Colour Transformation for Deuteranopic Viewers

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Abstract : Colour blindness, also known as colour vision deficiency, is the impairment of a person's ability to perceive colour differences. Most commonly, this is due to defects in one of the three retinal cones that facilitate perception of colour. The objective of this paper is to propose and implement an image processing algorithm that help red-green colour blind individuals perceive colour diversity in digital images. The algorithm is based on a modified LMS Daltonization process with Laplacian pre-processing performed before transformation to improve edge contrast as well as to accentuate and emphasize differences between adjacent shades of colours in the image. Deuteranopia has been chosen among the various forms of colour vision deficiencies as it is one of the most common types. The algorithm has been designed for deuteranopic viewers, who have anomalous vision in the medium wavelength region (green-yellow) of the visual spectrum.

Keywords : Colour-deficient vision, daltonization, image process-ing, deuteranopia, colour transformation

1. INTRODUCTION

Normal human vision is trichromatic –Image perception using information from the long, medium and short wave-lengths of light. People with colour deficient vision perceive images differently, since their colour perception is impeded or aberrated. There are three different types of cones in the human eye, each containing one type of photoreceptor cells, called cones. One type detects short (red) wavelengths, another detects medium (green) wavelengths, and the third detects long (blue) wavelengths [1].Persons with colour deficient vision have difficulty perceiving all three channels, *i.e.*, they are said to be dichromatic if they perceive only two wavelengths without aberration, or monochromatic, if they perceive just one [2]. There are three typical kinds of colour blindness
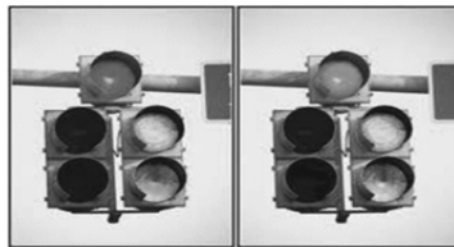

Fig.1. Effect of colour blindness

protanopia, deuteranoipia and tritanopia, which correspond to the deficiency of the L, M and S cones respectively [3]. People with these conditions have trouble perceiving the full spectrum of colours that a normal person is able to distinguish [4]. Colour blindness affects about 8% of males and 0.5% of females worldwide [5]. The scope of this paper is to discuss the most common kind of colour deficient vision – deuteranopia. Deuteranopia is a type of dichromatic vision, where the viewer is not able to process medium wavelengths (M) of light. Colour blind persons

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face difficulties in their day to day lives [1] (Fig 1). They cannot differentiate signals, caution lights and maps, and may be barred from certain occupations, particularly those pertaining to military or safety. In the case of deuteranopia, the medium wavelength sensitive cones (green) are missing. A person with normal vision can see 7 different hues whereas a deuteranopic person distinguishes only 2 to 3 different hues.

2. LITERATURE SURVEY

To analyze how colour blind people perceive colours in the world, Fidaner et al. [6] proposes an algorithm to sim-ulatedeuteranopia. The image is converted to LMS colour space (which classifies colours into Long, Medium and Short wavelengths), the M wavelength is removed, and data from the L and S wavelengths is used to fill in the missing data, thus simulating deuteranopic vision. Several approaches and methods have been proposed to adjust images for colour blind persons. Dougherty and Wade [10] propose an algorithm in which the red-green contrast in the image is increased, then the red-green contrast information is used to adjust brightness and blue-yellow contrast. In Rasche's approach [7], linear transform is used to convert colours to the CIELAB color space and enforce proportional color differences during the remapping, and transformations are applied so as to obtain an output more discernible to colour blind viewers. Halder et al. [9] describes a colour contrasting approach, wherein the contrast between different shades is altered to accentuate colour differences. Khurge [8] follows a different approach, using LMS Thresholding and Masking Algorithm to obtain the result. Thresholding checks the greylevel value of pixels with pre-defined thresholds and categorize them into one more classes. The resultant image is gamma corrected to ensure that relative differences between the individual channels in an image is preserved. Doliotis et al. [12] presents a very different approach, where colour clustering is performed to group individual colours into clusters, and applying colour transformations to each cluster to adjust the overall image and make it more perceptible for colour blind viewers. However, all the above specified algorithms have limitations - like the inability to preserve all the colour variations of the image, or oversaturation of the colours.

3. PROPOSED METHOD

To overcome the troubles faced by the colour blind viewers there are numerous techniques as described above. The most common ones are LMS Daltonization, Colour Contrasting technique and LAB Colour Correction method (which uses the CIELAB colour space for image transformations). In order to assess the effectiveness of any daltonization algorithm, a method of simulating an image through the eyes of a person suffering from deuteranopia has to be developed initially.

A. Simulation

The image is first converted to the LMS colour space, using some conversion matrix [4]. This operation, applied to every pixel of the image, yields a new set of pixels whose information is now defined for the LMS colour space.

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 17.8824 & 43.5161 & 4.11935 \\ 3.4565 & 27.1554 & 3.86714 \\ 0.02996 & 0.18431 & 1.46709 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

The image has now been converted to the LMS colour space. The information associated with the M (medium) cone is removed and replaced with information perceived by the L (long) and S (short) cones. An aspect to be noted here is that the M wavelength information is not empty, instead the following matrix multiplication operation is performed:

$$\begin{bmatrix} L_D \\ M_D \\ S_D \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0.49421 & 0 & 1.2427 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} L \\ M \\ S \end{bmatrix} \tag{2}$$

The medium wavelength information has been thus re-moved from the image. A proportion of information from the L and S cones is obtained experimentally and the new M pixel has been filled with this proportion. This is done since in deuteranopic vision, M wavelengths are perceived as being from the L and S bands instead. Hence, deuteranopia has been simulated. In order to view the results, the image is simply converted back to RGB colour space $(R_L; G_L; B_L)$ by again performing the inverse transformation of (1) on each LMS pixel.

$$
\begin{bmatrix} R_L \\ G_L \\ B_L \end{bmatrix} = \begin{bmatrix} 0.08094 & -0.13050 & 0.1167 \\ -0.01024 & 0.5401 & -0.1136 \\ -0.00036 & -0.00412 & 0.6935 \end{bmatrix} \times \begin{bmatrix} L_i \\ M_i \\ S_i \end{bmatrix} \tag{3}
$$

B. Laplician Filter

The input image may contain gradients of different shades of colour. In order to bring out the variations in the different hues among the different parts of the image, a Laplacian filter is applied on the image [11]. The Laplician filter is generally used for edge detection. It highlights the regions where rapid intensity change occurs. Its effect on the input image is to bring out boundaries between different shades in different parts of the image.

The Laplacian $f(x, y)$ of an image with pixel intensity values $I(x, y)$ is given by:

$$
\nabla^2 f(x, y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2} \tag{4}
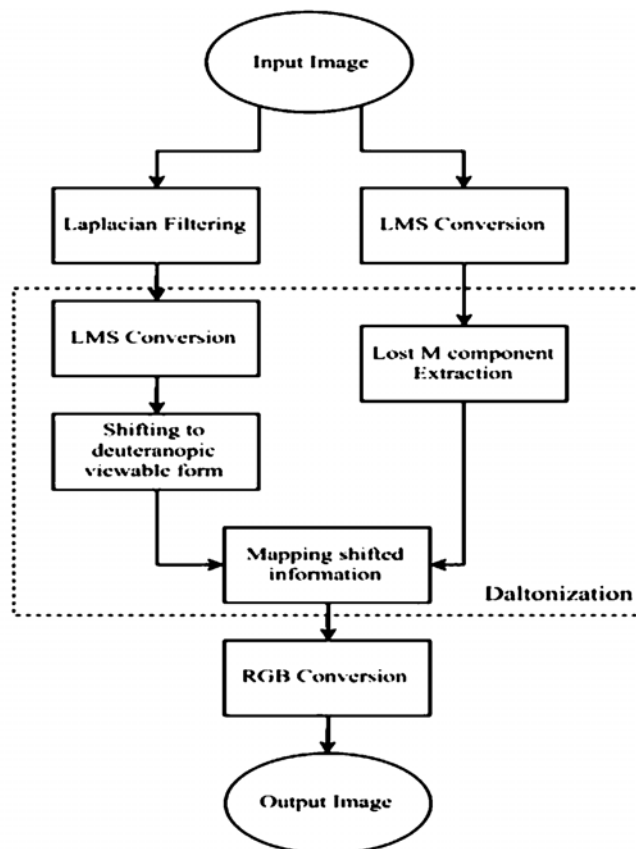$$

Fig. 2. Block diagram of proposed method.

C. LMS Daltonization And Thresholding

LMS Daltonization is a core step in the image transformation process. This process uses the information lost in the deuteranopia simulation in order to improve the original image. This lost information is calculated as the

difference between the input image and the simulation. This is converted from the LMS colour space to RGB and then mapped to wavelengths perceptible to the viewer, in the current case long and short wavelengths (mostly red and blue), to obtain the mapped components (R_M,G_M,B_M). The new mapped RGB components (R_M, G_M, B_M) are integrated to the original image to obtain the output image. The lost information is mapped using the following matrix multiplication:

$$\begin{bmatrix} R_M \\ G_M \\ B_M \end{bmatrix} = \begin{bmatrix} -1 & -1 & 0 \\ -1 & 0.8 & 1 \\ 0 & 1.1 & 1 \end{bmatrix} \times \begin{bmatrix} R_L \\ G_L \\ B_L \end{bmatrix} \tag{3}$$

Finally, the threshold of the output is evaluated and adjusted to ensure that no pixel value rises above one or zero.

The overall process of the algorithm is illustrated in the block diagram given in Fig 2.

4. RESULTS AND ANALYSIS

In order to evaluate the performance of the proposed al-gorithm, qualitative and quantitative analyses were performed. For comparison purposes, two commonly used daltonization algorithms were used - colour contrasting method [9] and LAB colour correction algorithm [7]. Sample images used for the analysis were chosen based on colour variation (number of different hues present in the image), presence of neutral colours (greys, whites) and saturation of the image (the intensity of each colour) (Table 1).
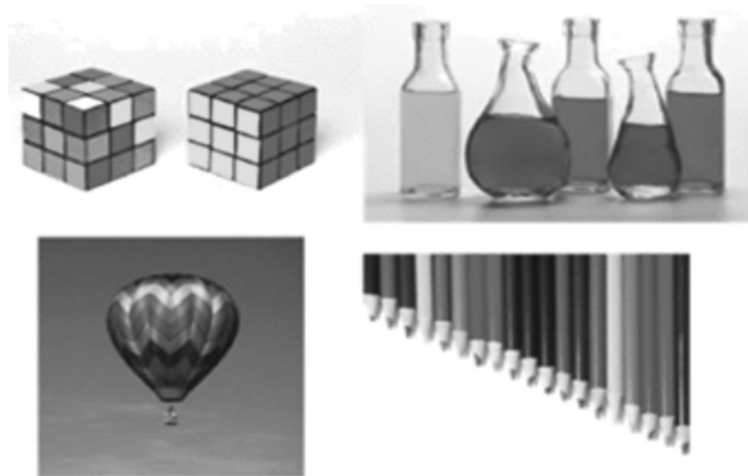

Fig. 3. Images used for testing the algorithms. Images are numbered 1-4, starting clockwise from top left.

Table 1. Criteria for Selection of Input Images

	Variance	*Neutral Colours*	*Saturation*
Image 1	High	High	High
Image 2	Medium	Medium	Low
Image 3	High	High	High
Image 4	Medium	Low	Medium

A. Simulation and Qualitative Analysis

Sample images were used to test the effectiveness of the proposed method. The algorithms were implemented on the input image (Fig 3)[15] using MATLAB R2015b [16]. The simulated image (Fig 4)shows, the image seen through the eyes of a deuteranopic patient From the simulation it is observed that the patient cannot distinguish the different shades of colours in the image. Hence there is a need to modify the image.

The objective of all the considered algorithms is to further enhance the differences between colours for a deuteranopic viewer. The simulations of the outputs of LAB colour correction algorithm [5] is shown in Fig 5, colour contrasting algorithm [7] in Fig 6, and the proposed algorithm in Fig 7.

From the simulations of the modified images, it can be observed that the proposed algorithm is more efficient than existing approaches as the deuternopic person can clearly distinguish individual shades in the image.
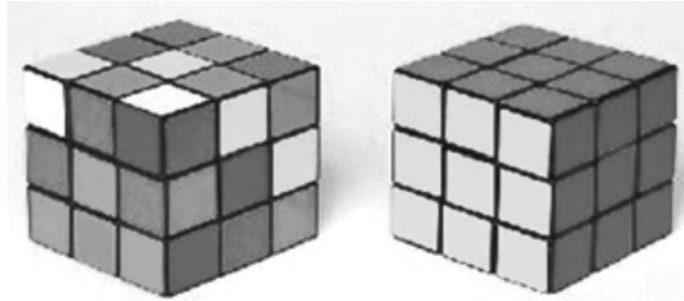
Fig. 4. Original image: Image seen by normal vision person.
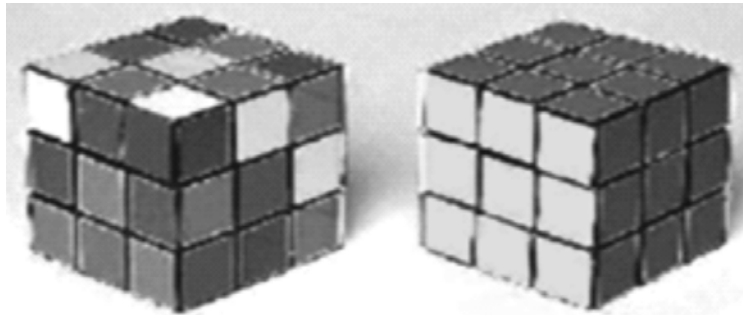
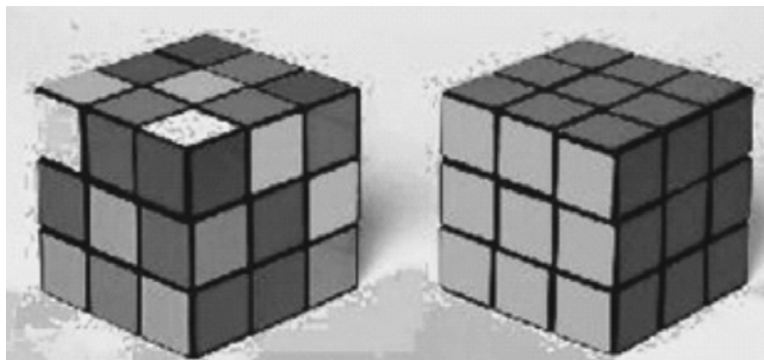**Fig. 5. Simulated image :image seen by colour blind person**

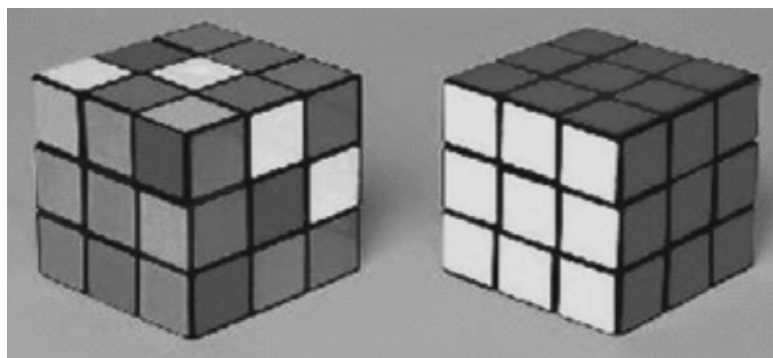**Fig. 6. Modified image by LAB Colour Correction Algorithm**

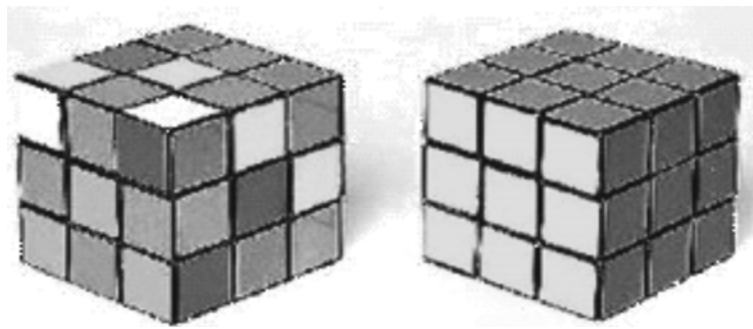**Fig. 7. Modified image by Colour Contrasting algorithm**

Fig. 8. **Modified image by proposed algorithm**

B. Quantitative Analysis - Delta E

Delta E is a popular metric for measuring colour difference. Here this metric is chosen in order to determine the extent to which the algorithm in the original image, Delta E is a popular metric for measuring colour difference. Here this metric is chosen in order to determine the extent to which the algorithm in the original image, i.e., negatively affecting the image as seen by viewers without colour blindness [12]. The Delta E algorithm is a simple operation and it can be applied to each pixel of an image. This function takes in two images in order to evaluate the colour difference between them. Both images are first converted from RGB to LAB colour space.LAB pixel values hold lightness L and colour coordinates A and B based on a compressed version of the standard XYZ colour space [14]. The actual Delta E value for each pixel is calculated as follows.

$$\Delta E = \sqrt{(L_1 - L_1)^2 + (A_2 - A_1)^2 + (B_2 - B_2)^2} \tag{6}$$

A lower Delta E values indicates lesser colour difference, therefore a colour transformation algorithm with a lower Delta E value can be considered to be more efficient.

Figures 9, 10 and 11 illustrate the delta E differences across the processed image on application of the colour contrasting algorithm, LAB colour correction and proposed algorithms respectively.

In Figure 10, the colour difference between the simulated image and the modified simulated image is illustrated. The green and yellowish regions show areas of larger colour difference, while the bluish regions represent lower colour difference values. The vertical and horizontal axes represent coordinates. The numbers on the vertical colour bar on the right indicate Delta E values.
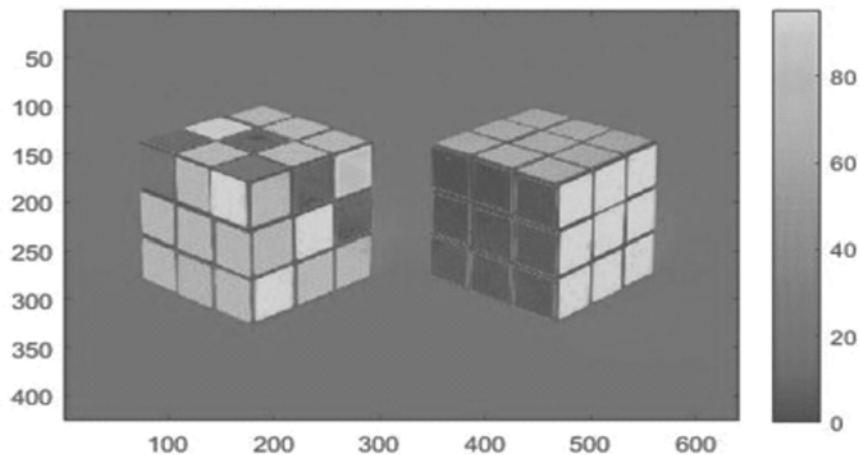

Fig. 9. **Delta E differences for colour contrasting algorithm**

From the Delta E difference images, it is seen that yellow and green regions are more prominent in the existing algorithms, and much less so in the proposed algorithm. Therefore it is apparent that the proposed algorithm produces better results, *i.e*, there is a lesser colour difference between original input images and the modified images produced as an output of the algorithm.

The algorithms were run on 100 input images and average Delta E values across each image for each algorithm was computed and recorded in Table II.
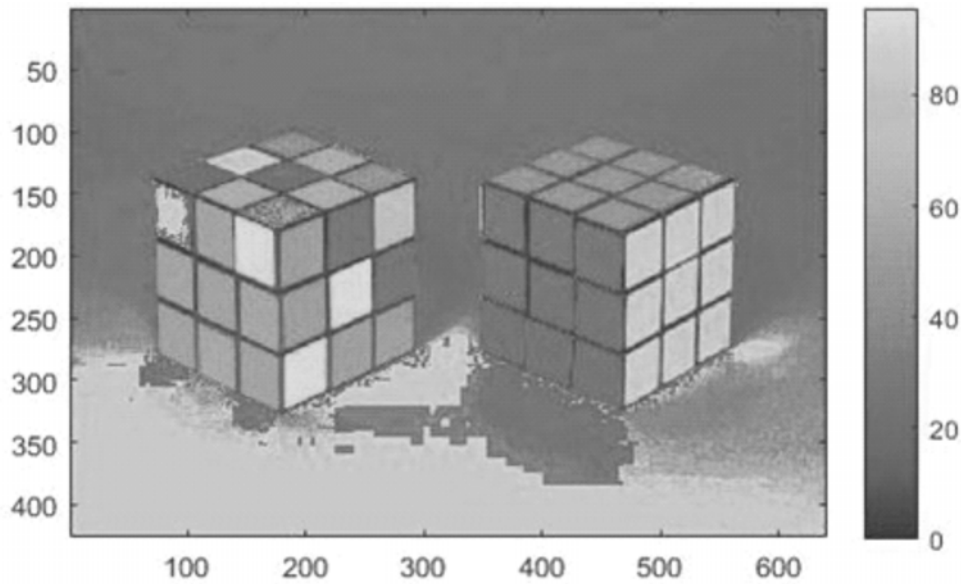

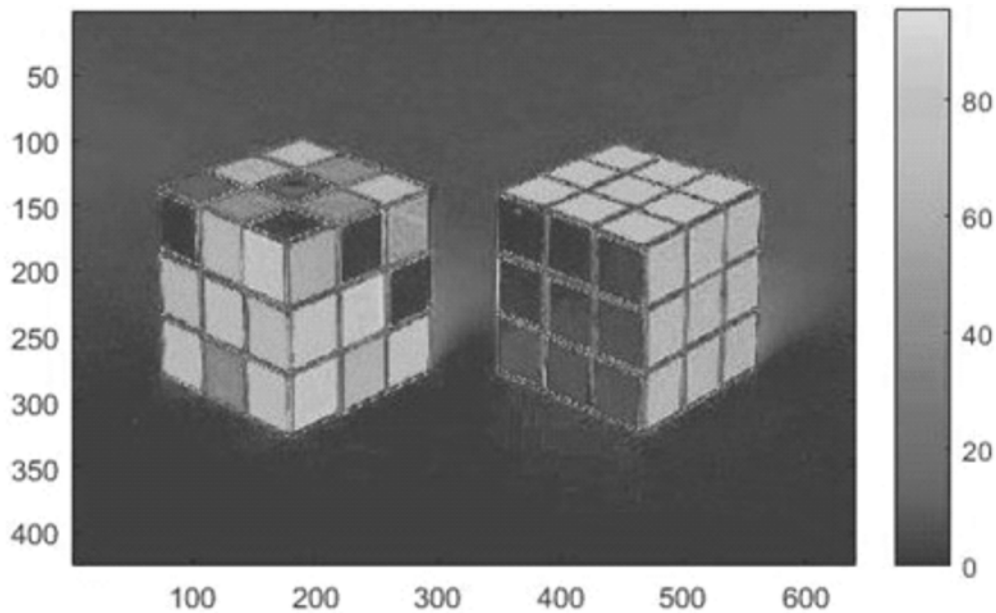**Fig. 10. Delta E differences for LAB colour correction algorithm**

Fig. 11. Delta E differences for proposed algorithm.

Table 2. Delta E Averages for Proposed, Lab Colour Correction and Colour Contrasting Algorithms

Algorithm	Image 1	Image 2	Image 3	Image 4
LAB	60.47	52.11	62.38	59.75
Col. Cont.	48.93	57.47	70.78	63.94
Proposed	29.76	33.21	55.42	41.33

All algorithms were implemented on larger sets of images and the average Delta E value across these sets was calculated (Table III).

Table 3. Average Values of Delta for Larger Input Image Sets

Algorithm	Avg of 10 Images	Avg of 20 Images	Avg of 30 Images
LAB	43.54	48.47	50.61
Col. Cont.	39.65	42.19	44.02
Proposed	32.28	36.22	35.86

From Tables II and III, it can be quantitatively established that the proposed algorithm has better output (lesser colour difference) as compared to existing algorithms.

5. CONCLUSION

An improved daltonization algorithm for the colour trans-formation in images for deuteranopic viewers has been proposed and implemented. The algorithm uses a modified LMS daltonization technique along with a Laplacian filter to produce the output. It can be concluded that the proposed algorithm produces output images which deuteranopic viewers are able to distinguish to a higher extent than existing algorithms. Experimental results establish qualitatively and quantitavely that the proposed algorithm outperforms existing methods, in terms of preservation of colours of the image.

6. FUTURE SCOPE

The same algorithm can be extended for protanopic or tritanopic viewers by altering the channel on which the colour transformation is performed. Also, in the proposed algorithm, the transformation parameters are specified and are fixed. A future improvement could be a dynamic transformation based on parameters of the input image. Moreover, a further extension of the method could be applied to video content. In the present form, this is not feasible because of the fact that the algorithm is performance intensive.

7. ACKNOWLEDGEMENT

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