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Visualizing High Dynamic Range Images in a Web Browser

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Abstract. We present a technique for embedding high dynamic range (HDR) images with interactive exposure control in a web browser. Multiple exposures are encoded as a combination of several basis images, which are stacked together and displayed with different opacity values. The combination of such basis images yields the resulting exposure image. An intuitive interface based on JavaScript callback functions provides control over exposure setting. The technique allows us to encode a series of 24 or more exposure images using only three basis images, without noticeable artifacts. A toolkit for generating web pages with an HDR image viewer is provided.

1. Introduction

A web search for images using the keyword "high dynamic range" yields over six million hits though none of these images contain high dynamic range data. High dynamic range (HDR) images are represented as floating-point numbers or encoded using a semi-logarithmic transfer function [Mantiuk et al. 04],[Reinhard et al. 05, Ch. 3] so that their pixel values are related to radiance or luminance units. Their dynamic range, which is the ratio between the brightest and the darkest spot in an image, often exceeds the contrast of a display and therefore cannot be faithfully reproduced on a computer screen. For this reason, most of the images tagged as "HDR" on the Internet are conventional images produced by tone-mapping algorithms [Reinhard et al. 05, Ch. 6–8]

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[Myszkowski et al. 08, Ch. 6] that reduce the original image contrast to that of the display.

A windowing technique is an intuitive method for viewing images of higher dynamic range than that of a display without introducing any contrast distortions. In this approach, a selected luminance range (window) of an image's entire dynamic range is mapped to the range of the display. The user can adjust the window by moving it either towards brighter or darker tones. Windowing is a standard procedure for viewing CT images in medical applications. In photographic applications it is also known as exposure control and is available in recent HDR-enabled photo-editing software, such as Adobe Photoshop CS2.

In this paper we present a method that utilizes the windowing technique in a web browser to display HDR images. The method minimizes the amount of data that needs to be transferred over the Internet and embeds the windowing algorithm in a web page. All changes in exposure settings are immediately reflected in the displayed image without any communication with a server. The method employs alpha blending and JavaScript for user control, which are natively supported by all major web browsers. Although there are Java Applets for viewing HDR panoramas [Dersch 03] and it is not difficult to develop Adobe Flash components or browser plug-ins with such functionality, these techniques are more cumbersome, less portable, and take a longer time to start in a web browser. We could run our viewer on a range of devices, including mobile phones and PDAs, on all major platforms (Linux, Microsoft Windows, and Mac OS X), and under a variety of web browsers (Firefox, Opera, Internet Explorer, Safari) and in all cases the viewer took a very short time to start and was very responsive. Moreover, our approach does not require devising a custom HDR image compression for transferring HDR images to a browser, as we can transfer HDR images as a series of JPEG files. Figure 1 shows an example of a web page with the high dynamic range image viewer, in which the user can change the displayed dynamic range by scrolling the semi-transparent window at the top of an image.

The primary purpose of the presented method is visualizing HDR images with non-distorted contrast in a web browser. This is especially desirable for browsing web galleries of light probes used in image-based lighting [Debevec 02] and web-based viewers of medical images. Another attractive application is a general purpose viewer for camera RAW and HDR images.

In a naive implementation of web-based windowing, a separate image could be sent to the web browser for each exposure selection. Assuming that the typical granularity of exposure control is 1/3 of an f-stop unit[1] and that many

[1] An f-stop is a unit commonly used in cameras that represents exposure adjustment; it is also known as the exposure value (EV). Adding 1 f-stop to the exposure settings doubles and subtracting 1 f-stop halves the amount of captured light. When photometric units (e.g., luminance) are plotted on the $\log_2$-axis, each logarithmic unit corresponds to 1 f-stop.

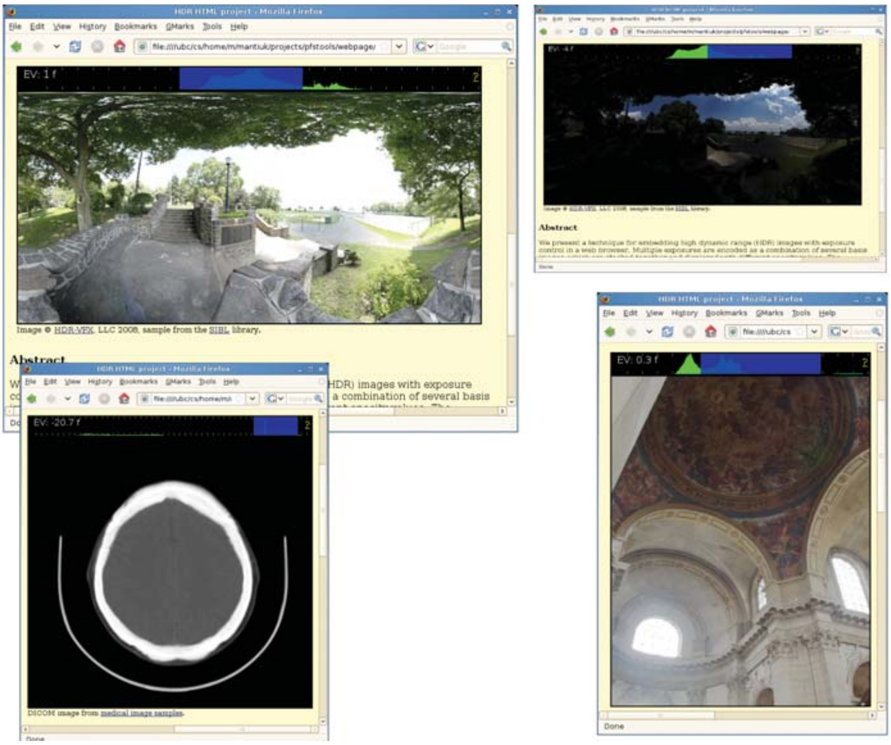
HDR HTML project - Mozilla Firefox
File Edit View History Bookmarks GMarks Tools Help
file:///ubc/cs/home/m/mantiuk/projects/pfstools/webpage/
EV: 1 f
EV: -4 f
EV: -20.7 f
EV: 0.3 f
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Image © HDR-VFX, LLC 2008, sample from the SIBL library.

Abstract

We present a technique for embedding high dynamic range (HDR) images with exposure control in a web browser. Multiple exposures are encoded as a combination of several basis

DICOM image from medical image samples.

Figure 1. Multi-exposure HDR viewer shown in HTML web pages. The JavaScript code replaces basis images and updates opacity settings for the image stack to provide fine control over exposure settings. Only a few JPEG basis images need to be transferred, and the entire exposure control code is executed in the web browser. A luminance histogram is shown on top of each image. The semi-transparent blue region represents the currently displayed dynamic range window, which can be scrolled with a mouse.

HDR images span a range of 16 f-stops, 48 separate "exposure images" would need to be stored on a server and then transferred. Such an approach is clearly impractical. There are also techniques for encoding HDR images as a pair of 8-bit images [Cohen et al. 01, Ward and Simmons 05], but reconstructing an arbitrary exposure from such a pair of images requires image operations that cannot be realized using HTML components. Therefore, instead, we employ the *opacity* property of the Cascading Style Sheets 3 (CSS3). Multiple exposures are encoded as a pseudo-linear combination of several basis images, which are stacked together with different opacity factors. This lets us encode 24 exposure images using as few as three low dynamic range basis images, thus greatly reducing the amount of data that needs to be sent to a web browser.

2. Windowing Technique

Even though the entire dynamic range for most HDR images cannot be reproduced on a computer screen, we can select a window of that range and map it to the available luminance range of a display. To do so, we need to apply an inverse display model that converts linear luminance (or radiance) values L of an HDR image to 3×8-bit pixel values V, which can be shown on a display:

$$V = IDM(L,e) = \left(\left[\frac{L\cdot e - b}{1-b}\right]_0^1\right)^{\frac{1}{\gamma}}, \qquad (1)$$

where $[\cdot]_0^1$ denotes clamping values in the range from 0 to 1. The variable e represents the exposure or the position of the dynamic range window that should be shown. Since all displays have limited contrast due to light leakage and ambient light reflected from a screen, the inverse display model above contains a black level factor b, which elevates the minimum luminance that is produced by the display. Although modern LCD displays can achieve a contrast up to $3000 : 1$, the peak luminance in a typical office setting does not exceed 100 cd/m^2, and the black level is strongly elevated by reflected ambient light and is usually close to 1 cd/m^2. This reduces the contrast ratio to $100 : 1$. For convienience, we assume an effective contrast of $128 : 1$, which corresponds to 7 f-stops, resulting in the black level factor $b = 1/128$. The majority of computer displays mimic the sRGB standard and have a *gamma correction* value close to $\gamma = 2.2$. Equation (1) is independently applied to three color channels (red, green, and blue).

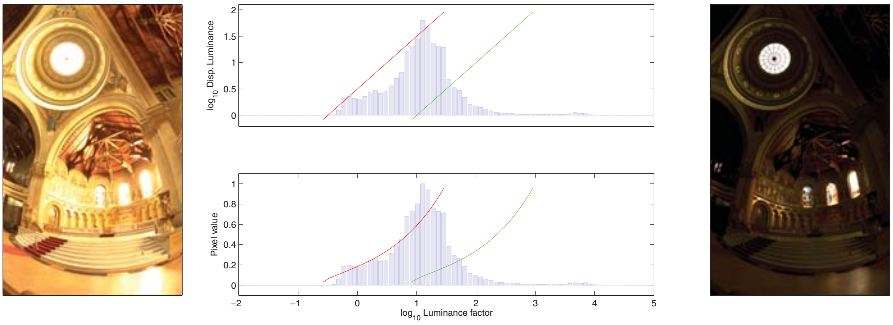

Figure 2. Example of the windowing technique: images on the left and right visualize two exposures of an HDR image and the two curves on each plot represent tone-curves used to generate these images. The plots show how the input luminance factor (HDR pixel values) is mapped to display luminance (top) or pixel values (bottom). Note that the windowing technique does not distort image contrast—the tone curves in the upper plot are straight lines with slope equal to 1.

Figure 2 shows two exposure images rendered from the same HDR image. The exposure correction introduces a horizontal shift on the log-luminance axis. Although linear interpolation between luminance values (top plot) can produce intermediate exposure values, this is not the case for the gamma-corrected pixel values (bottom plot), which are available in a web browser. Producing intermediate exposure images using a stack of semi-transparent images is not a trivial problem since the images in such a stack are gamma corrected and limited to the range from 0 to 1. The overexposed pixels (values > 1) in images with an opacity factor less than one will contribute erroneously to the rendered results in the sense of reducing contrast in highlights. Minimizing these distortions is the main problem that we solve below.

3. Alpha Blending in the Web Browser

The CSS3 *opacity* property for HTML elements [CSS Working Group, 08] acts as a multiplier of pixel values, which are then combined with the pixel values of underlying elements or with the background. If we stack N images $B_{1 \ldots N}$ on top of each other and set their opacities to $c_{1 \ldots N}$, the resulting pixel values can be found with the recursive formula [SVG Working Group, 03]:

$$\begin{aligned} &I_0 = b_0, \\ &I_i = c_i\, B_i + (1 - c_i)\, I_{i-1} \quad \text{for} \quad i = 1 \ldots N\,, \end{aligned} \tag{2}$$

where b_0 is the background color and B_1 is the bottommost image. All c and B values must be within the range 0 to 1 (negative opacity is not allowed).

4. Optimal Encoding of Multiple Exposures

The previous sections explain how to generate a single "exposure image" for a given dynamic range window and how the CSS3 opacity property modifies pixel values in an image stack. In this section we consider the best way to encode a set of exposures with the least number of semi-transparent images. Our task is to find the basis images $B_{i=1 \ldots N}$ and opacity coefficients $c_{i,k}$ (one for each basis i and for each exposure k), so that the blended image stack (Equation (2)) is as close as possible to the actual exposure image (Equation (1)).

Since image blending is spatially independent, we can operate on tone curves instead of pixel values of B_i, thus greatly reducing the number of optimized variables. For each basis image B_i, we assign a tone curve that maps input luminance (radiance) L to pixel values of the basis image:

$$T_i(L) = B_i\,.$$

If we assume that the background color is black (we found no improvement for different backgrounds), a tone curve for exposure k resulting from alpha-blending becomes

$$\begin{aligned}&H_0(L,k)=0,\\&H_i(L,k)=c_{i,k}\,T_i(L)+(1-c_{i,k})\,H_{i-1}(L,k)\quad\text{for}\quad i=1\dots N.\end{aligned}\tag{3}$$

If we summarize all the assumptions, our problem can be formulated as minimizing the differences between the ideal tone curves for exposures e_k (Equation (1)) and the tone curves resulting from alpha blending (Equation (3)):

$$\begin{aligned}&\arg\min_{c_{i,k},T_i}\sum_{k=1}^{E}\int_L\left(IDM(L,e_k)-H_N(L,k)\right)^2 dL\\ \text{subject to}\quad &0\geq B_l\geq 1,\\ &0\geq c_{i,k}\geq 1\quad\text{for}\quad i=1\dots N,\quad k=1\dots E.\end{aligned}\tag{4}$$

The above objective function integrates squared differences over the range of luminance values L and then sums the errors from each exposure $e_{k=1\dots E}$. The problem is non-linear due to clipping in the inverse display model (IDM); however, the optimum solution can be found efficiently using sequential quadratic programming. To solve for T_i and $c_{i,k}$, we used the algorithm available in the Matlab Optimization Toolbox (Version 4.0, R2008a). We did not observe local minima for any number of basis images that we considered (up to five), and the problem always converged to a global solution.

Although we could find optimal basis images and opacity values for each individual image, this is impractical since generating a single piece of HDR browser code would require solving an optimization problem. Instead, we precompute an optimal solution that can be reused for any number of images. This can be achieved under two assumptions: First, all luminance values have equal importance, which means that the objective function from Equation (4) is not weighted by a luminance histogram to find an image-specific solution. Second, the solution is found for a fixed segment of the dynamic range and is reused for the next segment. As a consequence of this approach, a certain number of tone curves (basis images) can be shared by two neighboring segments, thereby reducing the number of required basis images. For example, if an image spans 16 f-stops of the dynamic range, and we use two unique and one shared basis for each 8 f-stop segments, we need a total of $2\times 2+1=5$ basis images.

In our practical solution we use 8 f-stop segments and assume that one tone curve is shared, so that $T_N(L)=T_1(L\cdot 2^{-8})$. We approximate a tone curve with a piecewise linear function consisting of 40 segments. The exposures are selected with the same 1/3 f-stop granularity found in most photographic cameras, so that

$$e_k = 2^{-(k-1)/3} \quad \text{for} \quad k = 1 \dots E\,.$$

Overall, we need to optimize for 39 tone-curve nodes × $(N-1)$ non-shared basis images + $(N-1)$ opacity coefficients × 24 exposures (8 f-stops with a 1/3 f-stop step). The integral over the luminance range is approximated with discrete summation in the logarithmic luminance domain. Although we find an optimal solution for luminance/luma values, we apply the same tone curves to the red, green, and blue color channels.

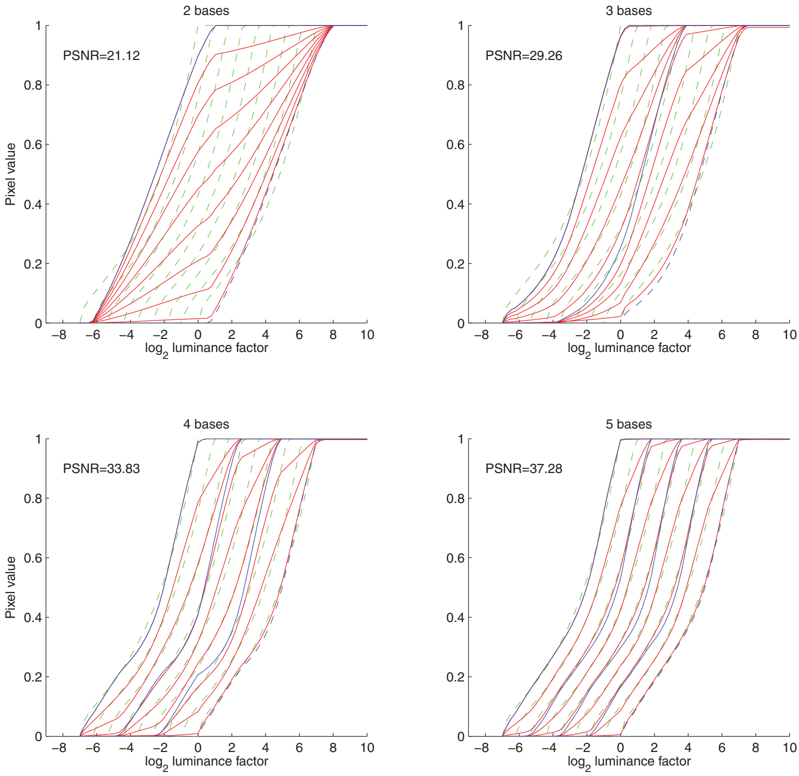

Figure 3. Tone curves resulting from an exact exposure rendering (green dashed lines) compared with the reconstructed tone curves (red solid lines). The reconstructed tone curves are a combination of the basis tone curves (blue lines) with different opacity settings. For clarity, only nine exposures (from 25) are shown on the plots. The dashed-blue line represents the basis tone curve that is shared with the next 8-fstop segment of the dynamic range (it is a shifted copy of the leftmost basis tone-curve).

5. Examples

The tone curves reconstructed from a combination of optimal basis tone curves (images) and optimal opacity settings are shown in Figure 3. Each plot represents a solution for a different number of basis images (tone curves). A smaller number of basis images results in fewer JPEG images that need to be transferred to and combined in a web browser, but it also produces a larger reconstruction error. The shape of the basis tone curves (blue lines in Figure 3) is similar but not identical to the ideal exposure tone curves (green dashed lines in Figure 3). The difference is especially significant for a lower number of bases. Two basis functions are, in general, not sufficient to correctly reproduce darker tones (see Figure 3 top left), but three or more basis tone curves can already produce a set of exposures that is difficult to discern from the exact solution. Although the PSNR values shown in Figure 3 may seem low, the approximation errors are not objectionable since all errors come from brightening, darkening, and contrast-change operations, for which the human eye is not very sensitive. This is demonstrated in Figure 4, in which exposures reconstructed using three or more basis images are very close to those produced by the inverse display model. The most noticeable difference is the color clipping, which is present in the reference exposure images, but is reduced in the reconstructed images. The reason for the reduction is the smooth round-off of the reconstructed tone curves for the maximum pixel values (refer to Figure 3).

6. Toolkit

We developed a toolkit for generating HTML pages with a multi-exposure HDR viewer from HDR images. The toolkit uses precomputed optimal basis tone curves to generate a set of JPEG images used as basis images for reconstructing multiple exposures. Then, it generates HTML and JavaScript code that offers intuitive control over exposure settings, as demonstrated in Figure 1. The JavaScript code updates opacity coefficients and replaces basis images in the image stack embedded in the web page. The resulting HTML can be used as a stand-alone web page or pasted in another web page. The URL link to the toolkit can be found in the Web Information section below.

7. Discussion

For most images the proposed technique lets us reduce the number of separately coded exposures from 48 (16 f-stops × 3 exposures per f-stop) to five (2 × 3 basis per each 8 f-stops - 1 shared basis). This allows for fine control over

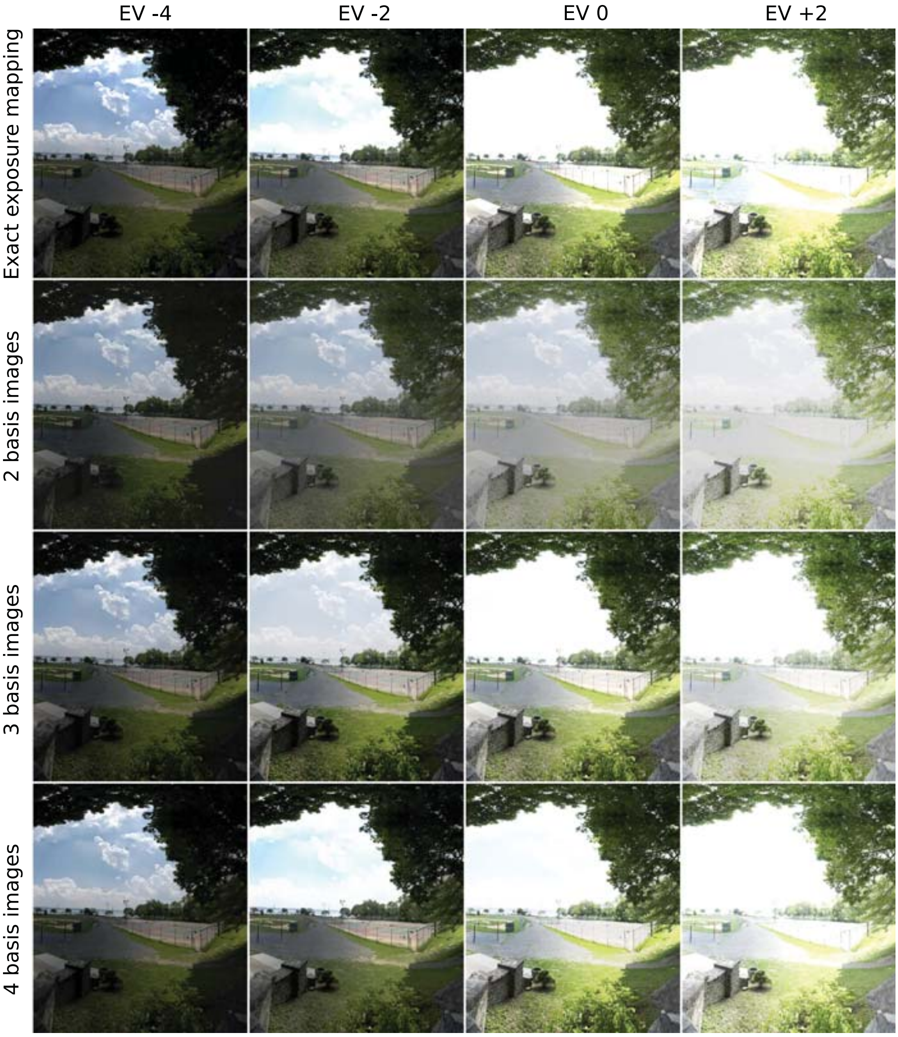

Figure 4. The result of an exact exposure rendering from an HDR image (top row) compared to the reconstruction from basis images (three lower rows). Three or more basis images per 8 f-stops are sufficient to produce multiple exposures without noticeable artifacts.

exposure settings in a web browser without the need to transfer prohibitively large amounts of image data.

Although the CSS3 specification has not been not finalized yet (as of November 2008), the *opacity* property is available in most web browsers. The exception is Internet Explorer 7, which still requires proprietary attributes to control opacity. We tested our code for several popular web browsers, including Firefox 3.0, Safari 3.2, and Internet Explorer 7.

The method has been demonstrated to work with the CSS3 opacity property but is also applicable to any 2D rendering engine that supports alpha compositing such as the Scalable Vector Graphics (SVG) renderer. The exposure control, which is the focus of this paper, is just one example of multiple operations that could be encoded using a set of basis images. The same technique could be used to encode other tone and color operations on images such as contrast, white-balance, highlight, and flood-light adjustments, found in typical image-editing software.

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Web Information:

http://jgt.akpeters.com/papers/MantiukHeidrich09/

The precomputed basis tone curves and opacity values, as well as the software for generating HTML pages with a multi-exposure HDR viewer, can be found at:

http://pfstools.sourceforge.net/hdrhtml/

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