Improved Linear Light Source Material Reflectance Scanning

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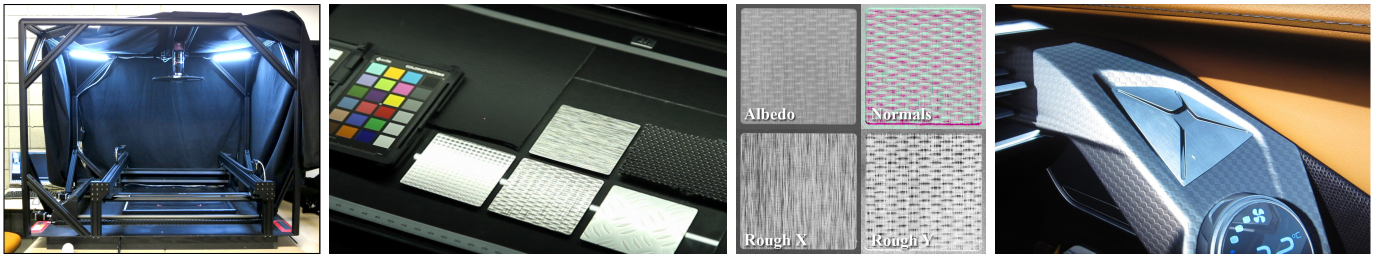

Figure 1: *Left to Right: (a) Scanner (b) Materials being scanned (c) Anisotropic specular parameters (d) Rendering with measured materials.*

Abstract We improve the resolution, accuracy, and efficiency of Linear Light Source (LLS) Reflectometry with several acquisition setup and data processing improvements, allowing spatially-varying reflectance parameters of complex materials to be recorded with unprecedented accuracy and efficiency.

Introduction Measuring the reflectance of spatially-varying materials is a topic of great interest in the graphics industry; however, no commercially available instrument measures spatially varying reflectance parameters for a wide range of materials in a way which is high resolution, efficient, and accurate. The basic problem is that moving a light to thousands of incident angles is extremely time consuming, and still typically fails to record highly specular materials accurately.

This problem can be alleviated using linear light sources [Gardner et al. 2003]: instead of moving a point light source to thousands of positions, a linear light source (LLS) is passed across the sample at a few different orientations and per-pixel reflectance is inferred from the resulting reflectance traces using a reflectance model.

Our new measurement setup (Fig. 1a) yields high-quality results for anything ranging from Lambertian to sharp specular materials. Unlike [Ren et al. 2011], which aims at quick measurements using a mobile device, the quality of measurements does not depend on the existence of a reference material database or the skill of the operator. In addition, our device also handles anisotropic materials successfully.

Scanner Design A significant limitation of previous LLS approaches is that the camera observes the sample at an oblique angle of approximately 45°. This keeps the light source from occluding sample points when the light is directly above, and separates the position of the diffuse and specular peaks so that they can be modeled independently. This limits resolution due to foreshortening and since the sample will likely extend beyond a high-resolution imaging system's limited depth of field.

We instead place the camera 1m directly above the material, observing the 30cm $\times$ 20cm sample region with an 11 megapixel Prosilica GE4000C camera with a 105mm lens. As expected, the LLS lights 10cm above the sample occlude the sample just as the LLS passes above it, obscuring important normal reflectance angles. We solve this by illuminating the sample from these lighting angles via a second, *virtual* LLS, constrcuted by aiming an LLS into the underside of a strip of half-silvered glass mounted at approximately 45°. The light reflects down to the sample and back up through the glass to the camera, yielding a light whose illumination is visible even though the lamp itself is unseen. Although the angular coverage of the virtual LLS is limited, it more than covers the angles blocked by the *direct* LLS, so all incident angles are covered.

With the camera looking straight down, the peaks of the specular and diffuse lobes become largely coincident, which makes diffuse and specular reflections challenging to separate and model independently. We place a strip of polarizing filter gel over each LLS, and a filter wheel in front of the camera so that polarization difference imaging can separate the diffuse and specular components from two passes of each light source. In total, the scanner has four linear light sources: a pair of virtual and direct LLS's to scan in both the horizontal and vertical directions. The camera records at 5fps and moves 3mm (the width of each LED light strip) per captured image, completing a scan in 20 minutes.

Data Processing As the lights pass over the sample, each sample point produces a *reflectance trace* of pixel values. We composite the unoccluded regions from the direct and virtual LLS traces together, and compute a specular-only trace by subtracting the cross-polarized diffuse-only trace from the parallel-polarized trace. We use Knuth's online algorithm to efficiently compute the sum, mean, and standard deviation of the reflectance lobe in each trace, yielding estimates of the albedo, surface normal, and specular roughness of each material point for both the diffuse and specular components. For rendering, these parameters are used to drive the Ashikhmin-Shirley reflectance model.

Results Fig. 1 shows several brushed and stamped metal samples being scanned, their recovered anisotropic reflectance parameter maps, and a real-time rendering of a car interior using several of the materials. Other examples appear in the supplemental material.

Acknowledgements We thank Ludwig Fuchs, Peter Roehner, Jeroen Snepvangers, Muybridge Digital Imaging, Happy Digital, Marco Tan, Danny Tierry, Andrea Gunschera, and Conny Denk for their contributions and support. Contact: **Jan.Meseth@rtt.ag**

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SIGGRAPH 2012, Los Angeles, California, August 5 – 9, 2012.
ISBN 978-1-4503-1435-0/12/0008