VIEWPOINT ADAPTIVE DISPLAY OF HDR IMAGES

Søren Forchhammer and Claire Mantel

DTU Fotonik, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark

ABSTRACT

In this paper viewpoint adaptive display of HDR images incorporating the effects of ambient light is presented and evaluated. LED backlight displays may render HDR images, but while at a global scale a high dynamic range may be achieved, locally the contrast is limited by the leakage of light through the LC elements of the display. To render high quality images, the display with backlight dimming can compute the values of the LED backlight and LC elements based on the input image, information about the viewpoint of the observer(s) and information of the ambient light. The goal is to achieve the best perceptual reproduction of the specified target image derived from the HDR input image in the specific viewing situation including multiple viewers, possibly having different preferences. An optimization based approach is presented. Some tests with reproduced images are also evaluated subjectively and by image quality metrics as HDR-VDP-2.

Index Terms— LED display, backlight, dual modulation, light field model, quality

1. INTRODUCTION

Display technology is developing at a rapid pace. The novel displays provide novel features as e.g. HDR and 3D and maybe more in a development stage light field displays are emerging [17-18]. One aspect is that the images perceived may change with the viewpoint. Even for 2D displays the quality of the perceived image may change with viewpoint and viewing conditions. To obtain full advantage of novel HDR displays, it may be important to take the viewpoint and viewing conditions into consideration. Striving for very high quality, careful modeling is required. In this paper, we shall consider HDR displays based on LED backlight and dual modulation, where both the backlight LEDs and the display LC elements are calculated based on the image input [1, 14, 15]. Backlight technology is also used in a light field display [18]. We shall focus on the 2D (and time) display and approach the modeling in a light field set-up, calculating the part of the light field in the analysis of the perceived quality dependent on the viewing angle(s) and light conditions. The overall goal is a light field description of first the physical signal displayed and then based on this a transformation to subjective perception. This will further be combined with the ambient light reflected from the screen.

We approach this in a number of steps to cope with the complexity. More specifically, we specify how this can be incorporated in the dual modulation control of e.g. HDR displays and how to assess the perceived quality. This work builds on and extends work on modeling of dual modulation, analyzing and optimizing it image dependently, e.g. [3, 10, 16]. First we review the influence of viewpoint and thereafter how we can extend to a situation of multiple viewers and include the ambient light. We shall both consider the effect of different viewpoints and possibly individual preferences.

In Sec. 2, we present the background for dual modulation and viewpoint dependent modeling of the perceived displayed image on the LED backlight LCD. In Sec. 3, we discuss how this can be extended to the multiviewer case and used in optimizing the backlight and include the ambient light in the evaluation. Some subjective experimental results are presented in Sec. 4 and discussed in terms of the light field approach to display analysis and optimization. In Sec. 5, we discuss the results and potential extensions.

2. LED BACKLIT DISPLAY

Dual modulation displays with LED backlight combined with LC elements facilitate the possibility of very bright areas in the image, e.g. up to 4000 cd/m^2 for the SIM2 HDR display [15]. The drawback is that the LC elements leak light, thus reducing the local brightness. This is especially pronounced when viewing the display at an angle. To mitigate this leakage, the backlight can be reduced giving a better black, but potentially leading to clipping of bright pixels. Thus the challenge is to image dependently strike the best balance between clipping and leakage in images with high contrast, and especially so for high local contrast. In this work we factor the model into a peak white of the display and a relative or normalized image displayed in the physical description. The peak white may (and should) influence the mapping from physical to perceptual values, though.

For the dual modulation display, the backlight is controlled by a number of light sources of much lower resolution than the LC elements, which are diffused to form the backlight $b(i,j)$ at pixel position (i,j). The LC element is then adjusted to the correct value, unless the leakage exceeds the target value or the target values exceeds the backlight value [4, 16].

Including a non-linear relation between the physical values and the perceived image values, the perceived luma, $l(i,j)$, may be expressed by [2]

$$l(i,j) = f^{-1}\left(b(i,j) \cdot \left[\frac{f(l_T(i,j))}{b(i,j)} \right]_{\alpha}^{1} \right), \qquad \textbf{(1)}$$

where f is a function mapping the target perceived luma, l_T, into physical luminance (both are normalized), and [ ] truncates to 1 as the max. value of the transmittance and α, as the angle dependent leakage value.

The leakage value in the model may be fixed, $\alpha=\varepsilon$, or angle dependent or generally expressed for each pixel, $\alpha=\varepsilon(i,j)$ reflecting the angle between the viewer and the pixel indexed (i,j) on the display. We may simplify to only consider the viewing angle dependence in the horizontal direction, $\alpha=\varepsilon(j)$.

Crosstalk between views and temporal effects were studied in [8] in extensions of the framework outlined above. Here we shall focus on the dependency on especially viewpoint and also subject preferences.

3. VIEWERS AND VIEWING CONDITIONS

The simple dual modulation model above (1) may be used to analyze and optimize the image display [2]. Here we shall extend to multiple viewers.

3.1. Viewer conditions and preferences

Multiple viewers will all be watching from a different position and thereby angle. For viewer k, we get the perceived luma, $l_k(i,j)$, by inserting $\varepsilon_k(i,j)$ in (1) for the pixel indexed (i,j).

Initially, we would like to minimize the distortion of the perceived image values, due to leakage and clipping:

$$d(i,j) = \|l(i,j)-l_T(i,j)\| \qquad \textbf{(2)}$$

The sign of $l(i,j) - l_T(i,j)$ reflects if the distortion comes from leakage or clipping, i.e. the upper or lower limit in (1). Correspondingly, we may split the distortion, d, in clipping, d_c, and leakage, d_l, and introduce viewer dependent weights, v_k and w_k, reflecting the viewers' individual preference. (We shall revisit this in Sec. 4.) In vector form, $\mathbf{d}$, for one image, we get for viewer k:

$$\|\mathbf{d}_k\| = \|\mathbf{v}_k \boldsymbol{d}_{k,c} + \boldsymbol{w}_k \mathbf{d}_{k,l}\| \qquad \textbf{(3)}$$

Combining for all the K viewers we get

$$\min \sum_{k=1}^{K} \|\mathbf{d}_k\| \qquad \textbf{(4)}$$

The resulting solution thus reflects multiple viewers, positioned at different viewing angles (by (1)) and each having an individual weight on the visual importance of clipping and leakage.

A simplified version would be to calculate for three fictive viewers: center viewer and one on each side sitting at horizontal angle ±β degrees, e.g. β = ±15°. For any given situation, weights could be assigned to each of the three viewers.

3.2. Influence of ambient light

The light conditions during viewing will both influence what the viewers see on the display, e.g. due to reflections in the screen, and the perception based on the light from the room coming to the viewers eyes, e.g. glare. The ambient light was included in the display modeling in [7]. In this paper, we focus on the effects on what is seen on the screen, i.e. the part related to the light field on the screen. For the modelled physical value rendered at (i,j), $y(i,j) = f(l(i,j))$ (1), we can add the light reflected by the display to get [10]

$$y_{light}(i,j) = y(i,j) + \frac{r}{\pi} E_{amb}, \qquad \textbf{(5)}$$

where y_{light} is the total luminance emitted and reflected by the display, r is the reflection coefficient of the display, (3% for the B&O BV7 used, Sec. 4) and E_{amb} is the ambient luminance in lux. We can now map to perceptual domain using f^{-1}, and apply it in (1-5). Combining with (1) using $\varepsilon(i,j)$, we can formulate a light field set-up in a perceptual domain for the display, where the model describes the values given by the viewpoint (here as a single point) relative to the display, which will determine the $\varepsilon(i,j)$ for each pixel on the display. This can be repeated for any point, e.g. for the multiviewer case (3-4).

4. DUAL-MODULATION EXPERIMENTS

We have conducted analysis and visual testing on two LED-LCD dual modulation displays [9-10]. Some results and findings are presented and discussed below.

4.1. Visual tests

We have conducted visual inspection and testing on two LED-LCD dual modulation display. A SIM2 47" HDR (direct backlit) display and a Bang&Olufsen, B&O BV7 (edge-lit) 46'' display, modified especially for dual modulation experiments. Viewing angles of both 0^0 and 15^0 relative to center of screen were tested. For the latter, the leakage ratio, ε, as a function of horizontal angle is depicted in Fig. 1. The increase of ε reflects both the decrease of the absolute value of light emitted and the increase of absolute leaked light.

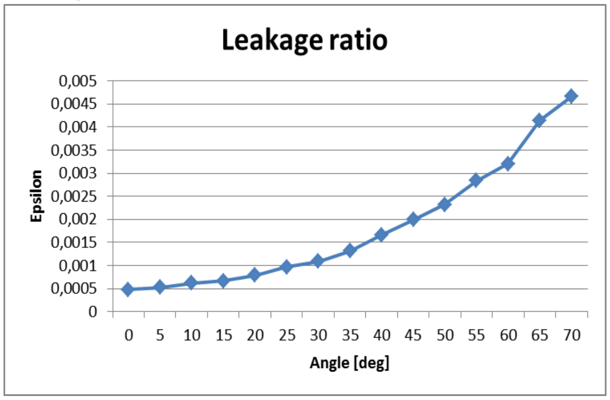

Figure 1 Leakage value as a function of horizontal angle [5]

A subjective test was set up in which 20 participants were asked to rate the visual quality of sequences [10]. In this test, the independent factors were the source sequence (5 sequences [10]), the backlight control method (2 methods), the peak white (maximum brightness of the display: 75, 200 or 490 cd/m2) and the ambient light (No light, 5 lux or 60 lux). The two backlight control methods are Full Backlight (FBL), for which all LEDs are set to their maximum intensity, and Gradient Descent (GD), which optimizes the local LED values according to image content according to Eq. (1-2) [3]. The major difference between those two control methods is the stability of the FBL and the spatio-temporal variation of the GD. The display was rotated anti-clockwise by an angle of 15°. Participants were located at 3 times the height of the display.

4.1.1. Viewer preference

An ANalysis Of VAriance (ANOVA) [6] was performed with the factor Subject as a random factor. The interaction of the factors Subject x Control Method x Sequence is significant (p<0.05, F=6.7). A closer look shows a bimodal distribution of the grades among the participants regarding the preferred control method. Therefore, two supplementary analyses were made, considering separately Subjects who prefer the FBL method (6) and those who prefer the GD.

It follows that 2 types of subjective preference could be defined. For Subjects who prefer the more stable and globally brighter FBL control method, the Ambient Light is not significant but the Peak White is (p<0.05, F=4). On the contrary, for those who prefer the more contrasted and more variable GD, the Peak white is not a significant factor but the Ambient Light is (p<0.05, F=5). This could roughly be summarized in two distinct sensitivities: either participants like a low minimum black level (GD, factor Ambient Light significant) or they prefer a bright image (FBL, factor Peak White significant). This is illustrated in Figs. 2 and 3. It should be noted that the objective of the study was to identify and test the best peak white for a given (measured) ambient light value. In this analysis (Figs. 2 and 3), we focus on the difference in viewer preference, which lead to dividing the subjects into two groups.

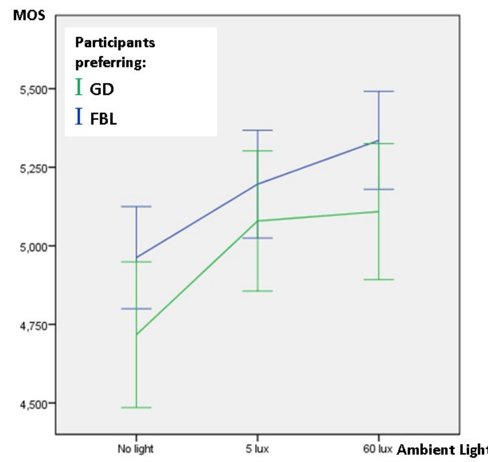

Figure 2 MOS as a function of Ambient Light

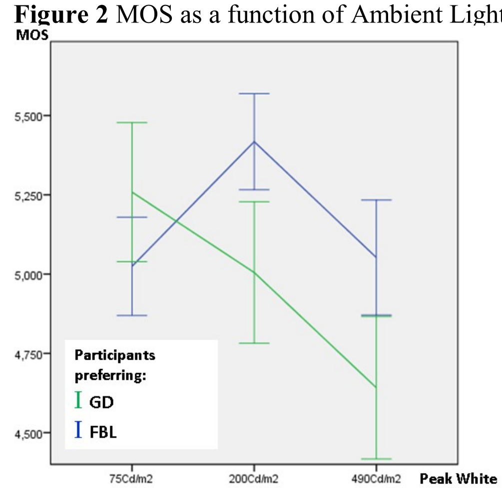

Figure 3 MOS as a function of Peak White

Based on the viewer preference from visual tests, as the small test mentioned above, we can infer the viewer dependent weights to be used in (3). It is a separate issue on how to actually infer the results from either selected data or testing on random images. Identifying the individual viewers is outside the scope of this paper.

4.2. Objective quality assessment metrics

The HDR-VDP-2 quality metric [12] takes as input the absolute physical displayed valued, $f(l)$, of each pixel and may thus be combined with the models of the displayed images in Sec. 3.

4.2.1. Results for model-based objective metrics

HDR-VDP-2 was thus applied to the sequences from the experiment described in Sec. 4.1, the displayed luminance being obtained from the model described in Sec. 3, i.e. using (1), and including the reflected ambient light (5). Comparison with the subjective Mean Opinion Scores from the experiment yields the following results: PCC=0.335, SROCC=0.324, RMSE=0.727, OR=0.8. These results were obtained with maximum Peak White (490 cd/m2) as reference. As during the experiment each Peak White level was evaluated independently (one after another without reference), using the currently evaluated Peak White as reference in the metric might be closer to perception and thus improve the metric results.
For quality metrics using pixel value (luma) as input, another challenge is the choice of the inverse of function f in (1) [10], that allows transforming perceived luma values to physical luminance. Taking PSNR as an example of such quality metric with two different f functions (gamma of 2.2, and PQ [13]), correlation with MOS shows best performance for PQ with PCC=0.49 as opposed to 0.02 for gamma (similar improvement is obtained for SROCC and of smaller magnitude for RMSE and OR).

4.2.2. Influence of viewing angle

In [9], it was shown that including leakage in the modeling gives statistically significant improvements to the performance of objective quality assessment metrics when evaluating the quality of videos displayed with local backlight dimming. The paper also showed that including the horizontal viewing angle of each pixel in the model gives significant improvements to the metrics performance when the subject views the display from a 0 degree angle. In Fig. 4, the linear correlation of MSE (2) (computed with γ=2.2 for f in (1)), with MOS scores from the subjective test is given as a function of the weight on leakage, w_k = 1- v_k (3). We observe that using the horizontally varying (HV)

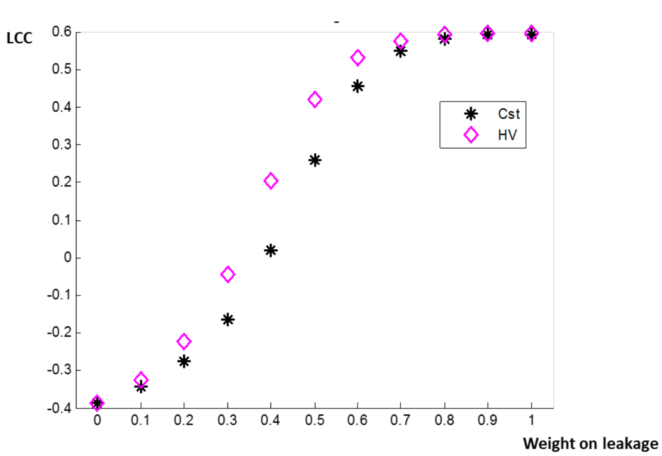

Figure 4 Linear correlation of MSE with subjective MOS as a function of weight on leakage, w_k.

dependence on leakage, $\alpha=\varepsilon(j)$ in (1), performs slightly better than a constant leakage (as observers sit at 3 times the height of the screen, the range of angles across the screen is approximately [-16°; 16°]). The sequences used were generally dark [9].

5. DISCUSSIONS AND FUTURE WORK

Here we have focused on defining a light field oriented model of the display and mapping the images displayed to a perceptual domain.

Future work includes analyzing the results and optimization using both the horizontal and the vertical viewing angle of each pixel, as well as performing the backlight optimization using all parameters in (1-5).

The frame work incorporating also ambient light and/or multiple viewers may on the physical side be extended to incorporate view cross-talk for 3D [8] and multi-view displays and temporal cross-talk for video. An open issue for the dual-modulation HDR displays is the definition of contrast, as the parameters of the display become image dependent and especially this is the case for globally optimized LED display. This will also apply to many tone-mappers. While the possible contrast over time between a dark image and a bright image may be expressed, within one image it is influenced by distance between pixels and areas in an image dependent and/or stochastic manner.

6. CONCLUSIONS

We have presented and discussed a framework for analysis and optimization of images and sequences displayed on an HDR monitor based on dual modulation. The approach has been to describe the light field as seen by the (multiple) viewers taking artifacts into account as clipping and leakage of the LED-LCD display as well as reflections of the ambient light. Viewer preference was also investigated and included. The framework includes a model description of the displayed images. Focus has been on single images or video as a sequence of images. Based on the modeled displayed images the quality may be evaluated. A small experiment revealing some viewer preference was also included. The presented framework provides and outlines a light field model for (backlit) displays. Future work includes extensions to incorporate other display types and to increase the correlation of the objective metrics with subjective test results.

7. ACKNOWLEDGEMENT

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