Refractive Index Dependent Bidirectional Scattering Distribution Functions

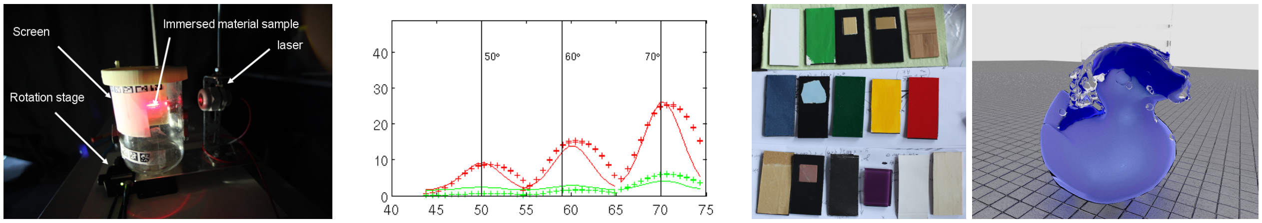

Figure 1: *We investigate on the reflectance of materials immersed into media of different refractive indices. We therefore use a capturing setup (left image), to place patches into different salt solutions representing different refractive indices. As a laser rotates around the patch, we take multiple pictures of the screen attached to cylinder. In the evaluation step, we fit a new physics-based BRDF model with a variable for the sampled refractive indices to the data (middle left image). A depiction of the complete material set is shown in (middle right image). Using the fitted parameters we can generate synthetic scenes showcasing surfaces exposed to water (right image).*

Abstract

We investigate the effect of immersing real-world materials into media of different refractive indices. We show, only some materials follow the Fresnel-governed behaviour. In reality, many materials exhibit unexpected effects such as stronger localized highlights or a significant increase in the glossy reflection due to microgeometry. We introduce a new setup to capture the refletance properties of immersed materials. Further, we built up a BRDF database of immersed materials using the introduced setup. In ongoing work we have shown Fresnel-governed behavior for a subclass of materials. Still, the captured results leave space for further investigations.

Keywords: image-based rendering, data acquisition

1 Motivation

A familiar effect in everyday life is that objects change their appearance when immersed in water or other substances with refractive indices different from air. This refractive index dependence of bidirectional reflectance distribution functions (BRDFs) has so far been mostly ignored. Implicitly it is assumed to be governed by the Fresnel equations via the refractive index dependence of the Fresnel reflection and transmission factors. We analyze the dependence of current physics-based BRDF models on the refractive index of the immersing medium. In particular, we show that the Fresnel term is the governing factor in those models.

2 Our approach

Capturing setup Our setup is shown in Fig. 1 (left image). Each material sample is immersed in a medium with a refractive index different from air. The cylinder contains the medium and the sample. A laser, mounted on a rotation stage, illuminates the sample from defined angles. Note, that the laser hits the glass cylinder wall orthogonally for all acquisition angles. This eliminates refraction upon entry into the medium, which would occur otherwise. The reflected light hits a screen which is attached directly to the cylinder wall and is then imaged by a CCD camera. The system is calibrated using fiducidal markers [Snavely et al. 2006]. The potentially spatially varying transmission properties of the screen are calibrated using a Spectralon patch. This material exhibits almost perfect Lambertian reflectance and a high albedo of $\approx 99\%$.

Preprocessing For each surrounding medium (with varying refractive index) each incident angle is imaged with different exposure times ($\frac{1}{4000}s$, $\frac{1}{1000}s$, $\frac{1}{250}s$, $\frac{1}{250}s$, $\frac{1}{60}s$, $\frac{1}{25}s$, $\frac{1}{4}s$). The images are combined to form a HDR-image. The cylinder geometry is approximated using RANSAC and the HDR-images are backprojected onto the surface of the cylinder. The resulting cylinder surface textures are downsampled to $249 \times 180px$ and used as input for the BRDF-Fitting.

BRDF Fitting We model the Fresnel-governed behavior of the surface patches with the following refractive index-dependent BRDF model, which is similar to [Torrance and Sparrow 1967]:

$$f_r(\omega_i;\omega_o;n_i;n_t) = \rho_d + \rho_s \cdot F_r(n_i;n_t) \cdot \frac{D(\omega_i;\omega_o)\cdot G(\omega_i;\omega_o)}{(4\cdot\omega_i\cdot\omega_o)}\,, \tag{1}$$

where $D(\omega_i;\omega_o)$ is the microfacet distribution and $G(\omega_i;\omega_o)$ is a geometric term (for ω_i the incident angle and ω_o the exitant angle). $F_r(n_i;n_t)$ denotes the Fresnel term with refractive indices for the surrounding medium and the material itself. We fit for the parameters ρ_d, ρ_s, n_i (index of the surrounding medium), n_t (index of the immersed material), Fig. 1 (middle left). The Fitting is based on the Levenberg-Marquardt nonlinear optimization [Madsen et al. 2004].

Results We captured the following classes of materials: Acrylic paint, aluminum, bamboo, ceramics, cloth, oil paint, plastic, sandpaper, stone, Teflon and wood. We found that bamboo, cloth, plastic, sandpaper and ceramics show the Fresnel-governed behavior and thus could be fitted with our proposed model. We compared the fitting results to the captured data, using the PBRT renderer.A typical result for cloth spilled with water of refractive index 1.33 is shown in Fig. 1 (right). Detailed results can be found in the supplementary material. However, this is still ongoin work and the captured data for the other materials are interesting and leave space for further investigations.

References

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