LUNAR ASTRONAUT NAVIGATION USING LASOIS: PERFORMANCE OF A SIMULATED APOLLO-14 TRAVERSE AT HALEAKALA NATIONAL PARK, HAWAII

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Introduction: The different environmental conditions found on the moon can significantly affect spatial orientation as experienced by landed lunar astronauts. During the Apollo 14 mission, astronauts successfully completed a traverse of about 1.4 km. However, disorientation due to a lack of spatial cues, altered gravity, and other factors prevented them from reaching their goal, Cone Crater, before they had to return to base to prevent their resources from running out [1, 2]. To help overcome these challenges on the lunar surface an astronaut navigation system, the Lunar Astronaut Spatial and Orientation Information System (LASOIS), has been designed and implemented to incorporate data from lunar orbital, ground, and suit-mounted (on-suit) sensors. This system has been tested multiple times in lunar-like environments, most lately at Haleakala National Park, Hawaii.

Methodology:

Components of LASOIS. The LASOIS system includes hardware for data acquisition along with software for the integration of multiple algorithms for data processing, integration, and display [3]. Orbital sensors incorporated into the network include the LROC (Lunar Reconnaissance Orbiter Camera) and the LOLA (Lunar Orbiter Laser Altimeter) altimeter. Sensors mounted on the astronaut suit include an IMU (Inertial Measurement Unit) mounted on one boot heel (right or left), a step sensor mounted on the bottom of the same boot, and a stereovision system (a pair of digital imagers) mounted on the chest (see Figure 1). The integrated IMU and step sensor data captures the distance of each astronaut stride, and 3D attitude. By tracking and matching ground features on the lunar surface, data from the stereovision system provides heading as well as positioning information.

Localization at the beginning of an Extra-Vehicular Activity (EVA) traverse. A panorama is taken at the beginning of an EVA traverse. Landmark matching (or DEM matching) is employed to register the panorama to orbital data [3] based on terrain features surrounding the starting point. Position and orientation are calculated from the computation of rotation and translation between the panorama and the orbital images through the landmarks (or DEMs).

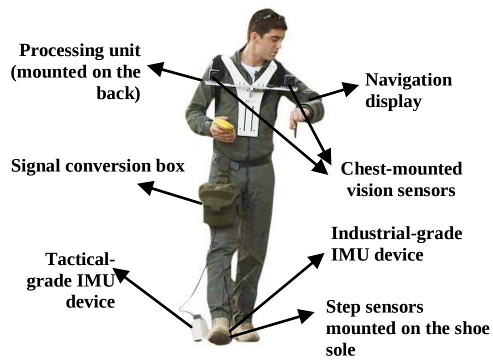

Figure 1. Suit-mounted sensors.

Continuous localization on an EVA traverse. During the EVA traverse, an Extended Kalman Filter is used to integrate signals from the IMU, the step sensor and the stereovision imagers in order to obtain in real time the changing positions and orientations of an astronaut. A boot-mounted IMU measures acceleration and the angular rate of change of the heel of the astronaut at a high frequency (up to 100 Hz). The step sensor records periods when the astronaut boot is not moving (a zero velocity phase). An algorithm of zero velocity updates (ZUPTs) is used to remove bias in the IMU whenever the step sensor detects a zero velocity phase for the astronaut. As a result, velocity and distance can be accurately reconstructed. Since the stereovision imagers usually provide better heading determination data, they can be used to further compensate for any bias in the heading direction found in the IMU signal. After sensor integration, astronauts can retrieve precise localization information concerning spatial position and orientation from a wrist-mounted interface display.

Figure 2. Designed Traverse in Experiment

Experimental Design: In the Apollo 14 mission, one of the important scientific target was Cone Crater, which was 340 m in diameter. The two astronauts had to walk approximately 1.4 km northeast of the landing spot in one and half hours while relying on a map and their own experience to locate this target of interest [2].

A traverse was designed for the field test at Haleakala National Park to simulate this Apollo 14 EVA traverse and to test the developed system. This simulated traverse is illustrated in Figure 2 as a white line. The human subject started at point A, then headed toward a crater named Halali'i that was 2 km to the northeast of the starting point. A looped traverse was performed after reaching Halali'i. The subject walked back to the starting point A. The distance of the round trip was 6.1 km.

During this traverse, the human subject was able to obtain real-time position information through the system's wrist-mounted display. It took 6500 seconds to finish the 6 km traverse at an average speed of 1 m/s. Along the traverse, 7800 images were taken. The sampling frequency of the IMU was 100 Hz.

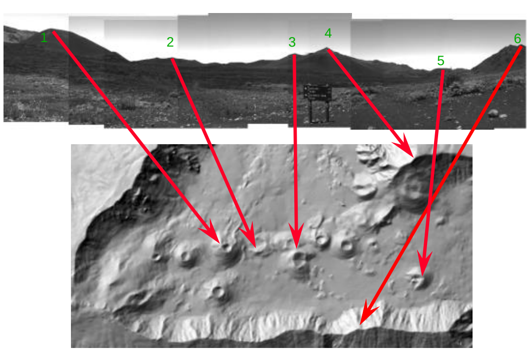

Figure 3. Landmarks matched on the panorama and the DEM.

Experimental Results and Conclusions: Six significant landmarks were selected on the images obtained by the chest-mounted vision system and registered with landmarks found on the global DEM derived from orbital data (See Figure 3). Localization accuracy at the starting point through this orbit-ground matching technique was 21 m. The traverse reconstructed by the LASOIS on-suit sensors is displayed as a blue line in Figure 4, compared with the ground truth obtained by GPS (red line). The LASOIS-derived end point of the traverse deviated from the starting point (A in Figure 2) of the ground truth by 150 m, making a disclosure error of 2.42% over 6.1 km. The maximum error of 200 m was found in about half way, about 3 km from the starting point. We conclude that LASOIS is capable of providing precise navigation information to enable lunar astronauts to safely navigate on the lunar surface, locate science targets, and return safely to the lander or vehicle.

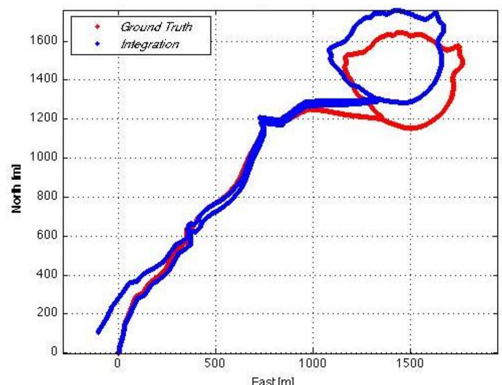

Figure 4. Experiment results.

References: [1] Jones E.M. (1995) Apollo 14 Lunar Surface Journal, http://www.hq.nasa.gov/alsj/a14/a14j.html. [2] Manned Spacecraft Center, (1971). Apollo 14 Mission Report. http://www.hq.nasa.gov/alsj/a14/A14MRntrs.pdf. [3] Li R. et al. (2011) LPSC, Abstract #2100.

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