High Dynamic Range Imaging

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C O N N E X I O N S

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Table of Contents

1 Motivation 1
2 Introduction 3
3 Background 5
4 Implementation: HDR Method 9
5 Implementation: Tone Mapping Method 13
6 Results 15
7 Conclusion 43
8 301 Poster 45
Attributions 46

Chapter 1

Motivation[1]

1.1 Motivation

When you take a picture with a modern digital camera, it can be seen that they cannot yet match the eye's ability to manage contrast. An image sensor or display medium's contrast ratio defines the distance between the darkest black and the lightest white that the device records or displays. The eye's contrast ratio of 1:100,000 is 24 times greater than the 1:4096 of a typical digital camera. As a result, even in correctly exposed photographs, shadows are often too dark and highlights too bright, creating a noticeable loss of detail.

Humans can discern very high range of brightness values. Photography is limited to a much lower dynamic range.

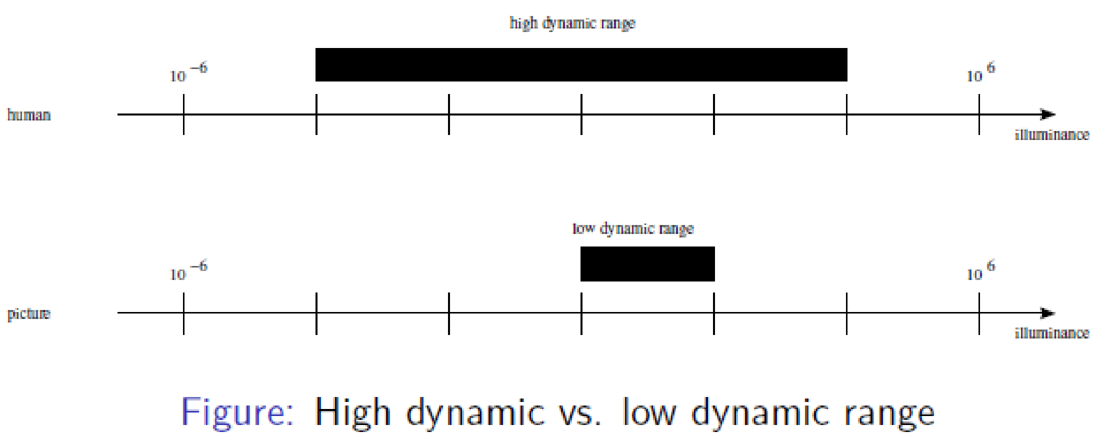

Figure 1.1

[1]This content is available online at <http://cnx.org/content/m45370/1.2/>.

Figure: From left to right: underexposed, correct exposure, overexposed

Figure 1.2

We can, however, compute a high dynamic range (HDR) picture from multiple exposures. Because we cannot display an HDR picture due to limitation, we will use tone mapping to compress contrast intro a displayable range.

Chapter 2

Introduction[1]

2.1 Introduction

High dynamic range (HDR) digital imaging systems increase visual fidelity by integrating contrast ratio with observer-based models of color perception across multiple exposures of a single scene. They use mathematical transformations known as tone mapping operators to display HDR images on low dynamic range (LDR) devices such as monitors.

We will uses a series of photographs of a scene to produce an image that is as close as possible to what the human eye would see. To turn a photograph into an HDR image, we first extract the radiance information from the photographs and then tone-map it into a single LDR image. Both the reconstruction and tone mapping algorithms rely on matrix operations so we will implement in MATLAB.

[1] This content is available online at <http://cnx.org/content/m45336/1.2/>.

Chapter 3

Background[1]

3.1 Background

HDR increases visual fidelity by integrating contrast ratio with observer-based models of color perception. Relative values of real scene radiances are rarely captured by cameras because of non-linearities and clipping. The response curve of a camera maps the real scene radiance to the digitized pixel values. HDR methods use response curve to find real scene radiances. Tone mapping filters such images for display on low dynamic range (LDR) displays.

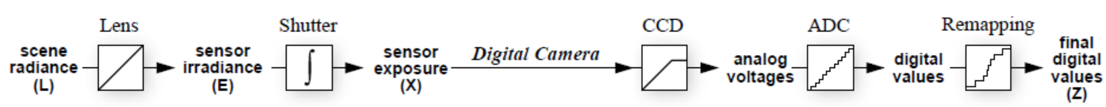

Figure 3.1

Radiance Mapping

The LDR of a single digital photograph contains accurate radiance information only for correctly exposed pixels. Changing the exposure captures radiance information for different sets of pixels. To accurately analyze a sequence of photographs to extract radiance information for the entire scene, we must take into account the way the camera sensor responds to different levels of light. First, we try and get the camera response curve f, which tells us how scene radiance E is mapped to pixel brightness Z. Using the inverse of f allows us to reproduce actual scene radiance E. The curve f is different for each camera and we compute f from a series of exposures.

[1]This content is available online at <http://cnx.org/content/m45368/1.2/>.

Figure: Exposure series used to compute camera response curve

Figure 3.2

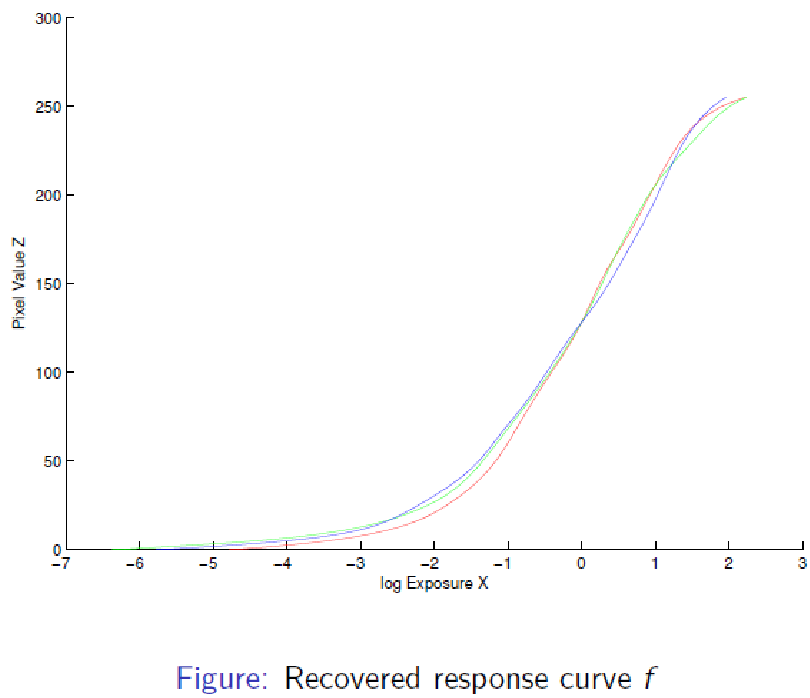
300
250
200
150
100
50
0
Pixel Value Z
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
log Exposure X
Figure: Recovered response curve f

Figure 3.3

Chapter 4

Implementation: HDR Method[1]

4.1 HDR

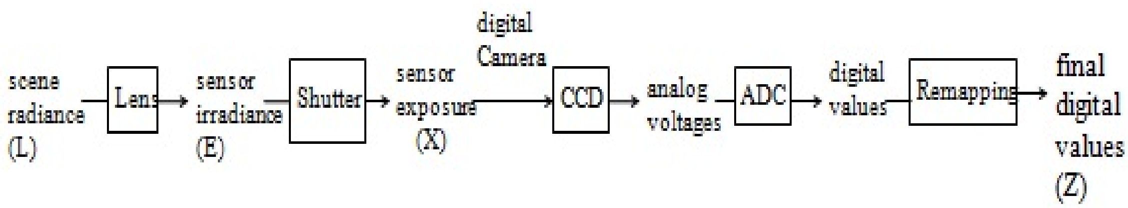

Figure 4.1: Image Acquisition Pipeline

From Figure 1: Image Acquisition Pipeline, we could see how the scene radiance(X) is non-linearly mapped into its final digital values(Z). In other words, f(X)=Z, the composition of the characteristic curve of a device and all the nonlinear mapping, is a nonlinear function. Non-linearity is mostly introduced by later processing steps such as analog to digital conversion and remapping. Therefore, our method to construct a High Dynamic Range(HDR) picture is to first recover the response curve, f(X)=Z and then by using the pixel values from the series of (LDR) pictures, we're able to get the scene radiance, which is like a reversed process. Finally, our HDR picture will be constructed from these values of scene radiance.

Our general process will be:

1. We'll take pictures with different exposure times.

a) Knowing the exposure X and the exposure time delta t, we're able to recover irradiance through formula E = X/delta t.

b) Since f(X)=Z and function f could be reasonably conceived as increasing function, its inverse function is well defined. Then, we have

[1] This content is available online at <http://cnx.org/content/m45500/1.1/>.

$$X = f^{-1}(Z)$$

Figure 4.2

c) Using the formulas in a) and b), we have

$$Z_{ij} = f(E_i \Delta t_j)$$

Figure 4.3

where i is the index of sample(pixel) and j is the index of pictures with different exposure times. The formula also equals to

$$f^{-1}(Z_{ij}) = E_i \Delta t_j$$

Figure 4.4

taking natural log on both sides, we will have

$$\ln f^{-1}(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

Figure 4.5

Making X=g(Z) the inverse function of Z=f(X), we get

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

Figure 4.6

d) Thus, we transform our problem into a problem minimizing least-squared error between g(Z) and ln(E) and ln(delta t), which could be summarized by the following formula:

$$\mathcal{O} = \sum_{i=1}^{N} \sum_{j=1}^{P} \left[g(Z_{ij}) - \ln E_i - \ln \Delta t_j\right]^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} g''(z)^2$$

Figure 4.7

Note that the second term here is for smoothing g(Z). And lambda is a scaling factor subject to different pictures.

3. After we get the response curve by solving the equation above, when we use the pixel values Z of those LDR pictures, we'll be able to get the values of irradiance X at each point of the scene. In other words, we're trying to figure out in different areas, which group of pixel values from different LDR pictures with different exposure times is closest to the corresponding irradiance and best to reveal details of that area. Thus, it enables us to construct HDR picture in which pixel values in different areas are extracted from the LDR picture that captures its details best.

4. We finish our task to construct a HDR picture here. However, we still have to solve another problem, which is to display a HDR picture on a LDR display. And this leads to the second part of our implementation: Tone- mapping.