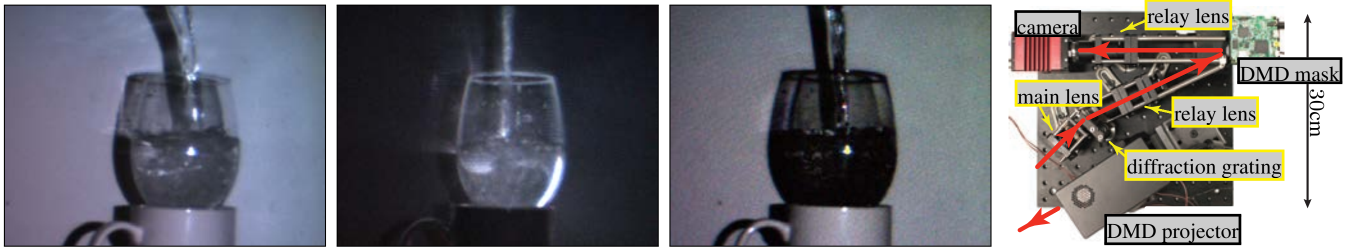
Visualizing Light Transport Phenomena with a Primal-Dual Coding Video Camera

Matthew O'Toole*
University of Toronto

Kiriakos N. Kutulakos*
University of Toronto



(a) conventional image (b) indirect image (c) direct image (d) our primal-dual coding camera

Figure 1: *Water pouring into a clear glass, captured with our primal-dual coding camera.* ***(a)*** *A conventional image of the scene,* ***(b)*** *an indirect-only image, and* ***(c)*** *a direct-only image (the difference between a conventional image and an indirect-only image).* ***(d)*** *Photo of our camera system. The camera consists of a DLP LightCrafter projector, a DMD (digital micromirror device) mask, a Prosilica GT1920 camera sensor, and various optics. The projector and DMD mask display codes at a rate of 2.7 kHz, producing 28 FPS primal-dual coded video.*

1 Overview

We present a primal-dual coding video camera, an optical device that captures video in which the flow of light through a scene has been manipulated. This camera has the ability to visualize indirect transport effects (caustics, inter-reflections, volumetric scattering, *etc.*), measure direct-only light paths (surface reflections), capture transport that occurs within specific regions of 3D space, and perform structured light imaging in the presence of complex indirect effects. The operating principle behind this technology is to simultaneously code the light that goes into a scene with the light that comes out. Specifically, over the course of a single camera exposure period, we project a sequence of light patterns onto the scene in lockstep with a second sequence of mask patterns that modulates the light incident on the camera sensor. This optical procedure creates RAW, unprocessed photos where a scene's light transport function appears to have changed.

2 Primal-Dual Coded Images

We demonstrate three main types of images captured with our primal-dual coding camera: photos that modify the direct and indirect lighting components of a scene, photos that code regions of space according to depth, and photos where only direct light paths transmit structured light patterns.

Modifying direct and indirect lighting Our camera has the ability to attenuate or enhance specific light transport paths, as demonstrated in Figure 1. For example, the direct-only mode visualizes the contribution of light due to surface reflections, whereas the indirect-only mode captures the light that bounces around a scene multiple times before reaching the camera.

*e-mail:{motoole,kyros}@cs.toronto.edu

SIGGRAPH 2014, August 10 – 14, 2014, Vancouver, British Columbia, Canada.

ACM 978-1-4503-2961-3/14/08

Coded regions of 3D space Our camera can selectively illuminate objects according to their position within a scene; objects placed within certain regions of 3D space appear normally to the camera, and objects placed outside these regions appear to receive no illumination. This imaging mode works by blocking light paths having select stereo disparities, which in turn corresponds to blocking light from objects placed at specific locations within a scene.

Indirect-invariant imaging Cameras that capture 3D geometry have widespread applications, from gaming systems to 3D printing. Many of these cameras sense depth by structuring the incident light and processing the direct light paths reflected back to the camera. As a result, these methods typically break down for scenes with complex indirect transport effects.

Our indirect-invariant imaging mode produces images where only the direct light paths preserve the structured light pattern being transmitted through a scene. This imaging mode makes existing structured light 3D sensing techniques robust to indirect lighting.

3 Our Live, Interactive Exhibit

Our prototype primal-dual coding camera (Figure 1(d)) captures conventional, direct, indirect, coded-region, and indirect-invariant images at live frame rates. A laptop controls the camera settings and streams the primal-dual coded video to an external monitor.

We encourage visitor participation by providing a variety of objects with complex transport phenomena to image with our primal-dual coding video camera. Our goal is to provide attendees with a new understanding and appreciation for the intricacies of light transport in real-world scenes.

References

O'Toole, M., Raskar, R., and Kutulakos, K. N. 2012. Primal-dual coding to probe light transport. *ACM Trans. Graph.*.

O'Toole, M., Mather, J., and Kutulakos, K. N. 2014. 3d shape and indirect appearance by structured light transport. *In Proc. CVPR.*