Mathematical Model for Pop-up Effect of ChromaDepth

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ABSTRACT

ChromaDepth glasses are microprism glasses that produce a pop-up effect by combining refraction and diffraction. In this paper, we formulate the relation between the pop-up distance and viewing distance using a mathematical model. Using our model and optical measurements, we evaluate the human perception of the pop-up effect for ChromaDepth glasses using a large distant display.

CCS CONCEPTS

• **Computing methodologies** → *Perception*;

KEYWORDS

ChromaDepth glass, 3D display, Depth perception, Pop-up effect, Viewpoint distance

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1 INTRODUCTION

Interest in stereoscopic three-dimensional (3D) displays has increased in recent years. Meanwhile, glasses that use the spectroscopic parallax method, called ChromaDepth or ChromaDepth™ glasses, have also been developed[3]. Because the glasses use microprisms to produce a parallax effect, the refraction angle depends on the wavelength of the incident light.[2] Therefore, longer-wavelength light, such as red light, can emphasize the pop-up effect [1].

The present paper clarifies the optical characteristics of ChromaDepth glasses and formulates the relationship between the viewing distance and pop-up distance using a mathematical model. Furthermore, we validate the fidelity of the model by measuring the optical characteristics of ChromaDepth glasses.

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2 ANALYSIS OF CHROMADEPTH GLASS

2.1 Principle of pop-up effect

ChromaDepth™ glasses are patented microprism glasses that produce a pop-up effect by combining refraction and diffraction. Light rays that pass through the glasses are bent according to the bending angle (which we call the *parallax angle*), which depends on the wavelength.

Unlike the case for other types of 3D glasses, an important characteristic of the ChromaDepth glasses is that the parallax angle is constant. This means that the parallax presented to the left and right eyes is independent of the distance of the display. This allows unique depth perception when viewing a huge distant display while wearing ChromaDepth glasses.

2.2 Mathematical model

The parallax angle illustrated in fig. 1 is defined as $\theta = \tan^{-1}(H/L)$. Because a microprism is placed in front of the left eye only, the small dot shifts horizontally in the left-eye view whereas it stays at the original position in the right-eye view as shown in fig. 1. This parallax phenomenon means that observers perceive that the depth of the small dot becomes less than the original depth. The distance between the original and perceived depths, which we call the *pop-up distance* D, can be formulated as

$$D = \frac{L\left(L^2 + \left(\frac{B}{2}\right)^2\right)}{\left(L + \frac{B}{2}\right)\left(L - \frac{B}{2}\right) + \frac{BL}{\tan\theta}}, \tag{1}$$

where the baseline B denotes the distance between left and right eyes.

3 EXPERIMENT

3.1 Optical measurement of ChromaDepth

We first measured the parallax angle for each color. To maintain a long viewing distance, we used a large display (i.e., a sphere with a diameter of 6 m). Parallax angles for red, blue and green

Table 1: Parallax angles for each color.

	Red	Green	Blue
Parallax angle [deg]	1.11	0.93	0.85

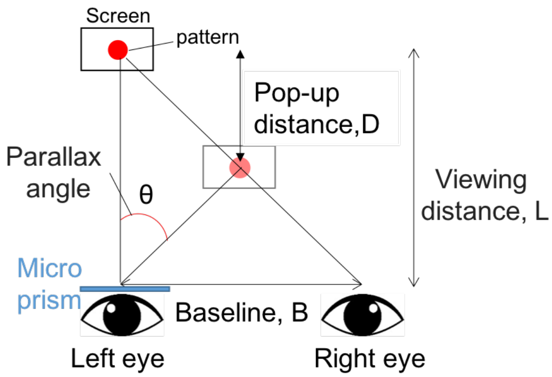

Figure 1: Percepted depth.

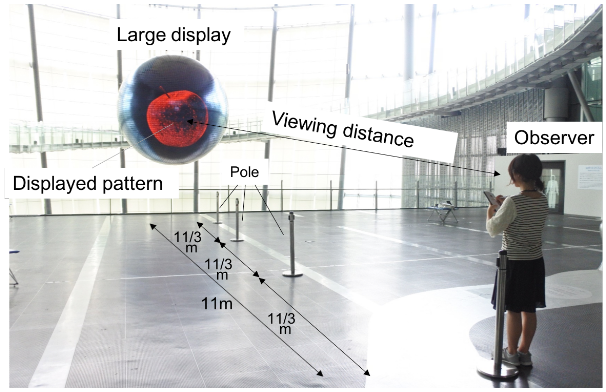

Figure 2: Experimental environment for evaluating human perception.

were measured as shown in Table 1. We see that the parallax angle depends on the color, with the angle for red light being larger than that for blue light. It is noted that the parallax angle is independent of the viewing distance. According to this measurement and our mathematical model shown in eq. (1), we calculate the perceived depth for each color.

3.2 Human perception of the pop-up distance

In eq. (1), we proposed a mathematical model that represents the apparent distance according to the parallax effect geometrically; however, there is still no obvious consistency between the model and human perception of the pop-up distance. To validate our mathematical model, we compared the pop-up distance calculated using eq. (1) and the same distance in human perception. In this experiment, the red illustration of an apple was displayed on a huge spherical display and observers viewed the illustration from five distances (i.e., 11, 22, 33, 44, and 55 m). To specify the perceived distance easily, we placed several poles at equal intervals along the depth direction as shown in Fig. fig. 2 and then asked the observers to report the perceived distance.

Result are presented in fig. 3. The red line represents the distance calculated using our mathematical model while the color dots are the distances perceived by the observers. Results of our model and the observers' perception both show that the pop-up distance increases with the viewing distance, but the trends slightly differ.

Our experiments revealed a shift of not only the red illustration but also the contour of the display itself when nothing was displayed on the screen. To consider this shift of the background display, we subtract the shift of the black background from the shift of the red illustration shown as a black curve in fig. 3. As a result, the trends of the calculated distance and perceived distance become closer.

Unfortunately, the tendencies of the calculated and perceived distances do not perfectly match. This discrepancy seems to be related to the human convergence angle.

4 CONCLUSION AND FUTURE WORK

We clarified the relationship between the viewing distance and pop-up distance and established a mathematical model, the results of which we compared with experimental results. The depth of the

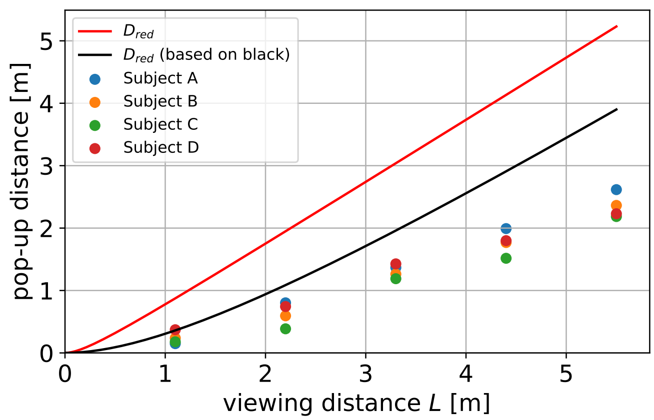

Figure 3: Comparison of two distances

mathematical model and the depth perceived by participants did not perfectly match, but we identified a factor of the discrepancy that allowed us to reduce the discrepancy a little. A future task is to achieve better agreement of the trends.

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