Inter-Reflection Compensation for Immersive Projection Display

Hitoshi HABE
Nara Institute of Science and Technology
8916-5, Takayama, Ikoma, Nara, JAPAN
habe@is.naist.jp

Nobuo SAEKI Takashi MATSUYAMA
Graduate School of Informatics, Kyoto University
Yoshida-Hommachi, Sakyo, Kyoto, JAPAN
http://vision.kuee.kyoto-u.ac.jp/

Abstract

This paper proposes an effective method for compensating inter-reflection in immersive projection displays (IPDs). Because IPDs project images onto a screen, which surrounds a viewer, we have perform out both geometric and photometric corrections. Our method compensates inter-reflection on the screen. It requires no special device, and approximates both diffuse and specular reflections on the screen using block-based photometric calibration.

1. Introduction

This paper proposes an effective method for compensating inter-reflection in immersive projection displays (IPDs). IPDs project images onto a screen, which surrounds a viewer, so that he or she can enjoy immersive experiences (Fig. 2). When we utilize IPDs, we have to perform both geometric and photometric corrections simultaneously for projecting high-fidelity images on the screen. In this paper, we propose a simple but effective method for compensating inter-reflection observed on a concave screen, as shown in Fig. 2.

It is well-known that because specular reflection observed on a screen's surface depends on the outgoing direction, and therefore its treatment requires excessive measurements or computation. Therefore, some compensation methods assume the screen to be a Lambertian surface. For example, Mukaigawa *et al*. analytically solved the inverse problem of inter-reflection based on the radiosity method[1]. In order to treat specular reflection, Seitz *et al*. measured the entire transportation of light including its diffuse and specular components using a laser beam[2]. Although theoretically correct solutions are obtained for the inverse problem, the measurements would be insufficient for practical use.

2. Proposed Compensation Algorithm

The proposed algorithm captures the reflection on the surface by projecting square patterns (*e.g.* 64 $\times$ 64 pixels).

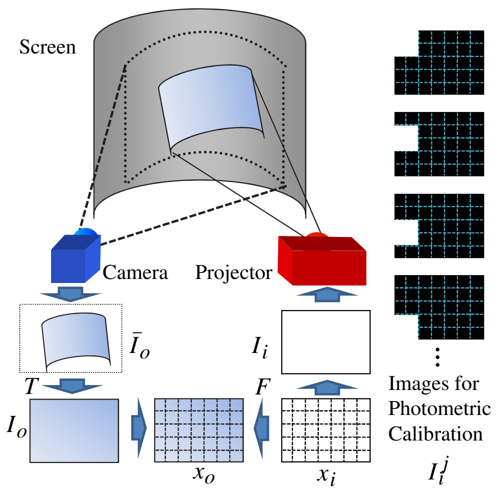


Figure 1. Overview of Proposed Method.

While a single pixel emits insufficient power to observe the reflection, square patterns give enough power and enable the observation using a conventional camera. This allows us to calibrate our compensation system without using any special devices such as laser beams. The proposed system comprises a projector, hemispherical screen, and camera. The camera is placed at the viewer's position and used for observing what he or she is observing. Hereafter, "projector plane" and "camera plane" denote the image planes in the projector and camera, respectively.

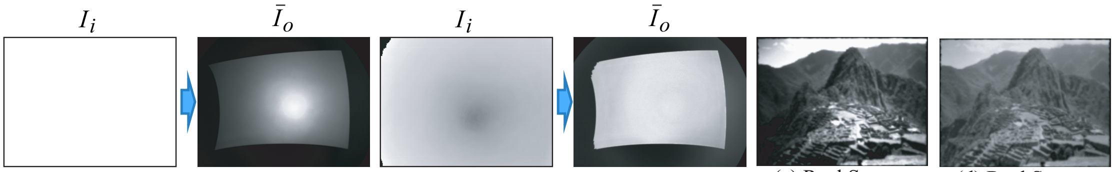
2.1. Calibration

Each device is first calibrated, *i.e.*, the geometrical distortion and photometric characteristics are corrected. The geometric relationship between the projector, screen, and camera is then determined and the reflection on the screen is measured as follows.

2.1.1 Geometric Calibration

Colored gray code patterns are projected onto the screen and their images are captured by the camera. The color patterns are more easily decoded than conventional B/W gray codes, particularly when inter-reflection is observed on the

Figure 2. IPD.



(a) White - Not Compensated (b) White - Compensated (c) Real Scene - Not Compensated (d) Real Scene - Compensated

Figure 3. Experimental Results.

screen. We can now transform an image in the camera plane $\bar{I}$ to the corresponding image on the projector plane I as follows:$I = T\bar{I}$.

2.1.2 Photometric Calibration

For photometric calibration, the projector plane is divided into N square blocks $B_k (k = 1, \ldots, N)$. Subsequently, we approximate the effect of inter-reflection to be uniform in each block, that is, the entire transportation of reflection can be described by $x_o = F x_i$, where x_o and x_i, corresponding to an observed image and an input image, respectively, are N-dimensional vectors whose components denote the average intensity in each block. Obtaining F is one of the goals of photometric calibration (Fig. 1).

Subsequently, images I_i^j are generated, where the neighboring four blocks are filled with white as shown in Fig. 1. We obtain $\bar{I}_o^j$ by projecting I_i^j on the screen, and transform it to the projector plane, *i.e.*, $I_o^j = T\bar{I}_o^j$. From I_i^j and I_o^j, we can generate x_o^j and x_i^j and derive $F = X_o X_i^-$, where X_o and X_i are matrices whose column vectors are x_o^j and x_i^j, respectively, and X_i^- denotes the generalized inverse of M_i. By filling neighbouring four blocks with white, accurate approximation of inter-reflection with higher S/N is obtained, because a large block in I_i^j, which emits higher power on the screen, reduces the noise of the observation, and inter-reflection can be accurately approximated by higher dimensional x_o and x_i, *i.e.* smaller B_k.

Further, we recode the ratio r between I_o^j and x_o^j for all the pixels to accurately compensate the direct reflection:

$$r(x, y) = \sum_j f(x, y, j) \frac{m_o^j}{I_o^j(x, y)}, \qquad (1)$$

where f is the weight function that takes a non-zero value when $I_o^j(x, y)$ corresponds to direct reflection.

2.2. Inter-Reflection Compensation

When an ideal image $\bar{I}_o^{\text{ideal}}$, *i.e.* an image should be observed from the camera, is provided, we obtain an input image I_i^{ideal} that compensates inter-reflection by the following processes.

First, $\bar{I}_o^{\text{ideal}}$ is transformed to the projector plane: $I_o^{\text{ideal}} = T\bar{I}_o^{\text{ideal}}$. Then, following the derivation of x_o^{ideal} whose components denote the average intensities of each block in I_o^{ideal}, we obtain $x_i^{\text{ideal}} = F^{-1} x_o^{\text{ideal}}$, which compensates reflection.

Finally, each pixel in I_i^{ideal} is calculated as follows:

$$I_i^{\text{ideal}}(x, y) = r^{-1}(x, y) x_i^{\text{ideal}}(k) + \sum_{j \neq k} x_i^{\text{ideal}}(j), \qquad (2)$$

where the k-th component of x_i^{ideal} includes (x, y).

3. Experimental Results

Fig. 3 illustrates the experimental results of the proposed method. First, a white (uniform) image is used as the ideal image. When no compensation method is applied, *i.e.* just project the white image, prominent inter-reflection is observed in the captured image $\bar{I}_o$, as shown in (a). By applying the proposed method, inter-reflection is successfully compensated, and the observed image has almost uniform intensities, as shown in (b).

When we use a real image, the images shown in (c) and (d) are observed. From these results, we can observe that the proposed method is effective for real images.

4. Summary

This paper proposed a method for compensating inter-reflection on concave screen. It does not require any special devices such as a laser beam to calibrate inter-reflection. Further, it does not assume the screen to be Lambertian. Hence, it is effective particularly for compact IPDs.

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References

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