QoE-based Brightness Control for HDR Displays

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***Abstract*—This paper proposes a brightness control method for retargeting legacy content on High Dynamic Range (HDR) displays. This method is based on a perceptual experiment that evaluates the brightness preference of users. We study the special case of screen content to better understand the effect of image statistics on human preference for brightness. The experiment concluded that brightness preference is highly content dependent. Using the data of the subjective study, we propose a new feature that analyses the source content to appropriately control the brightness of the HDR display. Based on this feature, we propose a brightness control algorithm that adjusts the luminance of display depending on the number of bright pixels in the content.**

Keywords*—*High Dynamic Range; Brightness Control; Tone Expansion; Screen Content

I. INTRODUCTION

Statistical studies on multimedia trends show that on an international average, people spend around 400 minutes every day looking at screens [1]. This includes consuming content in the form of watching TV, working on a computer monitor, spending time on smartphones and tablets, etc. Most content viewed on screens is not necessarily camera-captured content but may also contain computer graphics and text, often mixed with camera content. Graphics-based screen content is often characterized by no sensor noise, repeating patterns and few saturated colors [2]. With the arrival of new display technology, adapting existing screen content puts forth a new challenge especially since previous work on display retargeting mostly focuses on camera-captured content.

Amongst next generation displays, it is widely accepted that High Dynamic Range (HDR) displays are the most valuable in terms of Quality of Experience (QoE) [3]. These displays are characterized by a high peak brightness and contrast levels that preserves details in dark and bright regions [4]. This results in a user experience that has never been seen on traditional Standard Dynamic Range (SDR) or legacy displays. However, almost all existing screen contents are in a SDR format and have been designed for SDR displays. With the arrival of HDR TV sets, there is a growing interest in adapting legacy contents for these new displays. The process of retargeting SDR images into HDR ones is known as tone expansion or inverse tone mapping [5]. However, none of the existing tone expansion methods deal with the case of screen content nor consider the visual comfort aspect of QoE. In the following, we use the term retargeting for tone expansion.

In this paper, we explore the human preference for brightness, specific to tone expansion, and propose a novel brightness control model. Previous research scales SDR content to the maximum luminance provided by the display. Through a perceptual experiment we have observed that scaling often leads to an uncomfortably bright image, especially when applied to screen content. We also put into evidence that, when retargeting legacy content, brightness scaling is highly content dependent. We propose brightness control model that attempts to mitigate brightness discomfort. Our objective is to improve upon existing expansion techniques with a new method of brightness control.

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In summary, our contributions are: 1) a user study giving insight on human preference for brightness when looking at HDR contents; 2) a brightness control method for retargeting screen content that adheres to human visual comfort; 3) design of a novel feature that facilitates brightness retargeting for HDR monitors.

This paper is organized as follows. Section II reviews the related works. In Section III, we present the subjective evaluation methodology. Section IV details the analysis of the results and the brightness model. Finally in Section V, we conclude the paper.

II. RELATED WORKS

This section introduces the existing literature on tone expansion and perceptual studies related to brightness comfort. We discuss methods of brightness control and standardization efforts in brightness regulation.

A. Tone Expansion

In the recent years, a number of tone expansion operators have emerged in literature including global [6]–[8] and local [9]–[14] operators. De Simone et al. [15] have conducted a subjective quality assessment amongst various expansion operators and concluded that a global linear operator gives the best results. A recent approach presented in [8] and [16], supersedes the linear operator by using a global style-aware tone curve. A brief reporting on visual discomfort caused by tone expansion can be found in [17] where the authors describe an uncomfortable experience in viewing bright content on a 4000 nits HDR monitor. In all cases, none of these expansion operators or subjective evaluations consider retargeting screen content.

B. Perceptual Studies

Various subjective experiments, in the literature, have considered peak brightness as a user preference. In [18], Guterman et al. suggest user preference plateaus as maximum luminance level increases. This trend is confirmed by Hanhart et al. [19] for HDR displays claiming that human preference increases logarithmically with the increase in peak brightness at which an HDR content is displayed. Both studies use natural images or cinematic contents in their experiments and do not consider screen contents. Freysinner at al. [20] have conducted a study on brightness preference on signage displays reporting that the signage panel brightness was dependent on surround lighting. Similarly, Mantel et al. [21] have explored the impact of peak white and ambient light on video quality and proposed test cases for adapting both factors.

Visual disturbance is an important perceptual factor when considering brightness preference. The World Health Organization (WHO) defines visual disturbance as a high degree of visual discomfort typically occurring after prolonged visually intense activity, and the symptoms include fatigue, pain around the eyes, blurred vision, dry eyes or headache [22]. Among studies in HDR, Rempel et al. [23] have showed that viewing HDR content, even in dark environments, may not lead to visual fatigue. Na and Suk [24] have investigated visual disturbance caused by viewing mobile phones in low light conditions. They separate brightness comfort into two parts: 1) initial viewing comfort (reaction to brightness by turning on display) 2) continuous viewing comfort (reaction to brightness after prolonged viewing of content). In this paper, we focus on initial viewing comfort of screen content on HDR displays, and thus not consider modeling visual fatigue caused by brightness discomfort in continuous viewing.

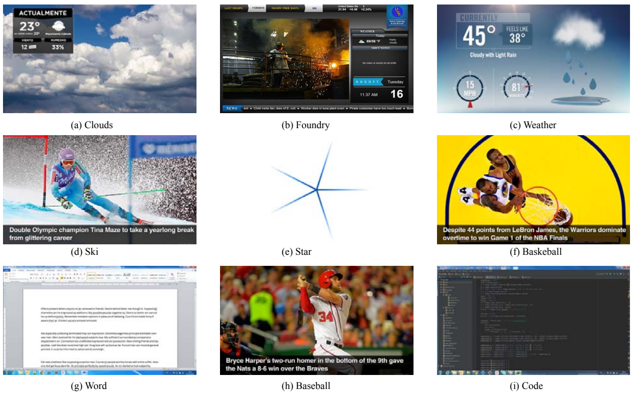
C. Brightness Control

Automatic brightness control is a prominent feature in most modern display technology today. Merrifield and Silverstein [25] define the general method of brightness control depending on the ambient light of the surroundings. This method has been improved over the years. More recently, Schuchhardt et al. [26] proposed a context-aware approach for mobile phones where screen brightness is determined as a function of ambient light, user preference, location, sun angle, battery level etc.

Brightness control is strongly correlated with TV power consumption. The International Electrotechnical Commission (IEC) have published the standard IEC 62087 [27] for monitoring display energy consumption and signifies importance of brightness control. With the introduction of HDR displays, power or brightness management has become even more necessary. To this effect, the Society of Motion Pictures and Television Engineers (SMPTE) have released SMPTE ST 2086 [28] which defines mastering metadata for HDR video including Maximum Content Light Level (MaxCLL) describing maximum brightness and Maximum Frame-Average Light Level (MaxFALL) describing the maximum value of the frame-average luminance of the content. These parameters are applicable to control the brightness of HDR displays on the consumer end [29]. However, to the best of our knowledge, no existing guidelines specify the management of excessively high brightness. This makes it a challenge for tone expansion and encourages the exploratory aspect of this study on HDR brightness preference.

III. SUBJECTIVE EVALUATION

The aim of our study is to investigate human brightness preference considering brightness comfort for special case of retargeted HDR screen content. The independent variable is the screen content and the measured variable is the brightness preference of the user. Through this experiment, we intend to



(a) Clouds (b) Foundry (c) Weather (d) Ski (e) Star (f) Baskeball (g) Word (h) Baseball (i) Code

Fig. 1. A subset of 9 screen content images used in the subjective experiments.

answer the following question: *what is the preferred brightness in terms of initial viewing comfort for a given retargeted screen content?* To this end, the user has been presented with screen content images on an HDR display and was instructed to vary the brightness level with a graphical slider. Details of the experiment such as stimuli, pre-processing, participants, apparatus and procedure are described in this section.

A. Stimuli and Pre-Processing

The dataset for this experiment contains 47 screen content images. This content varies significantly in appearance, style and image statistics. This included signage images, computer graphics, text documents, web browsers, desktop wallpapers, powerpoint slides, natural images with text, etc., as seen in Fig. 1. The stimuli used in this experiment is available in the additional materials and the processed HDR images are available upon request to the authors. All images are in 8 bit Full HD (1920x1080) resolution and in sRGB colorspace. We have processed these 8 bit images in this order: de-quantizing, converting to double precision, linearizing by applying an inverse gamma and extracting the SDR luminance component Y_{SDR}. The tone expansion step is defined by the following equation:

$$Y_{HDR} = L_{Max} \times Y_{SDR}^{\gamma} \tag{1}$$

where Y_{HDR} is the HDR luminance, L_{Max} is a brightness scaling factor and γ is a style adaptive parameter used in the state-of-the-art expansion operator provided in [8] and [16]. Finally, the resulting Y_{HDR} is used to determine the RGB values in HDR domain by subsequently performing an operation of luminance replacement:

$$\begin{bmatrix} R_{HDR} \\ G_{HDR} \\ B_{HDR} \end{bmatrix} = \frac{Y_{HDR}}{Y_{SDR}} \begin{bmatrix} R_{SDR} \\ G_{SDR} \\ B_{SDR} \end{bmatrix} \tag{2}$$

For this experiment, we vary the L_{Max} from 100 nits to 4000 nits with a step size of 100.

B. Participants and Apparatus

10 males and 6 females have participated in the experiment. The average age of the users was 24.2 and ranged from 19-48 years. 9 had previously seen HDR videos. 6 wore glasses and

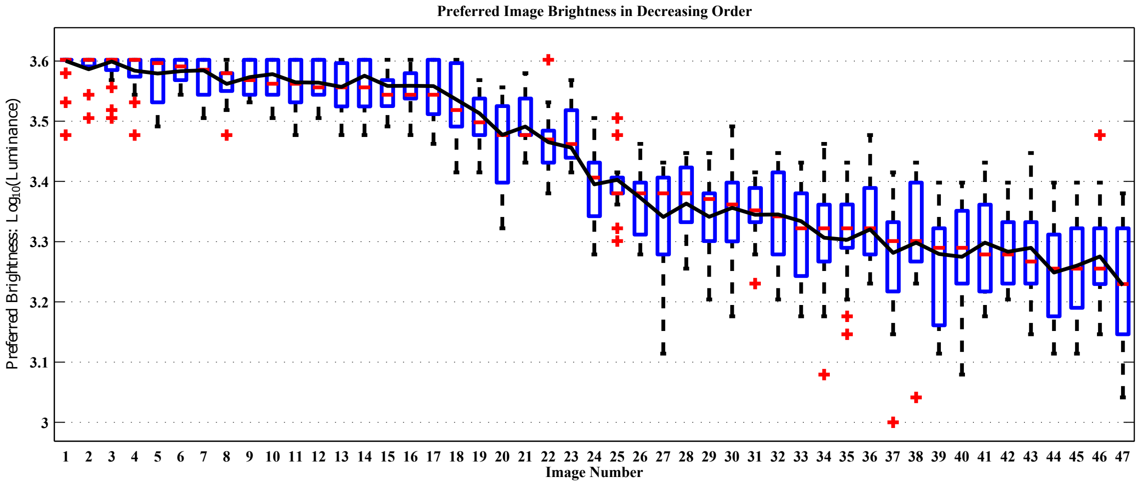


Fig. 2. A boxplot diagram of the results. Black line: 5% truncated mean, Red horizontal lines = median values; Blue boxes = inter quartile range; Dotted whiskers: adjacent values; red crosses = outliers. It can be observed that setting L_{MAX} to the maximum luminance of the target display is not always preferred for brightness comfort.

all have normal color vision. The experiments are conducted on the SIM2 HDR47 display, which has Full HD resolution, peak brightness of 4000 nits and contrast ratio higher than 4×10^6. The test has been conducted in a room within ambient luminance of approximately 5 lux and observers were positioned at a distance 3 times the height of the display. In this study, we purposely use a dark surround environment as it represents the worst case scenario, since the human visual system is more susceptible to brightness discomfort in a dark setting.

C. Procedure

The experiments began with a 5-10 minute introduction to the participant to HDR technology with few sample HDR images and videos. This step also permitted their eyes to adapt to the surround lighting conditions. This was followed by a short training session using images similar to the ones presented in [30]. The images displayed were scaled to $L_{Max} = 4000$ nits and the user was asked if the image was visually comfortable or too bright. If the image was too bright, the participant was requested to re-adjust the brightness to a comfortable setting and if not, they were asked to move on to the next image. Our choice for using this process is based on pilot studies, starting at $L_{Max} = 100$ nits or $L_{Max} = 1000$ nits did not create the necessary initial visual discomfort as compared to $L_{Max} = 4000$ nits. Once the user was comfortable in this methodology, they were asked to repeat the same with the testing screen content dataset.

The preferred brightness was selected by the user using a graphical slider representing an unlabeled continuous scale of $100-4000$ nits with a step size of 100 as mentioned in Section III-A. This slider was placed on the bottom middle part of display, ensuring it had no impact on user's vision. The knob of the slider was set to the extreme right ($L_{Max} = 4000$). The participants had to shift the knob to the left to reduce the brightness to their preference, after which they were instructed to click on the next button that recorded their chosen value and also allowed them to move on to the next image. A black image was placed in between images for a waiting time of 5 seconds, in order to simulate effective initial viewing comfort when viewing the retargeted image. Users were given around 10 seconds to choose their preferred brightness, however most users made their choices much quicker. Finally, we have concluded the study by asking the participants to fill in a questionnaire regarding visual comfort as in previous studies [15] [23].

IV. RESULTS ANALYSIS

In this section we analyze the results of the experiment, develop a model for preferred brightness using a new feature and validate the model.

A. Analysis of Experiments

The boxplot in Fig. 2 shows the dispersion in preferred brightness. It should be noted that we represent preferred brightness (measured in absolute luminance) in the logarithmic domain. We observe that, for some content, setting L_{MAX} to the maximum brightness of the target display is visually comfortable while for others it is not the case. There was a tendency amongst users to reduce the brightness of the display when the source content had large regions of white pixels or highly saturated bright colors. A limitation of the SIM2, is that if more than 40% of the back-light LEDs of the SIM2

TABLE I. RESULTS OF VISUAL DISCOMFORT QUESTIONNAIRE

Symptom	Mean	Std
Double vision	1,16	0,31
Problems in focusing	1,58	0,68
Burning/pricking sensation in the eyes	3,89	0,74
Tearing/Watery eyes	2,52	0,88
Pain around the eyes	2,26	1,36
Headache	1,64	1,38
Image floating	1,21	0,42
Color change	1,11	0,31

1 = *I did not perceive this symptom* - 5 = *I perceived this symptom a lot*

display are at full power, the global power of all LEDs is lowered and for a full white image, the peak brightness is only 2300 nits. In such scenarios, we observed that the users reduced the peak brightness far below this limit. For example, in Fig. 1 (e), on average the preferred brightness was 1700 nits. There were also cases where the users inquired if brightness could be scaled beyond the 4000 nits limit. These images are mostly the left plateau region of plot in Fig. 2. The result of the questionnaire on visual comfort differed significantly from [23] as users perceived uncomfortable sensations such as burning/pricking sensation in the eyes, tearing/watery eyes and pain around the eyes. This result highlights the importance of brightness control for retargeting screen contents.

We consider the 5% truncated mean of the boxplot (shown by the black line) to be a statistically reliable representation of the preferred brightness. To verify this, we have performed a one-way ANalysis Of VAriance (ANOVA) test of our data. This has yielded to F(46, 705) = 61.0 which is larger than the F-test critical value for p = 0.01.

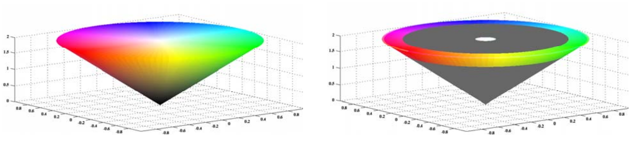
B. Modeling Brightness Preference

The previous section shows that scaling to peak brightness of the display is not always preferred. We believe that in order to control this brightness, L_{MAX}, we can derive information from the SDR image statistics. A variety of statistics have been considered in order to model our data of preferred brightness. This includes first order statistic of the luminance of the image such the mean, variance, skewness and kurtosis. HDR based first order statistics using the image key [31] has been taken into account. Furthermore, color related statistics such as lightness and colorfulness [32] have also been considered. Our first step was to compute a regression between preferred brightness and one of these predictors. Unfortunately, none of the regressions tested using a single variable resulted in $R^2 > 0.65$. The next approach, consisted of finding the best combination of variables, that provide the best fit in the form of a multi-linear regression using the methodology proposed in [33]. This method led to slightly improved goodness of fit for the regression but certain combinations of variables (image key variance and luminance skewness) could not be explained in terms of brightness comfort. We have concluded that existing image statistics have not been designed to model brightness preference and are thus ineffective. As a result, we have attempted to design our own feature.

Based on our observations, we have noticed that the user brightness preference decreases as number of bright pixels on the HDR monitor increases. We define the term bright pixels as a combination of white pixels and pixels with a high colorfulness value. We propose a feature that enables us to find the ratio of $Bright_{Pixels}$ with respect to the total number of pixels, as defined in (3):

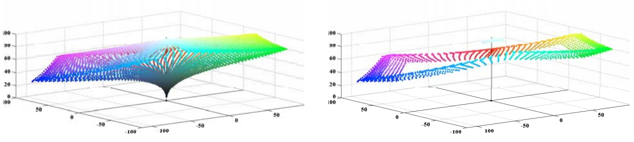
$$Bright_{Pixels} = \frac{1}{N}\sum_{k=1}^{N} White_{Pixels}[k] + Colorful_{Pixels}[k] \tag{3}$$

where N is the total number of pixels and k represents the pixel coordinates $\binom{i}{j}$. In order to get to (3), we follow a simple approach based on our knowledge of color appearance models. The process begins with converting RGB SDR images into the HSV colorspace and separating the $S[k]$ (saturation) and $V[k]$ (value or lightness) color channels. Although HSV is not a perceptually linear color space, it is chosen mostly because of its fast computation. Any other perceptually linear color space that can separate saturation and lightness, e.g. CIE-Lab, can also be considered. Using the $S[k]$ and $V[k]$, we determine the Chroma of the image as follows:



(a) sRGB Gamut in HSV colorspace

(b) Visually disturbing pixels in HSV



(c) sRGB gamut in CIE-Lab colorspace

(d) Visually disturbing pixels in CIE-Lab

Fig. 3. We can visualize the sRGb gamut on the HSV and CIE-Lab colorspace in (a) and (c) respectively. Applying the bright pixels feature on the sRGB gamut in (b) HSV and (d) CIE-Lab colorspace identifies the white and highly saturated colorful pixels that can potentially cause visual discomfort on high brightness displays.

$$V_T[k] = \begin{cases} 1 & \text{if } V[k] > \alpha \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

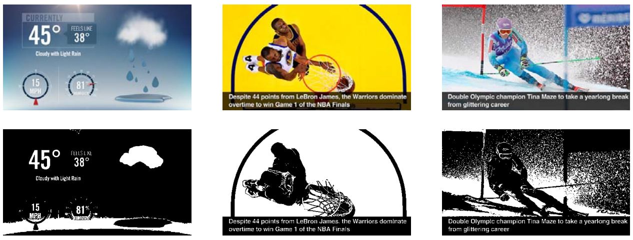
$$Chroma[k] = S[k] \cdot V_T[k] \tag{5}$$

The operation in (5) is analogous to the calculation of the $Chroma[k]$ used in color appearance models which is defined as the product of saturation and lightness in [34]. We purposely threshold the lightness channel using $\alpha = 0.8$ to preserve the brightest part of the image. Finally, to determine the $White_{Pixels}[k]$ and $Colorful_{Pixels}[k]$, we can segment the $Chroma[k]$ in the following manner:

$$White_{Pixels}[k] = \begin{cases} 1 & \text{if } Chroma[k] < \beta \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

$$Colorful_{Pixels}[k] = \begin{cases} 1 & \text{if } Chroma[k] > \theta \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

where $\beta < \theta$. We have chosen the values $\beta = 0.1$ and $\theta = 0.8$. The values of α, β and θ have been set empirically based on visual observations by the authors. These parameters could be



(a) Weather

(a) Basketball

(a) Ski

Fig. 4. A few examples of the segmentation results are shown. The white regions in the second row are identified as the brightest regions which cause visual discomfort. Brightness of the pixels can be represented as a percentage through the operation: $Bright_{Pixels} \times 100$. These values for the images above are: (a) Weather 14% (b) Basketball 58% and (c) Ski 29%. Clearly, images with a large number of bright pixels should be scaled appropriately.

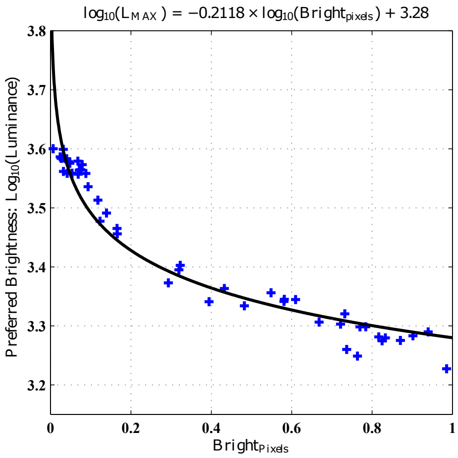


Fig. 5. Brightness Preference as a function of $Bright_{Pixels}$.

adjusted depending on the choice of the colorspace. We can visualize the effect of applying the bright pixels feature on the entire sRGB gamut in HSV and CIE-Lab colorspace in Fig. 3. Fig. 4 shows the bright pixel feature used on screen content images.

We model our preferred brightness data to the proposed bright pixels feature of the image. This yields our brightness control algorithm defined with the equation below:

$$log_{10}(L_{Max}) = -0.2118 \times log_{10}\left(Bright_{Pixels}\right) + 3.28 \quad (8)$$

The R^2 measure of goodness of fit is $R^2 = 0.9267$. Fig. 5 shows this equation in a graphical form. We can generalize (8) to absolute luminance by the expression:

$$L_{Max} = \frac{L_{Critical}}{Bright^{\mu}_{Pixels}} \quad (9)$$

where $L_{Critical}$ is the minimum preferred absolute brightness for a very bright content (when $Bright_{Pixels} > 0.95$) and μ is a decay factor. Our experiments on the SIM2 HDR display resulted in $L_{Critical} = 1905$ nits and $\mu = 0.2118$. It should be noted that we permit our model to predict preferred brightness beyond the measured values ($L_{Max} > 4000$ or $log_{10}(L_{Max}) > 3.6$). This is because we believe certain images can be perceived as visually comfortable beyond the 4000 nits limitation of the SIM2 HDR monitor. In order to avoid $L_{Max} \to \infty$ for the case where $Bright_{Pixels} \to 0$, we clip $Bright_{Pixels}$ within the range $[0.001, 1]$. Finally, our model for L_{Max} defined in (9) could be substituted into the original global operator in equation (1), resulting in a method for tone expansion with brightness control.

V. CONCLUSION AND FUTURE WORKS

In this paper, we proposed a brightness control method for retargeting legacy contents on to HDR displays. This method was developed with a help of a perceptual experiment evaluating user brightness preference. We intentionally have focused on screen content as stimuli due to their unique properties in image statistics. The experiment resulted in emphasizing that brightness preference is strongly content dependent. We found that existing image statistics were ineffective to model brightness preference and thus designed our own feature. This feature is based on a simple segmentation scheme that identifies the bright pixels in the image that may cause visual discomfort. Based on this metric, we have proposed a brightness control algorithm that adjusts luminance of display depending on the amount of bright pixels in the content.

Our work is a an effort towards improving QoE in terms of brightness comfort for SDR to HDR display retargeting. However, we feel this study is not only applicable for brightness control in tone expansion. As mentioned previously, most existing HDR video content is camera captured and little is known on generating HDR graphics for HDR TV sets. This work gives insight in creating HDR screen contents. Particularly, the segmentation technique, which identifies tentative regions that cause visual discomfort, could potentially assist content producers. This study also brings out the need of brightness regulation for avoiding excessive use of high brightness. We could envisage a future brightness model in the lines of existing loudness models in audio. Lastly, this work could also be used to devise new brightness comfort based metrics for QoE.

Given the novelty of this field of research, there is ample opportunity and requirement for future work. A limitation of our study is that we only consider initial viewing comfort. We plan to extend our work to a continuous viewing comfort and develop a brightness control model that alleviates visual discomfort as well as fatigue. Extending this model for continuous viewing also requires adapting to the temporal aspect of video, thus the final model should be free of temporal artifacts. A change in brightness also affects the color appearance, which is another important factor to be considered. Moreover, our brightness control feature only counts the number of bright pixels without considering spatial distribution of these pixels (i.e. dispersed or contiguous). This is a promising direction for future improvements. Furthermore, this work has been performed in a dark testing environment. A more rigorous evaluation calls for testing in different ambient lighting conditions for a more adaptable brightness model. It would also be interesting to explore whether our methodology could be extended to other display systems such as smartphones and tablets. Additional research could also be conducted amongst different age groups. It is well known that brightness comfort changes with age and it would be interesting if different targeting models are required for younger and older users. Finally, this paper deals with controlling brightness as a function of visual comfort. In real world scenarios, the display controls brightness based on energy consumption, image aesthetic quality and ambient lighting of surround. An ideal brightness model for displays should consider all these aspects as well.

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REFERENCES

[1] M. Meeker, “Internet trends 2014–code conference,” *Retrieved May*, vol. 28, p. 2014, 2014.

[2] J. Xu, R. Joshi, and R. A. Cohen, “Overview of the emerging HEVC screen content coding extension,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 26, no. 1, pp. 50–62, 2016.

[3] M. Narwaria, M. P. Da Silva, and P. Le Callet, “Study of high dynamic range video quality assessment,” in *SPIE Optical Engineering+ Applications*. International Society for Optics and Photonics, 2015, pp. 95 990V–95 990V.

[4] E. Reinhard, W. Heidrich, P. Debevec, S. Pattanaik, G. Ward, and K. Myszkowski, *High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting*. Morgan Kaufmann, 2010.

[5] F. Banterle, A. Artusi, K. Debattista, and A. Chalmers, *Advanced High Dynamic Range Imaging: Theory and Practice*. Natick, MA, USA: AK Peters (CRC Press), 2011.

[6] A. O. Akyüz, R. Fleming, B. E. Riecke, E. Reinhard, and H. H. Bülthoff, “Do HDR displays support LDR content?: A psychophysical evaluation,” in *ACM Transactions on Graphics (TOG)*, vol. 26, no. 3. ACM, 2007, p. 38.

[7] B. Masia, S. Agustin, R. W. Fleming, O. Sorkine, and D. Gutierrez, “Evaluation of reverse tone mapping through varying exposure conditions,” in *ACM Transactions on Graphics (TOG)*, vol. 28, no. 5. ACM, 2009, p. 160.

[8] C. Bist, R. Cozot, G. Madec, and X. Ducloux, “Style aware tone expansion for HDR displays,” in *Proceedings of Graphics Interface 2016*, ser. GI 2016. Canadian Human-Computer Communications Society / Société canadienne du dialogue humain-machine, 2016, pp. 57–63.

[9] L. Meylan, S. Daly, and S. Süsstrunk, “The reproduction of specular highlights on high dynamic range displays,” in *Color and Imaging Conference*, vol. 2006, no. 1. Society for Imaging Science and Technology, 2006, pp. 333–338.

[10] A. G. Rempel, M. Trentacoste, H. Seetzen, H. D. Young, W. Heidrich, L. Whitehead, and G. Ward, “Ldr2hdr: on-the-fly reverse tone mapping of legacy video and photographs,” in *ACM Transactions on Graphics (TOG)*, vol. 26, no. 3. ACM, 2007, p. 39.

[11] F. Banterle, P. Ledda, K. Debattista, and A. Chalmers, “Inverse tone mapping,” in *Proceedings of the 4th international conference on Computer graphics and interactive techniques in Australasia and Southeast Asia*. ACM, 2006, pp. 349–356.

[12] F. Banterle, S. Ledda, K. Debattista, and A. Chalmers, “Expanding low dynamic range videos for high dynamic range applications,” in *Proceedings of the 24th Spring Conference on Computer Graphics*. ACM, 2008, pp. 33–41.

[13] P. Didyk, R. Mantiuk, M. Hein, and H.-P. Seidel, “Enhancement of bright video features for HDR displays,” in *Computer Graphics Forum*, vol. 27, no. 4. Wiley Online Library, 2008, pp. 1265–1274.

[14] L. Wang, L.-Y. Wei, K. Zhou, B. Guo, and H.-Y. Shum, “High dynamic range image hallucination,” in *Proceedings of the 18th Eurographics conference on Rendering Techniques*. Eurographics Association, 2007, pp. 321–326.

[15] F. De Simone, G. Valenzise, P. Lauga, F. Dufaux, and F. Banterle, “Dynamic range expansion of video sequences: A subjective quality assessment study,” in *Signal and Information Processing (GlobalSIP), 2014 IEEE Global Conference on*. IEEE, 2014, pp. 1063–1067.

[16] C. Bist, R. Cozot, G. Madec, and X. Ducloux, “Tone expansion using lighting style aesthetics,” *Computers & Graphics*, vol. 62, pp. 77 – 86, 2016.

[17] C. Bist, R. Cozot, G. Madec, and X. Ducloux, “Tone compatibility between HDR displays,” in *SPIE Optical Engineering+ Applications*. International Society for Optics and Photonics, 2016, pp. 99 710D–99 710D.

[18] P. S. Guterman, K. Fukuda, L. M. Wilcox, and R. S. Allison, “75.3: Is brighter always better? the effects of display and ambient luminance on preferences for digital signage,” *SID Symposium Digest of Technical Papers*, vol. 41, no. 1, pp. 1116–1119, 2010. [Online]. Available: http://dx.doi.org/10.1889/1.3499851

[19] P. Hanhart, P. Korshunov, and T. Ebrahimi, “Subjective evaluation of higher dynamic range video,” pp. 92 170L–92 170L–13, 2014.

[20] J. P. Freyssinier, N. Narendran, and J. D. Bullough, “Luminance requirements for lighted signage,” in *SPIE Optics+ Photonics*. International Society for Optics and Photonics, 2006, pp. 63 371M–63 371M.

[21] C. Mantel, N. Burini, J. Korhonen, E. Nadernejad, and S. Forchhammer, “Quality assessment of images displayed on lcd screen with local backlight dimming,” in *5th International Workshop on Quality of Multimedia Experience (QoMEX 2013)*, 2013, pp. 48–49.

[22] S. Benedetto, A. Carbone, V. Drai-Zerbib, M. Pedrotti, and T. Baccino, “Effects of luminance and illuminance on visual fatigue and arousal during digital reading,” *Computers in Human Behavior*, vol. 41, pp. 112–119, 2014.

[23] A. G. Rempel, W. Heidrich, H. Li, and R. Mantiuk, “Video viewing preferences for HDR displays under varying ambient illumination,” in *Proceedings of the 6th Symposium on Applied Perception in Graphics and Visualization*, ser. APGV ’09. New York, NY, USA: ACM, 2009, pp. 45–52. [Online]. Available: http://doi.acm.org/10.1145/1620993.1621004

[24] N. Na and H.-J. Suk, “Adaptive and affective luminance contrast on optimal brightness of displays,” in *Color and Imaging Conference*, vol. 2014, no. 2014. Society for Imaging Science and Technology, 2014, pp. 81–84.

[25] R. Merrifield and L. Silverstein, “The ABCs of automatic brightness control,” in *Society for Information Display Internatiational Symposium Digest of Technical Papers*, 1988, pp. 178–181.

[26] M. Schuchhardt, S. Jha, R. Ayoub, M. Kishinevsky, and G. Memik, “CAPED: context-aware personalized display brightness for mobile devices,” in *Proceedings of the 2014 International Conference on Compilers, Architecture and Synthesis for Embedded Systems*. ACM, 2014, p. 19.

[27] IEC, “IEC 62087: 2008 (E): Methods of measurement for the power consumption of audio, video and related equipment,” 2008.

[28] SMPTE, “SMPTE ST 2086: Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images,” 2014.

[29] M. Zink, M. Smith, W. Bros, and L. Wavelet Consulting, “Managing HDR content production and display device capabilities,” in *International Broadcasting Convention*, 2015.

[30] V. Hulusic, G. Valenzise, E. Provenzi, K. Debattista, and F. Dufaux, “Perceived dynamic range of HDR images,” in *Quality of Multimedia Experience (QoMEX), 2016 Eighth International Conference on*. IEEE, 2016, pp. 1–6.

[31] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda, “Photographic tone reproduction for digital images,” *ACM Transactions on Graphics*, vol. 21, no. 3, pp. 267–276, 2002.

[32] D. Hasler and S. E. Suesstrunk, “Measuring colorfulness in natural images,” in *Electronic Imaging 2003*. International Society for Optics and Photonics, 2003, pp. 87–95.

[33] B. Masia, A. Serrano, and D. Gutierrez, “Dynamic range expansion based on image statistics,” *Multimedia Tools and Applications*, pp. 1–18, 2015.

[34] M. D. Fairchild, *Color Appearance Models*. John Wiley and Sons Ltd, 2005.