OVER TWO YEARS OF TOPOGRAPHIC MAPPING AND ROVER LOCALIZATION OF SPIRIT AND OPPORTUNITY FOR MER 2003 MISSION

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Introduction

In the 2003 Mars Exploration Rover (MER) mission, the two rovers, Spirit and Opportunity, have been exploring the Martian terrain for more than two years. During this period, The Ohio State University (OSU) team, in collaboration with Jet Propulsion Laboratory (JPL) and other teams of the mission, has been routinely producing topographic maps, rover traverse maps, and updated rover locations for the two rovers. Precise and updated rover traverse and various topographic mapping products have played an important role in the successful operations of the two rovers. Moreover, the mapping products have supported strategic mission operations and tactical scientific decisions. These maps and localization data are being provided to MER mission scientists and engineers through a web-based GIS (Web GIS). Here we present the rover localization and mapping products produced over the course of two years of the mission.

Rover Localization

Rover localization uses data collected by wheel odometer, IMU, and Pancam as a Sun imaging instrument. Visual odometry technique is applied for correcting errors caused by wheel slippage within a site. In order to achieve high accuracy for long traverses, bundle adjustment (BA) of an image network formed by integrating the Pancam (Panoramic Camera) and Navcam (Navigation Camera) stereo images taken by the rover during mission operations is employed. The rover experiences a significant amount of wheel slippage, especially during ascent and descent of steep slopes. BA helps in correcting the telemetry data (mostly based on wheel odometer and IMU) and furnishes an update precise rover position for each rover with respect to their respective landing site.

At the Gusev Crater site, localization of the Spirit rover has been performed sol by sol based on incremental bundle adjustment using full or partial Navcam/Pancam panoramic images, and, occasionally, forward- and backward-looking Navcam/Pancam middle-point survey images. As of January 30, 2006 (Spirit's Sol 738) Spirit has traveled 5.63 km (actual distances traveled rather than odometry measures). Starting from Sol 154, we performed a local comparison of rover traverses during spirit's ascent of Husband Hill where it experienced significant wheel slippages. The accumulated difference between the telemetry-derived traverse and the bundle-adjusted traverse during the ascent of the hill was 82.06 m, or 5.30 percent of the traveled distance of 1.54 km on Sol 648, with a maximum of 10.50 percent (56.6 m over 540.6 m) on Sol 337. During the descent of Husband Hill (Sol 649 to Sol 732), the accumulated error between the telemetry-derived traverse and the bundle-adjusted traverse was 71.81 m, or 7.40 percent of the downhill distance of 0.97 km, with a maximum of 9.5 percent (59.22 m over 620.77 m) on Sol 705. This demonstrates that the BA was able to correct significant localization errors.

As of Sol 718, Opportunity rover had traveled 6.3 km across the Meridiani Planum landing site of the Eagle crater. We conducted a BA within Eagle Crater (up to Sol 62) that was able to correct a localization error as large as 21% that was caused by wheel slippage. After leaving Eagle Crater, BA-based rover localization was impossible due to insufficient localization image data. Wherever we observed large features such as the Fram, Endurance, Argo, Jason, Naturaliste and Vostok craters, we were able to generate orthophotos of these features and compared them with the MOC NA base map to adjust the rover traverse. Though not optimal, this adjustment strategy enabled us to provide the 2D Opportunity traverse in a timely manner to support operations.

On November 2, 2005 (Spirit's Sol 652), MSSS acquired a MOC NA image centered at the Husband Hill summit. Although the rover track is not visible, the rover itself was identified on the image, and we were able to determine its position on our georeferenced base map. In comparing this rover location imaged in MOC with the bundle-adjusted rover position of Sol 652, a difference was found of about 20 m, or 0.4 percent of the overall traverse of 4559 m. It is important to note that the 20 m difference between the bundle-adjusted rover location and the rover location on the MOC imagery does not mean that the absolute accuracy of the rover localization is 20 m. The location difference may be largely contributed by the accumulated map georeferencing errors (a few strips cross the landing site without strict 3-D photogrammetric processing). Overall, rover location information from both ground and orbital imagery has been found to be complementary. Thus ground image-based rover localization is desirable and critical for sol by sol operations, while rover positions from orbital images provide a way to verify the BA results.

Topographic Mapping

After deriving corrected rover positions using the BA, different kinds of topographic products have been tailored to the needs of the mission scientists and engineers. These include traverse maps, detailed 3-D terrain models, slope maps, orthophotos, a solar energy map, and the drive metrics. By Sol 738 for Spirit and Sol 718 for Opportunity, we had generated topographic products including 115 orthophotos and DTMs and six 3-D crater models, as well as periodic traverse maps and vertical profiles. Most of these topographic products were automatically generated from single-site panoramic stereo images. Some of the products, such as the detailed 3-D models of major features, were generated from multi-site or single-site panoramic stereo images.

High-resolution (5 mm) orthophotos and DTMs of significant features including Larry's Outcrop and Methuselah were automatically generated from partial Pancam panoramas taken by the Spirit rover. These maps served as fundamental data for stratigraphy analysis of these features. Various slope maps that were generated from the stereo images taken in the direction of intended traverse successfully aided the planning team in determining the desired track for safe navigation of the rover.

For large features such as Endurance Crater (156 m in diameter) at Meridiani Planum (Opportunity) site, a single-site panorama was not sufficient for reliable mapping of the entire feature because of the low measurement accuracy for far-range terrain. The key to high-precision integrated mapping is bundle adjustment of all the relevant images to eliminate and reduce their inconsistencies. After an integrated bundle adjustment of stereo Pancam images from the west and southeast rims of Endurance crater along with the wide-baseline Pancam images taken within the crater, we produced a 0.30 m-resolution DTM. At the Gusev Crater (Spirit) site, an integrated DTM was generated and expanded using multiple Navcam and Pancam panoramas (including wide-baseline) taken from Sol 576 to Sol 696 at the Husband Hill summit and within the south inner basin of Husband Hill. We also produced special topographic products, a north-facing slope map and solar energy maps (with collaboration of USGS) that were computed based on the DTMs. These maps have been very helpful for choosing rover traverse areas where the Spirit rover can capture more solar energy in the upcoming Martian winter.