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Subjective viewer preference model for automatic HDR down conversion

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Abstract

Although the idea of tone mapping has a long history, there is no tone mapping operator fulfilling the requirements of (live) broadcasting completely. But in times of HDR standards [1] it is more important than ever to find a reliable automatic down conversion suitable for all kinds of scenes to get an integrated workflow for HDR and SDR and to let the majority of the viewers dealing with legacy displays benefit from HDR. Most of the tone mapping operators (TMOs) do not outperform a so called camera TMO (classic photographic s-shaped camera encoding) in comparison studies, which can be explained as a problem of goal. Modelling the human visual system (HVS) can be remarkable different from creating a pleasing image based on aesthetic wishes and artistic intends. The aim of the paper is to report on the results measuring the viewer preference at dynamic range compression and to set up a model which can be used to enhance existing TMOs. Therefore, probands had to do their own grading influencing brightness, contrast, saturation and homogenization under varying outer conditions. It can be shown that the most important aspect of HDR is the increased reproduction of the scene contrast range and not the increased brightness. By using an optimized gradation and a slight local tone mapping a close impression can also be displayed on SDR screens.

Introduction

High Dynamic Range (HDR) cameras in combination with HDR displays will produce a whole new way of immersive TV experience. But the majority of the viewers will deal with legacy displays in the coming years and therefore will not be able to participate in this new experience unless an adequate contrast compression will be performed. Such a compression can be done at the grading in the post production. But only a few productions will have the abilities to create different versions for HDR and Standard Dynamic Range (SDR). Furthermore broadcast often deals with a live environment limiting the correction opportunities.

It is obvious that an automatic down conversion from the HDR signal or from the camera signal itself is needed such as shown e.g. by Lenzen [2]. The adapted signal can be displayed at the installed ordinary SDR TV sets with the goal to significantly optimize the viewing experience with the given displays and let consequently all viewers benefit from the HDR image capture already today.

Nevertheless, while this method leads to an enormous increase in image quality, it is only based on assumptions about the viewer preference at dynamic range compression due to a missing model. Compared to the most classic tone mapping approaches, the goal of (live) broadcast is to create a pleasing image which can be very different from modelling the human visual system (HVS). The most realistic image will not match the aesthetic wishes and the artistic intend in all cases.

In this paper, we will start to setup a subjective viewer preference model which can be used to enhance existing tone mapping technics and reaching the viewers expectance. For that reason four parameters – namely brightness, contrast, saturation, and local impact – are investigated concerning their correlation with the display respectively the environmental luminance.

Of course, with a standard HDR down conversion one can only generate a single SDR version. In this case it is not possible to consider different SDR displays as well as room brightness levels. However, this model should not be limited just to this application area. Moreover this model could also be used for generating the best possible outcome for e.g. a particular installation with a given display and environmental brightness. In addition it would be possible to transmit the not-contrast-compressed HDR signal in the future performing the adaption of the particular outer conditions in the set top box. In this case, a best fitting version depending on the viewer preference model could be reached.

Related Work

TMOs and Evaluation

TMOs normally try to model the photoreceptor response, mostly cones some also rods, to create a similar experience as at the original scene. These TMOs are all very close to the Naka-Rushton-Equitation and result in an s-shape function as shown by Reinhard et al. [3]. The steepness of this function often depends on the contrast range of the scene. Therefrom, very high contrast scenes result in a flat gradation and have less subjective contrast. This leads to the first trade-off which should be investigated later on - the trade-off between subjective contrast and displayed scene contrast range.

When using a local TMO, every pixel has its own transfer function. Thereto a regional level of adaption is calculated, which results in a higher local contrast. If the local level of adaption is too high, the global impression gets lost. This leads to the second trade-off to deal with – the trade-off between local and global contrast (also called local impact in this paper).

Petit et al. [4] and Eilertsen et al. [5] compared a plurality of TMOs using subjective evaluations. Beside the problems depending on artifacts like flicker, halo, ghosting or noise, which could be overcome when using [2], a lot of TMOs do not outperform a classic photographic camera encoding TMO using an s-shaped transfer curve introducing a much smaller shadow and highlight compression which results in a more pleasant look. The camera TMO is a model set up Petit et al. [4] trying to rebuild a tone-curve (s-shape) used in commercial cameras.

Petit investigated the results concerning correlations. It could be shown, that high saturation images often go along with a higher rating. On the other side some TMOs were devaluated by Eilertsen because they produced oversaturated images. A lot of papers tried to find a function for compensation [6][7][8]. Consequently the saturation will be the third trade-off to be measured.

Beside the saturation also the brightness influenced the viewer's feedback. For daylight scenes a high brightness was preferred, in contrast to night scenes where a low brightness lead to a higher rating. The brightness will be the fourth and last trade-off.

Subjective Assessment of Viewing Conditions

A lot of studies investigated the influence of display and environmental luminance on the image brightness level. The first one was set up by Novick in 1969 [9] and redefined by De Marsh [10]. They looked for the best overall-gamma depending on the environment. It was defined to use 1.0 for a bright environment (69 cd/m^2), 1.2 for a dim (14 cd/m^2) and 1.5 for a complete dark one. Today's overall-gamma accounts for this and is defined as 1.2.

Another study was conducted by Stokkermans et al. [11] investigating the chosen key-value. The key-value was established for tone mapping by Reinhard et al. [12] as a user parameter to influence the brightness impression of the image. Daylight scenes usually deal with a key-value around 0.18 (inspired by 18% gray) and night scene use a much lower one. In the experiment the display was varied from 100 cd/m^2 to 550 cd/m^2 and the environment from 20 cd/m^2 to 275 cd/m^2. For both, a correlation could be found. While a bright display leads to a low key-value, it increased with the environmental luminance. In contrast, no correlation was found between the outer parameters.

Also the BBC considers display and environment in their recommendation for a *Display Independent High Dynamic Range Television System* [13] as can be seen in equation 1.

$$\gamma = 1 + \frac{1}{5} log_{10}\left(\frac{Y_{peak}}{Y_{surround}}\right) \qquad (1)$$

Although there are so many studies concerning the brightness, there is a lack of information when looking at contrast, saturation and local impact. The hypothesis which comes along with HDR is that the viewers accept a higher contrast range and therefrom a lower subjective contrast at higher display luminance levels. More on intuitive one would guess that at lower luminance levels more local contrast is needed – in the experiment called homogenization – to be able to have a strong contrast compression.

Due to a missing quantitative evaluation we set up the experiment following in the next-again section.

Simultaneous contrast range

It is commonly known that the HVS has a contrast range of about 10000:1 based on the experiments by Kunkel et al. [14] measured with a Gabor-grating. But this value can be seriously reduced depending on the image content. Especially bright highlights can limit the eyes sensitivity towards slight differences in the dark areas around.

Bychkov [15] investigated in his Master Thesis the influence of highlights on the simultaneous recognizable contrast range varying the size and the position of a white box compared to a gray box. Both were displayed next to each other on a black background. The viewers were asked to find the smallest brightness value for the gray box, where it gets noticeable. Three slightly different pattern were created:

- f (fixed): The size of the gray box stays the same whereas the height of the highlight was varying. The aim was to analyze how the sensation of a constant dark patch is influenced by the size of a highlight in the neighborhood.
- p (pair): The height of the gray box was altered in the same way as the highlight. This time it should be measured if the same sizes lead to identical results and therefrom compensate the influence measured with pattern f.
- s (surround): The highlight was surrounded by the gray boxes. Compared to the pattern p the size of the gray box was eight times bigger.

Figure 1 shows the three different patterns.

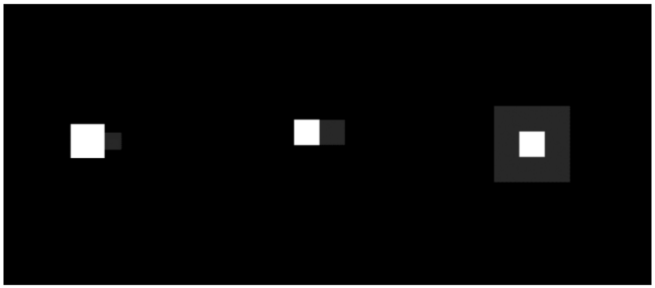

Figure 1. *The three different pattern from the Bychkov's experiment. From left to right: f = fixed, p = pair and s = surround.*

The test was performed in a dim environment. The height was varied from 20 to 160 pixels on a Full-HD screen. The test was repeated with different width for both – the white and black box. The used display (0.05 cd/m^2 to 100 cd/m^2) could only generate a contrast range of about 2000:1, but this was still enough to perform the experiment as can be seen by the following results. Column two to four showing the values for the height of 160 pixels, column five to seven the values for the 20 pixels. Lines three to seven representing the differences in width.

Simultaneous contrast range depending on the highlight

gray box width	noticeable luminance (min.) – height 20			noticeable luminance (max.) – height 160		
pattern	s	p	f	s	p	f
10	388:1	261:1		261:1	238:1	
20	826:1	550:1	550:1	550:1	434:1	316:1
30	826:1	625:1		826:1	550:1	
40	962:1	715:1	625:1	826:1	550:1	550:1

Especially for a very small width (10 pixels) the visibility is influenced substantially by the size of the highlight leading to a contrast range of 238:1 in the worst case. This effect is remarkable reduced when increasing the width of the box. However even in the best case it is "only" 715:1 (for pattern p).

Big differences can be found between the three patterns. As expected the fixed pattern is most affected. For the pair pattern the contrast range is increasing. For the surround pattern the contrast range is increasing again. 962:1 was the highest measured ratio, which is 10 times lower compared to the ideal conditions at Kunkel.

From this we can conclude that the simultaneous contrast range of the HVS will often be significantly reduced in natural images because of brighter parts. Although the display luminance was limited to only 100 cd/m^2 in this case the effect was obvious. For the much brighter HDR displays we can expect a rather higher impact of the beaming highlights. These results put into question if it is expedient to reproduce a higher contrast range even at the display side or if it would be more expedient to capture a high dynamic range and perform a contrast compression for reproduction.

Experiment

Based on the collaboration with five professional colorists, we designed a subjective evaluation based on proband gradings where the mentioned parameters could be tuned by the viewers directly. Because the most participants have never done image editing before, the parameters should be intuitive and easy to control. Furthermore, the test is repeated under changing outer conditions so that the number of parameters as well as the number of test images should be limited and chosen carefully. Most of the probands needed approximately one hour to finish the test.

The participants were asked to tune the parameters depending on their subjective favor. They were told to try all parameters first to get a better understanding what those mean (how does the particular parameter influence the look of the image) and about the adjustment range for each parameter. They had no information concerning the ideas of the evaluation.

Control parameters

The control parameters to influence the image appearance were displayed using an over layer as shown in figure 1. They were arranged in the following order:

Helligkeit: -0.28

Kontrast: -1.32

Sättigung: 0.714

Homogenisierung: 0.682

Figure 2. The viewer could control the four parameters, which were put on an overlay.

Brightness

The first slider could be used to control the brightness. It had a range from -2 to 2 (default 0). It was scaled related to exposure steps. 0 were linked to the average log luminance (Y_{mean}). The connected transfer function describes an s-shape of the following manner,

$$Y_{out} = \frac{1}{1+ e^{\left(-a*(\ln(Y_{in})-b)\right)}} \tag{2}$$

$$b = \ln(Y_{mean} - brightness * 5) \tag{3}$$

where Y_{in} was the incoming luminance and Y_{out} the outgoing luminance.

Contrast

The second slider could be used to control the contrast, which is the steepness of the s-shape function. It defines the f-stops which are preserved in the final image. The participants had the challenge to find a pleasing trade-off between subjective contrast and displayed scene contrast range.

The slider had a range from -2 to 2 (default 0). As can be seen in equation 4, 0 leads to a contrast range of 11 f-stops, which is a factor of six (2.5 f-stops) compared to the contrast range of Petit's camera TMO. Equation 5 was used to scale the f-stops so that they could be used in equation 2.

$$stops = 6 + (1 - \text{contrast}) * 5 \tag{4}$$

$$a = 0.0088 * stops^2 - 0.288 * stops + 2.99 \tag{5}$$

Saturation

The correction of the saturation was performed in the perceptually uniform IPT color space. The slider spanned a range from 0 to 1 (default: 0.5). 0 meant that the chrominance stayed untouched, while 1 meant that ratio of the luminance tone mapping was applied on the chrominance components, too. Usually the second case leads to the oversaturated images mentioned before.

$$\mathrm{P_{out}} = \mathrm{P_{in}} * \left(1 + \text{ saturation} * \left(\frac{I_{out}}{I_{in}} - 1\right)\right) \tag{6}$$

Homogenization

With the last slider the participants had the opportunity to control the calculation of Y_{mean}. The slider spanned a range from 0 to 1 (default: 0). 0 meant that one average luminance was calculated for the whole image, thus it was global tone mapped. 1 meant that the average luminance was computed depending on the pixels neighborhood. A rather wide range of about 300 pixels was used to calculate this local level of adaption. Values between 0 and 1 were mixed forms.

The slider was called homogenization, because it was the best decryption for its mode of action. By turning it up, bright parts of the image could be darkened and dark parts could be lifted. The brightness impression gets more homogeneous.

Viewing conditions

For the display luminance, three representative values have been selected: 100 cd/m^2 representing today's SDR standards [16], 300 cd/m^2 representing the most flat screen displays which are in use today at the viewer's home and 1000 cd/m^2 representing the HDR requirements [1].

Also for the environmental luminance three different levels where chosen. The steps should represent a dark, a dim and a bright environment, which is close to other studies in the past. Dim is also often referred as 10 cd/m^2 e.g. for subjective quality assessments [17].

To limit the number of rounds and the duration of the test, the display and environmental luminance where varied independently from each other. As a starting point the combination 300 cd/m^2 (display) and 10 cd/m^2 (environment) matching a typical viewing situation at home was selected. At first, the environmental luminance was fixed to 10 cd/m^2 and the display luminance was varied, because of this higher relevance. After that the display luminance was fixed to 300 cd/m^2 and the environmental luminance was varied. This approach necessitates that the effect of these two luminance values does not correlate, which was shown in [11] for a similar as the intended range.

The whole test was performed on the Panasonic VIERA TX-58DXW904 which is an Ultra HDR Premium television set having a very faithful color reproduction meeting the so called P3 requirements in [1] and can reach a peak luminance of over 1000 cd/m^2.

Test Material

The content used in the experiment was selected to span a wide range of possible broadcast scenes and genres. Overall 12 still images were used – six filmed by the University of Applied Sciences Wiesbaden and six filmed by Froehlich et al. [18]. The first six show scenes from a football game. The other six images show highly different scenes. The underlying idea was to first find a setup for one of the most important scenes of live broadcast (live sports) and after this to analyze if there is a correlation with the other scene. If so, the question is how these results could be generalized for all kind of scenes. Perhaps, every genre could need some kind of slight adjustments or transformations.

All test images can be found in the appendix using sectional tone mapping [2].

Participants

Overall 30 people participated at the subjective testing. All of them performed the completed test including all of the five different luminance setups. The overwhelming majority were non expert viewers. Only five said that they are familiar with image editing and quality analysis. The average age was 28.9 years, because a lot of participants where students from our university. Only a few were older than 50 years. No significant different results were found between these groups. There was also no significant difference found between men and women. 77 % of the participants were men, 23 % were women.

Results and Discussion

Correlation with the outer conditions

Overall 1800 data sets were produced consisting out of brightness, contrast, saturation, homogenization, display luminance and environmental luminance. Figure 3 shows an example 3D-plot from image three having brightness, display luminance and environmental luminance as the axis. Consequently the vertical lines are build out of the 30 chosen values at one condition. They are approximately scattered in a range of one exposure step. The standard deviation is 0.33. Plots using other images or another parameter values look similar.

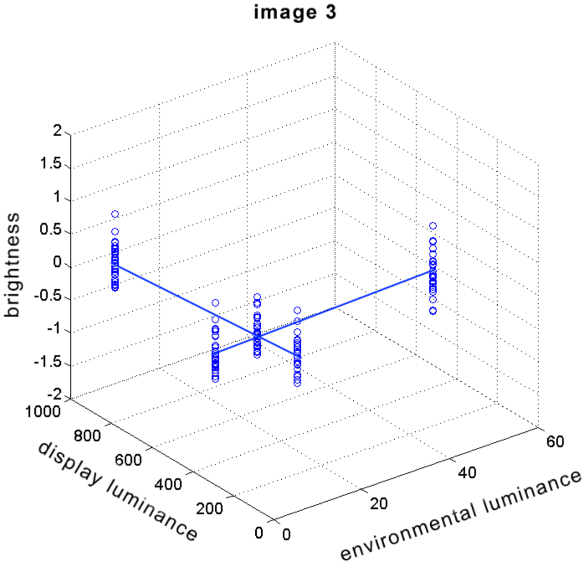

Figure 3. Every grading represented as a point in a XYZ-plot with the axis display luminance, environmental luminance and brightness.

To get an overall impression of the correlations between the outer conditions, the other user parameters and images it is more constructive using only the mean value of all of the 30 participants as done in figure 4. The user parameters are displayed on the y axis. The x axis is divided into the five different outer conditions. In the top row you can find the first six images, in the bottom row the second six images. For more clarity the standard deviations have been deliberately left out.

From the two diagrams on the left we can conclude that the

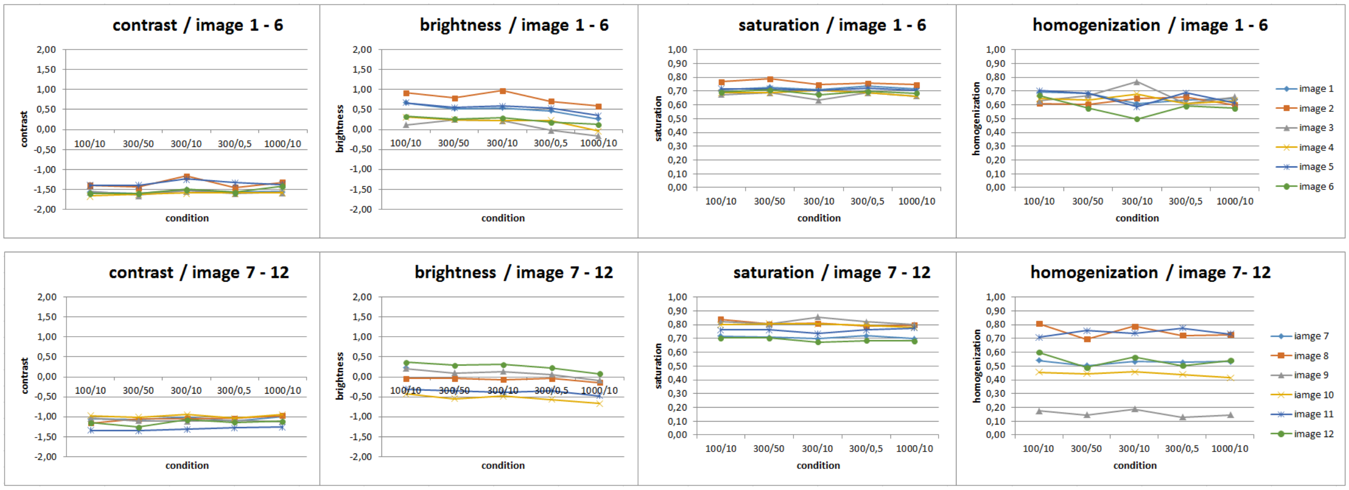

Figure 4. The average user parameter values at the 12 images and five outer conditions.

preferred contrast is independent from the outer conditions. There is no tendency visible in the line plots. Furthermore there are only slight changes depending on the image. In all cases a scene contrast range from about 12 to 12.5 f-stops is chosen. This is quite high and much higher than in television today (see above). Also some viewers choose the value -2 – corresponding to 13 f-stops – which was the highest possible contrast range. But for the overwhelming majority this leads to a too flat gradation. More over 12 f-stops were adequate to see what was happening in the shadows and in the highlights at the same time.

As an overall result it can be summarized that a higher scene contrast representation seems to be more important than a high subjective contrast, because the contrast range chosen by the viewers was about 4 f-stops higher than in television today accepting the accordingly flatter gradation.

The results concerning the brightness are different. On the one side it gets obvious that an increasing display brightness leads to a decreasing brightness value. The difference between the 100 cd/m^2 and 1000 cd/m^2 was about 0.4 stops. The environmental brightness seems to have only a very little impact. The difference between the 0.5 cd/m^2 and 50 cd/m^2 was about 0.06 stops. On the other side the brightness is dependent on the image content, which will be analyzed in the next section.

For the saturation all values are very close together reaching from 0.85 to 0.63 for all conditions and images. This leads to an average of 0.73 at a standard deviation of 0.05.

In the last two diagrams the highest fluctuation could be found. There are big differences in preference because of the image content. For the football scenes the average value is 0.64 at a standard deviation measured of only 0.03. But for the other scenes it varies about 0.2 at a center of 0.53. Image nine needs to be regarded as exceptional, because it shows a scene in back light. The camera is pointing directly into the sun. A high local impact leads to artifacts, when not regulated by a threshold. The area around the sun is shaded very much due to the huge highlight. As a result a gray ring appears and gets darker and larger when turning up the local impact. That is the reason for the small values.

Surprisingly the preference of homogenization is independent from the outer conditions. Even at very high luminance levels no significant different values are selected. Or in other words: Also when displaying a HDR source on a HDR display it is useful to perform a contrast compression to align the highlights and shadows. The reason for this could be find in the referred study by Bychkov, where a bright area reduces the visibility of the shadows. Compared to the natural scene the representation is much smaller and due to this the objects are much closer to each other penetrating a limited field of view. Moreover in discussions with the viewers it became obvious that big differences in brightness – observed for a longer time period – can be quite exhausting. As a consequence hereof it can be concluded that sectional tone mapping can help to increase the image quality also at HDR displays.

Correlation with the scene parameters

Another important issue to analyze more in detail are possible correlations on the scene describing parameters, namely the logarithmic average scene luminance, the scene contrast and the scene contrast range. The first was scaled in cd/m^2, the second represents the average difference in f-stops between the pixels value and the logarithmic average scene luminance and the third is the difference between the highest (99.9%) and lowest (0.1%) luminance of the scene.

The results are shown in figure 5. For the brightness a slight correlation with the average scene luminance could be found. The correlation coefficient r is -0.31. But it stays unclear if this is only a statistical coincidence.

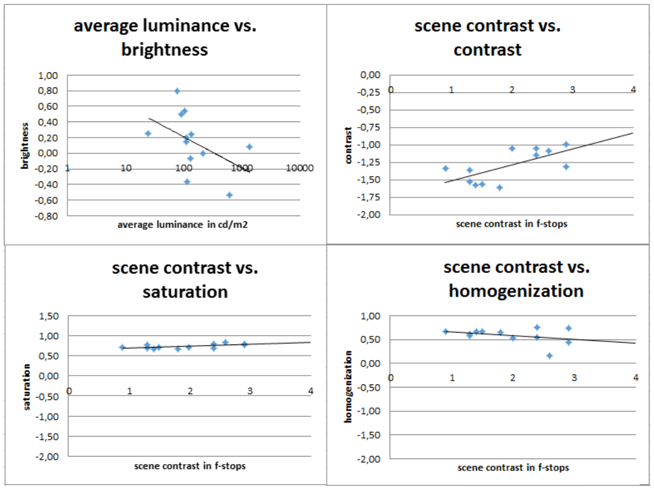

Figure 5. *Correlations between the user parameters and the scene describing parameters*

For the other three parameters some more or less clear correlations could be found with the scene contrast or the scene contrast range respectively. The values are 0.68 and 0.57 for the contrast, 0.59 and 0.11 for the saturation and -0.33 and -0.22 for the homogenization. While scene contrast and scene contrast range have a high correlation between each other (r = 0.78), the contrast seems to be in general a better representation of the scene, because it is not influenced by extreme values that much.

Critic

Although the experiment tried to cover a wide range of conditions, parameters and images those represent just a sample. Especially for the correlation between the user parameters and the scene describing parameters 12 images are still a small test group.

Furthermore only still images were investigated. This was also a lack of serval studies in the past and should be verified which videos in the future. But when thinking of a color grading it also starts using a representative frame from the sequence, because a video is to uneasy for turning the sliders and recognizing their effects.

Conclusion and Outlook

With the experiment described in the paper on hand we tried to establish a visual preference model for contrast range compression. By letting normal TV viewers grade 12 different images we analyzed how the chosen levels depend on the display and environmental luminance as well as on the image content itself. Of course some aspects need further evaluations in the future and only 12 images are tested. But the results are a good starting point for the given aim. Finally we can summarize that:

1. A much higher scene contrast representation is preferred compared to what we have in television today - although this comes along with a lower subjective contrast impression. At least 12 f-stops are chosen in all cases.

2. The chosen brightness behaves as expected. At a brighter display a lower brightness level has been selected. At a brighter environment a higher level was preferred.
3. At the saturation no significant correlation towards images or outer condition was found. A fixed parameter to compensate the change in the luminance component around 0.75 is a good choice for a wide range of cases.
4. The homogenization is independent from the outer conditions. Also at HDR displays tone mapping with a local impact should be used when following the viewer's preference. The precise ratio between local and global homogenization depends on the image content, however an equal weighting could be used as a good approximation for nearly all situations.

In addition to the individual results above we can conclude an overall perception: The significant increase in image quality by HDR does not depend on the higher brightness or a better (lower) black level at first. Rather it is important to represent a high contrast range of the scene. This could also be reached on an SDR display when using an optimized gradation and homogenization technics. Even very high brightness levels are not preferred by the viewers. Based on the above mentioned observations and analysis the authors have developed an automated sectional tone mapping algorithm which can be implemented in hardware or software for live Broadcast applications to enhance the image quality at HDR productions significantly for reproducing live images at SDR and HDR displays.

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Author Biography

Lucien Lenzen got his Master of Eng. in Media- and Communications Technology with a focus on television engineering in November 2014. Since then he is working as a research assistant at the University of Applied Sciences Wiesbaden (Hochschule RheinMain). His research topics are UHDTV and especially HDR down conversion. Moreover he is a Ph.D. student of Prof. Brandenburg at the Technical University Ilmenau. In 2016 he received the "Best Young Professional Award" of IET and IBC.

Prof. Dipl.-Ing. Mike Christmann got his diploma in 1990 after studying Telecommunication Technologies. Afterwards he worked for 13 years in different positions at Broadcast Television Systems, before he became a partner within FLYING EYE Management Consulting for Media Investments.

In August 2012 Mike Christmann became Professor for Media Technology, faculty of Engineering Sciences at the RheinMain University of Applied Sciences. His current research activities focus on UHDTV and image analysis.

He is the author in numerous publications and participated as a speaker in more than 50 conferences. Furthermore he holds three patents in the area of Broadcast and Film technology.

Appendix