High-Resolution BTF Capture for Delicate Materials

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Bidirectional Texture Functions [1] are data-driven appearance models that can accurately reproduce the visual appearance of real-world materials. Practically, BTFs are stored as a stack of 2-dimensional textures that describe a material's appearance at a given set of light and view directions. A typical BTF dataset contains up to tens of thousands of light-view combinations, for hundred thousands of texels. Different BTF measurement setups have been proposed, ranging from camera arrays [5] to mirror-based or kaleidoscopic systems [4], balancing hardware, acquisition time, computation and storage costs in different ways. We present a custom system with unique properties, developed for a commercial project.

Figure 1: Left: Our BTF capture system. Right: Sample holder.

Overview Our gonioreflectometer (Figure 1) consists of two computer-controlled arms that respectively carry a camera and a light source, and travel on a circular rail around a flat platform. Conceptually, the design is closest to the Stanford Spherical Gantry [3]. Via inclination of the arms, the camera and light effectively reach any position on the hemisphere above the platform, down to 5 degrees elevation above the sample holder's plane. Camera and light are pointed at the sample holder which rests in the centre of the platform. The system is designed to scan flat 10×10 cm material samples that the sample frame holds down. We use a Canon EOS 5DS R 50-megapixel camera along with a Canon EF 100mm $f/2.8$L lens, at 902 mm from the sample center. A Smart Vision SXA30-WHI LED light source delivers an even illumination over the sample and a balanced light spectrum. It travels on a slightly narrower hemisphere (757 mm radius) to avoid collisions with the camera arm, and should be kept at least at 5 degrees arc distance to avoid occluding the view. The entire system is located on vibration-isolating mounts in a dark room, and building materials are chosen such as to minimize stray light reflections.

Design Decisions Many BTF scanner designs simplify construction and reduce mechanical load by rotating the sample itself, already mapping up to 2 degrees of freedom (DoF) of the acquisition in the process. However, our design had to work for delicate soft structures like fabrics, that would change under gravitational influence. Accordingly, we accepted the overhead of mapping all four DoF to the articulation of camera and light source arms. Similarly, anticipating sharply varying reflectance lobes, our design forgoes a fixed grid of cameras or lights (a common strategy to accelerate capture times) in favor of both remaining freely positionable. We keep this overhead minimal by using very rigid but light-weight robotic arms on harmonic drives, allowing fast, jerk-limited motion. This eliminates waiting times for vibrations to subside, and allows new positions to be reached while the previous image is still downloading.

Acquisition At every combination of light/camera position, the system takes one image with programmable, diffuse ceiling lighting, one measurement with the LED and optionally one measurement in the dark, for situations where stray light might be expected. The last two are high-dynamic-range exposure stacks. BTF datasets at an angular resolution of 40×40 view/light direction combinations take around 11 hours to acquire. Pixel resolution reaches up to 37 μm at orthogonal views.

Data Processing Pipeline Processing raw BTF data involves many calibration and rectification steps. We first compensate camera intrinsics, then detect the positions of the green target disks in the image (Figure 2) to estimate the camera pose. The ceiling lighting is turned on to ensure full illumination and visibility of the targets, every time the camera position changes. The estimated perspective transformation is reversed to unwarp all the views into the same square grid. Furthermore, as most samples are not perfectly flat, we perform an additional parallax compensation step: The diffusely illuminated images are used to reconstruct a surface height field via a multi-view stereo algorithm. Even though materials like fabrics do not necessarily have a well defined surface, this is a useful geometry proxy to reduce misalignment in the unwarped grid.

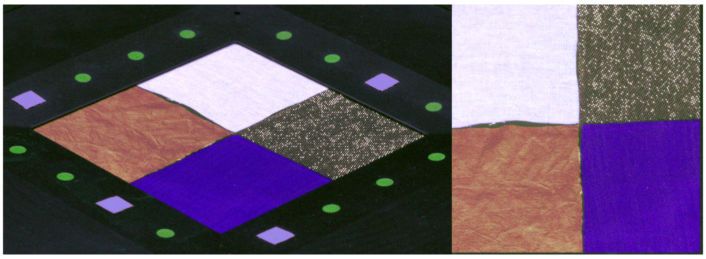

Figure 2: Left: Unprocessed image. Right: Extracted rectified texture.

After black-image subtraction, the HDR exposure stack is merged into a high-dynamic-range image. Prior measurements of a Spectralon ™ target and a color checker are used to determine the absolute intensity of incoming radiance, and a color homography matrix. This allows for radiometric and colorimetric calibration of the data.

Compression & Rendering The data processing cuts the size by a factor of a thousand (raw data in the order of terabytes), but the uncompressed BTF datasets still take up too much storage for practical rendering. We use our compression scheme [2] to further reduce the size to the order of one megabyte. We render directly from the compressed representation, with parallax mapping to reverse the height field compensation.

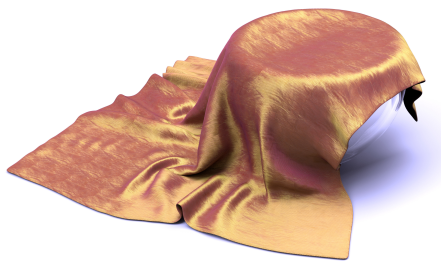

Figure 3: Full rendering in Mitsuba with our BTF plugin.

Future Work Currently, the main limitation of the capture system is acquisition time. Due to the relatively low illumination provided by the LED, the shutter times of the HDR stack are quite long, even after increasing the ISO. A stronger light source would allow quicker measurements and hence a denser sampling of the light and view hemispheres.

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