothly with the information mentioned in the video description table 3.

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
10	540*480	AVI	50	10	0.20^{th}s
30	540*480	AVI	50	30	0.60^{th}s
70	540*480	AVI	50	70	1.4^{th}s
100	540*480	AVI	50	100	2.0^{th}s

Table 3: Description of Input Video (Red) (2 seconds).

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20^{th}s
2500	1280*720	AVI	50	2500	50^{th}s
3500	1280*720	AVI	50	3500	70^{th}s
5000	1280*720	AVI	50	5000	100^{th}s
6000	1280*720	AVI	50	6000	120^{th}s

Table 4: Description of Input Video (Red) (2 minutes)

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20^{th}s
3000	1280*720	AVI	50	3000	60^{th}s
7000	1280*720	AVI	50	7000	140^{th}s
10000	1280*720	AVI	50	10000	200^{th}s
15000	1280*720	AVI	50	15000	300^{ths}s

Table 5: Description of Input Video (Red) (5 minutes)

The description table for the above video shows the parameters such as frame numbers for evaluation, resolution of the video, the format of the video in which it is stored, frames per second which are used for the smooth functioning of the video in the system, and total number of frames which is used to evaluate if there is any loss of frames. Frame numbers for evaluation describe various checkpoints, and information of each of it is used to cross-validate if there is any loss of frames at particular points and total frames recoloured.

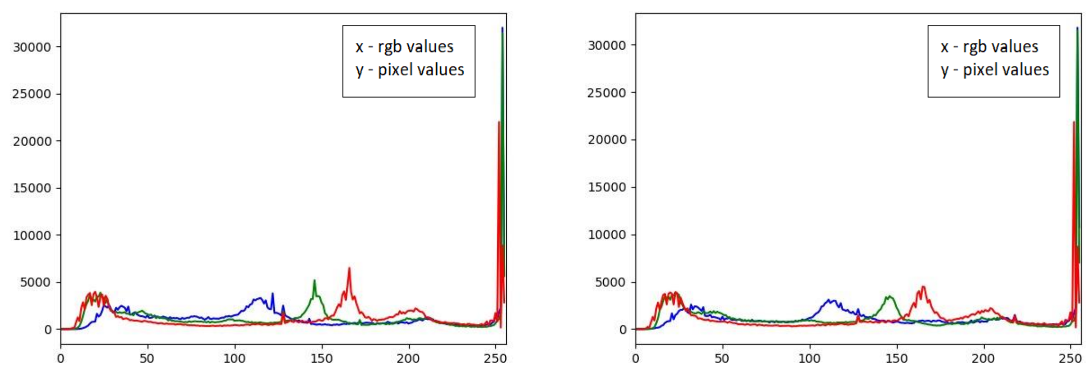

Figure 16: Graphical result for red

The graphical representation shows the RGB values of the first and last frame of the video in which only the red component changes as per the red anomaly CVD. If we have a closer look at the graph between the pixel range from 150-200 on x axis, the graphical result's red curve is changed towards pink in terms of the pixel value vs. rgb value.

4.1.2 Example 2

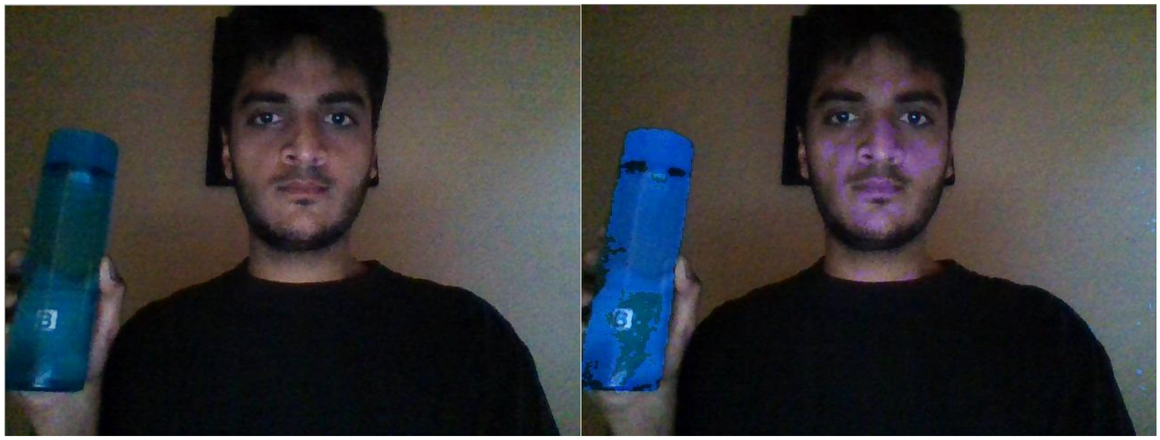

Figure 17: Recolouring of video with blue object

For experimental evaluation, we tested the proposed system on various video of different resolution and length. The above figure shows the live video recolouring results, consisting of the first and last frames of a complete video. The video shows a person holding a blue bottle which is recoloured specifically through the proposed system and particular colours are changed with respect to blue anomaly of colour vision deficient patients. However, other components of the colours remain intact, and the video runs smoothly with the information mentioned in the video description table 6.

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
10	540*480	AVI	50	10	0.20ths
30	540*480	AVI	50	30	0.60ths
70	540*480	AVI	50	70	1.4ths
100	540*480	AVI	50	100	2.0ths

Table 6: Description of Input Video (Blue) (2 seconds)

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20ths
2500	1280*720	AVI	50	2500	50ths
3500	1280*720	AVI	50	3500	70ths
5000	1280*720	AVI	50	5000	100ths
6000	1280*720	AVI	50	6000	120ths

Table 7: Description of Input Video (Blue) (2 minutes)

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20^{th}s
3000	1280*720	AVI	50	3000	60^{th}s
7000	1280*720	AVI	50	7000	140^{th}s
10000	1280*720	AVI	50	10000	200^{th}s
15000	1280*720	AVI	50	15000	300^{ths}s

Table 8: Description of Input Video (Blue) (5 minutes)

The description table for the above video shows the parameters such as frame numbers for evaluation, resolution of the video, the format of the video in which it is stored, frames per second which are used for the smooth functioning of the video in the system, and total number of frames which is used to evaluate if there is any loss of frames. Frame numbers for evaluation describe various checkpoints, and information of each of it is used to cross-validate if there is any loss of frames at particular points and total frames recoloured.

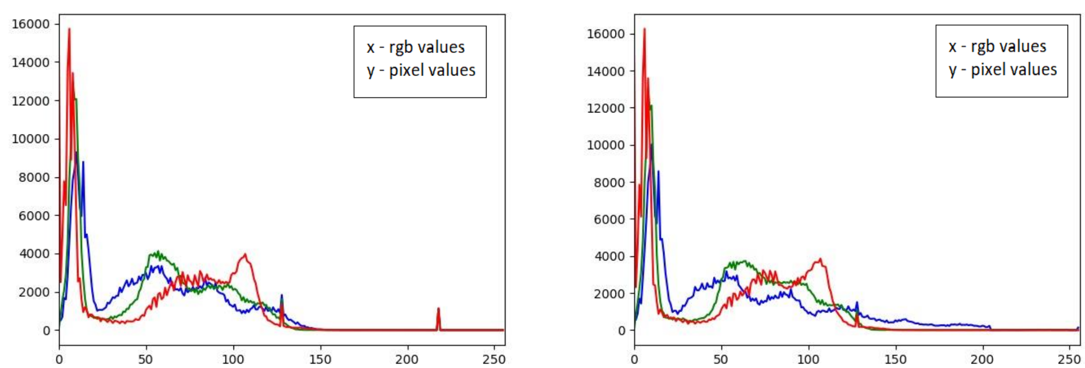

Figure 18: Graphical result for blue.

The graphical representation shows the RGB values of the first and last frame of the video in which only the blue component changes as per the blue anomaly CVD. If we have a closer look at the graph between the range of pixels from 100-200, the graphical result's blue curve is changed in terms of the pixel value vs. rgb value.

4.1.3 Example 3

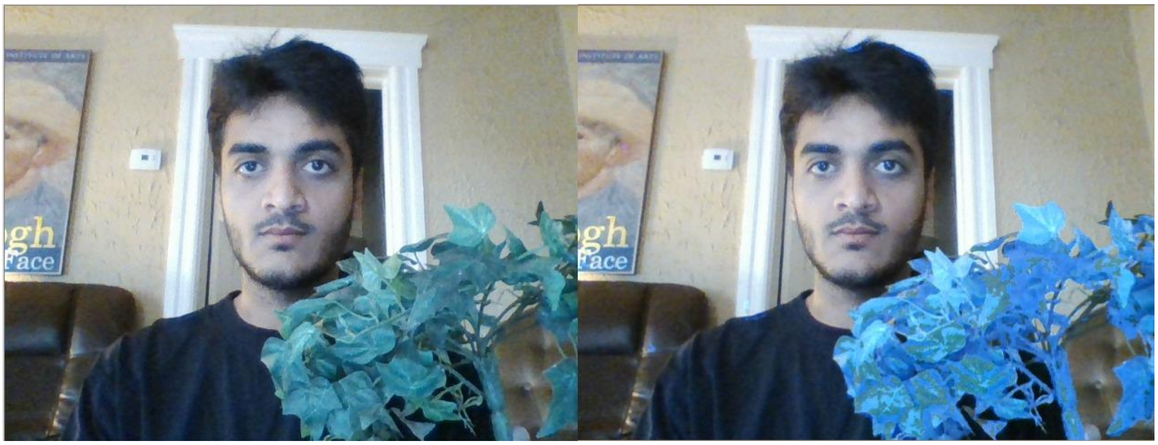

Figure 19: Recolouring of video with green object

For experimental evaluation, we tested the proposed system on various video of different resolution and length. The above figure shows the live video recolouring results, consisting of the first and last frames of a complete video. The video shows a person holding a bunch of green leaves which is recoloured specifically through the proposed system and particular colours are changed with respect to red anomaly of colour vision deficient patients. However, other components of the colours remain intact, and the video runs smoothly with the information mentioned in the video description table 9.

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
10	540*480	AVI	50	10	0.20ths
30	540*480	AVI	50	30	0.60ths
70	540*480	AVI	50	70	1.4ths
100	540*480	AVI	50	100	2.0ths

Table 9: Description of Input Video (Green) (2 seconds).

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20ths
2500	1280*720	AVI	50	2500	50ths
3500	1280*720	AVI	50	3500	70ths
5000	1280*720	AVI	50	5000	100ths
6000	1280*720	AVI	50	6000	120ths

Table 10: Description of Input Video (Green) (2 minutes)

Frame Numbers for evaluation	Resolution of video	Format of video	FPS (Frames Per Second)	Total Frames recoloured	Time of evaluation
1000	1280*720	AVI	50	1000	20^{th}s
3000	1280*720	AVI	50	3000	60^{th}s
7000	1280*720	AVI	50	7000	140^{th}s
10000	1280*720	AVI	50	10000	200^{th}s
15000	1280*720	AVI	50	15000	300^{ths}s

Table 11: Description of Input Video (Green) (5 minutes)

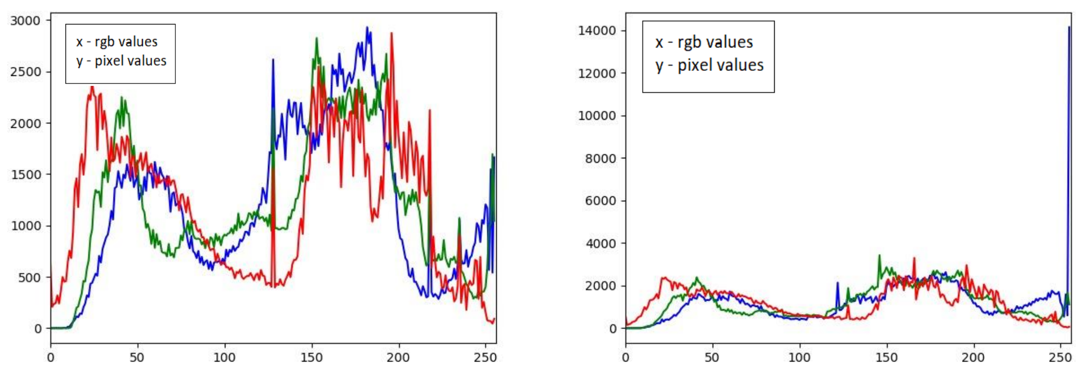

Figure 20: Graphical result for green

The graphical representation shows the RGB values of the first and last frame of the video in which only the green component changes as per the green anomaly CVD. If we have a closer look at the graph between the pixel range at 150, the graphical result's green curve is little changed in terms of the pixel value vs. rgb value.

4.1.4 Lag time for videos

Parameters	Video 1	Video 2	Video 3
Duration of videos	2 seconds	2 minutes	5 minutes
Time lag	0.29 seconds	1.59 seconds	2.38 seconds

Table 12: Results of lag time.

According to the description tables, the video processing is done at 50 FPS. This is much higher than the standard FPS. The standard rate of frames per second is 30. However, with our experiments, results were calculated with a range of 30 FPS to 50 FPS, and there was no loss of frames for processing. Moreover, at the end of processing the result is near to real-time, but we take into account the buffer processing time of hardware and a little lag of time function calculated for each epoch. Hence, for 2 seconds video the lag is approximately 0.29 seconds, for 2 minutes video it is approximately 1.59 seconds and for 5 minutes it is approximately 2.38 seconds. This time lag is an approximate value and is calculated using time function in python. The time lag is same for all 3 examples red, blue and green and it is very small and negligible.

4.2 Images

4.2.1 Protanopia:

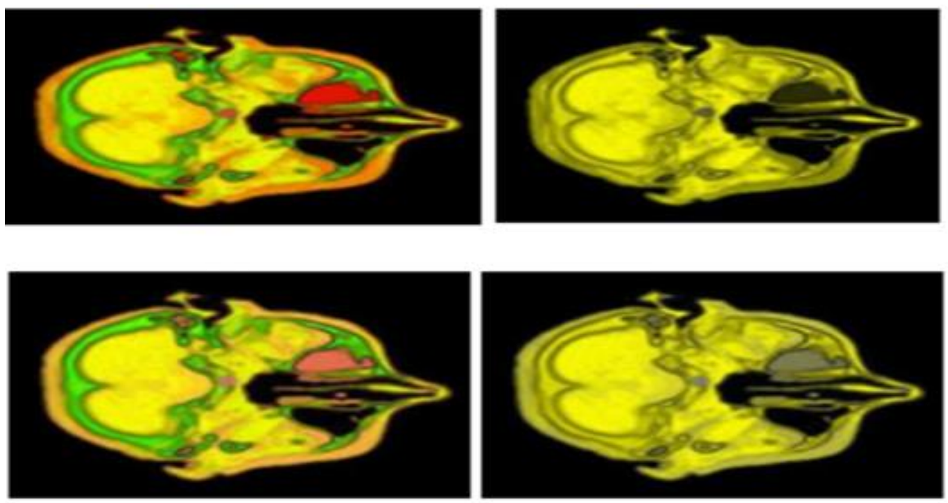

Figure 21: Protanopia

Discussion and keynote:

- To demonstrate the image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.

- Simulated Recoloured Image is the one which the colour vision deficient person will perceive from the recoloured image.

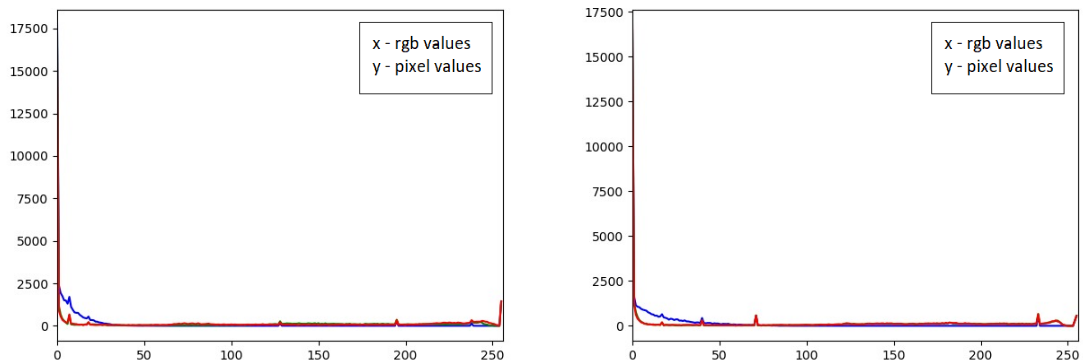

Figure 22: Graph for protanopia

- The above graphical results are for the original image and for the final simulated recoloured image. In the case of protanopia in which the red cones are missing, the RGB graph of pixel shows sharp increase in red colours between points 50-100 and after 200 on the x axis, which shows recolouring on the red pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos give the best possible results i.e., efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help process the video recolouring faster and more efficient output.
- As protanopia is one of the most common forms of colour vision deficiency, the patients suffering with this type of colour blindness are readily available and hence there might be sufficient sample dataset to verify the results of outputs of protanopia.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image and displaying all 4 images is 3 seconds.

4.2.2 Protanomaly:

Figure 23: Protanomaly

Discussion and keynote:

- To demonstrate the image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.
- Simulated Recoloured Image is the one which the colour vision deficient person will perceive from the recoloured image.

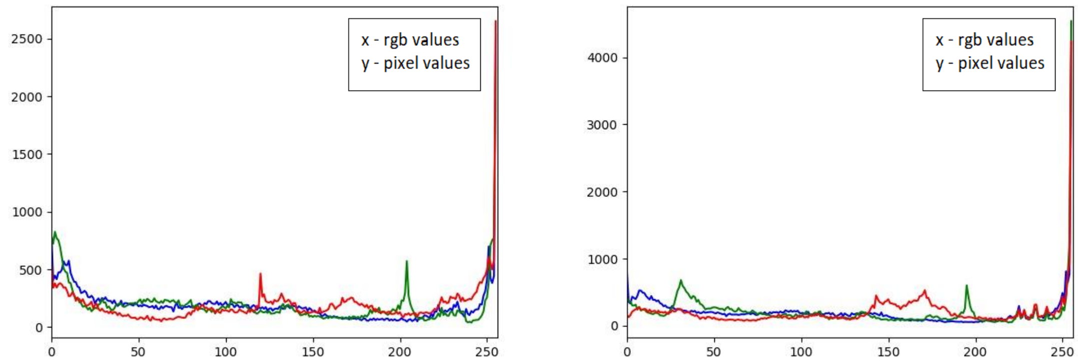

Figure 24: Graph for protanomaly

- The above graphical results are for the original image and the final simulated recoloured image. In the case of protanomaly in which the red cones are not aligned correctly, the RGB graph of pixel shows a sharp increase in red colours between points 100-150 and after 150 on the x axis, which shows recolouring on the red pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos gives the best possible results i.e. efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help process the video recolouring faster and more efficient output.
- As protanomaly is one of the most common forms of colour vision deficiency, the patients suffering with this type of colour blindness is readily available and hence there might be sufficient sample dataset to verify the results of outputs of protanomaly.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image, and displaying all 4 images is 3 seconds.

4.2.3 Deuteranopia:

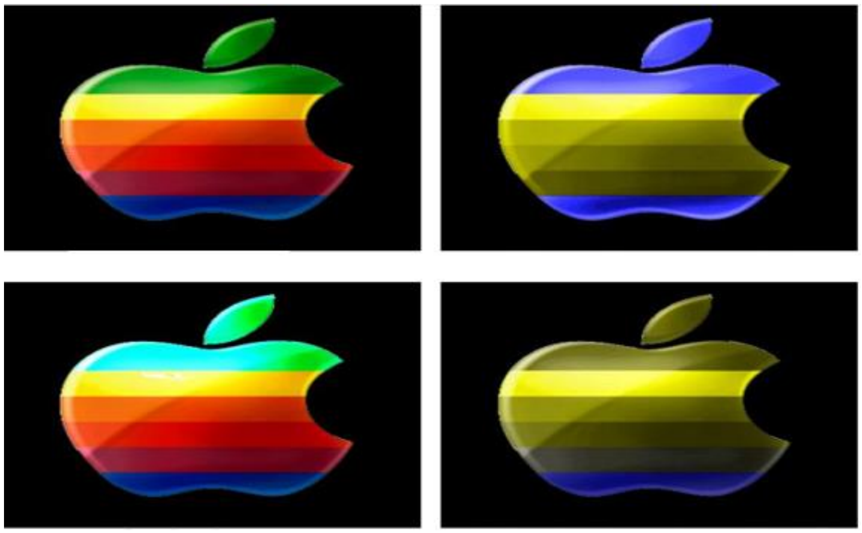

Figure 25: Deuteranopia

Discussion and keynote:

- To demonstrate image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.
- Simulated Recoloured Image is the one which the colour vision deficient person will perceive from the recoloured image.

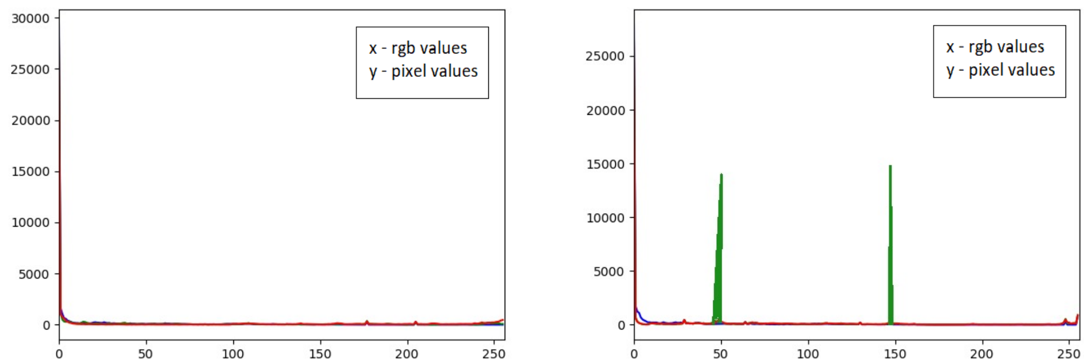

Figure 26: Graph for deuteranopia

- The above graphical results are for the original image and the final simulated recoloured image. In the case of deuteranopia in which the green cones are missing, the RGB graph of pixel shows sharp increase in green colours between points 50-150 on the x axis, which shows recolouring on the green pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos gives the best possible results i.e. efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help process the video recolouring faster and more efficient output.
- As deuteranopia is one of the common forms of Colour Vision Deficiency, the patients suffering with this type of colour blindness is just a bit rare and hence there might be sufficient sample dataset to verify the results of outputs of Deuteranopia.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image, and displaying all 4 images is 3 seconds.

4.2.4 **Deuteranomaly**:

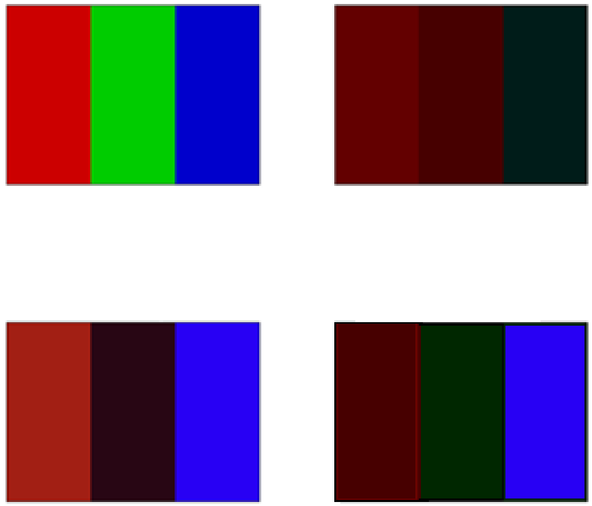

Figure 27: Deuteranomaly

Discussion and keynote:

- To demonstrate the image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.
- Simulated Recoloured Image is the one which the colour vision deficient person will perceive from the recoloured image.

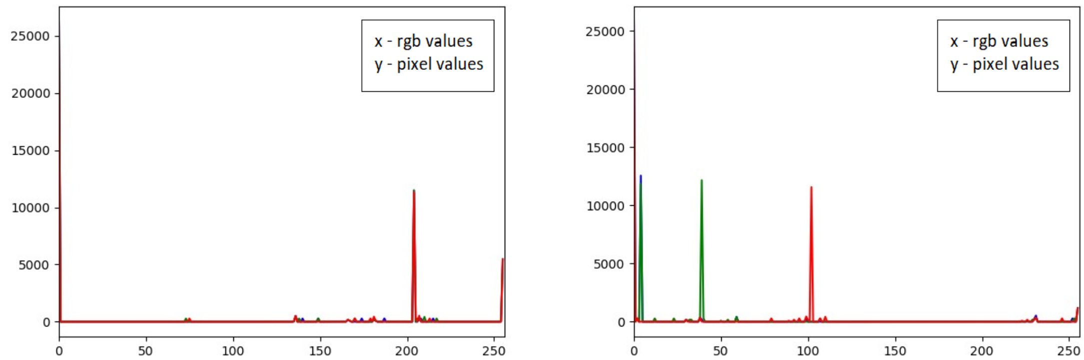

Figure 28: Graph for deuteranomaly

- The above graphical results are for the original image and the final simulated recoloured image. In the case of deuteranomaly in which the green cones are not aligned correctly, the RGB graph of pixel shows a sharp increase in green colours at point 50 on the x axis, which shows recolouring on the green pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos give the best possible results i.e. efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help in processing the video recolouring faster and more efficient output.
- As Deuteranomaly is one of the common forms of Colour Vision Deficiency, the patients suffering with this type of colour blindness is just a bit rare and hence there might be sufficient sample dataset to verify the results of outputs of deuteranomaly.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image, and displaying all 4 images is 3 seconds.

4.2.5 Tritanopia:

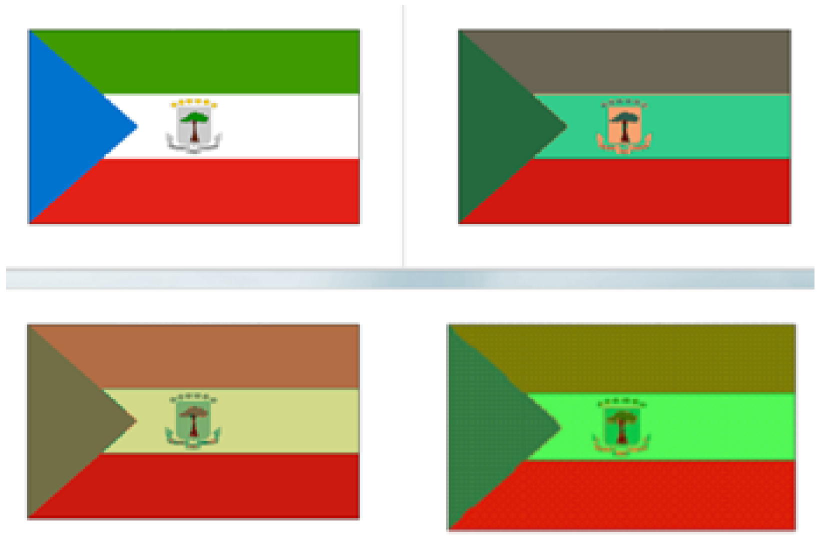

Figure 29: Tritanopia

Discussion and keynote:

- To demonstrate image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.
- Simulated Recoloured Image is the one which the colour vision deficient person will perceive from the recoloured image.

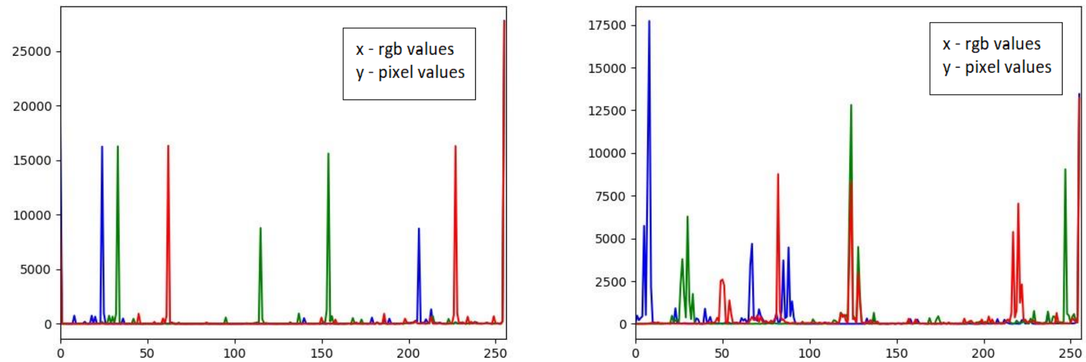

Figure 30: Graph for tritanopia

- The above graphical results are for the original image and the final simulated recoloured image. In the case of tritanopia in which the blue cones are missing, the RGB graph of pixel shows a sharp increase in blue colours between points 0-50 and at few other points at 100 on the x axis, which shows recolouring on the blue pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos gives the best possible results i.e. efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help process the video recolouring faster and more efficient output.
- As tritanopia is one of the rarest forms of Colour Vision Deficiency, the patients suffering with this type of colour blindness is sporadic and hence there is less sample dataset to verify the results of outputs of tritanopia.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image and displaying all 4 images is 3 seconds.

4.2.6 Tritanomaly:

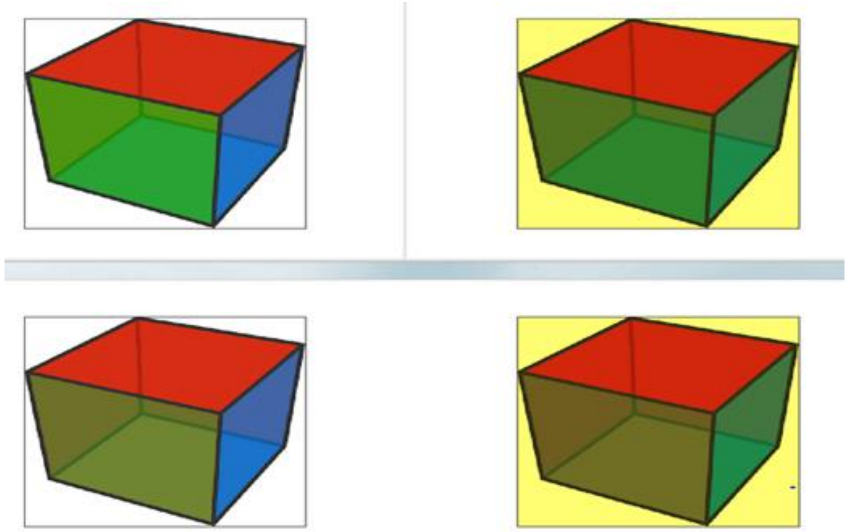

Figure 31: Tritanomaly

Discussion and keynote:

- To demonstrate image and its output, we recolor an original image 3 times, labelled as Simulated Image, Recoloured Image and Simulated Recoloured Image.
- Simulated Image means what the colour vision deficient person perceives from the original image before recolouring it.
- Recoloured Image means what the colour vision deficient person is expected to see and perceive all 3 primary colours.
- Simulated Recoloured Image is the one which the colour vision deficient will perceive from the recoloured image.

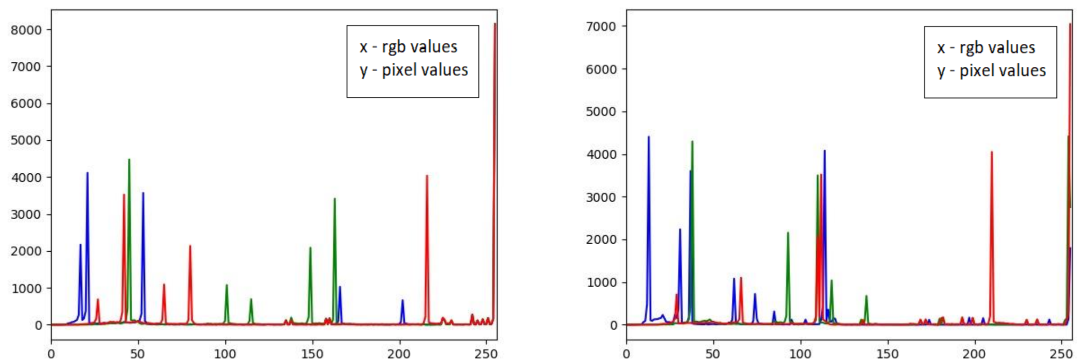

Figure 32: Graph for tritanomaly

- The above graphical results are for the original image and the final simulated recoloured image. In the case of tritanomaly in which the blue cones are not aligned correctly, the RGB graph of pixel shows a sharp increase in blue colours between points 0-50 on the x axis, which shows recolouring on the green pixel.
- The system for recolouring the multimedia supports all the formats, yet the .png format in images and .avi format in videos give the best possible results i.e. efficient and quicker in response time.
- Research suggests that using hardware such as Graphics Card (GPU) might help process the video recolouring faster and more efficient output.
- As tritanomaly is one of Colour Vision Deficiency rarest forms, the patients suffering with it is very rare to have this form of colour blindness.
- Thus, to conclude with the discussion, we can say that the recolouring of the image takes 3-4 seconds only per image and displaying all 4 images is 3- seconds.

4.3 Comparative Study

Model	Hardware Based	Software Based	All types of CVD are covered	Live Application	Video implementation
[1]	Y	N	N	N	N
[2]	N	Y	N	N	N
[3]	Y	Y	N	N	N
[4]	N	Y	N	N	N
[5]	N	Y	N	N	N
[6]	Y	Y	N	N	N
[7]	N	Y	Y	N	N
[8]	Y	Y	N	N	N
[9]	N	Y	N	N	N
[10]	N	Y	Y	N	N
[11]	N	Y	Y	N	N
[12]	N	N	Y	N	N
Our Approach	N	Y	Y	Y	Y

Table 13: Comparative Study Table

For most of the previously designed systems, the primary objective is to recolour the stored image depending on the CVD type. Incorporating these recolouring techniques in image and video recolouring and solving all CVD types' recoloring is quite tricky. Considering the overview of most techniques, a few recolouring systems can do it and provide solutions only for one type of CVD. The previous systems whose approach can be used for live video application of video and image recolouring are either having loss of data by missing frames or do not cover all CVD types. None of the recolouring systems have live applications, and the domain of the video is untouched. The proposed system supports all the types of CVD's that have the most considerable prevalence on earth.

X. Zhang et al. [12], also developed a similar system that generates recoloured images using GANS (Generative Adversarial Network). The main difference is that for images, it recolours and provides a solution only for dichromacy. Thus, anomalous trichromacy (one of the cones is misaligned) and live application in videos are not covered. Further, one of its significant limitations is its time complexity. Thus, time complexity when using daltonization technique (RGB to LMS) when integrated with GANS is very large. Thus, constructing a live application system is impossible as it requires preprocessing and cannot work on live video recolouring. The results for image recolouring using GANS are as follows: -

Methods	PSNR	SSIM	Time (hh:mm:ss.ms)
Pix2pix - GAN	16.1280	0.7155	00:00:54.14
Cycle-GAN	15.8396	0.7277	00:02:21.46
Bicycle-GAN	15.2814	0.7016	00:00:49.91
Groundtruth	15.6461	0.7430	00:38:50.50
Zhang's Model	15.1189	0.7568	00:00:56.49

Table 14: Validation Methods [12].

It uses three significant parameters for comparison: Peak-Signal-to-Noise-Ratio, Structural-Similarity-Index-Measure, and computational time.

- SSIM is used to measure the image quality, and the resulting value varies between 1.0 for identical images and 0.0 for entirely different images.

- PSNR is a measure for compression in the image and the videos. It also measures the quality of reconstruction, where the signal is the original data and noise is the error.
- Computational time is the time taken for the system to give the recoloured output.

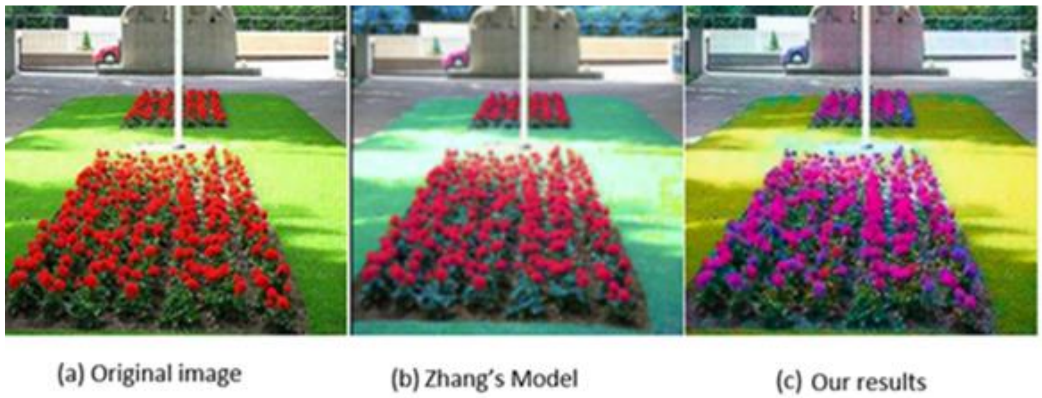

Figure 33: Comparative Results

The results obtained on comparing our system with X. Zhang et al. [12], based on SSIM, PSNR, and computational time are mentioned in the table below: -

Parameters	Zhang's Model	Our System
SSIM	0.7568	0.7911
PSNR	15.1189	19.6389
Time (hh:mm:ss.ms)	00:00:56.49	00:00:01.29

Table 15: Validation Results

Our designed system produces better results than Zhang's model in SSIM, PSNR, and time. On evaluation, the SSIM obtained for our system is 0.7911, which is better than the compared model as it is between 0 and 1 and closer to 1, which depicts the fact the structural similarity between the initial and the output image is very close in terms of similarity. However, the result for PSNR is 19.6389, which is higher than the base model. However, the results for SSIM and PSNR are calculated ten times, and the average of them is chosen for our system, i.e., SSIM: - 0.7911 and PSNR: - 19.6389. The time required for computation is approximately 1.29 s, including the buffer processing, which is very closed to live application. GMM clustering used in Zhang's model may produce an error in recolouring, which is not our system's case.

Akhil Khare [5] proposed a technique only for colour transformation of images in 2018. This research work primarily focused on only one type of CVD i.e., dichromacy, considering LMS Daltonization, RGB colour contrasting, and Lab colour contrasting. The entire research is based on dichromacy and does not provide results for anomalous trichromacy. The core idea of this research work is to apply LMS Daltonization and provide shifts in the colour contrast with the following values: -

- Wavelength shifting of 475 nm for protanopia.
- Wavelength shifting of 575 nm for deuteranopia.
- Wavelength shifting of 660 nm for tritanopia.

However, these values stand true only in dichromacy, where one of the cones is missing and provides satisfactory results. LMS Daltonization efficiently performs the shifting, and the RGB contrasting performs the colour adjustment for the CVD. The colour balancing is done by Lab contrasting between red and green. The results which are obtained for this system are suitable enough for dichromatic patients and not for others.

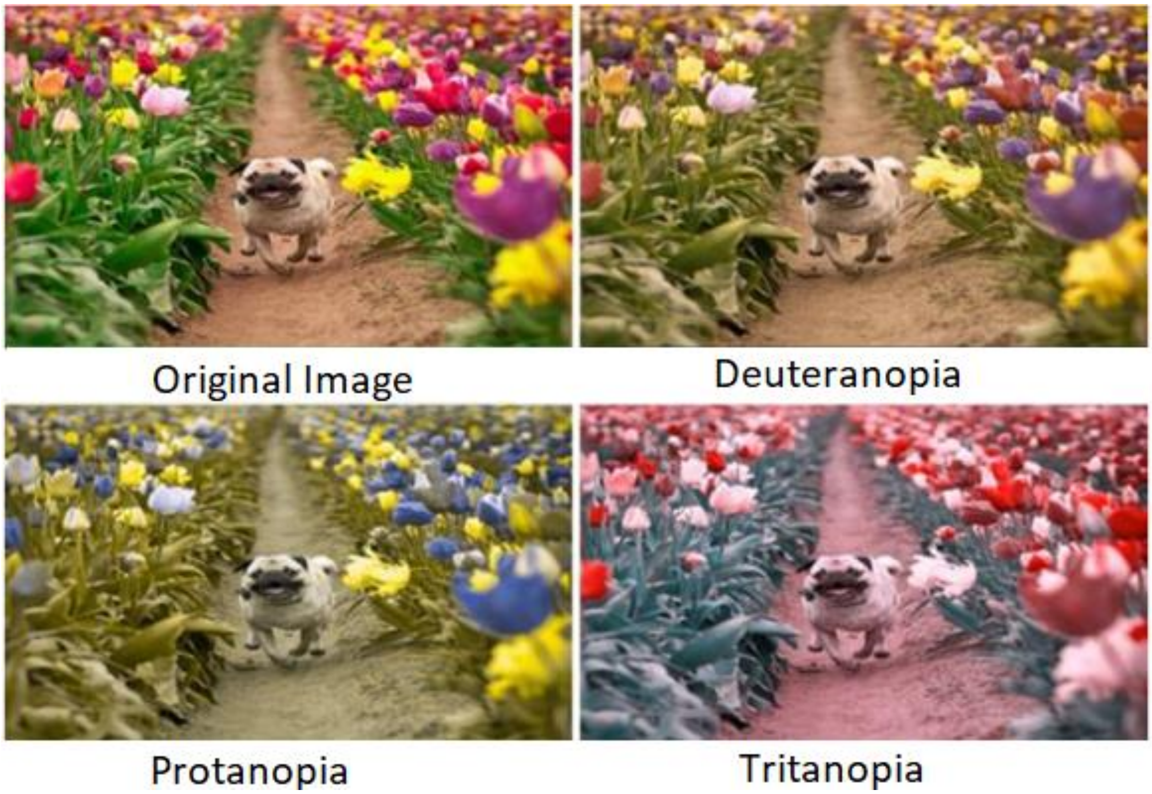

Figure 34: Results of colour correction [5]

Thus, considering the above system's research gaps, our proposed system is capable of providing the solution for anomalous trichromats as well. This is because in our proposed methodology, after the LMS conversion new RGB values are calculated and error values are identified. In the background gradient map method and other distances are calculated and based on the Ishihara test's input, two colours can be modified instead of one, which provides solution for anomalous trichromats as well. Our system's results consist of the recoloured images for dichromats and anomalous trichromats, which increases the scope of the previous system.

Figure 35: Results from our system

Video recolouring is not performed in the system by [5]. The computational time is quick, but it is not applicable in the videos as Lab contrasting requires multiple passes for pixel calculation. Preprocessing is one of the significant limitations of the system in [5]. The captured image needs to be converted into required planes, which affects the processing's computational time.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Generally speaking, colour blind people suffer from lack of self-motivation due to their colour vision impairment and usually feel the need to be like normal people. However, in the absence of any specialized hardware equipment, it is not possible for them to see colours. Even if such a tool is available, the cost may be a prohibitive factor and can limit its affordability. Therefore, a software solution may offer a better solution, allowing them to differentiate between different colours. Visual media, such as movies, pictures, learning, etc., is something that everybody is obsessed by. This is a bane for colour-blind individuals. Therefore, if they could discern colours, they would love the visual media as well, and it would turn out to be a boon for them.

The results of the re-coloured images and videos using different multimedia files are obtained in this thesis, using different colour blindness modules as the subject of colour vision deficiency. In our thesis work, different types of algorithms are implemented using the effectiveness of the current system's programming languages, giving a rapid response in terms of output, however, the performance is somehow lagging behind which can be improved in the future scope.

There can be any number of possibilities for features and parameters, and our system can handle files imported from other platforms in a compatible format, thus, providing flexibility to other fields to work with our system flawlessly. The above system may not give the deficient colour vision patients full satisfaction as they are not be able to see the real colour, but at least by differentiation, which eliminates uncertainty, this may be the beginning of a new 'visual' environment for them and this can help achieve 'complete satisfaction' in the future.

We are using NumPy arrays with pixel variation and other methods based on current video. This thesis's current scope is to capture the video and inhibit changes and save the necessary output with convenient file extensions. In addition to raising the processing power and specifications, GPU's can be used to provide a better medium to use the provided input images and other media types to split, simulate, recolour and display colours in relation to the patients' CVDs with regard to the deficiency.

5.2 Future work

- Processing through utilization of GPU processing capabilities can significantly enhance the current system. It is also possible to recognize uneven light as one of the vital impact factors that can be tackled, and other techniques can be created for skin tone masking. Creation of faster software to process and transform system with a better UI and graphical interface for simultaneous data access and report generation for in-depth data and disease analysis. Including the country and division of regions and the estimation of a certain percentage of affected diseases in persons with specific categories.
- Improving co-ordinates for recolouring images can make the results more precise in the future using optimized algorithms other than daltonization, which might be developed in the future. For .png images and .avi videos, our system can provide fast results but can take more time for other complicated image and video formats depending upon the type of operating systems as video quality improvement techniques like gaussian blurring and alpha blending makes use of kernel capacity.
- The main aim of choosing this research subject is to help the colour vision impaired, experience the primary colours. This can contribute to society in a way by supporting approximately 100-450 million people with colour vision problems under normal lighting conditions. Therefore, with online channels such as YouTube, Amazon Prime Videos, Daily-motions, and other streaming services and all online video buffering channels, we expect to incorporate the modules of all colour vision deficiencies. Thus, the aid of recolouring algorithms, gives colour vision impaired individuals an easy choice of a simple button to perceive the natural primary colours.

- Wrapping up in the form of an Application programming interface (API). After the production and testing of the system. This can be one of the major implementations for software developers to integrate new features in their systems.

REFERENCES/BIBLIOGRAPHY

[1] Tomoyuki Ohkubo and Kazuyuki Kobayashi, "A colour compensation vision system for colour-blind people," 2008 SICE Annual Conference, Tokyo, 2008, pp. 1286-1289.

[2] J. Rumiński et al., "Colour transformation methods for dichromats," 3rd International Conference on Human System Interaction, Rzeszow, 2010, pp. 634-641.

[3] J. Mcdowell, "Design of a colour sensing system to aid the colour blind," in IEEE Potentials, July-Aug. 2008, vol. 27, no. 4, pp. 34-39.

[4] P. K. Nigam and M. Bhattacharya, "Colour vision deficiency correction in image processing," 2013 IEEE International Conference on Bioinformatics and Biomedicine, Shanghai, 2013, pp. 79-79.

[5] Dr. Akhil Khare, "Improved image colour transformation for colourblind patients," International Journal of Creative Research Thoughts (IJCRT), February 2018, Volume.6, Issue 1, pp.103-106.

[6] B. S. Ananto, R. F. Sari and R. Harwahyu, "Colour transformation for colour blind compensation on augmented reality system," 2011 International Conference on User Science and Engineering (i-USEr), Shah Alam, Selangor, 2011, pp. 129-134.

[7] J. Huang, C. Chen, T. Jen and S. Wang, "Image recolourization for the colourblind," 2009 IEEE International Conference on Acoustics, Speech and Signal Processing, Taipei, 2009, pp. 1161-1164.

[8] B. R. Navada, K. V. Santhosh, S. Prajwal and H. B. Shetty, "An image processing technique for colour detection and distinguish patterns with similar colour: An aid for colour blind people," International Conference on Circuits, Communication, Control and Computing, Bangalore, 2014, pp. 333-336.

[9] S. Poret, R. D. Dony and S. Gregori, "Image processing for colour blindness correction," 2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH), Toronto, ON, 2009, pp. 539-544.

[10] L. Zhang et al., "Improved colour-to-grey method using image segmentation and colour difference model for colour vision deficiency," in IET Image Processing, 3 2018, vol. 12, no. 3, pp. 314-319.

[11] S. Angchekar, H. Gurav, and M. Darvesh, "An overview study of various re-colouring and wavelength adjustment algorithm for colour vision deficient individuals," 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), Chennai, 2017, pp. 1660-1668.

[12] X. Zhang, M. Zhang, L. Zhang, P. Shen, G. Zhu and P. Li, "Recolouring image for colour vision deficiency by gans," 2019 IEEE International Conference on Image Processing (ICIP), Taipei, Taiwan, 2019, pp. 3267-3271.

[13] "Importance of understanding of Colour Vision Deficiency," [Online]. Available: https://www.2020mag.com/article/the-importance-of-understanding-colour-vision-deficiency. [Accessed September 2020].

[14] Ken Wakita and Kenta Shimamura. "SmartColour: disambiguation framework for the colour-blind". In Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility. Association for Computing Machinery, New York, NY, USA, 2005, pp. 158–165.

[15] Luke Jefferson and Richard Harvey. "An interface to support colour blind computer users". In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, 2007, pp. 1535–1538.

[16] K. Rasche, R. Geist and J. Westall, "Detail preserving reproduction of colour images for monochromats and dichromats,". IEEE Computer Graphics and Applications, May-June 2005, vol. 25, no. 3, pp. 22-30.

[17] Kuhn, G., Oliveira, M., & Fernandes, "An efficient naturalness-preserving image-recolouring method for dichromats". IEEE Transactions on Visualization and Computer Graphics, 2008, vol 14, no. 6, pp. 1747-1754.

[18] "Definition for MATLAB," [Online]. Available: https://www.definitions.net-/definition/MATLAB. [Accessed October 2020].

[19] "Wikipedia," [Online] Available: https://en.wikipedia.org/wiki/Python. [Accessed October 2020].

[20] "Open CV," [Online]. Available: https://hpc.unt.edu/opencv. [Accessed November 2020].

[21] “Colour vision deficiency,” [Online]. Available: https://www.aoa.org/healthy-eyes/eye-and-vision-conditions/colour-vision-deficiency. [Accessed October 2020].

[22] Jia-Bin Huang, Sih-Ying Wu, Chu-Song Chen. “Enhancing colour representation for the colour vision impaired”. Workshop on Computer Vision Applications for the Visually Impaired, James Coughlan and Roberto Manduchi, Oct 2008, Marseille, France.

[23] “Types of Colour Blindness,” [Online]. Available: https://www.colour-blindawareness.org/colour-blindness/types-of-colour-blindness. [Accessed October 2020].

[24] “Daltonize.org,” [Online]. Available: http://www.daltonize.org. [Accessed October 2020].

[25] Pareyani, A., & Mishra, A. (2015).” Low Contrast Gray Image Enhancement using Particle Swarm Optimization (PSO) with DWT”. International Journal of Computer Applications, vol. 130, no. 8, pp. 8-13.

[26] N. Pendhari, R. R. Sedamkar, A. Pandey, A. Khan and A. H. A. Buddha, "Colour contrast enhancement in visual media for the anomalous trichromats," 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), Chennai, 2017, pp. 2207-2216.

[27] Hyun-Ji Kim, Jae-Yun Jeong, Yeo-Jin Yoon, Young-Hyun Kim and Sung-Jea Ko, "Colour modification for colour-blind viewers using the dynamic colour transformation," 2012 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, 2012, pp. 602-603.

[28] C. Huang, H. Lee and C. Chen, "Shot Change Detection via Local Keypoint Matching," in IEEE Transactions on Multimedia, Oct. 2008, vol. 10, no. 6, pp. 1097-1108.

[29] D. Q. Utama, T. L. R. Mengko, R. Mengko and M. N. Aulia, "Colour blind test quantification using RGB primary colour cluster," 2016 International Conference on Information Technology Systems and Innovation (ICITSI), Bandung, 2016, pp. 1-4.

[30] “Loading Images,” [Online]. Available: https://cvexplainedwordpress.com/loading-images. [Accessed June 2020].

[31] “Cv:VideoCapture,” [Online]. Available: https://docs.opencv.org/-3.4/d8/dfe/classcv_1_1VideoCapture.html. [Accesses October 2020].

[32] “Moviepy,” [Online]. Available: https://pypi.org/project/moviepy/. [Accessed October 2020].

[33] “Numpy,” [Online]. Available: https://anaconda.org/mingwpy/numpy. [Accessed October 2020].

[34] “Numpy,” [Online]. Available: http://www2.lawrence.edu/fast/GREGGJ/Python/-numpy/numpyLA.html. [Accessed October 2020].

[35] “Opencv-python-aarch64,” [Online]. Available: https://pypi.org/project/opencv-python-aarch64. [Accessed October 2020].

[36] “Package overview,” [Online]. Available: https://pandas.pydata.org/docs-/getting_started/overview.html. [Accessed October 2020].

[37] “pip-autoremove,” [Online]. Available: https://github.com/invl/pip-autoremove. [Accessed October 2020].

[38] “Cnn-Gan,” [Online]. Available: https://github.com/CNN-GAN/scikit-learn. [Accessed October 2020].

[39] “Scipy,” [Online]. Available: https://pypi.org/project/scipy/. [Accessed October 2020].

[40] Kulshrestha, R., & Bairwa, R. K. “Review of Colour Blindness Removal Methods using Image Processing”. International Journal of Recent Research and Review, 2013, vol. 6, pp. 18-21.

[41] Ribeiro, M., & Gomes, A. J. “Recoloring algorithms for colorblind people: A survey”. ACM Computing Surveys (CSUR), 2019, vol. 52, pp. 1-37.

VITA AUCTORIS

NAME:	Sami Ali Hussain Ali Choudhry
PLACE OF BIRTH:	Mumbai, India
YEAR OF BIRTH:	1996
EDUCATION:	Bachelor of Computer Engineering, 2015-2019 MH Saboo Siddik College, Mumbai, India Master of Science in Computer Science, co-op, 2019-2020 University of Windsor, Windsor, ON