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HDR Applications in Computer Graphics

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13.1 Introduction

One of the goals of computer graphics is to realistically render real objects and scenes taking their physical properties into account. Due to the high dynamic range (HDR) encountered in real scenes this requires performing most rendering steps with floating point precision. This was acknowledged early on and implemented in many software rendering systems. But the limited computational resources in hardware accelerated rendering systems often required developers to work with lower precision – typically 8 bit per color channel. With the advent of more powerful graphics cards, CPUs, and cluster rendering systems, an increasing number of systems incorporate now a full floating point rendering pipeline so that dealing with HDR data has become a standard requirement in computer graphics. One indication for this development is the now wide-spread use of HDR image file formats such as the OpenEXR format [1].

Without exact scene models (including materials, objects, lighting), realistic and physically correct rendering is, however, impossible. Graphics research is therefore also introducing methods to digitize various aspects of reality. Many of these methods are using camera systems as input devices and are therefore called image-based methods. One important aspect is hereby the ability to cope with the often huge dynamic range of the captured scene either using software or hardware system. In this chapter, we first discuss common approaches in the computer graphics area for capturing and calibrating HDR image data. We then describe several approaches for the digitization of real-world objects (Sect. 13.3) and for image-based lighting (Sect. 13.4). The chapter is concluded by a discussion of the requirements for HDR capture systems in computer graphics applications (Sect. 13.5).
13.2 Capturing HDR Image Data

One of the earliest examples of HDR imaging was introduced by Wyckoff and Feigenbaum [2] in the 1960s who invented an analog film with several emulsions of different sensitivity levels. This false color film had an extended dynamic range of about $10^8$ which is sufficient to capture the vast majority of scenes encountered in practice without changing any exposure settings (aperture, exposure time) or adding filters to the optical path. An additional advantage is that brightness levels can be easily compared between different images provided that camera settings remain unchanged.

13.2.1 Multiexposure Techniques

As in the case of analog film, the dynamic range of traditional CCD imaging sensors often used in computer graphics applications is quite limited (typically in the order of $10^3 – 10^4$). Several authors proposed therefore methods to extend the dynamic range of digital imaging systems by combining multiple images of the same scene that differ only in exposure time (multiexposure techniques). Madden [3] assumes linear response of a CCD imager and selects for each pixel an intensity value from the brightest nonsaturated image. This value is scaled according to the image’s exposure and stored in the final HDR image.

A large number of methods has been proposed by several authors including Mann and Picard [4],Debevec and Malik [5], Mitsunaga and Nayar [6] and Robertson et al. [7] that estimate the Opto Electronic Conversion Function (OECF) (mostly called response curve in computer graphics) from a set of images with varying exposure. Given the response curve, input images can be linearized and scaled according to their exposure settings. The final HDR image is computed as a weighted sum of these images, where the weighting function reflects the certainty with which the value of an individual pixel in any of the input images is known (e.g., pixel values close to over- or underexposure are assigned a low certainty and consequently a low weight).

Although capturing multiple images of the same scene with different exposure settings has several disadvantages (e.g., long acquisition times due to the multiple exposures, difficulties for dynamic scenes), it is used in many applications. Systems using cameras with native HDR sensors, which can avoid many of these problems, are only slowly gaining momentum (see also the discussion of camera requirements for computer graphics applications in Sect. 13.5).

13.2.2 Photometric Calibration

For many applications, photometric calibration of the captured image data is crucial. Most multiexposure techniques yield images with linear floating point data per pixel in unknown units. These can be related to physical quantities by performing absolute calibration with a test target with known luminance (e.g.,