An Assessment of Visual Discomfort Caused by Motion-in-Depth in Stereoscopic 3D Video

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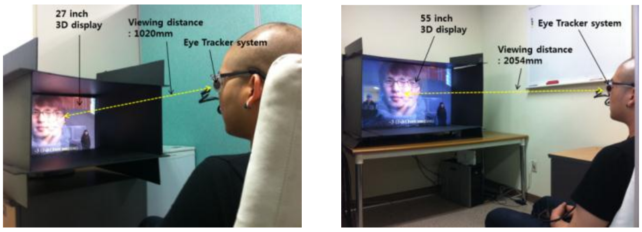
Stereoscopic image viewing comfort is one of the main problems that should be solved before the mass market proliferation of stereoscopic 3D content services. Recent research suggests that motion-in-depth could play a more important role in generating visual discomfort than lateral motion on vertical and horizontal axes in stereoscopic 3D displays [1,2,3]. However, previous studies did not consider other factors like viewing time and display size in evaluating visual discomfort. The main contribution of this paper is two-fold: (1) We analyze the effects of motion-in- depth, viewing time and display size in measuring visual discomfort. (2) The evaluation method for visual discomfort is proposed by integrating a subjective test such as a questionnaire, and an objective test such as eye blink rate detection.

The design of the experimental environment was in line of the recommendations of ITU-R BT.500-13 [4]. The experimental setup is shown in Figure 2 with the following specifications:

- Size: 55inch (passive type), 27inch (passive type)
- Aspect ratio: 16 : 9
- Spatial Resolution: 1920 * 1080
- Environmental luminance on the screen: 200 lux
- Participants: 20 subjects (14 males and 6 females, ages 20~35: medical condition checked)

Lighting conditions were held constant for all participants during all sessions. Any external illumination was completely blocked out by thick curtains. The temperature and humidity were maintained constantly and there were no vibrations or strong odors.



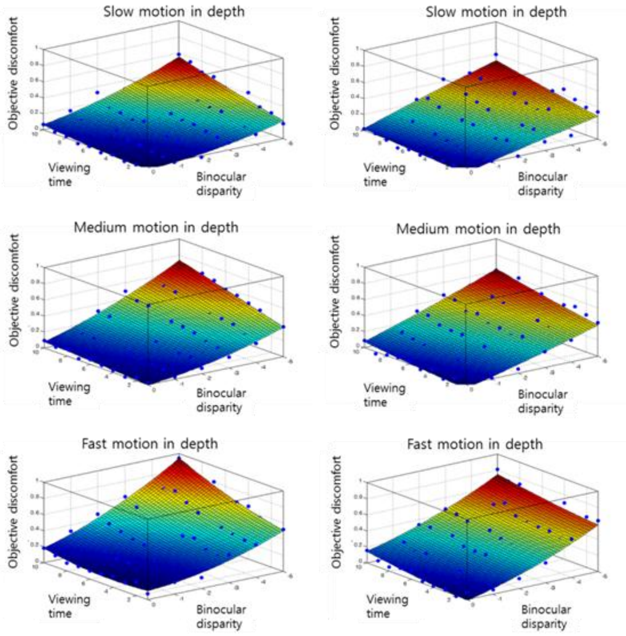
(a) (b)

Figure 1: Experimental setup: (a) 27 inch 3D TV ; (b) 55 inch 3D TV.

The subject closed their eyes and rested for 5 minutes. This stage was intended to eliminate eyestrain resulting from the subject's previous activities, and to achieve a normalized baseline for the experiment's diverse subjects. Then, the following eight questions were answered in a period of 2 minutes to check the subject's pre-stimulus subjective eyestrain. Next, the participant watched the 3-, 5- and 10-minute stereoscopic 3D video clips as shown in Table 2. While the subject was wearing polarized glasses equipped with an eye tracking device, we detected her eye blinking using eye blinking method as in [5] and measured her eyestrain response at one minute intervals with a hand held slider similar to [6]. The position of the slider could be adjusted along a graphical scale and including at regular intervals the adjective terms, [extremely uncomfortable]-[uncomfortable]-[middle]-[comfortable]-[very comfortable], in accordance with the ITU recommendation [4]. After watching stereoscopic 3D video, the subject re-answered the previously mentioned eight questions in a span of 2 minutes to measure the post-stimulus subjective eyestrain. The survey scores, representing the amount of subjective discomfort, were normalized between 0 and 1 after subtracting the pre-stimulus score from the corresponding post-stimulus score.

Visual discomfort was measured in respect to three kinds of motion-in-depth (slow, medium and fast motion), viewing time and display size. To begin with, we present our subjective assessment results based on the participants' questionnaires. An analysis of variance (ANOVA) was performed on the individual ratings of discomfort obtained through the questionnaires for each size of display. Note that we only use the median 50% of rating scores for analysis, while the upper and lower 25% of rating scores were removed as statistical outliers. As a result, only 6 questions were statistically significant across both sizes of display with a 95% significance level. Thus, we set discomfort value as an average of Q1, Q3, Q4, Q5, Q6, and Q7 rating scores. To model the subjective visual discomfort, we fit a two-dimensional function of binocular disparity and viewing time to the data for each motion in depth. To convert eye blinking rates into objective visual discomfort, we correlate the eye blinking rate with viewers' visual discomfort responses. The relationship between eye blinking rates and visual discomfort is modeled using the polynomial function.

By composite eye blinking rates and viewers' discomfort responses, we construct an objective visual discomfort model. For each size of display, observed eye blink corresponds to visual discomfort value by function h. From calculated visual discomfory values, we use the polynomial function to obtain objective visual discomfort model. Regression analysis was performed to find the optimal value of the coefficients. This is shown in Figure 2. Visual discomfort increases rapidly as the degree of binocular disparity increases in case of fast motion-in-depth. In addition, the smaller-sized display results in more eyestrain than the larger-sized display.



(a) (b)

Figure 2: Objective visual discomfort : (a) 27 inch; (b) 55 inch

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