Efficient Photometric Models of the Lunar Regolith for Virtual Reality Simulation

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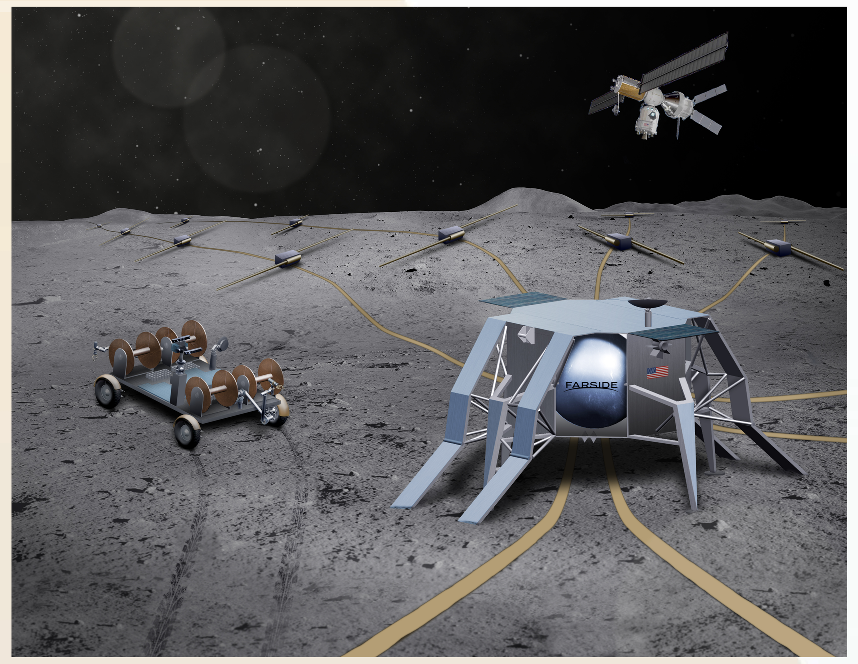
Question

Can we generate *functionally* photorealistic rendering of given lunar terrain geometry at near realtime frame rates (25-30Hz)?

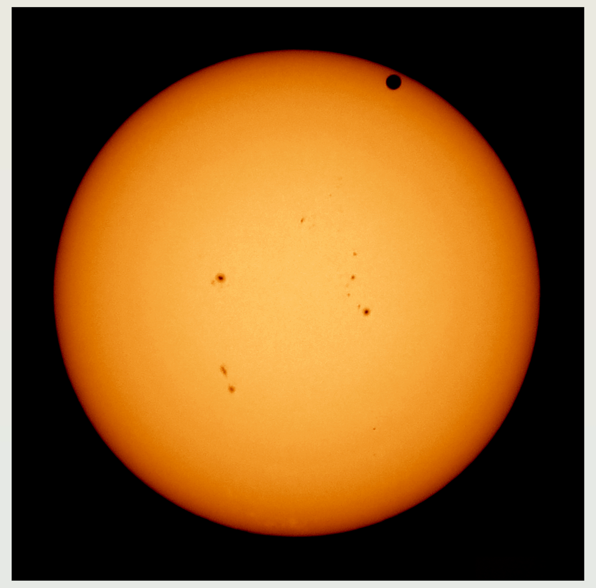
Background



Low Radio Frequency Array on the Lunar Farside (FARSIDE). P.I. of FARSIDE is Jack Burns. Figure is courtesy JPL

- Lunar exploration is resurging.
  - NASA returning to moon by 2024. Proposal for the development of a Lunar Gateway
  - Development of radio telescope on lunar farside for exoplanet detection
- Complicated surface construction requirements need robust surface telerobotic exploration/scouting missions.
- Virtual Reality(VR) simulators can help too.
  - Generate mission requirements from virtual analog missions.
  - Provide training for astronauts.
  - Help in operation planning
  - Reduce cognitive load on astronauts by intuitive information exchange modalities and distributed autonomy.

- VR simulators must work in real-time framerates(25-30Hz) and render the physics of the environment to meet functional requirements.
- In this work, focus is on methods to render the observed photometric properties of lunar regolith, namely absence of *Limb Darkening* and *Opposition Effect*(SHOE and CBOE).
- Simulating optical artifacts help give the operator good indicator on glare, can assist in testing SLAM algorithms, create path/operation planners.



(a) Limb darkening (sun)

Source: B. Inaglory, CC2.5

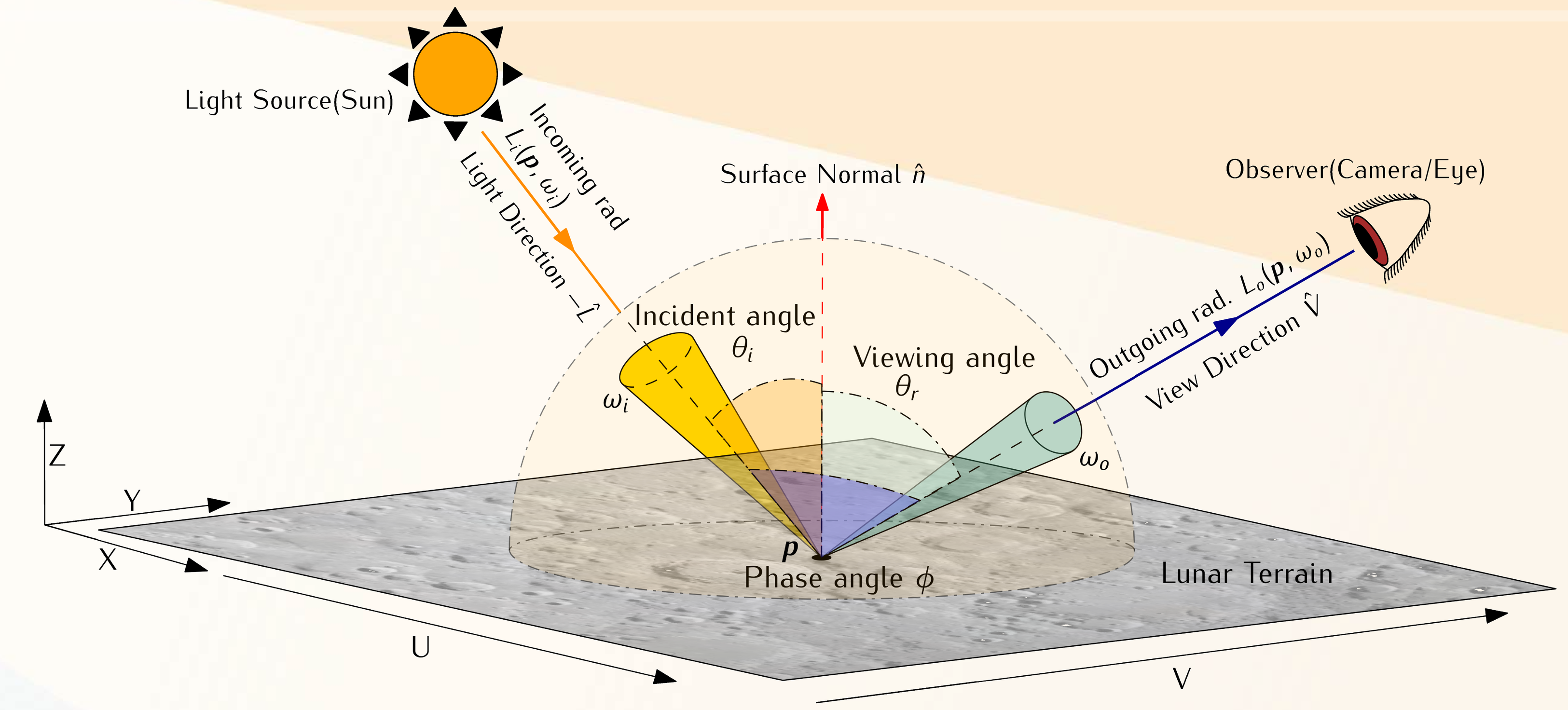
(b) No limb darkening (moon)

Source: NASA

(c) Opposition effect (moon)

Source: NASA

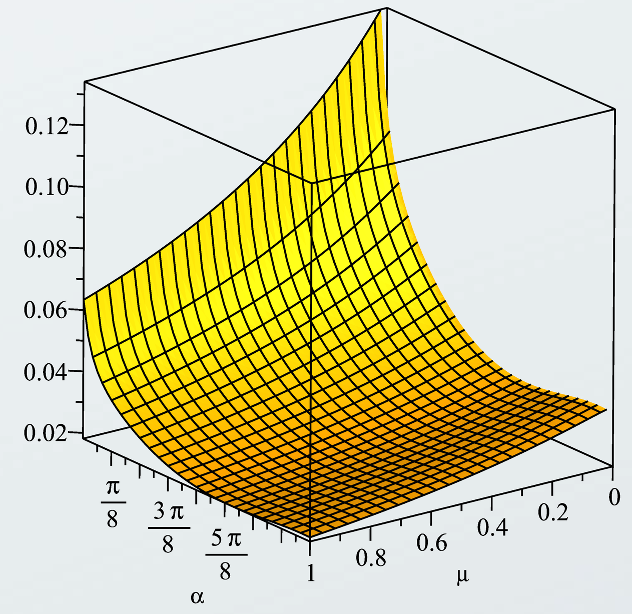
Method



BRDF simulates the reflective response of a surface-material combination. In lunar simulator, BRDF can help better test SLAM algorithms/provide better visual cues to operator to assist in planning

- Sun is the single light source modeled as directional light of pre-specified azimuth and elevation, producing slightly reddish(R:255,G:235,B:238) light.
- The base terrain is extracted from publicly available Digital Elevation Models (DEM) processed from stereoscopic and photogrammetric processing of Lunar Reconnaissance Orbiter Camera (LROC) - Narrow Angle Camera (NAC) using NASA Ames Stereo Pipeline.
- This is synthetically enhanced from $\approx 0.5m$/pixel resolution to sub-mm resolution by fractal expansion and used as input to VR simulator.
- Surface reflectance modeled by specific *Bidirectional Reflectance Distribution Function (BRDF)* which plug into the rendering equation[1] to generate the scene.

$$\underbrace{L_o(p,\omega_r)}_{\text{Light reflected towards eye}} = \int_\Omega \underbrace{f(p,\omega_r,\omega_i,\alpha)}_{\text{BRDF}} \times \underbrace{L_i(p,\omega_i)}_{\text{Incoming light}} \times \underbrace{\mu_0}_{\text{Angle weighting}} \times d\omega_i$$



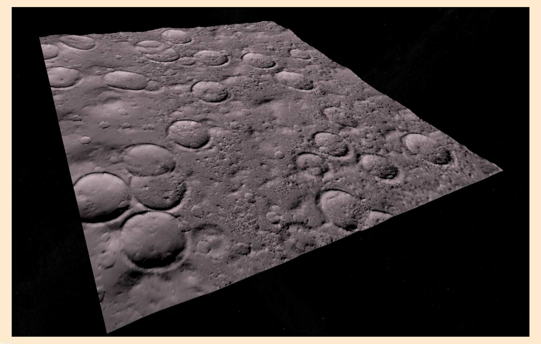
Hapke BRDF for incident factor $\mu_0 = \cos 45°$, viewing factor $0 \leq \mu \leq 1$ and phase angle $0 \leq \alpha \leq \pi$

- BRDFs in this case are functions of incident factor $\mu_0 = \cos\theta_i$, view factor $\mu = \cos\theta_r$ and phase angle α & parameters like Single Scattering Albedo(SSA) etc.
- Two BRDFs have been implemented differing in computational expense-accuracy.
  - Hapke model[2]: Expensive but accurate. 5 Hapke parameters derived for Mare Imbrium[3].
  - Hapke-Lommel-Seeliger model[4]: Less expensive, less accurate. Parameters used from [5].
- *Physically Based Rendering (PBR)* pipeline in Unity3D game engine is used with vertex and fragment shader workflow.

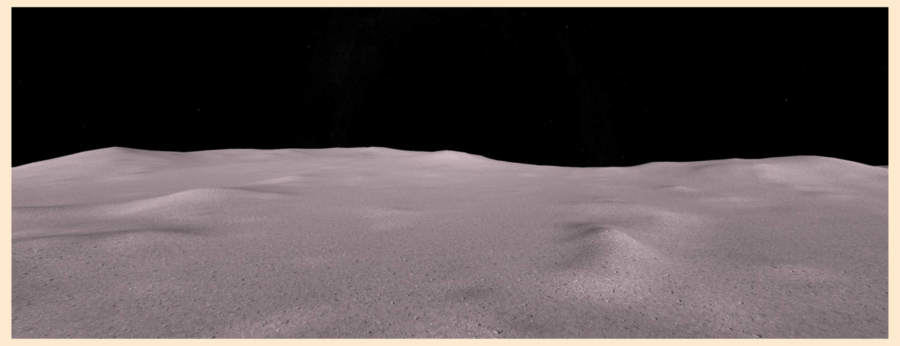
- Classical rendering pipeline used-Raytracing avoided because
  - SSA of lunar regolith is very low(≈ 0.15) and hence, secondary light sources are much reduced.
  - Raytracing is more expensive computationally.

Results

The modelling and rendering was done in Unity3D.



(a) Input Terrain



(b) Normal shader without Opposition Effect (OE)

(c) Hapke Shader

(d) Hapke-Lommel-Seeliger Shader

Both BRDFs produce visually pleasing effects. The parameters can be easily adjusted in runtime⇒ simulator can be used to create nominal/adversarial tests scenarios on the fly.

Future work

- Frame rate studies to be done, functions need to be approximated to reduce computational overhead the same.
- Normalizing factors to conserve energy needs to be incorporated into the BRDFs.
- Investigate using spherical harmonics to approximate incident sunlight to improve speed.
- Employ normal and height maps generated from observed fractal parameters of terrain from earlier missions so as to enhance resolution at rendering level, rather than at mesh level.
- Enhance terrain with sub-5m terrain features(craters, boulders) by sampling from observed Size-Frequency-Distributions[6].
- Employ memory management techniques to dynamically load/unload chunks of terrain to memory on demand.

References

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This work is directly supported by the NASA-SSERVI cooperative agreement 80ARC017M0006.