A Color Contrast Algorithm for E-learning Standard

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Summary
IMS consortium's accessibility standards for E-learning do not provide a clear definition and testing standards for color contrast, or recommendations on how to provide sufficient color contrast for people with learning disorders or color blindness. W3C released working draft of Web contents accessibility guideline 2.0 in November 2005. Guideline 1.4 in this guideline is showing a difference from the evaluation algorithm of the foreground color against the background color suggested in testing item 2.2 regarding accessibility evaluation and techniques of repair tools. In this research, we evaluate the appropriateness of both standards, and propose a new color contrast algorithm utilizing color temperature, which was a factor not considered in either of the standards in the W3C guideline. For clinical evaluation of the color contrast algorithm, a test was performed on 87 normal people in their 20's, and 10 children diagnosed with a learning disorder marked by sensitivity to color contrast, using 216 web safe colors. The results of the test were that proposed algorithm is superior to the existing algorithms with respect to the linearity of relationship between color contrast and readability rating. and that the group with the learning disorders required a higher contrast for securing readability than the normal.

Key words:
E-learning, Color contrast, Color temperature, Learning disorders, Accessibility, Readability

1. Introduction

Adoption of graphical user interfaces and content with a large variety of color is increasing rapidly not only in desktop computers but also in portable digital IT equipments such as mobile phones, PDAs and many other such devices. The move from WML to XHTML as a wireless internet programming language and the emergence of wibro and DMB phones are contributing to this trend. Users of portable display equipment are having more difficulty than desktop computer users in recognizing the contents due to the smaller size of their displays. The average user's eyesight is also rapidly degrading due many other factors, such as young people's excessive TV watching, increased time spent playing computer games and using the internet, making presbyopia and eyesight degradation prevalent not only among the older population but also in the middle aged population. Hindrance of image readability due to the colors of display equipment degrades the readability not only of graphic information but also text information, and it gets worse as the size of the characters gets smaller[1,2]. The accessibility issue due to colors can be classified by cause and shows different symptom by individual. But the common symptom is that low color contrast is the major reason for a degradation in readability.

So many e-leaning standards exist, yet standards for accessibility are rare[3]. Though the IMS standard, which includes accessibility, provides meta data, information models and accessibility guidelines supporting accessibility, it does not provide a standard for color contrast[4-6]. Therefore, we have no choice but to use the W3C standard for color contrast. For web documents, web content accessibility guideline 1.0 of the W3C Web Accessibility Initiative stipulates that HTML documents must be more accessible. Testing point 2.2 of guideline 2 stipulates that there should be enough contrast between the foreground color and the background color when viewed on a black and white screen and by people with color blindness[7]. Testing item guideline 1.4 of the draft web content accessibility guideline 2.0 released in November stipulates that the background image should be easily distinguished from the foreground information on sound, guideline 1.4.1 level 2 prescribes a minimum luminosity contrast ratio of 5:1, guideline 1.4.2 level 3 prescribes a minimum luminosity contrast ratio of 10:1[8]. Testing item 2.2 on accessibility evaluation and repair tool techniques recommends the use of backgound and text colors with a hue difference and luminosity difference greater than 125 and 500 respectively, in color contrast algorithm of A-prompt, University of Toronto's web accessibility evaluation and repair tool[9].

As Ridpath, who researched color contrast algorithm of A-prompt recognized, the color contrast standard in the W3C's accessibility evaluation and the draft repair tool is insufficient. He argued that there are other factors influencing readability, and reported cases where color combinations thought to have a large luminosity and hue difference according to the presented algorithm received low scores from test subjects, as well as cases where color combinations thought to have a very low luminosity

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and hue difference according to the presented algorithm earned a high reception from more than a few test subjects, He added that a very large hue difference causes insufficiency, degrading readability[10]. The algorithm proposed in his research did not use saturation, one of 3 color elements, and disregarded the contrast between warm colors and cold colors, one of the most robust elements in color psychology for color distinction. Thus, testing item 2.2 guideline in the W3C accessibility evaluation and repair tool technique is in great need of enhancement. Additionally, both test standards are mainly designed for desktop users, and thus may not be suitable for users of portable wireless internet terminals with much smaller displays. In this paper, we will first research and study through literature what relation the existing W3C color contrast evaluation standard has to color disorders due to color recognition deficiencies. Second, we will research and compare the existing color contrast evaluation algorithm, and through a clinical test on the combination of 216 web-safe colors, we will compare the differences and evaluate the algorithm's appropriateness. Though the color contrast standard depends on the target, the validity of a standard setup is important. However, studies that compared and evaluated validity were not found in this research. Third, we will attempt to propose a new color contrast algorithm, which complements the existing color contrast evaluation algorithm's weaknesses by considering the concept of color temperature emphasized in color psychology, and validate its appropriateness through clinical tests on a group of normal people and a group of children diagnosed with learning disorders.

2. The existing color contrast evaluation algorithm

In recognizing information which includes colors in a document, the contrast of one color against another imposes more influence on the process than the recognition of individual colors. Arditi proposed a document writing guideline which included three element of colors such as hue, luminosity and saturation to provide effective color contrast for web content[11]. But the guideline he provided is written in qualitative language, making it unusable for quantitatively evaluating the color combinations on web pages, as well as difficult to make a clear decision based on his writing.

Studies on the readability of web documents based on their background color and text color are rare. Hill and Schaff in their study presented the idea that high color contrast increases readability, though this relationship is not definite[12]. That is, yellow or black text on a light grey background showed better readability than black text on a white background. Research that quantitatively generalized the relationship between color contrast and readability include the research carried out by Ridpath at University of Toronto while studying A-prompt (a web accessibility evaluation repair tool), and the research performed by Vanderheiden at Trade Center, who developed the algorithm adopted in the draft WCAG 2.0. The evaluation algorithm proposed by Ridpath and others were adopted in testing item 2.2 for W3C's accessibility evaluation and repair tool technique. They defined color contrast based upon YIQ color space used in the NTSC television standard, divided color contrast into 7 stages regarding 216 web safe colors based on luminosity difference and hue difference, presented web pages to the users with combinations of 42 different background colors and text colors, and collected user's evaluations of their readability. The collected result was in line with the general theory that readability increases with color contrast when color contrast samples are prepared based on differences of luminosity and hue. However, a considerable number of users responded that the samples with a low color contrast were of good readability, and stages with a large selection change existed. As they conceded themselves in the study result, quantitative definitions of color contrast are insufficient in terms of readability and show considerable inconsistency in tests on users[10, 13].

Ridpath defined difference in brightness and hue as in formulae (1) and (2) respectively. Yet they did not make it clear how they reflected the difference in brightness and hue into the overall color contrast when classifying color contrast into 7 stages.

$$b_d = (299\,ABS\,(R_{text} - R_{back}) + 587\,ABS\,(G_{text} - G_{back}) + 114\,ABS\,(B_{text} - B_{back}))/1000 \quad (1)$$

In this formula, ABS is a function to yield absolute value and gets a value in the range of 0 to 255. Blue color is given much lower recognition brightness, while red color has a medium brightness. After figuring out the recognition brightness of the background and the text, the difference between the two values was used to determine the difference in brightness. Another standard defining the difference in brightness is Michelson's definition, and in this standard the difference in brightness between background and text divided by the sum of their brightness was used. The following algorithm was used to determine the difference in hue.

$$h_d = ABS(R_{text} - R_{back}) + ABS(G_{text} - G_{back}) + ABS(B_{text} - B_{back}) \quad (2)$$

In formulae 1 and 2, represents the red, green and blue elements of text color respectively while represents the red, green and blue elements of the background color. is a value between 0 and 765, with 0 meaning no difference in hue and 765 meaning the biggest difference in hue. In this computation, all values are to be rounded up.

Guideline 1.4 in the draft web contents accessibility guideline 2.0 released in November 2005 is necessary to make it easy to distinguish foreground information from background pictures and sounds. In this guideline, the algorithm used to decide the contrast between background and foreground is Luminosity Contrast Ratio as defined in formulae 3 and 4, and this algorithm was developed by Gregg Vanderheiden at Trade Center and Dave Kelso, as well as by visionary artist Aries Arditi at Lighthouse. LCR is defined as follows.

$$LCR = (L1 + 0.05)/(L2 + 0.05) \tag{3}$$

$$L = 0.2126R^* + 0.7152G^* + 0.0722B$$
$$where\, R^* = (R/FS)^{2.2}, G^* = (G/FS)^{2.2}, B^* = (B/FS)^{2.2} \tag{4}$$

In this formula, L1 and L2 mean a high LCR and a low LCR respectively. Therefore, no difference is made, regardless of whether a combination of the same colors is used for background or for text. FS means the overall scale, and has the value 255 in an 8 bit channel. One of advantages of this guideline is that it can be read with ease, as in WCAG 1.0, and presents a quantitative standard rather than ambiguous terms. In the discussion on the issue of visual and acoustic contrast, Arditi admitted no effective test is available for hue and color contrast, suggesting that the reason why is that the diversity of display equipment and hardware (maximum brightness, entire range of hue and linearity) and the variety of user requirements (indoor lighting, degree of reflected light) are so large that it is impossible to create a standard disregarding this variety in user requirements at the moment. Nonetheless, he did not provide any proof for disregarding AERT's hue contrast standard. Readability has the required LCR changed depending on the font size, so presenting a comprehensive two stage value without providing a quantitative LCR corresponding to font size and type can be seen as a presentation of an insufficient standard.

3. Color contrast evaluation algorithm and consideration of color temperature

Generally, measuring color contrast according to color temperature is known to be one of the most robust methods. Yet the way one defines cold colors and warm colors is different depending on the individual. The first person to classify colors as warm or cold was Hyater, an artist from UK. In 1813, he made a classification in an introduction on perspective as shown in Fig 1.

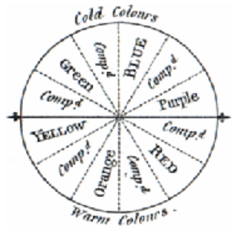

Fig. 1. cold/warm color circle by hyater

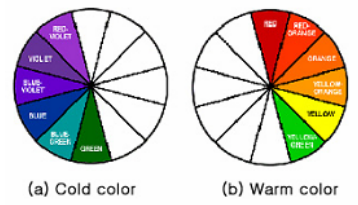

Fig. 2. cold/warm color circle by shaw

According to psychological processes, red or orange colors feel warm, and blue or green colors feel cool. As in Fig 2, if you divide the color circle with a straight line connecting yellowish green and purple, the half circle on the right side includes warm colors and the half circle on the left side is filled with cool colors. When the hue is the same, bright colors look cooler than dark colors. If colors are arranged on a plane, warm colors look projected while cooler colors look to be retreating. Projected colors look swollen while retreating colors look contracted. However this color circle does not match with any standard color circle of modern color system. Moreover, yellow Green was classified as a cold color in Hyater's color circle, while it was classified as a warm color in Fig. 2. In Rigden's web-safe color classification, even green is classified as a warm color[14]. Though the classification into cold or warm colors depends on the purpose of the classification, most of the difference is found in colors existing around the border of division. In this research, boundary colors such as green or pupple with a unclear color sense are classified as middle colors, while relative color sense is not taken into consideration and the 216 web-safe colors are divided simply into cold, warm and medium colors.

The classified color temperature is applied into the color contrast evaluation algorithm of the document containing colors, and color contrast is defined as the sum of hue contrast, luminosity contrast and temperature contrast. Color contrast can be expressed as in Fig. 5. In this formula, c, w and m are constants representing cold color, warm color and medium color respectively.

$$\begin{aligned}
&\text{if (temperature of Text_color = 'w' and temperature of background_color = 'c') or}\\
&\quad\text{(temperature of Text_color = 'c' and temperature of background_color = 'w') then } \widehat{t}_d = 1\\
&\text{else if (temperature of Text_color = 'w' and temperature of background_color = 'm') or}\\
&\quad\text{(temperature of Text_color = 'm' and temperature of background_color = 'w') or}\\
&\quad\text{(temperature of Text_color = 'c' and temperature of background_color = 'm') or}\\
&\quad\text{(temperature of Text_color = 'm' and temperature of background_color = 'c') then } \widehat{t}_d = 0.5\\
&\quad\text{else } \widehat{t}_d = 0;
\end{aligned} \qquad (5)$$

Different from hue contrast which has various values, color temperature contrast was made to have a value of 1 for the contrast between absolutely cold colors and absolutely warm colors, a value of 0.5 for the contrast between cold colors and medium colors or the contrast between warm colors and medium colors, and the a value of 0 for the contrast between rest, imposing great influence on overall color contrast. In this research, we made our definition as in the overall color contrast formula 6, applying weight to control the influence.

$$t\widehat{c}_c = (\widehat{h}_d + \widehat{b}_d + \alpha\widehat{t}_d)/3 \qquad (6)$$

In this formula, we set it up with an initial value of 1/3. The quantification of temperature contrast gets more difficult as we subdivide colors. Temperature contrast is expression of psychological perception, and it is different from the general definition of color temperature, meaning the radiation energy of light source needed to show a certain color. Generally, red colors show a low temperature and blue colors a high temperature, however, in psychological color sense, red colors are expressed as warm and blue colors as cold. Though this research classified 216 web safe colors into cold, warm or medium colors, if applied to all colors expressed over 16 bits, a significant number of ambiguous judgments can be made. Additionally, this kind of color sense is very non-linear when expressed in R, G, B.

4. Clinical test and evaluation

4-1. Evaluation of satisfaction frequency for the existing W3C algorithm

In total, 46656 combinations of web-safe colors are possible. With regards to the difference of hue and brightness defined in formula 1 and 2, testing item 2.2 of W3C AERT stipulates that color contrast without any problems in readability could be provided if there is a hue difference of more than and a luminosity difference of over 125 between the background color and the text color. The evaluation was carried out with this standard applied to the combination of web-safe colors. Out of 46656 color combinations of 216 web-safe colors, most color combinations proved not to provide enough color contrast, with 94.7% of colors not conforming to the standard. The application of this kind of standard severely limits the selection opportunities of web designers. Frequency of difference in brightness and hue is indicated in Fig. 3.

(a) (b)

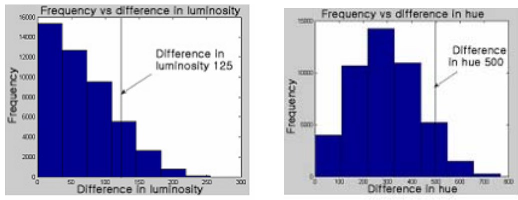

Fig. 3. Frequency of combination of web-safe colors about W3C AERT's difference in brightness and hue

W3C WCAG 2.0's luminosity contrast ratio is defined to be a minimum of 5.0 at level 2 and a minimum of 10.0 at level 3. The AERT standard limits the selection of most colors by regulating hue difference to be over 500 while WCAG standard strengthens the luminosity difference and disregards the hue difference. Nonetheless, the percentage color combinations with a luminosity contrast ratio of below 5.0 is 85.3% and the percentage below 10.0 is 97.1% and so if level 2 is selected, the opportunity for color selection is expanded somewhat. WCAG LCR frequency of web-safe color combinations is shown in Fig. 4. As both standards are making a negative judgment about color combinations, a limited color combination should be used to meet these standards, limiting the designer's possibilities for color selection.

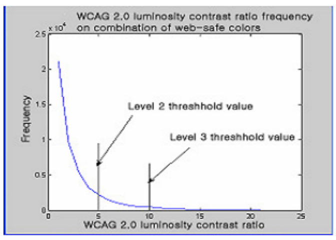

Fig. 4. WCAG 2.0 luminosity contrast ratio frequency on combination of web-safe colors

4-2. Readability evaluation test for color contrast

This test evaluated the color contrast effect on the readability of documents provided over the web. We classified the 46656 color combinations of web documents with each of the 216 text and background colors into document samples of 7 stages according to the degree of color contrast by applying a new color contrast algorithm that quantifies the existing W3C algorithm and color temperature, and applies it to color contrast. This test was carried out by checking the degree that users could read a total of 42 sample documents provided to test participants. The test evaluation program was written in visual basic and made downloadable from the web server to be installed on each user's computer before the test was conducted.

4-2-1. Test method

87 students of both genders who were taking a class given by the department of computer information engineering at university A, and 10 students diagnosed with a learning disorder at elementary and junior high school in North Choongcheong province participated in the test. The eyesight of the students participating in the test was not investigated, and no students with color blindness or color deficiencies joined the test.

Fig. 5. User screen of readability test evaluation program

After downloading the program evaluating document readability from the server and installing and executing it, we evaluated, in 7 stages, the readability of a single sentence with colors arbitrarily selected by the test evaluation program. No time limit was applied to the test. We had the test result analyzed by transferring the created test result file to the test participant's server. The user interface used in this test is shown in Fig. 5. On the right side is a section showing the RGB values of selected text and background colors, and this was made on the server administrator to validate the reliability of the test evaluation program. We had the users select the general readability test (basis group) and the readability test (revision group) considering color temperature in sequence, and did not use any terms that could hint at the test content when users made their selection. In each test, 6 color combination samples out of 6665 color combinations available for each group were presented, providing a total of 42 sample sentences. To secure the reliability of the test, two of the same samples were provided to each group, and if the readability selection for the same sample was not identical, we ruled out all selections by users in the corresponding stage. The presented level's group, in the case of the basis group, presented the screen by designating 7 to the group with the largest difference in hue and luminosity and 1 to the group with the smallest difference. The users were asked to choose a readability level on a scale of 1 to 7, from the most clear to the most unclear, and allowed to pick one of seven possible evaluation result options on the bottom of the screen after viewing the sentence and move on to the next phase. This selection method is different from the scheme that designated readability level with a percentage bar as used at the University of Toronto, and prevents the possibility that a quantifying psychological index could put pressure on the test participants.

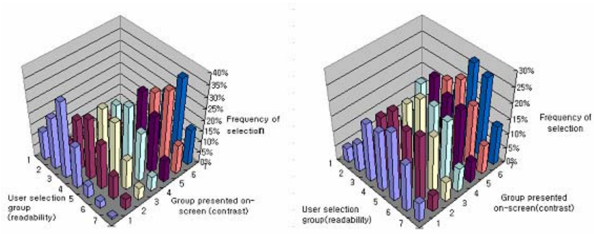

Fig. 6. Test results of AERT algorithm(a) and WCAG algorithm(b) for the normal

4-2-2. Results and discussion

The test result of applying the W3C AERT algorithm to the group of 87 students and the WCAG 2.0 LCR algorithm to the group of 87 students are shown in Fig 6, while the result of applying the same algorithms to the dyslexics are shown in Fig. 7. The test result of the AERT algorithm showed that readability generally increased by screen presentation group, that is, by color contrast ratio, which corresponds to the results found by Ridpath. Additionally, when an extremely high or low color contrast was presented, a considerable number of users selected either a low or a high readability score, as was also the case in the test by Ridpath. As shown in Fig. 6, the test result of the WCAG 2.0 algorithm showed that readability increases with contrast, as was also the result of the AERT algorithm, but less linearity is shown than for AERT and the readability distribution of the selection is marginally higher. This result corresponds to the argument by algorithm developers that RGB values of web-safe colors, if the LCR algorithm is applied to middle values ranging from 666666 to 999999, can provide appropriate contrast. Nevertheless, the fact that more test participants gave lower readability scores, in the case of the AERT algorithm, to group 7 presented on-screen meeting a contrast standard of level 2 or 3 implies that WCAG 2.0 color contrast standards has more issue than AERT. Test results for the group with learning disorders in Fig. 7 show relationship between readability and color contrast is more clear than the case for the normal and a tendency they may require more contrast to get the same readability compared with the normal.

The test result that factored color temperature into the AERT algorithm is shown in Fig. 8. We can see that most of tendencies that appeared in Fig. 7 are repeated in this test. Both an increase in readability with color contrast and a considerable number of users making unpredictable choices about color contrast were observed. The average of user selections about the group presented in the color contrast evaluation algorithm test proposed in W3C AERT and WCAG 2.0 is shown in Fig. 9. In this graph, we can see that the proposed algorithm shows a more enhanced linearity of better readability than the W3C algorithm as color contrast increases. Therefore, it is validated by this clinical test that color temperature should be adopted in evaluations of color contrast. However, this is not targeting the optimization of color temperature for color contrast.

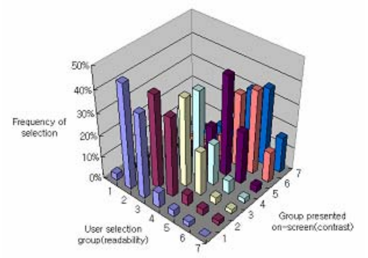

Fig. 7. Test results for the group with learning disorders

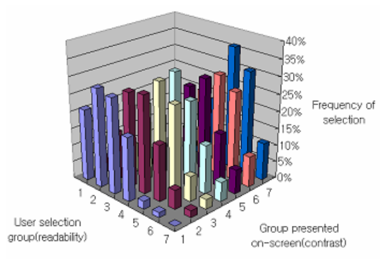

Fig. 8. Test results of the proposed algorithm for the normal

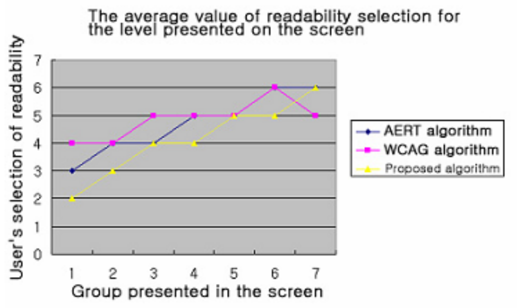

Fig. 9. Comparison of readability selection median suggested by the existing algorithms and the proposed algorithm

5. Conclusion

In e-learning contents and on information terminals, a minimum level of color contrast should be provided to prevent readability degradation resulting from lack of color contrast between text and background. This study analyzed the result of applying the representative color contrast evaluation W3C WCAG 2.0's luminosity contrast ratio algorithm and W3C AERT's color contrast algorithm to the combination of 216 web-safe colors. Compared with the AERT algorithm, the WCAG 2.0 algorithm provided web designers with an expanded range of color selection for a medium value of web safe colors, while it had a higher ratio of dissatisfaction in the selection of readability on color combinations that meet the standard. We performed the test by adding the contrast of color temperature to the AERT algorithm as an element of color contrast. As a result of the test, the method proposed by this research has seen a more linearity increase of readability with color contrast than with the W3C algorithm, and a pronounced enhancement of readability for dyslexics. Thus, the fact that color temperature greatly affects color contrast has been clinically examined, and we believe it is desirable that W3C's accessibility evaluation and repair tool technique's testing item 2.2 be enhanced by the inclusion of contrast of color temperature. However, more study is needed to determine quantitatively how this should be rendered. Moreover, the required degree of color contrast could change depending on font style and size, and additional research is necessary in this area.

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