Sensitivity of the HVS for Binocular disparity Cue in 3D Displays under Different Ambient Illumination Conditions

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Abstract —*In this paper, the sensitivity of the HVS towards binocular disparity depth cue, which is the most important cue in modern stereoscopic 3D displays, is investigated under different ambient illumination conditions. The experimental results indicate that as ambient illumination increases the sensitivity of the HVS for depth details increases or the Just Noticeable Difference in Depth (JNDD) decreases. It is expected that the investigation results will have important use cases in designing 3D display setups and 3D content production.*

I. INTRODUCTION

The depth perception ability of humans with the aid of two eyes is exploited by the stereoscopic 3-Dimensional (3D) displays to provide an additional sensation of depth in 3D video. As 3D video is a technology that exploits the properties of the Human Visual System (HVS), it is important to consider relevant human factors in designing 3D display systems and setups. One such factor to consider is the sensitivity of the HVS for perceiving depth cues in 3D displays. This factor enables the optimization of 3D content creation, capture, and display technologies. Furthermore, this information is also useful in assessing quality of 3D video. Another factor that affects the enjoyment of 3D video is contextual information about the users and environment surrounding them such as ambient illumination conditions and personal preferences.

In [1], the sensitivity for three depth cues, namely, binocular disparity, retinal blur and relative size are modeled and experimentally verified. The models proposed in [1], are used for display dependant 3D video processing in [2]. In [3], the authors suggest that the subjective 3D visual experience is affected by the ambient illumination conditions. Specifically, the overall perceived depth quality in 3D video sequences increases as the background illumination decreases. To explain the phenomenon reported in [3], in this paper, we extend the conclusions of [1] to include the effects of ambient illumination conditions. In other words, the sensitivity of the HVS for binocular disparity is measured at different ambient illumination conditions.

II. PERCEPTION OF DEPTH AND SENSITIVITY TO BINOCULAR DISPARITY

Depth can be perceived using physiological (e.g., accommodation, binocular disparity, etc) and psychological (e.g., aerial perspective, lateral motion, etc) cues available in real world [4]. Physiological cues exploit binocular vision whereas psychological cues are based on monocular vision. Binocular vision represents the vision in which the left and right eyes are utilized together. In the near field of vision (<10m) Binocular disparity is the most important depth cue that enables depth perception [4]. Furthermore, binocular disparity is the only additional depth cue provided by stereoscopic 3D displays.

In [1], it is derived that the sensitivity to binocular disparity or the Just Noticeable Difference in Depth (JNDD), Δd_S, depends on two factors, as given in (1).

$$\Delta d_s = \Delta d_{s,v} + \Delta d_{s,d} \qquad (1)$$

where $\Delta d_{S,v}$ is JNDD that depends upon the viewing distance (v) and $\Delta d_{S,d}$ is JNDD that depends upon the initial disparity (d).

$$\Delta d_s = \overbrace{0.94 \cdot \log_{10}(v) - 2.25}^{\Delta d_{s,v}} + \overbrace{K_w \cdot |d|}^{\Delta d_{s,d}} \qquad (2)$$

where, K_w refers to the Weber Constant for stimulation of binocular disparity.

According to (2), the sensitivity to binocular disparity changes linearly with the viewing distance. Thus, at a greater viewing distance, the JNDD is larger, or the sensitivity is lower. Furthermore, according to (2), as the initial disparity increases the JNDD also increases. This is due to the fact that binocular disparity acts as the stimulation for depth perception, and as the initial disparity increases the magnitude of stimulation increases. Thus, increasing the depth simulated by the stereoscopic display. According to the Weber's law [4], as the magnitude of stimulation increases, the difference in stimulation required to perceive a change of stimulation also increases. Note that this is independent of whether the initial disparity is positive (objects constituted in front of screen level) or negative. The slope of $\Delta d_{S,d}$ depends on the K_w. Fig. 1 illustrates the relationship between the JNDD and the simulated depth.

In the next section the behavior of the JNDD is investigated under different illumination conditions.

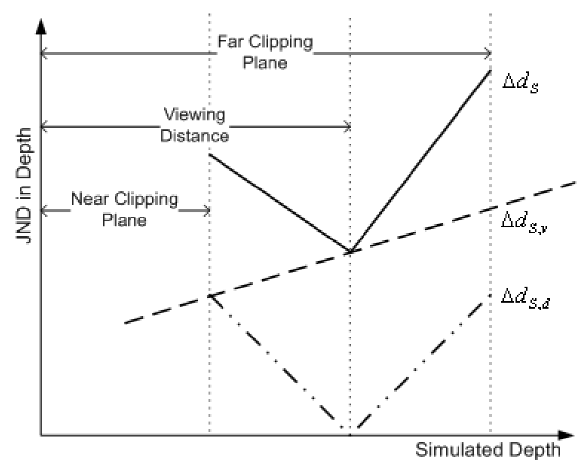

Fig. 1. JNDD for binocular disparity on stereoscopic displays

III. EXPERIMENTS

In this section, the experiments that are performed to measure the sensitivity of the HVS towards binocular disparity cue under different ambient illumination conditions are discussed. The test stimuli used in [1], which contains two images of a car, are used in the experiments (see Fig. 2). At the beginning of the experiments, both of the cars (i.e., left and right cars) are placed at the same depth level relative to the screen by initially giving the same horizontal disparity to both of them. Then, the disparity of the right object is gradually changed to reflect a movement towards or away from the user. The horizontal disparity of the left object is kept unchanged at the initial disparity level throughout the experiment as a reference point. The experiment is performed at five different initial binocular disparity levels (i.e., -16, -8, 0, 8, 16). The subjects need to signal the coordinator when they sense a change in the depth level difference between the two objects.

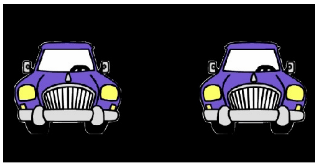

Fig. 2. The test stimuli used for the experiments

Three different ambient illumination conditions (i.e., 5, 98, 192 lux) created by the laboratory facilities are considered in the experiments. 5 lux corresponds to a dark condition, while 192 lux indicates a bright light environment. These conditions are measured using a Gretag Macbeth Eye-One Display 2 device [6].

The experiments were performed on a 46” JVC stereoscopic display with passive polarization glasses (Model number GD-463D10). The display resolution is 1920×1080 and the recommended viewing distance is 2 m from the screen [7]. The contrast ratio of this display is 2000:1. This display accepts left and right representation of 3D video. 16 observers (10 Males and 6 Females) participated in the experiments. All of the attendees were non-expert viewers, whose ages ranged from 20 to 35. The average JNDD was measured for the forward and backward movements at each disparity level using the results of the observers. The eye acuity of the subjects was tested against Snellen eye chart and the stereo vision was tested with the TNO stereo test. All of the viewers had a visual acuity of >0.7 and stereo vision of 60 seconds of arc. Furthermore, their color vision was verified with the Ishihara test, and all viewers were reported to have good color vision.

IV. Results and Discussion

The results obtained from the experiments described in the previous section are summarized in Fig. 3.

Following the pattern of the results in [1], a maximum sensitivity (lowest JNDD) at zero disparity and decreasing sensitivity (increasing JNDD) with increasing disparity is observed from the results. This observation is in accordance with the sensitivity model introduced in Section II. Most importantly, there are two main observations that arise from the results in different ambient illumination levels. Firstly, the JNDD at screen level, which is dependent upon the viewing distance, tends to increase as the ambient illumination increases. Secondly, the Weber Constant (K_w) that defines the slope of the JNDD graph tends to decrease as the illumination increase. Furthermore, it could be noted that the slope of the JNDD graphs are almost the same for both forward and backward moving objects.

Based on these experimental results, K_w in Eq. (1) could be modeled as a linear relationship with the ambient illumination level measure in lux (ξ) as given in Eq. (3),

$$K_w(\xi) = 0.001 \cdot \xi + 0.21 \qquad (3)$$

Thus, it is clear that $\Delta d_{s,v}$ is also a function of ξ. In general, the HVS is more sensitive to depth changes in darker environments than in brighter environments. Further, the variation of the sensitivity with disparity is low in brighter environments. Thus, it could be concluded that users are able to perceive finer depth details under darker environments and as a result enjoy 3D video better in darker environments [3]. However, this relationship tends to inverse at disparity values above a certain threshold.

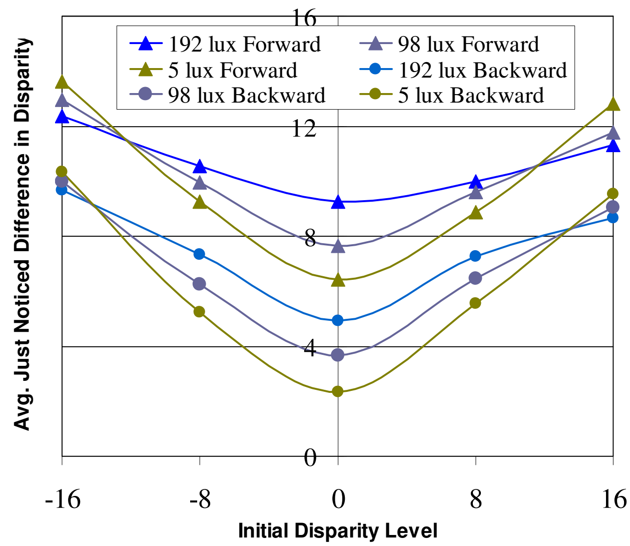

Fig. 3. Average of JNDD at various testing disparity levels

V. Conclusion

In this paper, the sensitivity of the HVS for binocular parallax depth cue has been investigated under different ambient illumination conditions. Users are most sensitive to depth changes occurring at screen level, and the sensitivity decreases as the initial disparity is increased. Most importantly, the sensitivity of the users for depth changes tends to decrease as the ambient illumination increases. Thus, it is understandable that the HVS perceives depth better in darker environment. However, this relationship tends to inverse at disparity values above a certain threshold. It could be concluded that the value addition of 3D displays over 2D displays is greater when they are used in darker environments.

Acknowledgements

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