AUTONOMOUS OPTICAL LUNAR NAVIGATION

Renato Zanetti,* Brian Crouse† and Chris D'souza‡

The performance of optical autonomous navigation is investigated for low lunar orbits and for high elliptical lunar orbits. Various options for employing the camera measurements are presented and compared. Strategies for improving navigation performance are developed and applied to the Orion vehicle lunar mission

INTRODUCTION

Autonomous navigation in proximity to the Moon presents challenges not found in near-Earth navigation. The most obvious difference is the absence of GPS as a possible measurement. During the Apollo era, navigation relied on tracking and state updates from the ground. The Orion program, however, is required to navigate autonomously from the ground. Due to absence of an atmosphere on the Moon, optical terrain navigation is a viable option and has produced good results in past studies [1, 2, 3].

Orion will have two star trackers and digital cameras onboard. The star trackers are required to detect both stars and terrain features on a single image. The digital cameras are primarily designed for proximity operations and docking, but they are potentially usable for surface feature tracking. The star trackers and cameras images will be processed to determine known features on the lunar surface. The position of the features in the image will provide azimuth and elevation information in the camera's own body-fixed frame. Strategies to include measurements in the navigation filter include:

1. Processing the unit vector obtained from the azimuth and elevation.
2. Processing the apparent angle between a landmark and a known star.
3. Processing the elevation between the lunar horizon and a known star.

While strategies 1 and 2 provide the same information, each have advantages and disadvantages. The elevation between the landmark and a known star is a scalar measurement. As such, it is attitude independent and is therefore immune to attitude estimation errors and camera misalignments. In order to avoid introducing errors due to relative misalignment between cameras, it is preferable that the same camera capture both the landmark and the star. However such a solution is strongly limited by the field of view (FOV) of the sensors. The mentioned measurements' sensitivity to the spacecraft's position have inverse proportionality to the distance to the Moon. However, it is expected that the landmark solutions will perform better closer to the lunar surface (where it is easier to capture the landmark) while the star-horizon elevation approach will perform better further away from the lunar surface (where it is easier to determine the horizon and the substellar point).

In this paper, models for all the above mentioned measurements are presented, together with trade studies to determine a mission strategy for their utilization. Studies were conducted for two trajectories: low lunar orbit (LLO) and highly elliptical lunar orbit. The Orion LLO is a 100 km trajectory that will be used while the astronauts are on the lunar surface. The high elliptical trajectory is used by Orion during its trans-Earth injection (TEI) 3 burn sequence.

*Senior Member of the Technical Staff, GN&C Manned Space Systems, The Charles Stark Draper Laboratory, 17629 El Camino Real, Suite 470, Houston, Texas, 77058. rzanetti@draper.com

†Second Lieutenant. US Air Force. Rice University Graduate Student and Draper Laboratory Fellow, The Charles Stark Draper Laboratory, 17629 El Camino Real, Suite 470, Houston, Texas, 77058. bcrouse@draper.com

‡GN&C Autonomous Flight Systems Engineer, Aeroscience and Flight Mechanics Division, NASA Johnson Space Center EG6, 2101 NASA Parkway, Houston, Texas, 77058. chris.dsouza@nasa.gov

OVERVIEW OF METHODOLOGY

The analysis was done with linear covariance (Lincov) techniques [4, 5]. This approach has the advantage of obtaining statistical properties of the estimation error in a single run and it is therefore very useful during the initial stages of navigation system design. The Orion CEV is still under development, and many of the vehicle and orbit specifications are continuously changing. Lincov analysis provides the capability for quick analysis of many variations of the navigation parameters.

OVERVIEW OF RESULTS

Figure 1 shows the position accuracy obtained by processing star elevation measurements. The two lines show elevation measurements from the landmark and the horizon. It can be seen that at low altitudes processing landmarks is preferable, while at higher altitudes horizon elevation measurements are recommended. Figure 2 shows the performance of the optical navigation filter during the TEI sequence.

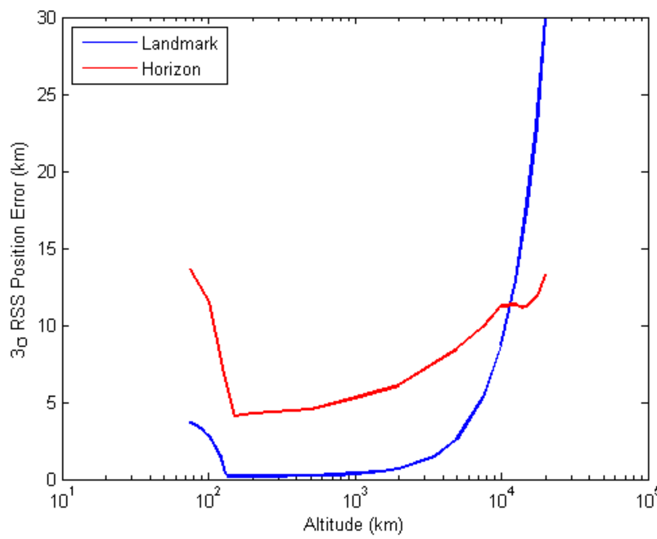

Figure 1 Star-landmark vs. star-horizon performance.

REFERENCES

[1] M. Osenar and F. Clark and C. D'Souza, "Performancs of an Automated Feature Tracking Lunar Navigation System," *AAS/AIAA Space Flight Mechanics Meeting*, Galveston, TX, 27-31 January 2008.
[2] K. J. DeMars and R. H. Bishop, "Precision Descent Navigation for Landing at the Moon," *AAS/AIAA Astrodynamics Specialist Conference*, Mackinac Island, MI, August 19–23 2007.
[3] C. C. van Damme and T. Prieto-Llanos and J. Gil-Fernandez, "Optical Navigation for Lunar Transportation Systems Contingency Scenarios," *AIAA/AAS Astrodynamics Specialist Conference and Exhibit*, Honolulu, HI, 18-21 August 2008.
[4] A. Gelb, ed., *Applied Optimal Estimation*. Cambridge, MA: The MIT press Massachusetts Institute of Technology, 1996.
[5] D. K. Geller, "Linear Covariance Techniques for Orbital Rendezvous Analysis and Autonomous Onboard Mission Planning," *Journal of Guidance Control and Dynamics*, Vol. 29, November-December 2006, pp. 1404–1414.

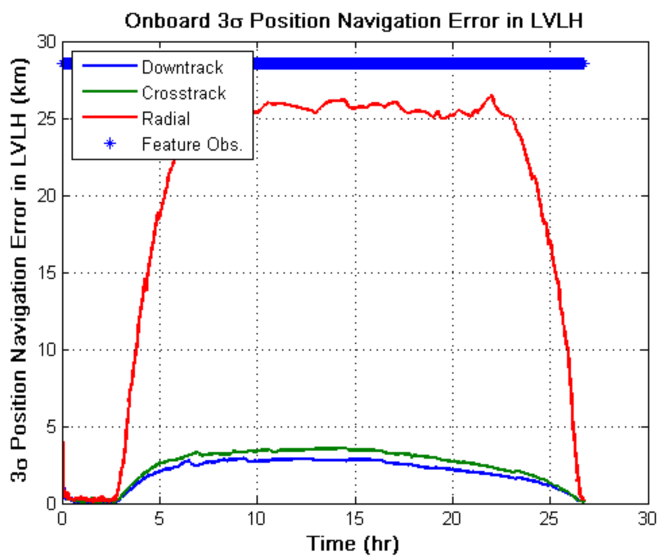

Figure 2 TEI navigation performance.