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Rendering diffraction Phenomena on rough surfaces in Virtual Reality

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ABSTRACT

Wave-optical phenomena, such as diffraction, significantly impact the visual appearance of surfaces. Despite their importance, wave-optical reflection models are rare and computationally expensive. Recently, we presented a real-time model that accounts for diffraction-induced color shifts and speckle. Given that diffraction phenomena are highly dependent on illumination and viewing directions, as well as stereoscopic vision, we developed a VR demo to evaluate the new model. This demo shows the substantial impact of diffraction on the appearance of rough surfaces, particularly in stereoscopic viewing.

CCS CONCEPTS

• **Computing methodologies → Reflectance modeling**.

KEYWORDS

Virtual Reality, Predictive Rendering, Diffraction, Modeling

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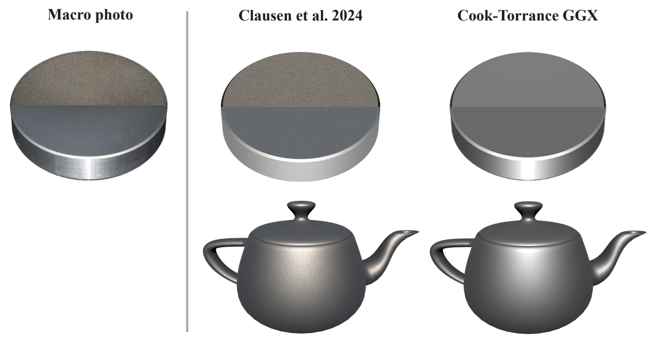

Figure 1: Upper row: Comparison of our model including diffraction phenomena and the Cook-Torrance model against macrophotos of a rough aluminum sample. Lower row: The teapot renderings demonstrate the huge impact of diffraction on the visual appearance.

1 INTRODUCTION

Virtual Reality (VR) systems, such as head-mounted displays (HMDs), offer significantly higher immersion compared to conventional monitors due to their larger Field of View (FOV), stereoscopic display, and interactivity. However, this heightened immersion often comes at the expense of render quality. To achieve the required high resolution and framerates, light simulation is typically simplified. Reflection models based on geometric optics are used, which assume light transport along rays and, thereby, neglect the wave characteristics of light. Nevertheless, wave-optical phenomena, such as diffraction, have a substantial impact on the visual appearance of rough surfaces, particularly under stereoscopic viewing [3].

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Recent advancements in reflection models have enabled the simulation of wave-optical phenomena occurring on rough surfaces [6–8, 10]. However, due to the computational cost, these models are not yet considered in VR applications. This omission results in a synthetic appearance of rough surfaces, as illustrated in Figure 1. Rendering rough aluminum samples using the popular Cook-Torrance GGX model [5, 9] fails to resemble reality accurately. In the macrophotos on the left, we observe color shifts leading to reddish and bluish appearances in forward- and backscattering, as well as speckle patterns. In previous works [2, 4], we developed a real-time model that closely approximates these phenomena, clearly improving realism as shown in the middle. However, since both phenomena are highly dependent on illumination and viewing angle, as well as stereoscopic vision, the quality of the diffraction model cannot be adequately evaluated on a conventional monitor.

To address this, we integrated the model into a popular game engine, enabling VR applications. We provide a VR demo that allows for further evaluation of the dynamic behavior of color shifts and, particularly, speckle patterns. This integration facilitates a more comprehensive assessment of the model's degree of realism.

2 DIFFRACTION MODEL

Our diffraction model extends the Cook-Torrance model by incorporating a shift function that approximates color shifts. The speckle patterns are modeled using a 4D simplex-noise function, with their distribution calculated by a multivariate distribution function.

Figure 2: Screenshot of VR demo.

An important material quality for stereoscopically viewed surfaces, such as those in VR, is highlight disparity [1]. Highlight disparity describes the difference in binocular disparities between a specular reflection and the underlying reflective surface. It enhances the realism of a material by strengthening its specular appearance. Although the diffraction pattern is not a specular reflection as defined by geometric optics, it exhibits highlight disparity. This can be observed on surfaces with a diffraction pattern, where the pattern requires a different eye convergence angle than the underlying surface.

Rendering small-scale effects, such as the proposed speckle pattern, involves managing minification. While the speckle pattern is clearly visible during close interactions, it can be problematic at greater viewing distances. When multiple speckles fall within the footprint of a single screen pixel, the diffraction pattern becomes a source of aliasing. To address this issue, we leverage the fact that the simplex distribution has a mean of zero and is superimposed on the shift value. As the number of speckles per pixel increases, the noise amplitude is reduced toward zero, causing the diffraction pattern to converge to the shift value. To prevent aliasing during this convergence, we also employ multi-sampling on the noise distribution.

3 VR-DEMO

To evaluate our diffraction model, we integrated it into the Unity game engine. As shown in Figure 2, we created a VR demo featuring a simple museum scene with four podiums, each displaying different exhibits illuminated by a central point light source on the ceiling.

The first podium features two knot objects: one rendered using our diffraction model and the other using the original Cook-Torrance GGX model. The curved and simple geometry of these objects allows for a clear assessment and comparison of the diffraction phenomena. The second podium displays two vases: one rendered with highlight disparity and the other without. This setup allows participants to easily compare the influence of highlight disparity on the visual appearance of rough surfaces. The third podium showcases two horse sculptures with more complex geometries. Despite the intricate details, the diffraction phenomena remain clearly visible on these objects. The final podium features three conic sculptures, all rendered using the diffraction model but with varying levels of roughness. The parameters for these models are derived from measured data, allowing for an accurate representation of different surface textures.

Since it is difficult to evaluate the dynamic speckle behavior during head movement, the participant can grab all exhibits with the controller and manipulate them freely in space thus continuously changing the illumination and viewing angle.

4 CONCLUSION

We provide a VR demo highlighting the importance of diffraction phenomena for realistic rendering. This demo enables participants to interactively examine diffraction effects on rough surfaces and compare them to renderings using the geometric optics-based Cook-Torrance model.

Acknowledgements

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