A Binned-Profile Approach to the Color Blending Problem

in Transparent See-Through Displays

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Abstract

Optical combiners such as transparent see-through displays allow users to view both digital content and physical objects at once. In such technologies, light coming from background objects mixes with the light originated in the display, causing what is known as the color mixing problem: a condition where the original digital hues are lost due to the mixing of light sources, and with the subsequent impact in legibility, color encodings, and general usability of the display. In this paper we present an approach aimed at preserving the original color regardless of the background and based on the observation that each display renders colors differently. For a given display we build a colorimetric profile of how such display shows colors. We validate our approach by measuring the accuracy of how the predictions of how digital and background colors mix. Then, we introduce a color correction algorithm. We investigated our approach with an extensive set of digital and background colors and different hardware configurations (we worked with projector-based and OLED displays). Finally, we elaborate on the usability and design implications of our approach to color preservation.

**Keywords**: Color Blending, Optical See-through Displays, Color Binning, Color Correction, Color Perception.

**Index Terms**: H.5 [Information Interfaces and Presentation]: H.5.1: Multimedia Information Systems — Artificial, Augmented, and Virtual Realities; H.5.2: User Interfaces — Ergonomics, Evaluation / Methodology, Screen Design, Style Guides

# Introduction

Optical see-through displays allow seeing both digital content and the real world. They come in multiple form factors: e.g. optical head mounted displays or projection-based surfaces; and are used in augmented reality (AR) as a way to enhance the real world with digital information. Although other technologies can be used for AR purposes (video-based displays), optical see-through displays have the advantage of letting users see the real world with their own eyes, without reducing its fidelity and preserving properties like lighting, blah, blah, blah. Research initiatives have used optical combiners for a wide range of applications including X, Y, Z; and a few consumer electronics have started to adopt them [Lenovo S800]. We can expect wider adoption of such technologies with the introduction of novel mobile AR platforms like Google Glass [], and the continuous development of transparent LCD [Samsung, Eyevis, Chinese] and OLED displays [].

An important aspect of optical see-through displays is that background light coming from real-world object mixes with the light emitted by the display, something that has been described as color blending [1]. Color blending is an important phenomenon as it can affect the legibility and color-encoding of digital information, and compromise the general usability of such devices. Gabbard et al. studied color blending and modeled the problem … Color blending is al present in other technologies like projector-based spatial AR. Despite being a widely acknowledge problem for the adoption of see-through displays and general AR applications, little research exists on how to correct or preserve digital colors exposed to color blending. Existing solutions, particularly from the field of spatil AR, consist in an iterative process of correcting the digital output and measuring the resulting projection. PROBLEMS WITH THIS APPROACH.

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In this paper we argue that an approach to preserve digital color in transparent see-through displays relies on its *prediction* accuracy, i.e. the capacity to estimate the blend resulting from a given background and digital colors and for a particular display. When trying to preserve a digital color, predictions are then used to find an alternative digital color which, upon blending with such background, comes closest to the desired digital color. We investigated three approaches to blend prediction: the *direct model*, the *chromatic adaptation transformation* (*CAT) model*, and our novel *binned profile model*. The binned profile model is based on the observations that (1) each display renders colors differently, and (2) that a background color changes as it passes a display media before blending.

We used a colorimeter to validate the predictive accuracy of the different prediction models (direct, CAT and binned profile) using different alternatives to estimate the effect of the background (pure background or reduced by the display media). Results showed that our profiled-based color blending prediction outperforms other methods by min XX *just-noticeable differences* (JNDs). Further, we compared the accuracy of color preservation using the binned profile model against using the direct model, with and without the effect of the display on the background. Results showed our model outperforms the direct model correcting a wider range of colors and with higher accuracy.

This paper contributes to the field of augmented reality in several ways: 1) we propose a novel approach to color preservation for optical-see through displays; 2) we validate our approach against other possible solutions; 3) we discuss the implications of color blending for situations where color preservation is not possible or contrast preservation is preferred; and finally 4) we discuss the challenges associated to incorporating our algorithm into everyday optical see-through display platforms.

# Color Blending and Preservation [1 column]

Describe color blending based on Gabbard et al.

Show Gabbard’

[Figure with Images Color Blending]

Describe what happens in the image (lay our Gabbard’s formula for color blending).

Introduce the Lab color space

Laid out then our formulation of color preservation.



Figure 1. Color blending as described by Gabbard et al. [1]: “source light (L1), background (B), and AR display light (L3) have a direct effect on the blended light that enters a user’s eye (L4), and thus on the perceived color (C)”

# Related Work [1 Column]

Field-studies of augmented reality.

Relocation of content.

Colorimetric compensation in projector-based see-through displays.

Color correction in projector-based spatial augmented reality

# Experimental Test-Bed

Box

Colorimenter

LCD as a background generator (discuss image)



Figure 2. Background color set in the experimental set-up.

Projector display 1

Projector display 2

OLED display

Software

# Color Prediction

Direct Model (show the binned-color space)



Figure 3. Left: The digital color #FF0000 and as displayed by different optical see-through displays. Right: The background color, and as it is seen through different optical see-through displays.

However, the colors involved in the blending differ from the “pure” ones assumed by the direct model. Figure 3-left shows

Show the new conception of color blending as presented in figure 4.

Say that to investigate this effect we took two approaches: cat and binned profile.

CAT (show image with the three cats for each display 3x3)

Binned-profile (show image with the binned-profile of each display), say that we are interested in this given the high variation of the CAT profiles. Tell hw we built each profile. Say that a limitation of this approach is the memory overhead (bytes per color pair).

## Data Collection

Describe how we collected data for each display

Describe how we computed the blending prediction for each model.

## Results

Show one sample 3D image for a given display with the direct model and the binned profile to demonstrate the differences in the blue dots.

Show the BIG bar charts image (5 models X 3 displays X 27 backgrounds)

# Color Preservation

Correctable range (by bg color)

# Discussion

Colors that can be corrected regardless of the background

Camera-based color correction

# Conclusions



Figure 4. Color blending including the screen distortions for background and digital colors.

References

1. Gabbard, J.L., Swan, J.E., Zedlitz, J., and Winchester, W.W. 2010. More than meets the eye: An engineering study to empirically examine the blending of real and virtual color spaces. In Proc. VR '10. IEEE, Washington, DC.
2. .