Evaluating the effects of colour blending on optical-see-through displays for ubiquitous visualizations - Supplementary materials

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1 Colour values of experimental conditions

Table 1 and Table 2 present the colour values of the *backgrounds* under the two *lighting intensities* and visual *mark colours* used in our psychophysical study. Figure 7 of the paper presents the chromaticity of these values in the xy plane of the CIE 1931 xyY colour space.

	Dim lighting			Bright lighting		
Background	x	y	Y	x	y	Y
Brick (brick)	.570	.381	.119	.474	.429	.443
Brick (mortar)	.481	.427	.305	.371	.400	.807
Paint	.342	.535	.168	.334	.527	.320
Wallpaper	.418	.408	.101	.334	.365	.424

Table 1: Colour values in CIE 1931 xyY colour space of the mean colours of each *background* under the two *lighting intensities* used in our psychophysical study.

Mark colour	x	y	Y
Blue	.194	.202	.207
Green	.313	.547	.194
Red	.565	.314	.207
White	.309	.330	.631
Yellow	.460	.479	.607

Table 2: Colour values in CIE 1931 xyY colour space of the *mark colours* used in our psychophysical study.

2 Display tuning for colour matching task

For colour responses collected on our opaque display (Samsung S7 FE tablet) to reflect the colours shown on the Hololens 2, displays needed to be tuned to ensure the colour appearances were the same once rendered. As the characteristics of the two displays vary (e.g., different colour gamuts), we could not assume rendering the same RGB triplet would produce the same colour appearance. We briefly describe below our tuning approach, inspired from Gabbard *et al.*'s method [1].

2.1 Apparatus

Similar to the method of Gabbard *et al.* [1], we tuned our OST and opaque displays in the CIE 1931 xyY colour space, where x and y represent the chromaticity of a colour ($[0, 1]$), and Y represents its relative luminance ($[0, 1]$) as a ratio of the maximum luminance Y_{max} emitted by the display.

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Figure 1: Colorimeter used to tune colour appearances between the Hololens 2 and the opaque display with its 5mm aperture attachment, allowing us to take contact measurements on the Hololens 2 displays.

We used an off-the-shelf display colorimeter, the i1Display Pro by X-Rite [1], which has an accuracy of $\pm.004$ on x,y measurements, and $\pm 4\%$ on luminance (at 100 cd/m^2). We adapted the colorimeter to take measurements of the smaller Hololens 2 display: We designed an attachment with a smaller aperture to allow for contact measurements, reducing the colorimeter's aperture from 24mm to 5mm (Fig. 1). We validated the accuracy of the adapted colorimeter by comparing contact measurements taken with and without the attachment on an opaque display (Samsung S7 FE tablet). We measured fourteen different colours, and found an average $\Delta x = .003$, and $\Delta y = .002$. Note that although the attachment reduced the amount of incoming light, relative luminance remained near constant: $\Delta Y_{rel} = .002$ over the same fourteen colours. Y_{max} corresponded to 42.3 cd/m^2 for the Hololens 2, and 68.4 cd/m^2 for the opaque display.

2.2 Method

Colour measurements on the Hololens 2 were taken in a dark room with no light sources (≤ 1 lux ambient lighting) to minimize any effects of colour blending in our results [2, 1]. The Hololens 2 was set up to render a flat coloured opaque object covering the entire field of view of the display. Display brightness was set to maximum, and the default colour calibration was used. Measurements were taken separately for each lens to account for potential differences between lenses [3]. The colorimeter was positioned to be in contact with the the centre of each lens. Colours on the Hololens 2 were tuned to be within 2 cd/m^2 and 0.01 chromaticity distance of the colours measured on the opaque display.

References

[1] J. L. Gabbard, M. Smith, C. Merenda, G. Burnett, and D. R. Large. A Perceptual Color-Matching Method for Examining Color Blending in Augmented Reality Head-Up Display

[1] https://www.xrite.com/categories/calibration-profiling/i1display-pro

Graphics. *IEEE Transactions on Visualization and Computer Graphics*, pp. 1–1, 2020. doi: 10.1109/TVCG.2020.3044715

[2] J. L. Gabbard, J. E. Swan, J. Zedlitz, and W. W. Winchester. More than meets the eye: An engineering study to empirically examine the blending of real and virtual color spaces. In *2010 IEEE Virtual Reality Conference (VR)*, pp. 79–86. IEEE, mar 2010. doi: 10.1109/VR.2010.5444808

[3] M. Wang, J. Ding, D. M. Levi, and E. A. Cooper. The effect of interocular contrast differences on the appearance of augmented reality imagery. *ACM Trans. Appl. Percept.*, aug 2023. Just Accepted. doi: 10.1145/3617684