FULLY CONTROLLING MARS RECONNAISSANCE ORBITER CONTEXT CAMERA IMAGES AND PRODUCING PHOTOMETRICALLY STABLE MOSAICS (2022 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 58 (December 2021, including data through May 2021), the instrument has returned over 120,000 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 v3–6*), 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 controlling Mare Australe ("MC-30"), covering south of –65°N, or 4.7% of Mars' surface [2], and all equatorial Mars Charts (MC-08 through MC-23, between ±30° latitude, covering 50% of Mars). We hope that by the time of LPSC 2022, the paper describing the equatorial mosaic will be in the peer-review process, and we are happy to announce that this work has been funded through a NASA-PDART grant to cartographically control all of Mars and produce the mosaics for release in the ≈2025 timeframe.

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 thousand images to facilitate the manual components), we divide the planet into "Mars Charts:" 30 approximately equal-area quadrangles. Images are processed through a standard CTX data reduction in *ISIS3* software, including an empirical along-track flatfield 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 cartographic control code uses Python and *ISIS* tools to judiciously create candidate tie points based on unique areas of overlap between images and the surface area of those overlaps. By creating a set maximum number of points for a given area, we can minimize inefficiencies and over-control problems of a more naïve grid approach, creating smaller networks in less time. Our workflow includes multiple templates to register tie points and additional checks for validity of the control points beyond those built into the *ISIS* tools (POINTREG). 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 only those areas.

In *most* regions of Mars, our older code (pre-2021) can control all quality images in *1/16th* of a Mars Chart on a high-end modern personal computer in ~one day, with no manual effort. Our new code can run on a *full* Mars Chart in ~5–15 days (depending on image number and how much Mars changes), and it produces control networks up to ~20× smaller, also with no manual effort. Polar areas can take ~10–30× longer than other regions of Mars because of the significantly larger numbers of overlapping images, temporal changes, and fewer features to match on the poles.

Manual Adjustment Workflow [2]: Then, several points in 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. When feasible, we do this process while a given region is running through the automated code to help ensure it converges to a low-residual, correct solution. After that, the network is checked for residuals and regions that lack sufficient tie points and manually edited to fix those issues.

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 *ISIS* 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-thread-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.*, the 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; by PDS release 58, the number was up >30%, so we will have better coverage in our 2025 product. PDS release 48 covers 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: We are now funded to do this work fully, globally, using all currently released CTX data. We expect to begin in September 2022 with Mars' poles, as they take the longest to control, and then we will work through other regions. We have partnered with CosmoQuest to have volunteer citizen scientists assist with the validation work. If time allows, we do hope to add in newly released images towards the end of our period of performance, but that remains to be determined.

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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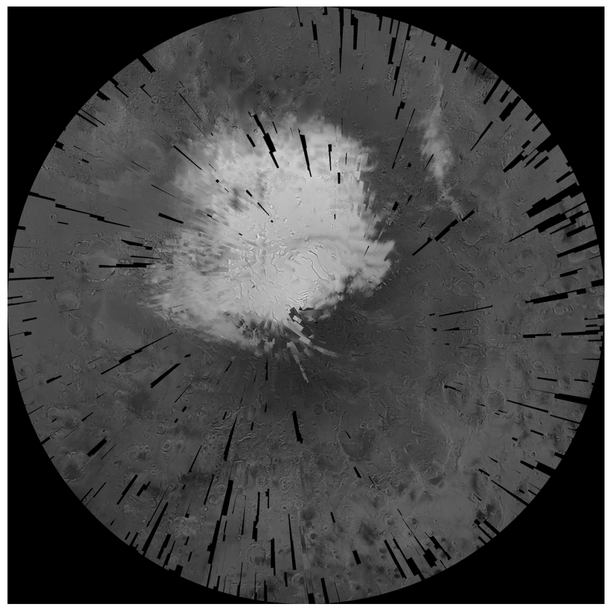

Figure 1: Very low-resolution version of the MC30 mosaic, with non-linear brightness scaling applied to reproduce well here.

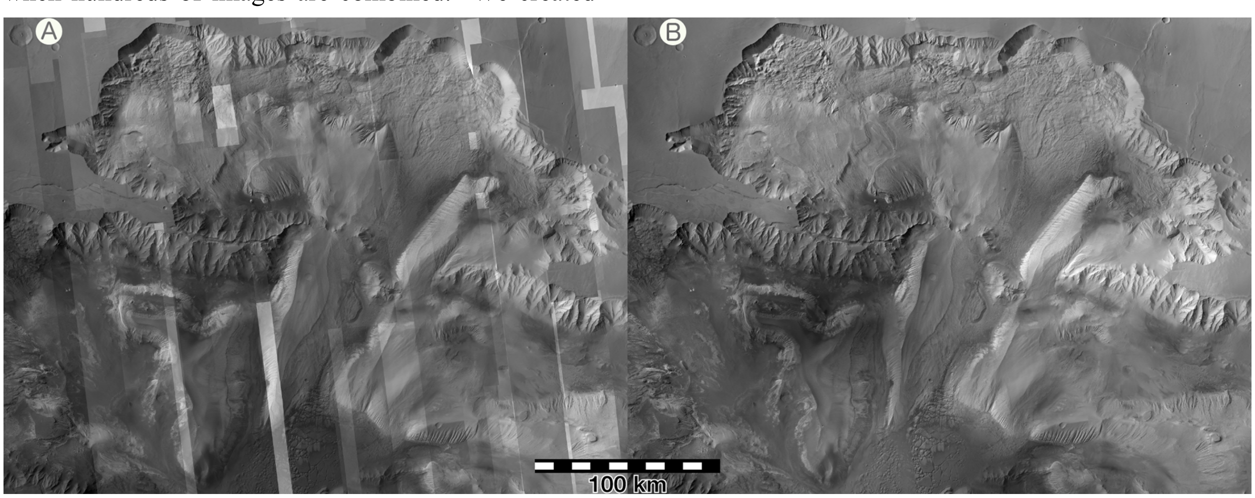

Figure 2: 162 image mosaic centered on Ophir Chasma, (A) cartographically and (B) photometrically controlled.