**THE LATEST PROGRESS OF LASOIS: A LUNAR ASTRONAUT SPATIAL ORIENTATION AND INFORMATION SYSTEM.** R. Li[1], S. He[1], B. Skopljak[1], X. Meng[1], A. Yilmaz[2], J. Jiang[2], M. S. Banks[3], S. Kim[3], C. Oman[4]. [1]Mapping and GIS Laboratory, CEEGS, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, li.282@osu.edu; [2]Photogrammetric Computer Vision Laboratory, CEEGS, The Ohio State University; [3]Visual Space Perception Laboratory, University of California Berkeley; [4]Man Vehicle Laboratory, Massachusetts Institute of Technology.

**Introduction:** The different surface environment experienced by lunar astronauts can affect their perceptions of spatial orientation and, thus, seriously impact their ability to achieve exploration goals. During the Apollo 14 mission, astronauts successfully completed a traverse of about 2 km. However, they suffered from disorientation due to several lunar environmental factors such as the influence of reduced gravity, different reflection properties, and lack of familiar reference points [1], so that they did not reach Cone Crater, their primary science target, before resources ran out [2]. According to the post-mission analysis, they were within 30 m of the crater when they were forced to return [3]. Thus enhancement of the spatial-orientation capabilities of astronauts on the surface offers significant opportunities to increase scientific return from lunar surface exploration [4].

A Lunar Astronaut Spatial Orientation and Information System (LASOIS) has been designed and developed, and is being tested by a group of researchers at The Ohio State University (OSU) with partners at UC Berkeley, NASA Glenn Research Center, and MIT. LASOIS is being designed to continuously provide spatial orientation and navigation information to astronauts and thereby reduce the effects of spatial disorientation.

**LASOIS Sensor Network:** The LASOIS system includes hardware for data acquisition (integrated sensor network) along with software for the integration of multiple algorithms for data processing, integration, and display [5]. Data from multiple sensors (suit-mounted or orbital) are integrated into a sensor network. Orbital sensors include the LROC (Lunar Reconnaissance Orbiter Camera) and the LOLA (Lunar Orbiter Laser Altimeter) altimeter that, when integrated, support high-resolution and highly accurate DEMs useful for lunar surface mapping and exploration. These DEMs are particularly useful in evaluating future landing site candidates. Sensors mounted on the astronaut include an IMU (Inertial Measurement Unit) mounted on one astronaut boot heel (right or left), a step sensor mounted on the bottom of the same boot, a stereovision sensor (a pair of digital imagers) mounted on the chest, and a "sky" camera (or star tracker) mounted on the top of the astronaut helmet, pointing skyward (see Figure 1). The integrated IMU and step sensor data captures the distance of each astronaut stride. By tracking and matching ground features on the lunar surface, data from the stereovision system provides heading information as well as positioning information (though at a sampling rate of 2 Hz). The sky camera serves a special purpose. It can provide independent heading readings for the astronauts, enabling the navigation system to work in an emergency mode.

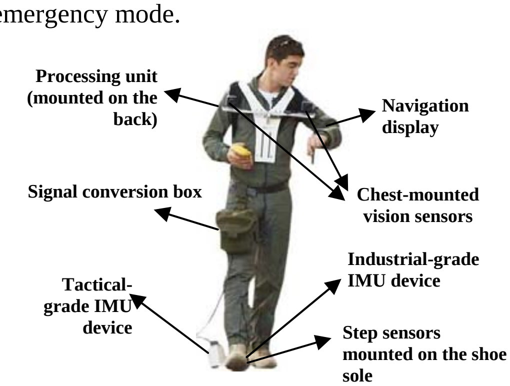

Figure 1. Suit-mounted sensors.

**Initial Localization and Orientation:** If an extra-vehicular activity (EVA) traverse begins from a position having landmarks (large craters, trenches, hills, etc.) the initial position and orientation of the astronaut can be obtained through the registration between a DEM generated from orbital sensor data and one based on data from the stereovision system. However, if the traverse begins from a position lacking landmarks, sky camera data, when integrated data from the tactical IMU, will be able to provide the absolute longitude and latitude of the starting point due to the highly accurate initial heading angle provided by the star tracker algorithm. Data from the sky camera, however, is not used for continuous navigation during an EVA traverse due to its very time-consuming computation requirements and the necessity for long period of absolute stillness for readings to be taken.

**Continuous Tracking and Navigation by Suit-mounted Sensors:** During a traverse, an Extended Kalman Filter is used to integrate signals from the IMU, the step sensor and the stereovision cameras to obtain in real time the changing positions and orientations of astronauts. A boot-mounted IMU measures the acceleration and angular rate of change of the heel of astronaut at a high frequency of up to 150 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 astronauts. As a result, velocity and distance can be accurately reconstructed. Since the stereovision sensors usually provide better heading determinations, they can be used to 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 displayed on a wrist-mounted interface.

**Star Tracker for Navigation:** As described above, sky cameras working with a tactical IMU can provide the absolute position information for astronauts. In case of emergency, (e.g., if the chest-mounted stereovision cameras stop working correctly), LASOIS can use the sky camera for accurate positioning. In addition, during an EVA traverse the sky camera can work as a "compass" to periodically provide highly accurate heading information which serves to significantly remove any drift in heading angles in the traverses reconstructed from only stereovision and IMU data.

**Test Results:** LASOIS has been field tested at lunar-like environments at Moses Lake, WA and Black Point, AZ. In Moses Lake, initial positioning was performed through matching an orbital DEM from GeoEye images to a DEM based on data from the on-suit stereovision cameras. Localization accuracy was found to be 12 m for initial positioning and 5° for initial orientation. At Black Point, a 4800-meter traverse was reconstructed using integrated data from the suit-mounted sensors (IMU, step sensor, and stereovision sensors). An overall error of 4% over the 4800-meter traverse was achieved. Thus the final point of the reconstructed traverse deviated 200 m from the real position (Figure 2). According to initial analysis on the performance of star tracker, the addition of star tracker data into this system is expected to reduce relative positioning error to around 1%.

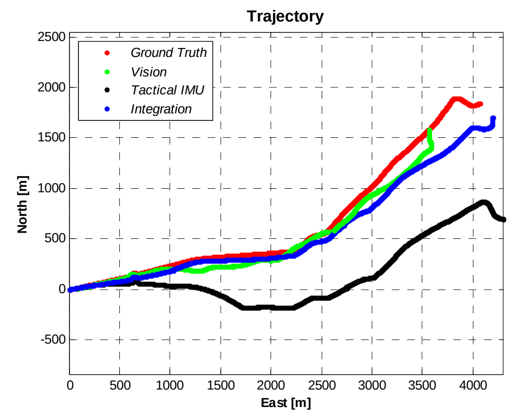


Figure 2. Traverse paths as reconstructed from: LASOIS (blue line), vision sensors (green line), and tactical IMU (black line). Red line represents ground truth.

Table 1. Errors in reconstructed traverses (4800 m overall length)

| | Error (m) | Relative Error |
|---|---|---|
| IMU | 1174.02 | 24.45% |
| Vision | 568.28 | 11.84% |
| LASOIS | 186.32 | 3.88% |

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**References:** [1] Oravetz, C. (2007). Human Estimation of Slope, Distance, and Height of Terrain in Simulated Lunar Conditions. Master of Science Thesis, MIT. [2] Jones E.M. (1995) Apollo 14 Lunar Surface Journal, http://www.hq.nasa.gov/alsj/a14/a14j.html. [3] Manned Spacecraft Center, (1971). Apollo 14 Mission Report. http://www.hq.nasa.gov/alsj/a14/A14MRntrs.pdf [4] Li R. et al. (2008) NLSC, Abstract #2069. [5] Li R. et al. (2010) LPSC, Abstract #1782.