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# Background- and Ambient-aware Image Visibility Enhancement for Transparent Displays

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## Abstract

*The transparent display has attracted attention from industrial and research fields due to its broad applications in many fields, including mobile displays, wearable devices, and head-up displays in automobiles. However, the visibility of images on transparent displays is degraded under bright ambient conditions and cluttered backgrounds. This paper analyzes visibility degradation under various backgrounds and ambient conditions. Then, a background- and ambient-aware visibility enhancement algorithm is proposed, where the transmittance rejection rate for degraded pixels is adjusted to enhance the visibility. The experimental results show that the proposed algorithm can enhance visibility under various backgrounds and ambient conditions, which promises the applicability of a transparent display in outdoor environments.*

*Keywords: Transparent display, Visibility Enhancement, Background-aware, Ambient-aware, Bright ambient*

## Introduction

Transparent display has been extensively studied for several decades due to its broad applications in many fields, including mobile displays, wearable devices, and head-up displays in automobiles. The transparent display allows information to be displayed without blocking the background, minimizing intrusion into the general view. However, compared to conventional non-transparent displays, the visibility of images on transparent displays becomes more degraded under bright ambient conditions, especially with close background objects. This paper analyzes visibility degradation under various backgrounds and ambient conditions.

When an image is viewed on a transparent display, not only the light emitted from the image on the display but also the light transmitted from the surroundings is perceived simultaneously, which can be formulated as follows:

$$L_d = L_e + L_b + L_g$$

where $L_d$, $L_e$, $L_b$, and $L_g$ denote the total luminance entering the viewer's eyes, the emission luminance of the image on the transparent display, the luminance of transmitted light through the transparent display from the background, and glare luminance reflected by the surface of the display, respectively. Compared to the conventional non-transparent displays, the visibility of transparent displays becomes degraded by additional lights ($L_b$, and $L_g$) according to the ambient conditions. Thus, several studies have been conducted on how the visibility of images on the transparent display is perceived, focusing on the influence of transparent display characteristics, such as ambient condition, transmittance, and pixel structure, on visibility degradation. Nevertheless, no studies have been conducted on the visibility enhancement algorithm for the transparent display under various ambient conditions.

This paper analyzes how the visibility of images on the transparent display is degraded under different ambient conditions and different backgrounds. Then, a visibility enhancement algorithm is proposed based on the background pattern and ambient analysis.

The main contributions of this paper are as follows.

- This paper analyzes the visibility degradation under various ambient conditions and background objects.
- This paper proposes an image visibility enhancement algorithm for a transparent display.
- The qualitative evaluation shows that the proposed algorithm can enhance visibility under various backgrounds and ambient conditions.

**Table1: Challenges of the transparent display**

| Scenario 1 (Far and dynamic background) | Scenario 2 (Close and static background) |
|---|---|
| Non-uniform spatial color distribution | |
| Low spatial resolution, artifacts | |
| Shadow | |
| Blurred backgrounds when seeing through the display | Distraction by background patterns |
| Visibility degradation in bright ambient | (Further) visibility degradation in bright ambient |
| Color degradation by lights (behind display) | |
| Focus – Convergence mismatch | |

***Figure 1. Visibility degradation according to the background brightness.***

## Challenges of Transparent Display

Potential applications of the transparent display can be implemented in two different scenarios depending on the background of the display. The first scenario is the display with far and dynamic background, e.g., head-up display or advertisement display. The second scenario is the display with close and fixed background, e.g., invisible display on a cockpit or furniture. For those two scenarios, the challenges of the transparent display are summarized in Table 1.

First, the transparent display can be distracted by background patterns, especially in the scenario 2. The transparent display is bright enough to hide the background patterns when displaying solid-pattern contents. However, contents of weak patterns can be distracted by the background patterns. This becomes more obvious when the background is close to the display (scenario 2).

When the light source is located behind the transparent display, shadows can significantly affect the quality of the displayed contents. For example, the object between the display and the light source can be observed through the display. Further, the light source behind the display causes color degradation.

In the scenario 2, observers often should see the background through the display, where the background is blurred, resulting in reduced user experience.

The visibility is reduced in brighter ambient environments. Especially, in scenario 2, the visibility degradation is significant due to the reflection from the close background. The amount of visibility degradation depends on the brightness of the background. As shown in Fig. 1, the visibility is more degraded for the brighter background than the darker background.

## Image Visibility Enhancement Algorithm

According to the visibility degradation analysis experiment, visibility is more degraded when the ambient condition is brighter, and the background objects are closer. The direction of the ambient source also influences the amount of visibility degradation. Further, the characteristics of background objects also influence the amount of visibility degradation, such as color, brightness, and reflectance rate.

Based on the analysis, we propose a background- and ambient-aware image visibility enhancement algorithm for transparent displays. As shown in Fig. 2, the background image is first analyzed to obtain a spatially varying background-aware degradation mask b(x), and the ambient visibility degradation degree a is calculated based on the ambient sensor output. Here, the background image is captured by the background camera in real-time or in the pre-capturing process according to the applications. Then, the input image is processed to enhance the visibility by adjusting the transmittance rejection rate for degraded pixels. The adjustment amount of the transmittance reject rate is based on the pixel-wise background-aware mask b(x) and ambient-aware visibility degradation degree a. The transmittance rejection rate for each pixel is increased as b(x) has a higher value, while the transmittance rejection rate is increased as a is increased.

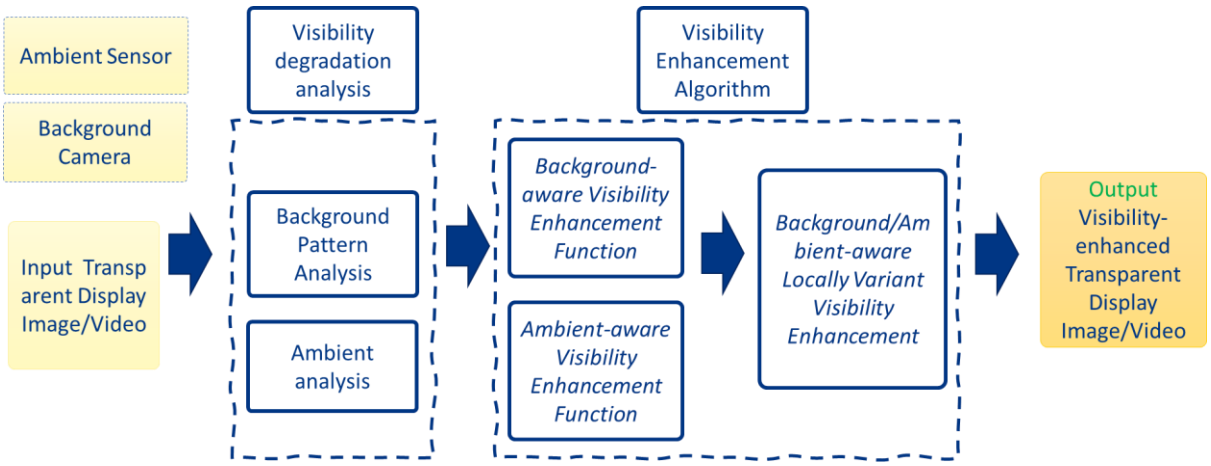


***Figure 2 The block diagram of the proposed visibility enhancement algorithm***

## Results

In order to evaluate the proposed algorithm, we conducted a qualitative evaluation on the PLAYNITRIDE transparent Micro LED display. The size and resolution of the display are 7.56 inch and 115 ppi (720x480). The transparency is 60% and the max screen brightness is 1,000 cd/m$^2$.

The qualitative evaluation shows that the proposed algorithm can enhance visibility well under various backgrounds and ambient conditions. Fig. 3 shows an example of the proposed algorithm under bright ambient conditions. The user evaluation study was also conducted, where 15 participants were asked to rate the visibility of contents in four different ambient conditions: 0, 100, 1000, 2000 Lux. The experiment showed that the proposed algorithm improved the visibility by 5% for w/o background pattern and by 51% for w/ background pattern scenarios.

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***Figure 3 An example of the proposed algorithm. Left: original image under bright conditions, and Right: processed image under bright conditions.***