# Texture Recognition for Users with Color Vision Deficiencies

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**Abstract.** In this study, we designed a new type of primary color recognition assistive system for this user group, adding (1) directly perceived labels (the label group), (2) shape and color related dots (the dot group), or (3) distinctive vein lines (the vein group) to help with the recognition of primary colors red, green, and blue. Verification and evaluation were done for each part of the results, in order to describe the accuracy and feasibility of each system. The study has been divided into two phases. The first phase is the preliminary experiment, in which the label group investigates and verifies the objects that represent each of the primary colors and transforms into representative labels. The second phase employs the results of the preliminary experiment from the three groups onto colored cards, forming experiment group through color vision deficiency simulators, then issue out questionnaires of performance evaluation and subjective preferences for each group. Experiment results show that regardless of group, there was significant help in color recognition, decreasing the recognition error rate and task completion time. In terms of subjective questionnaires, participants believe that the difficulty level of primary color recognition evidently decreased, with an average preference of 6 and above.

**Keywords:** Color vision · Color vision deficiency · Texture composition

## 1 Introduction

About 8 ~ 10 % male and 0.45 % female are affected by certain level of color recognition disability [1, 2]. Unable to recognize the correct color would cause inconvenience or even danger in life, with examples of the recognition of traffic lights and labels on medication packages. Limitations exist at work too, such as occupations in medicine, chemistry, electric engineering, and painting.

Currently in clinical medicine, human color vision deficiency can only be detected but not treated. Supplementary instruments such as the color blind simulator, the color blind glasses [3]., and the appearance enhancement are used [4]. These supplementary technologies mainly reconstruct the information of the original image and color into color ranges able to be seen by the color vision challenged. This can act as supplementary reference for graphic and web designers while selecting colors. However, the help in solving the problems in everyday life is still limited.


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Masataka brought forward in 2002, that different background texture can be added to unrecognizable color ranges to allow users with mild color-blind symptoms to distinguish the boundary line between different color regions [5]. However, the above mentioned method is yet to be organized into a systematic color recognition related texture or label for designers to search. Hence, although the color vision challenged can successfully recognize the boundary between color regions, they can not systematically tell what color each texture represents. For example, to distinguish between red and green pills in a first-aid kit, if dots are added to the red ones while check patterns are added to the green ones, then the two could be distinguished. However, users still can not tell which is red and which is green, unless he knew in advance that the dots represent red and the checks represent the green.

The current design solution for the color vision challenged is mostly adjusting to the colors recognizable by them. However, this would affect the vision for the other users. Some employs different shapes to represent different messages or adding frames to text and icons with a background color. Changing shapes, which is adding shape as an identifying element, is the most commonly suggested solution. However, this can only be used in the graphic design field such as item connections [6].

In addition, adding frames is commonly used to colored texts since when only different colors are used to differentiate between text and background color, it causes the color vision challenged difficulty in reading.

The Color Universal Design Organization in Japan, CUDO in short [7] mainly aims at solving inconvenience for the color vision challenged. They reward designs on the market for the color vision challenged and bring forward design suggestions and color selection standards. Most of the CUDO approved designs commonly use (1) Changing colors to avoid the colors that cause confusion for the color vision challenged; (2) Increasing the brightness and the hue; (3) Changing the color combination or enhancing the frame; these are done to make identification easier. However, changing the colors would sometimes affect the visual for common users or the performance of the colors.

The aim of this research is to solve the confusion the color vision challenged have with the three primary colors, to proceed with experiment and analysis according to the problem descriptions, hoping to achieve the following goals:

- Under the precondition of not influencing the visual of common users, using the principle of color dithering, adding tiny color dots to construct a dithering ratio for the new three primary colors.
- Evaluate whether the new color recognition supplementary system reliably increase the color recognition level of the color vision challenged.

## 2 Methods

This study employs the principle of color dithering, adding tiny colored dots to the primary colors. These tiny dots are undetected by people with normal visions, hence does not significantly affect the presentation and recognition of colors. However, for the color-blind, they are able to tell the different in texture.

This study is divided into three main parts. The first part adds icons to the corner of each color chip as labels. This part employs the color association theory of color psychology, using the experiment procedures and confusion matrix brought forward by Kaneko to evaluate. Selecting icons related to each primary color, we then employ the selected icons to proceed with tests.

The second part uses the principle of visual dithering, adding tiny dots to primary colors. People with normal visions are able to use the shape of the dots to recognize the real color. The third part adds tiny colored dots on the picture, using repeated dot patterns to create different texture (veins), using the existence of distinctive veins as the supplementary assistance in color recognition.

This study employs ColorDoctor, the color blind simulator, to simulate the color cards for the experiment. People with normal color visions were selected to avoid the established impression the color vision deficient have towards colors after a long term of trial and error experience and hence the difficulty to measure the difference this new type of assistive system brings. People with normal visions have no obvious association towards the colors seen by the color blind. Hence in the experiment, regardless of which assistive method is used, the color itself would not affect the judgment of users. The development of this new type of system aims at helping the color vision challenged people of all ages and levels to achieve more convenience in life.

## 2.1 Label Group – Preliminary Test

- *Label Group – Collection of the associative objects of the three primary colors*

According to the previously mentioned theories, participants were free to associate the colors with any concrete objects, such as sun for yellow and heart for red. The test was done on participants between 20 ~ 40 years old with the study procedure showing in Fig. 1. The first step of this experiment employed open questionnaire to collect all the concrete objects associated, then uses ranking method to select the 5 associated objects that come in the highest frequency. Participants of this step were selected to be designers or design students with at least a year of related background and were told in advance that the aim of the experiment and the use of these associative objects before asking them to write down five appropriate objects.

The results of the concrete object investigation are shown in Table 1. Since part of the participants were trained design-related workers and the aim and study goal were told, most of the objects of the highest frequencies were natural scenery objects without concepts of culture or habits. These concepts were developed and drawn into icons afterwards.

- *Label Group – Confirmation of concrete object and color association*

Through induction and arrangements, the icon selections of the associative objects were drawn. In order to increase experiment accuracy, different icons were drawn for each object for selection. The associative objects were proceeded with confusion matrix, asking participants to match the objects with the subjective associated color,

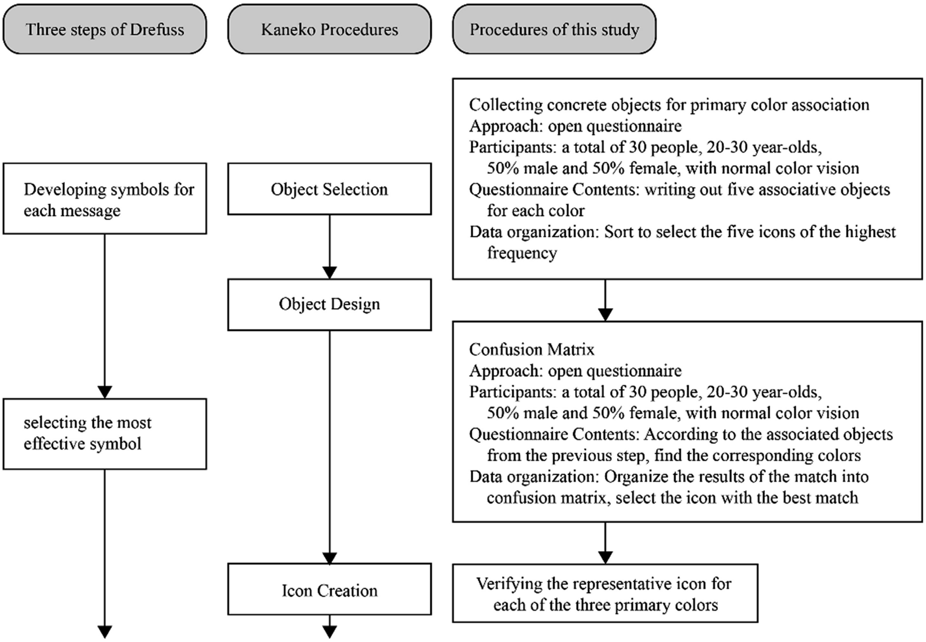


**Fig. 1.** Experiment parameters and procedures for the confirmation of associative objects of the three primary colors.

**Table 1.** Results of the concrete object investigation

| Color | Associated concrete objects(with the highest frequency) |
|---|---|
| Red | Apple, heart shape, fire, blood, sun |
| Green | Tree, mountain, grass, leaf |
| Blue | Ocean, snow, wave, water |

and evaluate the checked color and its icon for 0～10 points showing the level of representation of each icon. In this experiment, the questionnaires contain only the answering instructions, questions, and black icons to avoid influence of colored icons.

- *Label Group – Confirmation of the representative icons for the three primary colors*

Descriptive statistics were done to the questionnaire results done in step two, selecting the icons with the most color-icon connections (most votes) and the highest points in the representative grading. Table 2 shows the icons and results of the questionnaire (only the five icons with the most votes). The selected icons for each color were heart for red, tree for green, and water drop for blue. We concluded these three icons to be the representative icon for each of the three primary colors as the basis for further experiments.

**Table 2.** Dot color selection direction

| Background color | Dot color selection direction | Dot colors seen by the color blind | Dot shapes (Item) |
|---|---|---|---|
| Red | Purple-red | First and second color blind: blue | Square |
| Green | Blue-green | First and second color blind: blue | Triangle |
| Blue | Blue-purple | Third color blind: red | Circle |

## 2.2 Dot Group – Preliminary Test

- *Dot Group – Constructing dot diagrams*

The second part of this study integrates concepts of color-icon association and dithering, constructing dotted diagrams for the three primary colors. The first step is the establishment of a program to construct dots. The contents of the program are as follow:

- Produces dot diagrams with assigned color backgrounds. The dot shapes include squares, rounded triangles, and circles.
- Adjustable dot colors, sizes, and densities.
- Output dot diagrams as picture files and keeps a record of the diagram parameters.

Color dithering I used to adjust the color of the dots to avoid influence on people with normal color visions while the color vision challenged can tell the colors according to the Fig. 2. The color selection directions are shown in Table 2 (Fig. 3).

Based on the dot selection direction described above, integrating with the color resemblance suggestions (mono mode) from the Color Scheme Designer website, selecting three dot colors for the dots corresponding to the three primary colors for further experiments. The size, density, and color selected for the dots are listed in Table 3. In order to find the most compatible arrangement without influencing people

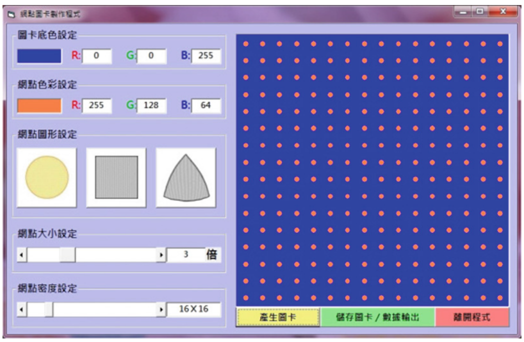


**Fig. 2.** Dot out program image (Color figure online)

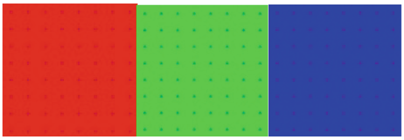

**Fig. 3.** Dot diagram generated by the program (not the original size) (Color figure online)

**Table 3.** Dot Group Preliminary Test – Colored Cards Selection Combination

| Chip color | Dot shape | Dot size (multiple) | Dot density (level) | Dot color (RGB) |
|---|---|---|---|---|
| Red | Square | 3 | 8 × 8 | 210.0.137 |
| | | 4 | 12 × 12 | 170.40.101 |
| | | 5 | 16 × 16 | 212.91.148 |
| | | 6 | 20 × 20 | |
| Green | Rounded triangle | | | 0.166.120 |
| | | | | 48.191.152 |
| | | | | 53.211.167 |
| Blue | Circle | | | 95.53.212 |
| | | | | 120.48.191 |
| | | | | 84.0.166 |

Note 1: The original color chip with dots output by the program is 8 $cm^2$.
Note 2: The dot size multiples are calculated by: Length of color chip (8 cm) ÷100 = diagonal length of square dot (1x) = distance of center to top vertex of rounded triangle dot (1x) = radius of round dot (1x).
Note 3: Dot density level calculation: 8 × 8 meaning dividing the color chipinto64 squares, where the center of the dots line up to define the center of the square. The same goes for 12 × 12, 16 × 16, and 20 × 20.

with normal color visions while the color blind can recognize the dot shapes, we use the program to produce 48 primary colored cards according to dot size, density, and color arrangements.

Using the ColorDoctor (Fujitsu) software, the 48 color cards described above were simulated under the color recognition deficiency mode. That is, red chip using first primary color blind mode simulation, green chip using second primary color blind mode simulation, and blue chip using third primary color blind mode simulation, producing 48 color cards after simulation (Fig. 4).

- *Dot Group – Dot diagram continuity interval approach clustering investigation*

In order to find the best combination of dots compatible to our goal, in this stage, the primary color and simulated color cards were investigated using the continuity interval clustering investigation. Participants were a total of 40 people between 20 ~ 30 years old with normal color visions. Participants were divided into original group and simulation group with 20 people each, proceeding with clustering of the 48 color cards. Since it is a large sample, in order to pursue the accuracy of clustering, we used two

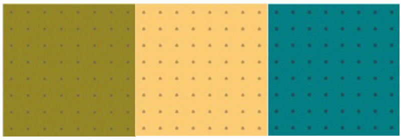

**Fig. 4.** Dot diagram after ColorDoctor program simulation (Color figure online)

levels of hierarchical clustering, clustering the color cards into three groups first, then further cluster into three groups within each cluster, obtaining nine color cards in total, as shown in Fig. 5.

The original group of participants clustered following the principle of “dot influencing visual”. The participants filled in group nine to group one following the order of most influence to the least. The simulation group of participants clustered following the principle of “clearly seeing dot shapes”. They filled in group nine to group one following the order of the clearest shape to the least clear Fig. 6.

The clustering results were compared to our experiment goal, extracting group one to three from the original group, that is, the cards from the three groups of the least influence, giving 3 points, 2 points, and 1 point respectively. We also extracted cards from groups 7 to 9 of the simulation group, giving 1 point, 2 points, and 3 points respectively, as shown in diagram 3−9.The color cards with the heist points are shown in Tables 2, 3 and 4. We have obtained the best combination of dots for each color as the basis for further experiments.

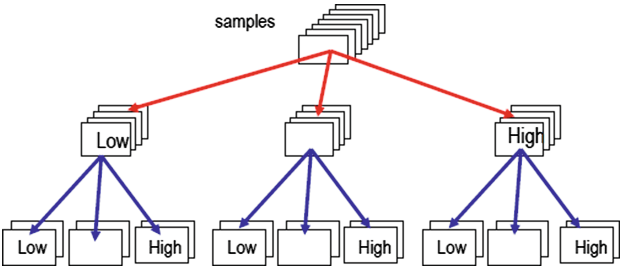


**Fig. 5.** Continuity interval clustering

**Fig. 6.** Continuity interval clustering experiment scene

**Table 4.** Results of color chip clustering experiment

| Color | Dot size (multiple) | Dot density (level) | Dot color (RGB) |
|---|---|---|---|
| Red | 5 | 8 × 8 | 170.40.101 |
| Green | 4 | 8 × 8 | 0.166.120 |
| Blue | 4 | 8 × 8 | 84.0.166 |

### 2.3 Experiment Verification and Evaluation

Three indices were used to rate the performance of the results. They are

- Reaction time: the time required for users to complete a certain task.
- Accuracy rate: The rate of users completing a certain task accurately.
- Preference: user's preference during the operation process.

In this study, we employed the three performance indices mentioned above, applying individual results from the preliminary experiments onto color cards, evaluate the recognition error rate and time and feasibility. This section is the analysis of results, comparing the error rate and recognition time of the new primary color assistive system with the original system without any supplements as the verification of the advantage of the new design. The subjective questionnaire evaluation was also integrated to further evaluate the advantages, disadvantages, and user preference between groups as the reference for further designs.

- *Primary color recognition assistive system performance evaluation experiment.*

(a) Experiment Objective
This experiment evaluates the new type of assistive recognition system developed in the previous stage. We test the new system with the old system without any assistive device to compare the color recognition level and observe the recognition time, in order to verify the feasibility of the new design, further reaching the objective of our study.

(b) Participants
There were 30 participants between the ages of 20 ~ 30 (average 22.87 years), 15 male and 15 female. They were physically and mentally healthy with normal visions.

(c) Experiment equipment and location planning
- Laptop (Sony VGN-SR15T)
- Video camera recorder
- Location: *Lighting*: Different light resources influence the color recognition reaction of our visual system. Therefore, under ideal conditions, color related experiments are required to be under the standard D65 (annotation) light source. Since this ideal light source is difficult to control, for the objectivity and enhance, we conducted the experiment in a steady experiment space, using normal white fluorescent lighting and a computer to minimize the error in color enhancing. *Annotation*: The definition of the standard D65 light source is the average sunlight two hours after and before sunrise (with a color

temperature of 6500 K). *Seating*: Adjustable seating is available according to requirement. *Distance to the screen*: As shown in the following figure, the steady visual distance is 60 cm.

(d) Experiment color cards preparation
Five groups of color cards were used and labeled as group A ~ E, containing six basic color cards including red, green, blue, and orange, yellow, purple have been added to increase experiment complexity to avoid memory effect. Group A (original group) uses original colors; Group B (simulation group) uses color cards of Group A simulated using ColorDoctor simulator; Group C (label group) uses color cards of Group B adding labels obtained in the previous stage in the bottom right corner. For unification purposes, the orange, yellow, and purple cards have used the sun, star, and grape icons; Group D (dot group) uses color cards of Group A adding dot combination results obtained from 3-3. For unification purposes, trapezoid, triangle, and oval dots have been added to orange, yellow, and purple cards. Dot colors were orange-yellow, yellow-green, and dark blue respectively. The size and density of the dots were based on the dots on the green card with minor adjustments. The six dot diagrams were further simulated using ColorDoctor; Group E (vein group) uses the green card produced from 3−4 and the five other cards from Group B. Of the simulated color cards of Groups B to E, the red cards were simulated using first primary color blind mode, the green cards the second primary color blind mode, the blue cards the third primary color blind mode. As for the three other colors, considering there is a higher ratio of color vision deficiencies in the second color blind group, were simulated using the second primary color blind mode.

(e) Experiment Variables
*Independent Variable*: The experiment is divided into five stages according to groups A ~ E. In which Group A is the testifying group, testifying unobstructed color recognition from the participants. Group B is the control group, and Groups C, D, and E are experimental groups. Therefore the experiment variables are the addition of the new types of assistive systems C ~ E.
*Dependent Variable*: Recognition error rate, recognition time length, subjective preference questionnaire

- *Experiment task design*

In this experiment, every participant is required to do the tests from Group A ~ E with 30 questions each. The questions include 10 questions of "select red", 10 of "select green", and 10 of "select blue" randomly. Four colored cards are shown in each question. Besides the correct answer, the other three cards were randomly chosen from the other five colors. The sequence of the four colored cards is also randomly arranged.

To avoid the learning memory effect of experiment groups C, D, and E, these three groups are required to proceed according to the order to retain objectivity. There are 30 s break times in between each experiment for all groups to reduce the influence of visual fatigue.

- *Subjective evaluation questionnaire*

  After the above experiment, participants were asked to write a subjective evaluation questionnaire. This questionnaire focuses on the evaluation of color recognition difficulty and feasibility of each group (including practical level, immediate level, learning level, application level, appearance, and preference).

## 3 Result and Analysis

This research uses color recognition to study the feasibility of three new types of assistive system, recording task completion time, error rate, and subjective evaluation questionnaire. In this section, we analyze the results by comparing the performances between using the three types of assistive system and with no assistive system. The three types of assistive system are (1) adding color related labels (label group); (2) adding shape and color corresponding dots (dot group); (3) adding color related distinctive veins (vein group) respectively.

The original color group (A) is the testifying group, therefore has not been listed into the statistic range. The Vein group (E) focuses the test on only the green color. Hence only the results of the green color tests are included in the statistics and discussions of average error rate, task completion time, and subjective questionnaire on difficulty.

## 4 Discussion and Conclusions

This study focuses on the three assistive system designed for the people with color vision deficiencies. The experiments results proved to be different from color recognition dependent only on memory or speculations. The probability of confusion has evidently decreased, and the accuracy rate increased. In addition, due to the assistive reference in color recognition, thinking time has largely decreased too.

Responding to the research objective described in the first section, we obtain the three following:

- Obtaining from experiment the intuitive representative icon of each color (label group)
- Application of geometric figures representing each color (dot group)
- Adding the use of veins, yet to be applied to all colors (vein group)

The three major color recognition assistive plans have the following advantages compared to the original:

- Lowered error rate. Participants were able to accurately select the corresponding colors.
- Shortened color recognition time and increased reaction speed.

For red, there was a significant difference in the lowering of error rate in both label and dot groups. However, the dot shapes were difficult to differentiate, therefore the task completion time was not significantly lowered as in the label group, but slightly increased. This shows that the dot group requires further investigation and improvement. In terms of recognition difficulty, participants believe that adding labels or dots both significantly decrease difficulty, showing practical assistance from these two groups of assistive system.

For green, the accuracy rate significantly increased with the addition of assistive system. However, since the dot on the green cards (rounded triangles) and the yellow cards (equilateral triangles) are very similar, it requires careful observation to tell the difference, the recognition time of the dot group has on the contrary increased. This same reason could also have been the cause of a low accuracy rate but short completion time in the simulation group test as participants guessed instead of observed. There were significant differences in the influence of difficulty between the three groups and the simulation group. This means the addition of any of the groups would significantly lower the difficulty level. There was significant difference between the dot group and the other two groups, showing that the assistance of the dot group is less than the other two groups.

For blue, since the simulated blue cards (simulation group) shows a blue-green color in the visual of the people with normal visions, it is easily differentiated and closer to the original hue when compared to the other colors of the simulation group (red, orange, yellow, green). Hence in the test of the simulation group, the error rate of selecting blue would be lower than the error rate of selecting red or green. This may be the reason that in terms of error rate, there was no significant difference between the simulation group and the other two experimental groups. In terms of recognition time, the label group has evidently lowered the recognition time, while the dot group, similar to the results of the green color, the similarity in shape and size has caused an increase in time. There was significant difference in difficulty level between the simulation group and the other two experimental groups. This shows a significant assistance from the two experimental groups in lowering the recognition difficulty of blue cards. In addition, the significant difference between the two groups also showed that the dot group did not perform as well as the label group in terms of lowering difficulty levels.

The label group has filtered the icons through the preliminary test and confusion matrix, obtaining the final icons that are highly representative, intuitive, and perceivable. This has been proved in the verification test where the participants do not need to spend extra time to memorize and are able to associate the icons with colors immediately. This has resulted in the best achievements and the highest scores in the seven subjective satisfaction indices. However, due to its characteristics, the application of the icons is not as expected. The suggested applications are the outlines light signals, label (such as cold and hot water indicators), or education purposes. In addition, the labels can also be used on annotations such as clothing tags to help people with color vision deficiencies to select the right colors.

The tiny shapes and the similarity between the colors have lead to a longer recognition time. In the performance indices, even though the assistance in color recognition still exists, the performance and subjective evaluation scores were lower when compared to label and vein groups. This shows a need of improvement. There were also suggestions that the dot group would be more compatible to large areas than the label group since the labels are only shown in a corner, while the dots can be evenly distributed and therefore easily observed. In addition, for people with normal visions, the dot group has a less influence on the visual of the picture, and can be applied on filling of areas.

The vein group has currently being tested on the color green. Participants believe the assistance is not extensive enough, and has influenced the scores on the subjective evaluation questionnaires. However, looking at the error rate and completion time of the vein group, it does achieve immediate results and essential help in color recognition. The application of the vein group has its limitations. On top of the age limitations mentioned earlier, it is also limited to plain areas. Areas with multiple texture and veins, such as knitwear or leather, are not compatible. Participants suggested supplementary tactile assistance in daily life applications to show its assistance. The construction of vein styles for other colors also needs to be further discussed.

In conclusion, the addition of the new color recognition assistive system does effectively help in the recognition of the correct primary color. Each group has its characteristics, advantages and disadvantages that need to be used in the correct way and appropriate scenes to display its maximum performance. The goal is to use them so they do not influence the visual of the people with normal visions nor cause visual burden to the people with color vision deficiencies, reaching the goal of universal design.

## References

1. Simunovic, M.: Colour vision deficiency. Eye **24**(5), 747–755 (2009)
2. Birch, J.: Diagnosis of defective colour vision. Oxford University Press, New York (1993)
3. Muttaqin, G. F., Suwandi, I.S.: Simulation system of color blind glasses by image processing. In: Electrical Engineering and Informatics (ICEEI) (2011)
4. CUDO. Color universal design handbook. CUDO, Japan (2006)
5. Okabe, M., Ito, K.: Color Universal Design (CUD)-How to make figures and presentations that are friendly to Colorblind people. (2008). http://jfly.iam.u-tokyo.ac.jp/color/index.html
6. Beveren, T.v. We are colorblind.com. http://wearecolorblind.com/
7. CUDO. Color Universal Design Organization. http://www.cudo.jp/index.html
8. Steven, H.S.: Visual Perception: A Clinical Orientation, pp. 6–9. McGraw-Hill Medical, New York (2010)
9. Kolb, H., et al.: WebVision (2009). http://webvision.med.utah.edu/