Assignment 3: High-Dynamic-Range Imaging - Lab session 4 -

1 Introduction

In this session, you will learn to:

1. generate and display High-Dynamic-Range (HDR) images;
2. review and test software to automatically combine multiple exposures into a single HDR radiance map; and
3. review and test different tone mapping algorithms to compress the dynamic range of the radiance map to a standard 8-bit range (allowing you to display the image on a screen);
4. capture and merge your own LDR images into an HDR image.

Items number 1 and 2 are included in Section 2 of this assignment. Item number 3 is included in Section 3 and Section 4 of this assignment. These three parts correspond to these papers: [1, 3, 2]. You will have to carefully read the indicated sections of the original papers in order to review and test the methods. You will apply the methods on a set of images provided in the data folder. The name of each image reports the exposure time used as a fraction. Item number 4 is described in Section 5. You can use the lab camera and tripod or your own ones for this final step.

2 HDR imaging

In the first part of this assignment, you will transform a stack of low-dynamic-range (LDR) images acquired at different exposure times into a single HDR image. To do so, you will have to review and test the method described in Section 2 of the work by Debevec and Malik [1].

2.1 Linearize images

Unlike the radiance map we want to obtain, the rendered JPEG images are not linear. The first step is, thus, to linearize the images. To do so, you will have to find the camera response function g as explained in Section 2.1 of the work by Debevec and Malik [1]. Below is a very brief explanation of the process (refer to the paper for more details).

Let Z_{ij} be the observed pixel values for pixel i in image j acquired with exposure Δt_j. This observed value is an unknown function of the scene radiance E_i at pixel i and the exposure duration:

$$Z_{ij} = f\left(E_i \Delta t_j\right) \tag{1}$$

Both f and E_i are unknown. However, we will use the fact that E_i is constant over our stack of images in order to recover f. More precisely, instead of directly solving for f, we will solve for:

$$g = ln\left(f^{-1}\right) \tag{2}$$

which maps the pixel values to the logarithm of the exposure values (Equation 2 in [1]).

We can recover g by least square minimization of the value of pixels from our different exposure images (Eq. 4 in [1]). In this linear system, you will have to solve for the value of g over all possible pixel values as well as the scene radiance for each pixel.

Once we have the response function g, it is straightforward to map the pixels from each picture to the radiance of the scene:

$$ln\left(E_i\right) = g\left(Z_{ij}\right) - ln\left(\Delta t_j\right) \tag{3}$$

In your report, plot the response function obtained with the full method, without the smoothness term (you can use a very low λ), and without using the weighting scheme. Comment on the features you see of the functions that you obtained by adjusting these different parameters. Note that you will have to sub-sample the images in order to solve the least square minimization. For example, you can regularly sample the images every 20 pixels in framing your least square minimization.

2.2 Obtain the radiance map

Now that you can get the radiance map from each image, you can construct an HDR image by averaging the values of the pixels from all the images in the stack. This is described in Section 2.2 of [1]. Reconstruct the radiance of the scene and store it as an HDR image. As in the previous subsection, try with and without the tent weighting scheme and analyze the difference in the final radiance map. In your report, show the radiance map obtained with and without weighting (you can use MATLAB's `imagesc` function).

3 Global tone mapping

In this section, you will review and test the global tone mapping operator described in [3] to display the HDR image you just constructed in the previous section. Carefully read Section 3.1 of the paper and review and test the method. You do NOT have to implement the automatic dodging-and-burning method described in Section 3.2 of the paper. This algorithm is an improved version of the basic tone-mapping operator $\frac{L}{1+L}$. In your report, show how the tone mapped image differs from using this simple operator, experience with different parameters and show how they influence the final image.

4 Local tone mapping

Finally, you will review and test a local tone mapping algorithm, for instance, the operation applied on each pixel is not exactly the same and depends on local contrast and details. You will review and test a simplified version of the method described in [2]. The paper in itself focuses on the implementation of a fast bilateral filter and you can find a brief description of their method in Section 6.

In practice, you will extract a base layer from your image by filtering the intensity with a bilateral filter and apply contrast reduction in the log domain. Then, you will bring back the details that were removed by the filter and the colors. The intensity can be computed as the average of all color channels. Be careful that in the linear domain, you will have to divide (or multiply) to isolate the colors of your image and get the intensity back; whereas in the log domain, you will have to subtract (or add) to isolate the details and put them back. The contrast reduction operation is a scaling of the image:

$$I' = (I - o) * s \tag{4}$$

where $o = max\,(I)$ and $s = dR/\,(max(B) - min(B))$. The offset o is such that the maximum intensity will be 1 in the linear domain, the scale s is such that the output intensity has dR stops of dynamic range. In practice, you can experiment with values between 2 and 8. For the kernel sizes of the bilateral filter, you can use the values recommended in the paper σ_s and σ_r. In your report, show the decomposition of the image (base and detail layer) as well as the tone mapped images. Experiment with the contrast reduction operator applied naively on the whole image (without using the filtering to conserve details) and compare with the result from the full method.

5 Try out with your own pictures

Now that you have explored these methods to generate an HDR image from a stack of low-dynamic-range (LDR) images and tone map it, try them on your own set of captured LDR images.

First, choose a scene with high dynamic range: typically any scene that shows indoors and outdoors (e.g. a room with a window), or two regions with very different illumination intensities (e.g. an illuminated hallway and a dark room, an outdoor scene on a very sunny day showing illuminated and shadowed surfaces). Make sure to choose a scene that requires HDR to display everything correctly. If a single LDR image already captures everything within range (without overexposed or underexposed pixels), the HDR results will have no interest.

Second, take multiple LDR photographs of the scene. There are several important aspects to account for:

- To avoid ghosting and misalignment artifacts, your camera should not move and the scene should be static between shots. For the best results, use a tripod (you can borrow one of ours), or put your camera on a (very) stable surface. Make sure the scene elements and the lighting conditions do not change.
- To avoid structural changes between images produced by different aperture, keep the aperture size and focal point fixed between shots (or at least keep a small aperture between shots). Ideally, you should vary only the shutter speed of the camera to change image exposure. If you use your phone, some applications such as OpenCamera for Android[1], allow for specific control of the shutter speed and other camera controls. If your camera does not allow control of the shutter speed, you can borrow the Canon 500D from the lab.
- When using your phone, DSLR, or mirrorless camera, make sure they are not shooting in RAW mode. RAW mode preserves a higher dynamic range than regular JPG, PNG, and HEIC images.
- If you use our phone camera, make your camera app does not already perform any HDR tone mapping as part of the image processing pipeline before saving a LDR image. On

[1] `https://play.google.com/store/apps/details?id=net.sourceforge.opencamera`

the native Camera app of the latest Android versions, this can be disabled in *Camera settings→Photo→HDR/Ultra HDR*. In the OpenCamera app, there are several HDR options under the *Settings → Photo settings* menu.

- Check if your DSLR/mirrorless camera settings or if your phone camera app have an automated exposure bracketing feature. This feature typically allows for automatic bursting of multiple images at equidistant exposure levels with a single press of the shutter button.

In your report, show two or three representative LDR images from your stack and explain why you chose that scene. Show the radiance map that you obtained, and your favorite tone mapped image for both algorithms along with the parameters that you used to produce them.

6 Deliverable

Your deliverable should be an archive file (e.g., a ZIP file) with the following items:

1. All your MATLAB code, including commented code, reviewing and testing the different sections of this assignment, as well as a README file explaining how to use the code. Comment your design choices in the code, if any.
2. An up-to two-page (plus figures) PDF report with all the intermediate and final results obtained. Comment on the different parameters we ask you to explore and explain what their effects are and which images you prefer.

7 Evaluation

The maximum score for this assignment is 10 points:

HDR imaging (Section 2)	3
Global tone mapping (Section 3)	2
Local tone mapping (Section 4)	2
Try out with your own pictures (Section 5)	3
Total	10

8 Acknowledgments

This assignment is adapted from James Tompkin's Computational Photography course (Brown University), and Ioannis Gkioulekas' Computational Photography course (Carnegie Mellon University). The images provided in this session have been downloaded from Paul Debevecs repository[2].

References

[1] Paul E Debevec and Jitendra Malik. "Recovering high dynamic range radiance maps from photographs". In: *Proceedings of the 24th annual conference on Computer graphics and interactive techniques*. 1997, pp. 369–378.

[2] `http://www.pauldebevec.com/Research/HDR/`

[2] Frédo Durand and Julie Dorsey. “Fast bilateral filtering for the display of high-dynamic-range images”. In: *Proceedings of the 29th annual conference on Computer graphics and interactive techniques*. 2002, pp. 257–266.

[3] Erik Reinhard et al. “Photographic tone reproduction for digital images”. In: *Proceedings of the 29th annual conference on Computer graphics and interactive techniques*. 2002, pp. 267–276.