AN ASSESSMENT OF SIMULTANEOUS DYNAMIC RANGE FOR HDR RENDERING

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ABSTRACT

High dynamic range (HDR) image rendering has been an active research area in the last two decades. In real-world scenarios, there is a wide range of luminance (around 14 log units) between highlights and shadows. However, according to previous reports, the simultaneous dynamic range of human vision is 3.73 log cd/m^2. This property suggests that it is unnecessary to compress the full dynamic range of luminance in a real-world scene for realistic rendering. In this study, we present a sequence of psychophysical experiments to determine an appropriate simultaneous dynamic range depending on the HDR scene using an HDR rendering algorithm. The experimental results are summarized as follows: (1) for an HDR scene within the range of human vision, a rendered image with a higher simultaneous dynamic range within this range is preferable, (2) for an HDR scene beyond the range of human vision, a rendered image with the same simultaneous dynamic range as that of human vision is preferable, and (3) a rendered image with a higher simultaneous dynamic range is preferably observed under ambient light rather than in a dark room.

INTRODUCTION

Owing to the popularization of the personal computer and the Internet in recent years, we have many opportunities to view digital images in daily life. We now use digital cameras as the most common imaging devices. However, a display monitor as a commonly used image display device has a narrow range of luminance (at most, only about 3 log units), while the real world has a much wider range of luminance (around 14 log units). Therefore, it is difficult to reproduce an HDR scene on the display. The technique that compresses the dynamic range to display an HDR scene on an LDR monitor is called “tone mapping,” and various methods have been proposed so far. In many of these methods, the S-shaped function [1] modeled by Naka and Rushton has been used. This model uses a sensitivity parameter that can change the simultaneous dynamic range that the human can perceive. However, the parameter had to be empirically determined.

In this study, we performed subjective evaluation experiments with HDR scenes to clarify the relationship between the dynamic range of the actual HDR scene and the simultaneous dynamic range for realistic HDR rendering [2] using the S-shaped function.

RENDERING ALGORITHM

In this study, we used the HDR rendering algorithm proposed in Ref.[2] to reproduce the images used in the evaluation experiments. The algorithm is a spatially variant operator for imitating the S-potential function and realizing the local adaptation process as follows:

$$R_s^{(i)}\left(\sigma_m,\sigma_d\right)=R_{\max}\frac{I_s^{(i)^n}}{L_s\left(\sigma_m,\{\sigma_d\}\right)^n+\sigma^n};\ i=R,G,B, \tag{1}$$

$$L_s\left(\sigma_m,\{\sigma_d\}\right)=\frac{1}{k_s}\sum_{p\subset\Omega} f_{\sigma_m}(p-s)\prod_j g_{\sigma_{d_j}}(I_p-I_s)I_p, \tag{2}$$

$$k_s=\sum_{p\subset\Omega} f_{\sigma_m}(p-s)\prod_j g_{\sigma_{d_j}}(I_p-I_s), \tag{3}$$

Here, $R_s^{(i)}$ is the LDR image output of the channel i at pixel s. $I_s^{(i)}$ is the HDR image intensity of i at s. L_s is the surrounding intensity, σ_m is the standard deviation for a Gaussian f in the spatial domain, and σ_d is the standard deviation for a Gaussian g in the luminance domain. K_m is a normalization factor, and Ω is the whole image. $R_{\max}$ is 255 for an 8-bit output device, and σ is the average luminance of the HDR image. In Eq. (1), n is the sensitivity parameter that determines the simultaneous dynamic range, and its value is generally determined empirically between 0.7 and 1.0 [3]. Figure 1 shows the different S-shaped functions for different sensitivity parameters for σ = 1. The simultaneous dynamic range widens if the sensitivity parameter n becomes small. We generate multiple images by changing n for the experiments.

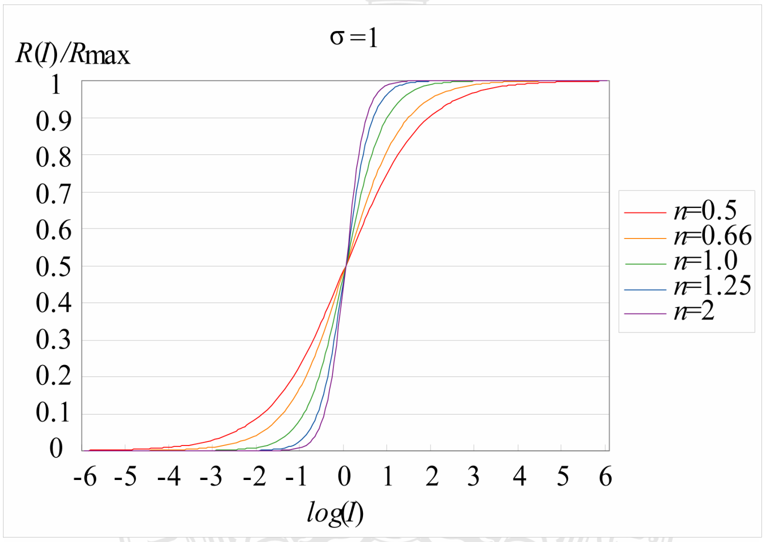


Figure 1. S-shaped response curves for different sensitivity parameters n.

EXPERIMENTS

EXPERIMENTAL METHOD

In our experiments, we used a Canon EOS-1Ds digital camera for capturing test scenes. Multiple images of the same scene captured with different exposure times were combined into an extended range image. We set up 3 HDR scenes with dynamic ranges of about 1, 2, and 4.00 log units as shown in Fig. 2. For each scene, we prepared a set of images, each with a different sensitivity parameter n as shown in Table 1. We used two different lighting conditions. (A) The target scene was illuminated by only a point light source (3070 K) in a dark room, and (B) the target scene was illuminated by ambient light from fifteen 100 W incandescent lamps (2760K).

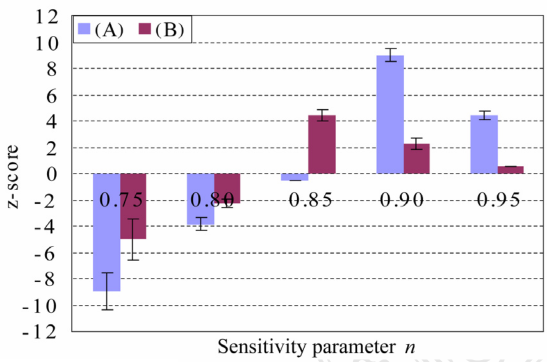
Rendered images were displayed on an Eizo ColorEdge CG221 LCD monitor. Three to Five subjects participated in each experiment. The experimental procedure was as follows. 1) Each subject memorized the scene for 3 min. 2) After viewing the scene, two images were displayed on the monitor in random order from image sets of the reproduced image. 3) The subject selected the image more similar to the memorized actual scene from the two reproduced images. This procedure was performed for all experimental conditions.

(a) 1 log unit in (B)   (b) 2log units in (A)   (c) 4 log units in (B)

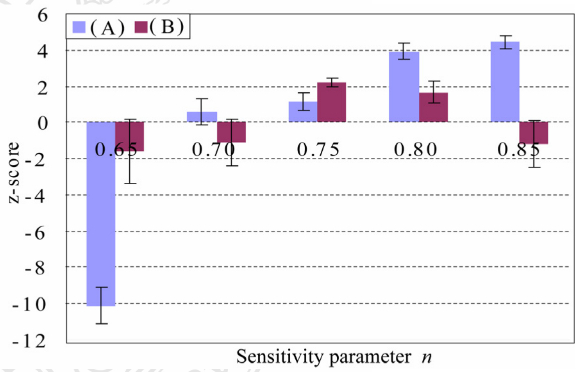
Figure 2. Examples of HDR test scenes.

EXPERIMENTAL RESULT

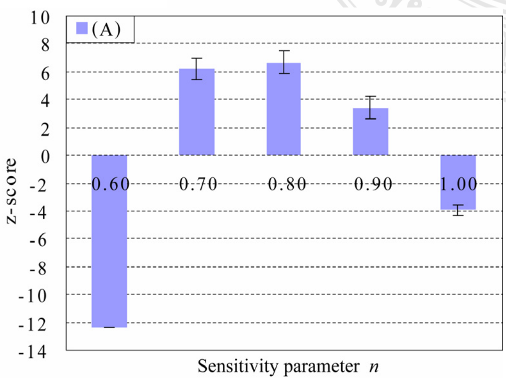
The evaluation result is summarized in Fig. 3. The vertical and horizontal axes of graphs show the Z-score and the sensitivity parameter n, respectively. Figure 4 shows a comparison between the dynamic range of the scene and the simultaneous dynamic range with the highest rating. According to Figs. 3 and 4, the rendered image with a higher simultaneous dynamic range was preferably observed under the ambient lighting condition (B) rather than in a dark room under the point-source lighting condition (A). These results suggest that the difference in surrounding brightness of the visual environment affects the appearance of the HDR scene in human vision. In addition, according to Ref. [4], the range of human vision is about 3.73 log cd/m^2. For an HDR scene within the range of human vision, a rendered image with a higher simultaneous dynamic range within this range is preferable. However, for an HDR scene with a dynamic range beyond that of human vision, a rendered image with the same simultaneous dynamic range as that of human vision is preferable.



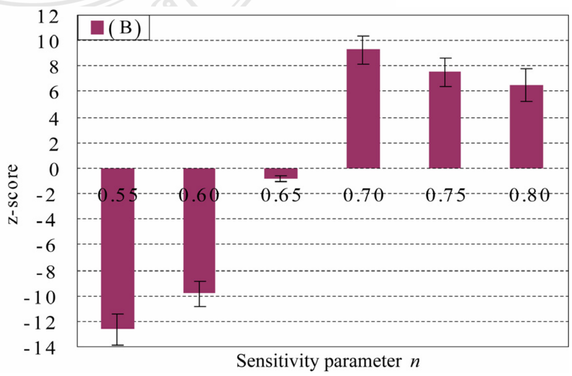
(a) Dynamic range of 1 log unit



(b) Dynamic range of 2 log units



(c) Dynamic range of 4 log units in (A)



(d) Dynamic range of 4 log units in (B)

Figure 3. The experimental results.

Table 1. Experimental conditions.

Dynamic range of the HDR scene	Lighting condition	Sensitivity parameter *n*	Simultaneous dynamic range for rendered images
$10^{1.00}$	(A)	0.75～0.95	$10^{2.74} \sim 10^{3.47}$
	(B)	0.75～0.95	$10^{2.74} \sim 10^{3.56}$
$10^{2.00}$	(A)	0.65～0.85	$10^{3.05} \sim 10^{4.00}$
	(B)	0.65～0.85	$10^{3.05} \sim 10^{4.00}$
$10^{4.00}$	(A)	0.60～1.00	$10^{2.61} \sim 10^{4.35}$
	(B)	0.55～0.80	$10^{3.27} \sim 10^{4.74}$

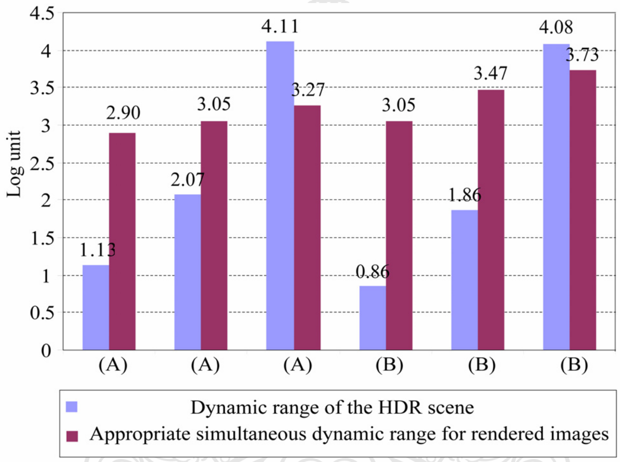


Figure 4. Appropriate simultaneous dynamic range for actual HDR scenes.

CONCLUSIONS

This study conducted subjective evaluations with HDR scenes to clarify the relationship between the dynamic range of the actual HDR scene and the simultaneous dynamic range for realistic HDR rendering. The experimental results determined the appropriate simultaneous dynamic range depending on the dynamic range of the actual HDR scene for image rendering.

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