Generating Perceptually-Correct Shadows for Mixed Reality

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ABSTRACT

When human cannot perceive the inconsistency of artificial shadows which are not physically correct, they are acceptable as “perceptually-correct” shadows. This paper focuses on the simplification of light-source models for generating the perceptually-correct artificial shadows. First, we conducted subjective evaluations to obtain knowledge about the human perception of the shadows. Then the knowledge was applied to control the resolution of the light-source map to generate perceptually-correct artificial shadows. Comparative studies among artificial and real shadows justified perceptually correctness. All experiments were done using still images, not videos. Our research becomes a reference to determine the resolution of light-source map in an MR scene.

CR Categories and Subject Descriptors: [I.3.7] Three- Dimensional Graphics and Realism

Additional Keywords: Photometric consistency, Soft Shadow, Image Based Lighting, Subjective Evaluation Experiment

1 INTRODUCTION

When we present virtual objects in an MR space, achieving geometric, temporal, and photometric consistency between the real and virtual worlds is important [1]. Photometric consistency consists of sensing properties of lights and photometric rendering of virtual objects. Especially, rendering shade and shadows significantly affect the presence of virtual objects [2]. For example, Haller et al. enhance the presence of virtual objects in MR space by casting real shadows onto virtual objects and virtual shadows onto real objects with each other [3].

Sensing photometric properties is very time-consuming for online processing [4], and calculating all of the dynamically changing global photometric conditions is difficult. As an approach to realize sensing and rendering in real time, Kanbara et al. proposed an MR system using an ARToolkit marker attached a small mirror dome to acquire both the geometric and photometric properties [5]. Supan et al. also proposed Image Based Shadowing to render soft shadows by calculating shadow buffer from a down-sampled light-source map [6]. Their research showed the necessity of reducing the resolution of sensing and rendering to achieve photometric consistency in MR. However, how accurately photometric properties should be sensed and rendered so that observers do not feel a sense of discomfort in MR has not been well investigated.

In this paper, we describe our trial to find the resolution of a light-source map to generate perceptually-correct shadows. First, we conduct a set of systematic subjective evaluations to obtain knowledge about the relation between the size and arrangement of light-sources and the human perception of the shadows generated by light-sources. Then the knowledge is applied to control the resolution of the light source map to generate perceptually-correct artificial shadows.

2 EVALUATIONS ON PERCEPTUALLY-CORRECT SOFT SHADOWS

2.1 Size of a single area light-source

As shown in Figure 1, Cones A and B are put in a CG space. We chose cones since their shape are simple and clearly indicate the lighting condition changes. We assume that Cone A is a real object and Cone B is a virtual in an MR scene. Area-Light A is a real light-source for Cone A, and Area-Light B is a virtual light for Cone B. The size of Area-Light A is the standard stimulus (SS), and the size of Area-Light B is the comparison stimulus (CS). Subjects were requested to change the size of CS until they perceived that the appearance of Cone B’s shadow resembled Cone A’s shadow generated by SS. The difference between CS and SS is assumed to be the difference threshold (DT) for SS.

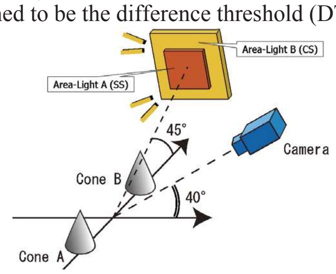

Figure 1. Evaluation by changing size of area light-source

2.1.1 Results and discussion

We randomly presented three standard stimuli. The results indicate that DT becomes larger when the size of SS. This tendency is determined to be statistically significant by the multiple comparison method. From the shadow generation point of view, when the size difference caused by the sampling error of a light-source map is less than DT, generated shadows are perceptually-correct.

2.2 Arrangement of multiple area light-sources

In this section, Area-Light A is CS and Area-Light B is the SS. The sizes of CS and SS are identical. But CS is quartered and the distances between the pieces are changed. As shown in Figure 2, the dotted line surrounding CS is the solid angle of CS (Ω_A), which changes when the pieces distance. The minimum value of solid angle ratio Ω_A/Ω_B is 1. Subjects were requested to enlarge the distance between the pieces until they could perceive that the appearance of Cone A’s shadow became different from Cone B’s shadow generated by SS. Ω_A/Ω_B is assumed to be the DT for SS.

2.2.1 Results and discussion

We randomly presented three standard stimuli. The DT becomes smaller when the size of the area light-source increases. However, this tendency is not significant in the multiple comparison method. The result indicates that we can generate perceptually-correct shadows by merging multiple real light-sources into a single virtual one, when Ω_A/Ω_B is less than the DT (around 1.3).

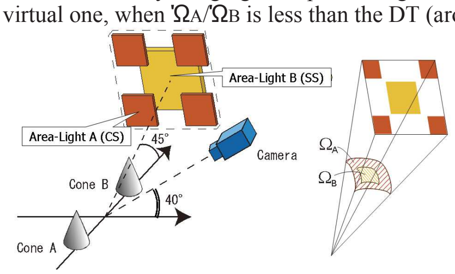

Figure 2. Evaluation by changing distance of multiple light-sources

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3 REDUCING RESOLUTION OF LIGHT-SOURCE MAP

3.1 Lighting conditions

We assume the target lighting condition for our experiment to be an ordinary office environment with many fluorescent lights. An original light-source map of a real room was captured by digital camera with a fisheye lens and was generated by HDRshop. As shown in Table 1, Six light-source maps are generated by down-sampling the original (B6). Three are shown in Figure 3. Each value in Table 1 represents the diameter of the light-source map.

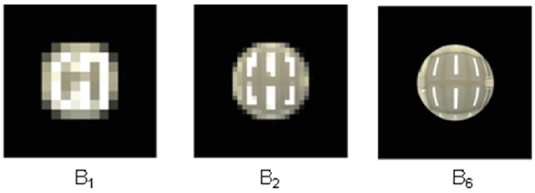

Figure 3. Generated light-source maps

Table 1. Resolution of light-source maps [pixels]

B_1	B_2	B_3	B_4	B_5	B_6
8	16	32	128	512	2048

3.2 Estimation of acceptable resolution

The area occupied by each fluorescent light on the light-source map is enlarged by down-sampling. Table 3 shows the ratio of the fluorescent area of light-source maps B1 through B6, using B6 as a base area. The area is measured by the solid angle subtending the fluorescent part on maps. Based on the results of Section 2.1, the DT is about 8% of the SS. From this point of view, only map B5 satisfies the DT. However, there are six fluorescent lights. This situation may relax the DT. Based on the results of Section 2.2, multiple light-sources can be merged into a single area light. Actually, each fluorescent light in map B6 consists of two fluorescent lamps that are close enough to be handled as a single.

Table 2. Ratio of fluorescent area on light-source map

B_1	B_2	B_3	B_4	B_5	B_6
4.90	3.44	2.31	1.22	1.13	1.0

3.3 Evaluation of reduced light-source maps

In this experiment, the dodecahedron was used as a target object because shadow of that is clearer than the cone. Six different virtual shadows were rendered by V-Ray 1.5. By arranging the real photo and one of the six CG scenes side by side, we prepared six images to present to subjects. Figure 4 shows one of them. The left is real, and the right is virtual. By randomly selecting two images from the six, we performed Scheffe's paired comparison in a 5-point scale. Each subject made 15 comparisons. At each comparison, two images were presented sequentially with 2 second intervals. A noise image was also presented during the intervals.

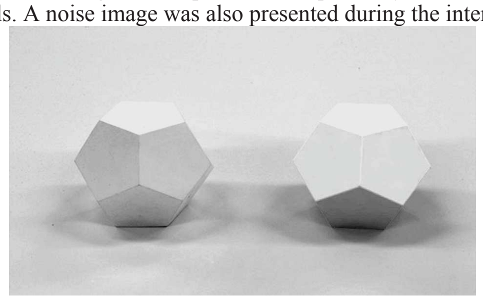

Figure 4. Presented image: left is real and right is virtual.

3.4 Results and discussion

A subjective evaluation was conducted by 10 males in their 20s. At each comparison, they chose the virtual shadow that they perceived to be more natural in a 5-point scale. For example, +2: the first shadow is definitely natural. 0: the first and second ones have no difference. -2: the second one is definitely natural. Figure 5 shows the results. The vertical axis represents the 15 pairs of the comparisons. The horizontal axis represents the average scores.

No clear difference was observed between highest resolution B6 and next B5. Maps B4 and B3 also have no clear differences with B6 and B5. This means that these maps effectively generate perceptually-correct shadows. Based on the multiple comparisons, there are significant differences between B3 and B2 and between B2 and B1. The resolution of B3 is 1/64 of B6's, but it still effectively generates perceptually-correct shadows. The data obtained in Section 2.1 suggest that B5 is the acceptable resolution of the light-source map. In a real office environment with multiple fluorescent lights, the DT may be largely relaxed because the cast shadows are blurred by multiple light-sources.

4 CONCLUSION

We discussed the simplification of light-source maps for generating perceptually-correct artificial shadows. Subjective evaluations showed that perceptually-correct shadows can be generated using light-source maps with fairly low resolution estimated by the knowledge derived from the experiments with a single light-source. The result shows the feasibility of generating perceptually-correct shadows with very low resolution light-source maps in a multiple light-source environment. Future works include systematic experiments in which we change the parameters in the environment with multiple light sources.

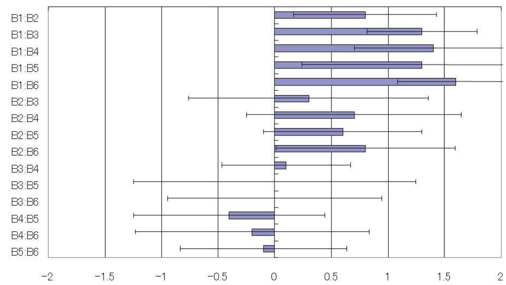

Figure 5. Result of Scheffe's paired comparison method

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