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How Mesoscale and Microscale Roughness Affect Perceived Gloss

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ABSTRACT

We have studied how perceived gloss varies with the change of both mesoscale and microscale roughness on 3D surface textures. The mesoscale roughness was changed by varying the roll-off factor (β) of $1/f^{\beta}$ fractal noise surfaces. The microscale roughness was changed by varying the microscale roughness parameter α in the microfacet reflection model. An HDR real-world environment map was used to provide complex illumination and a physically-based path tracer was used for rendering the stimuli. Each simulated surface was rotated about its vertical axis to generate an animated stimulus. Eight observers took part in a 2AFC experiment, and the results were tested against conjoint measurement models. We found that the perceived gloss changes non-monotonically with β (an asymmetric bell curve), and monotonically with α. Although both β and α significantly affect perceived gloss, the additive model is inadequate to describe their interactive and nonlinear influence, which is at variance with previous results [1].

Keywords

textured surface, perceived gloss, mesoscale roughness, microscale roughness, specular highlight

1. INTRODUCTION

Surface gloss has been studied both physically and psychophysically. Physical measurement of gloss is usually conducted by the aid of gloss meter, where surfaces need to fulfill certain requirements the major one being that they should be perfectly flat and free of relief structures. Real-world surfaces do not normally obey this constraint and often have distinct 3D surface texture (termed here mesoscale-structure). However, the majority of reported psychophysical experiments use smooth surfaces such as spheres. Exceptions to this include Ho et al who have found that higher physical 'bumpiness' of surface mesoscale-structures increases perceived glossiness [1]. In addition Wijntjes and Pont investigated apparent 'illusory' gloss of high surface-height RMS (Root Mean Squared) under the condition of distant and perpendicular lighting and viewing but restricted their studies to Lambertian surfaces [2].

This paper studies the influence of mesoscale roughness and microscale roughness on gloss perception. The former was investigated using a $1/f^{\beta}$ noise mesoscale model. The microscale was modeled using Ashikhmin-Shirley BRDF (Bidirectional Reflectance Distribution Function) [4]. To obtain more natural and realistic stimuli, we rendered the surfaces with a physically-based path tracer and an HDR (High Dynamic Range) environment map as the illumination. Four conjoint measurement models of perceived gloss as a function of mesoscale and microscale roughness levels were investigated.

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2. PSYCHOPHYSICAL EXPERIMENT

2.1 Stimuli

The $1/f^{\beta}$ fractal noise was used to generate surface height maps, which means that the height map has a magnitude spectrum with spatial frequency scaled by roll-off factor β: $H(f)= 1/f^{\beta}$. The phase spectrum was randomized using a uniform $[0, 2\pi]$ distribution. $1/f^{\beta}$ noise surfaces were sampled for 5 levels of mesoscale roughness (β=1.6, 1.8, 2.0, 2.2, 2.4). Cross sections of three surfaces are shown in Figure 4. These surfaces were rendered using LuxRender under an HDR environment map from Debevec's Light Probe Image Gallery [3] (Figure 1). The diffuse and specular component Ashikhmin-Shirley parameters were fixed at k_d=0.4, k_s=0.6, while the microscale roughness parameter α was logarithmically sampled for 5 levels (α=0.02, 0.01, 0.005, 0.0025, 0.00125). The mesoscale and microscale roughness levels used in producing the stimuli was chosen to be lower than that required to exhibit `distinctness of image' (DOI) gloss. To provide observers with improved surface shape perception, each surface was rotated about its vertical axis 25°in 1°steps at 24 frames per second to produce rotating animations. Sample images are shown in Figure 3.

Figure 1. HDR environment map "stpeters" from Debevec's Light Probe Image Gallery [3]

2.2 Procedure

Eight naive observers with normal or corrected to normal vision were paid to participate in a 2AFC (2 Alternatives Forced Choice) experiment. The full combination of the 25 stimuli (five values of α × five values of β) provided 300 pairs of stimuli. The pairs were randomly shown to the observers. In each trial, the order of the two surfaces was randomized with a black image being shown for 0.2s in between stimuli. This was followed by display of another black image until the observer indicated which surface they considered to be glossier. The next pair was then shown immediately. Each pair was presented three times providing each observer with 900 pairs.

3. RESULTS

The pair-wise comparison results from the experiment were used to estimate four conjoint measurement models of gloss: two *independent* models, an *additive* model and a *full* model [1]. The parameters for each of the four models were estimated for each of the eight observers to provide (8×4) parameter sets. These parameter sets were independently nomalised to the range 0-1 before averaging across the eight observers (parameter by parameter) to provide the four parameterized models. The parameters of the model are combination of mesoscale and microscale roughness levels (β and α respectively). The *full* and *additive* models are depicted in Figure 2.

A nested hypothesis test showed that both the mesoscale roughness β and the microscale roughness α have significant influence on perceived gloss when compared the *additive* model with *independent* models.

When comparing *additive* and *full* models, Ho et al. found the former adequately explained the influence of both mesoscale 'bumpiness' and reflection model parameters on perceived gloss for 3 out of 6 observers [1]. The remaining three observers could only be modeled using the full model.

However, for our results, the nested hypothesis test showed that for all eight observers, the *full* model is significantly better ($p<0.01$ at Bonferroni-corrected level) than *additive* model in describing the combined influence of mesoscale and microscale roughness on perceived gloss.

From Figure 2 it can be seen that for both models β provides a non-monotonic contribution (an asymmetric bell curve) to perceived gloss while α shows a monotonic positive contribution. The finding of α is consistent with literature [1] [5].

4. DISCUSSION

We attributed our findings to the combined influence of mesoscale roughness and microscale roughness on specular highlights since the specular highlights are the most important cue for gloss perception on rough surfaces as we eliminated the DOI gloss cue. We note that [6] has shown that the size, brightness (strength), orientation, placement (spread) of highlights and intensity gradient (shading) are the properties that people use to judge surface gloss.

As it has been studied extensively by literature, the microscale roughness affects specular highlights and perceived gloss in a monotonic way. Higher α level produces smaller but stronger specular highlights, contributing to higher perceived gloss. The mesoscale roughness changes surface local curvature and lower β level produces smaller but more specular highlights. Therefore the surfaces with medium β level were perceived glossier. However, surfaces of β level 1 and 2 are very rough that few surface facets can reflect specular reflection to viewing direction. They lose the capability of producing a pattern of specular highlight, and thus were rated least glossy.

The combined influence of mesoscale roughness and microscale roughness on specular highlights brings about the extra information that *additive* model cannot explain. Higher level of α decreases perceived gloss by further shrinking the size of specular highlights on very rough surfaces (in mesoscale). But this can be compensated by higher β level on medium rough surfaces (in mesoscale). This kind of combined influence of α and β on properties of specular highlights well explains our experiment results and the superiority of *full* model to *additive* model.

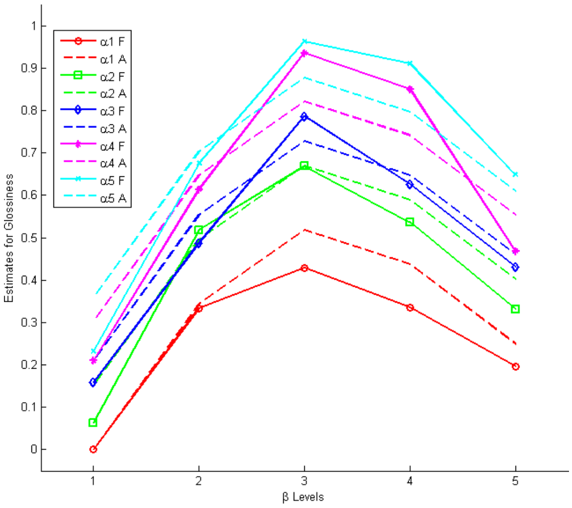

Figure 2. Full and additive conjoint measurement models. Full model is shown by the five solid plots while the additive model is shown by the dashed plots.

5. REFERENCES

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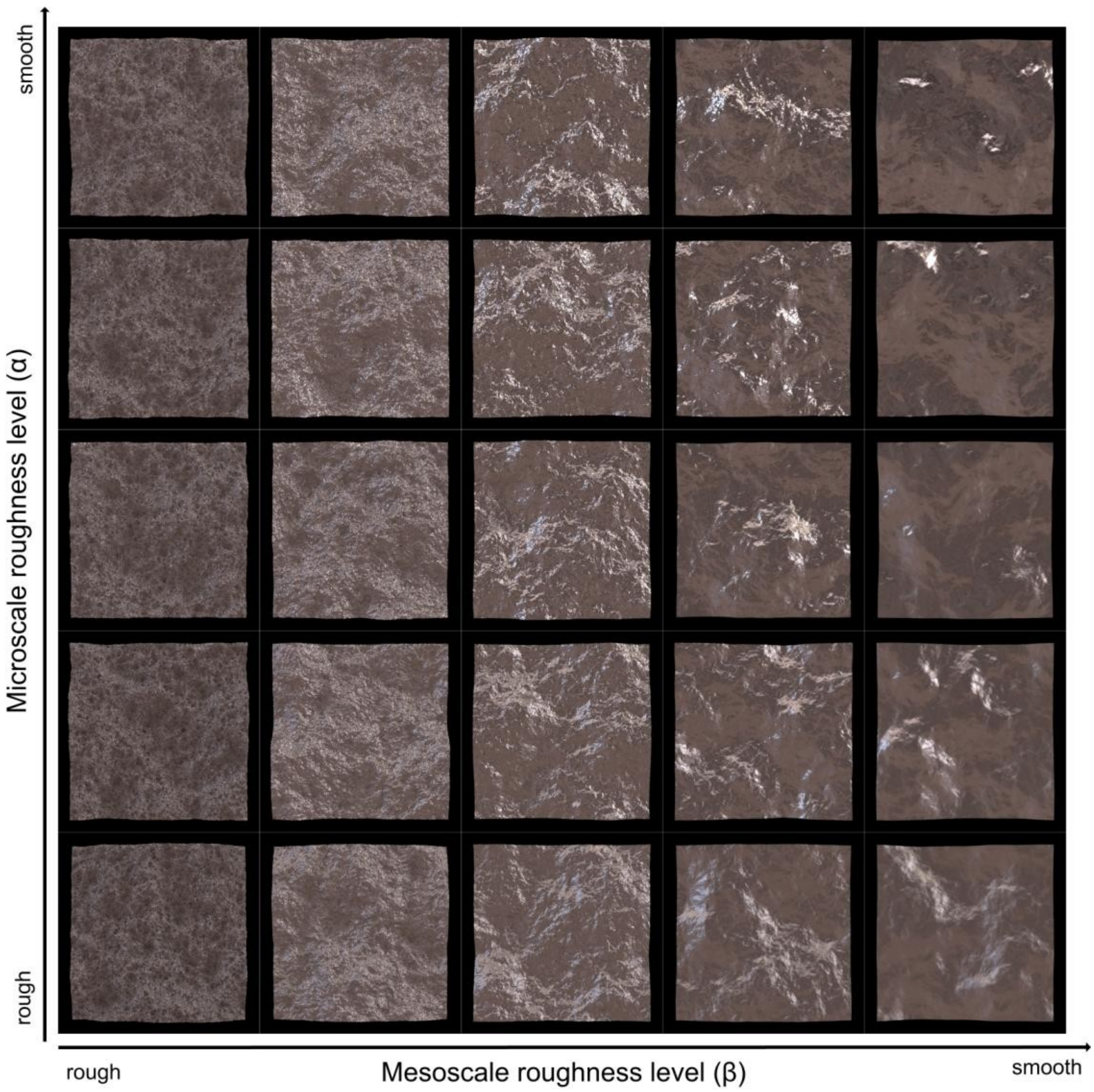

Figure 3 Sample images of the stimuli. The central image of each animation stimuli (slant 0°) is shown. The x-axis denotes the mesoscale roughness level and the y-axis denotes the microscale roughness level. These images have been adjusted by a nonlinear gamma for ordinary display.

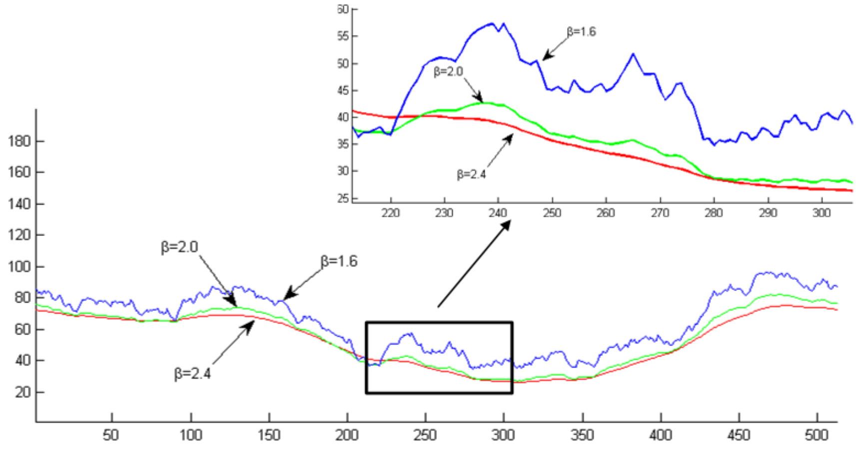

Figure 4 The cross sections of three surface height maps with β sampled at the level 1, 3, 5 in this study (β=1.6, 2.0, 2.4) with a zooming-in for a part. The surfaces were generated using an identical random phase spectrum for clarity.