Improving Visual Accessibility for Color Vision Deficiency Based on MPEG-21

Seungji Yang, Yong Man Ro, Jeho Nam, Jinwoo Hong, Sang Yul Choi, and Jin-Hak Lee

In this paper, we propose a visual accessibility technique in an MPEG-21 framework. In particular, MPEG-21 visual accessibility for the colored-visual resource of a digital item is proposed to give better accessibility of color information to people with color vision deficiency (CVD). We propose an adaptation system for CVD as well as a description of CVD in MPEG-21. To verify the usefulness of the proposed method, computer simulations with CVD and color adaptation were performed. Furthermore, a statistical experiment was performed using volunteers with CVD in order to verify the effectiveness of the proposed visual accessibility technique in MPEG-21. Both the experimental and simulation results show that the proposed adaptations technique can provide better color information, particularly to people with CVD.

Keywords: MPEG-21, digital item adaptation, color vision deficiency.

Manuscript received Apr. 8, 2003; revised Apr. 13, 2004.

This research was partially supported by "Development of service framework technology based on MPEG-21 merging broadcasting and communication network" project (2002-S-057 and 2003-S-022) in Korea.

Seungji Yang (email: yangzeno@icu.ac.kr) and Yong Man Ro (phone: +82 42 866 6129, email: yro@icu.ac.kr), to whom correspondence should be addressed, are with the Image and Video Systems Laboratory, Information and Communications University, Daejeon, Korea.

Jeho Nam (email: namjeho@etri.re.kr) and Jinwoo Hong (email: jwhong@etri.re.kr) are with Digital Broadcasting Research Division, ETRI, Daejeon, Korea.

Sang Yul Choi (email: power69@snu.ac.kr) and Jin-Hak Lee (email: jjhlee@plaza.snu.ac.kr) are with the Department of Ophthalmology, College of Medicine, Seoul National University, Seoul, Korea.

I. Introduction

The vision for MPEG-21 is to define a multimedia framework to enable transparent and augmented use of multimedia resources across different communities as well as across a wide range of networks and devices [1]. That is, everyone should be able to easily and equally access any kind of digital item. In MPEG-21, user accessibility is an important part of multimedia (or digital item) adaptation [2].

To achieve the goal of MPEG-21, a digital item is adapted based on a user's characteristics in the usage environment. MPEG-21 digital item adaptation (DIA) aims for a description of usage environments so that digital multimedia contents can be adapted to provide the best possible content consumption experience to the user [2]. In particular, visual accessibility in an MPEG-21 DIA includes a description of the characteristics of visually challenged people [3].

In conveying visual information in multimedia contents, color plays an important role as a fundamental visual feature since it is color that gives richness to the visual world. Recently, digital multimedia resources with high-quality color are accessible even with wireless personal communication devices such as cellular phones and PDAs.

Color visual information works well for people with normal color vision, but not for people with color vision deficiency (CVD). The use of rich color may even cause people with CVD to misread the true representation of the visual information. Although there is no treatment for CVD, many still and moving pictures, color documents, and web pages on the Internet have been designed without any consideration for the problem.

In this paper, we focus on visual accessibility for CVD. We propose an adaptation method as well as a description of CVD for MPEG-21. A resource adaptation technique for CVD is proposed based on the visual accessibility characteristics in MPEG-21 DIA [3], [4]. In particular, we focus on verifying the proposed visual accessibility for CVD in an MPEG-21 framework. Furthermore, we describe an adaptation algorithm in the proposed adaptation system.

This paper is composed of five sections. Section II includes characteristics of CVD, the proposed description of visual accessibility for users with CVD in MPEG-21, and the proposed adaptation system with the CVD description. In section III, a computer simulation using the CVD description is described. Section IV includes clinical experimental results and their statistical analysis. Finally, we conclude in section V.

II. Theory

1. Color Vision Deficiency

Human color vision is based on the response of three photoreceptors contained in the retina of the eye. It is initiated by the absorption of photons in three classes of cones where the peak sensitivities lie in the long-wavelength (L), middle-wavelength (M), and short-wavelength (S) regions of the spectrum [5]. Although the color stimuli of an object reflect one color, the human eye may perceive a completely different color, based on the sensitivity of the photoreceptors in the retina.

Defective color vision generally arises from either a complete lack of one of three classes of cone pigments or the modification of one of them. The former is called dichromacy and the latter is called anomalous trichromacy. There is also an extreme case, called achromatopsia, where an individual has no cone. Roughly, one out of twenty people has some kind of CVD [6]. Colors that are visible with a normal trichromat are changed to monochromatic stimuli for people with CVD. These monochromatic stimuli have two kinds of hue: blue and yellow for the protanope and deuteranope, and red and blue-green (cyan) for tritanope [9]. These degraded sensitivities of color causes the color information to be confused.

In an MPEG-21 framework, users perceive colors of a visual resource through a display device. Thus, we should also consider the characteristics of the display device to analyze how it helps a user perceive the color. The L, M, and S cone spectral responses for the individual primary phosphor emissions (R, G, and B phosphor) of a display device are written as

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \mathbf{T} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}, \quad where\ \mathbf{T} = \begin{bmatrix} L^r & L^g & L^b \\ M^r & M^g & M^b \\ S^r & S^g & S^b \end{bmatrix}, \tag{1}$$

where the matrix **T** denotes the relationship between the phosphor emission of the display device and the cone excitations of the human eye. The effect of each phosphor for each cone is written as

$$\begin{aligned} L^r &= k_l \int E_r(\lambda) L(\lambda) d\lambda, \\ L^g &= k_l \int E_g(\lambda) L(\lambda) d\lambda, \\ L^b &= k_l \int E_b(\lambda) L(\lambda) d\lambda, \end{aligned} \tag{2}$$

$$\begin{aligned} M^r &= k_m \int E_r(\lambda) M(\lambda) d\lambda, \\ M^g &= k_m \int E_g(\lambda) M(\lambda) d\lambda, \\ M^b &= k_m \int E_b(\lambda) M(\lambda) d\lambda, \end{aligned} \tag{3}$$

$$\begin{aligned} S^r &= k_s \int E_r(\lambda) S(\lambda) d\lambda, \\ S^g &= k_s \int E_g(\lambda) S(\lambda) d\lambda, \\ S^b &= k_s \int E_b(\lambda) S(\lambda) d\lambda, \end{aligned} \tag{4}$$

where $E_r(\lambda)$, $E_g(\lambda)$, and $E_b(\lambda)$ are primary emission functions for red, green and blue phosphors, respectively. And, $L(\lambda)$, $M(\lambda)$, and $S(\lambda)$ are each fundamental response functions for cones over the visible wavelength. When the primary emission of red, green and blue phosphors is maximal, a neutral LMS response is formed. In this paper, we assume that the display device has an ideal emission function so that the neutral LMS response is purely a white point. Given this condition, parameters of **K** in (2), (3), and (4) are computed, as the values satisfy $\Sigma L = \Sigma M = \Sigma S = 1$ [10].

2. Visual Accessibility for CVD

A. MPEG-21 DIA

In MPEG-21, a digital item is composed of resources and descriptions. Thus, MPEG-21 DIA is composed of two modules: resource and description adaptation modules. Figure 1 shows a DIA procedure in MPEG-21.

As shown in the figure, an engine called *DIA engine* performs the adaptation for a digital item. The adaptation procedure for a digital item is as follows. First, the original digital item is delivered from the digital item provider to the DIA engine. The DIA engine performs the adaptation of the digital item, based on the DIA description delivered from the consumer of the digital item (user). Then, the adapted digital item is transferred to the user. In the DIA engine, the description adaptation module adapts the description (D in Fig. 1) of the original digital item into a new or modified description (D' in Fig. 1). The resource adaptation module adapts the resource (R in Fig. 1) in the original digital item into a new or modified resource (D' in Fig. 1). To do so, the DIA engine needs a DIA description containing the user characteristics. As a result, the DIA engine can provide an equivalent accessibility of the digital item to users in any kind of environment.

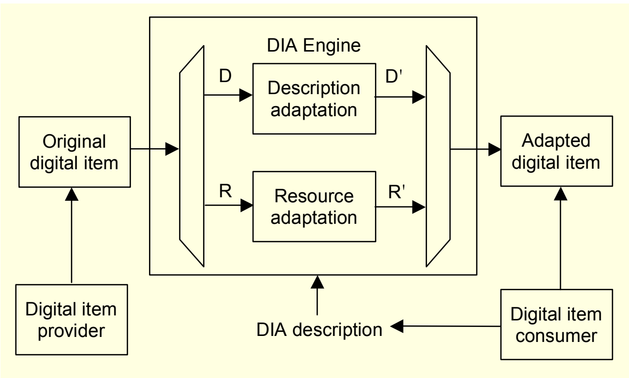

Fig. 1. Procedure of digital item adaptation (DIA).

B. MPEG-21 DIA for CVD

Visual accessibility in MPEG-21 is highly dependent on a user's visual characteristics. If a user has a visually challenged condition such as CVD, he or she suffers from an incorrect reading of the color information of the visual resource. That is, the user has a defective visual-accessibility of the visual resource (or digital item). The DIA engine takes the responsibility for providing reliable visual-accessibility for the user with CVD.

Table 1. Our DIA description for CVD.

Medical terms	ColorVisionDeficiencyInformationType		
	ColorVision DeficiencyType	ColorVisionDeficiency DegreeType	
		Textual DegreeType	Numerical DegreeType
Protanomaly	Red-Deficiency	Mild	0.1-0.9
Protanopy	Red-Deficiency	Severe	1.0
Deuteranomaly	Green-Deficiency	Mild	0.1-0.9
Deuteranopy	Green-Deficiency	Severe	1.0
Tritanomaly	Blue-Deficiency	Mild	0.1-0.9
Tritanopy	Blue-Deficiency	Severe	1.0
Achromatopsia	CompleteColorBlindness	NA	NA

Because users with CVD have different CVD characteristics, their visual accessibility of the same digital item also differs. A user's CVD characteristics should be sufficiently described in the DIA description so that the DIA engine can adapt the digital item using the DIA description. Therefore, the DIA description needs to be well structured so that it describes any user's CVD characteristics. In this paper, we propose a scheme for a DIA description of CVD based on an MPEG-21 framework.

The proposed DIA description for CVD consists of two kinds of description: the type of user's CVD and the degree of severity. Table 1 describes our DIA description for CVD.

As shown in Table 1, in TextualDegreeType, "mild" represents mild CVD (anomalous trichromat). Similarly, "severe" represents severe CVD (dichromat). NumericalDegreeType expresses mild CVD as a number from 0.1 to 0.9, and severe CVD as the number 1.0 [7], [8]. The DIA description containing a user's CVD type and severity is delivered to the DIA engine. The DIA engine performs a user-optimal adaptation according to the

Table 2. XML representation of a DIA description for CVD.

```
<complexType name="ColorVisionDeficiencyType">
  <sequence>
    <element name="ColorVisionDeficiencyInformation"
            type="ColorVisionDeficiencyInformationType"
            minOccurs="0" maxOccurs="unbounded"/>
  </sequence>
          <attribute name="UserID" type="ID" use="required"/>
          <attribute name="UserName" type="string" use="optional"/>
          <attribute name="protected" type="boolean" use="optional"/>
          <attribute name="ColorVisionDeficiencyOrNot"
            type="boolean" use="required"
          <attribute name="Sight" type="float" use="optional"/>
          <attribute name="IlluminanceDegree" type="float" use="optional"/>
</complexType>
<complexType name="ColorVisionDeficiencyInformationType">
  <sequence>
    <element name="ColorVisionDeficiencyType"
          type="ColorVisionDeficiencyType" minOccurs="1" maxOccurs="1"/>
    <element name="ColorVisionDeficiencyDegree"
          type="ColorVisionDeficiencyDegreeType" use="optional"/>
  </sequence>
</complexType>
<simpleType name="ColorVisionDeficiencyType">
  <restriction base="string">
    <enumeration value="Red-Deficiency"/>
    <enumeration value="Green-Deficiency"/>
    <enumeration value="Blue-Deficiency"/>
    <enumeration value="CompleteColorBlindness"/>
  </restriction>
</simpleType>
<complexType name="ColorVisionDeficiencyDegreeType">
  <sequence>
    <element name="TextualDegree" type="TextualDegreeType"/>
    <element name="NumericalDegree" type="mpeg7:ZeroToOneType"/>
  </sequence>
</complexType>
```

DIA description.

MPEG-21 DIA requires that any DIA description have a description scheme using the XML (eXtensible Markup Language) format. Thus, we also propose a DIA description using this format, as shown in Table 2. In the XML description, ColorVisionDeficiency describes the characteristics of a particular user's CVD.

In this paper, we also propose an adaptation method using the proposed DIA description. The proposed resource adaptation engine identifies the visual resources in the digital item and then adapts the visual resources using the DIA description of a user with CVD.

The proposed resource adaptation is divided into two parts: adaptation for both severe and mild CVDs. This division is needed because severe and mild CVDs have different causes and therefore bring about different symptoms. Since users with severe CVD are unable to see certain portions of the normal visible spectrum, it is impossible for them to see the original color of a visual resource [6], [11]. On the other hand, users with mild CVD can see most portions of the visible spectrum normally, but they have a weak sensitivity towards the remaining portions [6], [11]. Thus, it may be possible for users with mild CVD to see the original color of a visual resource. A user's CVD type and CVD degree type, described by TextualDegreeType or NumericalDegreeType in the DIA description, decide which adaptation should be performed.

3. Resource Adaptation for CVD

A. Resource Adaptation for Severe CVD

The resource adaptation for users with severe CVD aims to enhance the color information readability for the user, even though it cannot make the user sense the original color of the visual resource. The resource adaptation engine converts some of the colors confused by a user into colors that the user can see. Consequently, the resource adaptation gives better color information to the user, i.e., it enhances visual accessibility.

The color components which can be used to distinguish one color from another are hue, saturation and intensity (HSI); intensity refers to brightness. HSI color space is known to be an ideal tool for developing image processing algorithms based on the color sensing properties of the human visual system. In this paper, to discern among the confused-color set, we employ two chromatic components, hue and saturation.

Figure 2 shows the adaptation procedure for a severe CVD case. For resource adaptation, the RGB values of an original resource are first converted into HSI values, and the hue and saturation of the HSI values are then adapted into other HSI values according to the user's CVD description. Finally, the adapted HSI values are converted into the adapted RGB values.

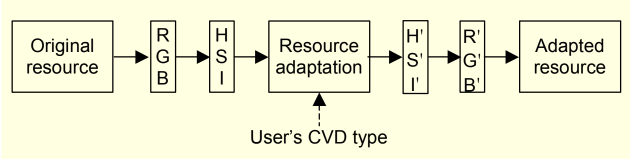

Fig. 2. An adaptation procedure for severe CVD.

The target of the adaptation may not be the whole range of a visual resource. That is, the adaptation can be applied specifically to the region where a user with CVD has difficulty in differentiating the colors. Thus the process to detect the necessary adaptation region should precede the adaptation itself.

People with severe CVD are often able to see only two hue types: blue and yellow for severe red and green CVD, and red and blue-green (cyan) for severe blue CVD [9]. Thus, one of the two hues should be converted to another hue that is recognizable to people with the corresponding CVD. After hue adaptation, if the color is still not discernable to a user with severe CVD, its saturation is modified. The proposed saturation adaptation reduces the chromatic information of the color, decreasing the saturation.

B. Resource Adaptation for Mild CVD

The purpose of the proposed adaptation for mild CVD is to let people with mild CVD see the original color of a visual resource. To do that, we first define the matrix $\mathbf{T}_{normal}$ that denotes the relationship between the phosphor emission function of a display device and the LMS cone excitations of a user with normal color vision. The matrix $\mathbf{T}_{normal}$ is computed by (1) with normal L, M, and S cone responses. Similar to $\mathbf{T}_{normal}$, the matrix $\mathbf{T}_{abnormal}$ is defined as the relationship between the phosphor emission function of the display device and the LMS cone excitations of a user with mild CVD with abnormal L, M, or S cone responses.

Figure 3 shows the adaptation procedure for a mild CVD case. To do that, the RGB values of a visual resource are first converted into LMS values of normal color vision by using $\mathbf{T}_{normal}$. The LMS values are converted into the RGB values of mild CVD cases by using $\mathbf{T}_{abnormal}^{-1}$.

Consequently, the resource adaptation becomes a kind of simulation that helps people with mild CVD to see color that people with normal color vision see. The proposed adaptation

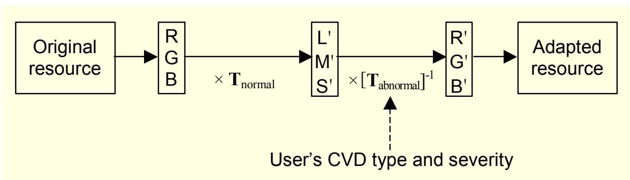

Fig. 3. An adaptation procedure for mild CVD.

highlights the colors that are insensitive to people with mild CVD. The kind and amount of color to be highlighted are determined by the type and severity of the mild CVD. Therefore the more severe CVD the user has, the more highlighted the color is.

III. Computer Simulation for CVD

To verify the proposed resource adaptation, we performed a computer simulation. Through the computer simulation, we qualitatively compared the visual accessibility of visual resources before and after applying the proposed method. Our verification focused on how well people with CVD could perceive the color information of the visual resource.

1. Computer Simulation for Severe CVD

In some clinical experiments, the monochromatic stimuli for severe CVD are known as blue (474 nm) and yellow (575 nm) for severe red and green CVD, and cyan (485 nm) and red (660 nm) for severe blue CVD [9]. The monochromatic stimuli form two defected planes in LMS space.

For a computer simulation of severe CVD, RGB values of a visual resource are first converted into LMS values. Next, the LMS values are projected onto the two defected LMS planes. The simulated RGB values were obtained by converting the defected LMS values into values of RGB space. We also obtained adaptation images using the method mentioned in section II.3.A.

We conducted visual comparisons using four images as shown in Fig. 4: an original image, a CVD-simulated image of the original image, an adapted image using user CVD information, and a simulated adapted image for people with CVD. Figure 4(a) is a presentation image where three bars with different information are discerned only by color. Figure 4(b) shows that people with severe red CVD cannot get the information that the green and yellow bars represent since people with severe red CVD see the color of green bars as yellow. The two bars in the adapted image in Fig. 4(c), however, are discernable to people with severe red CVD, who see the image as shown in Fig. 4(d).

Likewise, simulation results for severe green and blue CVD showed that the proposed DIA could enhance visual accessibility for people with this type of CVD in an MPEG-21 framework.

2. Computer Simulation for Mild CVD

A computer simulation for mild CVD needs to be different from the computer simulation for severe CVD. In this paper,

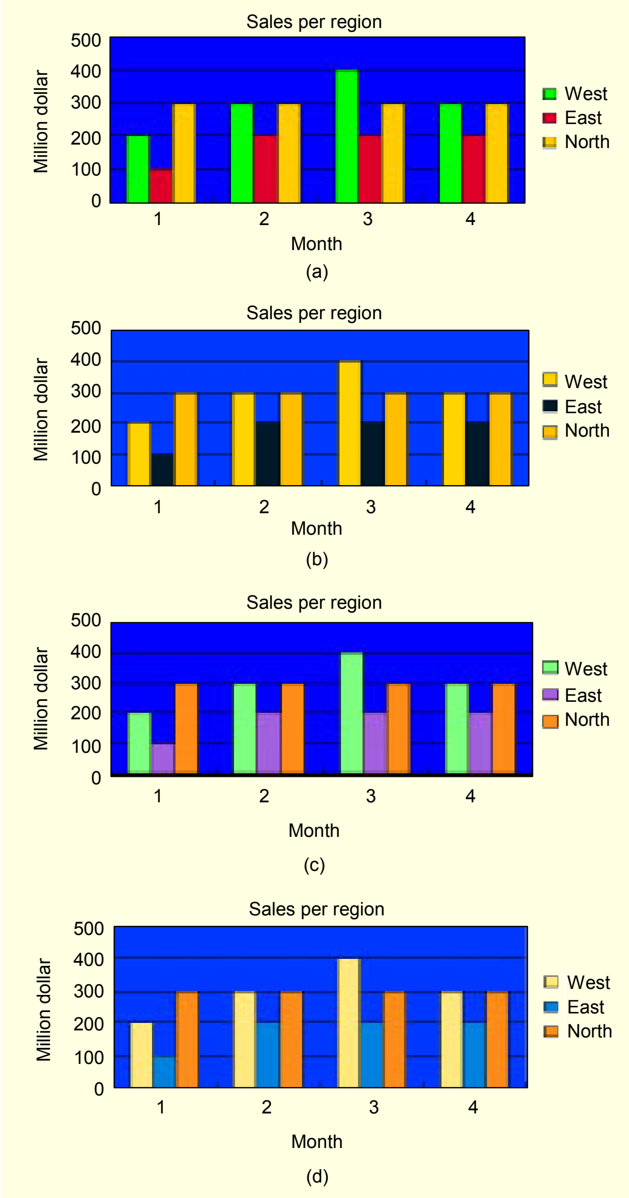

Fig. 4. Simulation results for severe red-CVD: (a) an original image, (b) a CVD simulated image from the original image, (c) an adapted image with user CVD information, and (d) a simulated adapted-image for people with CVD.

we assumed that mild CVD would be caused by a shift of one of the LMS cones, which is known as a major cause of this disorder [12].

Figure 5 shows a simulation procedure for the mild CVD case. For a computer simulation for mild CVD, RGB values of the visual resource are first converted into the LMS values of mild CVD by using $\mathbf{T}_{abnormal}$. The LMS values are converted into RGB values of normal color vision by using $\mathbf{T}_{normal}$. The RGB values are the simulated color that people with mild CVD see. We also obtained adaptation images using the method mentioned in section II.3.B.

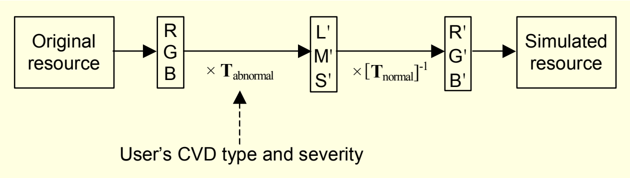

Fig. 5. A simulation procedure for mild CVD.

Similar to the cases of severe CVD, we conducted visual comparisons using four images: an original image, a mild CVD simulated image derived from the original image, an adapted image with user CVD information, and a simulated adapted image for people with mild CVD. Figure 6 shows the simulation and adaptation results for mild red CVD. Figures 6(a), (b), (c) and (d) show an original image, a simulated image with mild red CVD, an adapted image with user CVD information, and a simulated adapted-image for people with mild red CVD, respectively.

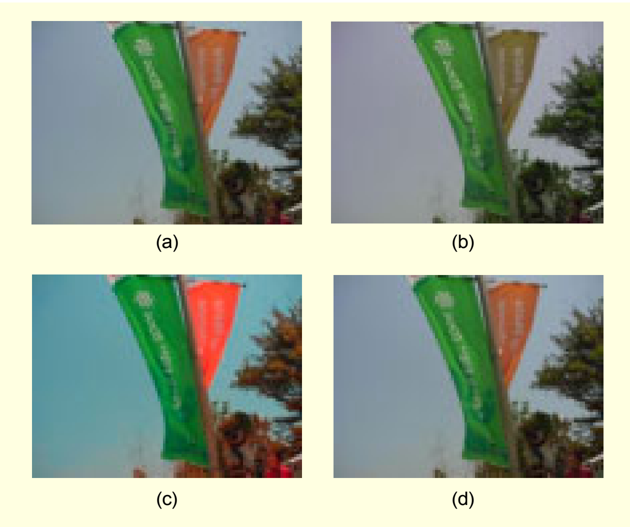

Fig. 6. Simulation results for mild red CVD: (a) an original image, (b) a mild red CVD simulated image from the original image, (c) an adapted image with user CVD information, and (d) a simulated adapted image for people with mild red CVD.

Figure 6(a) is a natural image where red and green objects have different information. Figure 6(b), which has the L cone shifted by 10 nm, shows that people with mild red CVD cannot see the original red color, since the users are insensitive to red. However, Fig. 6(d) shows that the adapted color in the adapted image shown in Fig. 6(c) is normally perceptible to people with mild red CVD.

Likewise, simulation results with mild green and blue CVD showed that the proposed DIA could enhance the visual accessibility for people with CVD in an MPEG-21 framework.

IV. Experiment

To verify the proposed adaptation system for people with CVD, we performed a clinical experiment using volunteers with CVD. To choose the final testees from the volunteers, we excluded people with severe low-vision or neurological abnormality, people of more than 40 years old, and people taking medicine to affect their sense of color.

At first, we performed an HRR (Hardy, Rand, Ritter) pseudoisochromatic color vision test [13] and an Ishihara color vision test [14] on the volunteers and then diagnosed them for CVD type and severity. To achieve a more accurate diagnosis about CVD, we performed an additional Seohan computerized hue test [15]. Those color vision tests were performed using a single eye of the testees in a laboratory where the illumination condition was about 500 Lux.

The final testees consisted only of people with red and green CVD since blue CVD cases are very rare. For the clinical experiment, we showed the original image and its adapted version to the testees and then asked them some questions about the images. The questions were about the parts of the images that the volunteers with CVD found confusing. For each original image and its adapted image, we asked whether the confusing colors in the original image were more clearly discernable in the adapted image or not. In addition, we checked the cases where the testees did not see any difference in color information readability between the two images.

Table 3 shows the results of our clinical experiments with the testees. As shown in the table, the average number of testees for each image was about 18 persons. The average numbers of approximately 11, 5, and 3 persons responded "better," "equal," and "worse," respectively.

In Table 3, most testees answered "worse" for the 5th and 7th images. The two images were created especially for detecting very mild CVD. They consisted of several small rectangles with a very low saturation of reds and greens in front of a gray background. For those with severe cases of mild-CVD, the rectangles would be seen quite similar in both the original and color-adapted images.

To verify the proposed method, we performed a hypothesis testing using the experimental results. Here, a null hypothesis is defined as H_0, and an alternative hypothesis as H_a. In the hypothesis testing, we assumed that the proposed method would be effective only if it was expected that more than half of the testees selected better.

Thus, we set the null hypothesis to $H_0 : \mu = \mu_{th}$ and the alternative hypothesis to $H_a : \mu > \mu_{th}$, where μ_{th} was set to 9.05, which was half of the average number of testees, as shown in Table 3. We then tested whether there was sufficient evidence to reject the null hypothesis.

Table 3. Results of clinical experiments.

Image shown to testees	The number of testees who confirm color information readability by the proposed MPEG-21 description as…			The number of testees
	Better	Equal	Worse	
1st	15	4	1	20
2nd	11	5	3	19
3rd	14	5	0	19
4th	14	5	0	19
5th	7	2	8	17
6th	10	4	1	15
7th	6	5	8	19
8th	10	5	4	19
9th	13	3	1	17
10th	8	7	2	17
Total number of testees	108	45	28	181
Average ratio of testees (%)	58.66	24.86	15.47	100

So we performed the test with $H_0: \mu = 9.05$ against $H_a: \mu > 9.05$. The sample size n was 10. The sample mean was a point estimator of μ that was an approximately normal distribution with $\mu_{\overline{Y}} = \mu = 10.8$ and $\sigma_{\overline{Y}} = \sigma / \sqrt{n} \approx 0.9993$. Hence, our test statistics (Z) are as follows:

$$Z = \frac{\overline{Y} - \mu_{th}}{\sigma_{\overline{Y}}} = \frac{\overline{Y} - \mu_{th}}{\sigma / \sqrt{n}} = \frac{10.8 - 9.05}{3.16 / \sqrt{10}} = 1.7513, \qquad (5)$$

where Z is the test statistics of the normal distribution. The *p-value* is a measure of how much evidence we have against the null hypotheses. The smaller the *p-value*, the more evidence we have against H_0. In this experiment, since the test statistic (Z) was 1.17513, the *p-value* falls into a value between 0.0359 and 0.0446. That is, the null hypothesis (H_0) should be rejected with about 4 to 5% type I error (which occurs if the null hypothesis is rejected when it is true). The evidence is sufficient to indicate that the proposed adaptation method is efficient for people with CVD.

V. Conclusion

In conclusion, we propose a resource adaptation technique for CVD within an MPEG-21 framework. First, we visually verified the proposed adaptation through a simulation for people with CVD. In addition, statistical analysis based on the results of our clinical experiment using volunteers with CVD showed that the proposed adaptation method is helpful for people with CVD. So, the proposed adaptation method provides sufficient visual accessibility for people with CVD. The proposed method was applied only for the image resource within a digital item. In the future it should be extended to apply to other types of visual resources such as video in a digital item.

References

[1] MPEG Requirements Group, *MPEG-21 Overview*, ISO/IEC JTC1/SC29/WG11 N4511, Pattaya, Thailand, Dec. 2001.

[2] MPEG Requirements Group, *MPEG-21 Requirements on Digital Item Adaptation (DIA)*, ISO/IEC JTC1/SC29/W G11 N4511, Jeju, Korea, Mar. 2002.

[3] MPEG MDS Group, *MPEG-21 Digital Item Adaptation CD*, ISO/IEC/JTC1/SC29/WG11, Awaji, Japan, Dec. 2002.

[4] Y.M. Ro et al., *Report on CE for Visual Accessibility - Part1: Color Vision Deficiency*, ISO/IEC JTC1/SC29/WG11 M8543, Klagenfurt, July 2002.

[5] V.C. Smith and J. Pokorny, "Spectral Sensitivity of the Foveal Cone Pigments Between 400 and 700 nm," *Vision Research*, vol. 15, Feb. 1975, pp. 161-171.

[6] D. McIntyre, *Color Blindness*, Dalton Publishing, 2002.

[7] J.I. Song, Y.M. Ro et al., "Digital Item Adaptation for Color Vision Variations," *Proc. Electronic Imaging of SPIE*, Jan. 2003.

[8] S.J. Yang, Y.M. Ro et al., "MPEG-21 Digital Item Adaptation for Color Vision Deficiency," *Proc. Int'l Workshop Advanced Image Technology (IWAIT)*, Jan. 2003.

[9] H. Brettel, F. Vienot, and J.D. Mollon, "Computerized Simulation of Color Appearance for Dichromats," *Journal of Optical Society of America*, vol. 14, no. 10, 1997, pp. 2647-2655.

[10] G. Kovacs, I. Kucsera, G. Abraham, and K. Wenzel, "Enhancing Color Representation for Anomalous Trichromats on CRT Monitors," *Journal of Color Research and Application*, vol. 26, 2001, pp. 273-276.

[11] G.W. Meyer and D.P. Greenberg, "Colour-Defective Vision and Computer Graphics Displays," *Journal of IEEE Computer Graphics and Applications*, vol.8, no. 5, Sept. 1988, pp. 28-40.

[12] J. Pokorny and V.C. Smith, "Derivation of the Photopigment Absorption Spectra in Anomalous Trichromat," *Journal of Optical Society of America*, vol. 63, no. 2, Sept. 1977, pp. 232-237.

[13] I. Hardy, G. Rand, and C. Rittle, "HRR Poly-Chromatic Plates," *Journal of Optical Society of America*, vol. 44, 1954, pp. 509-523.

[14] D. Alwis and C. Kon, "A New Way to Use the Ishihara Test," *Journal of Neurol.*, vol. 239, no. 8, 1992, pp. 451-454.

[15] M.S. Kim, J.H. Lee et al., "Seohan Computerized Hue Test [1]: The Development of Computerized Color Vision Test and Pilot Study," *Journal of Korean Ophthalmological Society*, vol. 41, no. 1, 2000.

Seungji Yang received the BS degree in information and telecommunication engineering from Kangwon National University of Korea in 2001 and MS degree in image and video processing from Information and Communications University of Korea in 2002. Since 2002, he has been a PhD student in the same university. He received the 14th Outstanding Science and Technology Thesis Award sponsored by the Korean Federation of Science and Technology Societies in 2004. His research interests include multimedia retrieval/indexing, image/video processing, MPEG-7, and MPEG-21.

Yong Man Ro received the BS from Yonsei University, Seoul, Korea in 1981 and the MS and PhD degrees from the Korea Advanced Institute in Science and Technology (KAIST), in 1987 and 1992, respectively. In 1987, he was a staff associate at Columbia University, and from 1992 to 1995, he was a visiting researcher in University of California at Irvine and KAIST. In 1996, he was a Research Fellow at Department of Electrical Engineering and Computer Sciences in University of California at Berkeley. In 1997 he joined Information and Communication University, Korea, where he is currently Associate Professor and Director of Image Video System Lab. His research interests include image/video processing, MPEG-7, MPEG-21, image/video indexing, media QoS, visual data mining, ubiquitous watermarking. He received the Young Investigator Finalist Award in ISMRM in 1992 and the This Year's Best Scientist Award in 2004. He is a senior member of IEEE and member of SPIE and ISMRM.

Jeho Nam received the BS degree in electrical and control engineering from Hong-ik University, Seoul Korea, in 1992 and the MS and PhD degrees in electrical and computer engineering from the University of Minnesota at Twin Cities, Minneapolis, in 1996 and 2000 respectively. Dr. Nam is currently a Senior Member of Engineering Staff with Digital Broadcasting Research Division at Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea. His research interests are in the area of signal processing for digital video technologies and multimedia applications. He is a member of the IEEE and ACM.

Jinwoo Hong is a Team Leader and Principal Member of the Technical Staff in the Digital Broadcasting Research Division of ETRI, Korea. He received the BS and MS degrees from Kwangwoon University, Korea, in 1982 and 1984, and the PhD from the same university in 1993. Since he joined ETRI in 1984 he has been involved in developing digital audio systems, IPMP, and broadcasting technology. His recent work has been focused in developing a multimedia framework for the convergence of broadcasting and telecommunication based on MPEG-21 technology. His main interests are in the areas of multimedia signal processing, IPMP, and digital audio broadcasting.

Sang Yul Choi received the BS and MS degrees from Seoul National University, Seoul, Korea in 1994 and 2002, respectively, and is in the PhD course at the same school. In 2002, he was a fellow at the Department of Ophthalmology in Seoul National University Hospital. He is currently Assistant Professor at the Department of Ophthalmology, Sacred Heart Hospital, Hallym University. His research interests include color vision, corneas and cataracts.

Jin-Hak Lee received the BS from Seoul National University, Seoul, Korea in 1972 and the MS and PhD degrees from Seoul National University (SNU), in 1975 and 1981, respectively. He passed the Korean Medical Doctor License Examination to be a medical doctor in 1972. He became a Clinical Instructor at Seoul National University College of Medicine in 1980, an Assistant Professor at Seoul National University College of Medicine in 1983, from 1983 to 1984 an Exchange Professor at USA Kresge Eye Institute, Associate Professor at Seoul National University College of Medicine in 1988, Professor at Seoul National University College of Medicine in 1993, from 1980 to 1982 the Director of general affairs department at The Korean Ophthalmological Society, from 1984 to 1990 the Director of planning department at The Korean Ophthalmological Society, from 1992 to 1994 the Director of scientific department at The Korean Ophthalmological Society, and from 2003 to now the Chief Director at The Korean Ophthalmological Society. His research interests include computerized color vision tests, computerized objective visual acuity tests, artificial cornea and drug delivery systems. He is a member of KSCRS and member of ASCRS and ESCRS.