FULLY CONTROLLING MARS RECONNAISSANCE ORBITER CONTEXT CAMERA IMAGES AND PRODUCING PHOTOMETRICALLY STABLE MOSAICS (2021 UPDATE). 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 (5–6 mpp) and -quality data of Mars' surface for over a decade. As of PDS release 54 (December 2020, including data through May 2020), the instrument has returned over 115,000 images that cover ~99% 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 >50% of its surface. Over the past year, we have rewritten much of our workflow to make it more efficient: It can now control a full Mars Chart (~1/30th Mars) in a few weeks, producing an efficient control network only on the order of 100 MB.

While our process at its heart is aimed towards producing updated SPICE camera and spacecraft kernels, the primary output most researchers would be interested in is a mosaic. The CTX instrument is poorly calibrated, and mitigating factors like seasonal and atmospheric changes 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.

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 can further divide these into 16 equal latitude/longitude regions (thus, each region is *roughly* 1/480th of the planet), whish were used in our code prior to mid-2020. The result is a median of ~250 images per region, though areas of high interest have more images (*e.g.*, poles, Valles Marineris, landing sites). Images are processed through a standard CTX data reduction in *ISIS3* software, including an empirical along-track flat-field to remove edge darkening. Images are 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 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 code re-write over the past year does not rely on a grid of points on image overlaps, but instead treats every unique image overlap separately and creates points randomly across it, trying to match features. By creating a set maximum number of points for a given area, we can minimize inefficiencies and over-control problems from before, creating smaller networks in less time. 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 matched again with different templates, and removed if residuals are not sufficiently reduced. The code then identifies areas that lack good point coverage and tries to create more in just those areas.

In *most* regions of Mars, our older code can control *all* quality images in a 1/480th region on a high-end modern personal computer in ~one day, and it requires no manual effort. Our newer code can run on 1/30th of Mars in a few weeks and is up to 10× faster. Polar areas can take ~10–30× longer than other regions of Mars: We are running the north polar cap (north of +83.5°, and it is estimated to take >200 days). Polar areas take longer because of the significantly larger numbers of overlapping images, temporal changes, and fewer features to match on 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 and lighting differences 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 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 so we can take advantage of modern high-core-count computers, allowing it to scale well, even up to a cluster. Only a few tasks truly need to be done in serial, on one processor (*e.g.*, JIGSAW network solver).

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 3.1M tie points, and 99.73% of them have residuals ≤1 pixel. The product is available from the USGS Astrogeology's data portal. It was made with our older code so has a less efficient control network.

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 >50% of the globe to try to demonstrate the success of our process.

Photometric Correction [4,6]: 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 [5] 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 [6]. 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. (2020). "Fully Controlled 6 meters per pixel Mosaic of Mars' South Polar Region." doi:10.1029/2019EA001053. [3] Dickson et al. (2018). LPSC #2480 doi:10.1029/2010JE003755. [4] Robbins et al. (2020) "Empirical Photometric Control of Mars Context Camera Images." doi:10.1029/2019JE006231. [5] Michael et al. (2016) doi:10.1016/j.pss.2015.12.002. [6] Robbins (2020) "Mars' Red … Reflectivity Averaged Over Mars Year 24–28 from Mars Orbiter Camera." doi:10.1029/2019EA001053.

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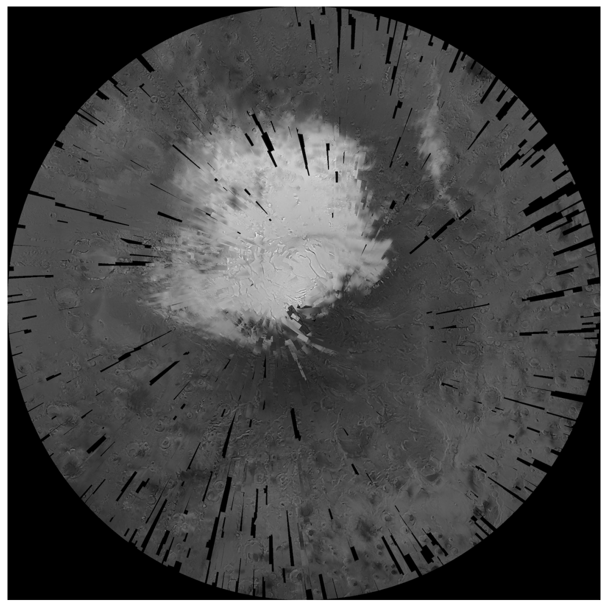

Figure 1: Very low-resolution version of the MC30 mosaic, with non-linear brightness scaling applied to reproduce well here.

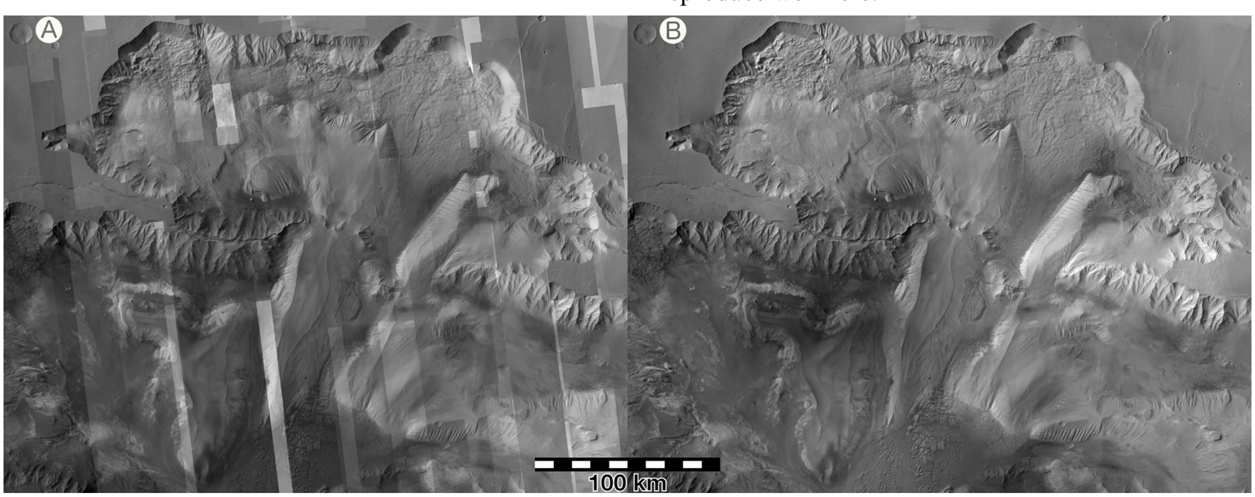

Figure 2: 162 image mosaic centered on Ophir Chasma, (A) cartographically and (B) photometrically controlled.