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Performance of Global 3D model retrievals of the Martian surface using the UCL CASP-GO system on CTX stereo images on Linux clusters and Microsoft Azure® cloud computing platforms

Y. Tao*[a], J-P. Muller[a]

[a]Imaging Group, Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey, RH5 6NT, United Kingdom

ABSTRACT

In this paper we introduce the Mars planet-wide 3D surface modelling work performed within the EU FP-7 iMars project which completed last year. In this report, we describe a fully automated multi-resolution DTM processing chain developed by the Imaging Group at UCL-MSSL, called CASP-GO based upon the heritage NASA Ames Stereo Pipeline (ASP) and the Gotcha image matcher. The CASP-GO system has been integrated into the Microsoft Azure cloud computing environment and successfully processed ~5,300 unique CTX DTMs covering ~19% of the Martian surface at 18m resolution.

Keywords: 3D model, DTM, CASP-GO, cloud computing, Mars, stereo, CTX

1. INTRODUCTION

3D modelling is essential to improving our understanding of the formation processes of the Martian surface as well as for future robotic exploration and human colonisation. Over the last 5 decades, many areas on Mars have been imaged with serendipitous stereo for scientific studies. Within the completed European Union's Seventh Framework Programme (EU FP-7) iMars (http://www.i-mars.eu) project, we focused on developing tools and producing high quality co-registered Digital Terrain Models (DTMs) and corresponding terrain-corrected OrthoRectified Images (ORIs), using data from different NASA and ESA instruments.

In order to produce high quality DTMs large-scale batch processing is required which require a massive number of NASA Mars Reconnaissance Orbiter (MRO) data in a comparably short time period. A fully automated multi-resolution DTM processing chain for the MRO Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) stereo-pairs, called the Co-registration Ames Stereo Pipeline (ASP) Gotcha Optimised (CASP-GO) [1]. CASP-GO is based on the open source NASA ASP [2], with Gotcha sub-pixel refinement [3] and a unique tie-point based multi-resolution image co-registration system [4]. The CASP-GO system [1] guarantees global geo-referencing congruence with respect to the aerographic coordinate system defined by the ESA Mars Express High Resolution Camera (HRSC), level-4 products and thence to the MOLA, providing much higher resolution stereo derived DTMs.

The CASP-GO processing chain was applied to generate ~5,300 CTX stereo-derived 3D imaging products using the MSSL-Imaging processing cluster and the Microsoft Azure® cloud computing platform. These DTMs cover ~19% of the Martian surface at 18m/pixel grid-spacing compared to the current HRSC DTM coverage of around 50% with grid-spacing from 50-150m grids. All those which have been quality assured to date are visible through the iMars webGIS [5] system.

2. THE CASP-GO SYSTEM

The CASP-GO software is based on the ASP pipeline with enhancements from several advanced computer vision algorithms developed at UCL. CASP-GO takes a HiRISE or CTX stereo pair and a reference HRSC ORI as input for CTX processing or a CTX ORI in the case of HiRISE processing. It uses a combination of the ASP functions and the 5th generation of an adaptive least squares correlation (ALSC) and region growing matcher called Gotcha [3], which

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provides accurate and robust sub-pixel conjugate points. CASP-GO generates raster products such as ORIs and DTMs that are co-registered to either a previously processed CTX ORI and DTM or one generated from HRSC.

A workflow of the CASP-GO workflow is shown in [Figure 1] for CTX DTM production consisting of an: (a) ASP image pre-processing; (b) ASP disparity map initialization; (c) UCL fast Maximum Likelihood (f-ML) matching and the building of a "float" initial disparity map; (d) ASP Bayes Expectation Maximisation (BEM) weighted affine adaptive sub-pixel cross-correlation; (e) UCL refined outlier rejection gap erosion scheme to remove and eliminate mis-matched and unreliable disparity values; (f) UCL ALSC based sub-pixel refinement (speeded-up Gotcha referred to below as sGotcha); (g) UCL Gotcha refinement and densification method to refine the disparity value and re-match previously un-matched or mis-matched area; (h) UCL co-kriging grid-point interpolation to generate ORI and DTM as well as generate height uncertainties for each DTM point; (i) UCL ORI co-registration/geocoding with reference to HRSC or CTX orthoimage and DTM adjustment. The outputs consist of a DTM at 18m for CTX or 75cm for HiRISE which is co-registered to HRSC or CTX respectively and thence to MOLA.

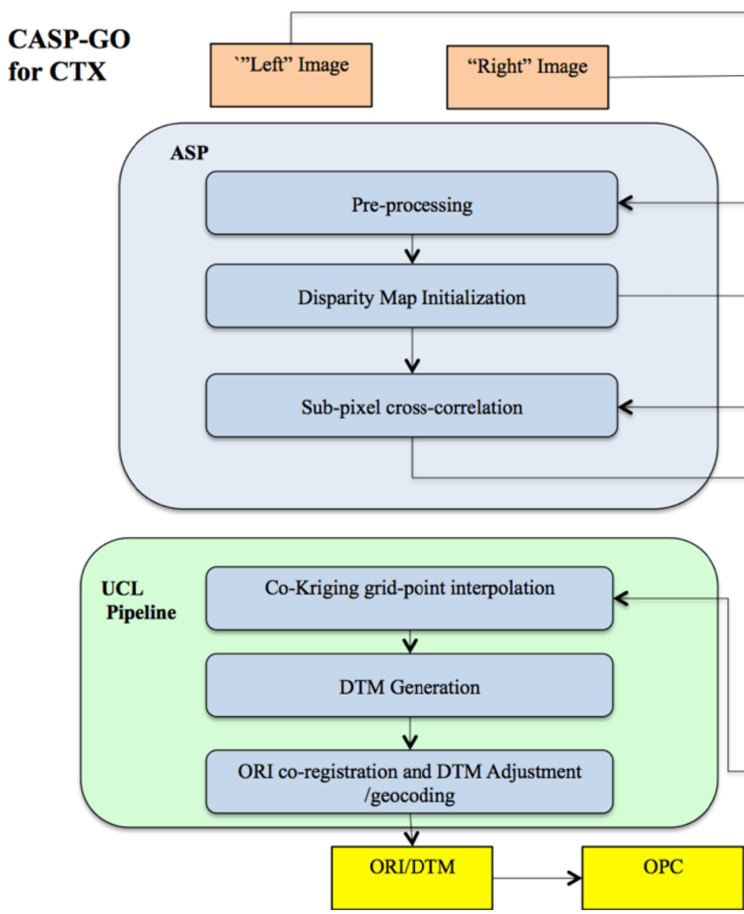

Figure 1 Flow diagram of the CASP-GO system [1]

3. DATASETS AND PRODUCTS

Since 2007, the MRO CTX instrument captures repeat pass single panchromatic grey-scale images at ~6m/pixel over a swath-width of 30km with a large range of stereo angles. The level-4 ESA HRSC products provide the fundamental 3D mapping products as the baseline, where they are available (i.e. for approximately 50% of Mars). When CTX stereo products are also available over the same areas as HRSC (i.e. for approximately 20% of the surface) then the CTX products can be co-registered with HRSC and CTX 3D mapping products can be employed as the baseline for 3D rectification of higher resolution images such as HiRISE.

CTX does not have a capability to capture single-pass multi-angle stereo. Therefore, HiRISE and CTX stereo pairs are composed of images acquired at different times and slew angles. At the time of defining CTX stereo pairs, an overlap threshold was set to 90%. We therefore defined 3,963 CTX stereo pairs all over Mars (http://www.i-mars.eu/publications/products/ctx), together with the 1,540 CTX stereo pairs previously defined in (https://raw.githubusercontent.com/zmoratto/Mars3DGearman/master/CTX_ stereo_pair.txt), resulting in 5,349 unique good quality CTX stereo pairs successfully processed using the CASP-GO system. Figure 2 shows the footprints of the processed iMars CTX and HiRISE DTMs displayed on top of the HRSC level 4 DTM products and MOLA DTM. Figure 3 shows an example 3D model of one of the processed 18 CTX DTMs for the MC11 area at Ares-Vallis, visualised using the Fledermaus® 3D viewer.

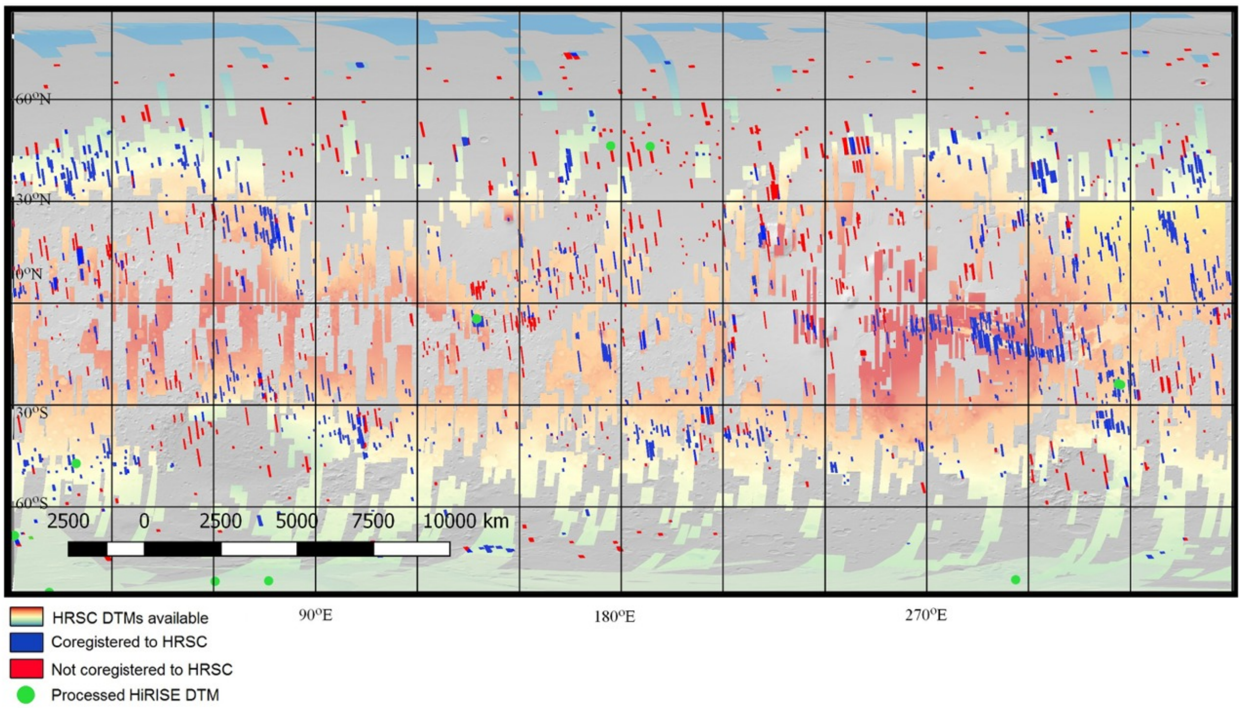

Figure 2. Footprints of the processed CTX and HiRISE DTMs displayed on top of the HRSC level 4 DTM products and MOLA DTM

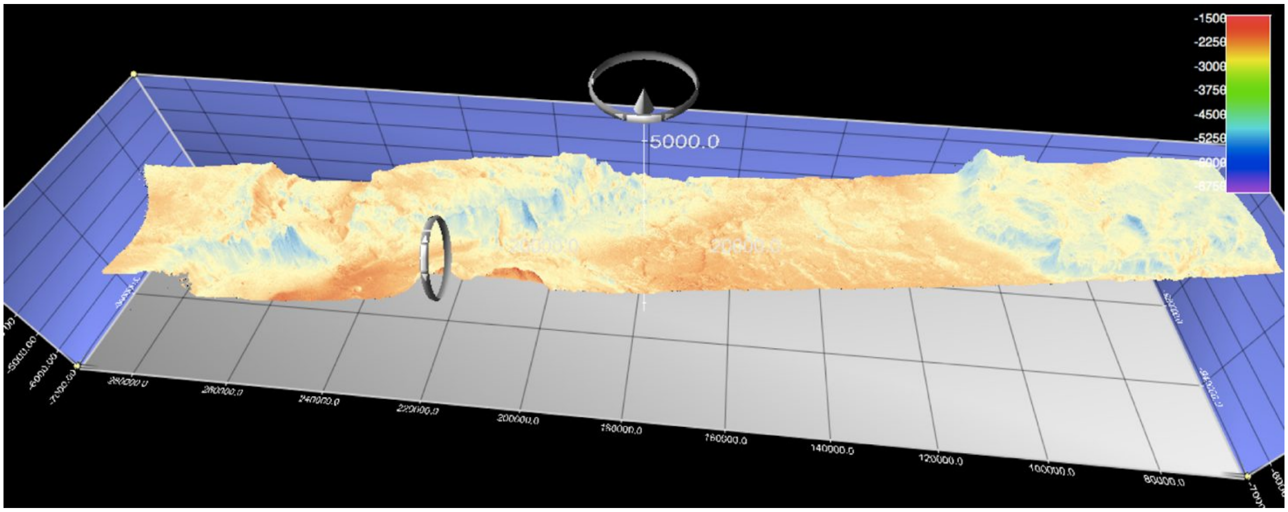

Figure 3. An example of the processed CTX 3D model over Ares-Vallis shown using the Fledermause® 3D viewer.

4. BATCH CTX PROCESSING ON MSSL'S IMAGING CLUSTER

Given the challenges for large data volume and processing complexity to produce high quality DTMs, we initially set-up a batch processing system at the MSSL-Imaging processing cluster for the first 115 CTX stereo pairs. The ESA HRSC and NASA CTX, HiRISE Planetary Data System (PDS) data are continuously synchronized to the shared storage system locally at MSSL due to various project demands. The batch mode of the CASP-GO system running at MSSL-Imaging clusters loads the PDS or PSA data directly from the local PDS or PSA mirror with an option such that if data is unreadable it can be automatically downloaded from the original source at the Planetary Science Archives at European Space Astronomy Centre (ESAC) or the NASA PDS at JPL.

The software is installed in a shared directory, which is accessible from 14 Linux processing blades (10 with 16 cores and 48GB RAM; 4 with 24 cores and 96GB RAM). Jobs are controlled via a local desktop machine and distributed to the 14 processing blades with multiple sessions of multi-threaded processing. Processed results are stored in RAID storage disk partitions and logged back to the local controlling desktop. Failed jobs (at a rate of 2.7%) can be examined through detailed log files and could, if required be reprocessed with different set-ups. A schematic diagram of the UCL-MSSL in-house DTM production workflow is shown in Figure 4. The processing of the first 115 CTX stereo pairs for the Mars MC11 quadrangle took ~3 weeks to complete. It was estimated that the processing time for all the stereo-pairs would be 54,000 hours (≈6 years) using the 24 core blades. Therefore, for the rest of the ~5,300 CTX stereo pairs, we decided to use cloud-computing resources.

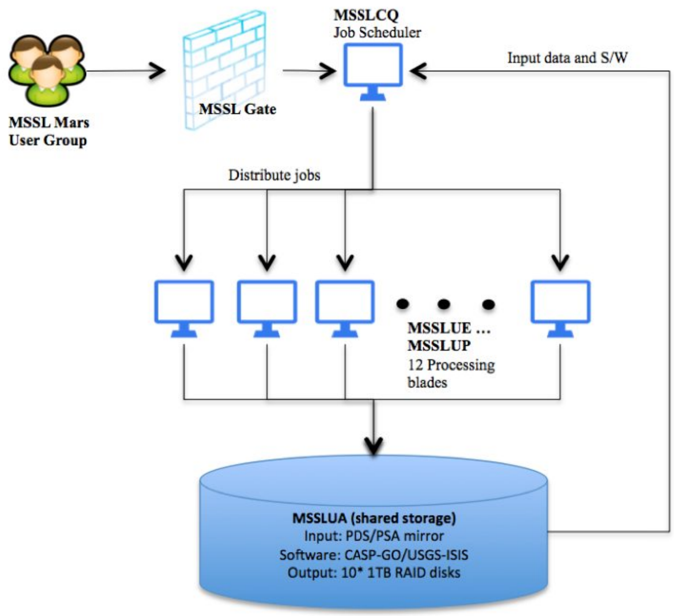

Figure 4 CASP-GO processing set-up at UCL-MSSL's imaging cluster [1]

5. BATCH CTX PROCESSING ON MICROSOFT AZURE CLOUD VMS

In mid 2016, Microsoft Research offered a year of sponsorship to access Microsoft Azure's High Performance Computing (HPC) resource. With Azure HPC, users can deploy a cluster of Virtual Machines (VMs) to the cloud for a short time and scale it up and down for massive parallel compute jobs. The VMs on Azure cloud can be configured automatically using a JSON script specifying the computer grade, login, name, operating system (OS), storage, and networks. The Azure Resource Manager (ARM) is used to combine the resources that comprise applications such as VMs, database, Virtual Networks, and storage accounts into groups so that the entire application can be deployed at the same time. In this work, we configured 70 "Fs" type and 90 "Ds" type VMs running RHEL Linux v7.2 located in the U.S. west area. The "Fs8" VM uses Intel® Xeon® E5v3 processor, with 8 cores and 112GB RAM. The "Ds4" VM uses Intel Xeon® E5-2673 processor with 4 cores and 56GB RAM. A total number of 5,503 CTX stereo pairs were processed using the Azure cloud VMs using a similar batch processing set-up at MSSL's Imaging cluster. The input data is directly downloaded to the VMs from the PDS nodes at NASA JPL. 5,349 (out of 5503) good quality CTX stereo pairs were successfully processed to DTMs and other products. Processing results were temporarily stored on the cloud storage space and downloaded back to MSSL later on. A systematic diagram of the CASP-GO processing set-up at Microsoft® Azure® cloud computing VMs is shown in Figure 5.

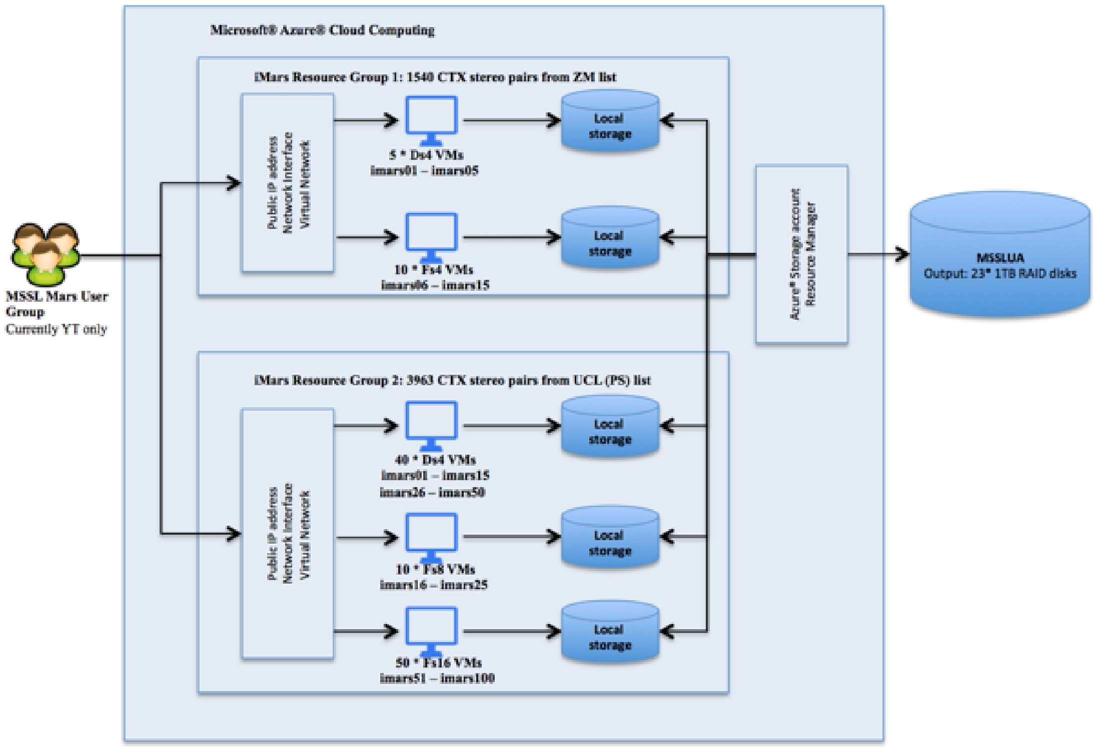

Figure 5 CASP-GO processing set-up at Microsoft Azure® cloud computing platform [1]

The total data volume of the processed CTX DTMs is ~18 TB including metadata and scientific products consisting of matched seed-points, disparity maps at various stages, quality masks, uncertainty maps, XYZ files, ORIs, and colour hillshaded products.

SUMMARY AND FUTURE WORK

In this paper, we introduced the UCL CASP-GO system for fully automated high-quality MRO CTX and HiRISE DTM production. We experienced many difficulties during the processing chain development and testing stage with handling large data size and large data volumes. With help from the Microsoft Azure HPC cloud resource, a total number of ~5,300 CTX stereo products have been produced covering the planet-wide Martian surface. This more complete and fused multi-resolution co-registered 3D models allow a much more comprehensive interpretation of the Martian surface, available to the international community of planetary geo-scientists through an interactive webGIS system (http://www.i-mars.eu) and in the future, will be converted into PDS4 format and released through the ESA PSA host.

ACKNOWLEDGEMENTS

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