PRODUCTION OF THE INSIGHT WORKSPACE MOSAICS. R. G. Deen[1], F. Ayoub[1], H. E. Abarca[1], N. A. Ruoff[1], and J. N. Maki[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, Bob.Deen@jpl.nasa.gov, Francois.Ayoub@jpl.nasa.gov, Hallie.E.Gengl@jpl.nasa.gov, Nicholas.A.Ruoff@jpl.nasa.gov, Justin.N.Maki@jpl.nasa.gov.

Introduction: The InSight lander's two major instruments, the seismometer (SEIS) and the heat probe (HP3) had very specific requirements and "desirements" on where they can be placed on the ground, covering properties like surface tilt, roughness, absence of rocks, soil cohesion, thermal noise, etc [1]. The Instrument Site Selection Working Group (ISSWG) was responsible for determining where to place the instruments given these criteria. The primary data sets used for this were the workspace mosaics, which were produced by the Multimission Image Processing Lab (MIPL) team using data from the Instrument Deployment Camera (IDC) [2]. This abstract discusses how they were created.

Mosaic Descriptions: There were actually several workspace mosaics produced for ISSWG:

- Vertical projection of ICC
- 2 mm "low-res" mosaic
- 1 mm "high-res" mosaic

The Instrument Context Camera (ICC) is a single, non-stereo camera [2]. Since stereo data was unavailable, these initial, approximate maps were made using a vertical projection [3,4], which assumes a flat planar surface. This mosaic is not discussed further here.

The rest of the mosaics are orthomosaics [3,4] using stereo data derived from the IDC camera. They were produced in multiple coordinate frames based on customer needs.

The 2mm mosaic was the primary mosaic used to determine instrument placements. Covering the entire workspace, it was acquired on sol 12 at a distance of ~1.5 m from the ground. The area under the tether box was imaged on sol 14, and added to the mosaic.

After the ISSWG team chose initial placements on the 2 mm mosaic, those areas were imaged again on sol 16 from a distance of ~1.2 m in order to create the 1 mm mosaic. This was used to confirm placement locations.

Bundle Adjustment: The IDC is not a traditional stereo camera. Rather than two cameras with a fixed and known baseline as in most other Mars surface missions, the IDC is a single camera on a movable arm. The separation between images needed for stereo ranging is created by moving the arm. Since the arm's position is only known to ~1 cm, this introduces a great deal of uncertainty in the baseline between stereo pairs, and accurate knowledge of the baseline is critical for stereo ranging. Thus, the position of the cameras had to be adjusted using a process known as bundle adjustment (BA) [5].

Bundle adjustment uses tiepoints, which indicate the same features in multiple images, to correct the camera locations. In brief, it moves the cameras around in space in order to minimize the error from projecting tiepoints into different images. Under the hood the BA uses a nonlinear least square optimization.

This was complicated by the lack of control points – there were no XYZ reference points in the workspace. Although the lander has fiducial markers on the deck with known XYZ coordinates, pre-landing analysis showed errors of 10-15 pixels in their expected locations, likely due to errors in the arm kinematic solution, so they were considered unreliable.

Despite these kinematic errors, the telemetered pose of the camera was close enough to use as a starting point. This was critical to maximize the chances of the BA converging at the global minimum, as *a priori* knowledge helps reduce the possibility of spurious solutions. Also helping the process was the extremely high overlap between frames, required due to the obscuration of the arm. This allowed the selection of ground features visible in multiple images, which brought strong geometric constraints to the BA.

The bundle adjustment process is somewhat self-correcting, especially when provided with *a priori* camera pose information. Nonlinearities in the camera model combined with variations in the terrain make it such that the global minimum is very likely the correct solution if the camera model is accurate. Finding the global minimum is key, and *a priori* pose information is the best way to do that reliably.

Figure 1 shows the DEM (Digital Elevation Model) from the 2 mm mosaic before and after BA. Errors in Z before adjustment averaged 5.0 mm, up to 10.0 mm, while after BA they averaged 1.9 mm, up to 3.9 mm. Figure 2 shows the corresponding image mosaic.

It is interesting that the results obtained on Mars were significantly better than those obtained during any of the pre-landing tests. This may be attributable to better performance of the flight unit's arm kinematics vs. the testbed, or a material that is easier to tiepoint (the testbed uses a crushed garnet with a fairly large grain size, which is hard to correlate on).

The 1 mm mosaic was similarly bundle adjusted, but the 2 mm mosaic was used to create a control network (i.e. the 2 mm mosaic was "fixed" and not allowed to move during BA). Thus, the 1 mm mosaic was coregistered with the 2 mm mosaic.

Mosaic Production: The MIPL pipeline [3,4] does automated stereo processing of all stereo pairs from InSight. However, when the camera poses change as the result of BA, the XYZ coordinates of each pixel must be recomputed. Fortunately, the stereo correlation process, which is the most time consuming part of stereo analysis, need not be rerun. Scripts were used to recompute all of the XYZ data based on the BA results.

The marsortho program [3,4] was used to create orthomosaics. These orthomosaics create a true overhead view using the XYZ coordinate of each pixel to place that pixel in the correct spot in the mosaic.

Despite being radiometrically corrected, the mosaic had significant brightness seams. A brightness correction process [3], similar to BA but adjusting the brightness and contrast of each frame in HSI color space, brought all the brightness seams into line.

Placement Products: The MIPL team developed a series of analysis programs to help ISSWG determine where to place the instruments. These programs analyzed the part of the workspace reachable by the arm, the tilt of the instrument if it were placed at each point, and several aspects of surface roughness under the in-

these into one summary product, per instrument, showing where the instrument could be placed [3,4].

As luck would have it, InSight landed in an almost perfectly flat, rock-free location. Thus, almost the entire workspace was green, meaning it met all tilt and roughness criteria. After working with challenging workspaces on every prelanding test, this was quite a surprise to the team! Figure 3 shows the goodness maps for SEIS and HP3.

Although the benign environment means the placement programs turned out to not provide much additional information, they may see another life, as the team is considering how to re-use them to characterize landing sites for the helicopter on the Mars 2020 mission [6], which has much in common with instrument placement.

References: [1] Golombek, M. et al (2018), Space Sci Rev 214:84. [2] Maki, J. et al (2018), Space Sci Rev 214:105. [3] Deen, R.G. et al (2018), PDS InSight Camera SIS. [4] Abarca, H. et al (2018), Space Sci Rev (in review). [5] Triggs, B. et al (2000), IWVA 1999 pp.298-372. [6] Balaram, B. et al (2018), doi: 10.2514/6.2018-0023
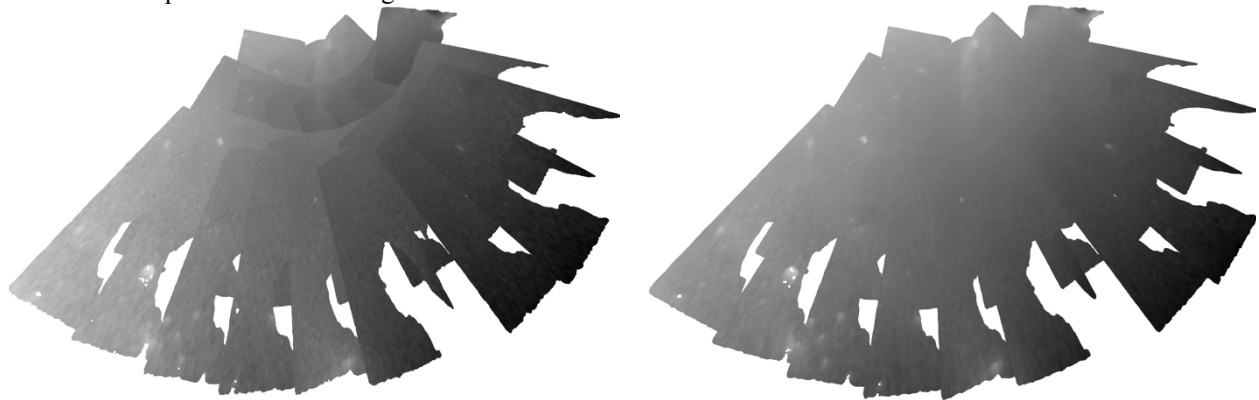

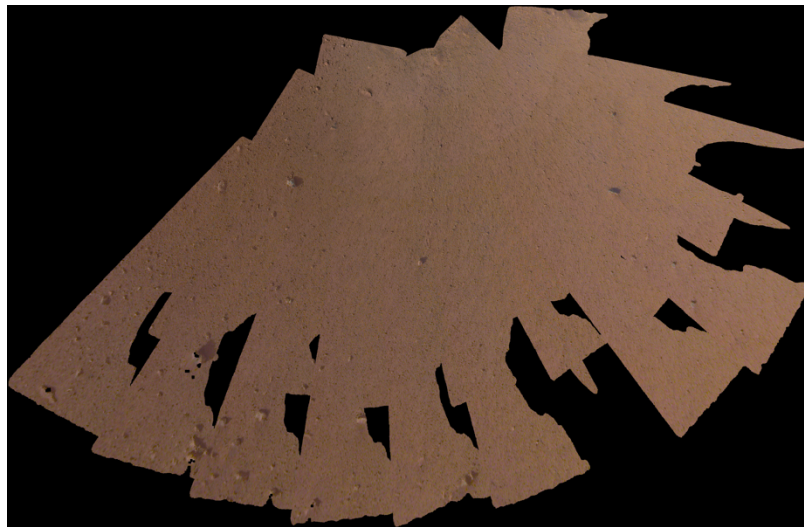**Figure 1: Workspace 2mm DEM before (left) and after (right) bundle adjustment**
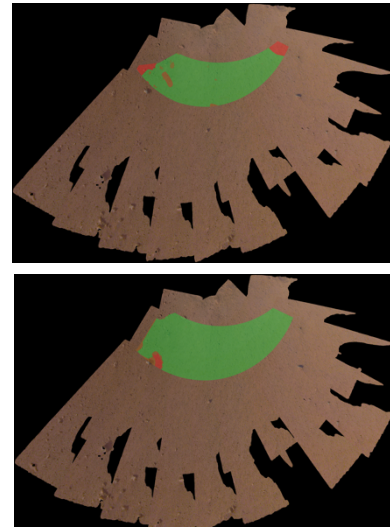

Figure 2: 2mm workspace mosaic

Figure 3: Goodness map for SEIS (top) and HP3 (bottom)