Title:
Computational Investigation of the Effect of Luminance Contrast on Depth Perception in Physical and Simulated Scenes

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Introduction:
The development of high dynamic range (HDR) imaging and its related technologies has advanced the visual realism of digital representation to physical accuracy. Both the existing and imaginary scenes can be recorded and simulated in an HDR format that encompasses the complete dynamic luminance range of the scene it represents using related technologies of HDR photography, and the lighting simulation program RADIANCE [5] [9]. Perceptual-based tone-mapping techniques were developed to compress the dynamic range of HDR images to enable viewing them on a common display device's displayable range based on the light processing technique used by the visual system [5]. As a result, the visual realism of digital representation generated by HDR-related technologies has advanced from physical accuracy to perceptual realism, and it provides a possible alternative environment to conduct a perceptual study that is restricted by the physical environment.

Prior studies conducted psychophysical experiments using computer images generated by HDR-related technologies to investigate the effect of luminance distribution of a scene on depth perception [6]. The principles of using luminance contrast to enrich spatial experience in architectural design were generalized and verified using the same computational environment [7] [8]. Although the visual realism of the used HDR technologies and their outputs have been previously established in terms of lighting simulation and depth perception [6], the visual realism of digital representation of experimental settings used in previous perceptual studies is yet to be verified using stimulated physical scenes. In this study, experimental scenes were generated using HDR images of the physical model, as well as the computer simulation of the same physical model with the image-based lighting technique applied through RADIANCE. There are two objectives of this study. First, to compare the effect of luminance contrast in the physical scenes with that in the computer-simulated scenes, and second, to verify the reliability of the application of luminance contrast in architectural design through the computer-aided design process using pictorial environments generated by HDR-related technologies.

Main Idea:
The HDR-related technologies of HDR photography and physically based lighting simulation using image-based lighting were used to generate the experimental scenes. Figure 1 illustrates the physical model. It comprised four 60 cm × 60 cm × 40 cm modules. At the center of each module was a 25 cm × 25 cm opening. Two interior luminance distributions of *Even* and *Contrast* were generated by controlling the four openings as all open; and as half open, open, closed, and half open, respectively. A 4-cm-diameter ping-pong ball was spray-painted red, and left hanging in the space 15 cm above the ground as a visual target. For the test scenes, the visual target was located 150 cm away from the viewpoint; both the conditions of *Even* and *Contrast* were used to generate two test scenes with different interior luminance distributions. For comparison scenes, the luminance distribution condition was controlled as *Even*; the visual target was placed at seven different locations ranging from 120 cm to 180 cm away from the viewpoint to create seven comparison scenes. Each of the test

and comparison scenes was recorded with multiple exposures by a CANON Mark 5D III digital camera with a 50-mm lens and the images were assembled by Photosphere with the calibration of the luminance measurement to generate HDR images [5]. The HDR images were further tone-mapped by the Photographic tone-mapping operator into JPG images [4].

The experimental setting was configured using a 3D modeling program and simulated using RADIANCE. An HDR photo of the environment where the physical model was placed was captured using a CANNON Mark 5D III camera with a Sigma 8-mm circular fisheye lens. The HDR image was used as the light source in RADIANCE, as illustrated in Figure 2. The same settings of the test and comparison scenes were rendered through RADIANCE and tone-mapped using the Photographic tone-mapping operator into the JPG format. Figure 3 illustrates the test and comparison scenes for the physical and computer-simulated scenes. Each of the test scenes was paired with one of the seven comparison scenes to be presented to the subjects. The subjects were required to inform the researcher on the visual target that he or she perceives to be closer. Both the test scenes under the luminance distribution conditions of *Even* and *Contrast* were presented with seven different comparison scenes ten times in a random order. The experiment was repeated twice with the experimental scene set of the physical model and computer simulation. The perceived distance of the visual target was measured using the constant stimuli method [3]. Ten subjects participated in the experiment, and a total of 280 perceptual judgments were obtained.

Fig. 1: Physical configurations to generate experimental scenes.

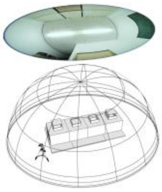

Fig. 2: Setting of image-based lighting.

Fig. 3: Test and comparison scenes (upper: physical scenes; lower: computer-simulated scenes).

Table 1 summarizes the experimental results. The measured perceived distance of the visual targets was derived by the Probit analysis [2]. Under the *Even* condition, the luminance distributions are identical between the test and comparison scenes. In both the physical and simulated scenes, the measured perceived distances are approximately equal to the actual location of 150 cm, as 149.00 ± 0.07 cm and 149.98 ± 0.62 cm, respectively. On the other hand, under the *Contrast* condition, the measured perceived distances of the visual targets in the test scenes both increased by 8.36% to 161.46 ± 0.65 cm, and 6.36% to 159.51 ± 0.60 cm, respectively.

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Luminance Distribution	*Even*	*Contrast*	% Increase
Perceived distance of the visual target 150 cm away in physical scene	149.00 ± 0.07 cm	161.46 ± 0.65 cm	8.36%
Perceived distance of the visual target 150 cm away in simulated scene	149.98 ± 0.62 cm	159.51 ± 0.60 cm	6.36%

Tab. 1: Comparison of the effect of luminance contrast on the perceived distance in the physical and simulated scenes.

Conclusions:

There are two objectives of this study. The first is to investigate the effect of luminance contrast on depth perception in the physical and simulated scenes. The second is to validate the visual realism offered by digital simulation using the HDR-related technologies to envision the depth effect resulting from luminance contrast. The results of the perceptual study demonstrate that luminance contrast is an effective parameter that can increase the perceived distance of the visual targets in a scene. This study thus concludes that the computer-generated environment generated using the HDR-related technologies can provide necessary visual realism to study and envision the effect of luminance contrast on depth perception; and this alternative pictorial environment requires much less effort to generate experimental scenes with precise variable control.

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