# A Study on the Hardware Structure of a Real-Time Confusion-Line Separation Algorithm for Smartphone of Color Vision Deficiency

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**Abstract.** This paper investigates the hardware structure of a real-time confusion-line separation algorithm for color vision deficiency using a high-speed color region segmentation—based confusion line separation technique. The overall structure of the proposed hardware is composed of a YUV422toRGB converter, hue generator, hue histogram memory generator, low pass filter and local maxima processor, des-sorter, segmentation, and color compensation processor. To verify the proposed algorithm, the performance of the algorithm is compared with that of existing color compensation techniques through clinical trials using the 3-AFC method conducted with actual color vision defectives to verify and identify the excellent performance of the proposed algorithm.

**Keywords: Color Vision Deficiency, Compensation Technique, Hardware Structure, Real-Time, Segmentation, Confusion-Line Separation**

## 1 Introduction

Thanks to the rapid development of color publishing and color information-display technologies, numerous color expression methods have recently been developed, ranging from the Internet to magazines, on small smart phones to ultra-large display devices, enabling people to enjoy more vivid and splendid color information. However, despite this, those with color vision deficiency (CVD)—accounting for approximately 8% of the world's population—have been alienated, as they are unable to share these pieces of color information. Thus, the development of color correction technology for CVD is urgently needed. CVDs are generally divided into three types: protan, deutan, and tritan. The majority of people with CVDs have protan and deutan problems in L-cone and M-cone cells. The remaining CVDs are classified as having tritan, which is a problem in the S-cone cells. The color correction technologies for people with CVD that have been developed thus far involve color conversion in diverse color spaces, including RGB and CIE Lab, through various approaches. The Daltonization [1-2] method expresses the values of LMSs and globally transfers them using color conversion matrices. A method proposed by Huang [3] is intended to correct colors naturally in CIE Lab color spaces. Furthermore, Bo Liu et al. [4] presented recoloring using video frames. In addition, in a recent study by Yu-Chieh Chen, color correction technology was implemented in real time by hardware [5]. However, most of these methods globally converted whole images or LMS signals. This has resulted in a problem, as color identification effects for people with CVD were reduced when the densities of pieces of color information in input images were low or the distribution of color in images was irregular. To solve this problem, the present paper proposes a color compensation algorithm for high performance and real-time processing based on protanopia and deuteranopia, which account for the great majority of CVD. This research involved the development of efficient software structures for easy hardware implementation and clinical trials were conducted using the three—alternative forced-choice (3-AFC) method with actual CVD to verify the excellent performance of the proposed solution compared to existing color compensation algorithms. The method was also designed for the hardware structure considering real-time processing.

## 2 The overall hardware structure

Figure 1 shows the overall hardware structure of the color region segmentation based color compensation algorithm for high-speed implementation proposed in this paper. The hardware structure consists of a hue generator block, seed point generator block, color region segmentation block, confusion line judgment block for hardware implementation, and color compensation block.

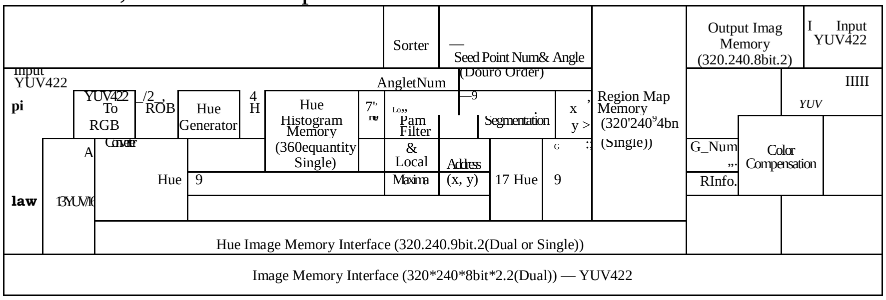



**Fig. 1.** Color compensation hardware structure for CVD

### 2.1 Color compensation algorithm

**We first obtained** simulation data on color recognition from individuals with CVD using the process simulating color recognition in protanopia and deuteranopia presented in a study by Vienot et al. [6]. Furthermore, we investigated confusion-line maps of color regions through the process of simulating and correcting color recognition by people with CVD. Then, in order to increase the legibility of the color information in images, we segmented images by hue into several regions and transformed the colors so that all regions of the image were located on different confusion lines. Based on these results, we verified that optimum color identification effects could be provided to people with CVD, as shown in Figure 2.

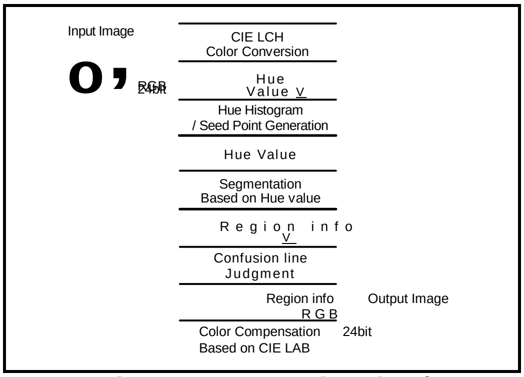



Fig. 2. Color compensation algorithm for CVD

## 2.2 Hue generator block

The hue generator changes RGB input values into CIE LCH color spaces to extract only hue values. The hue values are extracted through sequential XYZ, LAB changes intended to alter RGB input values into CIE LCH spaces, as shown in Figure 3.

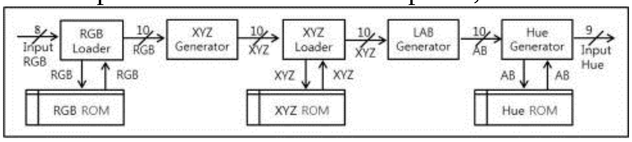



Fig. 3. Hue generator block

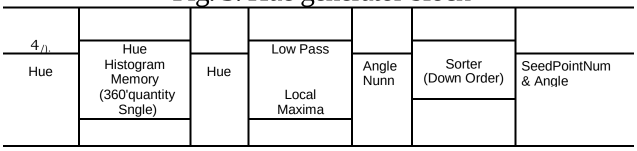


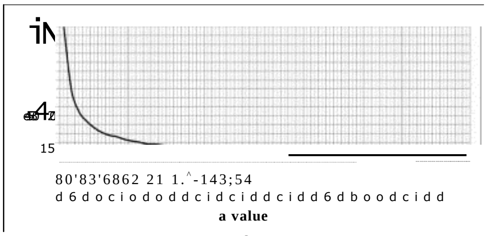

Fig. 4. Seed point generator block

## 2.3 Seed point generator block

The seed point generator changes the hue values passing through a low-pass filter and arranges the hues in descending order to configure those pixels corresponding to the hue that shows the largest distribution in images as seed points (see Figure 4).

## 2.4 Color segmentation block

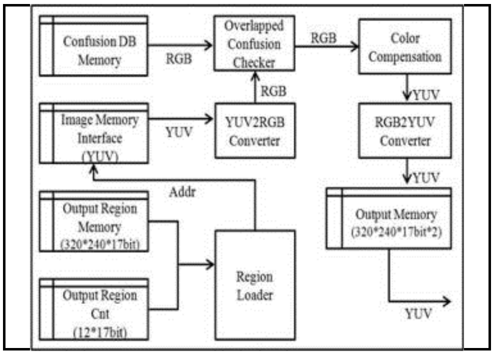
The color segmentation block segments regions using regions grown from seed points obtained from the hue generator block, as shown in Figure 5(c). With the hue values of the largest distributions stored in the hue-num memory and the relevant location information stored in the hue memory as inputs, this block recursively searches for similar hue values with a neighborhood hue detector using a stack memory. Finally, the counting of the relevant region is added to the Output Region Cnt memory to determine the region of the largest area. The coordinate information of the region of the largest area is stored in the output region memory. Through these processes, each input image is segmented into several regions of similar hues. Figure 5(a) shows the number of segmented regions based on the choice of a value in equation (2). As the a value approaches 0, the number of segmented regions increases unnecessarily. When the a value is near 0.1, the number of generates regions remains constant and coincides with human decision. Figure 5(b) shows the number of segmented regions based on the choice of p value in equation (3). Here, the a value is set to 0.1. As approaches 1, the number of segmented regions also increases unnecessarily. In this pa s er, coefficient a was defined as 0.1 and 4 as 0.8.



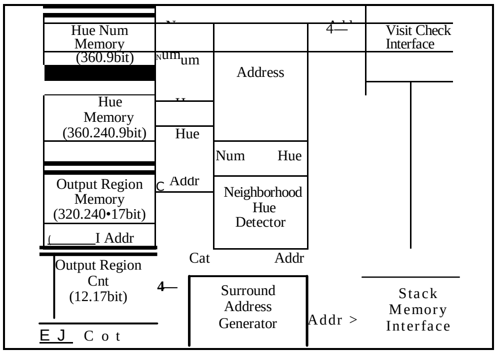


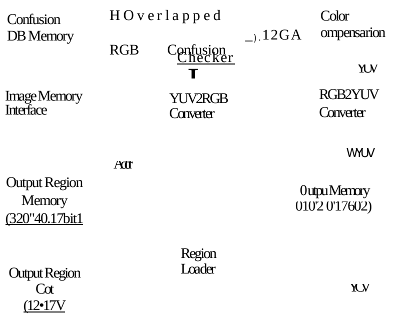
(a) Number of segmented regions with different a values

(b) Number of segmented regions




with different 13 values (= 0.1)




(c) Color segmentafon block

(d) Color compensation block

**Fig. 5** Color segmentation and compensation block

$$z - z\ seed\ l < hue\_threshold$$

$$hue\_threshold = I \max hue - \min\_hue\ 1 * a$$

$$\sum_{i=o} Ri > R * fl \qquad (3)$$

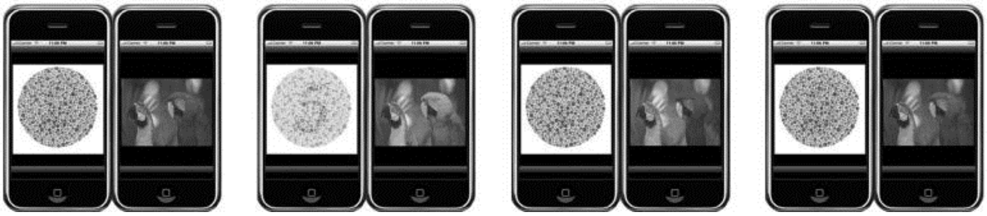
## 2.5 Color compensation block

The purpose of the color

compensation block is to compensate segmented regions based on the confusion line map, as shown in Table **1,** so that all of the regions are located on different confusion lines from one another. Figure 5(d) gives a diagram of the structure of the color compensator block. The representative RGB values of the pixels of several segmented regions stored in the region memory are judged to see if any of them are located on the same confusion line through the confusion line map to store all of them in different confusion line memories from one another for color compensation.

**Table 1.** Confusion line map for protanopia and deuteranopia

| Type of CVD | Type of confusion line | Representative box position (R G B) | Box positions in same confusion line (R G B) |
|---|---|---|---|
| Protanopia | P1 | 000 | 000, 100,200 |
| | ≈ | | |
| | P52 | 7 7 7 | 766,767,777 |
| Deuteranopia | D1 | 111 | 000,"-z1,211 |
| | | ≈ | |
| | D41 | 477 | 277,377,477 |



(a) Original image (b) Daltonization [2] (c) Chen et al. [6] (d) Proposed method

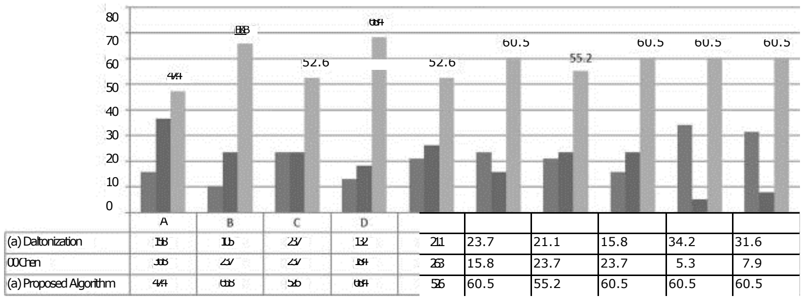



**Fig. 6.** Test image set samples for CVD

• On Daltonization • 09 Chen • (a) P oposed Algo ithm

**Fig. 7.** Results of the choice using the 3-AFC method

## 3 Experimental Result

The performance of the proposed algorithm was compared with that of Daltonization [2], which is the most widely known of the CVD color correction algorithms, and Chen et al.'s [5] algorithm, which was recently proposed. In the experiment, 38 carefully selected images, such as the Ishihara test images and other images that are frequently used in color image processing, were recolored using the three algorithms. The resultant 38 image sets were provided after hiding the names of the algorithms to conduct blind tests. Figure 6 shows two sample image sets used in the test. Among 38 test image sets, just three test image sets are shown in this figure. The test was conducted using the 3-AFC method. The 10 CVDs were male 11th grade high school students; they were asked to unconditionally select an image with the largest color-separating effect among three given images. Figure 7 shows the results of using the 38 test sets conducted through the 3-AFC method, and represents that 58.4% on average of the 10 CVDs' preferred the proposed algorithm. The names of the CVDs are not disclosed; instead, they are referred to using letters A to J. The findings showed that the results of the algorithm proposed in this paper were the best. Furthermore, while the other algorithms modified the overall color of the test images, the proposed algorithm preserved most of the color region and just modified the color region that is confused in CVD.

## 4 Conclusion

This paper proposed a study on the hardware structure of a real-time confusion-line separation algorithm for color vision deficiency using the high-speed color region segmentation—based confusion line separation technique based on this high-speed software algorithm. The proposed color compensation algorithm for CVD can fundamentally solve the problem of the possibility of different colors overlapping after color compensation that existed in previous color compensation studies; with the high-speed algorithm, repetitive color compensation structures were revised into structures suitable for hardware. In order to verify the performance of the high-speed color compensation algorithm proposed in this paper, a clinical trial of two existing color compensation algorithms and the proposed algorithm was conducted with actual color vision defectives using the 3-AFC method. Based on the results, the performance of the algorithm proposed in this paper was identified to be the best.

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