Production of the InSight Workspace Mosaics

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2mm "Low-Resolution" workspace mosaic from sol 12

1mm combined HP3 and SEIS "High-Resolution" mosaic from sol 16

Introduction

- InSight's two primary instruments (SEIS and HP3) had specific requirements and "desirements" on where they could be placed[1,4]
- Instrument Site Selection Working Group (ISSWG) was responsible for determining where to place them[4]
- Workspace mosaics were the primary data sets used to make this determination

Workspace Mosaics for ISSWG

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

Vertical Projection of ICC

- ICC (Instrument Context Camera) is a single, non-stereo camera[2]
- Approximate maps made using a vertical projection[3,4]
  - Assumes a flat, planar surface
- Not discussed further here

2mm/pixel "Low-Res" Mosaic

- Primary mosaic used to determine instrument placements
- Covered the entire workspace
- Acquired on sol 12, ~1.5m from ground, 26 stereo pairs
- Area under tether box was acquired on sol 14

1mm/pixel "High-Res" Mosaic

- Used to confirm placement locations
- Acquired on sol 16, ~1.2m from ground
- Two of these, one for the SEIS location and one for the HP3
  - 12 stereo pairs each (24 total)
- SEIS and HP3 mosaics overlapped, so usually presented together

Bundle Adjustment

- IDC (Instrument Deployment Camera) is not a stereo camera, rather it is a single camera on an arm[2]
- Arm moves to create offset needed for stereo imaging
- Position knowledge accuracy is ~1cm
  - Thus, the camera baseline is not well known
  - This introduces significant error into the stereo ranging
- Bundle Adjustment[5] (BA) is used to adjust position of cameras
  - Tiepoints indicate same features in different images
  - BA moves the cameras around in space to minimize the error projecting tiepoint from one image to another
  - Nonlinear least squares optimization, implemented using the Ceres solver[7]

Control Points

- 2mm mosaic had no control points
- Fiducial markers on deck were not considered reliable
  - 10-15 pixel errors in pre-landing analysis
  - Likely due to errors in arm kinematic solutions
  - Issues compounded by markers being ~1m above the scene
    - Using them tended to skew the solution significantly
- Relied on *a priori* information as a starting point
  - Telemetered location and orientation of camera
  - Reduces the chances of spurious solutions
- Extremely high overlap helped BA as well
  - Required due to obscuration by the arm
- BA is somewhat self-correcting
  - Especially when provided with *a priori* pose information
  - Nonlinearities in camera model and variations in terrain make it likely the global minimum is correct if camera model is accurate
- 1mm mosaics used 2mm mosaic as a control network
  - Ensured coregistration between the 1mm and 2mm mosaics

Bundle Adjustment Results

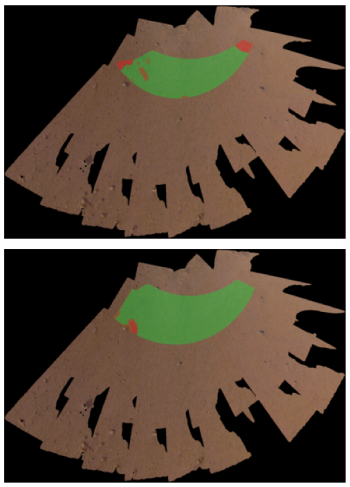
- Before BA: Z errors averaged 5.0mm, up to 10.0mm
- After BA: Z errors averaged 1.9mm, up to 3.9mm
- No ground truth, so "error" is defined as differences between overlapping frames
- Results on Mars were significantly better than any pre-landing tests
  - May be due to better performance of flight arm's kinematics vs. the testbed
  - May also be due to materials that are easier to tiepoint
    - Testbed uses a crushed garnet with a fairly large grain size

Mosaic Production

- MIPL pipeline[3,4] does automated stereo processing of all (non-BA) stereo pairs
- BA results required XYZ coordinates to be recomputed
  - But the time-consuming correlations could be re-used
- "marsortho" program[3,4] created orthomosaics
  - True overhead view using the XYZ coordinate of each pixel to place that pixel in the correct spot in the mosaic
- Brightness correction process[3] used to reduce brightness seams
  - Similar to BA, but adjusts brightness and contrast of each seam in HSI (Hue, Saturation, Intensity) color space
  - "Tiepoints" are mean and standard deviation statistics of pixels in overlap areas

Placement Products

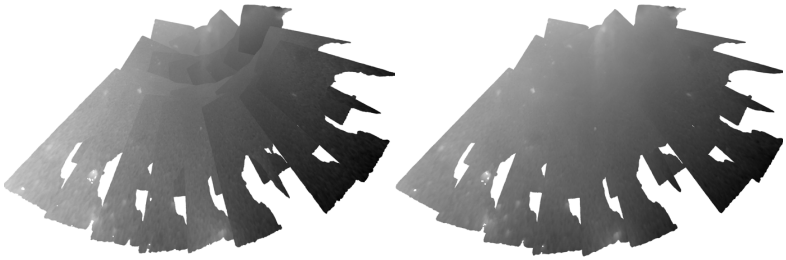
- A series of analysis programs helped ISWG determine where to place the instruments[3,4]
- Each examined one aspect of the instrument to asses how it would perform if placed at each pixel
  - Workspace reachability (based on arm kinematics)
  - Instrument tilt
  - Instrument body roughness (are there "hills" underneath that could touch the instrument belly)
  - Instrument feet roughness (will the feet be stable)
- Goodness map combined all of these into one summary product



Goodness map for SEIS (top) and HP3 (bottom). Green meets all criteria; red fails one or more.

Conclusion

- InSight landed in an almost perfectly flat, rock-free location
- Almost the entire workspace showed green in all criteria
- Quite a surprise to the team, after having challenging workspaces in every pre-landing test
- Instruments were deployed successfully
- Placement programs may be re-used to characterize landing sites for the helicopter on the Mars 2020 mission[6], which has much in common with instrument placement



2mm Digital Elevation Model (DEM). Uncorrected on left; after Bundle Adjustment correction on right

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References

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