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POSTER

Bridging Reality and the Virtual Environment: Perceptual Consistency and Visual Adaptation

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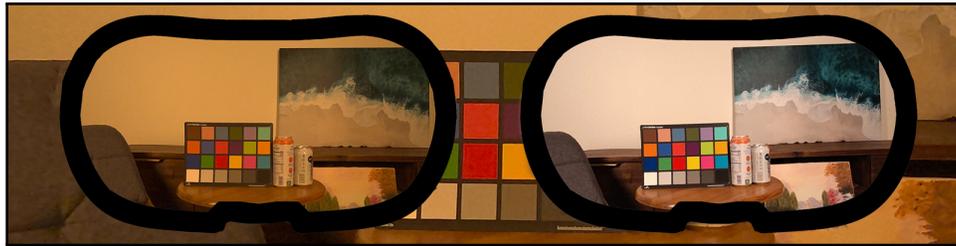


Figure 1: Images captured from HMD in warm (2500K) and low lighting condition. Background: Ground truth. Left: Results of perceptual brightness and CCT user studies. Right: Photographic camera-like brightness and CCT.

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1 Introduction

Perceptual consistency between the real and virtual world is important for immersion when using mixed reality (MR) head-mounted

displays (HMD) [Fairchild 2013]. When donning and doffing MR devices, users are susceptible to noticing differences between the real and virtual environment (e.g., brightness and correlated color temperature (CCT)). This study aims to understand human visual adaptation and perception in color and brightness within MR, achieve perceptual consistency, and enhance user experience. Our contributions include 1. designing and conducting psychophysics experiments, 2. developing mathematical models and metrics, and 3. providing a baseline for image quality to achieve perceptual consistency.

2 Our Approach

There are two important factors that contribute to perceptual accuracy that can be easily tuned: brightness and CCT. We collected perceptual and objectively measured data under two lighting conditions: 1. a neutral CCT (6500K) to study brightness tuning (Fig 2) and 2. a representative of typical indoor brightness (100 lx) to study CCT tuning (Fig 2). The subject (either the participant or the HMD) was placed in front of an 18% gray patch scene. For perceptual

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measurements, participants donned the HMD in passthrough and made adjustments until a perceptual match to the environment was reached. For the objective measurements, a spectroradiometer was used to measure the center of the HMD. The scene was luminated with standard 45° light sources creating a uniform lighting and HMD device situated perpendicularly one meter away from the gray patch.

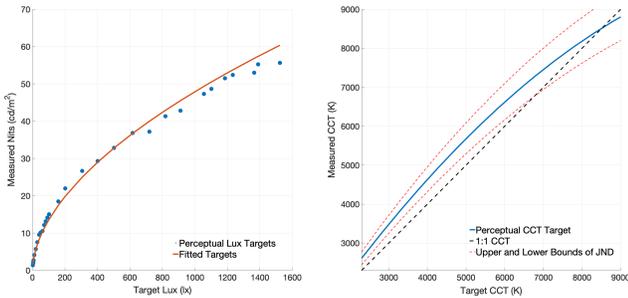


Figure 2: Left: Perceptual display brightness. Right: Perceptual CCT. 1 JND is also shown as dotted red line.

2.1 Brightness

To collect user brightness preferences, we digitally dimmed (measured in %) the display brightness. User study participants were asked to adjust the brightness to a level which was comfortable in increments of 5% for coarse tuning, and then in increments of 1% for finer tuning. For low-light conditions (<100 lux), data was collected in smaller increments since people are more sensitive to small changes in darker environments (Fig 2) [Fairchild 2013]. In parallel, we created a mathematical model to map the digital brightness measured on the display to nits creating absolute brightness mapping ensuring that the measurements are device independent. Our results corroborated existing literature that indicated human eyes are much more susceptible to brightness shifts in dimly lit environments [Fairchild 2013].

2.2 Correlated Color Temperature (CCT)

For CCT tuning, we created a tool to effectively override the white-point of the display. A carefully tuned 3-by-3 matrix based on black body curve was used to change the CCT [Fairchild 2013]. User perceptual CCT matching [Wei et al. 2022] data was collected for approximately 2300K to 9300K in 500K increments (Fig 2). Just-noticeable difference (JND) study was done to provide a perceptual limit for differences in CCT. We observed that participants preferred slightly cooler CCT on the display.

2.3 Chromaticity

After adjusting brightness and CCT, we further fine-tuned hue and chroma to develop a color appearance model (CAM) [Fairchild 2013]. Participants were asked to memorize a single color from the Macbeth ColorChecker (MCC) for up to 30 seconds and then, after donning the HMD, match the chroma and hue to the memorized color seen under different lighting conditions (3600K and 6500K).

Participants were given 10 seconds of adaptation time after donning the HMD to perform the matching. We observed that there is a preference for slightly higher saturation (Fig 3).

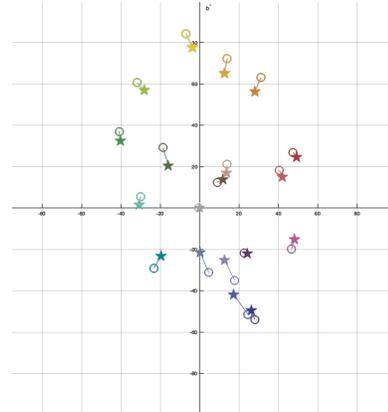


Figure 3: 18 color patches of Macbeth ColorChecker and 18% gray are mapped in CIELAB color space. Reference color is shown with a star, and perceptual color under 6500K through the display is shown with circle.

2.4 Color Discrimination

To determine color perception tolerance when comparing the memorized color of the real world to the color produced on an immersive HMD, we conducted a two-alternative forced choice (2FAC) study using color samples from the MCC under various lighting conditions. The results aid in defining color rendering targets for perceptually matching colors in MR. Our preliminary results indicate that participants are more sensitive to changes in primary colors than in tertiary colors (Fig 4) [Wei et al. 2022].

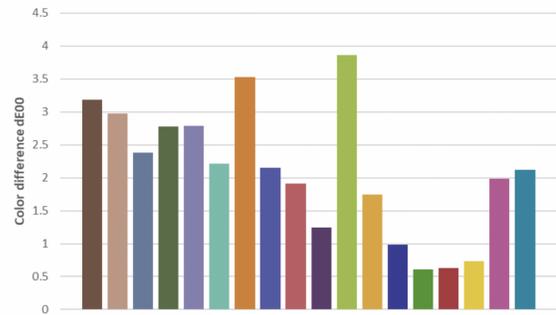


Figure 4: 2FAC results from user studies; average ΔE_{00} for 18 color patches from MCC is approximately 2.3.

3 Discussion and Conclusion

We present the above described methods as an approach to calibrating perceptual matching between the real and virtual environment. By calibrating brightness, CCT, chromaticity, and considerations of color discrimination, the virtual display can be brought into alignment with the user's physical environment (Fig 1).

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