Preference for Key Parameter of Tone Mapping Operator in Different Viewing Conditions.

M. G. M. Stokkermans, M. J. Murdoch, & U. Engelke

Philips Research, Eindhoven, the Netherlands

Introduction

The outside world offers, and the human visual system is capable of dealing with, a much larger luminance range than can be displayed on a regular display. High-dynamic-range (HDR) photographs or renderings therefore have to be compressed in dynamic range to be displayed. To preserve the visual appearance of the original scene, tone mapping operators (TMOs) are used (Reinhard, Ward, Pattanak & Debevec, 2006).

The key of a scene is a subjective concept derived from photography that indicates how light or dark the scene is perceived. High-key scenes are for instance white-painted rooms, and low-key scenes are for instance dark parking garages (Reinhard, Stark, Shirley & Ferwerda, 2002).

For an image of a scene to be perceived similarly to the scene itself, the scene key must be preserved in the image reproduction. This may be done in the exposure settings or via a specific parameter in a TMO. For the current study we focus on Reinhard's photographic tone reproduction operator for digital images (Reinhard et al., 2002), which provides a key parameter that affects the overall intensity of the reproduction. The key parameter may be individually set to a preferred value, or computed via algorithm depending on the minimum, the maximum, and the average luminance values of the scene (Reinhard, 2003). For scenes where the average luminance is closer to the maximum luminance than to the minimum, a high key is preferred.

However, for determining the preferred key of an image reproduction, more than only the luminance values of the scene itself are important. Key preference can also depend on viewing conditions. Mantiuk, Daly and Kerofsky (2008) include possibilities for different display and ambient settings in their TMO, and Reinhard (2003) also confirmed that certain images could still benefit from manual parameter selection due to viewing conditions.

How viewing conditions can affect key preference can be best anticipated by considering a few color-appearance phenomena. Firstly, simultaneous contrast describes the effect that the same stimulus appears lighter on a dark background, and vice-versa (Fairchild, 1998). Secondly, the Hunt effect (Hunt, 1952) and the Stevens effect (Stevens & Stevens, 1963) respectively describe that colorfulness, and brightness (or lightness) contrast increase with increasing luminance. Therefore objects typically appear more vivid and have more contrast outside in the sun, than indoors (Fairchild, 1998). Lastly, Bartleson and Breneman (1967) found that perceived contrast of the image increased with increased surround luminance (Fairchild, 1998).

For the present study we hypothesize that the TMO key parameter can be used to compensate for different viewing conditions, to optimize image appearance.

Methodology

Design

This study followed a within-subject design using two display luminance settings (full white: 102 vs. 550 cd/m^2), two surround (wall washing behind display) luminance settings (20 vs. 275 cd/m^2), and three different images (1: HDR rendering of an office room; 2: HDR photograph of a lab booth; and 3: HDR photograph of snow scene (see Figure 1)). The dependent measure was the preferred key value, and was assessed twice for every condition, to determine within-observer consistency.

Fig. 1: 1) Rendering of office room, 2) Photograph of lab booth, 3) Photograph of snow scene.

Stimuli

The images were specifically chosen to research both high-key and low-key scenes. The image of the room was a physically-based rendering of an accurate 3D model, and the two HDR images came from Fairchild's HDR Photographic Survey[1]. The key parameter of the images was adjusted and tonemapped using the freeware Luminance HDR[2] with TMO 'Photographic tone reproduction for digital images' (Reinhard et al., 2002). For the room rendering, participants could choose from 47 different key values, ranging from 0.005 to 1. For the snow scene, there were 45 different key values, ranging from 0.0025 to 1. For the lab booth photograph, there were 34 different key values ranging from 0.0025 to 0.25. The key parameter affects the image in a visually non-linear fashion, leading to a larger increase in perceived intensity at the lower part of the scale than in the higher parts. Thus, we selected levels of the key parameter distributed so that we could present them to the participants in an approximately visually linear way. Because the room and snow scene are originally high-key scenes, we selected a larger range of key values for the participants to choose from than for the low-key lab booth scene.

All images were shown on a calibrated NEC P462 46" LCD. The participants sat at a distance of one meter from the display, and the image was presented with a width of 53° of their field of view. The surround was illuminated from a cove located at ceiling height (3.25 meter), 0.9 meter behind the display, directed at the wall.

All images were presented in four blocks of equal display/surround luminance (for convenience with respect to adaptation time). The four blocks were presented in a counterbalanced order, and within each block the images were randomized.

Participants

A total of 20 participants (10 male, 10 female) participated in this study. Their average age was 26.2 (Standard Deviation: 3.9), ranging from 22 to 38. The participants had various nationalities and backgrounds.

Procedure

We welcomed the participants and asked them to take a seat in front of the display. First, the participants read the instructions and informed consent form. Then, the participants adapted for three minutes to the surround lighting/display settings of the first block while looking at a mid grey image at the display. After adapting, the first image was shown. To avoid confusion about the term 'key', we asked the participants to select their preferred intensity for that given image and viewing conditions. This could be done by using the arrow keys of the keyboard. Next, the researcher recorded the result and showed the following image. After completing each block, the participants adapted for three minutes to the next surround/display settings, before the next block started.

Analyses

To test the hypothesis as stated in the introduction, correlation analyses, and a repeated-measures ANOVA were performed using SPSS 17.0. For statistical analysis, the key values were first transformed to a visually linear scale (the levels presented in the experiment). For visualization in tables and graphs, the original key values are shown.

Results

Results showed that there was a clear distinction in preferred key value between

[1] http://www.cis.rit.edu/fairchild/HDR.html
[2] http://qtpfsgui.sourceforge.net/

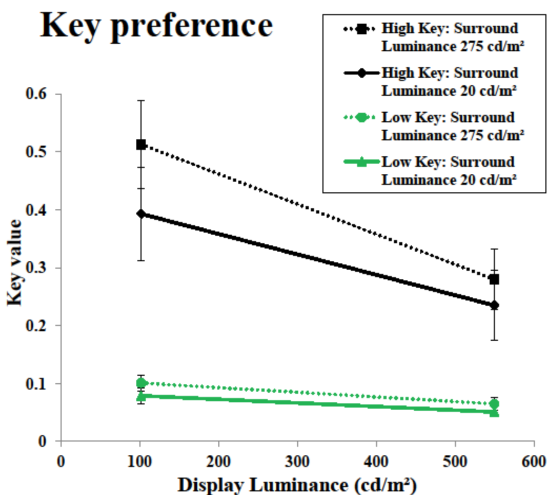

Fig.2: Key preference depending on display and surround luminance and on original scene key (low key scene is lab booth; high key scene is average of room and snow scene).

the low and high-key scenes [F (2, 18) = 480, p < .001]. The rendering and the snow scene were high-key, and were also preferred in a high key by the participants. Post-hoc results further showed that there was no significant difference between these images (p = .444). The lab booth was a lower key scene, and was also preferred in a lower key. The differences in key preference of the lab booth compared to both the rendering and the snow scene showed significant post-hoc test results (p < .001). This is also clearly visible in Figure 2.

Besides this, effects of display and surround luminance on key preference were both found. Higher display luminance values led to a lower preferred key value [F (1,19) = 71.2, p < .001], while higher surround luminance led to a higher preferred key value [F (1,19) = 21.6, p = .001]. There was no significant interaction effect of surround luminance and display luminance [F (1,19) = 1.25, p = .277]. Interaction effects were present for both surround luminance and the

Table 1: Mean (M) & Standard Error (SE) of key preference repeats per image, averaged over all conditions.

Image	***Preference 1***		***Preference 2***	
	M	SE	M	SE
1) Rendering	.350	.028	.372	.032
2) Lab booth	.071	.004	.077	.005
3) Snow scene	.339	.036	.36	.038

original key of the scene [F (2,18) = 15.2, p < .001], and for display luminance and the original key of the scene [F (2,18) = 25.3, p < .001], pointing towards larger effects of surround and display luminance for high-key scenes than low-key scenes. All these effects are also depicted graphically in Figure 2.

Considering the within-observer consistency regarding this preference, results showed a high Pearson correlation between the first and the second preference assessment of .823 (p < .001). On the other hand, the ANOVA showed that the two repeats of preference were significantly different from each other [F (1,19) = 7.9, p = .011]. Looking at the preferred key values themselves provided some perspective: the average difference is 1 'step' or less, so we argue that the consistency in preference is quite good. Table 1 provides information regarding the two preference measures for each image.

Discussion

A few interesting conclusions can be drawn from the present study. Firstly, people set the key parameter for the images similarly to how we would categorize the original scene as high or low-key. Secondly, as expected, this study showed that preference for key depends also on the viewing conditions (display and surround luminance) in which the image is assessed.

Results showed that increased surround luminance values led to an increase in preferred key. Intuitively it makes sense that for instance for comfort reasons, participants did not want a large difference in perceived brightness between the display and the surround, and compensated for this by increasing the key of the image. The simultaneous contrast phenomenon possibly even enhanced this effect. However, besides this, the Photographic TMO has a confounding effect: at higher key values, contrast is reduced in the light areas of the image (Reinhard, 2003). Thus, because increased surround luminance leads to increased contrast perception (Bartleson & Breneman, 1967), participants might have compensated for both this effect and the overall luminance at the same time by increasing the key.

We found that increased display luminance led to lower preferred key values. This is probably again to keep the total perceived brightness ratio of the image and display versus the surround similar. Additionally, it is also possible that people may have corrected for the Hunt effect. Regarding the Stevens effect (perceived contrast increases with luminance); we acknowledge that this is contradicting earlier reasoning. However, we think that preferred key might have decreased even more if this were not coupled to a contrast increase.

Furthermore, this study stresses the importance of the display. Display luminance has a larger effect on key preference than surround luminance, even though the change in surround luminance was 2.5 times larger than the change in display luminance. This seems rational because the display of course dominates central vision.

The present study focused on two variables with two luminance values, which makes it difficult to generalize conclusions for a wider range. We selected these values since they cover typical values for normal viewing environments. However, researching intermediate values, or possibly even more extreme values in future studies, would provide valuable information. Nevertheless, we believe the present study is a first step to accounting for the effect of viewing conditions in tonemapped images.

Additionally, we think that other factors should be taken into account as well. For instance, for the surround luminance, it is important how the luminaires are directed. In our set up, cove luminaires were close to the wall behind the display, and caused minimal reflections on the display. In the study of Mantiuk and colleagues (2008), the ambient lighting was directed on the display and therefore did cause reflections. Their results showed that increased room lighting or outside lighting led to lower contrast, and adapted their TMO to compensate for this. Since this difference in set up might lead to different results, we argue that the possibility of reflections of the display is an important variable to take into account.

Lastly, comparing the displayed HDR image directly to a real environment would be interesting for future research, though we realize that doing so will require careful handling of adaptation.

Conclusion

This study showed first results regarding the effect of viewing conditions on preference for key as a TMO parameter. Increasing surround luminance led to higher preferred key values, while increasing display luminance led to lower preferred key values. Therefore, it is important to account for the effect of viewing conditions while tuning the key parameter in a TMO. However, before this can be generalized, or implemented in a TMO, it is advised to study a wider range of luminance values, and possibly also take other factors like reflection of the display into account.

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