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False Color Visualization for HDR Images

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Abstract

Photographic visualization of high dynamic range (HDR) images on low dynamic range (LDR) displays, known as tone mapping, is a well-known problem. However, no well-defined method exist to visualize HDR images for the purpose of scene analysis and understanding. In this paper, we aim to fill this gap by first outlining a general framework that can be used to visualize HDR images using false (i.e. pseudo) colors based on pixel luminances. We then experiment with several simple false coloring functions that can be used within this framework, and evaluate their effectiveness through a small user study. Our results indicate that a tone mapping like false coloring function gives the best results in general. However, we also find that the performance of different false coloring methods depends on the dynamic range of the HDR image, and therefore different images may require different strategies for best results.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.3]: Picture/Image Generation—Display algorithms; Image Processing and Computer Vision [I.4.8]: Scene Analysis—Color

1. Introduction

Processing of HDR images for the purpose of display on low dynamic range monitors, known as tone mapping, is a well-known and commonly studied problem [RWPD10, BADC11]. However, we observe that an equally important problem has received much less attention; visualization of HDR images for the purpose of scene analysis and understanding.

Using digital images for scene analysis and understanding is prevalent in many disciplines such as paleontology, archeology, structural engineering, architecture, medical imaging, and forensics. Given that HDR images represent the real world much more faithfully than conventional images, the use of HDR content in various fields that require luminance measurements is indispensable [Ina06]. However, for HDR images to be used in these tasks, it is important that they can be visualized effectively. In particular, false color visualization of HDR images to study the luminance distribution in a given scene can be an important step for scene understanding.

Various scientific visualization approaches exist in literature to allow exploration of data in various forms and for various goals [BCE*92]. However, we are not aware of a rigorous description for how to best visualize an HDR image for the purpose of scene luminance analysis (hereafter referred as HDR false coloring). In this paper, we aim to draw attention to this important problem and show that the choice of the false coloring algorithm can play an important role in descriptiveness of the visualization.

In particular our goals are, (1) formulate a general framework for false coloring HDR images; (2) experiment with several simple luminance mapping functions within this framework; (3) evaluate the effectiveness of these functions through a user study; (4) outline future directions for false coloring HDR content and draw attention to this important problem.

2. Background

Visualization is the process of presenting data graphically in such a way to quickly gain insight and understanding from it [BCE*92, CMS99]. Color plays a crucial role in visualization. While the good use of color can significantly increase the expressive power

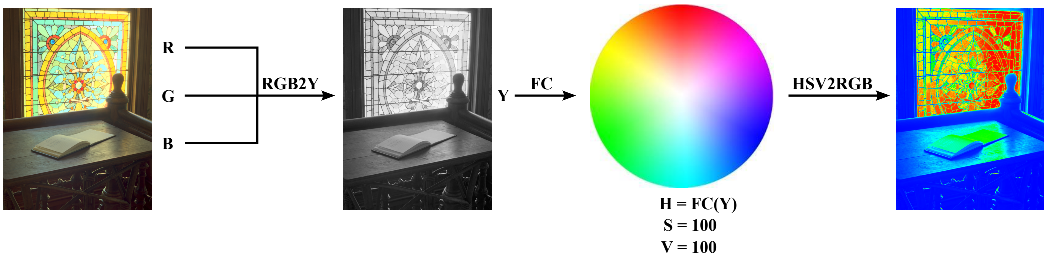


Figure 1: The high level view of our HDR false coloring framework.

of visualization, its misuse can cause further confusion [Mac99].

One of the most important tasks in color visualization is to choose an appropriate color space. In general, there is no single best color space for every visualization task; one needs to choose the color space based on the requirements of the task and the nature of the data to be visualized [LH92]. For instance, if the source data has some order, it may be desirable to choose a color space that has the notion of order between different colors such as black to white or cold to hot.

Another concern is the separability of colors in that any palpable difference in data points should correspond to perceivably different colors in the visualization [Tru81]. This may not always be achievable especially if the dynamic range of the source data is significantly higher than that of the target color space. There are other important considerations when choosing an appropriate color space, but a comprehensive review is beyond our scope. We therefore refer the readers to a recent review by Silva et al. [SSM11].

Visualization of HDR images for luminance analysis is an important problem for many disciplines. However, we observe that no rigorous study has been conducted in this field. The most popular method remains to be using the log space for visualization. However, it is not clear that whether this choice is optimal for false coloring all HDR images. Our study aims to draw attention to this problem through a mini experiment. We, in fact, find that a sigmoidal tone mapping like false coloring strategy produces more representative visualizations compared to logarithmic mapping.

3. HDR False Coloring

We first describe our framework that can be used to generate false colored representation of HDR images. We then discuss several specific mapping functions that can be used in this framework.

3.1. General Framework

The high-level workflow of our algorithm is illustrated in Figure 1. We start with an HDR image which we assume to be in a linear color space with sRGB primaries. We then compute luminance by:

$$Y = 0.2126R + 0.7152G + 0.0722B. \tag{1}$$

As our goal is to assign different colors for different luminance values, we choose the HSV color space, also known as the rainbow scale [BT07] as an intuitive choice. This color space has the desired property that transition from dark to light values can be easily represented by transition from cold (blue) to hot (red).

Although the HSV color space encompasses a cylindrical volume, we decided to use a single hue slice that has the highest possible value and saturation for maximizing visibility. Thus, in our visualization framework we set $S = V = 100$, and compute the hue angle as a function of luminance:

$$H = 240^\circ(1 - FC(Y)). \tag{2}$$

The false coloring function, FC, is a parameter of our framework. We experimented with several functions as explained in the next section.

Note that in the HSV color space, the hue angle of 0° corresponds to red and a hue angle of 240° blue colors. From 240° to 360° the colors transition from blue to violet and back to red. Therefore, to avoid mapping both low and high luminances to similar hue values, we exclude the violet portion of the hue circle. Finally, we convert the computed HSV values back to RGB to obtain the false colored HDR image [RKAJ08].

3.2. Specific False Coloring Functions

We experimented with several simple false coloring functions to be used in Equation 2. These were two version of linear scaling with clipping (FC_1 and FC_5), logarithmic mapping (FC_l), and sigmoidal mapping (FC_s) inspired by Reinhard et al. [RSSF02]. Linear


(a) Memorial (b) Desk (c) Tree

Figure 2: The HDR images used in our experiment.

Image	**DR**	**DR^1**	**DR^5**
Memorial	5.53	3.81	2.02
Desk	8.74	4.68	3.60
Tree	6.99	3.87	3.29

Table 1: Dynamic ranges of the HDR images used in the experiment given in orders of magnitude. The superscript 1 and 5 indicate the dynamic range computed after excluding the corresponding percentage of pixels from both ends.

scalings are defined as:

$$FC_1(Y) = \frac{[Y]^{1\div 99} - [Y]^1}{[Y]^{99} - [Y]^1}, \quad (3)$$

$$FC_5(Y) = \frac{[Y]^{5\div 95} - [Y]^5}{[Y]^{95} - [Y]^5}, \quad (4)$$

where $[.]^m$ denotes the value at the m^{th} percentile and $[.]^{m\div n}$ is an operator that clamps its input within the given percentiles. Logarithmic scaling is defined as:

$$FC_l(Y) = \frac{\log(Y+\epsilon) - \log(Y_{min}+\epsilon)}{\log(Y_{max}+\epsilon) - \log(Y_{min}+\epsilon)}, \quad (5)$$

where a small epsilon value (ϵ) is used to avoid singularity for black pixels. Finally, the sigmoidal mapping is given by:

$$FC_s(Y) = \frac{Y_s}{1+Y_s} \text{ where } Y_s = \frac{a}{\bar{Y}}Y. \quad (6)$$

Here, a denotes a user specified key value (we used $a = 0.18$) and $\bar{Y}$ is the log-average luminance.

4. Experiment

We conducted a small user study to evaluate how well each visualization method describes the luminance distribution in a given HDR image. In the experiment, we used the three HDR images shown in Figure 2, which are also commonly used in the literature. The dynamic range of each image with respect to three measurement conditions are reported in Table 1.

For each HDR image, we prepared four false colored representations using the equations given in the previous section (the results for only the memorial image are shown in Figure 3). We then asked a group of participants to rank the false colored images according to how well they convey the luminance distribution in the HDR images. The participants could switch between these images and the original HDR image to make their decisions. Our interface allowed the HDR images to be viewed at different exposure levels to facilitate studying various regions.

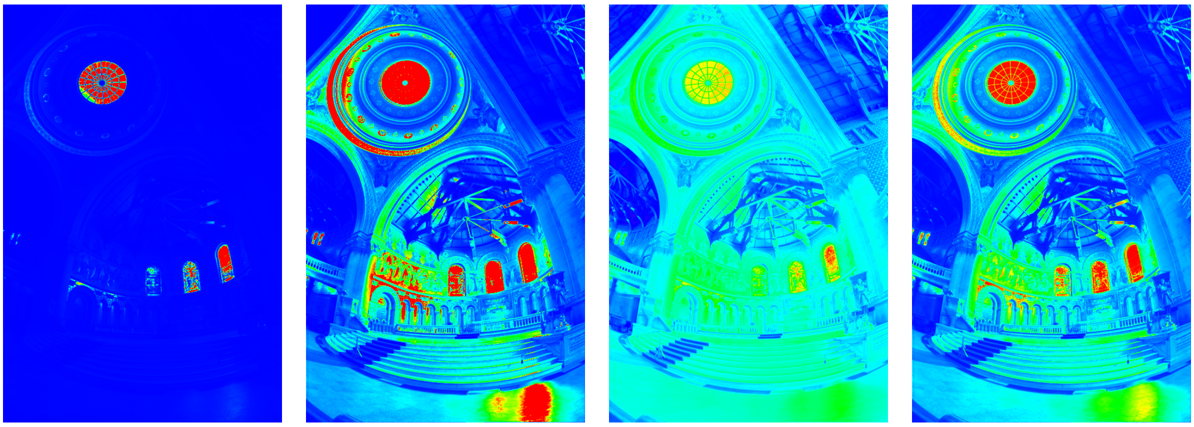
The participants were specifically instructed not to base their decisions on the aesthetical aspects of the false colored images. They were also familiarized with the rainbow scale so that they could understand the relationship between luminance and the progression of colors. 14 participants with 3 females and 11 males between the ages of 20 to 30 took part in the experiment. The total experiment duration was approximately 15 minutes for each participant.

Our results for all images are shown in Figure 4. In each plot, we show how many times each visualization method was ranked in which ranking. For instance, for the memorial image, Figure 4 shows that sigmoidal mapping was ranked as the best method for 8 participants. Logarithmic mapping, on the other hand, was ranked the best only once and linear scaling with 5% clipping was ranked the best 5 times. The last column shows that linear scaling with 1% clipping was ranked as the worst method for 12 out of 14 participants.

Our results indicate that the sigmoidal mapping was consistently selected as the best (i.e. most descriptive) false coloring strategy for all images. The second best strategy appeared to have been the logarithmic scaling, although in the memorial image it was surpassed by linear scaling with 5% clipping. Linear scaling with only 1% clipping consistently performed as the worst false coloring strategy.

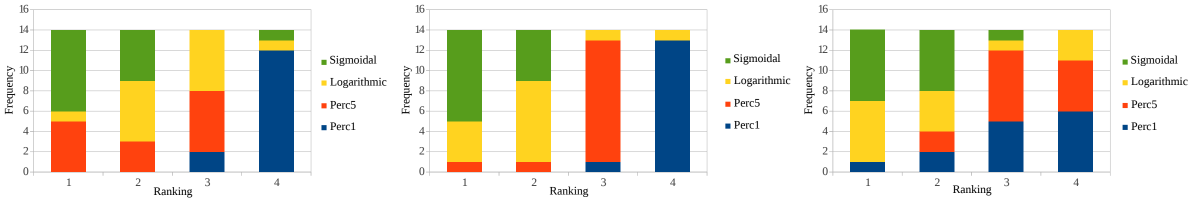
How can we interpret these findings? We believe that these findings suggest a correlation between the dynamic range and the effectiveness of the visualization methods. We can see that the image with the highest dynamic range (desk) benefited the most from a tone mapping like sigmoidal compression. For the desk image, 9 out of 14 participants chose the sigmoidal method as the best visualization strategy. While sigmoidal compression was still the best for the other images, it was not as dominant.

Another evidence that supports this correlation can be observed for the memorial image. This image had the lowest dynamic range within our image set. As such, linear scaling with clipping performed better for this image than the images with higher dynamic ranges. This may be likened to linear scaling with clip-



(a) 1% clip + linear scaling (b) 5% clip + linear scaling (c) Logarithmic scaling (d) Sigmoidal scaling

Figure 3: The choice of the false coloring algorithm can play a significant role in the visualization result. Here, we compare the outputs of several HDR false coloring strategies. From left to right: linear scaling with 1% and 5% clipping, logarithmic and sigmoidal scaling.



(a) Memorial (b) Desk (c) Tree

Figure 4: Participant rankings for all images. Each column represents how many times different false coloring methods were ranked as the first, second, third, and fourth. Perc5 and Perc1 denote linear scaling with 5% and 1% clipping respectively.

ping being a plausible tone mapping operator for images with low to moderate dynamic ranges.

To summarize, our results suggest that the sigmoidal compression seems to be the best HDR false coloring strategy. This is followed by logarithmic scaling and then linear scaling with 5% and 1% clipping. The results also suggest that the participants' preference seems to be affected by the dynamic range of the input images. Images with higher dynamic ranges seem to benefit more from a sigmoidal compression, whereas lower dynamic ranges images benefit from a linear compression.

5. Conclusions and Future Work

Tone mapping of HDR images for realistic display purposes is a commonly studied problem; however, their scientific visualization for the purpose of scene luminance analysis has received much less attention. In this paper, we described a general framework that can be used for this purpose and proposed four false coloring strategies that can be used within this framework. We evaluated the effectiveness of each strategy through a small user study. Our findings indicate that sigmoidal compression was generally found to be the best one in terms of conveying the luminance distribution in a given scene. We also found that the effectiveness of each strategy depends on the dynamic range of the scene in question.

Our study opens up some future research questions. The most immediate one is that if a tone mapping like sigmoidal compression was selected as the best, how would other tone mapping algorithms perform in the task of false coloring? The second question is whether one can better visualize the luminance distribution using a local tone mapping function instead of a global one. Finally, how could one make better use of the HSV color space to achieve a more descriptive visualization. In this study, we only varied the hue while keeping saturation and value constant. Is it conceivable that better results can be obtained if these two attributes are also allowed to change? Our future work will try to answer these questions.

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