A Fast Compensation Method of Inter-reflection for Pattern Projection onto a Non-planar Surface

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Abstract

If a pattern is projected onto a non-planer screen, the desired view cannot be correctly observed due to the influence of inter-reflections. This paper proposes a new algorithm that compensates for inter-reflections based on the radiosity method. The significant advantage of our method is that iterative calculations are not necessary because it analytically solves the inverse problem of inter-reflections.

1. Introduction

When a pattern is projected onto a concave screen, the reflected light on the surface illuminates other surfaces again and the desired view cannot be correctly observed. Recently, Bimber et al. [1] proposed a method to compensate inter-reflections based on the radiosity method [2]. However, their method requires iterative calculations because the inter-reflection problem is not analytically solved.

In this paper, we show a fast calculation algorithm for compensating inter-reflections without iterative calculations. In the computer vision field, Fournier et al.[3] proposed a photometric analysis method which takes inter-reflections into account and our approach is similar to this idea. By analytically solving the inverse problem of inter-reflections, our method does not require any iterative calculation. Moreover, our method can treat not only 2-bounce reflections, but also the multiple-bounce ones.

2. Compensation Algorithm

2.1. Modeling of Pattern Projection

In this research, we focus on how to reduce the influence of inter-reflections. Therefore we simplify the task setting. We use a set of a projector and a range finder, and assume that the non-planar screen has a white Lambertian surface. We also assume that the user's position is fixed and known.

First of all, we assume the simplest case where inter-reflection does not occur. Now, we consider the ideal situation that the projection value (video signal to the projector) corresponding a white patch i is p_i, and that the patch is illuminated from the direction of the surface normal by illuminance L_i and desired radiance c_i is obtained. In general, the projection value and the illuminance on the screen have a nonlinear relationship that depends on the individual equipment. Therefore, we directly measure the illuminance of the projector light using an illuminometer. This relationship can be formulated using function f as follows,

$$L_i = f(p_i). \tag{1}$$

If the reflectance is r, the radiance is expressed as follows,

$$c_i = rL_i. \tag{2}$$

Next, we assume that the patch i leans θ_i from the direction of the projection. Then, the radiance c'_i attenuates according to the incident angle as follows,

$$c'_i = rL_i \cos\theta_i. \tag{3}$$

Finally, we assume more general situations in which inter-reflections occur. Radiosity is a method for calculating the propagation of energy in an entire scene based on a form factor. The form factor F_{ji} denotes the propagation ratio of energy that patch i receives from patch j. Since the form factor is independent of the projected pattern and the reflectance of the screen, it can be calculated in advance. The radiance c'_i which takes inter-reflection into account based on the form factor is calculated by

$$c'_i = rL_i \cos\theta_i + r\sum_j F_{ji}c'_j. \tag{4}$$

2.2. Compensation for Inter-reflection

Eq.(4) indicates the situation where the wrong radiance c'_i is obtained by the unsuitable illuminance L_i. Now let's consider the ideal situation where the correct radiance c_i is obtained by the compensated illuminance $\hat{L}_i$ as follows,

$$c_i = r\hat{L}_i \cos\theta_i + r\sum_j F_{ji}c_j. \tag{5}$$

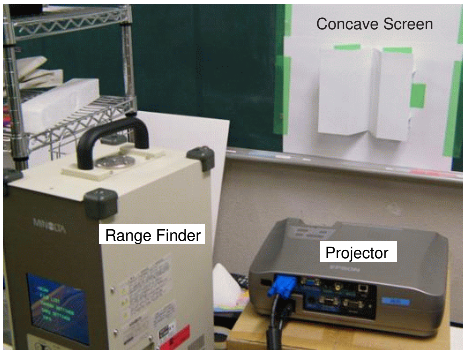


Figure 1. Overview of the system.

It is important that Eq.(2) remains valid because it describes just the relationship between illuminance and radiance. The relationship is independent of the existence of inter-reflections. Therefore, the compensated illuminance $\hat{L}_i$ is calculated by

$$\hat{L}_i = \frac{c_i - r\sum F_{ji}c_j}{r\cos\theta_i} \quad (6)$$

$$= \frac{rL_i - r\sum F_{ji}rL_j}{r\cos\theta_i} \quad (7)$$

$$= \frac{L_i - r\sum F_{ji}L_j}{\cos\theta_i} \quad (8)$$

$$= \frac{f(p_i) - r\sum F_{ji}f(p_j)}{\cos\theta_i}. \quad (9)$$

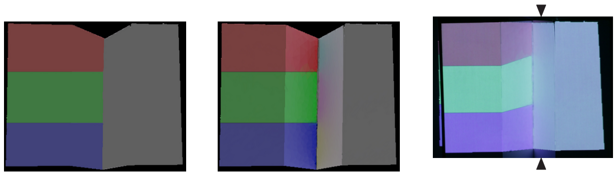
Since the function f is a monotonically increasing function, the inverse function f^{-1} can be easily defined. Hence, the compensated projection value to the patch i is calculated by

$$\hat{p}_i = f^{-1}\left(\frac{f(p_i) - r\sum F_{ji}f(p_j)}{\cos\theta_i}\right). \quad (10)$$

In this algorithm, the compensated pattern is directly calculated from Eq.(10) without any iterative calculation. Moreover Eq.(10) can compensate for multiple-bounce reflections.

3. Experimental Results

Figure 1 shows the experimental environment. The screen has a convex part whose angle is about $60°$. The 3D shape of the screen was modeled as a set of 4200 triangular patches. Figure 2(a) is a projected color pattern. The left half is divided into three stripes of R, G and B, and the right half is uniform gray so that we can easily confirm the effectiveness. In the compensated pattern (b), the opposite side to the green changes the color from gray to cyan because this gray part is predicted to be affected by indirect green illumination. In fact, the right half of the actual appearance is a uniform gray as shown in (c).



(a) Original (b) Compensated (c) Actual view

Figure 2. Photometric compensation for color pattern.

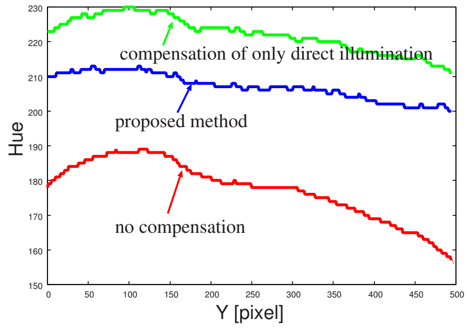


Figure 3. Transition of hue along the concave edge.

For a quantitative evaluation, we analyzed the hue of the right part of the screen. The transition of the hue is checked along the vertical line between the ▲ and ▼ marks in Fig.2(c) where the inter-reflection is strongly observed. Figure 3 shows the transition of the hue. Since the hue of the proposed method is almost uniform compared with the other two results, we can confirm that the influence from inter-reflection is drastically reduced.

In this experiment, compensation could be undertaken within 0.12 second for each pattern using a Pentium4 2.53GHz. This speed is fast enough for many purposes such as a presentation. Moreover, if the number of patches of the 3D screen shape can be reduced, it will be possible to compensate for inter-reflection in video in real time.

4. Conclusion

Our future work will be to deal with a glossy screen where specular reflections are observed. As well, a faster compensation process will be necessary to project movies.

References

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