# Techniques to Enhance the Sense of Depth Using Visual Perception Characteristics

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## Abstract

*This study aimed to enhance the cubic effect by representing an image with a sense of depth using chromostereopsis, among the characteristics of human visual perception. An algorithm that enhances the cubic effect, based on the theory that the cubic effect of the chromostereoptic effect and the chromostereoptic reversal effect depends on the lightness of the background, classifies the layers of the image input into the foreground, middle, and background layers according to the depth of the image input. It is suitable for human visual perception characteristics, controlling the color factor that was adaptively detected through experiments on each layer; and it can obtain the enhanced cubic effect that is suitable for the characteristics of the image input.*

***Index Terms*** *— Visual cubic effect, Chromostereopsis, Human visual perception, Depth*

## 1. Introduction

There can be many clues to the increase in the depth perception that can heighten the sense of depth among the visual processes of depth, and chromostereopsis is one of them. Colors with long wavelengths feel closer than those with short wavelengths; but as the lightness of the background comes closer to white, the reversal phenomenon takes place, so the depth perception may differ according to the lightness of the background. In other words, in addition to the existing hypothesis on the chromostereoptic effect according to the wavelength, it can be assumed that the cubic effect can also be increased by controlling each color element according to the lightness of the background.

This study controlled the properties of colors through contrast and harmonization of neighboring colors with respect to the properties of human visual perception. Based on the chromostereoptic theory, changes in the cubic effect, depending on colors and information on the lightness of the background through psychophysical experiments, were examined. In addition, by applying the results of the experiments directly on an image, a copy of the image with greater depth perception and cubic effect was reproduced.

## 2. Experiments on Color Factors and Neighboring Colors Controlled According to the Background Lightness

In the experiments that were conducted in this study, according to the lightness of the white, grey, and black backgrounds, when the representative Munsell color patches of red (long wavelengths), green (middle wavelengths), and blue (short wavelengths) were compared in CIECAM02, which is closest to human visual perception, with different J (lightness) and C (chroma) values, the main color factors that should be controlled to enhance the cubic effect were examined. For the method of the experiments, in the representative color patches for each wavelength, the J and C elements of CIECAM02 were converted to -Δ, 0, and +Δ. In other words, the experiments were conducted and repeated after the representative colors, which had a total of nine different J and C values, were distributed to the backgrounds with different degrees of lightness. The experiments were carried out on the 10 subjects in a darkroom. As to the questionnaires that were used in the experiments, the respondents were asked to select the patch that they believed had the greatest cubic effect and depth perception among those presented on the monitor.

As a result of the experiments, despite their two-time repetition, more than 90% of the answers were that the patch with simultaneously increased J and C values, regardless of the wavelength, had the greatest cubic effect.

(A) (B)

***Fig. 1.*** *(A) Short wavelength with nine different J and C values (left) and (B) effect of the neighboring colors that were used in the experiments.*

The next experiment tried to examine what color factors should be controlled for the sequential enhancement of the cubic effect or the depth perception according to the neighboring colors and the lightness of the background. The colors that were used were divided into red, which represents the long wavelength; blue, which represents the short wavelength; and green, which represents neutral colors. The experiment was conducted with the patches representing the overlapping wavelengths, as shown in Fig. 1 After the color patches that overlapped with each other were put against backgrounds with different degrees of lightness, the pair of color patches that produced the cubic effect most sequentially was selected.

Since it was concluded that if both the lightness and chroma elements were enhanced, the greatest cubic effect would be produced, the aforementioned result was applied to the red patch that was positioned at the top, among the overlapping color patches that were used in the experiment. In reference, in this experiment, the color factors that should be controlled to enhance the cubic effect of the blue patch that was positioned in the second position, that is, in the middle position (the middle layer), were identified depending on the hue combination among the neighboring colors and the background lightness, instead of finding out the color factors that affected the red patch (foreground layer) that was positioned at the top (Fig. 1). The results of the color factor control, considering each property of the overlapping neighboring colors that were obtained from the experiment, are as follows.

**Table1. Lightness control method for neighboring colors**

| Class | Foreground | Middle | BG (0~30) | BG (31~60) | BG (61~100) |
|---|---|---|---|---|---|
| A | Red | Green | Increase | BYPASS | Decrease |
| B | Red | Blue | BYPASS | Decrease | BYPASS |
| C | Green | Red | BYPASS | Decrease | Increase |
| D | Green | Blue | Decrease | BYPASS | BYPASS |
| E | Blue | Red | Decrease | Increase | Increase |
| F | Blue | Green | Increase | Increase | Increase |

**Table 2. Chroma control method for neighboring colors**

| Class | Foreground | Middle | BG (0~30) | BG (31~60) | BG (61~100) |
|---|---|---|---|---|---|
| A | Red | Green | Increase | BYPASS | Decrease |
| B | Red | Blue | BYPASS | BYPASS | BYPASS |
| C | Green | Red | Increase | Increase | BYPASS |
| D | Green | Blue | BYPASS | BYPASS | BYPASS |
| E | Blue | Red | Decrease | BYPASS | BYPASS |
| F | Blue | Green | Increase | Decrease | BYPASS |

Tables 1 and 2 show the results of the experiments on the methods of controlling the lightness and chroma of the patch that was positioned in the middle, according to the lightness of the background. For example, suppose that the background lightness of the input image is 50, and the representative hue of the color patch at the top is positioned in the red area, which has a long wavelength, whereas the color patch in the middle of the blue area, which has a short wavelength, is Class 'B'. This reflects the result that for the color patch in the middle, a patch with decreased lightness but without any separate chroma processing had a more sequential cubic effect or depth perception than others with controlled color factors, as shown in Tables 1 and 2.

## 3. Advanced Technology Algorithm of Depth Perception based on Chromostereopsis

Fig. 2 shows a block diagram of the constitution of the advanced technology algorithm of depth perception based on the chromostereopsis that was developed in this study and based on the experiment results.

The existing cubic-effect-enhancing technique reproduced the enhancement of two-step depth perception processing by classifying depth into the foreground and the background, or the object and the background. The multi-layering process, however, can reproduce images with greater depth perception step by step by adding a middle layer between the foreground layer and the background layers. The middle layer is the one positioned between

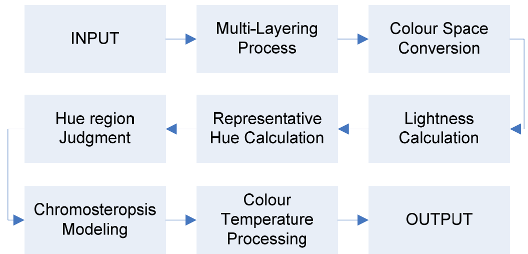


*Fig. 2. Depth perception based on the chromostereopsis methodology*

the foreground and background layers, and represents the degree of depth between the foreground layer and the background layer. Similar to this, the R, G, and B values of the input image that was divided into the foreground, middle, and background layers based on the depth map converted the color space to J, C, and H in CIECAM02, which is the most similar to human visual perception, to convert the pixel value of the input image.

For the layers that were divided according to their depths, a process of choosing pixels with accent colors in the middle layer and the background layer, and then changing the pixels to the depth value of the foreground layer, was carried out. The values that were changed to CIECAM02, whether C (that is, the chroma value that is discernable in visual perception is over 20) or not and whether or not the pre-set value was within the range of H, were extracted from the middle layer and the background layer of the image input. The depth of the extracted pixels from the middle and background layers was changed to that of the foreground layer, and the upward gain value under the foreground layer was applied to the corresponding pixels. Since the accent color refers to a pixel that has the strong energy of the color with the first visual attention, if the gain value of the pixel that corresponds to it is reduced, the cubic effect and the sense of depth are lost, so a process of processing the pixel appropriately to attain such characteristics, such as that described previously, is necessary.

In the lightness calculation, the average lightness value of the background layer, which was adjudged to have been at the backmost, was found, with the lowest depth among the layers classified according to the degree of depth. The formulas that were used to implement the image with depth perception according to the lightness value of the found background layer are as follows.

$$G = \frac{\alpha - \beta}{D_{\max\_fore} - Th_1} \times (D_{in} - Th_1) + \beta \qquad (1)$$

$$G = \frac{\beta - \gamma}{Th_1 - Th_0} \times (D_{in} - Th_0) + \gamma \qquad (2)$$

Equation (1) represents the foreground layer, and Equation (2), the method of controlling the lightness and chroma of the middle layer. The foreground layer, which had the greatest depth, adjusted the enhancement of a certain gain using the value, and the J and C values of the middle layer were controlled according to the hue combination of the foreground layer and the middle layer. *D*max_fore represents the maximum depth value of the foreground layer, *Th*1, which is the depth threshold value upon separation of the foreground layer from the middle layer. In addition, *Th*0 is the depth threshold value of the middle layer and the background layer.

The graph in Fig. 3 shows an example of controlling the lightness and chroma for each layer. Region 1 shows the control of the color factors in the area of the foreground; Region 2, in the middle layer; and Region 3, in the background layer.

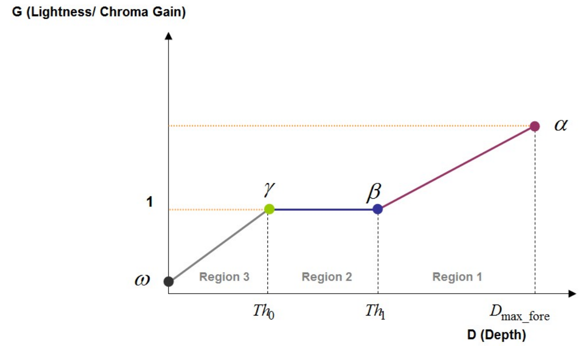


***Fig. 3.*** *Example of control of the lightness and chroma in each layer*

In the Representative Hue Decision, the representative hue represents the foreground layer, and the middle layer is found with the average Hue value, or the average value of the part where the hue portion is concentrated, which can be found by classifying the layer by grid. The representative hues of the selected foreground layer and the middle layer will later be used as information for controlling the lightness and chroma of the middle layer. The hue that represents each layer is defined in the CIECAM02 color space; and while the hue is classified broadly into four areas in CIECAM02, in this study, the areas of each wavelength band were defined using the hue in CIECAM02 according to the properties of the monitor that were randomly used in the experiment. The red series, which represents the long wavelengths, was set at 0-61 and 270-360; the green series, which represents the neutral colors, at 61-184; and the blue series, which represents the short wavelengths, at 185-269.

In the chromostereopsis modeling, through the lightness of the background layer and the hue combination of the foreground layer and the middle layer, based on the results of the psychophysical experiment and the J or C in CIECAM02, the depth perception factors that can control the properties of the chromostereopsis are controlled differently. The foreground layer increases both the lightness and chroma by as much as the gain set, which no longer decreases the lightness or chroma. For the background layer, if the representative hue of the foreground layer is below the long wavelength, the gain value that controls the lightness value decreases; and if it is below the short wavelength, it increases.

Color temperature processing adjusts the chromostereopsis according to the representative hue combination and the background lightness of foreground and middle layers. The layers that are adjusted at this time are the foreground layer and the middle layer, whereas the background layer remains the same; and on the background layer, information only on the lightness is used. Since the foreground layer should be processed in an image so that it is perceived most closely to the user, if chromostereoptic modeling is processed on the middle layer and the background layer using the chromostereoptic characteristics and the reversal effect, the color temperature processing changes the color temperature of the foreground layer, by applying chromostereopsis and the chromostereopsis reversal effect, and the color temperature of the foreground layer is changed by applying chromostereopsis and the chromostereoptic reversal effect according to the adjustment of the color temperature. For example, for 'black,' in which the average lightness of the background is below 30, the existing chromostereoptic theory is applied, and the color temperature of the foreground layer is changed to near-infrared wavelengths--in other words, to Warm. In contrast, for 'White,' in which the average lightness of the background is over 30, the existing chromostereopsis reversal effect is applied, and the color temperature of the foreground layer is changed to the direction of the short wavelength infrared--that is, to Cool. Also, for the middle layer, in contrast to the foreground, the depth difference from the foreground layer takes place as the color temperature is changed, so that an image with a greater sense of depth can be produced. In Table 3, 'W' means a change to a Warm color temperature, 'C' stands for a color temperature change to Cool, and the part that is indicated by '0' means that there is no change in the color temperature.

**Table 3. Color temperature control method for the foreground and middle layers**

| | BG Lightness (0-30) | | BG Lightness (31-60) | |
|---|---|---|---|---|
| Class | Foreground | Middle | Foreground | Middle |
| A | W | C | C | W |
| B | W | C | C | 0 |
| C | W | 0 | C | W |
| D | W | C | C | 0 |
| E | W | 0 | C | W |
| F | W | C | C | W |

## 4. Verification of the Advanced Technology Algorithm of Depth Perception based on Chromostereopsis

The advanced technology algorithm of depth perception based on chromostereopsis was developed in this study by examining the visual assessment of satisfaction with the cubic effect between the image in which the color attributes were adaptively controlled and the original image cubic effect. In this section, the performance of the developed algorithm will be assessed.

(A) (B)

***Fig. 4.*** *Experiment setting for the depth perception based on chromostereopsis. (A) Original and (B) applied algorithm*

During the experiment, the observers compared each transformed image with the original image. The observers did not know which images were the original ones. The degree of the color combination was measured with the likert scale. The likert scale is a bipolar scaling method that measures either positive or negative response to a statement. Each respondent is asked to rate each item on a scale.

After the experiments, the cubic effect of the image to which the proposed advanced technology algorithm of depth perception based on chromostereopsis was applied was compared with the original image. The latter showed a cubic effect of about 66.4%, and the image to which the algorithm was applied showed a cubic effect of about 89.9%, due to its enhancement by about 23.5% compared to the latter.

## 5. Conclusion

The aerial perspective method that has been used to promote depth and the cubic effect in existing 2D images is used to make the perspective felt by decreasing the lightness or chroma according to the sense of distance, by dividing the image into the foreground and the background. The advanced technology algorithm of depth perception based on chromostereopsis that was proposed in this study is different in that it can reproduce images with greater depth perception by dividing the layers according to depth, and by controlling them not only by processing the foreground and the background between the divided layers but also by simultaneously considering the chromostereopsis and the neighboring colors on the layer with the middle depth.

## 6. References


[1] Bajcsy, R. & Lieberman, L., "Texture gradient as a depth cue. Computer Graphics and Image Processing, " 5, 52-67, 1976.

[2] Dengler, M. & Nitscheke, W., "Colour stereopsis: a model for depth reversals based on border contrast, " Perception & Psychophysics, 53, 150-156, 1993.

[3] Gibson, J. J., "The perception of the visual world, " Houghton Mifflin: Boston, 1950.

[4] Guibal, C. R. C. & Dresp, B., "Interaction of colour and geometric cues in depth perception: when does red mean near?, " Psychological Research, 69, 30-40, 2004.

[5] Wither, J. Hollerer, T., "Pictorial depth cues for outdoor augmented reality, " Wearable Computers, 2005.

[6] Vincent A. Nguyen, Ian P. Howard, and Robert S. Allison, "Detection of the depth order of defocused images", Vision Research, 2004.

[7] Peter W. Battaglia, Robert A. Jacobs, and Richard N. Aslin, "Depth-dependent blur adaptation", Vision Research, 2003.

[8] Jonathan David Pfautz, "Depth Perception In Computer Graphics", 2002.

[9] Geoffrey S. Hubona, Philip N. Wheeler, Gregory W. Shirah and Matthew Brandt, "The Relative Contributions of Stereo, Lighting, and Background Scenes in Promoting 3D depth visualization", ACM Transactions on Computer-Human Interaction, 1999.


## Author Biography

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