

# Color Correction for Optical See-Through Displays Using Display Color Profiles

Srikanth Kirshnamachari Sridharan<sup>\*1</sup>, Juan David Hincapi-Ramos<sup>†1</sup>, David Flatla<sup>‡2</sup> and Pourang Irani<sup>§1</sup>

<sup>1</sup>Department of Computer Science, Winnipeg, Manitoba, University Of Manitoba

<sup>2</sup>Department of Computer Science, Saskatoon, Saskatchewan, University Of Saskatchewan

## Abstract

In optical see-through displays, light coming from background objects mixes with the light originating from the display, causing what is known as the color blending problem. Color blending negatively affects the usability of such displays as it impacts the legibility and color encodings of digital content. Color correction aims at reducing the impact of color blending by finding an alternative display color which, once mixed with the background, results on the color originally intended.

In this paper we model color blending based on two distortions induced by the optical see-through display. The render distortion explains how the display renders colors. The background distortion explains how background colors are changed by the display material. We show the render distortion has a higher impact on color blending and propose binned-profiles (BP) descriptors of how a display renders colors to address it. Results show that color blending predictions using BP have a low error rate within 9 just noticeable differences (JND) in the worst case. We introduce a color correction algorithm based on predictions using BP and measure its correction capacity. Results show light display colors can be better corrected for all backgrounds. For high intensity backgrounds light colors in the neutral and CyanBlue regions perform better. Finally, we elaborate on the applicability, design and hardware implications of our approach.

**CR Categories:** I.3.3 [Computer Graphics]: Three-Dimensional Graphics and Realism—Display Algorithms I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Radiosity;

**Keywords:** radiosity, global illumination, constant time

**Links:**  DL  PDF

## 1 Introduction

Optical see-through (OST) displays allow users to view digital content and physical objects simultaneously. They come in multiple form factors (e.g. head mounted displays, projection-based and transparent LCD and OLEDs) and are widely used in augmented

reality (AR) applications including medical, maintenance, education and training (see [4][7] for a comprehensive list of applications). OST displays can be additive (have their own light source e.g. projection-based displays or transparent OLED) or subtractive (filter white light from an external source e.g. LCD). With a few consumer electronics starting to adopt them [12][9] and the continuous development of transparent OLED (Futaba Corporation [link], Fujitsu [link], Winstar [link]) and LCD displays (Samsung NL22B [link], Eyevis [link]) we expect they will be widely available.

An important aspect of additive OST displays is that light coming from real-world objects mixes with the light emitted by the display: also known as color blending [10]. Color blending is an important issue as it affects the legibility and color-encodings of digital information and compromises the general usability of such devices. Existing solutions include using a spatial light modulator (SLM) to block background light [17][19], an approach requiring extra hardware on the display at the cost of non-transparency. Color correction is another solution where the system finds an alternative digital color which, upon blending with the background, comes closest to the desired color [32].

In this paper we argue that effective color correction depends on an accurate color blending model. We propose a model that takes into account two distortions induced by the display (see Figure 1): the render and background distortions. The render distortion explains how a particular display renders colors. The background distortion explains how the display material (acrylic or glass) changes background colors. Characterizing these two distortions enables us to use our model to predict color blending, which in turn allows us to create an effective color correction algorithm.

## 2 Exposition

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in

<sup>\*</sup>e-mail: kirssri@cs.umanitoba.ca

<sup>†</sup>e-mail: jdhr@cs.umanitoba.ca

<sup>‡</sup>david.flatla@usask.ca

<sup>§</sup>e-mail: irani@cs.umanitoba.ca

culpa qui officia deserunt mollit anim id est laborum.

$$\sum_{j=1}^z j = \frac{z(z+1)}{2} \quad (1)$$

$$x \ll y_1 + \dots + y_n \quad (2)$$

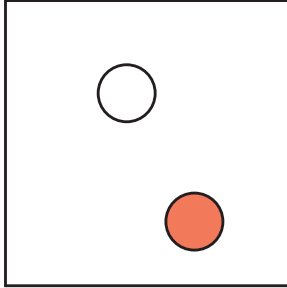
$$\leq z \quad (3)$$

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

### 3 Exposition

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum. Lorem ipsum



**Figure 1:** Sample illustration.

dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

### 4 Exposition

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

### 5 Conclusion

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

### Acknowledgements

To Robert, for all the bagels.