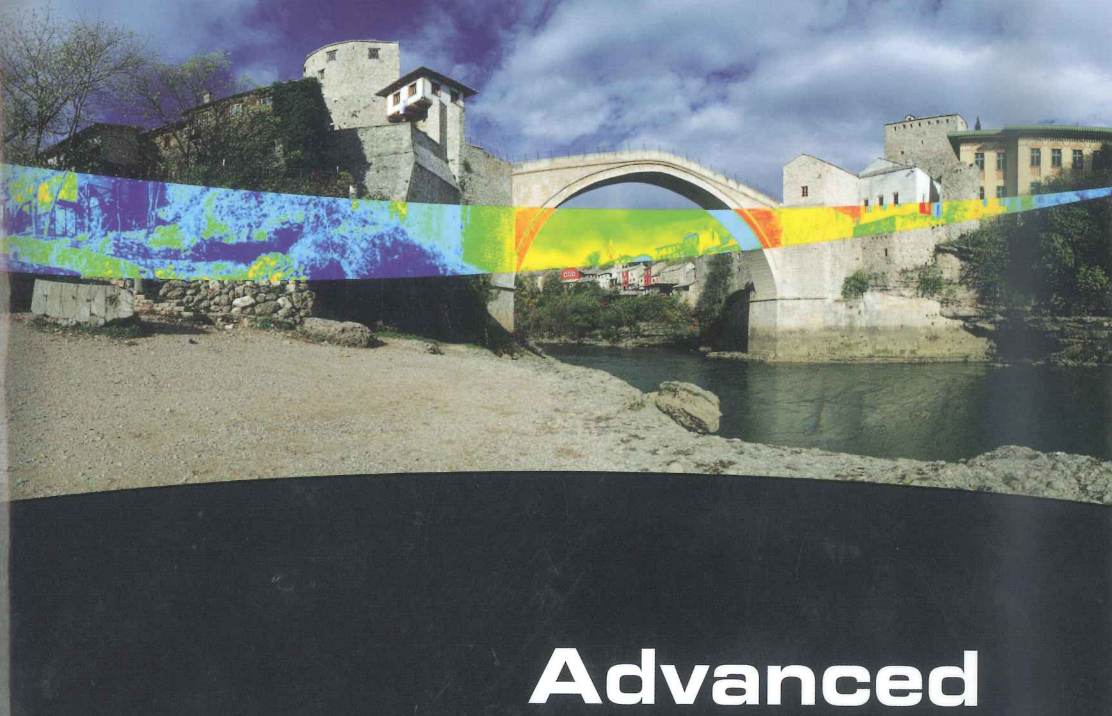
Foreword by
Holly Rushmeier

Francesco Banterle
Alessandro Artusi
Kurt Debattista
Alan Chalmers



Advanced High Dynamic Range Imaging

Advanced High Dynamic Range Imaging

Theory and Practice

Francesco Banterle
Alessandro Artusi
Kurt Debattista
Alan Chalmers

A K Peters, Ltd.
Natick, Massachusetts

1 Introduction

The computer graphics and related industries, in particular those involved with films, games, simulation, virtual reality, and military applications, continue to demand more realistic images displayed on a computer, that is, synthesized images that more accurately match the real scene they are intended to represent. This is particularly challenging when considering images of the natural world that present our visual system with a wide range of colors and intensities. A starlit night has an average luminance level of around 10^{-3} cd/m^2, and daylight scenes are close to 10^6 cd/m^2. Humans can see detail in regions that vary by 1:10^4 at any given eye adaptation level. With the possible exception of cinema, there has been little push for achieving greater dynamic range in the image capture stage, because common displays and viewing environments limit the range of what can be presented to about two orders of magnitude between minimum and maximum luminance. A well-designed cathode ray tube (CRT) monitor may do slightly better than this in a darkened room, but the maximum display luminance is only around 100 cd/m^2, and in the case of LCD display the maximum luminance may reach 300–400 cd/m^2, which does not even begin to approach daylight levels. A high-quality xenon film projector may get a few times brighter than this, but it is still two orders of magnitude away from the optimal light level for human acuity and color perception. This is now all changing with high dynamic range (HDR) imagery and novel capture and display HDR technologies, offering a step-change in traditional imaging approaches.

In the last two decades, HDR imaging has revolutionized the field of computer graphics and other areas such as photography, virtual reality, visual effects, and the video game industry. Real-world lighting can now be captured, stored, transmitted, and fully utilized for various applications

(a) (b) (c)

Figure 1.1. Different exposures of the same scene that allow the capture of (a) very bright and (b) dark areas and (c) the corresponding HDR image in false colors.

without the need to linearize the signal and deal with clamped values. The very dark and bright areas of a scene can be recorded at the same time onto an image or a video, avoiding under-exposed and over-exposed areas (see Figure 1.1). Traditional imaging methods, on the other hand, do not use physical values and typically are constrained by limitations in technology that could only handle 8 bits per color channel per pixel. Such imagery (8 bits or less per color channel) is known as low dynamic range (LDR) imagery.

The importance of recording light is comparable to the introduction of color photography. An HDR image may be generated by capturing multiple images of the same scene at different exposure levels and merging them to reconstruct the original dynamic range of the captured scene. There are several algorithms for merging LDR images; Debevec and Malik's method [50] is an example of this. An example of a commercial implementation is the Spheron HDR VR [192] that can capture still spherical images with a dynamic range of $6 \times 10^7 : 1$. Although information could be recorded in one shot using native HDR CCDs, problems of low sensor noise typically occur at high resolution.

HDR images/videos may occupy four times the amount of memory required by corresponding LDR image content. This is because in HDR images, light values are stored using three floating point numbers. This has a major effect not only on storing and transmitting HDR data but also in terms of processing it. As a consequence, efficient representations of the floating point numbers have been developed for HDR imaging, and many classic compression algorithms such as JPEG and MPEG have been extended to handle HDR images and videos.

Once HDR content has been efficiently captured and stored, it can be utilized for a variety of applications. One popular application is the relighting of synthetic or real objects. The HDR data stores detailed lighting information of an environment. This information can be exploited for de-

Computer Graphics

Advanced High Dynamic Range Imaging

Francesco Banterle • Alessandro Artusi
Kurt Debattista • Alan Chalmers
Foreword by **Holly Rushmeier**

High dynamic range (HDR) imaging is the term given to the capture, storage, manipulation, transmission, and display of images that more accurately represent the wide range of real-world lighting levels. With the advent of a true HDR video system and its 20 year history of creating static images, HDR is finally ready to enter the "mainstream" of imaging technology. This book provides a comprehensive practical guide to facilitate the widespread adoption of HDR technology. By examining the key problems associated with HDR imaging and providing detailed methods to overcome these problems, the authors hope readers will be inspired to adopt HDR as their preferred approach for imaging the real world. Key HDR algorithms are provided as MATLAB code as part of the HDR Toolbox.

"This book provides a practical introduction to the emerging new discipline of high dynamic range imaging that combines photography and computer graphics....By providing detailed equations and code, the book gives the reader the tools needed to experiment with new techniques for creating compelling images."

—From the Foreword by Holly Rushmeier, Yale University

Using **MATLAB**

Download MATLAB source code for the book at www.advancedhdrbook.com

ISBN 978-1-56881-719-4

9 781568 817194

A K Peters, Ltd.