Web-Page Color Modification for Barrier-Free Color Vision with Genetic Algorithm

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Abstract. In this paper, we propose a color modification scheme for web-pages described by HTML markup language in order to realize barrier-free color vision on the internet. First, we present an abstracted image model, which describes a color image as a combination of several regions divided with color information, and define some mutual color relations between regions. Next, based on fundamental research on the anomalous color vision, we design some fitness functions to modify colors in a web-page properly and effectively. Then we solve the color modification problem, which contains complex mutual color relations, by using Genetic Algorithm. Experimental results verify that the proposed scheme can make the colors in a web-page more recognizable for anomalous vision users through not only computer simulation but also psychological experiments with them.

1 Introduction

Due to the rapid development of computers, internet, and display and printing techniques we can take advantage of color to describe and deliver digital information. The colors themselves used in the description of a message often contain very important information. For example, various colors of text, graphics, and images have been used in the web pages on the internet, in which color difference often classifies the importance of information, such as a linkage to another page, and so on. However, from a medical point of view, colorful information description does not always provide real convenience and easy understanding of the information to all users. It is well-known that 5-8% of men, with so-called anomalous vision, have difficulties recognizing certain colors and color differences rather than normal people. Those who have a different color vision from normal people (anomalous vision people) may miss the information that can be recognized by normal vision people, which causes the disparity of capability getting

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information between them. In this paper, we focus on this problem and try to modify the colors used on the web pages to colors that could be more recognizable for anomalous vision people in order to realize barrier-free color vision in the IT society.

The anomalous vision has been mainly verified by lots of psychological experiments in medical field so far [1,2]. From an engineering point of view, Kondo proposed a color vision model which can describe the anomalous color vision to simulate (display) the colors that the anomalous vision people may observe [3]. In this model, the anomalous vision can be considered as if a certain unit or a channel between units in the model is broken or their functions are deteriorated. In this paper, we follow this fundamental research and propose a novel web page color modification method to realize a barrier-free color vision. In this paper, we first propose an abstracted image model for general color images and apply it for web pages. Next, we propose an optimization method of color arrangement in the abstracted image model for web pages. When we increase the number of colors used in a web page, the complexity of color arrangement increases rapidly. In this paper we use Genetic Algorithm (GA) for color arrangement optimization of web pages, which is widely known as a robust optimization method [4]. We show some experimental results and give a discussion about those.

2 Color Vision Model

First of all, we show a normal vision model based on the stage theory in Fig. 1, which is an equivalent circuit to explain the phenomena on color vision. In this figure, R, G and B denote cones that produce output signals depending on input stimuli. The output signals from cones produce a Luminance signal L through a unit denoted as V, and two opponent color signals, $\mathrm{C_{rg}}$ and $\mathrm{C_{yb}}$ through opponent processes denoted by r-g and y-b via intermediate units r and y. Here the function proposed by Smith and Pokorny [5] is used as the cone sensitivity function in Eq.(1), where $\overline{\mathrm{x}}(\lambda)$, $\overline{\mathrm{y}}(\lambda)$ and $\overline{\mathrm{z}}(\lambda)$, are the color matching functions.

$$\begin{pmatrix} \mathrm{S_r}(\lambda) \\ \mathrm{S_g}(\lambda) \\ \mathrm{S_b}(\lambda) \end{pmatrix} = \begin{pmatrix} 0.15514 & 0.54312 & -0.03286 \\ -0.15514 & 0.45684 & 0.03286 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \overline{\mathrm{x}}(\lambda) \\ \overline{\mathrm{y}}(\lambda) \\ \overline{\mathrm{z}}(\lambda) \end{pmatrix} \tag{1}$$

L, $\mathrm{C_{rg}}$ and $\mathrm{C_{yb}}$ in Fig. 1 are obtained by Eq.(2), which is derived from a linear combination of cone sensitivity functions given by Eq.(1) with a suitable normalization and rounding off small fractions for simplicity.

$$\begin{pmatrix} \mathrm{C_{rg}}(\lambda) \\ \mathrm{C_{yb}}(\lambda) \\ \mathrm{L}(\lambda) \end{pmatrix} = \begin{pmatrix} 2.00 & -2.00 & 0.00 \\ 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 \end{pmatrix} \begin{pmatrix} \overline{\mathrm{x}}(\lambda) \\ \overline{\mathrm{y}}(\lambda) \\ \overline{\mathrm{z}}(\lambda) \end{pmatrix} \tag{2}$$

Next, we show an anomalous vision model [3], in which some units and channels in the normal vision model are partially changed. First, in the model of "protan", the normal cone R changes to an abnormal one R′, which changes the

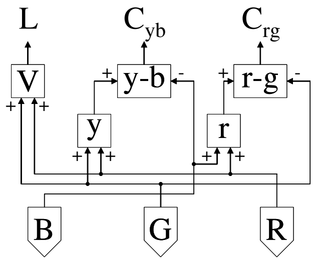


Fig. 1. A normal vision model

channel from R and the output from R′ goes only to r as shown in Fig. 2(a). Because the output signal from R′ is very weak and fragile, we can explain the phenomena of "protan" without contradiction to medical knowledge. In Fig. 2(a), the parameter $K_P (0 \leq K_P < 1)$ denotes the degree of color weakness. The case $K_P = 0$ corresponds to a complete "protanopia", $K_P > 0$ does to a "protanomalia". (The case $K_P = 1$ means the hypothetical "protan" who has an anomalous cone but a perfect hue discrimination capability like normal ones.) The opponent signals $\mathrm{C_{rg}}$ and $\mathrm{C_{yb}}$ and the luminance one L are obtained by

$$\begin{pmatrix} \mathrm{C_{rg}}(\lambda) \\ \mathrm{C_{yb}}(\lambda) \\ \mathrm{L}(\lambda) \end{pmatrix} = \begin{pmatrix} 0.252K_P & -0.203K_P & -0.011K_P \\ -0.155 & 0.457 & -0.251 \\ -0.155 & 0.457 & 0.033 \end{pmatrix} \begin{pmatrix} \overline{\mathrm{x}}(\lambda) \\ \overline{\mathrm{y}}(\lambda) \\ \overline{\mathrm{z}}(\lambda) \end{pmatrix}, \tag{3}$$

where the coefficients are derived from numerical experiments. Similarly, in the model of "deutan", the normal cone G changes to an abnormal one G′, which changes the channel from G and the output from G′ goes only to r-g as shown in Fig. 2(b). In this figure, the parameter $K_D (0 \leq K_D < 1)$ denotes the degree of color weakness. The case $K_D = 0$ corresponds to a complete "deutan", $K_D > 0$ does to a "deuter anomalopsia". (The case $K_D = 1$ means the hypothetical "deuteranopia".) The output signals $\mathrm{C_{rg}}$, $\mathrm{C_{yb}}$ and L are obtained by

$$\begin{pmatrix} \mathrm{C_{rg}}(\lambda) \\ \mathrm{C_{yb}}(\lambda) \\ \mathrm{L}(\lambda) \end{pmatrix} = \begin{pmatrix} 0.105K_D & -0.132K_D & 0.020K_D \\ 0.155 & 0.543 & -0.969 \\ 0.155 & 0.543 & -0.033 \end{pmatrix} \begin{pmatrix} \overline{\mathrm{x}}(\lambda) \\ \overline{\mathrm{y}}(\lambda) \\ \overline{\mathrm{z}}(\lambda) \end{pmatrix}. \tag{4}$$

We can simulate the anomalous color vision by using Eq.(3) and (4) and the inverse transformation of Eq.(2). That is, first we input RGB signals into the anomalous color vision model and output the corresponding $\mathrm{C_{rg}}$, $\mathrm{C_{yb}}$ and L signals. Then we input them from the output-side of Fig. 1, and transform them to RGB signals by the inverse transformation of Eq.(2).

Through this calculation, we can obtain the colors that the anomalous vision people may observe. If two colors obtained through this process are similar (close to each other), we can judge that it might be a hard combination of colors for anomalous vision people. When we select a number of color pairs, which are hard to recognize the difference for anomalous vision people, and plot them on

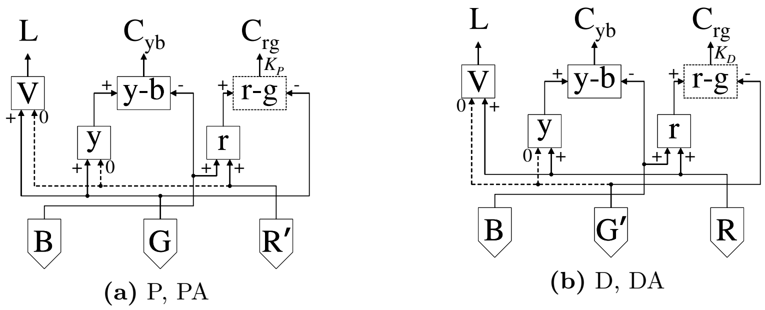


Fig. 2. Models of anomalous vision

Table 1. Chromaticity coordinates for protanopic and deuteranopic convergence points

	x	y
Protanopic	0.7465	0.2535
Deuteranopic	1.4000	-0.4000

the chromaticity diagram, they tend to be on some straight lines. Such lines obtained are called "confusion lines" and they converge to a point called "convergence point" of confusion lines. This unique point is experimentally obtained and several values have been so far proposed. In this paper, we adopt the results proposed by Smith and Pokorny [5].

3 Abstracted Image Model and Color Modification

3.1 Abstracted Image Model

We consider a color image as a combination of several color regions, each of which contains similar colors in it. In this paper, we call a color image, which is divided into several regions with colors, as the abstracted image model as shown in Fig. 3. In this model we can define some relations between regions as follows. We define "included" as the relation that a region completely contains another region (regions). The region containing a region is called "parent region" and the region included by the "parent region" is called "child region". In Fig. 3, since region D contains F, we describe this relation as

$$D \supset F. \tag{5}$$

On the other hand, we define "even" as the relation in which two regions have a same "parent" region. Note that the outside of an image can be considered as the "parent" region. In Fig. 3, since regions D and E are "even" with each other, we describe this relation as

$$\{D, E\}. \tag{6}$$

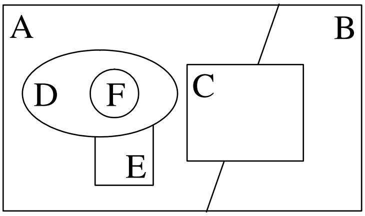


Fig. 3. An example of the abstracted image model

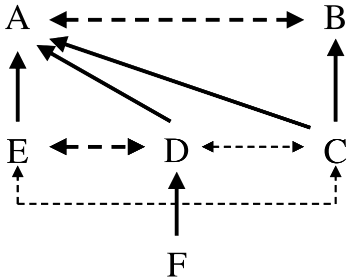


Fig. 4. Mutual color relations to be considered

These "included" and "even" relations are often satisfied inter-regionally. For example, since the region A contains two regions D and E, which are "even" with each other, we can describe $A \supset \{D, E\}$. As another example, since both regions A and B contain region C, we can describe $\{A, B\} \supset C$. Therefore, we can describe the entire relations in Fig. 3 as

$$\{\{A \supset \{\{D \supset F\}, E\}\}, B\} \supset C. \tag{7}$$

3.2 Color Modification for Divided Regions

When we human beings recognize regions by using colors, we make use of color difference between regions. Because in case of "included" and "parent" region and its "child" region are neighbors with each other, it could be easier for us to recognize the boundary if we enhance the color difference between regions. In case of "even", we can make the boundary more recognizable by enhancing color difference between regions but we should additionally consider the distance between regions. That is, the necessity to enhance the color difference between "even" regions varies depending on the distance between regions. We depict the graph which shows mutual color relations to improve the recognizability of Eq.(7) in Fig. 4. The solid and broken lines denote "included" and "even", respectively. And bold line shows the necessity of color difference enhancement between regions. In this paper, we modify all colors of regions by considering such mutual color relations in the image in order to obtain more recognizable color combinations for anomalous vision users.

3.3 Applying the Abstracted Image Model to Web-Pages

Let us consider the application of the abstracted image model to web-pages described by the HTML markup language. In the HTML description we can specify colors for a background, characters, part of characters, figures, tables, and so on. The background and characters on it have an "included" relation between them. Also, two different colors of characters have an "even" relation. Since the background should be "parent" region and the characters on the background should be "child" regions of it, the "child" regions have a single "parent" region and might not be contained in multiple "parent" regions. In this case, since the "child" region (a color of characters) is being neighbors with the "parent" region (a color of background), we enhance the color difference between them in order to make a given web-page more recognizable. In case of "even" we should consider mutual color relation between characters, a portion of characters has a different color from the color of other characters, for example, for specifying a linkage function to users. In this case, we enhance the color difference between two colors in characters. We should consider balancing the weight for color modification between "included" and "even" cases.

When we enhance the color difference in HTML description, we should consider the controllable range of it. Because we specify the colors to be used with RGB color space and the dynamic range of (R, G, B) signals are limited to 0-255, we can not describe all colors in the chromaticity diagram [6]. Also, since (R, G, B) signals must be positive, the colors which can be displayed are limited to a narrow range when the lightness of the color is low or high. In this paper, we distinguish the color into lightness and spectral colors, and separately evaluate them for optimization.

The number of colors used in the entire web-page could be an important parameter when we optimize to modify all colors in it. In general, the mutual color relations to be considered increase as the number of colors n increases. Thus in this paper we use Genetic Algorithm (GA) [4] to solve the complex color modification problem.

4 Color Modification with Genetic Algorithm

4.1 Individual Representation

We try to generate the optimum color vector $(C_1^*, C_2^*, \cdots, C_n^*)$ for the original color vector $(C_1, C_2, \cdots, C_n)$ in terms of making the web-page more recognizable for anomalous vision users. To accomplish this purpose we design the individual which has all n kinds of color information in it. However, the amount of information an individual has becomes large, which enlarge the solution space and thus the search speed might be deteriorated remarkably. We can specify mutual color relations in the HTML description by analyzing the scanned web-page. Thus we divided the entire solution space into n sub-spaces for each color $C_i (i = 1, 2, \cdots, n)$. Therefore, each individual is described with 24 bits binary representation (8 bits for each (R, G, B) component). (The way of evaluation by considering mutual color relations will be mentioned in 4.3.)

4.2 Design of Fitness Functions

We design the function that can evaluate a fitness value between the color represented by an individual and a basis color C_B. We achieve the evaluation in the Luv perceptually uniform color space [6]. Here we denote the color represented by an individual as $C = (L, u, v)$ and its filtered one by the computer simulation of anomalous vision as $C' = (L', u', v')$. Similarly, we denote the basis color and its filtered one by the computer simulation of anomalous vision as $C_B = (L_B, u_B, v_B)$ and $C'_B = (L'_B, u'_B, v'_B)$ respectively. Also, we denote the original color and its filtered one as $C_O = (L_O, u_O, v_O)$ and $C'_O = (L'_O, u'_O, v'_O)$ respectively. Also, we define a normalized spectral color difference between two colors C_x and C_y in Luv color space as

$$d_{(C_x,C_y)} = \frac{\sqrt{(u_x - u_y)^2 + (v_x - v_y)^2}}{d_{max}}, \tag{8}$$

where d_{max} is the maximum color distance in Luv space. Furthermore, we define a normalized lightness difference between two colors as

$$b_{(C_x,C_y)} = \frac{|L_x - L_y|}{b_{max}}, \tag{9}$$

where b_{max} is the maximum brightness in Luv space.

(1) Weighting Coefficient between Spectral Colors and Brightness. As described in 3.3 it is difficult to control the color difference with spectral colors when the lightness of the color is low or high. In this case, we stress on the lightness enhancement. On the other hand, when the lightness of the color is medium, we stress on color difference enhancement with spectral colors. In this paper, we define the weighting coefficient $\alpha (0 \leq \alpha \leq 1)$ between spectral colors and brightness as a function of L'_B. We designed $\alpha(L'_B)$ such that $\alpha(L'_B) \approx 0$ as L'_B is low or high and $\alpha(L'_B) \approx 1$ as L'_B is intermediate.

(2) Evaluation for Spectral Colors. We positively evaluate the color difference $d_{(C',C'_B)}$ between C' and C'_B obtained through the simulation of anomalous vision, but negatively does the difference $d_{(C,C_O)}$ between $C$and C_O in order to keep the original colors as possible as we can. Thus in this paper we use the following function to evaluate the color C represented by an individual

$$f_c = d_{(C',C'_B)} \left[1 - \left\{ d_{(C,C_O)} \right\}^{g_c\left(d_{(C'_O,C'_B)}\right)} \right], \tag{10}$$

where $g_c\left(d_{(C'_O,C'_B)}\right)$ is a constraint function on the original spectral colors. The constraint gradually increases as g_c approaches to 0.

(3) Evaluation for Brightness. We evaluate the brightness of the color properly to control it depending on the brightness of C'_B and the brightness difference between C and C_B by

$$f_b = b_{(C',C'_B)} \left[1 - \left\{ b_{(C,C_O)} \right\}^{g_b\left(b_{(C'_O,C'_B)}\right)} \right], \tag{11}$$

where $g_b\left(d_{(C'_O,C'_B)}\right)$ is a constraint function on the original brightness. The constraint gradually increases as g_b approaches to 0.

(4) Combined Fitness function. We combine two evaluation functions f_c(Eq.(10)) and f_b(Eq.(11)) with the weighting coefficient α as

$$f = \alpha f_c + (1 - \alpha) f_b. \tag{12}$$

With this equation, we finally evaluate the color represented by an individual C and the basis color C_B.

4.3 Evaluation Method by Considering Mutual Color Relations

Each color $C_i (i = 1, 2, \cdots, n)$ has some mutual color relations with other colors in $(C_1, C_2, \cdots, C_n)$ obtained by scanning a HTML web-page data such as "included" and "even" as described in 3.1. Thus we should construct an evaluation method such that we can consider such mutual relations in colors. Fig. 5 shows the way of mutual evaluation method between two colors C_1 and C_2. Although C_1 and C_2 should be determined by considering their partner colors, both colors will be changing (evolving) along with the alternation of generations by GA. In the proposed scheme, the individuals in the population P_1 for the determination of C_1 are evaluated with the best individual $C_2^{*(t-1)}$ by $(t-1)$-th generation in the population P_2 for the determination of C_2. Note that the best individual in P_1 at $(t-1)$-th generation, $C_1^{*(t-1)}$, is re-evaluated with $C_2^{*(t-1)}$ and we determine the best individual $C_1^{*(t)}$ among the individuals in $P_1^{(t)}$ and $C_2^{*(t-1)}$. Similarly, the individuals in the population P_2 for the determination of C_2 are evaluated with the best individual $C_1^{*(t-1)}$. When a color has more than two relations, the fitness values for multiple basis colors are averaged. In this way the proposed scheme synchronizes to evolve all the evolution of the populations $P_i (i = 1, 2, \cdots, n)$ corresponding to the colors $C_i (i = 1, 2, \cdots, n)$ generation by generation. Finally, the best individuals $(C_1^*, C_2^*, \cdots, C_n^*)$ collected from fully matured populations are output and displayed as the modified colors.

4.4 Genetic Operators in GA

In the proposed scheme we employ an improved GA (GA-SRM) [7,8] to achieve efficient and reliable optimization. GA-SRM uses two kinds of cooperative and competitive genetic operators and combines them with an extinctive selection method. It has been verified that this framework is quite effective for 0/1 multiple-knapsack problems [7,8], NK-Landscape problems [9,10], and image halftoning problems [11,12]. In this paper, we follow the basic framework of GA-SRM. That is, we create offspring with CM (Crossover and serial background Mutation) and SRM (Self-Reproduction with Mutation) operators in parallel. Their offspring compete for survival through (μ, λ) proportional selection [13]. We adopt one-point crossover and background mutation with the mutation probability $P_m^{(CM)}$ for CM. On the other hand, for SRM we adopt ADP (Adaptive Dynamic Probability) mutation strategy [7] which adaptively reduces the mutation probability $P_m^{(SRM)}$ depending on a mutants survival ratio.

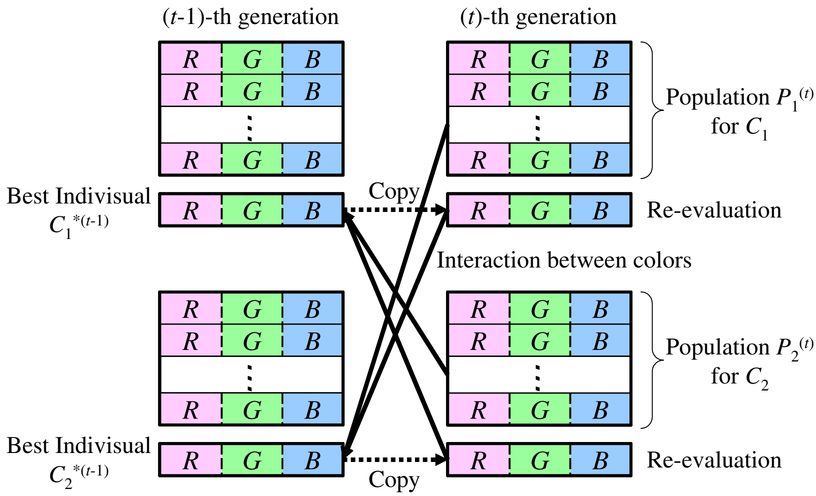


Fig. 5. Mutual evaluation method between two colors

5 Experimental Results and Discussion

In this paper, we use the following functions as $\alpha(L'_B)$, g_c and g_b. The parameters in these equations are experimentally determined.

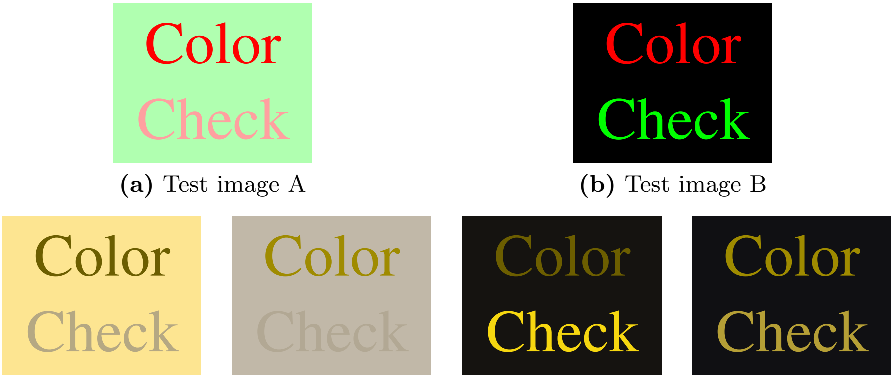
$$\alpha(L'_B) = 0.1 + 0.65 \left\{ 0.5 \cos \left(\frac{|L'_B/b_{max} - 0.5|}{0.5} \pi \right) + 0.5 \right\} \tag{13}$$

$$g_c \left(d_{(C'_O, C'_B)} \right) = 0.6 \left\{ 0.7 \left(1 - d_{(C'_O, C'_B)} \right) + 0.3 \right\} \tag{14}$$

$$g_b \left(b_{(C'_O, C'_B)} \right) = 2 \left\{ 0.7 b_{(C'_O, C'_B)} + 0.3 \right\} \tag{15}$$

First, we prepared two kinds of test images (image A and B) described with HTML markup language as shown in Fig. 6(a) and (b). In these examples, we can describe the color relations as $C_1 \supset \{C_2, C_3\}$ with a background color C_1, and two kinds of colors for characters C_2 and C_3. First we show the results through the computer simulation of anomalous color vision [3] in Fig. 6(c)$\sim$(f), where the degree of color weakness, K_P and K_D, are set to 0. We can consider these images as the color appearance observed by anomalous vision people. We can see that the colors in all images are deteriorated and it becomes hard to recognize the characters from the background and between set of characters.

Next we show the results after applying the proposed scheme to the test images in Fig. 7. Here we set the weight between "included" and "even" relations to 2:1 and use the genetic parameters in Table 2. In Fig. 7, we show the images with modified colors and their appearance through the computer simulation of anomalous color vision. Compared with the ones without modification in Fig. 6, we can see that color differences are enhanced, and becomes more recognizable



(a) Test image A **(b)** Test image B

(c) Appearance of anomalous vision (protan, image A) **(d)** Appearance of anomalous vision (deutan, image A) **(e)** Appearance of anomalous vision (protan, image B) **(f)** Appearance of anomalous vision (deutan, image B)

Fig. 6. Test images and their appearance through computer simulation of anomalous color vision

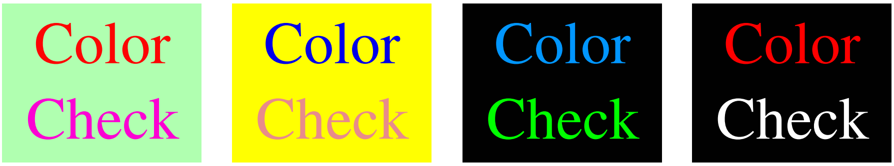
Table 2. Genetic parameters of GAs

	cGA	GA-SRM
Crossover ratio P_c	0.6	1.0
Mutation ratio P_m	$\frac{1}{24}$	$P_m^{(CM)} = \frac{1}{24}$ $P_m^{(SRM)} = \left[\frac{1}{8}, \frac{1}{24}\right]$ [7,8]
Selection method	Proportional selection (μ, λ)Proportional selection	(μ, λ) Proportional selection
Population size N	64	64
Evaluation numbers T	128,000	128,000

(distinguishable) the characters from the background and between set of characters by our scheme. It could be an evidence that the fitness functions designed in 4.2 are working effectively.

Next we show the evolution of solutions achieved by GA-SRM in Fig. 8(a). The figure also shows results by cGA (canonical GA) and GA(μ, λ) (cGA with (μ, λ) proportional selection but no parallel varying mutation). These plots are averaged over 100 random runs. From this figure we can see that GA-SRM can generate a high-fitness solution with less evaluation times compared with other configulations. Also we depict the standard deviation σ around the average of 100 runs corresponding to Fig. 8(a) in Fig. 8(b). We can see that the standard deviation attained by GA-SRM is very small and we can achieve reliable solution search with GA-SRM.

Furthermore, we conducted psychological experiments with the cooperation of actual anomalous vision people (a protan, a protanomalia, a dutan and a duteranopia, totally 4 examinees). We prepared 15 sample pages including two colors (a background color and a character color) and 16 samples with three col-

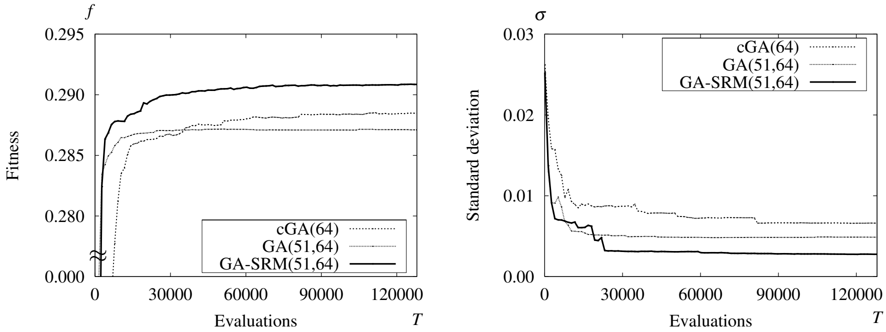


(a) Output image with modified colors (protan, image A)
(b) Output image with modified colors (deutan, image A)
(c) Output image with modified colors (protan, image B)
(d) Output image with modified colors (deutan, image B)

(e) Appearance of anomalous vision for (a) (protan)
(f) Appearance of anomalous vision for (b) (deutan)
(g) Appearance of anomalous vision for (c) (protan)
(h) Appearance of anomalous vision for (d) (deutan)

Fig. 7. Output images with modified colors and their appearance through computer simulation of anomalous color vision

ors (a background color and two character colors). All pages have different color combinations. We showed two pages for each sample to the examinee, one was the original page and the other was its modified one by the proposed scheme. The original and its modified page were randomly displayed on the right-hand side or left-hand side on the screen. To avoid that the examinees expect either one to be surely recognizable from another one, we randomly included some dummy pages, in which both pages were the same (no change). We asked examinees which page is recognizable or even, and how recognizable (somehow/remarkable) in case the examinee chose either one. We keep score as follow: 0 point to even, +1 point to somehow recognizable for the modified page, +2 points to remarkably recognizable for modified page, -1 point to somehow recognizable to the original page, and -2 points to remarkably recognizable to the original page. Finally, we sum up all points for all sample pages to measure the color recognizability improvement. The obtained results are shown in Table 3. It can be seen that around +1.0 points are obtained for achromatopsia examinees ($K_P = K_D = 0$) in average and a positive points (around +0.7) obtained for dyschromatopsia ones. The reason why lower points were obtained for the latter case is that some original pages without modification can be recognizable for dyschromatopsia examinees. In general, the effect of color modification increases as the font size decreases. This is becasue it is sometimes very hard even for normal color vision people to distinguish the color of small font characters on a background color. Also, we can see the improvement is slightly deteriorated in case of three colors, which is mainly caused by a compromise between mutual color relations. Nevertheless, we have never scored negative point for the modified page for all samples and achieved a positive +0.85 points as the entire average. Therefore, we can



(a) Fitness **(b)** Standard deviation

Fig. 8. Performance achieved by cGA and GA-SRM

Table 3. Results by psychological experiments with actual anomalous vision people

type	protan	protanomalia	deutan	deuteranomalia
Two colors (10pt)	+1.23	+0.83	+1.10	+0.83
Two colors (12pt)	+1.20	+0.87	+1.13	+0.77
Two colors (18pt)	+1.10	+0.37	+1.03	+0.77
Two colors (Average)	+1.18	+0.69	+1.09	+0.79
Three colors (10pt)	+0.88	+0.94	+0.84	+0.72
Three colors (12pt)	+0.94	+0.84	+0.78	+0.63
Three colors (18pt)	+0.88	+0.22	+0.91	+0.59
Three colors (Average)	+0.90	+0.67	+0.84	+0.65
Total average	+1.03	+0.68	+0.96	+0.72

say that the proposed scheme successfully modifies colors on web pages to more recognizable ones for anomalous vision users.

6 Conclusions

In this paper, we have proposed a color modification scheme for web-pages described by HTML markup language in order to realize barrier-free color vision on the internet. We solved the color modification problem, which contains complex mutual color relations, by using an improved Genetic Algorithm (GA-SRM). Through computer simulation and psychological experiments we verified that the proposed scheme can make the colors in a web-page more recognizable for anomalous vision users. The proposed scheme can be implemented in web servers or PCs on the internet. With these options, because all web pages that transit our system will be displayed after color modification, anomalous vision users can always view recognizable pages.

As future works, we should further investigate on the implementation aspects of this scheme. Also, we are planning to extend this scheme which can modify colors in any kind of color images, such as natural images, to further realize barrier-free color vision in the internet society.

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