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Evaluation of Tone Mapping Operators for HDR video on small form factor displays

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Abstract

It is still hard to be able to capture, store or deliver content that is capable of representing the dynamic range of the human eye with the conventional imaging technologies. High Dynamic Range (HDR) imaging has the goal of overcoming that issue and providing an enhanced viewing experience through significantly increased physical realism, colour gamut and contrast ratio. In order to reduce the dynamic range of HDR content so that it can be shown on conventional displays, Tone-mapping Operators (TMOs) are required.

In this paper we present the results of psychophysical experiments that evaluate six TMOs using seven different examples of HDR video footage. The participants ranked the different tone mapped HDR video footage shown on a tablet with an HDR display as a reference.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation— Display algorithms; I.4.0 [Computer Graphics]: General - Image displays

1. Introduction

HDR's impact embraces all aspects of digital imaging, ranging from scientific image processing and high fidelity production of photo realistic computer graphics, to home-entertainment or security applications. HDR provides an enhanced viewing experience. . HDR is emerging and it is a valuable addition to the imaging technology. However, as most of the conventional displays are not HDR, there is a need to perform the dynamic range reduction through the use of Tone-Mapping Operators (TMOs).

Nowadays, the popularity of mobile devices has been growing dramatically and they have been increasingly and widely used to access multimedia content. Indeed, the development of multimedia content now takes into account the characteristics of mobile devices, especially devoting special attention to their displays and supported resolutions.

We intend to explore the growing interest in mobile devices and provide them with the advantages in image quality that HDR video can provide. There has been little work to date investigating the delivery of HDR video for mobile devices. In fact, only recently, the first HDR video player [goH13] has appeared that allows HDR video to be played on iOS [App13] devices. The player provides the user with a choice of tone mappers for displaying the HDR video on the mobile device's Low Dynamic Range (LDR) display.

There are a number of constraints when considering showing HDR video on mobile devices. The first one is that, while HDR displays do exist, there are currently no small form factor HDR displays available. In order to optimise the visual experience for the user, we need to consider if there are TMOs that are preferred for watching HDR video on mobile devices.

In this paper an evaluation of six TMOs that are suitable for HDR video is presented. The evaluation is made by means of an HDR display as reference and a tablet display with 9.7" screen.

Section 2 presents related work, focusing on the TMOs that were considered for this evaluation and previous work on TMO evaluation. Section 3 presents the methodology used for the experiments, Section 4 discusses results, and section 5 concludes and provides some suggestions for future work.

2. Background

Since there are no HDR small form factor displays yet, reducing dynamic range becomes necessary so that HDR video can be displayed on LDR small form factor displays. Many such TMOs have been proposed [BADC11].

TMOs can be divided into two main categories: global and local. Global TMOs consider processing the image as a whole and give the same treatment to each pixel of the image. Local TMOs, on the other hand, compute the value of each pixel independently, taking into account information about the overall image as well as adjacent pixels. When dealing with HDR video, another important factor is temporal coherency. This is because the video consists of a sequence of images in which a drastic change of illumination may occur. The tone mapper must thus take into account other frames in the sequence in order to avoid flicker between the frames.

TMOs have been evaluated and rated according to several image characteristics but none of them has been developed with the purpose of serving small screens. Urbano et al. [UMM*10] is one of the few examples of TMO evaluation for mobile devices. This study concluded that user preferences for TMOs change according to the display that is reproducing the HDR video content.

2.1. Tone-mapping operators evaluated

Since our goal is to evaluate TMOs for reproducing HDR video on mobile devices, we considered 6 TMOs that are time-dependent: Spatio-Temporal Tone Mapping Operator based on a Retina model [BAHC09]; the model of visual adaptation [FPSG96]; the TMO proposed by [VH06] that deals with the encoding of high dynamic range video with a model of human cones; the display adaptive TMO [MDK08]; time-dependent visual adaptation [PTYG00]; and on the TMO proposed by [BBC*12] whose target is the temporal coherency for video tone mapping.

The Spatio-temporal TMO has is inspired by the work done by Meylan et al. [MAS07] where the retina model and its local adaptation properties are described. It attempts to conjugate the simulation of the foveal retina functionalities and temporal coherency. The model of visual adaption developed by Ferwerda et al. is based on psychophysical experiments and uses Threshold-vs-Intensity (TVI) functions to account for photopic and scotopic vision. The work developed by Hateren is based on the model of human cones and performs two main steps: it uses a combination of nonlinearities and reduction of noise through a low-pass filtering that adapts to the scene luminance. The work developed by Mantiuk takes into account the environmental variables like the luminance levels or the displays´ characteristics such as the screen reflectivity. Pattanaik's TMO relies on the fact that the human visual system takes some time to adapt to big changes of luminance and uses the human visual response as a key for performing the tone-mapping. Boitard's TMO attempts to preserve the overall contrast of the video through perceptual consistency.

2.3 TMO Evaluation

To identify which TMOs are the most reliable under difference circumstances, evaluations are typically used as there is no objective metric [LCTS05]. The evaluation procedure can follow one of the two approaches as presented next: Error metrics and psychophysical experiments. The first method is objective and is based on mathematical models using computers to compare images. One of the most used procedures for evaluations is the VDP (Visual Difference Predictor). Such an approach simulates the HVS while processing the image pixels in order to identify which aspects of the image would be perceived by the HVS. The second approach is subjective and is based on psychophysical experiments. There are many variations of psychophysical experiments and they usually take place in a room where variables such as luminance, temperature and/or noise are controlled. The participants are asked to rank, rate or make a paired-wise comparison between a set of images. A ground truth may or may not be used as a reference.

Regarding psychophysical experiments, Drago et al. [DMMS02] was one of the first experiments to evaluate TMOs. The comparison was made between seven TMOs using four different scenes. 11 participants made a pairwise comparison on a CRT display.

The first experiments to make use of an HDR display as a reference were conducted by Ledda et al [LCTS05]. In those experiments, six TMOs were evaluated. The six TMOs were applied to 23 images that were examined by 18 participants. The experiments were conducted using a new methodology that consisted of using two LDR screens with an HDR display as reference in the middle. The participants just had to identify which of the two tone-mapped images most closely resembled the reference.

The experiments conducted [UMM*11] were one of the few evaluations that took into consideration small screen devices. The experiment consisted of a pairwise comparison of tone mapped images using a real scene as reference. Two 17" displays and one 2.8" displays were used. The goal of the work was to understand if the rankings between small displays and regular displays were different.

3. Experimental Setup

The following experiment is aimed at identifying which of the selected TMOs are most suitable for reproducing HDR video on mobile devices. With the obtained results it is possible to draw some conclusions about which characteristics are more important to users when reproducing HDR video on mobile devices. Participants had to rank a set of 7 HDR videos where the six TMOs mentioned in Section 2 were used. To facilitate the ranking, a 37" HDR display developed by Brightside [Bri13] was used as the reference.

In the experiment the participants had to rank the tone-mapped videos reproduced on a tablet. The experiments were done on a room were the environment variables were controlled.

3.1. Apparatus

One HDR display was positioned in front of an iPad 4 placed on a table close to where the participant sat. The table was put at 2.5m from the HDR display so the user could have the perception that the video that was being reproduced on the tablet had the same size as the one playing on the reference. A brief description of the displays specifications is shown on Table 1.

Table 1 – Technical specifications of the displays used

Display	Size	Luminance (Min – Max)	Contrast Ratio
HDR	37"	0 – 4000 cd/m^2	200,000:1
Tablet	9.7"	0.48 – 476 cd/m^2	877:1

Despite the fact that the videos were playing with the same resolution, the pixel densities on the mobile device is higher, making a video of the same resolution seem consequently smaller. The general setup of the experiments is shown in Figure 1.

Figure 1: *Scheme of the experiments environment.*

The software used for the experiments allowed the users to rank the video by dragging the thumbnails of the tone-mapped videos to a set of numbered empty slots. The choices criteria were based on the degree of resemblance of the tone-mapped video with the reference. The participants were able to view any of the tone-mapped videos or the reference at any time by double clicking on the thumbnail of the respective video. A print screen of the comparison application used is shown on Figure 2.

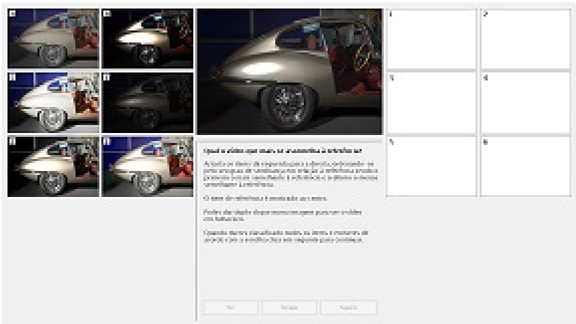

Figure 2: Screen shot of the experimental software

3.2. Procedure

Each participant evaluated 7 videos, were each video was tone mapped by the 6 different TMOs. Since the parameters of a TMO can have a large impact on its output, all TMOs were used using the default parameters established by the authors. Thumbnails, showing a single frame, of the videos used are shown in Figure 3. A study was conducted with 15 participants who evaluated the seven tone-mapped videos.

4. Results

To analyze the results, a score system was created that gave each first rank a score of 6, a second rank a score of 5 and so on until the sixth place with a score of 0. These results were normalized into percentages and are shown on Table 2. To better illustrate the results, the TMOs that achieved a percentage under 10% are shown in pink, the TMOs with a percentage between 10% and 20% are shown in yellow and the TMOs with a percentage of 20 or above are shown in green.

Table 2 – Results obtained.

	CGR	Jag	Kal	Mor	Exp	IDL	Med
Fer	1%	9%	9%	8%	11%	5%	6%
Pat	12%	26%	26%	21%	21%	20%	13%
Hat	8%	2%	10%	3%	1%	2%	2%
Man	29%	23%	32%	22%	29%	32%	29%
Ben	24%	16%	4%	20%	10%	20%	20%
Boi	26%	24%	18%	26%	28%	21%	30%

5. Conclusions and future work

The evaluation presented in this paper intends to understand the performance of TMO for video on mobile devices. The results obtained show that there is some variation between all the methods and the best TMO for one video is not necessarily the same for the remaining videos. The best TMO for each video depends on the video attributes and they can vary according to the video´s overall luminance, sudden light changes, action scenes, etc. Overall, Mantiuk’s TMO was the one which had a more stable performance and achieved a good ranking in all evaluations. Boitard and Benoit also had positive evaluations on the majority of the videos.

If a video has direct influence on the TMO preference, future work is needed to investigate HDR videos with specific scenes such very bright scenes, mainly dark scenes, indoor, outdoor, sudden luminance changes, amongst others.

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Figure 3: Thumbnails used for each tone-mapped HDR video footage. **CGR: CGRoom, Jag: Jaguar, Kal: Kalabsha, Mor: Morgan Lovers, Exp: Explosion, IDL: IDL Wedding, Exp: Explosion, Med: Medical.**

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