DTU Compute
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Embedded Information in Surfaces

Utilizing Engineered Surface Microstructure

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1. Introduction

Tracking of products during their entire lifetime from production to end-of-use is a widespread challenge. The typical approach is to label the product, but for some products this is not desirable nor possible. An alternative to labelling the product is to *embed information directly into the product surface* – that is what we are trying to accomplish in the best way possible.

One way of embedding information into surfaces is to control the reflection of light by modifying microscopic surface features also called microfacets as described by A. Luongo et al. [1]. By controlling these microfacets it is possible to create an anisotropic effect with high contrast between the same surface features only altered by their rotation. This allows a binary pattern (dark and bright) to be recognized by e.g. a camera and thereby effectively offers a means to embed information into a surface.

Figure 1 shows a surface structure outline (based on ridges) capable of reflecting light in an anisotropic manner. Figure 2 shows an image of a produced sample with the same ridge structure.

Finding the optimal way to embed information can be done by simulation of different ridge outlines in combination with Image Synthesis using a model such as the microfacet model by Torrance-Sparrow [2] (see also Equation 1).

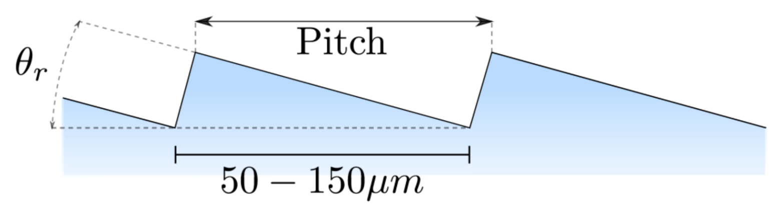

Figure 1: Theoretical outline of Ridges

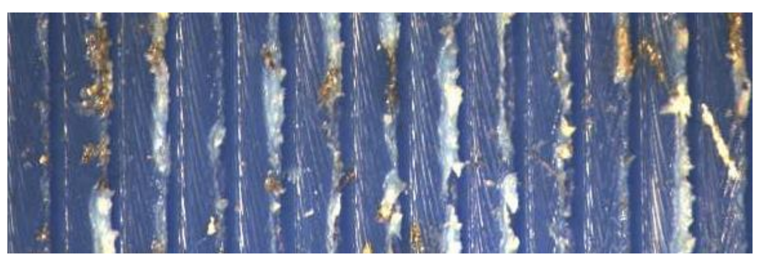

Figure 2: Top-down microscope image of ridges (650 nm)

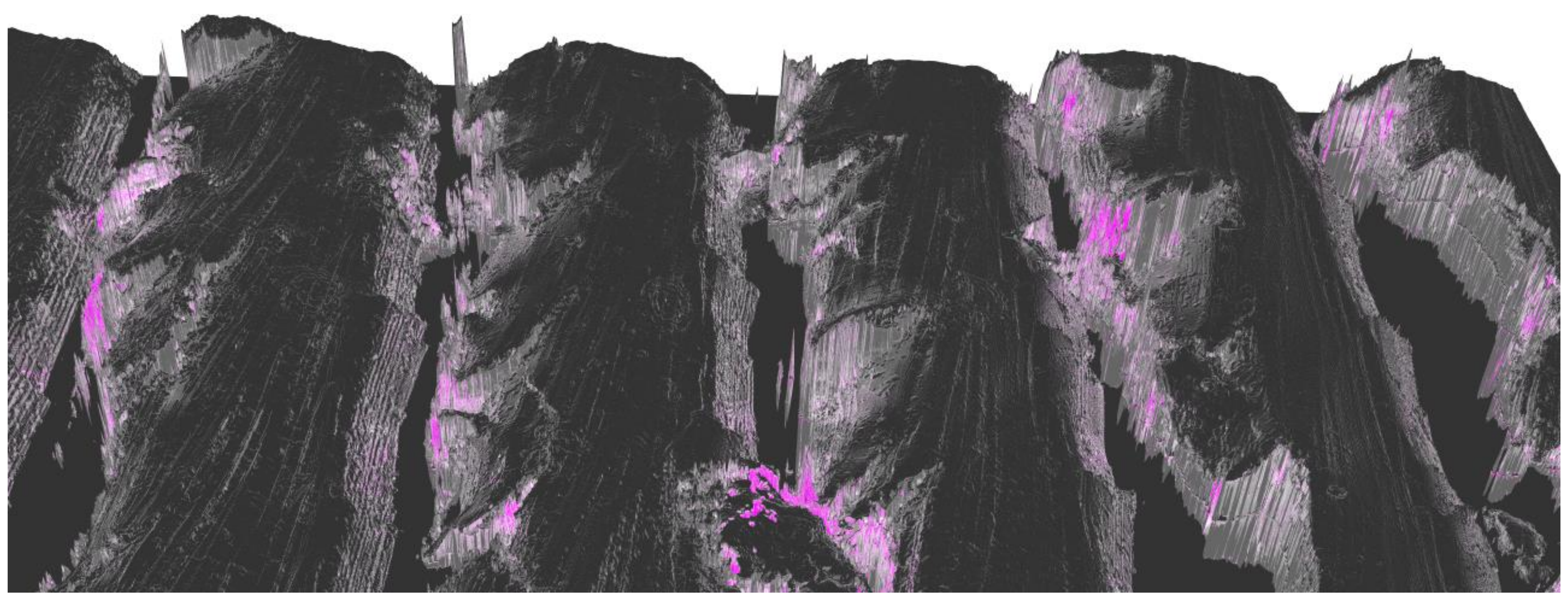

Figure 3: 3D visualization of engineered surface geometry based on data from a scanning electron microscope (SEM)

$$f_r(\mathbf{x}, \vec{\omega}_i, \vec{\omega}_o) = \frac{FGD}{4(\vec{n} \cdot \vec{\omega}_i)(\vec{n} \cdot \vec{\omega}_o)} = \frac{FGD}{4 \cos\theta_i \cos\theta_o}$$

Equation 1: Torrance and Sparrow BRDF model [1967].

$$L_N(\mathbf{x}, \vec{\omega}) = L_e(\mathbf{x}, \vec{\omega}) + \frac{1}{N} \sum_{j=1}^{N} \frac{f_r(\mathbf{x}, \vec{\omega}'_j, \vec{\omega}) L_i(\mathbf{x}, \vec{\omega}'_j) \cos\theta}{\mathrm{pdf}(\vec{\omega}'_j)}$$

Equation 2: Monte Carlo estimator of the rendering equation.

2. Simulation and Image Synthesis

Figure 3 shows a visualization of an engineered surface based on a heightmap obtained from an electron microscope. The heightmap is used as a baseline input to an algorithm generating a replica of the surface with high geometric detail.

We use this virtual replica to construct a dataset which holds information on how light is reflected based on directions to both light-sources and viewing direction. This dataset directly correlates to the masking effect (G) (Equation 1).

The dataset can be used for rendering an arbitrary surface. E.g. with a ray tracer engine utilizing the Monte Carlo estimator (Equation 2). Figure 4 shows a synthesized image using the dataset in our rendering pipeline visualized in Figure 5.

Figure 4: Synthesized image using the simulated dataset

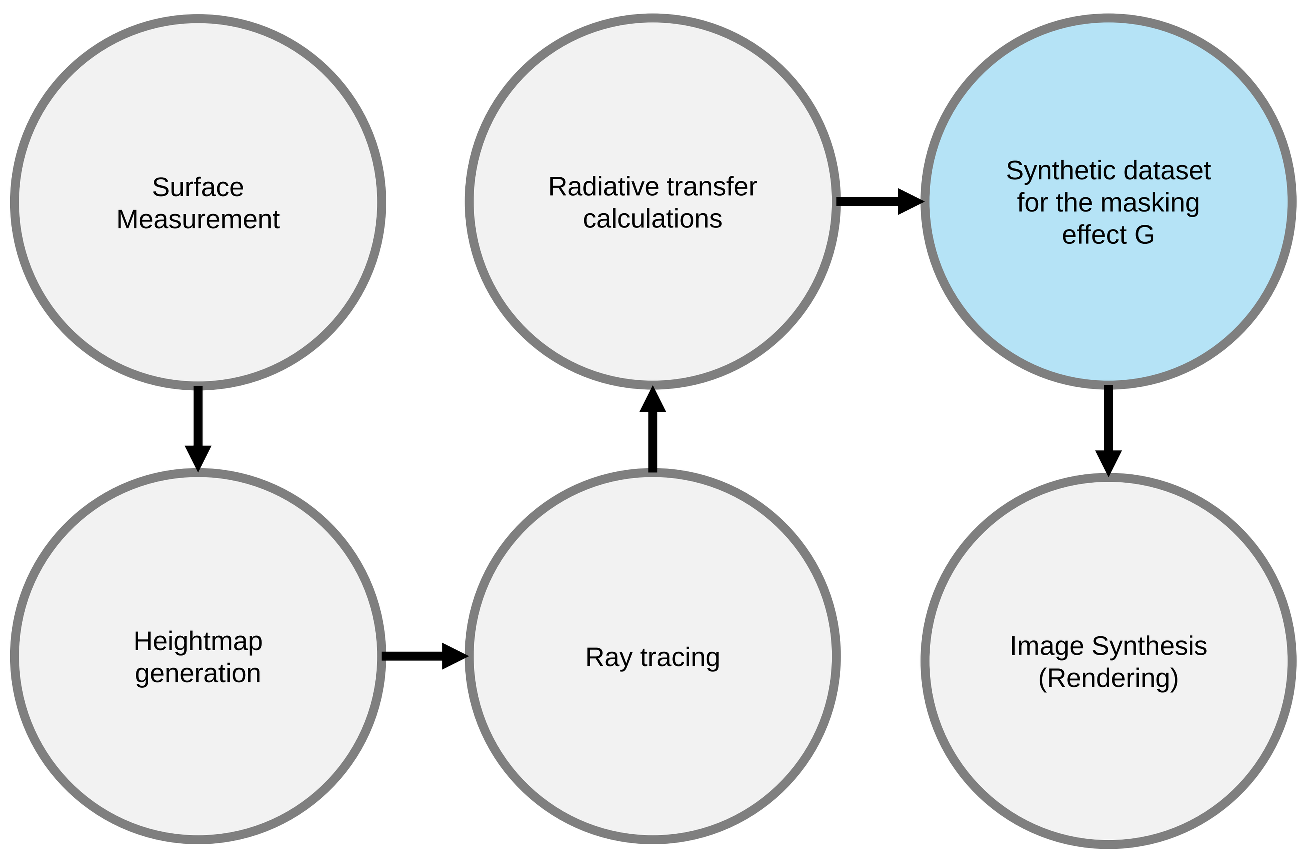

Figure 5: Simulation pipeline

Future work

As Figure 4 shows, we are capable of combining simulated geometric detail which in combination with the Torrance and Sparrow BRDF model is capable of simulating high spatially varying contrast. This effectively provides the ability to investigate, simulate and ultimately find which optimal micro structures to use when embedding information into surfaces.

References

[1] A. Luongo et al., "Modeling the Anisotropic Reflectance of a Surface with Microstructure Engineered to Obtain Visible Contrast After Rotation," 2017 IEEE International Conference on Computer Vision Workshops (ICCVW), Venice, 2017, pp. 159-165. ICCVW.2017.27

[2] Torrance, K. E., and Sparrow, E. M. Theory of off-specular reflection from roughened surfaces. Journal of the Optical Society of America 57(9), pp. 1105-1114, September 1967.