FULLY CONTROLLING MARS RECONNAISSANCE ORBITER CONTEXT CAMERA IMAGES AND PRODUCING PHOTOMETRICALLY STABLE MOSAICS. S.J. Robbins[*,1], M.R. Kirchoff[1], R.H. Hoover[1]. [*]stuart@boulder.swri.edu, [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302.

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 51 (December 2019, including data through May 2019), the instrument has returned over 100,000 images that cover >98% of the planet in good quality. However, 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 developed an efficient, accurate workflow within *ISIS3* (USGS's *Integrated Software for Imagers and Spectrometers v3*), driven by Python scripts, to automate much of the control process to create a fully controlled CTX dataset. We demonstrated the viability of this workflow by producing a mosaic of Mare Australe ("MC-30"), covering south of –65°N, or 4.7% of Mars' surface [2]. We have also done other regions of Mars, totaling >25% of its surface.

While our process at its heart is aimed towards producing updated SPICE camera and spacecraft kernels, we realize that the primary aspect most researchers would be interested in is a mosaic. Unfortunately, the CTX instrument is poorly calibrated, and mitigating factors like seasonal changes and atmospheric clouds and aerosols prevent seamless mosaics from being constructed. While [3] have presented a workflow to create the appearance of a seamless product by mosaicking images along lines of minimal contrast, we have developed a different method of empirical photometric control [4], which uses a reference source to produce an equalized product that minimizes brightness mismatches. At the time of this writing, the method [4] and photometric source [5] are in peer-review, but we demonstrate them here, as well.

Automated Control Network Workflow [2]: To begin with manageable regions (generally limited to a few hundred images to facilitate the manual components), we divide the planet into "Mars Charts:" 30 approximately equal-area quadrangles. 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 ~250 images per region, though areas of high interest have significantly more images (*e.g.*, poles, Valles Marineris, landing sites). Images 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 manually screened to ensure surface features are visible with reasonable signal-to-noise, and they are removed if not.

We use standard tools within *ISIS3* to create a relative control network, including FINDIMAGEOVERLAPS*, AUTOSEED*, 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. Our code uses an iterative spacing for candidate tie points, creating an initial coarse grid, then creating additional, finer grids only where needed due to lack of well registered points from the initial grid. *We have created an *alternative* version of these *ISIS3* programs, within Python, to deal with known issues of single-threading and RAM usage in calculating polygon overlaps.

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 no manual effort. Polar areas can take ~10–30× longer than other regions of Mars (a few weeks). This is because our adaptive grid approach to creating candidate tie points relies on the idea that significantly less surface area each time needs more points, such that the number of new candidate points does not increase dramatically. So, despite the finer spacing, less time is needed to register them. This is not the case in areas with temporal changes, like the poles.

Manual Adjustment Workflow [2]: After each region is relatively controlled through these fully automated steps, the network is checked for residuals and regions that lack sufficient tie points. Then, several 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. For polar regions, we use the MOLA gridded data product which has high enough spatial coverage poleward of ±65° that larger features in CTX data can be reasonably recognized. This process is 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. Thus, the networks for adjacent regions merge together well without need for manual effort.

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 libraries to divide the work for each region into multiple files such that we can take advantage of modern high-core-count computers, allowing our code to generally run in a day as opposed to two weeks, per region. Only a few *ISIS3* tasks truly need to be done in serial, on one processor (*e.g.*, JIGSAW, and AUTOMOS).

South Polar Mosaic [2]: MC-30 (Mare Australe) is about 4.7% of Mars' surface and, as of PDS release 48, has roughly 10,000 images that met our quality requirements. These cover 95.5% of the surface area of the region, though it is significantly more complete south of about –70°N (Figure 1). The final network has 3 million tie points, and 99.77% of them have residuals ≤1 pixel (RMS = 0.255 pixels). The products will be released as a PDS product pending acceptance of our manuscript to *Earth & Space Science*.

Additional 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. In pursuit of that, we have controlled >25% of the globe to try to demonstrate the success of our process.

Photometric Correction [4,5]: Normal equalization methods that adjust brightness and contrast are insufficient for images that are internally variable relative to others, such as containing an along-track gradient. A method that has been somewhat informally used in the literature but described in detail by [6] is to use a low-resolution, photometrically stable source image or mosaic, and tie the brightness of the higher resolution images to it. Mars Orbiter Camera Wide-Angle images, taken limb-to-limb, have this property when hundreds of images are combined. We created mission-averaged mosaics at cardinal L_s times (±5°) to generate this photometrically stable, low-resolution (9 ppd) basemap [5]. To that, we tie CTX images in order to create a photometrically stable, high-resolution product (Figs. 1–2).

References: [1] Malin et al. (2007). doi:10.1029/2006JE002808. [2] Robbins et al. (in rev). "Fully Controlled 6 meters per pixel Mosaic of Mars' South Polar Region." [3] Dickson et al. (2018). LPSC #2480 doi:10.1029/2010JE003755. [4] Robbins et al. (in rev) "Empirical Photometric Control of Mars Context Camera Images." [5] Robbins (in rev) "Mars' Red … Reflectivity Averaged Over Mars Year 24–28 from Mars Orbiter Camera." [6] Michael et al. (2016) doi:10.1016/j.pss.2015.12.002.

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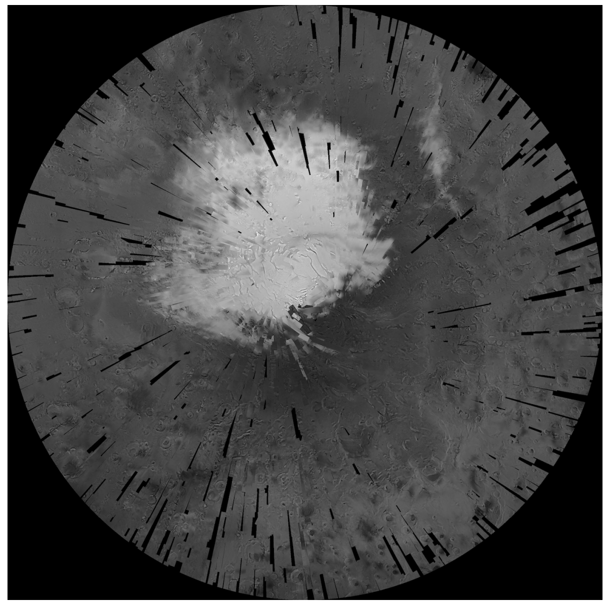

Figure 1: Very low-resolution version of the MC30 mosaic, with non-linear brightness scaling applied to reproduce well here.

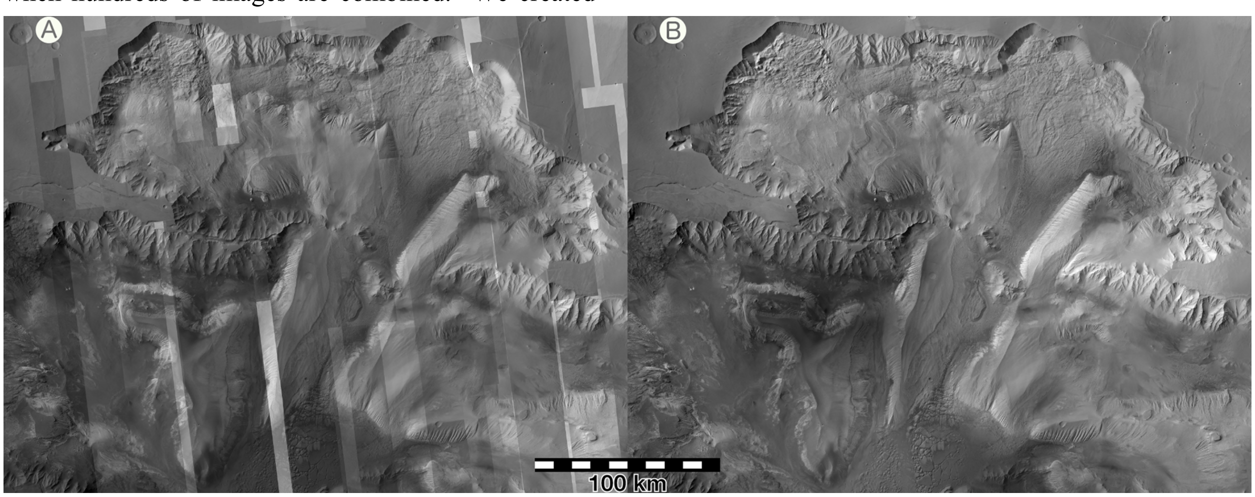

Figure 2: 162 image mosaic centered on Ophir Chasma, (A) cartographically and (B) photometrically controlled.