Complete Digital Workflow for HDR Photography

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HDR (High Dynamic Range) imaging is the general name of the technology to capture, store, and edit images with a luminosity range exceeding the capabilities of standard technologies. It allows recording much greater range of tonal detail than a camera could capture in a single exposition. Standard dynamic range photos allow representing the dynamic range of luminosity of about 1000:1 while real scenes often possess a dynamic range of 100000:1 or higher [1]. The goal of our research is to correctly manage the colors of HDR photos which includes the tonal range of real-world scenes. Using the HDR technology allows working with the full range of luminosity of the scene since HDR images use floating-point values with 32 bits per color channel.
The investigation focuses on development of a predictable workflow of graphic data for HDR photography for further automation. The basic and extended workflow is demonstrated and tunable algorithm of HDR merging is proposed.

1. Introduction

The main idea of an HDR is to highlight the best exposure for different areas of the same photo. Dynamic range is defined as the difference between the lightest tonal values (highlights) and the darkest tonal values in which minimal details can be perceived (the shadows). Bright areas, that are so bright that no details are to be seen are said to be "blown out"; dark areas that have gone totally black are "plugged". Mastering the craft of extending digital dynamic range opens the possibility of compositions that would have been impossible in the past because of dynamic range limitations [2]. HDR photography typically works best when applied to photos taken outdoors or when there is a wide range of light/color present. Scenes suitable for HDR techniques are shown in Figure 1.

HDR had the most rapid progress with the digital age arriving and the exponential creation of new software, each version released more powerful than the precedent and with enough possibilities to choose the most appropriate method for our workflow. But, actually, the first ideas of how to extend the dynamic range on a photograph emerged 1850 when Gustave Le Gray tried to render landscapes of the sea and the sky [3]. Such rendering was impossible at the time using standard methods, the luminosity range being too extreme. Le Gray used one negative for the sky, and another one with a longer exposure for the sea, and combined both and thus invented HDR imaging. Later, in 1954, some experts tried to make the first tone mappings using methods like dodging and burning, increasing or decreasing the exposition of the negatives trying to extract all the dynamic range they could.

In general, HDR means combining multiple captures (3 or more) with different exposure settings for extending the dynamic range (Figure 2) [4]. The brightness distribution of digital images is represented in the histograms below. If the image has optimum contract (as in result of merging) the histogram includes practically all

Figure 1: Examples of scenes suitable for HDR techniques

brightness from highlights to shadows. If the image has low contrast (original images with exposure bracketing -2, 0, +2), the histogram includes only a small number of values. Out-of-range values would be recorded as "black" (underexposed) or "white" (overexposed) rather than the precisely graduated shades of colour and tone required to describe "details". For example, first image on a Figure 2 is underexposed, second image has a normal exposition and third is overexposed. HDR photos improve over LDR (Low Dynamic Range) images because there is a severe limitation regarding LDR images in terms of how much information can be stored. A typical conventional LDR image is stored with three channels: R, G, and B. Each channel contains 8 bits of data per pixel to store the intensity of a particular pixel in a particular channel. 8 bits of data per pixel just allows 256 different integers. In 8-bit mode 0.49999 would have been read roughly as 0 instead of 0.49999. HDR images are freed from this limitation. Instead of integers floating point values are used, while the precision varies depending upon which kind of floating point storage is used and the architecture of the computer.

With HDR images, it is possible to record in one photo the range from dark to light that is detectable by the human eye. In such photos in the same time details in shadows, highlights and mid-tones can be recorded. To merge a high dynamic range image from a set of differently exposed images of the same scene, pixels in

Figure 2: HDR Photo Exposure Bracketing (-2, 0, +2 stops and result of merging)

the individual exposures have to be related to the corresponding pixels in the other exposures.

2. HDR photo workflow

The HDR digital photo workflow consists of four main phases: taking a series of photos with different exposures, merging for HDR, digital image processing or editing and preparing for output [5-7]. During that workflow image details and significant colors have to be preserved.

The workflow includes every step of the photographic process from selecting camera settings and composing a frame to the final print or published web-gallery. The main workflow phases are presented in Figure 3.

All shown phases and steps present the basic components of each digital HDR photo workflow. They could be modified for personal needs and requirements in respect to productivity, HDR merging result quality or desired final print quality. The manifold variety of types of images require specific methods of merging and further corrections. That is why recommendations of using different techniques of merging depending on content of the scene are given. Basic steps involved in the HDR workflow are discussed below.

3. Data capturing for HDR

The workflow begins with camera settings before exposure: dynamic range evaluation of the scene, general camera settings, image specific camera settings and composing a frame. Also file format has to be mentioned: JPEG or RAW. RAW files are just the raw sensor data. In JPEG files all automatic and manual settings of the camera (e.g. white balance, contrast, tonal value corrections, sharpness, color interpolation plus JPEG specific data reduction algorithms) are automatically merged to the image data stored. To assure image data without unknown alterations and compressions is to use RAW format.

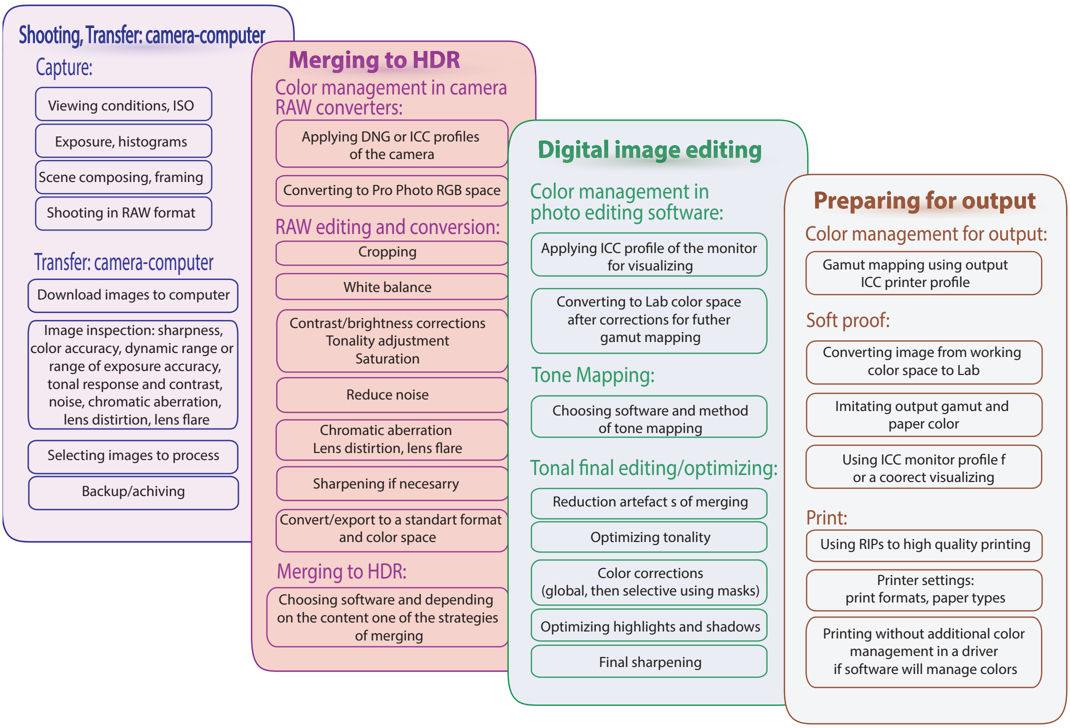

Figure 3: Complete digital workflow from capturing RAW data and rendering HDR scenes to an output-referred encoded image

When using the multiple exposure method of capturing data for a single HDR image, it is necessary to take multiple shots altering the exposure for the different light levels. Depending on the type of the scene and its dynamic range different capturing strategies can be applied. For example, in case of midday sun with strong shadows it will be enough to take 3 shots at about 1 ~ 1.33 stops apart; inside buildings with some light coming through the windows at least 5 bracketed shots with about 2 stops apart have to be taken.

The shutter speed should be varied rather than the f-stop since varying the f-stop will introduce differences in focus due to varying depth of field. The best details levels and the clarity are achieved by starting with a very fast shutter speed – just enough to pick up the brightest highlights in the scene with none of the pixels reaching a value of 255. For the next exposure, the exposure time should be doubled, repeating this until the image is mostly white, with just the darkest objects showing some detail. It is not necessary to take an exposure at every f-stop. It is possible to increase the exposure by two stops or several stops. Each image represents a slice of the scene's dynamic range and then could be digitally merged to have a high dynamic range image.

For a successful recovery of the original dynamic range, the dynamic ranges of individual exposure slices have to overlap. Otherwise, the combination algorithms can not join them. It is important to get free noise reduction out of that because each pixel in the resulting HDR represents the average of the most useful parts of each exposure. The most important are the middle tones. The shadows, where all the image noise tends to get overwhelming, are generally blown out and replaced with the corresponding color values from the lower exposures.

After multiple shots it is necessary to check the exposures using histograms, white balance and the ISO settings. After this, all the photos in RAW format should be transferred from the camera to computer.

4. HDR merging

Processing HDR photos involves the following stages: editing RAW data of source images (i.e. correction of the colors and geometrical distortions such as alignment, rotation, cropping), converting RAW files into RGB color space, merging a series of source images into a single HDR image, tone mapping and tonal final optimization. When multiple exposures are combined we preserve the information from each of the exposures. Then, the resulting 32-bit images are ready to have its wide contrast range adjusted to fit into the contrast range of the monitor or the output device.

4.1 RAW editing, conversion and color translation

RAW conversion process is presented by translating the Bayer pattern from the sensor of the camera using a camera ICC or DNG profile into RGB format. This processing involves a number of operations, such as: decoding the image data of raw files; demosaicing (interpolating the partial raw data received from the color-filtered image sensor into a matrix of colored pixels); changing white balance (if we need to correct color temperature of the light that was used to take the photo); straiten, rotation or crop (if necessary); exposure correction (in a small range); defective pixel removal (replacing data in known bad locations with interpolations from nearby locations); noise reduction (removing small defects or fluctuations, eliminating small detail for smoothness); removal of systematic noise; optical correction (lens distortion correction, vignetting correction, and color fringing correction); contrast enhancement, tune brightness, saturation; color corrections (first globally, then selectively), sharpening (increasing visual acuity by unsharp masking) and final color translation (converting from the camera native color space defined by the spectral sensitivities of the image sensor into an output color space ProPhoto RGB).

Gamuts of the various color spaces on Figure 4 indicate that there are colors that can be printed on an Epson 4900 that fall outside both sRGB and even Adobe RGB. ProPhoto RGB can contain all colors that a digital camera can capture–even highly saturated colors. Cameras don't capture and inkjet printers don't print in sRGB color space [8, 9]. That's why it is recommended to select ProPhoto RGB as output color space. Also it is recommended to avoid applications that could not use embedded ICC profiles, because the colors that could be observed on a screen or on a final print will be unpredictable.

Some raw formats also allow nonlinear quantization. This nonlinearity allows the compression of the raw data without visible degradation of the image by removing invisible and irrelevant information from the image. Although noise is discarded this has nothing to do with (visible) noise reduction.

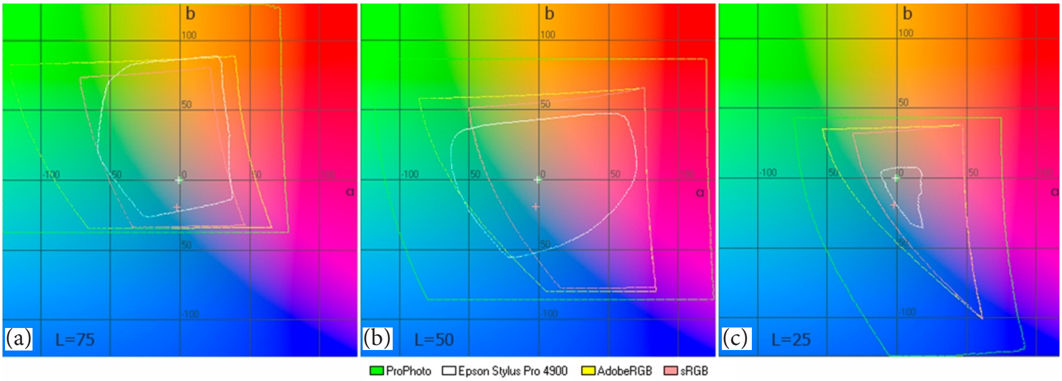

Figure 4: Comparison of gamuts of various color spaces in Gamut View a) highlights L=75, b)midtones L=50, c) shadows L=25

4.2 Strategies of manual and automate merging

There are quite a lot software programs available to be used to automatically combine the different exposure versions (such as Photomatix Pro, Adobe Photoshop HDR Pro, Picturenaut, Luminance HDR, easy HDR, DynamicPhoto HDR). The program searches for correctly exposed image areas and ignores overexposed and underexposed regions of the photo. Every program has its own method to achieve this, but HDR images are rarely perfect when the HDR program finishes with them. That's why, graphic artists and photographers prefer to apply manual adjusting after the merging process and using additional layers of images with different exposures to archive their goal for every specific photo.

Depending of the content photographer can select one of the 3 strategies of manual HDR image rendering:

- Using automated algorithms and then adding layers to auto-HDR. It works when photographer want to reach some special glow or highlight one specific area in the image. With automatic HDR we have a base for further manual processing. Then we can add a few hand-processed layers on top to reach special artistic idea (Figure 5, a).
- Using as a base an image with normal exposure and then adding lighter and darker versions on top (Figure 5, b).
- Using as a base the darkest image and then adding lighter images to highlight some details of the scene: This means processing the darkest, most underexposed capture first, then blend successively lighter versions on top (Figure 5, c).

When the picture contains many details and, therefore, manual merging becomes a significant problem and causes technical difficulties like curving every leaf in the plant (Figure 5, a) the automatic merging is preferable. In the work, there has been proposed a highly-tuneable algorithm for creating an HDR image. The algorithm is based on main principles of manual image rendering. It does not involve image recognition techniques and implements weighted patches summation based on their histograms only (1).

$$imageHDR\,|_{R,G,B} = image_1|_{R,G,B}\cdot c_1 + image_2|_{R,G,B}\cdot c_2 + image_3|_{R,G,B}\cdot c_3,\qquad c_1 + c_2 + c_3 = 1 \tag{1}$$

Where c_1, c_2 and c_3 are weights defining the transparency of each image.

After all three images are loaded, the auxiliary grayscale images are created using the relation [10]:

$$GRAY = R\cdot 0.2989 + G\cdot 0.587 + B\cdot 0.1140 \qquad (2)$$

which are then used for the coefficients estimation at every nearly-uniform patch.

Initially, the size of the patches to analyse was taken 8x8. The histograms of the three patches from different images were analysed. We have first found the weighted centres of each histogram using the expression (3):

$$Mid_j = \frac{\sum_{i=0}^{255} i\cdot h_i}{\sum_{i=0}^{255} h_i} \qquad (3)$$

According to the positions of the Mid_j the transparency coefficients are selected. A problem appeared at the gradient colors where, according to this technique, a sharp edge appeared between two parts taken from different images. However, the problem have been overcome by using smoothing function close to the boundary brightness, like this:

$$c_3 = 0.5 - 0.5\cdot\sin\left((Mid_1 - b_1)\cdot\frac{2\pi}{4\cdot\tau}\right),$$
$$c_2 = 1 - c_3 \qquad (4)$$

Where b_1 is the brightness limit for the shadows and τ is the transition zone. An example of the coefficients computed for some specific of b_1, b_2 and τ are presented in Figure 6.

As a result, instead of sharp edges a smooth gradient appears in the picture which is a mix of two different images.

One of the major problems of technique proposed was due to a stable patch size. Because of this, the defects appear at the edges of the objects. However, we have overcome this problem by analyzing the patches histogram dispersion found as follows:

$$D_j = \frac{\sum_{i=0}^{255} h_i\cdot\left|Mid_j - i\right|}{\sum_{i=0}^{255} h_i} \qquad (5)$$

Figure 5: Different scenes which required different strategies of HDR merging

It is obvious that if the patch contains parts of two objects, the dispersion of its histogram will be much larger than the one of the uniform and even slightly gradient image. If the dispersion exceeds certain limit, the patch is subdivided and its parts are analyzed separately until the largest element with satisfying histogram dispersion is found. Result of such HDR merging by two different tools without additional post-processing is presented in Figure 8b.

Analyzing the histograms the important conclusions can be made. Namely, our approach allows preserving more details in whole dynamic range. The histogram looks more uniform covering more shades (15…25) and semi-tones (130…200). On the other hand, comparing the images, the one with wider histogram (see figure 8b) looks more contrast without introducing any additional effects.

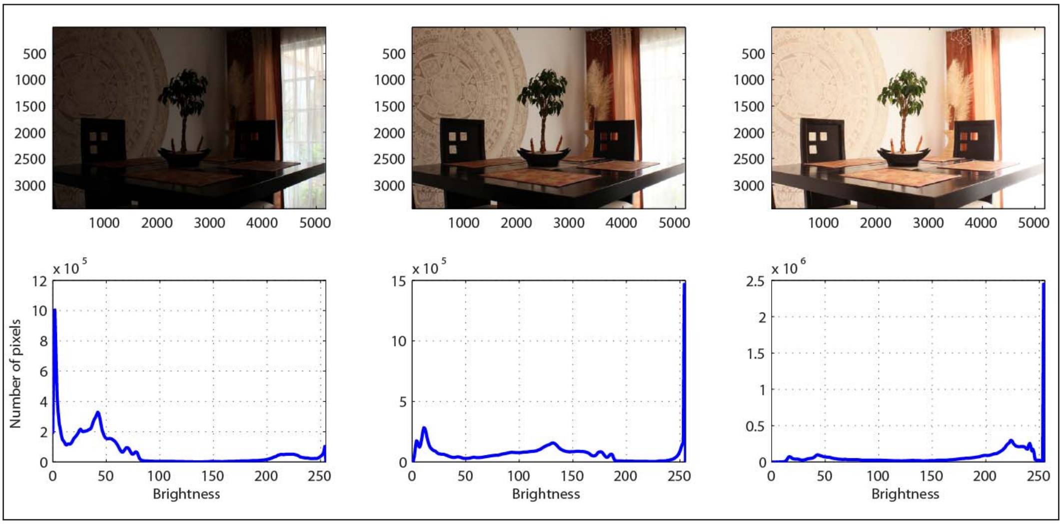

Figure 6: Images for HDR merging (0, -2, +2 stops) and their histograms in MATLAB

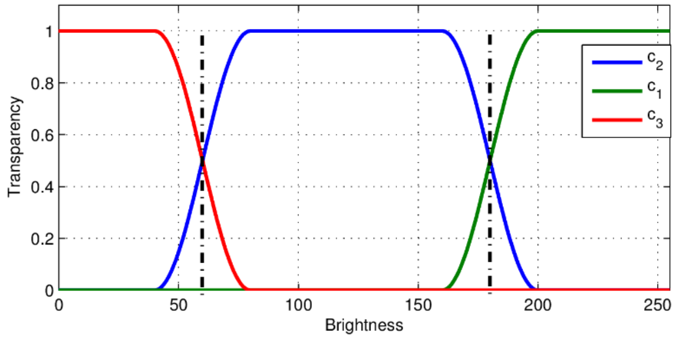

Figure 7: Transparency coefficients for merging the images into HDR according to (1)

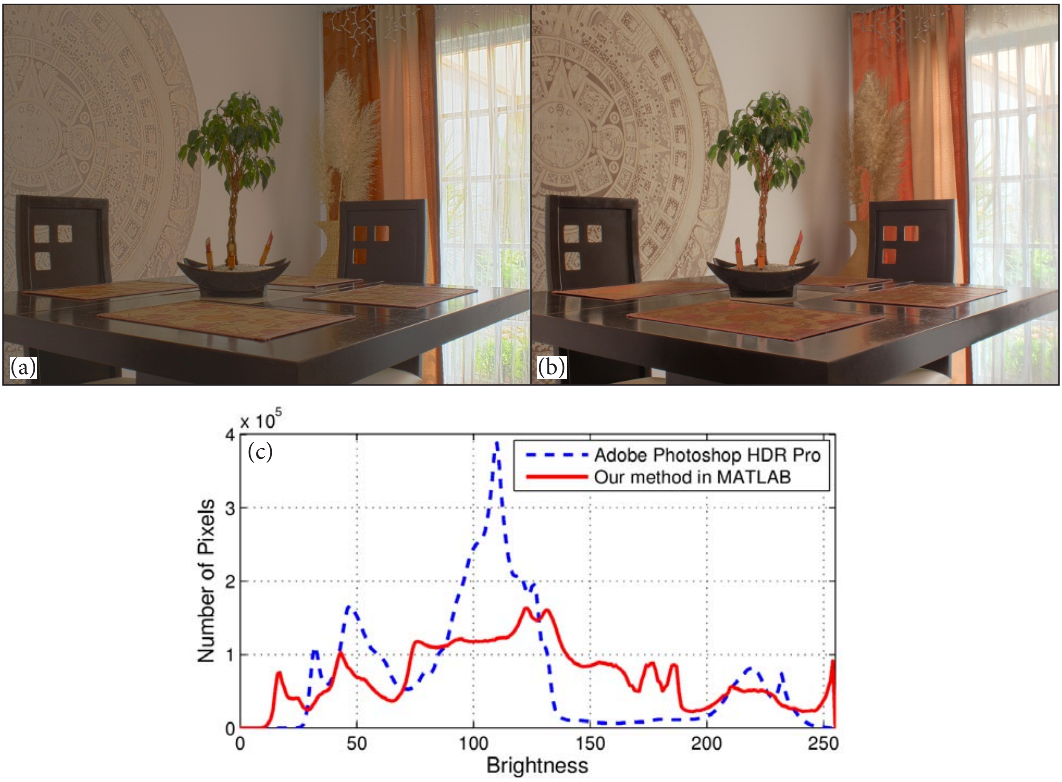

Figure 8: Result of HDR merging and their histograms – a) result of merging in Adobe Photoshop HDR Pro, b) our method realized in MATLAB, c) histograms

5. Post-processing and preparing for output

The resulting HDR image with such high-color-depth needs to be rendered for pleasing effect and correct viewing on low-dynamic-range monitors or prints. The next step of HDR image production (tonal mapping) involves reducing the image's tonal range to a viewable/printable format without losing any important information (details). The tone-reproduction rendering often includes separate tone mapping and gamma compression steps. Most HDR programs offer various tone mapping methods with various parameters for adjustment. Depending on the particular photographer needs (e.g. producing just aesthetically pleasing images, reproducing as many image details as possible, maximizing the image contrast) there can be selected one of tone mapping methods. Tone mapping methods allow reducing the dynamic range or contrast ratio of the entire image while retaining localized contrast between neighbour pixels, trying to represent the whole dynamic range while retaining realistic color and contrast.

Among final steps of the digital HDR workflow we also should mention image optimization and preparing to output. During optimization it is often necessary to selectively dodge/burn specific parts of a finished HDR photo, or to adjust the colors to more realistic level. Then depending on type of the media that photographer can choose (inkjet prints, publishing on the Web or producing other types of output) the whole phase can be divided into several steps: backup HDR images, scale images for output, output sharpening, generate output (convert to output device color space), soft proof, check results and publish.

6. Conclusions

In the paper, different approaches to HDR image capturing, rendering and latest post-processing techniques have been joined into one general workflow. For convenience, we have presented all the stages of the workflow as a single flowchart for further process automation as a multiparameter optimization problem. Obviously there is no unique way to achieve a final goal. Photographers always have to adapt the general complete workflow to their personal experience, content of the images, available software and peculiarities of their job. Moreover, proposed basic structure of the workflow should help the photographers, guide them in developing specialized workflow for HDR panoramic images, close-ups, high-contrast scenes and architecture photography.

As a first step towards full automation of the personalized HDR workflow it has been proposed an HDR merging algorithm involving many parameters which leads to further optimization works.

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All photos in this paper taken by Natalia Gurieva. Camera: Canon EOS REBEL T3i, lens: EF-S18–55mm f/3.5-5.6 IS II.

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