A Psychophysical Validation of Tone Mapping Operators using a High Dynamic Range Display

Patrick Ledda*
University of Bristol, UK

Alan Chalmers
University of Bristol, UK

Helge Seetzen
Sunnybrook Technologies

1 Introduction & Experimental Framework

The natural world presents a wide range of colors and luminance levels. Night scenes can have luminances of 10^{-4} cd/m^2 or less, while daylight scenes are close to 10^5 cd/m^2. Although various techniques are available which allow us to generate high dynamic range (HDR) images, generally, it is not possible to linearly display this wide luminance range. A typical monitor, for example, is only capable of displaying a contrast ratio of approximately two orders of magnitude which is a tiny fraction of the natural world dynamic range. Tone mapping operators (TMO) aim to generate images visually similar to a real scene by careful mapping to a set of luminances that can be displayed on a low contrast ratio display. Many tone mapping operators are capable of enormous reductions in contrast to fit the displayable range and manage to produce satisfying and visually pleasing results. In this work we conduct a formal investigation to determine whether in fact these results are indeed a good representation of the real-world scene they are attempting to portray.

We study the TMOs by comparing their results with a *reference* scene displayed on a high dynamic range monitor. This is a novel approach. The HDR technology allows us to make direct comparisons of various stimuli which simplified the validation process because subjects had a specific reference when making judgments of test scenes. An objective methodology was developed and a large psychophysical experiment was conducted with over 160 subjects.

For this investigation we ran three separate psychophysical trials. The HDR display used to linearly display the reference test scenes is the Sunnybrook Technologies SBT1.3 High Dynamic Range (HDR) Display. This is a rear-projection based dual-modulation display system capable of accurately portraying color video images over a dynamic range of 75,000:1 [Seetzen et al. 2003].

For the investigation, we chose seven operators. These TMOs have been often cited in the literature and produce images that are visually very impressive. For the trials we specifically chose test images with a contras ratio displayable in our HDR device. Most tone mapped images were either kindly produced by the authors, generated by the available source code or in some cases by our own implementation of their algorithms. We obviously understand that some of the operators' performance could be improved by modifying various parameters. For this work, however, we attempted to use, whenever possible, their standard settings.

Trial 1: Visibility Comparison. For the *visibility* reproduction experiment we asked a sample with normal or corrected to normal vision, to read several letters written on a Pelli-Robson contrast sensitivity chart. During the experiment, the sample was divided into eight groups, one for each of the seven operators tested, along with one for the HDR display. Each group was given the same task of reading letters on the chart. A score was assigned for each correctly read letter. The goal of this investigation was to determine which operator statistically obtained the closest score to the reference image displayed on the high contrast ratio display.

Trial 2: Similarity of Stimuli. The second study had the objective of measuring the general *similarity* between each image and a reference image. This was achieved by a three-way comparison between two tone mapped images and the reference image, which was the linearly mapped image on the HDR display. Subjects were asked to observe a pair of images and determine which of the two was closest to the reference image in terms of (a) visibility and detail, and, (b) overall. To support the results from this trial, subjects were asked to rank on a Likert scale between 0-5, how close each tone mapped image was to the reference.

Trial 3: Contrast Comparison. In a final trial, we wanted to investigate the contrast reproduction of the seven TMOs. As in Trial 2, the participants were asked to make a three-way comparison, however, in this occasion we specifically instructed the sample (a group of computer graphics students) to make their assesment based on *contrast*. The test scenes were two contrast sensitivity charts as well as four more natural images. As above, subjects were separately asked to rank the test data.

2 Discussion and Future Work

We presented a psychophysical framework to validate several tone mapping operators. We believe that this is extremely valuable, not only for the tone mapping community, but also for any application considering high dynamic range imaging. Ideally, this methodology would assist us in selecting the most appropriate algorithm for a particular scene or application. Thanks to new HDR technology, we were able, for the first time to test different operators against a reference that is a close representation of reality and determine, with confidence, if the images produced by these algorithms are accurate. Of course, much more work is needed.

We have already begun conducting more trials with a greater number of test scenes. We are also refining our methodology and intend to conduct both an objective and subjective investigation. In the future we would also like to evaluate not only static images but also dynamic scenes. There is little doubt that high dynamic range devices are likely to become more prevalent in the near future. Such HDR devices will not, however, do away with the need for tone mapping. In many cases, the chosen luminance level may be reduced to prevent eye fatigue, and of course, the luminance values found in the natural world may still be higher than what can be displayed linearly on HDR devices. The knowledge that we can gain from such evaluations should lay the foundation for the development of a new generation of tone mapping algorithms for current display technology, printing applications and future high dynamic range display devices.

*e-mail: ledda@cs.bris.ac.uk

References

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