[POSTER] BrightView: Increasing Perceived Brightness in Optical See-Through Head-Mounted Displays

Shohei Mori*
Keio University

Sei Ikeda†
Ritsumeikan University

Christian Sandor‡
Nara Institute of Science and Technology

Alexander Plopski§
Nara Institute of Science and Technology

ABSTRACT

Virtual content on optical see-through head-mounted displays (OST-HMDs) appears dim in bright environments. In this paper, we demonstrate how a liquid crystal (LC) filter can be used to dynamically increase the *perceived* brightness of the virtual content. Continuously adjusting the LC filter opacity attenuates the real scene and increases the perceived brightness without being noticed by the user. The results of our psychophysical experiment with 16 participants validate our prototype OST-HMD. Our design could be combined with existing and future OST-HMDs to improve the visibility of the virtual content in augmented reality.

Keywords: OST-HMD, optical see-through displays, illumination shedding, liquid crystal visor, brightness adaptation

Index Terms: H.5.1 [[Information Interfaces and Presentation]: [[Multimedia Information Systems]: —

1 INTRODUCTION

Photometric consistency in mixed and augmented reality (MR, AR) is important, not only to provide realistic experiences, but also to help users better understand the augmented space [1]. Applying these findings in MR and AR is challenging because most studies employ projection-based displays in a controlled environment to gain enough contrast and brightness between real and virtual objects. Optical see-through head-mounted displays (OST-HMDs) are rarely used in these scenarios since their display dynamic range is limited. The brightness range of current off-the-shelf OST-HMDs covers at most a few thousand cd/m^2. However, our visual system can perceive luminance ranging from approximately 10^{-2} to 2×10^5 cd/m^2. Although some outdoor digital signage exceeds 6×10^3 cd/m^2, building OST-HMDs with such capability is difficult [2] in terms of field-of-view, portability, energy consumption, and transparency, all of which are necessary for OST-HMDs.

To account for the reduced luminosity, a number of OST-HMDs have an attachable visor to reduce scene luminosity (e.g., Microsoft HoloLens, Epson BT-200/300, and Google Glass), or an optical combiner with low transparency (e.g., TRIVISIO LOC.20/ARS.30 and Brother AiR Scouter WD-200B). However, manually selecting and attaching visors to address different illumination conditions inevitably lowers the realism of the AR/MR experience. Even if an HMD is equipped with automatic on/off LC visors (e.g., AlphaMicron e-tint), instant switching of the shielding will cause temporal discontinuity in brightness due to the afterimages caused by the visual adaptation delays. Although it is possible to gradually decrease the amount of incident light using LC and photochromic materials (e.g., Seiko Transitions), there is no literature showing the validity of such an approach using an actual OST-HMD [3].

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*e-mail: s.mori.jp@ieee.org
†e-mail: ikeda.sei.jp@ieee.org
‡e-mail: chris.sandor@gmail.com
§e-mail: plopski@is.naist.jp

Perception of brightness changes has been investigated in detail in the field of lighting engineering. Illumination shedding is a method for reducing power consumption and improving the endurance of illumination by dimming light without making the user aware of it [4]. Shikakura et al. [5] pointed out that the detectability of brightness changes depends on the task the user faces. However, it remains unknown if this effect applies to AR tasks as well, or how it affects the perceived brightness of the virtual objects.

In this paper, we investigate if an adjustable LC visor can increase the perceived brightness of the virtual content shown on an OST-HMD, without affecting the perceived brightness of the scene. Our contributions are:

- A prototype OST-HMD equipped with an adjustable LC visors, capable of gradually changing the perceived brightness of the real scene and the virtual content.
- We show that users do not notice changes in the OST-HMD's LC visor opaqueness when the change is slow enough.
- We investigate how different dimming periods impact the perceived brightness of the virtual content.

2 PSYCHOPHYSICAL EXPERIMENT

We recruited 16 participants (14 men and two women; age 20 to 24) with normal or corrected vision and conducted a psychophysical experiment to demonstrate our prototype OST-HMD by which real light is dimmed (Fig. 1).

2.1 Experimental Setup

We conducted the experiment in a dark room. Participants sat 1 m from the flat screen (Pioneer PDP-434CMX, 952.3 mm × 536.1 mm, 1100 cd/m^2) displaying a still image as a real scene, which was kept constant throughout the experiment. During the experiment participants focused on a center point displayed at the center of the field-of-view (FOV) on a flat monitor with a disparity corresponding to the depth of the screen (50 cm).

We followed the magnitude estimation method to investigate how the perceived brightness changed. In each trial, we showed the fixation point as a virtual object of a certain brightness. During the trial, the transparency α was changed from $\alpha_s = 22.7\%$ to $\alpha_e = 9.0\%$. The duration of this change was 5, 10, and 20 s. We used a linear dimming function that decreases in steps of seven percentages or less at a time according to [5, 6]. For comparison, we
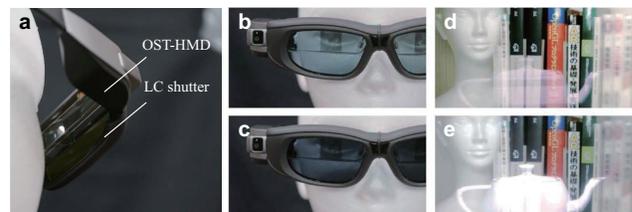
Figure 1: Our prototype OST-HMD (a-c) and conceptual images captured with a camera with automatic gain control (d, e). Our OST-HMD gradually reduces LC transparency (b to c) and increases the perceived brightness of the virtual content (Utah teapot) without making the user aware of real scene dimming (d to e).

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added a control condition where the transparency of the LC visor kept α_s for 20 s. We asked each participant to wear an OST-HMD (Epson BT-300) with shutter glasses (Root-R RV-3DGBT1). The participant was then asked to rate the magnitude of the perceived brightness of real scene or virtual point at the end of LC opacity transition, given a reference of 100.

The participants were divided into two groups. One group evaluated the virtual object for the first half of the trials, and then the real scene for the second half of the trials. The other group performed the same task in reverse order. We conducted two trials for each condition. We obtained a total of 256 raw magnitudes (= 2 targets $\times$ (1 control + 3 durations) $\times$ 2 times $\times$ 16 people).

2.2 Analysis Method

According to Stevens' law, the relationship between perceived brightness P and physical brightness S is $P = CS^k$, where C is a constant value and k is set to 0.31 and 0.6 for simple and complex scenes, respectively [7]. In our experiments, the brightness of the real and virtual objects did not change in the observation and the evaluation phases; thus, S is a constant value. However, as the transmittance of the LC changed from α_s to α_e, the luminance of the real object changed accordingly from $\alpha_s S$ to $\alpha_e S$. The ratio of the brightness of the two real scenes is $P_e / P_s = (\alpha_e / \alpha_s)^k$, where P_s and P_e are the perceived brightness before and after changing the transmittance, respectively. Since this study is different from Stevens experimental conditions, there is a possibility that this equation will not hold. We describe the deviation rate as

$$\varepsilon = \frac{P_e}{P_s} \left(\frac{\alpha_e}{\alpha_s} \right)^{-k}.$$

If ε is close to 1, then the perceived change is consistent with the actual change in the scene brightness. If ε is significantly larger than 1, a phenomenon that does not meet Stevens' experimental conditions occurs. This holds for real ε_r and virtual ε_v objects. Therefore, $\varepsilon_v > 1$ means that users perceive the virtual object as being brighter than the Stevens's law prediction. From these observations, we formulate the following three hypotheses:

H1: After a gradual increase in the opaqueness of the LC visor, users do not notice a decrease in the brightness of the real scene ($\varepsilon_r > 1$).

H2: After a gradual increase in the opaqueness of the LC, users perceive the virtual content to be brighter ($\varepsilon v > 1$).

H3: If the brightness is adjusted over a longer period, the perceived deviation values become larger.

2.3 Results

In the experiments, the transmittance of the LC panel was reduced from 22.7% to 9.0%, thus reducing the luminance of the light from the real scene to approximately 39.6%. According to Stevens' law, without a visor effect, i.e., for $e_r = 1$, participants were expected to answer that the brightness decreased by 57.4% (= $0.396^{0.6}$). This assumption holds in the control condition.

Fig. 2a shows the comparison between the control condition and our method when the LC opacity was changed over a period of 20 s. For the real scene, the deviation rate ε_r was 1.050 ± 0.064 in the control condition and 1.509 ± 0.257 with our method. Welch's t-test showed that ε_r was significantly higher ($p < 0.01$) when the transparency of the LC was changed over time (H1 holds). For the case of the virtual object, since its luminance did not change during the experiment, the perceived brightness should not change without the visor effect. The deviation rate ε_v was 1.002 ± 0.077 in the control condition and 1.158 ± 0.263 with our method. This shows that the participants did not notice a brightness change without the visor but perceived brightening when the LC was changed over time. The Welch's t-test showed a significant difference ($p < 0.01$) between the ε_v values in the two conditions (H2 holds).
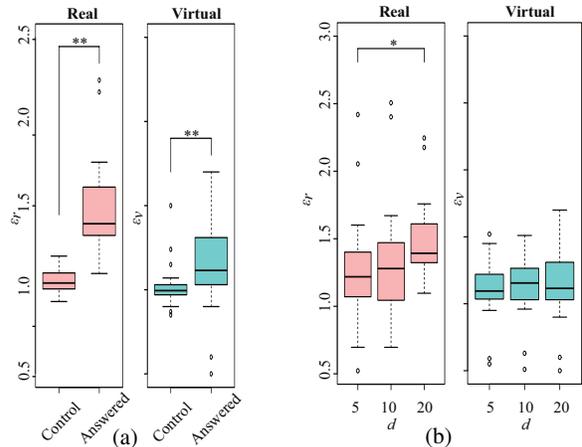
Figure 2: Experimental results for $d = 20$ (a) and impact of the LC change duration d (b). Significance: [**] p < 0.01 and [*] p < 0.05.

To understand the impact of the change duration d, we evaluated three different conditions, d=5, 10, and 20 s. The right image in 2b shows how different duration values impact the deviation rates of the real and virtual scenes. The mean value of e_r was 1.251, 1.297, and 1.477 when d was 5, 10, and 20 s, respectively. We found highly significant difference between 5- and 20-second conditions ($F_{2,93} = 3.829$, p < 0.05) with analysis of variance (ANOVA; the Tukey-Kramer test). The mean of e_v was 1.105, 1.142, and 1.148 for d of 5, 10, and 20 s, respectively. We did not find any statistically significant difference for the brightness of the virtual object with ANOVA. This result for the real scene is consistent with the the hypothesis H3 while the same effect for the virtual object could not be found.

3 CONCLUSIONS

In this paper, we presented a prototype of an OST-HMD with an LC visor to increase the perceived brightness of virtual objects by decreasing real light without it being noticed by the user. The results of the psychophysical experiments demonstrates the potential of the effectiveness of our OST-HMD. In the future, we plan to formulate the real and virtual brightness relationship in our visual perception to effectively control real and virtual light. We will also investigate how dynamic backgrounds and variety of virtual contents affect the perceived brightness.

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