AUTOMATED DTM GENERATION AND SUPER-RESOLUTION RESTORATION FROM NASA MRO CAMERAS AND IN FUTURE FROM TGO16 CASSIS. Y. Tao[1], P. Sidiropoulos[1], J.-P. Muller[1], [1]Imaging Group, Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey, RH56NT, UK. (yu.tao@ucl.ac.uk; p.sidiropoulos@ucl.ac.uk j.muller@ucl.ac.uk)

Abstract: An automated MRO camera DTM production pipeline for planetary mapping and separate pipeline for repeat imaging based super-resolution restoration is introduced.

Keywords: HiRISE, CTX, stereo, automated, DTM, Super-resolution restoration, CaSSiS, Gotcha

Introduction: This paper will introduce recent results from a wide range of research and development activities, achieved within the EU FP-7 iMars and PRoViDE projects, in the area of automated 3D reconstruction/DTM generation and super-resolution restoration, both based on the use of the 5th generation of an adaptive least squares correlation matcher, called Gotcha [1]. The experiments focus on the NASA MRO CTX and HiRISE instruments but are planned to be extended to future ESA Mars orbital missions such as ExoMars Trace Gas orbiter (EXMTGO) 2016.

Automated DTM pipeline: The automated DTM processing chain, called Co-registered Ames Stereo Pipeline [2] with Gotcha refinement and Optimization (CASP-GO), takes ISIS formatted "left" and "right" MRO images (HiRISE or CTX) and reference HRSC orthorectified images as inputs. Using a combination of the UCL-Gotcha and NASA Ames Stereo Pipeline (ASP) to generate ORI and DTM in a co-registered geospatial context w.r.t HRSC (and thence to a MOLA reference). The complete workflow has 10 steps: (1) ASP "left" and "right" image pre-processing (image normalisation, LoG filtering, pre-alignment); (2) ASP disparity map initialisation (pyramid cross-correlation and building a rough disparity map); (3) Maximum likelihood sub-pixel refinement and build a sub-pixel initial disparity map; (4) ASP sub-pixel correlation; (5) Reject mis-matched disparity values and erode matching gaps; (6) ALSC sub-pixel refinement; (7) Gotcha (ALSC with region growing) densification of disparity maps; (8) Co-kriging grid-point interpolation to generate ORI and DTM as well as height uncertainties for each DTM point; (9) ORI co-registration/geocoding with reference to HRSC orthoimage and DTM adjustment. (10) Generation of Object Point Cloud (OPC) for 3D real-time visualisation on GPU using Pro3D®, specifically for HiRISE products.

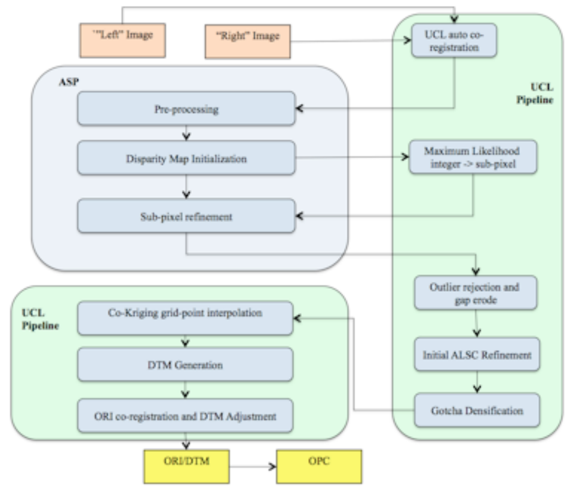

Figure 1 Flow diagram of UCL CASP-GO automated DTM processing chain.

In CASP-GO, we have developed this fully automated processing system with improved performance compared to the original ASP system: (1) Co-registered geo-spatial coordinates w.r.t HRSC (and MOLA) data; (2) Improved DTM completeness for unmatched areas; (3) Reduced DTM artefacts; (4) Improved DTM accuracy; (5) Fully documented uncertainty for every height.

The CASP-GO processing system has been initially applied to MER, MSL, and MC11-E CTX stereo images and is being streamlined to be applied to all HiRISE and CTX stereo pairs (≈3,000 pairs) in the iMars project. Figure 2 shows an example of a colourised hill-shaded DTM and orthorectified image in 3D over Gale crater (MSL).

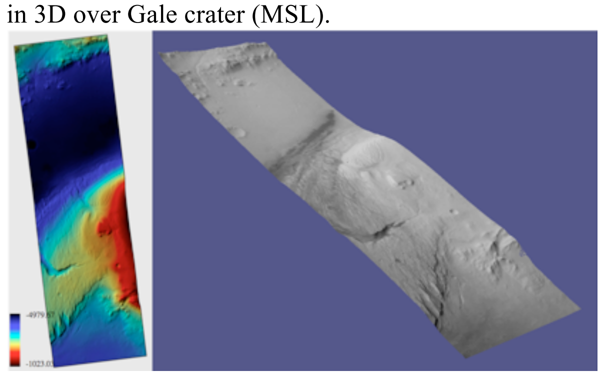

Figure 2. Example CTX DTM and ORI (in 3D) over MSL site.

GPT super-resolution restoration: We have also developed a novel super-resolution restoration (SRR) algorithm/pipeline, called Gotcha-PDE-TV (GPT), to be able to restore higher resolution images from the non-redundant sub-pixel information contained in multiple lower resolution raw remotely sensed images. The GPT-SRR technique [3] was developed in the PRoViDE project to obtain improved scientific understanding of the Martian surface using a combination of orbital and rover imagery in order to better support several critical engineering rover operations, such as landing site selection, path planning, and optical navigation for automated rover localisation. The technique is, we believe, unique, since (a) we not only use sub-pixel information from small translational shifts but also restore pixels onto an orthorectified grid from different (comparably large) viewing angles, and are therefore able to achieve a 2-5x enhancement in resolution; (b) we use a novel segmentation-based approach to restore different features separately; (c) apply a state of the art Gotcha matcher and PDE-TV regularization to provide accurate and robust (noise resistant) restoration. GPT-SRR is applicable whenever there exist sub-pixel differences and there are comparably large view zenith angle differences, which is always the case in orbital images, even between multiple image acquisitions taken at different times with different solar illumination conditions. Each view is subject to different atmospheric blurring and scattering but as long as the atmospheric transparency is sufficiently high, Gotcha-PDE-TV SRR can be applied.

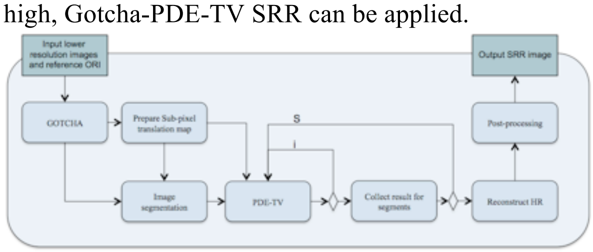

Figure 3 Flow diagram of GPT SRR processing chain (see [3] for further details).

The GPT SRR technique has been initially applied to a stack of 8 MER-A HiRISE images at the Homeplate area (see Figure 4) but has since been applied to image areas comprising the entire Mars rover traverse for MER-A and MSL and due to the poor quality of the HiRISE images to part of the MER-B rover traverse providing an enhancement factor of 2-5x.

We have produced a rock size distribution study [5] using a similar method to [4] and compared these distributions with what we can see and measure automatically on 25cm HiRISE, 6.25cm SRR image and 0.5cm (down-sampled to 2.5cm) Navcam mosaics (JPL vertical projected RDR).

The results suggest that the GPT-SRR algorithm is able to delineate sub-pixel features to enable individual rocks (sizes smaller than 75cm and larger than 30cm), which are not clear or unrecognizable in the original HiRISE image. Accumulated rock numbers between SRR and Navcam mosaic have shown good correlation for rocks larger than 50cm and even 25cm in some cases.

Future work: For the automated CASP-GO DTM pipeline, we have processed some 60 stereo-pairs fully automatically in 10 days are currently about to start processing all the CTX and HiRISE stereo pairs accumulated to date which have overlapping HRSC DTM+ORI coverage in a matter of several months on a large linux cluster. We also aim to process all available image datasets in future where we have repeat multi-view imagery starting with HiRISE first (≈400 locations) and then apply these techniques to CTX after porting the GPT SRR software onto a GPU. We plan to develop this capability for the ExoMars Trace Gas Orbiter 2016 CaSSiS instrument (zooming-up from 4m up to ≤1m/pixel) including both 3D and SRR images from multiple overlapping colour stereo-pairs. All these data products will be distributed through http://www.i-Mars.eu/

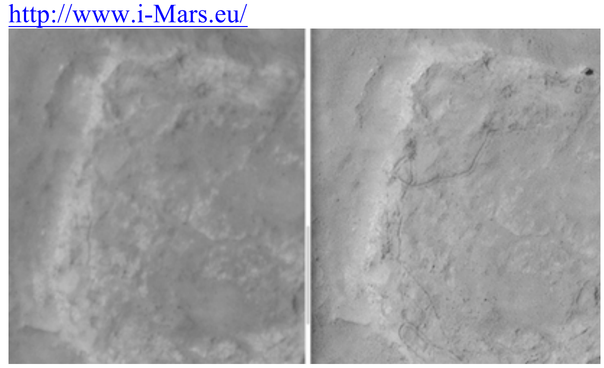

Figure 4. 25cm HiRISE (left) and 5cm super-resolution imagery generated from 8 25cm inputs.

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References: [1] Shin, D. and Muller, J.-P. (2012) Pattern Recognition, 45(10), 3795 -3809. [2] Moratto et al., 2010. LPSC 41, 2364; [3] Tao, Y. and J.-P. Muller, 2015. *Planet. Sp. Sci.*, http://www.sciencedirect.com/science/article/pii/S0032063315003591.[4] Golombek et al., 2012. Space Science Reviews, 170(1-4), 641–737. [5] Tao, Y. and Muller. J.-P., 2015. *European Planetary Science Congress*, vol. 10, EPSC2015-359.