Brightness Adaptation of HDR Content

Anupreet Mahrok, Xuemeng Li, Hans Zhang, Ravneet Kaur

Department of Electrical and Computer Engineering
University of British Columbia

Abstract

Presently, HDR displays are becoming more and more prevalent in the market. They provide a substantially better viewing experience than that of traditional SDR displays. However, one disadvantage of watching HDR content at a high brightness level is that it can cause discomfort to the human eye. The objective of our project is to mitigate this flaw by adjusting the brightness of the video content based on the surrounding luminance. By utilizing the Human Visual System equation, we can manipulate our video in such a way that the human does not perceive a difference despite the change in luminance. A subjective test of eighteen subjects was then devised to determine the efficacy of this algorithm.

Keywords: Adaptation, Luminance, Contrast, High Dynamic Range (HDR)

1 Introduction

Current High Dynamic Range (HDR) televisions available on the market provide significantly greater brightness and dynamic ranges as compared to that of traditional Standard Dynamic Range (SDR) televisions. For context, SDR displays typically show up to 100 nits in brightness, whereas HDR displays can show up to 1000 nits. While it is beneficial to be able to display content at higher brightness, there are some drawbacks that come with this improvement in displays. One of the drawbacks is that the human eyes will experience visual fatigue when exposed to extended periods of high luminance. Various technologies have been discovered to make human experience better by exploring functionalities that automatically increases or decreases its video brightness depending upon the ambient luminance.

Our approach to making the human experience better takes contrast sensitivity of the human eye into account so that the users viewing TV would have a more pleasant experience. We have worked on HDR video content, extracted the frames of YUV video and updated the luminance of the video at the pixel level. The luminance change of the video content is as per the ambient brightness. We have done the calculations within Perceptual Quantization (PQ) domain throughout the entire conversion process so that brightness adjustment would be proportional to the way that the human visual system (HVS) processes the light.

Section 2 describes the background of the existing solution for Brightness Adaptation. Section 2.1 and 2.2 introduces the concepts of HVS and PQ. Section 3 and 4 describes the related work and issues with current technology. Section 5 describes the step by step procedure for the proposed solution. Section 6 and 7 show the subjective tests conducted and their results respectively. Section 8 describes the future work and the conclusion.

2 Background

2.1 PQ

Perceptual Quantizer, abbreviated as PQ, is the transfer function for the HDR. PQ uses the human eye as the basis for the signal-to-light relationship. For this reason, it is highly efficient from very low to very high light levels and is used for encoding HDR images. The human's visual system processes luminance in a nonlinear way. For example, as the surrounding luminance becomes brighter, changes in brightness become harder to discern. The HDR uses physical light intensities while the SDR uses relative light intensities. PQ is a function for adjusting the distribution of these brightness intensities. The adjusted brightness intensities are linear with the perception of human's visual system. It implies that a change of brightness intensity corresponds to the same change in the human's perception.

2.2 HVS

The human visual system (HVS) consists the eye and part of the brain that is responsible for processing the visual information. Whenever the light hits the eye, it hits the retina first, which contains photosensitive cells i.e. rods and cones. The cones in our eyes are responsible for the perception of color, finer details and rapid changes. Our eye has about 5 million cones and can only operate in daylight; they stop functioning when there is not enough light entering the eye. Rods, which are about 125 million in number in the human eye, are highly sensitive to light and responsible for low-light condition.

The human visual system (HVS) is a very complex model and is not only limited to the eyes but also pertains to the neuronal reception, processing, and interpretation of information. The spectral sensitivity, the sensitivity to the different wavelengths of light, of the pigments in rods and cones also affect our perception. The visual receptors of the human visual system are responsible for receiving the light in a logarithmic manner. The HDR image/video has wider color gamut and dynamic range visible to the human eye, which can make the eye uncomfortable at the higher brightness levels. Depending on the brightness of the ambient luminance, the brightness of the HDR content could be adjusted to provide a better visual experience.

$$HVS_{Response} = \frac{L_{HDR}{}^{n}}{L_{HDR}{}^{n} + L_{Adaptation}{}^{n}} \qquad n = 1$$

Equation 1: HVS Equation

Equation 1 shows the human visual system response to a particular luminance of the HDR content (L_{HDR}) and surrounding luminance ($L_{Adaptation}$). L_{HDR} is the luminance of the pixels of the HDR video.

2.3 Adaptation

The visual pigment of the receptors of the human eye affects our perception. Depending on the brightness change, the eye must adapt to the surrounding environment. The adaptation occurs in two scenarios:

I. Dark Adaptation:

Whenever the surrounding brightness drops from a high brightness level to a low brightness level, the brightness of the display device becomes too bright and uncomfortable when viewed by the human eye. After some time, the eye adjusts to the new surrounding brightness.

II. Light Adaptation:

Whenever the dark room increases in brightness, the video content on the display device is initially very difficult to see due to the display being too poorly lit. However, after a short period of adjustment, the light going into the human eye decreases, so eye adapts to the new and higher surrounding.

Adaptation to the HDR content is taken into consideration whenever the surrounding brightness suddenly changes. In this paper, we are proposing a solution to eliminate the problem of brightness adaptation as the brightness of the video changes with the change in ambient brightness.

3 Related Work

Currently, ambient light sensing (ALS) technology is being used for display devices to change the brightness of the display device automatically when the brightness of viewing environment changes. The main goal of this technology is to reduce the energy consumption of the display device. The ALS technology does not focus on enhancing the user experience and as a result, the user’s perception of the video/image content does not remain the same [3]. The Ambient Light Sensor technology is expertly used in Samsung The Frame 2.0 which does not look like a traditional TV, but rather a framed photo or a piece of art printed on paper. Samsung refers to this new technology as the “invisible TV”. This is because the ambient light sensor strategically dims the brightness of the screen to match the surroundings, even matching the color to the color temperature of the room it’s in [1]. However, ALS technology does not contemplate the human visual experience during scenarios of sudden brightness change.

ALS is also used in various portable and handheld devices and has proved to reduce the power consumption of the device by 30% [3][4]. The brightness level change occurs as per the brightness level of the room, using the ambient light sensor which is mounted on the TV which captures the surrounding brightness [2]. The signals generated by these sensors are used to get display luminance control signals which are used to adjust the display luminance of device. The luminance of the display device is changed continuously according to the readings of the surrounding brightness sensor and display luminance sensor [4]. The change only stops when the display device is switched off.

4 Issues with Current Technology

The main goal of ALS technology is to reduce the energy consumption of the display device. The ALS technology does not focus to enhance the user experience and the user’s perception of the video/image content remains the same [3].

Today’s television displays use the Gamma Curve as an EOTF (Electro-Optical Transfer Function) to convert input signal to the visible light. Whereas, the HDR is developed to give user’s better viewing experience with the brighter whites and the deeper blacks in the video [6]. To properly display HDR content, it's not enough to simply raise the level of brightness — it's crucial to display color and tones in a way that matches human eyesight and keep the perceptual same.

5 Proposed Solution

In this project, our proposed algorithm updates the luminance of the video content as the surrounding brightness is changed. During the luminance changes, the contrast to human eye is kept the same. In this section, our methodology will be outlined and detailed.

The method takes YUV video as input and updates the luminance of the video at the pixel level based on the change in the surrounding brightness. As human eyes perceive light in a logarithmic manner and not linearly, we are doing all the conversion and calculation in PQ domain.

In our method, the first step is to read the 1000 nits YUV video (4:2:0 Chroma) and extract YUV frames from the video. Then chroma up-sampling is performed on the extracted frame to make the ratio 4:4:4. After applying Chroma up-sampling, the 1000 nits YUV frame is normalized to values that are between 0-1. Once this is done, we converted the normalized YUV frame to the RGB frame and extracted the R, G and B components from the RGB frame. Figure 1 shows the normalized RGB and luminance of one frame.

Next, after capturing the brightness of the room with light meter, we converted the luminance values into the PQ domain. Based on the Human Visual System Response (HVS) equation as described in Equation 2, we calculated the HVS. To keep the simplicity, we omitted the frequency change and kept the constant "n" as 1.

$$HVS_{Response} = \frac{{L_{HDR}}^{n}}{{L_{HDR}}^{n} + {L_{Adaptation}}^{n}} \qquad n = 1$$

Equation 2: HVS Equation

To ensure that the user's perception of the content remains same when the surrounding brightness changes, we kept the HVS constant while adjusting the $L_{Adaptation}$. By updating $L_{Adaptation\_New}$, the luminance for each pixel is calculated with Equation 3.

$$L_{HDR\_New} = \frac{HVS_{Response} \times L_{Adaptation\_New}}{1 - HVS_{Response}}$$

Equation 3: Solved equation for HVS

Figure 2 as follow shows the luminance channel for one of the frames when the surrounding brightness is increased from 16 nits to 45 nits.

Figure 1: Normalized RGB (0-1) and Luminance in PQ domain

Figure 2: Luminance changed from 16 nits(left) to 45 nits(right)

Figure 3: RGB Frame with luminance changed from 16 nits(left) to 45 nits(right)

Figure 4: RGB Frame with luminance changed from 45 nits(left) to 16 nits(right)

Since converting from YUV to RGB is linear, we applied the ratio of luminance change to each channel of RGB. Figure 3 is the RGB channel with surrounding brightness increased from 16 nits to 45 nits.

Similarly, figure 4 is the RGB channel when surrounding brightness is decreased from 45 nits to 16 nits.

Lastly, the RGB frame is converted to YUV frame. By applying the above steps for each frame, the video is modified and regenerated with new luminance values for each pixel.

By applying the luminance change onto each pixel of the frame with the above workflow, we regenerated the new HDR video that adapted to the new surrounding luminance and same human eye contrast.

Figure 5 shows the overall workflow for our design.

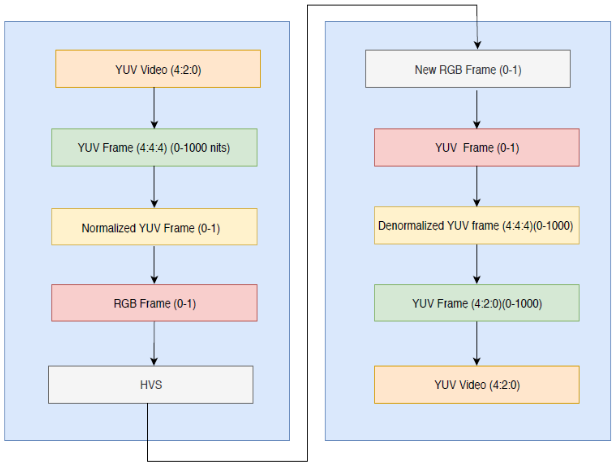

Figure 5 Design Workflow

6 Subjective Tests

6.1 Training Sets

Prior to the test, we showed the subjects a series of two 10-second videos that were pre-assigned to be a better viewing experience as compared to the reference video under certain luminance changes. Our two training scenarios featured a transition from 16 Cd/m^2 to 84 Cd/m^2 as well as a transition from 84 Cd/m^2 to 16 Cd/m^2. Similar to the test setup, the training setup had the video shown beside the reference video. During each training condition, dark or bright luminance, the subjects were told that the training video provides a better viewing experience than that of the reference video. However, the subject was also told that he/she is free to choose whichever video he/she prefers during the test case, even if it goes against what the convention of the training videos.

To eliminate any variance and provide consistency, a script was read to the test subjects during the training set. This script included instructions on how the subjects should interpret each training video.

6.2 Subjective Test Methodology

There are two main forms of subjective tests: "assessments that [seek to] establish the performance of systems under optimum conditions", and "assessments that [seek to] establish the ability of systems to retain quality under non-optimum conditions that relate to transmission and emission".

The subjective test was conducted in a room that is compliant with the ITU-R BT.500-13 Recommendation. Prior to testing, all subjects participated in a training session that outlines the scoring metrics and parameters of the tests and procedures. On top of this, the subjects were tested for eye acuity and color-blindness. A form of consent was also signed by the subject prior to any testing.

We employed the Stimulus Comparison Method Scale to evaluate the quality of our brightness adapted video. Specifically, we used the AB Comparison Method. This test method requires a reference video to be displayed beside the test video. The test subject was then given the following options to evaluate the left video compared to the right video.

" A ": Left video is perceived to be more comfortable to view during the change in luminance

" B ": Right video is perceived to be more comfortable to view during the change in luminance
" = " Both videos are perceived to be equally comfortable to view during the change in luminance

A total of eighteen subjects were polled in our trials where each subject was given ten test cases to watch and rate. In each of the test cases, the reference video and the brightness adapted video were placed either in the A slot or B slot of the monitor in order to eliminate any bias by the subject to choose one slot over the other. In each case, the videos were played simultaneously and contain the same contact. At the five second mark, the luminance was changed from the initial ambient luminance to the new ambient luminance. After ten seconds had elapsed, the test subject was given 5 seconds to choose their answer.

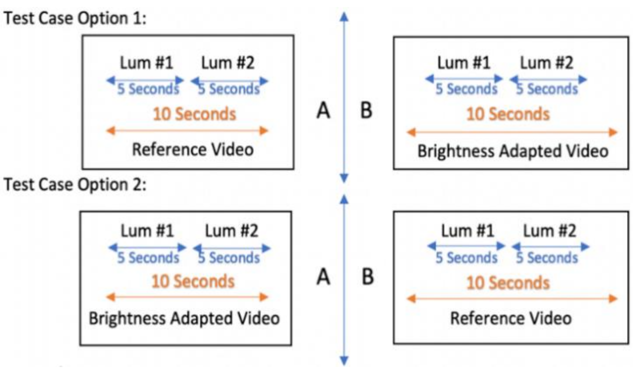

Figure 6: Subjective Test Methodology

7 Analysis and Results

It can be shown from the results of Graph 1 that Test Case 2 to 5 did not yield the expected results our test model predicted. In these cases, more subjects chose the reference video over the brightness adapted video. However, in Test Case 6 to 9, the test subjects chose the reference video over the video that was oppositely adapted to the changing luminance. Test cases 1 and 10 both showed the same video, but four out of eighteen subjects still chose one video or the other instead of selecting the equal option.

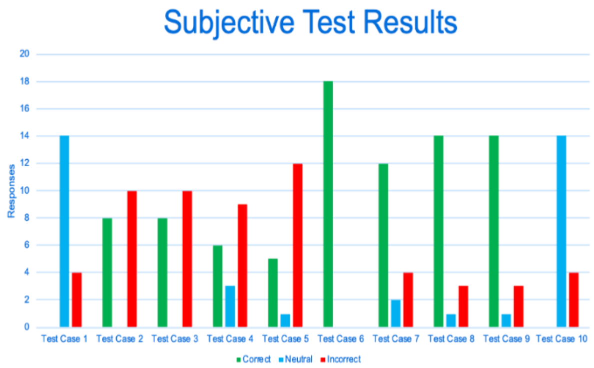

Figure 7: Subjective Test Results

One of the cause of discrepancies in the results can be the timing of luminance change. The timing of the luminance change was prone to human error, as the lights behind the subjects were changed manually based on a timer that started as soon as the video started. This meant that the video and luminance change could not be succinctly changed right at he five second mark. Any margin of error could negatively impact a user's experience with the brightness adapted video. For example, if the luminance was changed slightly too soon, the user's eyes would notice the gap between the two scenes of the brightness adapted test video. If the luminance was changed slightly too late, the user would also notice the gap prior to the two scenes and then notice an abrupt luminance change. Both of these cases would likely deter the user from selecting the brightness adapted video.

8 Conclusion and Future Work

Through subjective tests, we have established that brightness adaptation has a positive impact on a viewer's perception of videos. However, there are a few areas where improvements in algorithm can be seen. For example, in our brightness adapted algorithm, we utilize the HVS formula to find our new luminance. This algorithm fit the scope of our project but was not a very comprehensive model and therefore limited our ability to create the optimal sets of brightness adapted video. If we were to improve on our design, an algorithm using the Barten Model [7] for contrast sensitivity of the human eye would be more appropriate and robust.

$$S(u,L)=\frac{1}{m_t(u,L)}=\frac{M_{opt}(u,L)/k}{\sqrt{\frac{2}{T}\left(\frac{1}{X_0^2}+\frac{1}{X_{\max}^2}+\frac{u^2}{N_{\max}^2}\right)\left(\frac{1}{\eta pE(L)}+\frac{\Phi_0}{M_{lat}^2(u)}+\Phi_{ext}\right)}}$$

where

- X_0 angular extent of the object
- X_{max} maximum integration angle of the eye
- N_{max} maximum number of cycles over which the eye can integrate

Figure 8: Barten Model [7]

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