Paper:

Projector Camera System Presenting Color Information for the Color Vision Deficient

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There are people who cannot distinguish between specific colors easily. This paper presents an improvement to a system for the color vision deficient. The system consists of a camera that acquires an image of an object and a projector that projects light on that object. One of the features of the system is that it handles real-life objects. When objects have colors that cannot be distinguished, the system converts the color to a distinguishable one using the projector. The improvement in the proposed system is that it produces images with patterns and blinking light to handle conventional color conversion operations that cannot produce distinguishable color images because of excessive multiplicity of color combinations. We verify through experiments the effectiveness of the proposed color projection system with its patterns and blinking light.

Keywords: projector camera system, color vision deficiency, image processing

1. Introduction

There are individual differences in color vision. Human beings sense colors as the reactions of three types of cones. The spectral sensitivities of the cones differ; S, M, and L cones are maximally sensitive to short, medium, and long wavelengths, with their peak sensitivities in the blue, yellowish-green, and yellow regions of the spectrum, respectively. When one type of cone is low or lacks sensitivity, it is difficult for the person to distinguish between specific color combinations. While those without a loss of any types of cones are called normal, those who do not have the L cone are said to have protanopia, those who do not have the M cone are said to have deuteranopia, those who do not have the S cone are said to have tritanopia, and those who do not have two types of cones are said to have cone monochromatism.

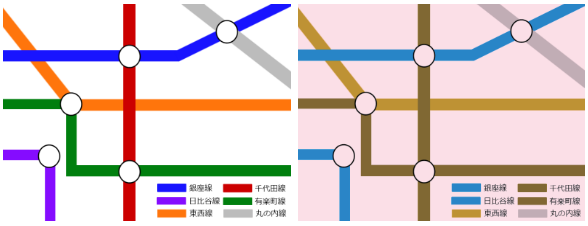
In recent years, elderly and disabled people have been supported by universal design and barrier-free approaches. In regard to color vision, it is said that color combinations distinguishable by people with any type of color vision should be used. However, this has been implemented in only some route maps, and not ones that are commonly used.

Figure 1 is an example of a route map. **Fig. 1(a)** shows the map in normal color vision, and **Fig. 1(b)** shows the map in simulated deuteranopia vision. In **Fig. 1(b)**, it is difficult to distinguish between the routes corresponding to the red and green routes in **Fig. 1(a)** because the two routes are in the same color in **Fig. 1(b)**.

In this paper, we propose for people with color vision deficiency a color information presentation system that uses a projector and a camera.

To help people with color vision deficiency, there have been studies that use color conversion methods and target web page and image viewing [1–3], but these methods do not apply to real objects. For them to recognize real objects, it is effective to use a projector camera system [4, 5] that can be used in many places to help color deficiency. The method proposed in [4] enhances the appearance of a scene for the visually impaired, while a method proposed in [5] presents color information when there are indistinguishable color combinations. The latter method, however, has a problem in that the system cannot support multiple color combinations. Additionally, observed colors in this system are not to the same as the target colors because the method does not take into account the reflective properties or the target color.

In order to solve these problems, in our study, the system uses color feedback to make an observed color the same as the target color, and the system projects color information using distinguishable colors for people with color vision deficiency. In addition, the system projects patterns and blinking light so that it can be applied to sit-



(a) Normal color vision (b) Deuteranopia simulation

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

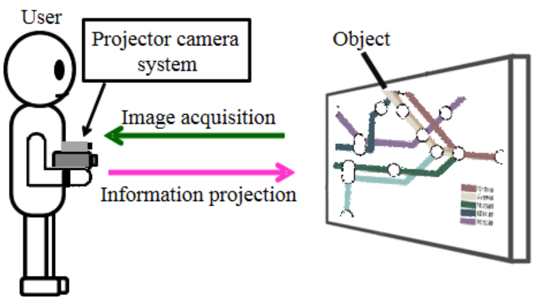


Fig. 2. Proposed projector camera system.

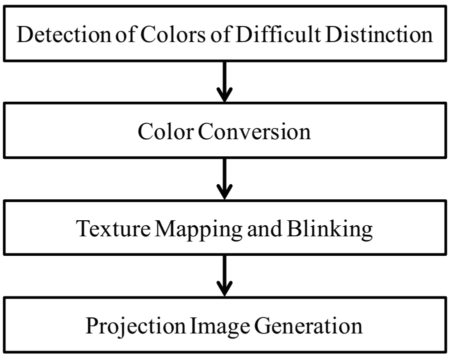


Fig. 3. Outline of process.

uations in which multiple combinations of indistinguishable colors exist.

2. System Overview

Figure 2 shows the proposed projector camera system. A user holds the system and directs it toward an object. The camera acquires an image of the object, and the system generates a projection image that the projector lays over the object. The projected image presents color information about the object for the color vision deficient.

Figure 3 is an outline of the process. First, the system detects colors in the image acquired with the camera that are difficult for the color vision deficient to distinguish. If such colors exist, the system produces an image in which a color is converted to a different, distinguishable color. If simple color conversion is not sufficient because of multiple combinations of colors to distinguish between, the system produces an image with patterns and blinking light. Finally, the system uses color feedback to generate the projection image, which makes the observed image equal to the target image.

3. Color Information Presentation

3.1. Color Conversion

Prior to color conversion, our method detects areas in an acquired image that have colors that are confusing for the color vision deficient. It does this by using color confusion lines [6, 7]. Color confusion lines are straight lines radiating from the center of the confusion (copunctal point) on the CIE1931 x-y chromaticity diagram. The center of the confusion lines is defined for each type of color deficiency [6], and colors on the same color confusion line are indistinguishable to those who suffer from the specific type of color deficiency.

Colors on a color confusion line are difficult to distinguish between for those with color vision deficiencies. In the previous study [5], the system judged whether to project color onto an area or not based on the following two conditions: two colors are (1) indistinguishable for the color vision deficient, and the colors are (2) distinguishable by people with normal color vision. Conditions that make colors indistinguishable are (1) a small angle between color confusion lines of two colors and (2) a large distance between the two colors on the x-y chromaticity diagram. Regarding point (2), color combinations that people with normal color vision see as similar are not extracted. In addition to these two points, color combinations with different degrees of lightness are ignored since they can be distinguished even by those who have color vision deficiency.

Therefore, our system determines that pairs of colors are indistinguishable for the color vision deficient and decides to converted them if all of the following conditions are satisfied. Refer to [8] for a definition of the color difference.

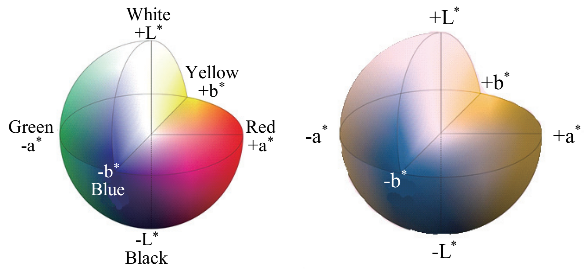
1. The angle between the color confusion lines of two colors is small ($\Delta\theta < \Delta\theta_{threshold}$).

2. The color difference between two colors is large ($\Delta E_{00} > \Delta E_{00threshold}$).

3. The difference in lightness between two colors is small ($\Delta Y < \Delta Y_{threshold}$).

The acquired image is segmented into areas of colors by clustering using the ISODATA algorithm [9]. Representative colors of the areas are calculated, and combinations of color regions are examined to determine whether or not they are difficult to distinguish. If the two areas have colors that are difficult to distinguish for those with the type of color deficiency, the smaller area is recolored with a color that is distinguishable from the color of the other area.

In our system, color conversion is made in the $L^*a^*b^*$ color system [10], as shown in **Fig. 4**. The L^*, a^*, and b^* components show the lightness of color, the hue from



(a) Normal color vision (b) Deuteranopia simulation

Fig. 4. L*a*b* color system.

green to red, and the hue from blue to yellow, respectively. Changing the value of a* does not contribute much to the color change in deuteranopia, as shown in **Fig. 4(b)** [11]. Then, in the system, colors are converted to distinguishable colors by changing b* and L*. The color conversion method is as follows.

First, the color difference is calculated while the value of b* of the representative color of the area to be converted is gradually changed. If the method meets the value of b* where the color difference exceeds a threshold, this value is determined to be the value for conversion. If a sufficient color difference cannot be obtained by changing the value of b*, the value of L* is changed until the color difference exceeds the threshold.

3.2. Pattern Mapping and Blinking

In our method, the system performs pattern mapping and blinking in addition to color conversion. If the system performs only color conversion, it cannot be applied when multiple combinations of indistinguishable colors exist.

The system projects a pattern when color difference cannot be sufficiently expressed by color conversion. The pattern is selected in advance from a set of patterns. However, users cannot see the pattern when there is not enough surface on which to project it. In such cases, the system projects blinking light. Using these methods, the system can be applied to multiple color combinations. The system uses the following method to determine whether to choose pattern mapping or blinking (**Fig. 5**).

First, the system makes a label image of connected pixel areas of homogeneous colors by labeling the resulting image of color conversion. Then, for each label whose corresponding pixel color is difficult to distinguish, the system scans the label image with a rectangular window. If a window comes across a location where all pixels within the window have the same label, it is determined that pattern mapping is to be applied to the connected area of the label. Otherwise, blinking is applied to the areas. The size of the window is considered to be sufficiently large if users of the system can recognize the pattern projected onto it. If areas with pattern mapping and areas with blinking are the same color, the system changes the pattern mapping projection to blinking light. This is because the system needs to project the same color information on areas of the same color.

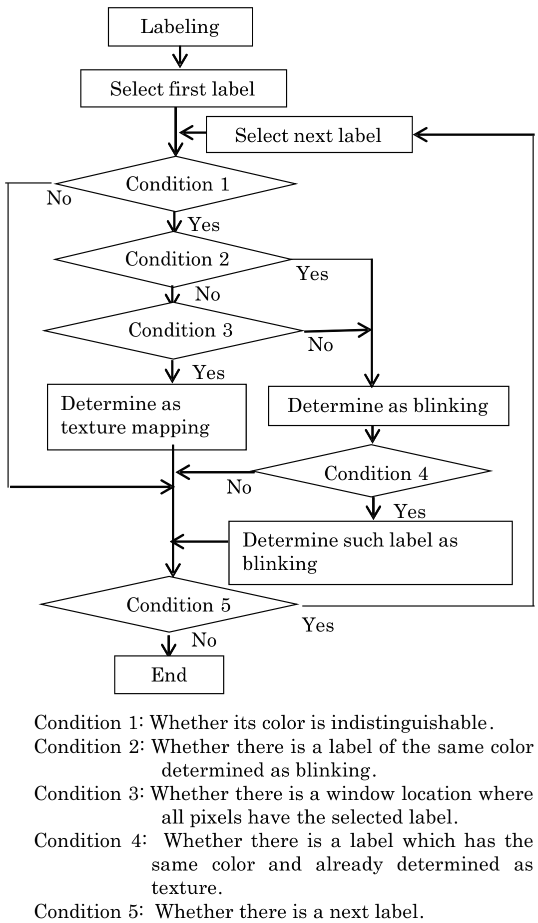


Fig. 5. Flowchart of the procedure for pattern mapping/blinking determination.

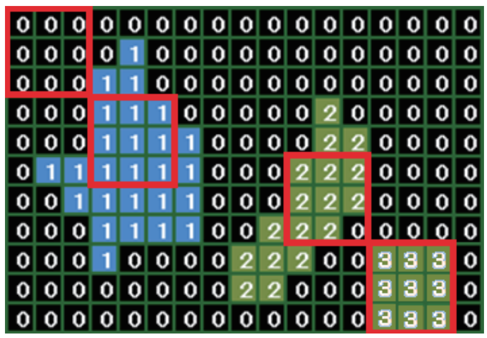
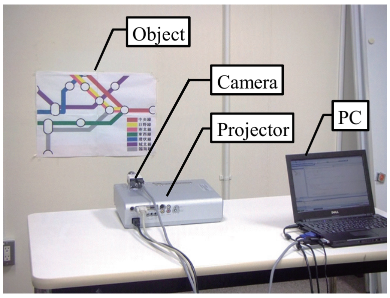
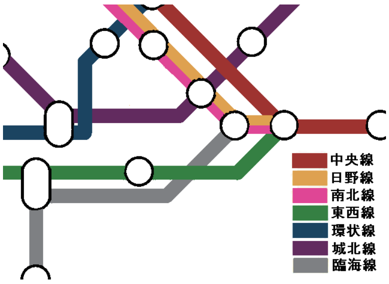


Fig. 6. Example of pattern/blinking determination.

Figure 6 shows how this is determined. In **Fig. 6**, there are four areas (area 0, area 1, area 2, and area 3, each of which has its identical label), and area 2 and area 3 are the same color. Here, let area 1, area 2, and area 3 be areas on which pattern or blinking light should be projected. The system decides to project a pattern on area 1 because the area includes a rectangular window of a certain size. The system projects blinking light on area 2 because no rectangular window of that size can fit within the area. Although there exists a window included in area 3, it is determined that blinking light is to be projected on area 3 because its color is the same as that of area 2.



(a) Experiment setup



(b) Experiment object

Fig. 7. Experiment setup and object.

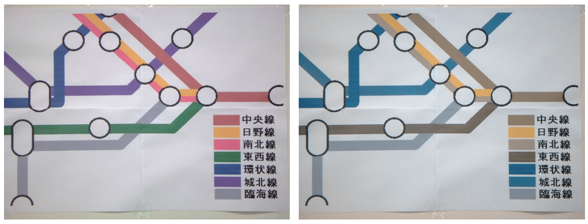

(a) Normal color vision (b) Deuteranopia simulation

Fig. 8. Acquired image before projection.

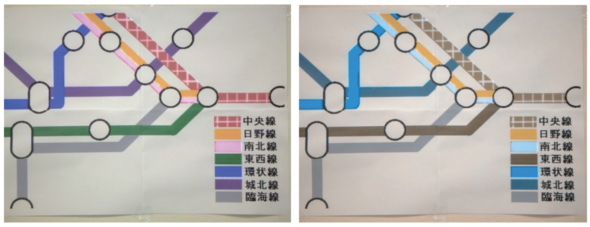

(a) Normal color vision (b) Deuteranopia simulation

Fig. 9. Result with blinking light on.

When the system projects blinking light, the number of cycles must be considered because the blinking could cause photosensitive epilepsy. By setting the cycles below 3 Hz, the risk of photosensitive epilepsy can be reduced. Therefore, the system projects blinking light with the cycles set below 3 Hz.

3.3. Projection Image Generation

If the system simply projects a target image on a target object, the observed color and a target color are not exactly equal. Therefore, it is necessary make an observed color equal to a target color by means of color feedback. Our color feedback method is based on the method proposed by Amano and Kato [4].

In our method, it is possible to control the appearance systematically by using a reflectance estimation and model predictive control. In order to implement this method, it is necessary to calibrate the colors of the camera and the projector as well as to linearize the input-output characteristics between the input RGB values of the projector and the output RGB values of the camera. To do this, we employ a method proposed in [12] in which R, G, B monochromatic lights are projected onto a white plane from the projector to obtain a color conversion matrix.

It is also necessary to generate a projection image for blinking if there are regions which have been designated for blinking. A projection image for blinking is generated by converting a region determined to be blinking into a white region in the projection image generated by the color feedback method. The cycles of the blinking are determined, and the system creates blinking by switching between the original projection image and the white region image.

4. Experiment

4.1. Setup

The experimental device consists of a projector and a camera (**Fig. 7(a)**). The experiment was performed in a room under fluorescent light. **Fig. 7(b)** shows the object used in the experiment, and the system projected color information on this object. Thresholds set for determining that colors were indistinguishable were $\Delta\theta_{threshold} = 3.0$, $\Delta Y_{threshold} = 8.0$ and $\Delta E_{00threshold} = 20$.

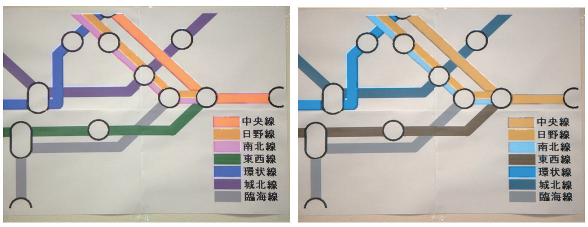
4.2. Results

Figure 8(a) shows an acquired image before projection. The image size was 640 by 480 pixels. Note that colors in the original object (first image) are different from those in the acquired image due to the lighting conditions. Color information for the original image (**Fig. 7(b)**), captured image (**Fig. 8(a)**), estimated image (used for evaluating indistinguishable colors), target image for color feedback, and projected image (**Fig. 9(a)**) is provided in **Table 1**. σ in the table denotes the standard deviation of color for a region with 200 to 400 pixels. Note that the realized color of the Chuo line (中央線, #1 in the legend) was evaluated without the pattern, and the realized color of the Nanboku line (南北線, No. 3 in the legend) was evaluated with blinking light. Including the color feedback process, the projection of colors took a total of 60–100 seconds.

Figure 8(b) shows the results of the deuteranope simulation for **Fig. 8(a)**. The combination of the brown area and green area in **Fig. 7(b)** is indistinguishable in **Fig. 8(b)**. Also, the combination of the blue area and purple area and the combination of the gray area and pink area in **Fig. 7(b)** are indistinguishable in **Fig. 8(b)**. The result of color conversion is shown in **Fig. 10**, in which the combination of the brown area and orange area in

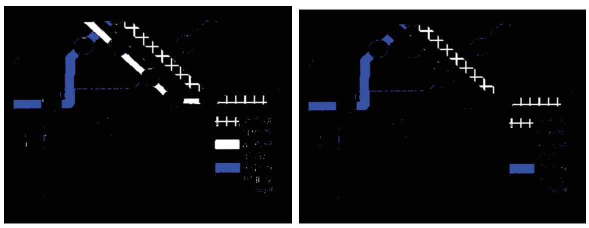
Table 1. Information of original, observed, target, and resultant colors. $^{(*1)}$ was evaluated excluding texture and $^{(*2)}$ was evaluated with blinking light.

Name of railway		Chuo (中央線)	Hino (日野線)	Nanboku (南北線)	Tozai (東西線)	Kanjo (環状線)	Johoku (城北線)	Rinkai (臨海線)
Original color	R	172.3	219.9	207.6	43.9	54	126.1	145.5
	G	78.1	206	98.6	114.9	91.9	75.4	142.5
	B	86.4	66.4	130.4	96.7	160.1	147.1	153.4
	L^*	59.7	86.8	69.2	66.4	52.9	52.9	76.2
	a^*	63.6	0.8	54.6	−68.5	−21.1	49.6	0
	b^*	20.1	41.9	−17.3	66.1	−23.4	−42.3	0
Observed color	R	172.3	219.9	207.6	43.9	54	126.1	145.5
	G	78.1	206	98.6	114.9	91.9	75.4	142.5
	B	86.4	66.4	130.4	96.7	160.1	147.1	153.4
	$\sigma_R, \sigma_G, \sigma_B$	1.8, 2.4, 3.2	3.5, 3.3, 4.6	3.5, 3.4, 4.9	4.7, 3.0, 3.6	4.3, 2.4, 2.7	2.6, 2.9, 2.6	2.3, 1.9, 2.2
	L^*	68.5	90.8	75.2	68.5	65.6	66.4	79.9
	a^*	25.1	−10.5	27.5	−23.5	−0.5	23.8	1.9
	b^*	6	45.7	−1.8	0.4	−27.2	−21.3	−3.1
Estimated color (Used for evaluating color conversion)	R	122.2	254.6	162.9	51.8	35.7	67	145.6
	G	38.8	224.3	53.7	73.8	58.5	40.8	136.8
	B	38.9	67.4	80.9	67.8	117.9	83.8	157.5
	$\sigma_R, \sigma_G, \sigma_B$	9.4, 2.6, 3.4	2.1, 6.0, 4.3	8.9, 3.3, 4.3	3.8, 3.2, 3.8	3.5, 3.1, 5.1	4.6, 2.5, 4.4	6.8, 4.7, 6.2
	L^*	54.2	94.3	62.5	58.9	54.8	51.2	79
	a^*	29.9	−8.6	5.3	−9	3.4	19.8	4.2
	b^*	12.9	50	−0.3	0.3	−29	−19.4	−5.6
Target color	R					83		
	G	Texture	–	Blinking	–	118	–	–
	B					217		
	L^*					73.6		
	a^*					4.2		
	b^*					−31.0		
Resultant (projected) color	R	$^{(*1)}$181.4	221.4	$^{(*2)}$253.7	42.9	123.3	124.7	151.7
	G	87.7	210.1	221.9	119.2	132	80.9	150.5
	B	89.6	60.8	253	87.8	254.7	138	151.5
	$\sigma_R, \sigma_G, \sigma_B$	1.7, 1.3, 4.5	3.7, 4.5, 5.9	1.4, 3.8, 2.3	5.3, 3.0, 4.1	1.8, 1.7, 0.7	2.9, 2.8, 2.8	2.4, 1.4, 2.4
	L^*	71.1	91.3	96.2	69.1	78.8	67.3	81.4
	a^*	22.9	−11.8	7.4	−26.9	11.9	19.7	0.4
	b^*	8.2	49.1	−5.1	5.2	−32.3	−16.8	−0.2



(a) Normal color vision (b) Deuteranopia simulation

Fig. 10. Result of color conversion.

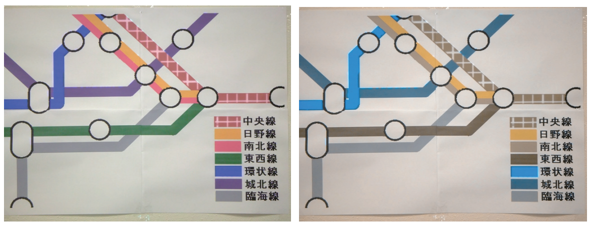


(a) With blinking light on (b) With blinking light off

Fig. 11. Projection image with pattern and blinking.

Fig. 7(b) is indistinguishable. **Figs. 11(a)** and **11(b)** are projection images in which the blinking light is on and off, respectively. The window size for pattern and blinking determination was 15 by 15 pixels.

Figures 9 and **12** show the results obtained by projecting the image with a pattern and blinking light on and off, respectively. So that the blue area may be distinguished from the purple area in **Fig. 7(b)**, the system converted the color of the blue area. Also, in order to make the brown area distinguishable from the green area in **Fig. 7(b)**, the



(a) Normal color vision (b) Deuteranopia simulation

Fig. 12. Result with blinking light off.

system projected a pattern on the brown area, and in order to make the pink area distinguishable from the gray area in **Fig. 7(b)**, the system projected a blinking light on the pink area. The experiment shows that it is possible for people with color vision deficiency to distinguish between these color areas.

5. Conclusion

We have proposed a projector camera system for presenting color information to people with color vision deficiency, and we have confirmed the effectiveness of the system experimentally. Our system can project color information as distinguishable colors, patterns, and blinking lights, so it can be applied to various color combinations. Though we believe the presented method with color conversion, pattern mapping, and blinking can cover most cases in practical use, it will be possible to increase the types of patterns and frequencies of blinking. Note that we will have to apply lower-frequency blinking to increase the variety because of the limitation on the frequency of blinking, and this may necessitate longer times for discrimination between multiple frequencies.

As future work, the system should be applicable to not only 2-D but also 3-D objects. Patterns to be projected should be selected automatically, depending on the shape of the target area. Consideration of a possibility that the proposed color projection might cause indistinguishability against a color in a neighboring area will improve the robustness of the system. Interactive selection of colors for blinking is another function that would improve the utility of the system.

Acknowledgements

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Membership in Academic Societies:
• The Institute of Electrical and Electronics Engineers (IEEE)
• Association for Computing Machinery (ACM)
• The Robotics Society of Japan (RSJ)
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Main Works:
• Y. Ikemoto, T. Miura, and H. Asama, "Adaptive Division-of-Labor Control Algorithm for Multi-robot Systems," J. of Robotics & Mechatronics (JRM), Vol.22, No.4, pp. 514-525, 2010.

Membership in Academic Societies:
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• The Japan Society of Mechanical Engineers (JSME)
• The Robotics Society of Japan (RSJ)