Physics-based Rendering of Irregular Planetary Bodies for Sensor Modeling

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Introduction

This work intends to develop a tool for physically-based renderings (*PBR*) using high fidelity models such as the Hapke model. For this purpose, Blender's Cycles **ray tracing rendering engine** has been used [5], and the custom shaders have been implemented in Open Shading Language (OSL), a shading language developed by Sony Pictures Imageworks, [4].

Why PBR?

Accurate prediction or estimation of the lighting conditions on the surface of planetary and small bodies is crucial for **mission planning purposes** and for **autonomy perception simulations**. Physically-based techniques strive to simulate reality by using principles of physics to model the interaction of light and objects.
The aim is to **help the landers** that use computer vision to explore better and avoid obstacles while navigating in their landing site, producing realistic simulations of RADAR and LiDAR guidance sensors and onboard navigation cameras.

Ray-casting method has been adopted for shadow's implementation.

Computational costs

The Hapke model has the fastest rendering time because it has been implemented and optimized inside a custom shader.

- Hapke model : ∽ 40 s
- Lambertian and Oren-Nayar models: ∽ 60 s

Hapke Model

Bruce Hapke has published his theory in several papers and books, accounting for improvements and modifications, [1-2-3].
The adimentional quantity $r(i,e,\alpha)$ is the radiance coefficient, which describes the relation between the reflected radiance I in the camera direction to the incident solar irradiance F , as a function of incident angle i, emission angle e, and phase angle α.

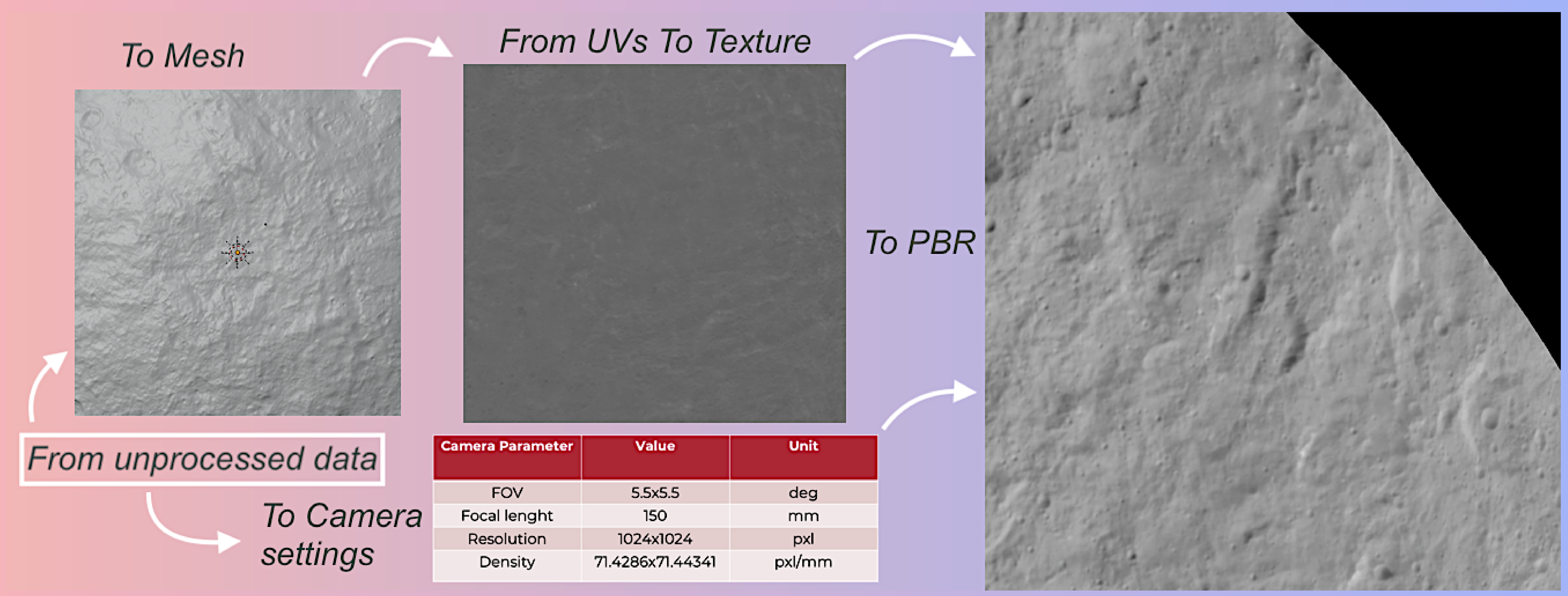
$$r(i,e,\alpha) = \frac{w}{4\pi}\frac{\mu_{0e}}{\mu_{0e}+\mu_e}\left(\left[1+B_{sh}(\alpha)\right]p(\alpha)+H(\mu_{0e})H(\mu_e)-1\right)\left(1+B_{cb}(\alpha)\right)S(i,e,\phi)$$

Where μ_{0e} and μ_e are the cosines of the reflection and incidence angles considering the mean roughness slope angle, and:

- $\frac{w \cdot \mu_{0e}}{\mu_{0e}+\mu_e}$ represents the reflectance per solid angle due to single scattering.
- $p(\alpha)$ is single-particle **phase function** which describes the angular pattern of scattering for irregular particles.
- $H(x)$ is the analytical approximations to the Chandrasekhar's H function for isotropic scatterers.
- $B_{sh}(\alpha)$ is the **shadow-hiding opposition effect**.
- $B_{cb}(\alpha)$ is the **coherent backscatter opposition effect**.
- $S(i,e,\phi)$ is the general **macroscopic roughness**.

Ceres case study: from unprocessed data to PBR

To apply the model to Ceres's surface coming from a **Depth Elevation Map**, we needed to create a mesh object from a set of unprocessed data, including vertices, normalized albedo values, and other info regarding the Camera to set the scene. For this purpose, we have implemented a tool that allowed us to parse the data and create the mesh's faces and edges, followed by the generation of the UV map and the texture itself.

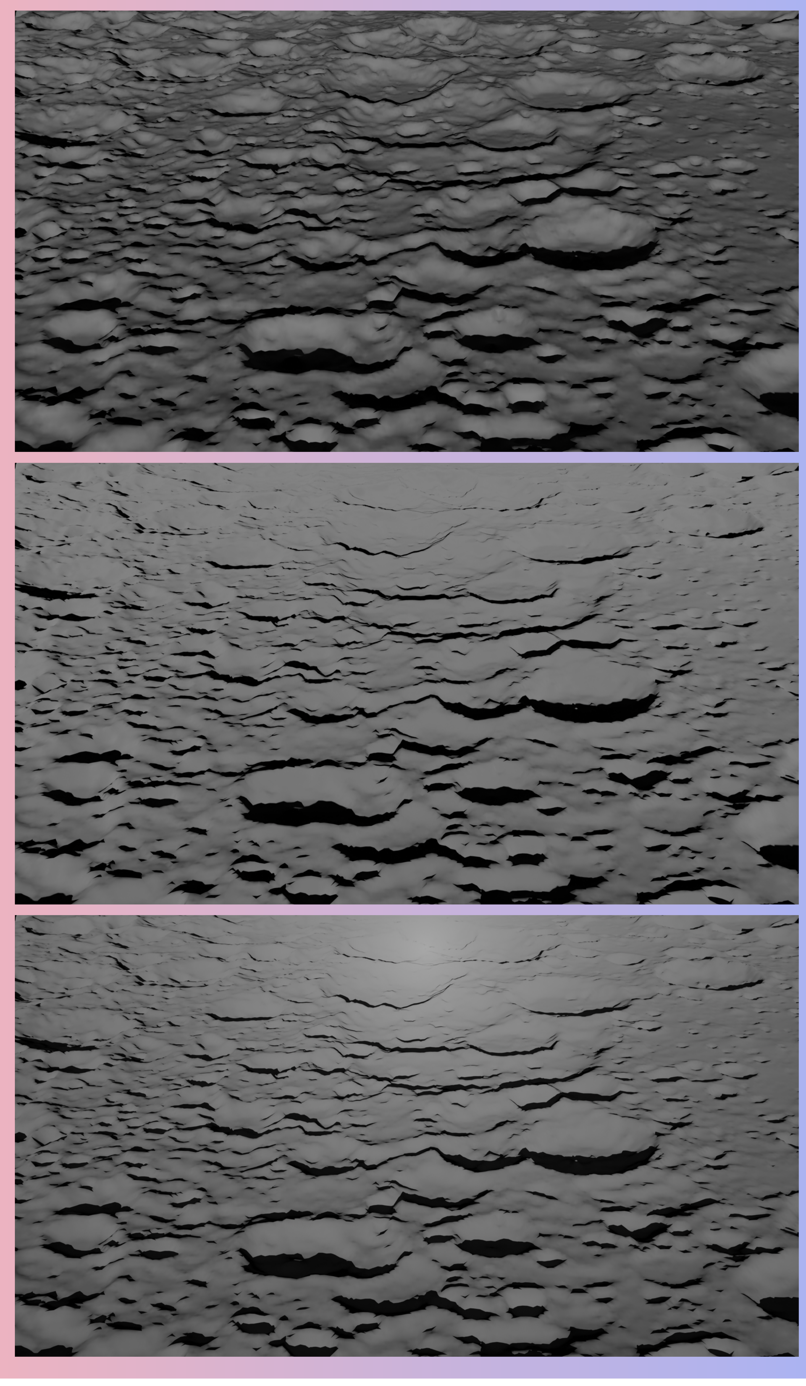


Camera Parameter	Value	Unit
FOV	5.5x5.5	deg
Focal lenght	150	mm
Resolution	1024x1024	pxl
Density	71.4286x71.44341	pxl/mm

Acknowlegement: Ceres data provided by N. Mastrodemos.

Other Lighting Models

The **Lambertian** *(top)*, **Oren-Nayar** *(middle)*, and **Hapke** *(bottom)* models have been applied to the mesh of the far side of the Moon to better understand the influence of the opposition effect, visible only in the Hapke model image. The opposition effects, are responsible for an **increase of brightness at opposition**, thus it leads to an inability to observe details at low phase angle. These effects characterize all porous, particulate media, and for this reason, their contribution is particularly significant when dealing with regolith bodies.



Conclusions & Future work

To improve autonomy perception simulations, we developed a tool for PBR, using the Hapke model to represent the surface of regolith bodies. Our aim is to update the model for **real-time applications** and add realistic **sensors**.

References

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