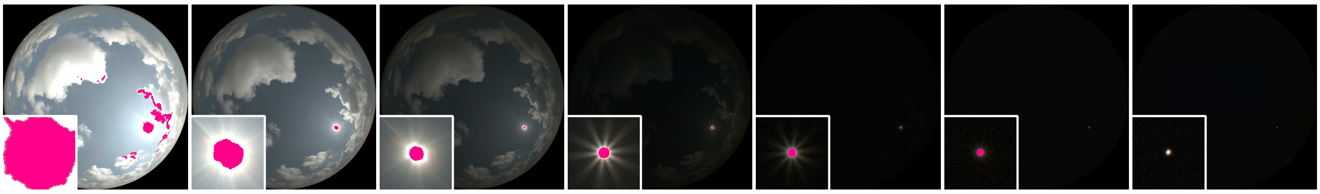
Direct HDR Capture of the Sun and Sky

Jessi Stumpfel Andrew Jones Andreas Wenger Chris Tchou Tim Hawkins Paul Debevec
University of Southern California Institute for Creative Technologies



f/4, 1s | f/4, $\frac{1}{4}$s | f/4, $\frac{1}{32}$s | f/16, $\frac{1}{16}$s | f/16, $\frac{1}{125}$s | f/16, $\frac{1}{1000}$s | f/16, $\frac{1}{8000}$s

Figure 1: HDR sequence spanning 17 stops of the sky and sun in 7 exposures. A detailed view of the sun is shown in the bottom left of each image; pink regions indicate saturated pixels.

Recent techniques employing omnidirectional high dynamic range photography have produced useful datasets of real-world illumination environments [Debevec and Malik 1997], which have been used as sources of illumination for rendering. While much work has been done to simulate sky models [Preetham et al. 1999], current techniques have not been able to record an outdoor environment that includes a directly visible sun, which is an important type of environment to capture.

There are two principal challenges in capturing the full dynamic range of outdoor illumination. The first is the breadth of the range - the sun can be well over five orders of magnitude (or seventeen stops) brighter than the sky and clouds, which is a greater range than can be covered with typically available shutter speeds. The second is the absolute intensity of the sun, which is much brighter than what cameras are designed to capture.

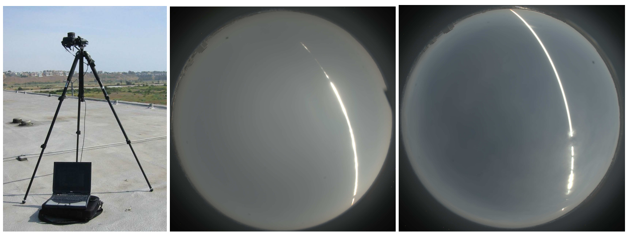
The entire 180° hemisphere of the sky can be imaged by setting up a Canon DOS 1DS camera pointing up, equipped with a 8mm Sigma fisheye lens, as seen in Figure 3. A library provided by Canon [Can 2004] allowed us to control the camera from a laptop, while downloading the images to the laptop's disk. We developed a program to adjust not only the shutter speed, but also the aperture, to span the dynamic range of the sky. Over the course of the day, sky brightness can change drastically with sun position and weather. The camera control is designed to analyze images as they are downloaded to determine the necessary camera settings for the HDR sequence of images.

A typical image sequence, detailed in Figure 1, required approximately 50 seconds to acquire and download. The addition of a 3.0 neutral density (ND) filter to the lens reduces the amount of light passing through by a factor of 1000. This ND filter allows us to directly capture the sun's intensity, but caused a chromatic shift which had to be corrected. This correction was accomplished by imaging a Macbeth color chart through the ND filter.

Figure 2: This is a rendering of the Parthenon with lighting from 7:04am and 4:11pm captured in Marina Del Rey, CA and displays post-processed sun flare.

Captured lighting can be used to render any outdoor scene providing realistic illumination and sky backdrop, as in Figure 2. However due to the extreme contrast between the sun and sky, the standard global illumination algorithms produce a large amount of noise, as they have difficulty sampling the sun sufficiently. We utilize a simple solution, approximating the sun as a directional light, while using traditional sampling techniques for the remainder of the sky.

Using this capture technique we have recorded several days of light under different weather conditions. We believe these HDR images are the first accurate captures of natural illumination in high resolution including a visible sun. These datasets have allowed us to visualize the full dynamic range of natural illumination over the course of the day, as seen in Figure 3. These datasets will be made available on the web: http://www.ict.usc.edu/graphics/SkyProbes/ .



(a) (b) (c)

Figure 3: (a) The capture equipment including a laptop, camera, fisheye lens, and neutral density filter. (b) and (c) are the average of 700 full dynamic range images of the sky taken on February 19, 2004 (b) and February 23, 2004 (c) at one minute intervals over two separate days of light. The sun streak is occluded at times by clouds over the day, and individual clouds are averaged to a constant color.

References

2004. Canon digital camera software developers kit information. http://www.powershot.com/powershot2/customer/developer.html.

DEBEVEC, P. E., AND MALIK, J. 1997. Recovering high dynamic range radiance maps from photographs. In *Proceedings of SIGGRAPH 97*, Computer Graphics Proceedings, Annual Conference Series, 369–378.

PREETHAM, A. J., SHIRLEY, P. S., AND SMITS, B. E. 1999. A practical analytic model for daylight. In *Proceedings of SIGGRAPH 99*, Computer Graphics Proceedings, Annual Conference Series, 91–100.