Outline

University of Colorado Boulder

Future Work

- Frame rate studies
- shaders to be optimized
- BRDF normalizing factors to conserve energy needs
- Investigate use of spherical harmonics to represent sunlight
- Calibrate the surface shader using ground truth experiments (Allan et al. 2019)
- Generate normal and height maps using derived fractal parameters of terrain from earlier missions (Robbins 2018)
- Add sub-5m terrain features obeying Size-Freq.-Distr. (SFD) (Heiken et al. 1991)
- Dynamic load/unload of terrain chunks on-demand

OUTLINE

Creating a Virtual Lunar Testbed

Question

Can we develop a virtual testbed on which to test/ refine SLAM/ planner algorithms and VR telerobotic interfaces ?

- Simulator must be close to real time (fast)
- Must have sensor/actuator models with synthetic noise
- Functionally simulate physical interactions with environment

Outline

University of Colorado Boulder

Scope of Work

Develop an integrated virtual testbed for autonomous algoritms (SLAM/ planning etc.), distributed autonomy and teleoperation interfaces

- Synthetic terrain
- Photometric mdls.
- Soil mdls.
- Actuator mdls. (mech., wheel, motor)
- User control interface
- Sensor mdls. (IMU, LIDAR, camera)

Outline

Framework Overview

- Environment in Unity3D, algo. comp. in ROS
- Sensor data Unity $\rightarrow$ ROS
- Actuation feedback ROS $\rightarrow$ Unity

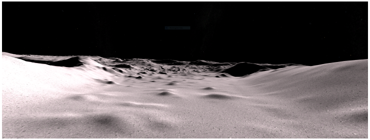
Status

- ROS $\longleftrightarrow$ Unity3D connection established
- Virtual Laser Scanner, Camera functioning
- Currently testing and comparing state-of-the-art SLAM algorithms

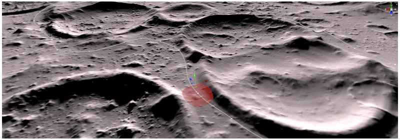
Outline

Snapshots of the Framework Running

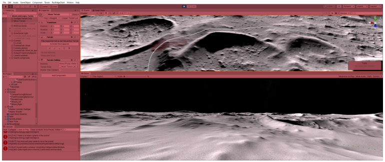
Virtual camera traverses synthetic terrain (simulate vehicle movement) in Unity. Trajectory reconstruction attemped in ROS. (Demo Videos: Unity3D, SLAM, Full-System)



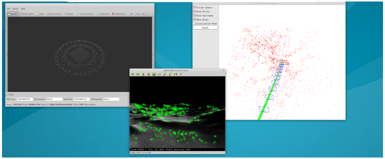
Camera Frame View



View of Camera Path



Unity3D Interface



SLAM Algorithm Interface

Outline

Future Work

- Add realistic noise to IMU, camera, laser scan
- Model soil interaction physics with realistic uncertainities in bearing strength, skid/slip/sinkage
- Check for SLAM loop closure
- Evaluate algorithms for performance w.r.t accuracy, robustness
- Include boulders/craters/calibration targets in sub-5m resolution based off SFD to help in feature matching
- Add rover dynamics with soil interaction physics to close actuation-sensing loop
- Analyze shortcomings of SLAM algorithms, design improvements specific to Lunar environment

References I

Allan, M. et al. (2019). "Planetary Rover Simulation for Lunar Exploration Missions". In: *2019 IEEE Aerospace Conference*. IEEE, pp. 1–19.

Hapke, B. (2012). *Theory of reflectance and emittance spectroscopy*. Cambridge university press.

Hapke, B. W. (1963). "A theoretical photometric function for the lunar surface". In: *Journal of Geophysical Research* 68.15, pp. 4571–4586.

Heiken, G. H., D. T. Vaniman, and B. M. French (1991). "Lunar sourcebook-A user's guide to the moon". In: *Research supported by NASA,. Cambridge, England, Cambridge University Press, 1991, 753 p. No individual items are abstracted in this volume.*

References II

Jensen, H. W. et al. (2001). "A physically-based night sky model". In: *Proceedings of the 28th annual conference on Computer graphics and interactive techniques*. ACM, pp. 399–408.

Kajiya, J. T. (1986). "The Rendering Equation". In: *Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques*. SIGGRAPH '86. New York, NY, USA: ACM, pp. 143–150. URL: http://doi.acm.org/10.1145/15922.15902.

Robbins, S. J. (2018). "The fractal nature of planetary landforms and implications to geologic mapping". In: *Earth and Space Science* 5.5, pp. 211–220.

References III

Sato, H. et al. (2014). "Resolved Hapke parameter maps of the Moon". In: *Journal of Geophysical Research: Planets* 119.8, pp. 1775–1805. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2013JE004580. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2013JE004580.