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색각 이상자들의 감각 유지를 위한 대비기반 색변환 방법

안지혜*, 박진호**

요 약

색각 이상자들은 채도와 명도가 낮은 색채들에 대해 분별력을 갖지 못할 뿐 아니라 감성 왜곡과 관련하여 부정적인 감성을 표출한다. 감성의 기본이 되는 감각에 대한 왜곡을 바로 잡고자 함은 색각이상자들이 디지털 문화콘텐츠에 접할 때 느끼는 부정적인 감성보다 긍정적인 감성을 높이기 위해서이다. 대비는 채도와 명도간의 변환되는 방향이 다르게 하여 높이고, 이를 통해 원본 이미지가 전달하는 동적과 정적, 선명함과 칙칙함이라는 감각 왜곡을 감소시켜 색각 이상자에게 전달한다. 이를 색변환이 이뤄지는 영역에 대하여 채도와 명도를 변환하는 대비기반 색변환 방법을 제안하고 이 방법이 감각 왜곡을 감소시킨다는 것을 색변환 시뮬레이션과 사용자 테스트를 사용하여 확인한다.

키워드 : 색변환, 색각 이상, 감성 왜곡, 감각 유지

A Contrast-based Color Conversion Method for the Maintenance of Sense of the People with Color Vision Deficiency

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Abstract

Color deficient people do not have sufficient discernment for the colors with low saturation and brightness and at the same time express their negative emotions regarding emotion distortion. The purpose of recovering the distortion of the vision which is the basis for emotion is to increase positive emotions rather than negative ones that those with color vision deficiency feel when they experience digital culture contents. Contrast increases saturation and brightness by differing the direction of their conversion and by doing so, delivers emotion distortion such as dynamic vs. static and vivid vs. somber that the original images intend to convey to those with color vision deficiency by reducing such a contrast. In this respect, this study proposes a contrast-based color conversion method to convert saturation and brightness in the zone of color conversion and identifies if this method can reduce emotion distortion by using color conversion simulation and user test.

Keywords : Color conversion, color vision deficiency, emotion distortion, sense maintenance

1. Introduction

1.1 Background

This study proposes a color conversion method to maintain our senses in comparing dynamic vs. static and vivid vs. somber which are our distorted senses. People with normal color vision feel a dynamic sense when red and green are combined. But, people with red-green color vision deficiency can't feel a dynamic sense but feel a static sense because there is no big difference between red and green. Additionally, color distortion makes the sense that ought to be felt as being vivid feel like being somber. Like this, what one feels with a contrary sense without feeling the

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originally intended sense is called as emotion distortion. Maintaining such a sense means that the degree of distortion is reduced after color conversion rather than before color conversion. In other words, the distorted sense was reduced and the original sense that was maintained increased. In a dictionary definition, what can be discerned when a certain stimulus is given is called as sense and the property that is felt based on an individual's propensity, experience, and environment is called as sensibility. The reason why our color conversion is called as sensibility-based is because it's not the color conversion for distinguishing the colors that are problematic like the existing color conversion methods, but the color conversion for minimizing the distorted senses. Contrast-based color conversion method is easily applied to the cultural contents on digital programs such as mobile, web, and video because it's based on saturation and brightness conversion rather than color conversion. It's also highly usable to the display screens because color conversion is based on simple algorithms, which can minimize the emotion distortion of those with color sense deficiency.

1.2 Necessity of Research

Those with color sense deficiency do not have enough discernment of the colors with low saturation and brightness and at the same time express negative emotions regarding emotion distortion. To reduce the emotion distortion, it is necessary to reduce the distortion of senses. Additionally, in cultural contents, images are greatly influenced by the sensibility of users[1], If it is possible to develop color conversion techniques to minimize their emotion distortion, those with color sense deficiency will be able to feel the same emotion as normal people and psychologically better because their positive emotions will increase more than their negative emotions. Like Doliotis et al.[2] and Huang et al.[3]'s methods, most methods present the methods to differentiate the colors that those with color sense deficiency cannot differentiate from. Converting the colors that they cannot differentiate into the other colors cannot maintain the original sensibility although it might be able to improve their cognitive skills of the colors.

1.3 Technical Contributions of Our Proposed Method

We use contrast-based color conversion but do not use hue conversion for maintaining our distorted senses dynamic vs. static and vivid vs. somber. If hue is changed, there occurs a distortion of the emotions that are recollected depending on their experiences or conditions and only if the hue conversion occurs in the problematic area, there might be a distortion in delivering the information of the original image. Distortion in information delivery means perceiving the information that the image gives in a wrong way, for example, accepting the popular information like 'well-ripe apples are red' as 'well-ripe apples are blue.' So our proposed method reduces emotion distortion by contrasting saturation and brightness rather than hues in HSV color space. In our proposed method, the contrast in saturation and brightness maintains our senses on dynamic vs. static and vivid vs. sombre and maintains continuity between pixels and finally reduces the distortion in image information delivery. If the contrast-based color conversion method is complemented and developed in the future, it may reduce a psychological sense of unease as it is not strange to normal people because colors don't change and emotion distortion is reduced to those with color sense deficiency and it will also be used for the development of cultural contents like mobile, web, and video and for the field of welfare like psychological therapy that belongs to them.

2. Existing Research Analysis

2.1 Physiology-based Color Sense Simulation

In an attempt to make a visual approach to those with color sense deficiency, Machado et al.[4] and Brettel et al.[5] presented the methods to simulate the color recognition of those with color sense deficiency. However, Brettel et al.[5]'s method is not appropriate for the color sense simulation for us to make an experiment because it simulates the color recognition of the 2nd color sense deficiency(green color sense deficiency) which occupies the highest percentage among those with color sense deficiency. Machado et al.[4] presents a physiology-based model for simulating the color recognition of those with color sense deficiency. They referred to Bratkova et al.[6]'s researches to understand the relative color space based on the relative color theory. They presented the defective color vision simulation using the LMS data reported in electrophysiological researches. LMS data means the data designated by the reaction of three cone cells in the eye by the long(L), medium(M), and short(S) wavelength of light. In checking the color conversion for most of those with color sense deficiency, Machado et al.[4]'s proposed method is used. This method is precise because the degree of color sense deficiency is simulated using the difference in the movement of LMS curve (in nanometer). This is why it has disadvantages in that it is less practicable to be used for color conversion while checking the LSM data of users and on the other hand has advantages in that it is highly accurate to be used for comparison between before vs. after color conversion because anomalous color vision simulation is very precise. To analyze the existing researches on color conversion, this study conducts a research on the physiology-based defective color vision simulation, uses Color Oracle[7]'s color sense simulation that indicates color sense simulation in a similar movement to this method, and uses each simulation to represent the anomalous color vision image of experimental images.

2.2 Recoloring Method for Information Delivery

The color conversion methods are basically rule-based method and optimization-based method. Rule-based color conversion methods take a short time to perform because they are performed with simple rules, but if color conversion is difficult by the rules proposed, the performance of color conversion might be deteriorated. Conversely, optimization-based color conversion methods take a longer time to perform color conversion than rule-based, but it has advantages in that the performance of color conversion is better than the rule-based color conversion methods. Jeong et al.[8]'s proposed color conversion methods improves the rule-based color conversion methods that color conversion speed is rapid and so like the optimization-based color conversion methods, the performance of color conversion is not deteriorated in any cases, color conversion is rapid, and it's not awkward to normal people. Their proposed methods may represent natural images to those with normal color sense (type C) because color conversion happens while maintaining the ratio of red vs. green, but the difference in the colors whose colors are converted to those with color sense deficiency may be recognized, but rather the maintenance of vivid and dynamic senses that may be caused by contrast between color and brightness might be deteriorated because of the existing methods.

2.3 Color Conversion Method that Corrects Distorted Color Zone

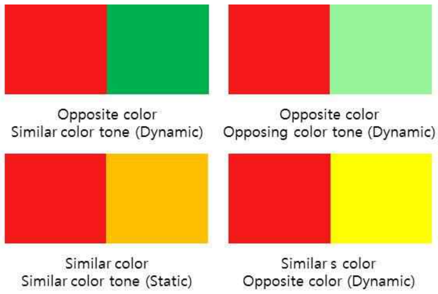
Kim Hyunji and Goh Sungje[9] and Rumiński et al.[10]'s proposed color conversion methods correct colors in a way to reduce the problematic zones to those with color sense deficiency and increase the zones that they can recognize and present the methods to apply the color conversion suitable for individuals with color sense deficiency by correcting brightness in the zones where brightness is mistakenly recognized. However, this method does not act for maintaining the emotion of those with color sense deficiency. The reason is because reducing the color zones that they cannot recognize and expanding the color zones that they can recognize means that color conversion happens and if color changes, the original sense that the color has on its unique way might be lost although it might be a color that is difficult to be recognized by them. [14] offers information about processing effective images through data about the effect of the visual depth that applies the color correction during the post-production stage.

3. Our Proposed Method

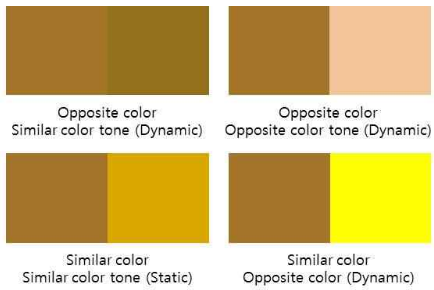
Those with green color sense deficiency don't have enough discernment for the colors with low saturation and brightness and at the same time express negative emotions in relation to emotion distortion [11]. It is also important to set the color zone that those with color sense deficiency can recognize and the color zone that they can't [12] Those with red color sense deficiency (Type P) recognize red much darker and those with green color sense deficiency (Type D) recognize green much darker. This is why their discernment is reduced for the colors with low saturation and brightness as well as color problems. As their discernment of saturation and brightness is reduced, those with color sense discernment have a negative emotion because the entire images become unclear. So this study presents the contrast-based color conversion methods that saturation(S) and brightness(V) are adjusted in HSV color space based on the color conversion that reduces their emotion distortion.

3.1 Distorted Sense Analysis

Summarizing the emotions that they feel depending on combination of colors is called as *color combination image*. Such color combination image is correlated with language image scale. For this, image scale has basically two axes: one dynamic axis and one static axis which are basics for emotion distortion. This study selected two emotion axes of vivid and somber. These two axes were selected as follows. In case of type C, in combination of colors, if similar hues although antagonistic colors are combined, if antagonistic hues although antagonistic colors are combined, if antagonistic hues although similar colors are combined, and if similar hues although similar colors are combined, a sense like in (Figure 1) may be felt. However, to type P, a sense like in (Figure 2) may be felt.

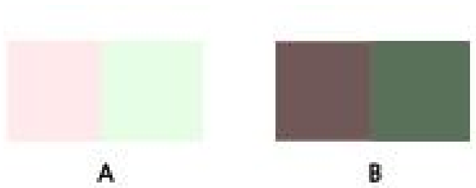


(Figure 1) Simulation color for type C



(Figure 2) Simulation color for type P

In other words, to type P, similar hues although similar colors are felt like being static. Also, if antagonistic hues although similar colors are combined and if antagonistic hue and antagonistic color are combined, dynamic sense remains as it is because there is a big difference in saturation or brightness. However, in case of similar hues although antagonistic colors, the sense that ought to be felt as dynamic is distorted to static sense. This is why this study sets one axis of sense that becomes the basis for color conversion as dynamic or static. And the images that consist of the colors that are difficult to differentiate from the eyes of those with color sense deficiency of each type distort the senses because of distortion in saturation and brightness and deteriorate a clear sense of the entire image. This is why another axis of sense that becomes the basis for color conversion is vivid or somber. To look at the color zones of color conversion depending on the axis of sense of dynamic vs. static and vivid vs. somber, the colors that has L value less than 40 or S value less than 20 to the eyes of type P and type D don't require color conversion because the static sense that the original colors give is maintained. Here, L is Lab color space and S HSV color space.



(Figure 3) Static mood example for the color arrangement with contrast color and similar tone

And the colors that have such L values and S values don't convert colors because as shown in (figure. 3), such colors have a static sense although such colors are similar hues despite the antagonistic colors and to the type C, they are not seen as being in big contrast and to those with color sense deficiency, recognition of brightness is only possible, but the recognition of colors is deteriorated. However, if L is 40 and S exceeds 20, color recognition becomes possible and dynamic senses are felt to some extent. To those with color sense deficiency, dynamic senses are distorted. To correct this, color conversion must happen in this zone. The setup of L value and S value for the color zone that those with color sense deficiency can recognize is based on our experimental experiences.

In the classification of color conversion, L and S are located at the different color spaces because it is difficult to calculate brightness in Lab color space. Lab color space is a relative color space and a indicates red and green and b indicates green and yellow. This is why it is difficult to measure the saturation of a certain color. In addition, HSV color space uses S value, but does not use V and Lab color space uses L because human eyes recognize colors in separate pairs in combination of three primary colors accepted by each of three cone cells and such colors are combined in the brightness of green and yellow, and red and green before delivering to the brian. So this study uses L in Lab color space and S in HSV color space to set color zones.

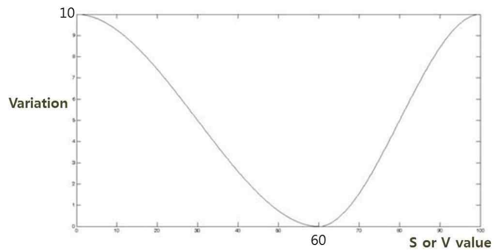
3.2 Classification of Region of Chromatic

As color changes distort the unique sensibility of color, in our proposed method, colors do not change and simply depending on type P and type D, red zone and green zone are divided. The association of colors is greatly influenced by an individual's experiences and preferences. Association is influenced by color viewer's experiences or memories, knowledge, and environment and appears differently depending on gender, age, personality, living environment, and vocation and differs in terms of region, climate, nationality, cultural background, and period. And to those with congenital color sense deficiency who have already established their association with colors, if color conversion happens, it might rather distort their sensibility. So we do not convert colors. However, since the zones that ought be changed in terms of saturation or brightness on the basis of type P and type D which happen the most to those with color sense deficiency are red and green, this study sets the color zones for red and green (Figure 4). The zone of red where sense distortion happens ranges from 342° to 18° and the zone of green ranges from 60° to 170°. Setting the color zones is based on the color adjustment devices and methods for the contents for those with color sense deficiency[13].

(Figure 4) Original image(Left) and R and G segmentations for type P

3.3 Increase in Contrast between Saturation and Brightness

This study converts saturation and brightness based on the central values while maintaining the continuity between pixels by comparing the saturation and brightness of red zone and green zone. In case of type C, they recognize red better when they see red and green with the same saturation and brightness. To our eyes, ρ cells which are long wavelength cells that are used to recognize red are distributed more than the γ cells that recognize medium wavelength and the β cells that recognize the short wavelength. This is why this study distinguishes red zone from green zone and then in case of type P, reduces the saturation of the red zone and increases the brightness of green zone. After than, in case of type P, this study increases the brightness of red zone and reduces the brightness of green zone. By doing so, saturation and brightness can be converted into relative directions and the width of contrast can be larger than the conversion at only one zone. In this way, dynamic sense can be maintained by contrast and vivid senses can be maintained for objects. Here, maintaining senses means that the degree of emotion distortion after color conversion is smaller that before color conversion. The changes in saturation and brightness happen in divided red zone and green zone and the changes of saturation and brightness in such zones change around the highest variance and central values. The central values are set as the average value of the average saturation value and the average brightness value in the entire images and the farther away from the central values, the higher the degree of variance. In other words, it means that if it is farther away from the central values, the wider the width of changes is. This is a setting for maintaining the continuity between pixels in the surroundings although saturation and brightness conversions happen. (Figure 5) represents the difference in values that change depending on the values of saturation and brightness of each pixel if the highest variance is 10 depending on the degree of anomalous color vision when the central value of saturation and brightness in red and green zones is 60.



(Figure 5) S (or V) variation graph (max. 10) with center value 60

3.4 Variance in Saturation and Brightness

The variance in saturation and brightness as mentioned above is set depending on the degree of anomalous color vision and the variance is curve. So it maintains continuity between pixels. To look at the degree of changes in saturation and brightness, the closer to the central values depending on the function, the smaller it is, and the farther away from the central values, the bigger it is. This study increases and decreases this variance to the original saturation and brightness to contract between saturation and brightness in red and green zones, and the converted images maintain senses to the eyes of those with color sense deficiency due to the maintained continuity between pixels and distort image information delivery. Also, in case of adjacent pixels, if they have similar saturation values or brightness values, it may cause no big difference in saturation and brightness, which reduces damages in image. If the biggest variance in saturation is $S_{\max}$, the value of saturation in each pixel S, and the value of average saturation in the entire image S_{avg}, the variance ΔS's formula is as follows:

$$\Delta S = S_{\max} + \left[2\left(\frac{S}{S_{avg}}\right)^3 - 3\left(\frac{S}{S_{avg}}\right)^2\right] S_{\max}, \quad S \le S_{avg}$$
(1)

$$\Delta S = -\left[2\left(\frac{S - S_{avg}}{100 - S_{avg}}\right)^3 - 3\left(\frac{S - S_{avg}}{100 - S_{avg}}\right)^2\right] S_{\max}, \quad S > S_{avg}$$
(2)

Formula (1) is used to obtain the variance ΔS when S is less than or same as S_{avg}, and Formula(2) is used when S is bigger than S_{avg}. The color converted S' by color pixel is the value that reduced ΔS to the original S, in case of type P, when it belongs to red zone (formula (3)) and when it belongs to green zone, it has an increased value by ΔS from the original S.(formula (4))

$$S' = S - \Delta S \quad (3)$$

$$S' = S + \Delta S \quad (4)$$

Unlike type P, type D has a reduced value by ΔS when it belongs to red zone and has an increased value by ΔS when it belongs to green zone. Like saturation, brightness similarly converts by using formula (1) to formula (4) and the converted V' is, in case of type P, is obtained as $V + \Delta V$ in red zone and as $V - \Delta V$ in green zone. (Figure 5) represents ΔS graph when $S_{\max} = 10$, $S_{avg} = 60$.

4. Result

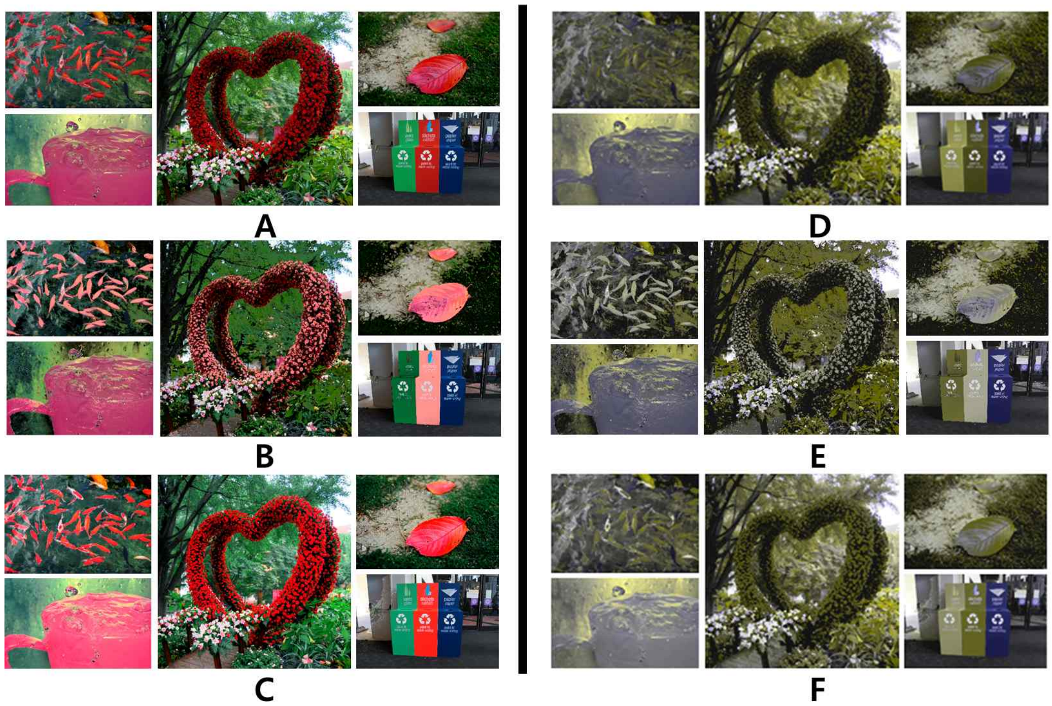
By using our proposed color conversion method and [9]'s method, this study measured and compared color converted speed and after checking if distorted senses are maintained for the color converted images by using color sense simulation [7], this study checked if emotion distortion was reduced in those with color sense deficiency.

This study our proposed method and [9]'s color zone correction method with MATLAB and the unit of measurement speed experimented in Intel(R) Core(TM) i3-2350M, CPU 2.30GHz, 2.30GHz, 8.00GB RAM environment is second.

Image	Image Size	Our Method	Color Section Revision
Fish	1119 * 749	6.3960	8.1277
Cup	500 * 315	1.0920	1.4976
Heart	1935 * 1935	26.3642	37.1282
Leaf	1116 * 749	5.5848	8.1433
Trash	3568 * 2368	51.9327	99.0918

<Table 1> The color conversion performance (seconds) in MATLAB

The image used in color conversion speed test is the image (A) shown in (Figure 6), and from <Table 1>, it is found that our method proposes a rule-based and optimized color conversion method and that the conversion speed is faster than [9]'s method. The reason why our proposed method is faster in speed during color conversion is because color conversion does not happen and although it does not do color conversion, unlike [9], it's faster although saturation change occurs. To look at the color conversion in (Figure 6), in case of type P, the biggest variance in saturation is 50 and the biggest variance in brightness is 80 when the degree of defective color vision is 1, baseline. To look at the (Figure 7) that divided the (D), (E), and (F) images in (Figure 6), it is found that our proposed method maintains a dynamic sense. To look at the first fish image in (Figure 7), there is a small contrast between fish and floor as indicated by blue circle in (D), which suggests that vivid and dynamic senses are small. To look at the color converted (F) in [9]'s method, fish and floor are distinguished compared to (D), but it is not enough to say that the dynamic sense that the contrast between red and green gives was maintained. However, to look at the contrast-based color converted (E),



(Figure 6) orignal (A), our method (B), method in [9] (C) of color transformed image. Simulation image by [7] for type P with deficiency degree 1 (D, E, F)

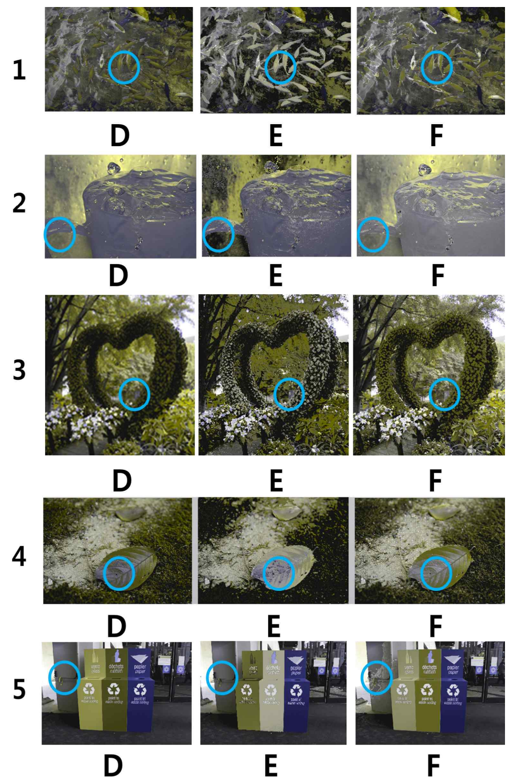
fish and floor are well distinguished and the contrast is bigger compared to (D) and (F), which suggests that dynamic senses are maintained. To look at the inside of the circles in (D) and (E), there is a small contrast between cup handle and background and so dynamic sense is small. However, in (E) where color was converted with our proposed method, there is a bigger contrast compared to (D) and (F), which suggests that it is smaller than the degree of emotion distortion of the original image. To look at the circle marked in the third heart image, there are red and green panels. To look at the color converted image (F) with [9]'s method, to the eyes of those with color sense deficiency of type P, the colors of red panel and red heart-shaped flower may be recognized as different colors. However, in image (E) which color was converted and simulated with our proposed method, the color of red panel was converted to the similar color of red heart-shaped flower, which suggests that they are similar red colors each other. This is why to the eyes of those with color sense deficiency, the senses that similar colors deliver are maintained. Furthermore, from the entire image, it is found that the dynamic senses that the contrast between heart-shaped flowers and background gives and the vividness of flowers are maintained. To look at the circle in the fourth leaf image, to the eyes of those with color sense deficiency, a stain in the leaf is not seen well, However, to look at the color converted image (E) with our method, it is found that the stain is well alive and that dynamic sense is maintained because there is a big contrast between leaf and floor. Finally, to look at the garbage can image (F), if doing color conversion with [9]'s method, color is converted and so there is a broken continuity between colors in pixels. But to look at the color converted image (E) with our method, there is a continuity between pixels and also the dynamic sense that red and green give is maintained.

To look at the images converted with our method through color sense simulation, there is a contrast, which causes vividness in the entire and continuity between pixels and the dynamic sense is better maintained than the images color converted with the original image and [8]'s method. Based on this, this study thought that emotion distortion was reduced even to the eyes of those with color sense deficiency and found this through user test. This study saw color converted images at the baseline of 0.5 for the degree of defective color vision between the original vs. the converted one targeting 40 images that consist of red and green in ordinary monitor environment by having four individuals with color sense deficiency of type D (two individuals in their teens and twos in their twenties) and tested their responses on 90 questions. <Table 2> represents the result of user test with images that give a lot of dynamic senses to type C, but givese static senses to those with color sense deficiency.

	Original Image	Our Image (D, 0.5)	Our Image Percent
Dynamic	58	22	27.5%
Static	20	48	70.5%
Clear	64	18	21.9%
Dark	17	55	76.3%

<Table 2> User test of type D

As indicated in (Figure 7), the fact that the dynamic and vivid sense that the contrast between the color converted images gives is not better than the original images to the eyes of users can be found in <Table 2>. However, given the fact that sensibility is based on senses and the senses are formed based on user's experiences and environment, it means that there happens a variance in senses that the original images give to them. In addition, among the four users, the users in their teens who are relatively less experienced showed positive responses for the converted images. Accordingly, this suggests that the senses mentioned above depend on an individual's experiences and environment and the development of color conversion that reduces the emotion distortion in those with color sense deficiency is important. Of course, this test led to this result that when the saturation and brightness of red and green are are at a similar level, the color converted images are more dynamic and vivid and thus easy to be recognized, but when there is a difference in saturation and brightness between two colors, it is rather difficult to maintain senses and recognize because of the color converted images. This indicates the lack of the values that are used to set the zones that color conversion does not happen and the variance in saturation and brightness. But if solving such problems, it will be used sufficiently for welfare, digital cultural contents, etc.



(Figure 7) Simulation images by [7], for original (D), our method (E), and method in [9]. Type P with deficiency degree 1

5. Conclusion

Contrast-based color conversion method maintains dynamic emotion and brightness delivered by the original image better than the existing color cognition-based color conversion method.

Since this doesn't convert colors to maintain hue's own sensibility, this has a better computational efficiency than the existing color conversion method. Besides, this is useful in applying to digital cultural contents, because colors are converted quickly.

The suggested method needs to remedy the accuracy of classifying variables optimized for emotion maintenance and color regions, though this reduces sense distortion of color blind people. For remedying this, first of all, precise examination of the central value and the maximum change and optimization are required. In other words, there is a need to maintain their senses more efficiently than now, by accurately analyzing the central values of optimized saturation and brightness and the minimum contrast interval between saturation and brightness for emotion maintenance, like the color cognition-based color conversion method in [9] to improve cognitive ability through inter-region color conversion using color differences.

Moreover, it is required to classify color regions more precisely, since in some cases, the continuity between converted color regions and pixels near the regions is cut. In future, we should find the minimum contrast interval between saturation and brightness to maintain senses of color blind people and improve the continuity between pixels in converted color regions and pixels in color regions which are not converted.

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