Color Information Presentation for Color Vision Defective by Using a Projector Camera System

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Abstract. There are individual differences in color vision. It is difficult for a person with defective cones in the retina to recognize the difference of specific colors. We propose a presentation method of color information by using a projector camera system. The system projects border lines or color names on real object surfaces when they have specific color combinations. Effectiveness of the proposed method is verified through experiments.

1 Introduction

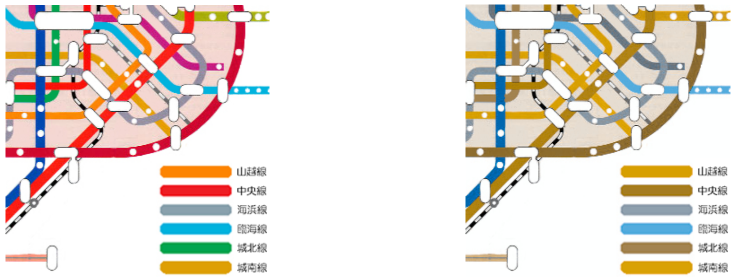
In this paper, we propose a color information presentation system for color vision defective by using a projector camera system.

There are individual differences in the color vision. Human eye has cone cells that can sense colors. Cone cells are divided into three types by a difference of the spectral sensitivity; the long-wavelength-sensitive (L) cone, the middle-wavelength-sensitive (M) cone, and the short-wavelength-sensitive (S) cone. The individual difference in color vision comes from the lack or low sensitivity of three cone cells. The condition of the cone of all types without loss is called normal, the condition with a loss of the L cone is called protanopia, the condition with a loss of the M cone is called deuteranopia, the condition with a loss of the S cone is called tritanopia, and the condition of the cone of two kinds with loss is called cone monochromatism, respectively. It is difficult for a person with defective cones in the retina to recognize the difference of specific colors. For example, a person who lacks L cone has low sensitivity in red color. In this case, he or she may feel inconvenience in everyday life.

Figure 1 shows a route map in which the difference of colors indicates different routes. Figures 1(a) and (b) show a normal color vision and a color simulation result that a color vision defective (deuteranopia) senses[1], respectively. In Fig. 1(b), green and orange routes are difficult to distinguish with each other. Therefore, support system for visually impaired people is very significant.

In color universal design and color barrier-free approaches, color combinations that any color vision person is easy to distinguish should be used. However, such concepts do not spread in present day. Barriers are also left in several environments and situations such as route maps, signboards, posters and so on.

[1] In this paper, color simulation results are generated by using “UDing simulator” (Toyo Ink Mgf. Co., Ltd.).



(a) Normal color vision. (b) Deuteranope simulation.

Fig. 1. Example of individual difference in color vision.

Therefore, there are studies of the use of image processing for supporting the visually impaired people [1–3], and especially for the color vision defective [4–6]. The main purpose of these studies for the color vision defective is constructing color conversion algorithms, and there are few studies that deal with real applications such as web page browsing [7] and a head mount display (HMD) [8]. A color modification method for web pages [7] does not treat with real objects. An HMD system [8] detects colors that are difficult to distinguish in acquired images by using a camera, and then displays boundary lines of color edges for users by using the HMD. However, registration between real objects and images that are displayed in HMD is not considered. In other words, color information is only in computer in these studies.

As to the presentation of color information, one of the most fruitful merits of augmented reality (AR) and mixed reality (MR) technologies is that we can recognize displayed color information in the same manner as real objects.

In some situation, an HMD is enough for a user to get visual information with using AR technology like AR tool kit [9]. The advantage of an HMD is that it is unaffected by environment light and does not prevent multi-user situations because it does not change environment [10]. However, an HMD is not suitable for a long time use because it gives a user a feeling of constraint. On the other hand, the method using not an HMD but a projector is also proposed [11]. A projector can easily add information over real objects. A projector is suitable for a long time use compared with an HMD. Therefore, we consider that the place that the system can use is not limited for living environments.

2 Purpose and Outline of Color Information Presentation

In this paper, we propose a presentation method of color information by using a projector camera system. The proposed system is adaptive to the individual and the place that the system works is not limited. The camera acquires color information and the projector presents color information (Fig. 2).

The system projects not only border lines [8], but also draws color names or overlays (paints) alternate colors on real object surfaces when they have specific

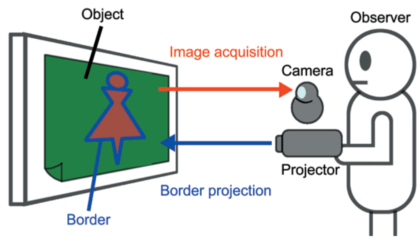
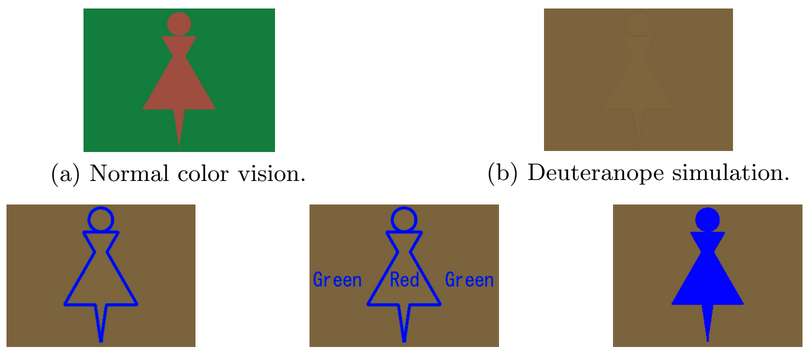


Fig. 2. Proposed projector camera system.



(a) Normal color vision. (b) Deuteranope simulation.

(c) Borderline. (d) Color name. (e) Painting.

Fig. 3. Color combination difficult to distinguish and color information presentation.

color combinations. This is a practical AR/MR application trying to improve a user's color perception.

In our system, the three dimensional (3D) relationship between the projector and the camera is fixed. However, in mobile applications, the 3D relationship between the projector camera system and objects changes. Therefore, registration of projected images and real objects is realized by using projected markers.

In Fig. 3(a), a red picture is drawn on a green background. A deuteranope can hardly distinguish the difference of colors because the difference between green and red is not recognized like Fig. 3(b). Therefore, a color camera detects image regions that may appear ambiguous to a viewer. Then the projector overlays color information with three modes; by displaying boundary lines (Fig. 3(c)), by displaying color names (Fig. 3(d)), and by painting in another color (Fig. 3(e)).

The processing flow is shown in Fig. 4. At first, the system projects markers on real objects by using the projector. The camera acquires image and detect color(s) or color combination(s) that are difficult to distinguish. If there are color(s) or color combination(s) that are difficult to distinguish, the system generates an image that is projected on real objects. In this step, a projected image is registrated with real objects by using projected markers. The system repeats the above procedure. If the 3D relationship between the system and real objects changes, the system detects motion and reprojects a new image.

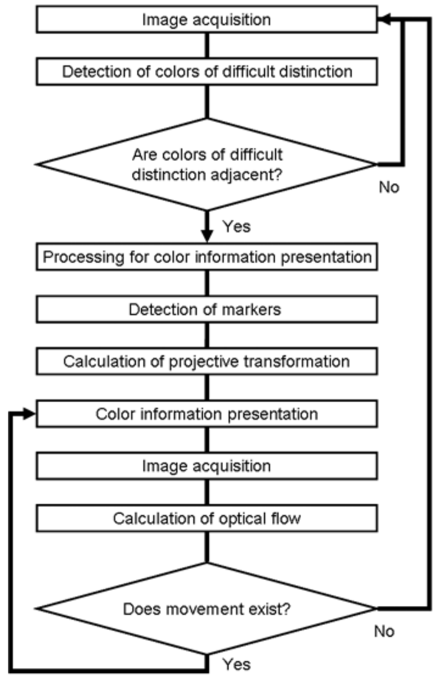


Fig. 4. Processing flow.

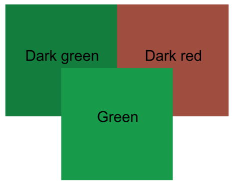
3 Color Image Processing

The system examines color combinations that are difficult for the user to distinguish. At first, the system judges whether the acquired image has colors of difficult distinction.

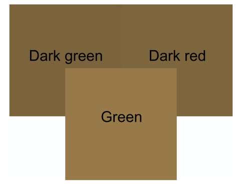
In our system, color combination that the normal color vision feels similar is not extracted as difficult distinction color. For example, dark green and green are not a color combination of difficult distinction in Fig. 5(a), because the normal color vision people feels they are similar. On the other hand, dark green and red in Fig. 5(b) is judged as difficult distinction, because the color vision defective cannot judge them although they are different color.

In order to examine colors of difficult distinction, color confusion lines are used [12, 13]. A color confusion line is a straight line radiated from the center of confusion (copunctal point) on the CIE1931 x-y chromaticity diagram (Fig. 6). The center of confusion is given by the type of the color vision [12]. Colors on a color confusion line are difficult to distinguish. Our method calculates a color confusion line that is linked from the center of confusion to a color of a pixel in an acquired image.

When the angle which two colors of color confusion lines make is small and two color points are away on the x-y chromaticity diagram, the system determines that two colors are colors of difficult distinction.

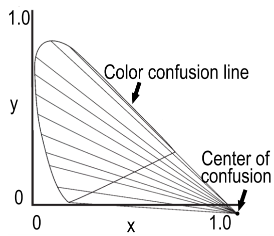


(a) Normal color vision.

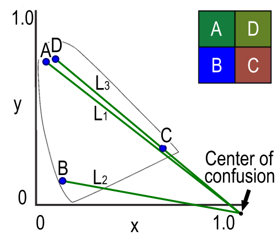


(b) Deuteranope simulation.

Fig. 5. Example of color combination.



(a) CIE1931 color space.



(b) Colors of difficult distinction.

Fig. 6. Color confusion line.

For example, when the color of the pixel in the acquired image is given as point A (dark green) of Fig. 6(b), the color confusion line becomes line L_1. In the same way, color confusion lines of B (blue), C (dark red), and D (green) are L_2, L_3, and L_4, respectively. The combination of color A and color B is not judged as difficult distinction color, because the angle between line L_1 and line L_2 is large. The angle between line L_1 and line L_3 is small, and the distance between point A and point D is small. Therefore, the combination of color A and color D is not difficult distinction color. On the other hand, the distance between point A and point C is large. Therefore, the combination of color A and color C is difficult distinction colors.

The color that is projected is decided by considering the user's color vision characteristics[2] (Fig. 7).

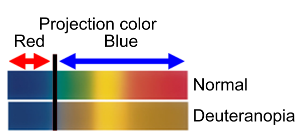


Fig. 7. Projection color.

[2] The characteristics of the scene are not considered. The color of the surface affects the color of projected lights. In future work, the color for painting should be decided more carefully to show the information with appropriate color to the user.

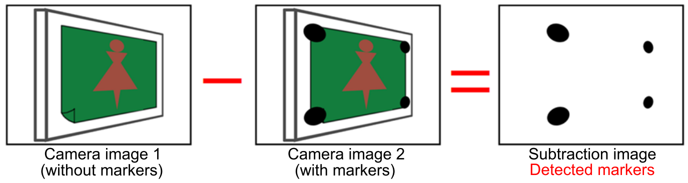


Fig. 8. Marker detection by subtraction.

The system provides three ways of color information presentation.

(1) boundary line presentation: the system projects boundary lines on the place of the real object corresponding to pixels judged to be adjacent.

(2) color names presentation: the system detects the area of each color and determines the presentation point of color names. The system projects color names on the presentation point of the real object.

(3) painting presentation: the system projects colors on places of the real object corresponding to detected areas.

4 Registration of Projected Image and Real Object

In our proposed method, objects are assumed to be planar such as a signboard and a bulletin board. The system performs registration of a projected image and real objects by using projected markers.

First, the system projects markers on real objects. Next, the system takes an image of real objects with using a camera and detects markers in an acquired image. The system calculates a projective transformation matrix from detected markers. Finally, the system transforms a projection image by using calculated projective transformation matrix.

Our proposed method assumes that a user holds the system and uses it. Relative position and posture between the system and objects may always change. Therefore, the system projects and detects markers to make the registration of the projected image and the real objects every time at the image acquisition.

Markers are detected by using subtraction (Fig. 8). The system subtracts an acquired image without projecting markers from that with projecting markers, and detects marker positions. This processing is repeated and the marker positions are updated.

The system calculates the homography matrix $\mathbf{H}$ from relations between measured marker positions in the acquired image and marker positions in the projected image. The projection image is transformed by using $\mathbf{H}$ for registration of projected images and real objects.

Our system detects whether there is a movement between the system and real objects by using optical flow. If there is a movement, $\mathbf{H}$ is recalculated.

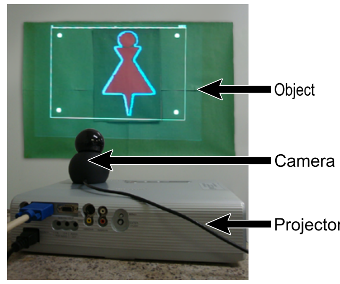
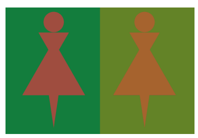
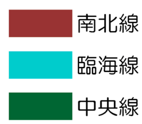


Fig. 9. Experimental equipment.



(a) Symbol mark.



(b) Legend.

(c) Route map.

Fig. 10. Objects in experiment.

5 Experiment

The experimental device consists of a projector, a camera (logitech web camera), and a computer (CPU: Intel Core 2 Duo 3.0GHz, Memory: 4GB) (Fig. 9). The experiment was performed in a room. The resolutions of acquired images were 640×480pixel. A threshold of an angle between two color confusion lines was decided in advance by trial and error.

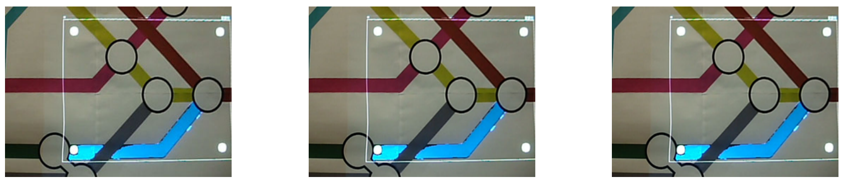
Figure 10 shows planar objects to use for experiment. Figure 10(a) shows printed emblems. In Fig. 10(a) from the left, the dark red emblem is drawn on a dark green background, the orange emblem is drawn on a yellow green background, and the red emblem is drawn on a white background. Figure 10(b) shows a legend of a map. In Fig. 10(b) from the top, a dark red quadrangle is drawn, a light blue quadrangle is drawn, and a dark green quadrangle is drawn. Figure 10(c) shows printed a route map. In Fig. 10(c), a red and a green route are drawn. Those objects were used for presentation experiment of boundary lines, color names, and painting, respectively.

Figure 11 shows a registration result of a projection image and a real object. In these figures, blue lines are projected boundary lines, and black dotted lines are boundaries of green and red regions (ground truth of boundary lines). Without registration (Fig. 11(a)), blue and dotted lines do not coincide with each other. On the other hand, they coincide with each other with registration (Fig. 11(b)).

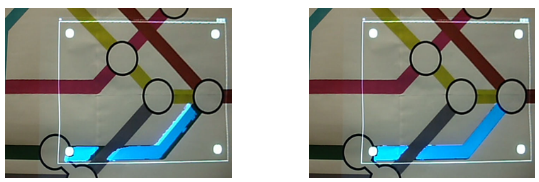
Figure 12 shows the border projection result while the position of the projector camera system was changing. The computation time was about 4fps on an average. The system and the object were not moving between Fig. 12(a) and

(a) Without registration. (b) With registration.

Fig. 11. Registration of projection image and real object.



(a) $t = t_0$. (b) $t = t_0 + 0.5$. (c) $t = t_0 + 1.0$.



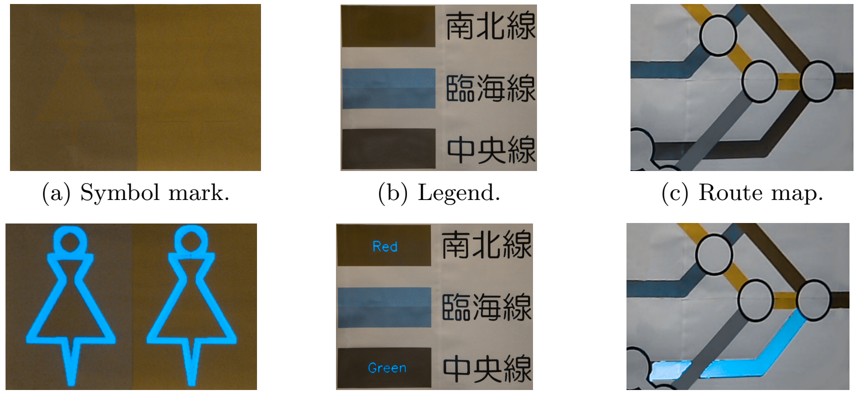
(d) $t = t_0 + 1.5$. (e) $t = t_0 + 2.0$.

Fig. 12. Result of continuous border projection.

Fig. 12(c), while the relationship between the system and the object changes between Fig. 12(c) and Fig. 12(e) because the system moved. The movement was not detected from Fig. 12(a) to Fig. 12(c), and the system continued to project the same image and stable projection of color information was realized in Figs. 12(b) and (c). On the other hand, the movement was detected between Fig. 12(c) and Fig. 12(d), the system executed registration from the information of Fig. 12(d), and projected another image in Fig. 12(e). In Fig. 12(e), gap between the projected image and the real object was resolved. In this way, the system could successfully detect the motion of the system, and the projected images that coincided with the targets.

Figure 13 shows a result of the boundary line presentation, the color name presentation, and the painting presentation, respectively.

In Fig. 13(a), the angle between the dark red of color confusion line and the dark green of color confusion line is small with less than 1 degree. The distance between two colors is small. Therefore, boundary lines are projected on the border between the dark red and the dark green. Similarly, boundary lines are projected on the border between the orange and the yellow green. On the other hand, the angle between the dark green of color confusion line and the yellow green of color confusion line is as small as 2 degree. However, the distance



(a) Symbol mark. (b) Legend. (c) Route map.

(d) Borderline. (e) Color name. (f) Painting.

Fig. 13. Results of projection.

between the two colors is not small. Therefore, boundary lines are not projected on the border between dark green and the yellow green.

In Fig. 13(d), boundary lines are projected on the border between the dark red and the dark green, and between the orange and the yellow green. Therefore, the method makes it easy to see emblems that are hard to see in Fig. 13(a).

In Fig. 13(e), letters of "Red" are projected on a red part and letters of "Green" are projected on a green part. Whereas it is hard to distinguish the top quadrangle and the bottom quadrangle in Fig. 13(b), the method makes it easy to distinguish the top quadrangle and the bottom quadrangle in Fig. 13(e).

In Fig. 13(f), green line is painted with blue. Whereas it is hard to distinguish the red line and the green line in Fig. 13(c), the method makes it easy to distinguish the red line and the green line in Fig. 13(f).

The effectiveness of the method is shown by these results of boundary lines, color names, and painting presentation.

6 Conclusion

We propose a presentation method of color information with a projector camera system based on registration of projection image and real object using projected markers. We confirmed the effectiveness of the method by experimental results. The solution in this paper is simple yet effective. A color camera detects image regions that may appear ambiguous to a viewer. The projector then overlays lines, regions, and text to assist the viewer.

In future work, color calibration of the camera should be done in adapting to lighting condition change. Color information presentation must be considered when an object has a color gradation.

This system can be developed for tourists visiting other countries. Reading a subway map in Tokyo (Japan) is very difficult for non Japanese speaking/reading individuals, because the subway map in Tokyo is very complicated. There is a potential in our work for such applications, *e.g.* character translation which deserves to be explored.

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