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Gaze Analysis of BRDF Distortions

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Abstract

BRDFs are currently used as a standard representation of material surface reflectance properties either in the from of tabulated measurements or a parametric model. However, the compression of tabulated representations as well as their fitting into such a parametric model typically introduces some visual degradations. We describe our analysis of the human gaze behavior in two types of standard visual experiments, where the common task is to compare a pair of BRDFs. The analysis was carried out across six different isotropic/anisotropic materials and three application-relevant BRDF degradation models.

1. Introduction

Understanding of human perception of materials requires to develop and use suitable rendering methods that convey material appearance with high fidelity. This paper analyses human subjects' ability to recognize small differences between original and distorted BRDFs. The original BRDF comes from the measurement and distorted BRDF is obtained by fitting of parametric BRDF models. We performed our tests across three isotropic and three anisotropic BRDFs. The subjects were asked to evaluate the differences between a pair of BRDFs and at the same time the corresponding eye-fixations have been recorded.

2. RelatedWork

In the past visual psychophysics put great effort in understanding a way people perceive and assess objects of different reflectance properties under specific illumination conditions. [Fle14, CK15]. A psychophysical analysis of bidirectional reflectance distribution functions (BRDF) dependently on different shapes and illumination environments was performed in [VLD07, RFWB07, KFB10, Fil15]. Also human gaze analysis has been widely used in many applications [Duc02] such as visual search [OHVE07], web-site usability [NP09], predicting of fixations in computer games [SSWR08], assessing visual realism of medical scenes [ENC*08], or the quality of BTF resampling [FCH09]. Eye-tracking methods have also been used to analyze the way people perceive or recognize simple 3D objects [LRRA09]. A gaze data was employed in the correlation analysis of fixations density for several statistical texture features [FHC10]. The effects of shape and texture on subjects' attention were analyzed [FVH12] identifying relation of the average local variance of a surface shape and texture with observers' gaze attention to both texture and its underlying geometry.

3. Reflectance Distortions Rendering

For visual comparison we used a surface optimized to a high coverage of illumination and viewing angles as proposed by Havran et al. [HFM16]. We rendered such a surface for the optimized light and camera positions. We used six materials from the UTIA BRDF database [FV14] as shown in Fig. 1.

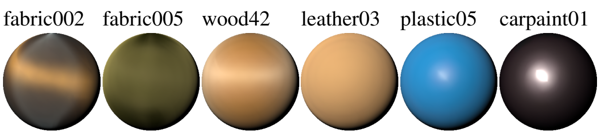

Figure 1: *Tested materials: first three anisotropic, second three isotropic.*

Further, we suggested three degradation filters, which represent typical inaccuracies in BRDF modeling and compression:

1. *smoothing* – filtering of azimuthal directions in BRDF using a box filter,
2. *anisotropic flattening* – a gradual transition between the anisotropic and isotropic appearance [Fil15],
3. *resampling* – down-sampling of the measured azimuthal directions.

See [HFM16] for details on each particular filters implementation.

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4. Psychophysical Study and Eye-Tracking

We investigate two types of psychophysical experiments:

Threshold experiment – As experimental stimuli we have used pairs of rendered static images of size 1920 × 1080 pixels, representing a material BRDF rendered on a surface. The experiment arrangement on the display was so that each pair consisted of the reference and degraded BRDFs as shown in Fig. 4-a. We used five levels of degradation for all distortion types. Pairs of images were displayed simultaneously, side-by-side in a random order. Three different surfaces were used: *sphere*, *blob*, and *surface1*. For each combination of material and distortion type there were six stimuli giving in total 6×(3 anisotropic×2 filters + 3 isotropic×3 filters) = 90 stimuli (note that *anisotropic flattening* applies to anisotropic materials only). The subjects were asked to identify whether there is a visible difference between the two images. The pairwise psychophysical data averaged across all subjects are represented by the psychometric function $\psi(x)$ [WH01], which specifies the relationship between the underlying probability ψ of detecting visual differences and the stimulus intensity.

Thurstonian scaling – As the threshold experiment does not provide us with a precise scaling of larger distortion magnitudes, in another experiment we employed Thurstonian scaling, i.e., measurement of the psychological scale separation between any two stimuli derived from Thurstone's Law of comparative judgment [Thu27]. We used a two-alternative forced choice (2AFC) experiment design with the reference BRDF shown at the display top (see Fig. 4-b). The subjects were asked to indicate which of the two bottom images was visually closer to the reference. As the bottom images can represent any combination of five degradation levels or the reference image, the final number of stimuli would be 5×5=25 per material and filter. This would expand to 25×(3×2+3×3)=375 stimuli. To make the experiment feasible we turned to an incomplete paired comparison design [SF01], and we restrict the comparison to two closest degradation levels, which reduces the number of stimuli to 255 images. To avoid a pixel-wise comparison, the upper reference image is always rendered for a slightly rotated viewing angle (2^o).

General settings – Both experiments have been performed by 13 subjects; all had normal or corrected to normal vision, and were naive about the purposes of the experiment. Each subject used two remote Nintendo Wii controllers to answer the questions (the first controller in one hand, the second controller in another hand), so that they could fully concentrate on the visual task. All stimuli were presented on a calibrated 24" LCD display (60 Hz, resolution 1920 × 1200, peak luminance 120 cd/m^2, 6500 K, gamma 2.2). The experiment has been performed under dim lighting conditions. The participants viewed the screen at a distance of 0.6 m. To acquire subjects' gaze fixation data, we eye-tracked their gaze using GazePoint GP3 eye-tracker. The device was calibrated for each subject individually and provided the location and duration of each fixations at a rate of 50 samples/s. The shortest fixation duration to be recorded was set to 10 ms.

5. Results

Fig. 2 shows the psychometric function from the threshold detection experiment, and JND scaling as a function of the degradation level from the Thurstonian scaling experiment across all subjects and for individual materials. Here we see that specular materials *carpaint01* and *plastic05* are the easiest to analyze by the subjects. The difference between isotropic and anisotropic materials is negligible, therefore we assume that the intensity of the specular highlights is the most important factor driving visual attention.

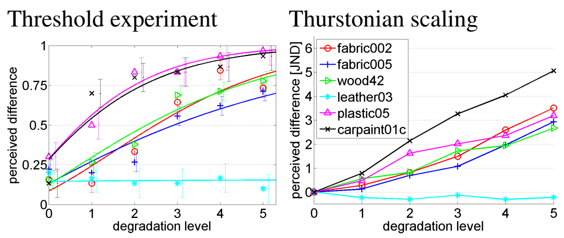

Figure 2: *Results of the threshold experiment (left) and Thurstonian scaling (right) for tested BRDFs.*

The hotspots maps aggregating fixations across all subjects and stimuli images in Fig. 4 reveal that a majority of fixations were focused on the central spherical shape of the surface. The maps overlaid across a single stimulus image are shown for individual materials in Fig. 3. The subjects tend to observe the central part of the shape, presumably as it provides enough information about specular or anisotropic highlights. Also the tangents' singularity at the top of the sphere was likely used for the identification of anisotropic properties of the material.

A typical example of the saccades as captured during subjects' visual search for two different materials is shown in Fig. 5. The red spots size correspond with the fixation duration. We observe that for materials that have distinct visual features like highlights or anisotropy the subjects' fixations focus closely around these features as they appear in the central sphere while scanning all compared images (as shown for material *fabric002* on the left), while for more diffuse materials the search path is more scattered as the subjects consider also other visual features at different locations in stimulus images (as shown for material *leather03* on the left). Note that the visual search task is very individual and not all subjects fit to typical viewing scenario as shown on example of two distinct subjects in Fig. 6. We analyzed also

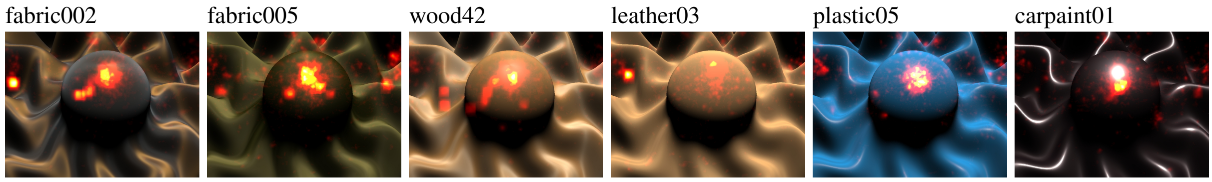

Figure 3: *Hotspots maps for each tested materials averaged across all subjects and overlaid over single stimuli images (threshold experiment).*

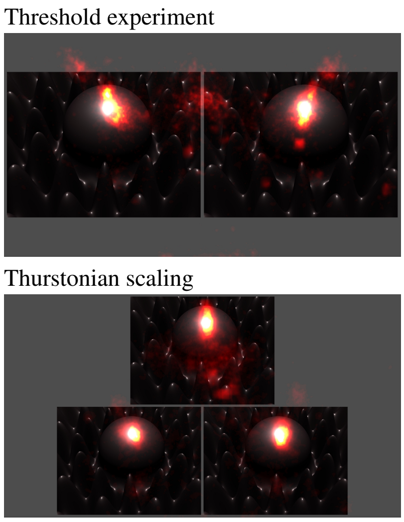

Figure 4: *Hotspots map across all subjects and materials.*

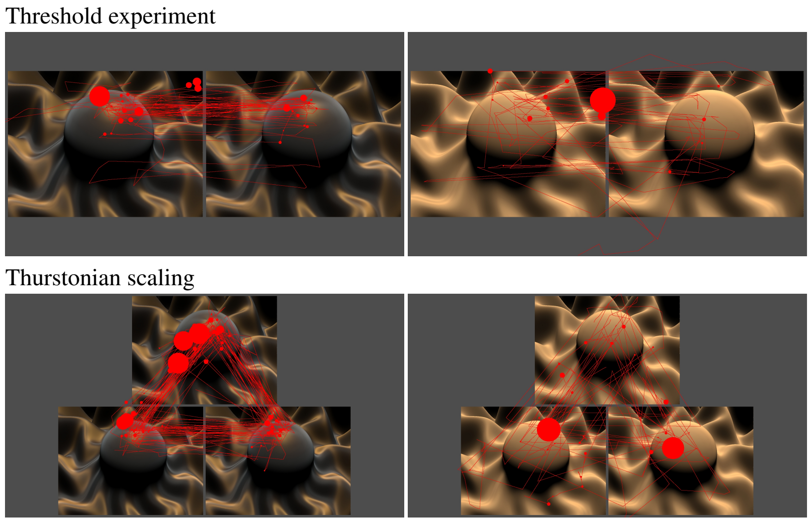

Figure 5: *Examples of psychophysical stimuli with typical eye-tracking pattern for anisotropic/specular materials (left) and isotropic/diffuse materials (right).*

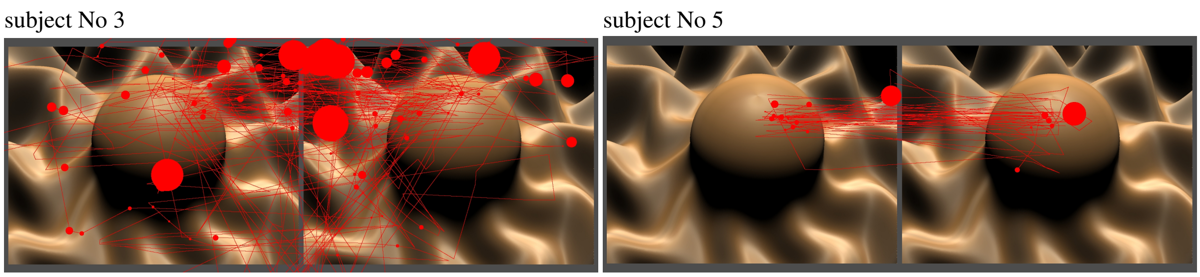

Figure 6: *Example of two subjects' visual search for material* wood42.

the number and duration of fixations for individual materials and filter types aggregated for all observers. While the average duration was very similar, the average number of fixations differs as shown in Fig. 7. We observe that anisotropic materials (the first three) receive in average slightly more fixations that takes longer. One can also see higher spatial variance of fixations for diffuse material *leather*, this is due to missing significant perceptual features, e.g., highlights.

Also the results for individual degradation filters in Fig. 8 suggest that the effects of *resampling* filter (the angular down-sampling) are the most difficult to distinguish as it received the highest count of fixations especially for anisotropic materials. This might be because this filtering is performed in the angular domain of the BRDF, and this translates into smooth spatial patterns which are less apparent, than modification of anisotropic highlight or blurring introduced by the remaining filters.

6. Conclusions

In general we can conclude that the subjects were more successful in finding the differences for specular materials, where they focused on locations near specular highlights. Spotting such differences for diffuse materials was difficult as effects of degradation filters on such materials were negligible. All tested anisotropic materials received similar re-

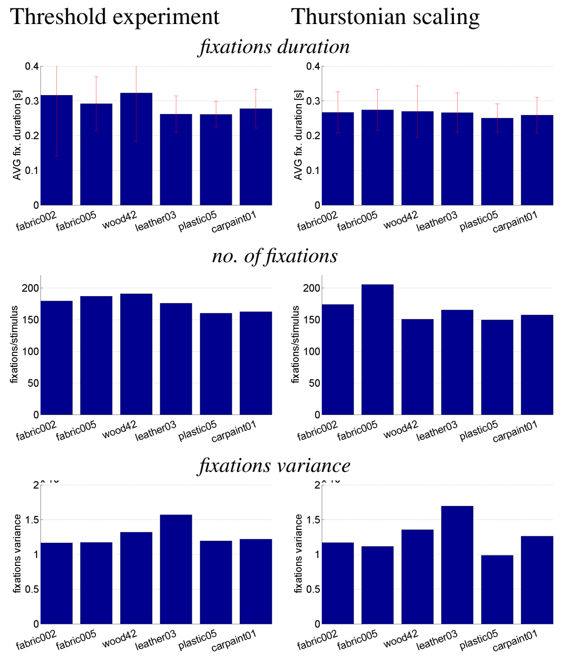

Figure 7: *Fixations statistics for individual materials: the average fixation duration, the number of fixations per stimulus image, and spatial variance of fixations.*

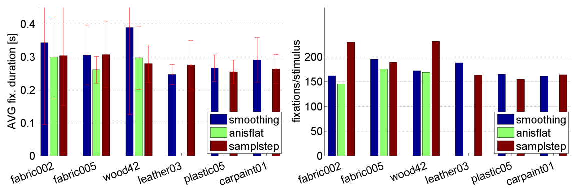

Figure 8: *Fixations statistics for individual materials and degradation types: the average fixation duration (left), and the number fixations per stimulus image (right).*

sponses, however the subjects observed them more carefully with more dense individual visual search trajectories.

Acknowledgment

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