FULLY CONTROLLED 6 METERS/PIXEL MOSAIC OF MARS' SOUTH POLE AND EQUATOR FROM MARS RECONNAISSANCE ORBITER CONTEXT CAMERA, II. S.J. Robbins[*,1], R.H. Hoover[1,2], M.R. Kirchoff[1]. [*]stuart@boulder.swri.edu, [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302, [2]University of Colorado Boulder, Boulder, CO.

Introduction: The Context Camera (CTX) aboard NASA's *Mars Reconnaissance Orbiter* (*MRO*) spacecraft [1] has been returning high-resolution and -quality data of Mars' surface for over a decade. As of PDS release 47 (December 2018, including data through May 2018), the instrument has returned over 100,000 images that cover 97.8% of the planet's surface. However, the images often have ~100s meter offsets from each other and a controlled ground source, resulting in seam mismatches when mosaicking and poor matches to other high-resolution datasets. We have developed an efficient, accurate workflow within *ISIS3* software and driven by Python scripts to automate much of the control net process for purposes of creating a fully controlled CTX dataset while maintaining our work environment within the community standard that is *ISIS3* (USGS's *Integrated Software for Imagers and Spectrometers v3*). Here, we demonstrate the viability of our process by creating a mosaic of the south polar quadrangle ("MC-30") and an equatorial region (±7.5° N, 0–360° longitude) that total 17.8% of Mars' surface area.

Workflow, Automated: To begin with manageable regions (generally limited to a few hundred images to facilitate the manual components – see "Workflow, Manual" section), we divide the planet into the historic "Mars Chart" regions, 30 approximately equal-area quadrangles used in the mapping community. We further divide these into 16 equal latitude/longitude regions (thus, each region is *roughly* 1/480th of the planet). The result is a median of ~200 images per region, though areas of high interest have significantly more images (*e.g.*, poles, Valles Marineris, landing sites). Images in these regions are extracted and processed through a standard CTX data reduction workflow in *ISIS3* software, including an empirical horizontal flat-field process to remove edge darkening. Images are then <u>manually</u> screened to ensure surface features are visible with reasonable signal-to-noise, and they are removed if not.

We then use a process of standard tools within *ISIS3* to create a relative control network, including FOOTPRINTINIT, FINDIMAGEOVERLAPS*, AUTOSEED*, CNETREF, POINTREG, and JIGSAW. (Relative control is when the same feature in multiple images projects to the same location on a planet, though that location may not be the "correct" location.) Our workflow includes multiple templates to register control points and additional checks for validity of the control points beyond those built into the *ISIS3* tools. For example, after a control network is created and validated, high residual points are automatically extracted, attempted to be registered again with different templates, and removed if residuals are not sufficiently reduced.

In *most* of the 480 regions of Mars, this entire process can fully control *all* quality images in the region on a high-end modern personal computer in less than one day, and it requires <u>no</u> manual effort. In fact, most of the equator has been running on a 20<u>08</u> MacPro, and taken 25–30 hours (middle range).

However, a modification to this workflow is required for polar regions: Instead of registering all images together initially, sub-sets of images are controlled separately. The sub-sets are grouped by L_s (season) such that the same seasonal processes should be recorded in the images. The L_s boundaries of the image lists overlap each other such that, after each set is completely controlled, they can be merged into a final control solution without islands. The image overlaps ensure there will be one, fully connected network rather than several separate networks. These separate image lists do significantly increase the CPU time required to process the region, and the highly variable south polar features and lighting at CTX scales mean that our extra validation and adding of points steps have more work. This, combined with needing to test more possible points before finding good matches, results in the polar regions requiring on the order of ~10× more time than any other region of Mars (roughly two weeks each).

*In cases of significant numbers of overlapping images, FINDIMAGEOVERLAPS can catastrophically crash, and before crashing, use an extreme amount of computer resources (*e.g.*, 500 GB of RAM). We have created an alternative version in Python of FINDIMAGEOVERLAPS and AUTOSEED that we use near the poles in order to mitigate this issue.

Workflow, Manual: After each region is relatively controlled through these fully automated steps, several control points throughout the region are constrained through registration to a known ground source. For non-polar regions, we use the fully controlled THEMIS Daytime IR mosaic available from USGS, but which does not yet exist for polar areas. For polar regions, we use the MOLA gridded data product which has high enough coverage poleward of ±65° that larger features in CTX data can be reasonably interpolated and recognized. This process is currently manual due to the significant scale differences and resulting false matches between CTX and either THEMIS or MOLA.

Finally, when separate, adjacent regions are fully controlled, the networks are merged together. CTX is a linescan camera and *MRO* has a tilted orbit such that all images on the edges of regions are also in adjacent regions. So, the networks for adjacent regions merge together well, without issue nor need for manual effort.

For mosaicking, we use several built-in tools in *ISIS3* for image-image equalization and tone-matching. Image order is initially an automated process based on a custom code that assigns scores to images based on L_s, pixel scale, emission angle, and incidence angle compared to a reference ideal. Once completed, we also manually inspect every mosaic to determine if there are seam mismatches (and need to manually add or remove control points) and to adjust image order (to emphasize the highest quality images).

Figure 1 illustrates in a few frames the effect of our process and comparison with THEMIS.

Standards: We emphasize that our work uses the community-standard *ISIS3* software, meaning that all tracking of uncertainties and other types of output produced by this software are maintained. Our Python wrapper uses standard libraries and, via its nature, Python is a free compiler that can be run on almost any computer. Additionally, we use native Python tools to divide the work into multiple files such that we can take advantage of modern high-core-count computers. Only a few *ISIS3* tasks truly need to be done in serial, on one processor (*e.g.*, JIGSAW, and AUTOMOS).

South Polar Mosaic: MC-30 (Mare Australe) is about 4.7% of Mars' surface and, as of PDS release 47, has 8467 images that met our specifications to mosaic (see the manual screening discussion in the "Workflow" section). These cover 95.6% of the surface area of the region, though it is significantly more complete south of about –70°N. Significant seasonal effects made the automated networking difficult in some locations so that some manual effort was required for a few of the images. These manual effort locations coincided with areas of poorer signal-to-noise images and images that had *significant* variations in appearance. We expect to have a completed mosaic near the time of this meeting that we can present, and it will be submitted to *Earth & Space Science*; when accepted by that journal, the mosaic and SPICE data will be released to PDS.

Equatorial Mosaic: We have constructed a fully controlled equatorial mosaic of Mars, spanning ±7.5° latitude. This constitutes 13.1% of Mars' surface and, as of PDS release 47, has 13,603 images that met our specifications to mosaic. These cover 97.9% of the surface area of the region. Our processing code worked well enough such that no manual effort was required until the full control step, tying the images to THEMIS Daytime IR. We consider this a first step, proof-of-concept for a fully controlled global product and, therefore, we have no plans to broadly publicly release it. However, interested parties can contact us to request a copy.

Future Mars Work: Our goal is to create a fully controlled CTX dataset, from which to create a fully controlled 6 m/pix mosaic of the surface, using our established and proven workflow. We would publicly release the mosaics, SPICE solutions, and other data such as the control network. We are currently pursuing funding towards this goal.

Future Non-Mars Work: While our workflow was developed specifically for CTX data, it should be generalizable to other imagers that were sent to other bodies. We have done preliminary adaptations of our code for *MESSENGER* MDIS, *Cassini* ISS, and *New Horizons* LORRI, but further work is contingent upon additional funding.

References: [1] Malin et al. (2007). doi:10.1029/2006JE002808.

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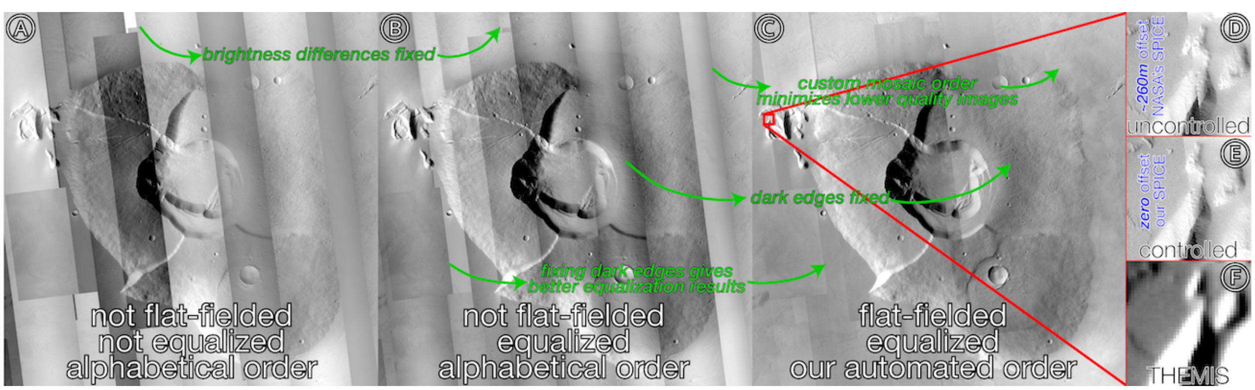

Figure 1: Mosaic with Ⓐ no corrections; Ⓑ with tone-matching; Ⓒ with tone-matching, flat-fielding, and our automated image ordering. Some seams are still visible, but the mosaic is *much* more even, and the northeast portion of the volcano is now apparent. Ⓓ Uncontrolled mosaic with default SPICE has ~260m offset between these images, while Ⓔ is fully controlled and shows no offset, and Ⓕ shows the THEMIS Daytime IR mosaic for resolution comparison.