A Single-Shot Light Probe

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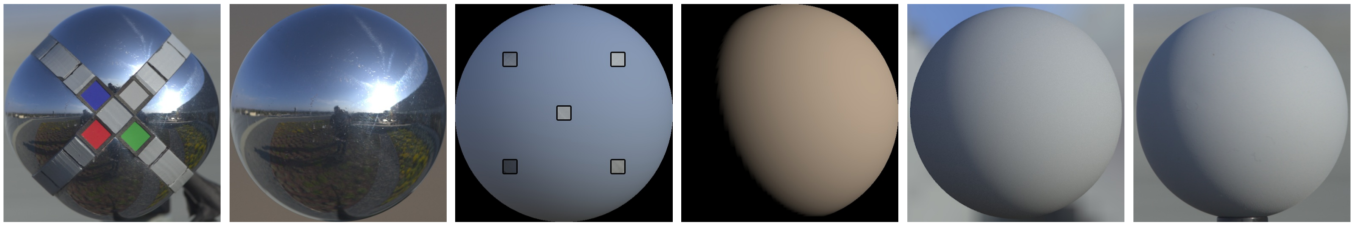


Figure 1: *L-R: (a) Single-shot light probe (b) Reconstituted LDR mirrored ball image (c) Convolved clipped probe with overlaid irradiance samples (d) Computed sunlight (e) Virtual diffuse sphere lit by recovered HDR light (f) For validation, real diffuse sphere in recorded light.*

Abstract We demonstrate a novel light probe which can estimate the full dynamic range of a scene with multiple bright light sources. It places diffuse strips between mirrored spherical quadrants, effectively co-locating diffuse and mirrored probes to record the full dynamic range of illumination in a single exposure. From this image, we estimate the intensity of multiple saturated light sources by solving a linear system.

Introduction Recording on-set illumination to render virtual objects into a real scene is often accomplished by acquiring a panoramic, high-dynamic range (HDR) image where the object is to be inserted, and to use this HDRI map as an image-based lighting source on the CG object [Debevec 1998]. The spherical panorama can be obtained by stitching HDR fisheye images from different directions, or more rapidly by photographing a mirrored sphere.

Shooting HDR is necessary to capture light sources – they typically exceed ambient light by several orders of magnitude – but it requires recording, aligning, and assembling a range of exposures which can be time-consuming and complicates dynamic capture. [Reinhard et al. 2005] showed that if there is just one bright light in the scene, its intensity can be determined from an image of a diffuse gray ball, with the remaining illumination imaged accurately in the mirrored sphere. Even so, two images are required, and only one saturated light source is estimated. We relieve both restrictions.

Probe Construction We machined four 73mm-diameter hollow chrome spheres (originally, Baoding exercise balls) into segments slightly larger than fourths by making two cuts at right angles, each 53% across the diameter. We mounted them to a cross of intersecting 11.5mm-thick plexiglass sheets, laser cut to support the cross-sectional shape of the quadrants (see Fig. 1(a)). Before mounting, we spray painted the plexiglass with 32% reflective flat gray primer. For color balance, we affixed four color squares – the red, green, blue, and 36% gray squares from a ColorChecker chart – leaving a flat patch of the gray paint between them. Finally, we painted black lines indicating 30° and 60° rotation into grooves in the gray strips.

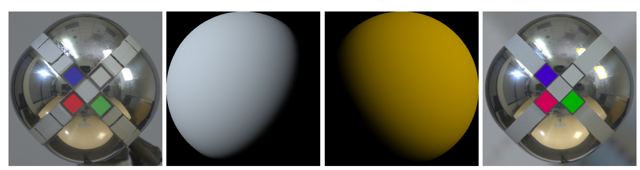
Using the Probe We photographed the probe with a Canon 1D Mark III camera in RAW mode from 1.5m away using a 200mm lens, yielding a near-orthographic image, with the grey strips oriented diagonally to better cover the upward directions. We intentionally underexpose the ambient light by $1\frac{1}{2}$ stops, allowing saturated light sources to appear small enough to note their direction with some precision. We composite the four quadrants into a complete mirrored sphere image, blending across the overlap of the larger-than-90° quadrants.

Gathering Data From the clipped probe P, we determine the unit direction vector ω_i at the center of each saturated light source. We then measure the irradiance B from each of the gray strips at several direction vectors μ_j, including 0°, ±45°, and optionally ±75° away from the frontal direction along each strip. We compute the diffuse Lambertian convolution D of P at the these same directions μ_j.

Solving for Clipped Lights If no light sources clip, then D should equal B for all samples μ_j. We solve for which light source intensities α_i, when added to the clipped light from the environment, explain the irradiance samples $B(\mu_j)$. The irradiance $L_i(\mu_j)$ from a unit-intensity light i in direction ω_i onto the probe at direction μ_j is the positive-clamped cosine between these angles $L_i(\mu_j) = \max(\omega_i \cdot \mu_j, 0)$. Thus:

$$\forall j, D(\mu_j) + \sum_i \alpha_i L_i(\mu_j) = B(\mu_j)$$

This yields a set of m equations equal to the number of irradiance samples $B(\mu_j)$ with n unknown light intensities α_i. If $m > n$, we can solve for α_i with linear least squares. If not, a regularization term which encourages nearby light sources to have similar intensities is required.



(a) (b) (c) (d)

Figure 2: *L-R: (a) Single-shot probe indoors. (b,c) Solved illumination from left light and right sources (+2 stops). (d) Virtual version of probe lit by recovered light.*

Results Fig. 1 uses the single-shot probe to record sunny outdoor illumination conditions, with the sun as the one saturated light source. The recovered illumination lights both a diffuse sphere and a chrome sphere similarly to how they actually appeared in the environment. Fig. 2 shows studio-like lighting and solves for two saturated light sources of somewhat different colors and intensities. The recovered lighting produces a close match on a virtual version of the single-shot probe. Validation comparisons to full-HDR IBL are provided in the supplemental material

References

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REINHARD, E., HEIDRICH, W., PATTANAIK, S., AND DEBEVEC, P. 2005. Image-based lighting. In *High Dynamic Range Imaging*. Morgan Kauffman, ch. 9, 396–401.