8-3: Invited Paper : Light Steering Projection Systems and Attributes for HDR Displays

Light Steering Projection Systems and Attributes for HDR Displays

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Abstract

New light steering projectors in cinema form images by moving light away from dark regions into bright areas of an image. In these systems, the peak luminance of small features can far exceed full screen white luminance. In traditional projectors where light is filtered or blocked in order to give shades of gray (or colors), the peak luminance is fixed. The luminance of chromatic features benefit in the same way as white features, and chromatic image details can be reproduced at high brightness leading to a much wider overall color gamut coverage than previously possible. Projectors of this capability are desired by the creative community to aid in and enhance storytelling. Furthermore, reduced light source power requirements of light steering projectors provide additional economic and environmental benefits. While the dependency of peak luminance level on (bright) image feature size is new in the digital cinema space, display technologies with identical characteristics such as OLED, LED LCD and Plasma TVs are well established in the home. Similarly, direct view LED walls are popular in events, advertising and architectural markets. To enable consistent color reproduction across devices in today's content production pipelines, models that describe modern projectors and display attributes need to evolve together with HDR standards and available metadata. This paper is a first step towards rethinking legacy display descriptors such as contrast, peak luminance and color primaries in light of new display technology. We first summarize recent progress in the field of light steering projectors in cinema and then, based on new projector and existing display characteristics propose the inclusion of two simple display attributes: Maximum Average Luminance and Peak (Color) Primary Luminance. We show that the proposed attributes allow a better prediction of content reproducibility on HDR displays. To validate this assertion, we test professional content on a commercial HDR television system and show that the proposed attributes better predict if a pixel value lies inside the capabilities of a display or not.

Author Keywords

Light Steering Projection System; High Dynamic Range; Displays Capabilities; Peak Luminance.

1. Introduction

High Dynamic Range (HDR) and Wide Color Gamut (WCG) pixel representations significantly increase the amount of light and color values that can be designated. Indeed, HDR imagery can represent the full range of perceptible shadow and highlight details, while WCG technology increases the amount of visible color that can be represented [1]. These new standard pixel representations far outreach the capabilities of traditional display technologies and thus HDR capable displays such as light steering projectors, dual amplitude modulation (DAM) [2] or self-emitting light devices such as OLED [3] have been introduced.

In this article, we first summarize efforts towards high brightness

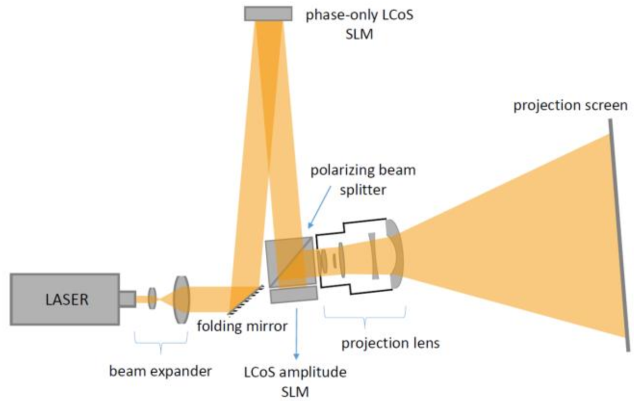

Figure 1. System diagram of a light steering projector architecture (single color channel only): light from an expanded and collimated laser beam reflects off a phase-only modulator. The per-pixel phase retardation causes a steering effect and light from dark parts of the image can be used to create high luminance features and to reduce the black level.

HDR projection in cinema using light steering technology [4] and analyze the similarities between light steering and other HDR display technologies such as direct view LED walls, DAM, OLED and Plasma, all of which can produce brighter than full screen white (FSW) highlights for small image features. Legacy attributes that characterize traditional displays, fail to accurately describe the extended capabilities of modern HDR technologies. Both in cinema and in the home, accurate display descriptions help predicting which pixel values will be reproducible and in which cases further processing, such as tone or gamut mapping should be performed in order to maximize the visual quality of the HDR content.

To better describe the impact of a light and power budget on HDR display capabilities, we propose two additional attributes: **Maximum Average Luminance (MAL)** and **Peak Primary Luminance (PPL)**. These attributes were designed to describe the extended capabilities of upcoming light steering projection systems. We validate the pertinence of our attributes for other HDR display technology by testing professional content on a commercial HDR TV and show that the proposed attributes predict more reliably if a pixel value lies inside the display's capabilities or not.

The remainder of the paper is organized as follows. Section 2 summarized recent work in light steering projector technology. Section 3 describes typical power budgets of HDR displays and proposes two attributes to better predict luminance and color performance. Section 4 applies the new attributes in a real-world example scenario to illustrate the improvement in prediction accuracy. Finally, Section 5 concludes this article.

2. Light Steering Projection Technology

With rapidly improving display technologies for the home, cinema needs to remain competitive in terms of achieving the highest image quality on screen. While high frame rate and high spatial resolution are common features today, even the most advanced cinema projectors rely on light attenuation as an image formation model (i.e. filtering light on a per-pixel basis to reduce the luminance down from FSW). At the same time, image statistics suggests that HDR content achieve low average image intensity in controlled viewing environments [4]. Previous work in HDR emphasizes the importance of high in-scene contrast and more importantly high peak luminance as essential perceptual attributes for images to look realistic [5]. This inefficient use of light makes it impossible for incumbent projection technologies to achieve meaningful high peak luminance levels.

Recently, a new type of projector for cinema has been introduced that forms images based on light steering, for example by utilizing a phase modulator to distort the wavefront of incoming light, and *steer*s light away from dark and into bright areas. Figure 1 depicts a basic example architecture of a light steering system using LCoS display technology as modulators. In such light steering systems, the maximum peak luminance depends more on the average (light) power of an image rather than to the FSW luminance. The relationship between peak luminance and average power is also present in modern displays that produce light only where needed to increase bright feature higher than full screen white luminance.

3. Display Attributes for HDR Displays

Display attributes characterize the capabilities of a display. Example of legacy attributes are: Contrast, Peak Luminance (PL), Black Level and Gamut Coverage. Although these attributes are important, we believe that they are not enough to describe the characteristics of a light steering projection system.

Modern displays such as light steering projector and OLED TVs can achieve very high peak luminance values for a finite number of pixels. This number of pixels depends on the maximum available light budget that can be distributed over the image plane. Light budget is directly related to the maximum available power. For light steering projection systems, the light budget feature should be well defined for colorists to exploit the full latitude of capabilities of the projector. For television systems, the distributed unique graded content might well end up above the power budget of many television systems, thus clipping will occur. Figure 2 illustrates this clipping effect by plotting the PL response of a commercial HDR television when varying either the light level of a surround image or the size of a white patch ("LXX" corresponds to the percentage area of the image that the patch covers). Note how the PL converges toward the full white screen luminance when the white patch gets bigger or the surround luminance gets higher. Figure 2 demonstrates that the PL attribute alone is not enough to predict the capabilities of such a HDR display system.

Table 1. PL and MAL attributes (in cd/m^2).

Patch Size	OLED Television		Light Steering Projector	
	PL	MAL	*PL*	MAL
L25	782	129	1796	113
L50	456	120	453	114
L75	224	118	227	128

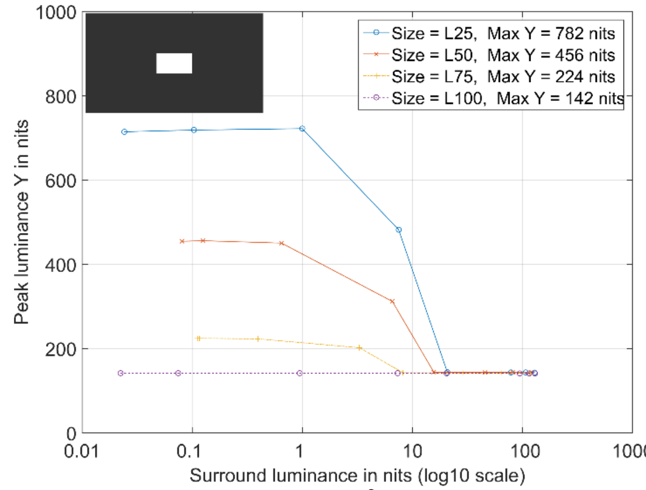

Figure 2. Measured PL in cd/m^2 of a HDR TV for various surround luminance values and patch sizes.

To better characterize this power budget, we propose a **Maximum Average Light (MAL)** attribute which indicates the quantity of light power available to be distributed among all pixels. Although this attribute is directly inspired from light steering projection systems, we will show that HDR commercial television can greatly benefit from such an attribute. Indeed, from the data plotted in Figure 2, the MAL can be derived using either the L100 plot (white patch covering 100% of the picture size) or by averaging the light from the white patch and its surround.

$$MAL = A_w * PL_w + (1 - A_w) * L_s \,, \qquad (1)$$

where A_w represents the normalized area of the white patch while PL_w and L_s correspond to the measured luminance of the patch and surround area respectively. Table 2 reports the relationship between PL and MAL for different patch sizes measured on a light steering projection prototype and on a commercial HDR television. For small patch sizes and similar MAL, the light steering projector reaches a much higher PL values.

In addition to the power budget, the luminous efficacy of a display's primary also affects the peak luminance of saturated colors. Indeed blue light emitting devices require more power than green ones to achieve the same luminance values. In other words, even at full power, saturated colors reach different peak luminance values. This limitation applies to any display technology since it is related to the luminous efficacy of the human vision system at different wavelength [6]. Light steering technology circumvent this limitation by reaching much higher luminance levels than other HDR display technologies for saturated colors. Although much higher, these levels still need to be defined and understood for colorists to efficiently exploit this expanded gamut.

Thus, we propose the **Peak Primary Luminance (PPL)** attribute which corresponds to the peak luminance reached when only a single primary is powered. Figure 3 plots the expected and measured peak luminance for each primary of a commercial HDR television. The expected luminance corresponds to the contribution of each primary to the white channel based on the luminous efficacy of the display primaries (P3 primaries [7]). The difference between expected and measured peak luminance is around 67% for Red and Green and 57 % for Blue. Such differences mean that highly saturated colors expected to be

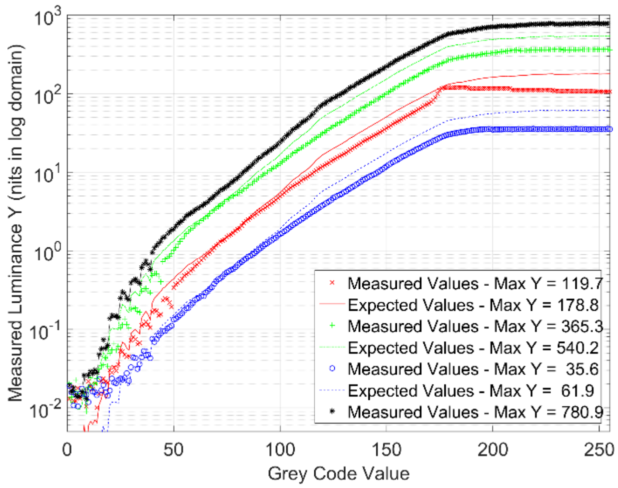

Figure 3. Measured and expected maximum luminance per color channel.

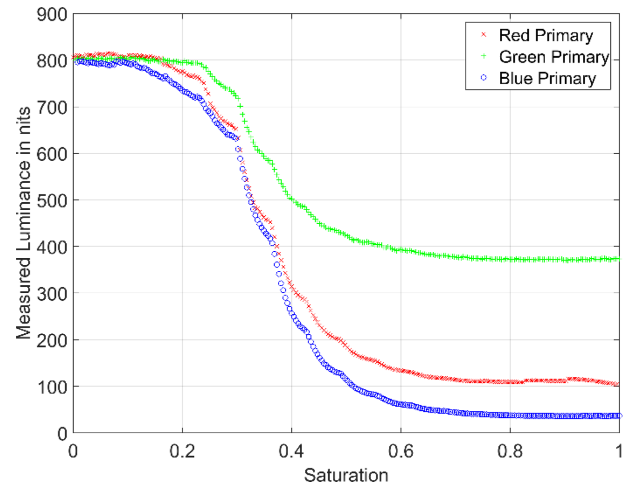

Figure 4. Saturation versus peak luminance.

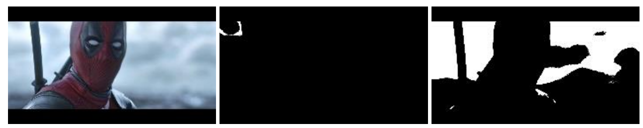

Figure 5. Clipped pixels prediction for Deadpool: tone mapped (left), clipped pixels predicted by the PL only (middle) and predicted using both PL and MAL (right).

inside the display capabilities will be clipped either to a lower luminance value to preserve the saturation or desaturated to preserve the luminance value. This trade-off between saturation and PPL is illustrated in Figure 4Figure where one of the primaries is always fully powered while the other two primaries are increased simultaneously. Table 2 reports the PPL attribute for a light steering projector prototype and a commercial HDR television. Similarly to the PL, the light steering prototype can reach higher PPL values.

Table 2. PPL (in cd/m^2) for a light steering projector and a commercial HDR television.

Primary	OLED Television		Light Steering Projector	
	PPL Measured	*PPL Expected*	*PPL Measured*	*PPL Expected*
Red	119.7	178.8	527	471
Green	365.3	540.2	1016	1217
Blue	35.6	61.9	78.5	106

Table 3. Statistics and predicted clipped pixels for a frame of Deadpool depending on display attributes.

Version	*Maximum Luminance*	*Average Light Level*	*Percentage Clipped*
Original	822.48	180.37	0%
Clipped PL only	782	180.36	0.31%
Clipped PL+MAL	345.16	141	26.3%

Table 4. Statistics and clipped pixels prediction for a frame of Life of Pi with expected and measured blue PPL.

Version	*Maximum Luminance*	*Average Light Level*	*Percentage Clipped*
Original	224.02	20.65	0%
Expected Blue PPL	81.02	17.45	11.25%
Measured Blue PPL	81.02	12.18	20%

4. Using Attributes to Predict Clipping

The proposed attributes aim at better predicting the full capabilities of a display system. For cinema applications, display characterization is important to predict if graded content on high-end projection systems (for example light steering) can be directly used on projection systems with lower capabilities. If this is not the case, another grading should be performed for the lower-end projection system. Knowing the full capabilities also allows colorists to better exploit the full potential of a projection system. For television applications, display characterization allows to predict which pixels will be clipped. Due to the high variety of televisions, regrading content for each display capabilities is highly unpractical. Thus detecting clipped pixels can help guiding the clipping process toward the best subjective quality. Although designed for light steering projection systems, we argue that the proposed attributes apply to most HDR displays technologies. To validate this statement, we compare the clipping prediction, using traditional and proposed attributes, of two HDR frames when displayed on a commercial HDR television. Both frames were graded for HDR television on a reference display with higher capabilities than the tested display.

The first frame reaches a slightly higher peak luminance than the capabilities of the display (782 cd/m^2) but a much higher average light level than the MAL (see Table 3, row "Original"). Since traditional attributes would detect luminance values above the peak luminance, we clip those to 782 cd/m^2 (row "PL Clipped" in Table 3). Then we used the MAL attribute to simulate the clipping of pixels (row "PL+MAL Clipped" in Table 3). Our simulation assumes that pixels contributing the most to the average light level of the picture will be reduced until reaching the MAL. Results show that the percentage of clipped pixels predicted using only the PL (0.31%) is significantly lower than when using both PL and MAL (26.3%). Note that displays can have different proprietary solutions to handle the power

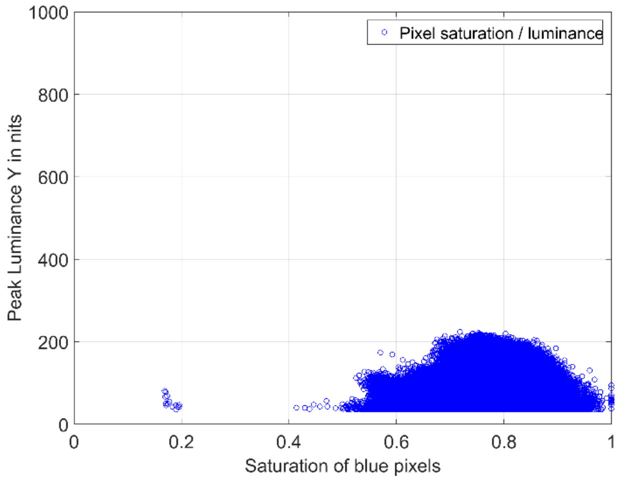

Figure 3. Saturation and luminance values of blue pixels with luminance above 35.6 cd/m^2.

distribution of light. Figure 5 illustrates the percentage difference in affected pixels using both prediction methods. Contrary to the traditional method that only indicates the highlights as clipped, our proposed attributes identify most of the sky as affected by the clipping.

The second test frame statistics are below the PL and MAL of the display (Table 4, row "Original"). However, a significant amount of saturated blue pixels have a luminance value above both assumed and measured peak primary luminance for blue. Figure 6 plots luminance value depending on the saturation for all blue pixels with a luminance value above 35.6 cd/m^2 (measured peak blue luminance of the display). A significant amount of highly saturated pixels are above this luminance threshold. Figure 4 indicates that the maximum luminance barely varies for saturation values above 0.8. When assuming that the display can reach the expected peak blue luminance, only 11.25% of the total pixels are predicted to be clipped. However, this percentage rises to 20% when relying on the measured peak blue luminance value. Note that this prediction is very conservative and a higher number of clipped pixels would be predicted using a model that assume the peak luminance for each saturation values. However such a model would be display and technology dependent and we believe not generic enough to be included in this paper. Finally Figure 7 illustrates the percentage difference in affected pixels using both prediction methods.

5. Conclusion

Light steering technology brings extra brightness capabilities to cinema projection. However, without an accurate characterization of these extra light and color values, colorists might not be able to exploit these new capabilities to their fullest. To this end, we proposed in this article two attributes to better characterize light steering capabilities. The **Maximum Average Luminance (MAL)** describes the power budget that defines most current HDR display technologies. The **Peak Primaries Luminance (PPL)** describe more accurately the luminance level that saturated values can reach. These attributes, while simple, better represent

Figure 4. Clipped pixels prediction for Life of Pi: tone mapped (left), clipped pixels predicted by the PL only (middle) and predicted using both the PPL (right).

the image formation models used in HDR display technologies and thus provides a better characterization of displays. For television applications, such characterization helps predicting which pixel values will be clipped and thus proprietary technology can be embedded in commercial television to increase the subjective quality of clipped pixels.

We demonstrated the principal validity of both proposed attributes using professional HDR content and measurement on a commercial HDR television. We believe that standards, such as ACES Output Device Transform (ODT), could greatly benefit from including the proposed attributes.

6. Acknowledgements

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7. References

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