MULTI-RESOLUATION EXTRA-TERRESTERIAL DTM CONSTRUCTION AND GEDETIC CONTROL

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ABSTRACT: In inaccessible topographies such as the planetary surface, stereo analysis of in orbital imagery provides highly valuable data for scientific research. In order to fully utilize the data derived from image systems carried on various planetary orbiters, the generalised algorithms of stereo image processing and photogrammetric Mars DTM extraction have been developed by Kim and Muller (2009). In this study, the integration and improvement of these algorithms were proposed. It is enhanced with the feed-forwarded model based matcher exploiting planetary topographic data hierarchy. Due to the successful "from medium to high" control strategy performed during processing, stable horizontal and vertical photogrammetric accuracy of resultant DTMs were achievable, even without directly measured ground control information. To demonstrate the potential of the stereo routines, the DTMs obtained from various orbital images such as HRSC (High Resolution Stereo Camera) of Mars Express, CTX (Context Camera) and HiRISE (High Resolution Imaging Science Experiment) of MRO (Mars Reconnaissance Orbiter) were processed in few sample test sites. The comparisons with the height spots of MOLA (Mars Obiter Laser Altimeter) showed high agreements and proved the effectiveness of overall processing strategy.

1. INTRODUCTION

The heritage of in-orbit high resolution imaging technology has been implemented in a series of planetary mission, especially over Mars, such as HiRISE and CTX onboard the MRO. The stereo topographic product from such in-orbit imagery with the full verified geodetic control is the essential requirement for the all scientific researches such as the analysis of planetary fluvial activity, volcanology and aeolian process. However the standardized processing method to fully utilize their stereo capability and to attain high enough geodetic accuracy does not exist. For example, the HiRISE and CTX processing using the commercial SOCET S/W developed by USGS Astrogeology team (Kirk et al., 2008) required huge amount of manual works to achieve photogrammetric control as the absence of ground control information has been always prevents the easy system implementation. Hence, Kim and Muller (2008) firstly tackled the problems with "from medium to high" control and then stable horizontal and vertical photogrammetric accuracy of resultant Mars DTM were achieved. Together with the geodetic control problem, the insufficient coverage of stereo imagery has been one of biggest barrier for the utilization of planetary stereo products. Therefore, in this study, we propose a hierarchical planetary topography refinement system based on the above stereo control method.
A few test areas where CTX and HiRISE stereo coverage exists were chosen for the processing capability demonstration of proposed routines and the results are verified compared with MOLA data. The comparison results between laser altimeter height points and stereo DTMs showed extremely good agreement except a few rough topographies.
Conclusively, the quality of the extraterrestrial topographic products created by the hierarchical stereo line was verified and showed the potential for various scientific applications.

2. BACKGROUND

After worldwide devotion, to the understanding of the planetary surface for the last few decades, we are capable of observing various topographic phenomena occurring on the planet. In order to further investigate, analyze and explain mechanisms responsible for their formation, planetary topography data provides critical information and hence plays an essential and important role for these tasks.
The sensor technology and spatial resolution of data over the planetary surface have been rapidly improved. In case of inner planets such as Mars, Moon and Mercury, the resolution of optical sensor is now updated even upto sub-meter spatial resolution. In addition to the spatial resolution of optical image instruments, the 3D pointing accuracy of data integrated from radio tracking and the navigation equipment has been dramatically increased. The most significant improvement in this area is probably the introduction of active measurements by the laser altimeter. Due to the high accuracy, the topographic product derived from laser altimeter has been treated as the geodetic reference data as well as the base standard. An example of the laser altimetry observation for such purposes is MOLA (Smith et al., 2001) onboard the Mars Global Surveyor(MGS). It was the first case of the comprehensive planetary topography measurements with the geodetically verified active sensor (Neumann et al., 2001). The MOLA data sets provide not only the full planetary surface coverage but also reliable geodetic control information for optical

imagery. For the latter contribution, an example is the processing chain called DLR-VICAR (Scholten et al., 2005) dealing with image data acquired by High Resolution Stereo Camera (HRSC) on Mars Express. It employed the MOLA data sets for the control of exterior orientation of HRSC stereo imagery. With such geodetic control strategy, the vertical accuracy of HRSC topographic products up to 40 m (Spiegel,2007; Heipke et al., 2007) was achieved. Due to the satisfactory performance, the HRSC topographic products has been systematically created and has covered more than 40% Martian surface nowadays. It is demonstrated that the idea to make geodetic control of optical imagery using laser altimeter over planetary surface is now widely accepted. Therefore the same kind of laser altimeter such as Lunar Orbiter Laser Altimeter (LOLA) and Mercury Laser Altimeter (MLA) are equipped on the Lunar Reconnaissance orbiter (LRO) for Moon exploration and Messenger in Mercury. Such laser altimetry data sets will be able to be incorporated with the optical imagery and produce geodetically reliable topographic products.

In martian surface, the Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) onboard the Mars Reconnaissance Orbiter (MRO) are also capable of producing stereo optical products (McEwen et al., 2007). Moreover, the spatial resolution of images achieved from 6m to 0.2-0.4m. The idea, MOLA DTM is again applied as geodetic control for processing HiRISE and CTX images through intermediate HRSC DTM and ortho image products was implemented by Kim and Muller (2007, 2009)'s approach and can be enhanced by Lin et al., (2010) surface matching.

As shown in here, a great number of technical improvements in planetary topography observation have been accomplished. However, it is found that the interpretation of planetary topography is still limited even with the large technical improvements. Two of the key issues for comprehensive planetary topographic mapping are the coverage of stereo data and quality of constructed planetary topographic product. In order to address such issues, also to handle the rapidly increasing demand for the topographic datasets for the understanding of the geological, climatic and potentially exobiological evolution of the planet, we proposed to establish a generic topography reconstruction system employing algorithms by Kim and Muller approaches and hierarchical stereo topography updating scheme. Theoretically, the system is capable of processing any planetary stereo data with very high speed and the minimum manual interaction.

3. THE DESIGN OF PROCESSING SYSTEM

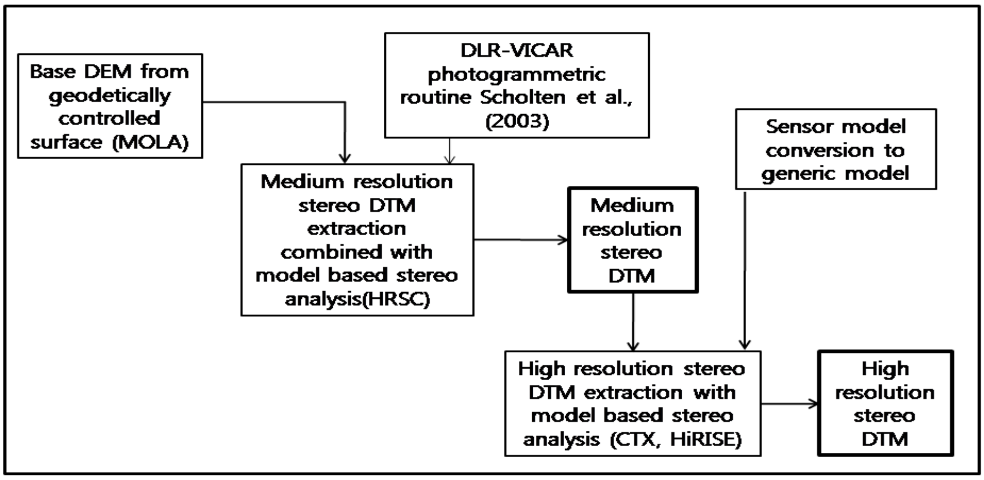


Figure 1. System configuration for stereo and data fusion processors in Martian surface

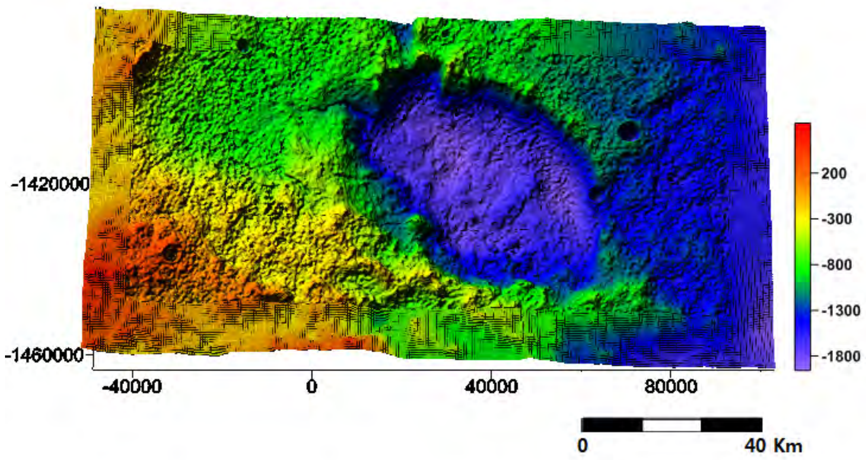
Figure 1 showed the system implementation for the planetary stereo images especially in Martian surface. Main improvement of system compared with the Kim and Muller (2009)'s original are the feed-forward delivery of DTM product in each processing hierarchy for the model-based matching .

Based on the planetary surface observation carried out in last few decades, it is found that a pyramidal hierarchy of topographic data with various spatial resolutions is well established. Take Mars for example, the full Martian surface is covered by MOLA DTM. Medium resolution stereo data sources from HRSC occupy a part of the surface with the improved spatial resolution. Stereo imagery acquired by CTX and HiRISE cover relatively small part of Martian topography with very high resolution. Due to the characteristic, the stereo processing model using hierarchical refinements between each stereo data sources and base topography can be established accordingly. DTM output in a processing step was delivered to next stage and then used to estimate the initial disparity in stereo processors. For example the HRSC DTM was re-employed for the next level CTX stereo line to estimate roughly the initial disparity. It refined by the image matchers based on Gruen's ALSC (Adaptive Least Squared Correlator, Gruen, 1985) algorithms which possess sub-pixel matching capability then delivered to the next image level such as HiRISE. It is highly efficient to process huge stereo coverage with maximum detail. Also it should be noted that the requirement of unified sensor model for providing highly accurate photogrammetric co-registration information which is essential for such strategy was satisfied by the Kim and Muller's control method. The distinguished characteristics of this approach compared with existing planetary stereo processing line are: (1) the geodetic accuracy of resultant topographic products were verified; (2) the "coarse-to-fine" hierarchical processing strategy (HRSC-CTX-HiRISE) for geodetic control is successfully performed to produce Martian DTMs with various resolution; (3) the method can be easily integrated into the high speed processor. To demonstrate the scientific application of this scheme, the test processing over martian surface will be performed as shown in below.

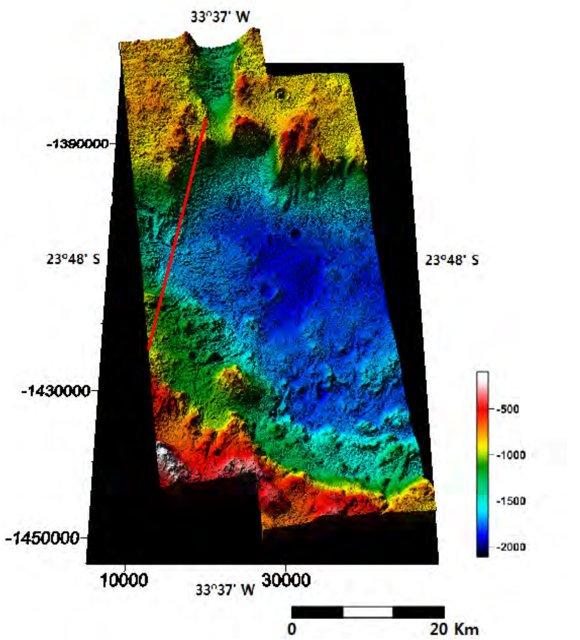
4. PROCESSING RESULTS AND GEODETIC CONTROL ASSESSMENTS

The DTMs by the implemented system were demonstrated in Figure 2 for the Eberswalde crater and Figure 3 for Warrego Valles. It should be noted that DTMs from both CTX and HiRISE were reconstructed from the same hierarchical stereo processor in this study.

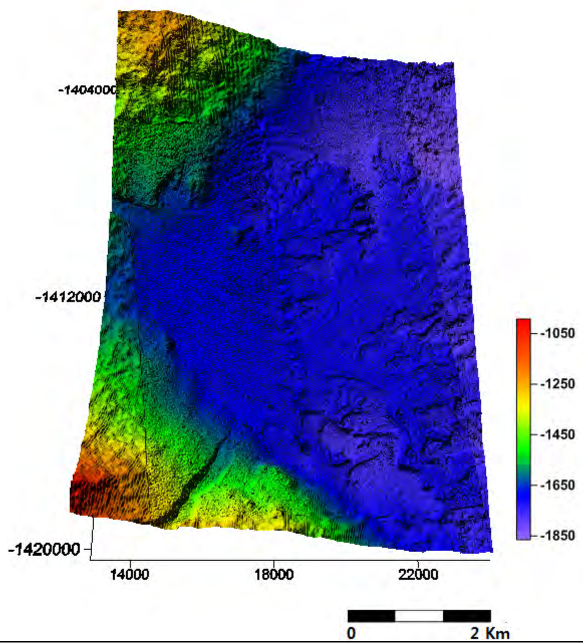
It was very clearly demonstrated that our hierarchical processor well worked through the data pyramid for stereo image coverage. The resulting DTMs from a prior processor were correctly delivered to the next processing hierarchy according to our strategy, as the DTMs didn't show any significant discontinuity around the mosaic boundaries in Figure 2 and Figure 3. The quality assessments of the products employing MOLA height points showed the highly accurate geodetic controls over the stereo DTM coverage (see Figure 4). A little mismatch between MOLA and stereo topography in Figure 4 (a) showed a possibility of small horizontal shift of constructed DTM. The discrepancies as observed in the left portions of Figure 4 (b) may result from some matching blunder in the dark shadowed areas by the highly sloped topography and partly not fully addressed photogrammetric control. However, overall geodetic accuracy is highly accurate even compared with the terrestrial stereo products made by the commercial satellites which have normally decameter scale shifts in horizontal and vertical direction.



(a) 50m HRSC DTM overlapped over 500m grid spacing MOLA DTM background

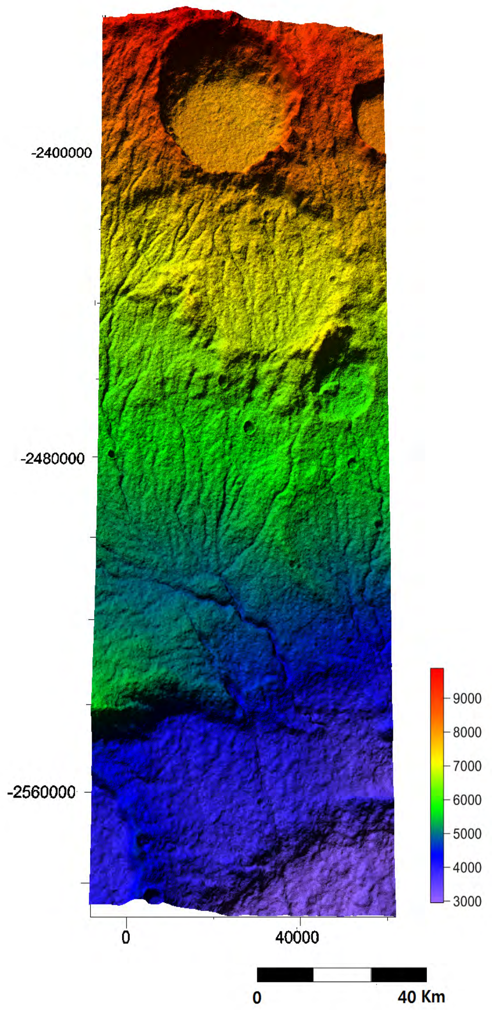


(b) Mosaic of two CTX DTM with 20m grid spacing (note : red line is the MOLA track location for DTM validation)

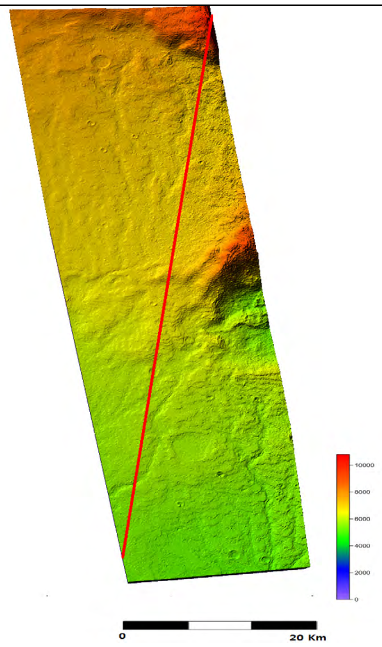


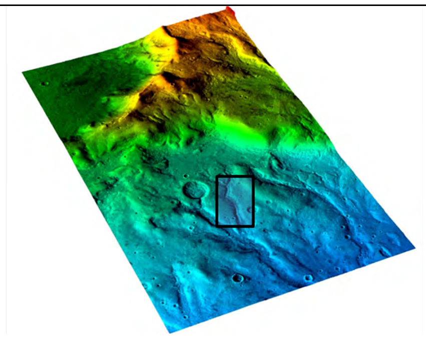
(c) Mosaic of two HiRISE DTMs with 2.5m grid spacing overlapped over CTX DTM in (b)

Figure 2. Multi-resolution DTMs over Eberswalde crater.



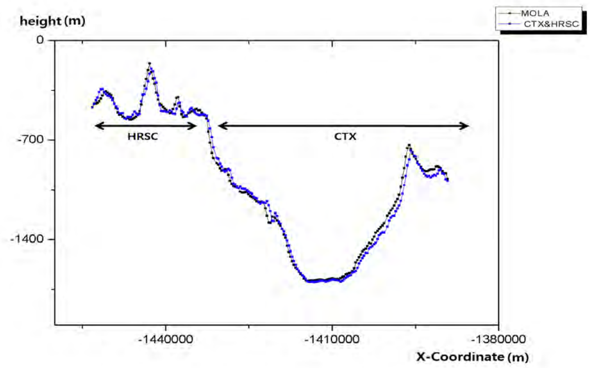
(a) 50m stereo DTM from HRSC image



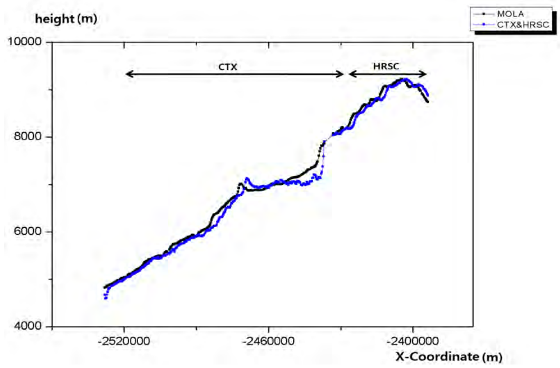


(b) 24m stereo CTX DTMs (upper : the processing result in upper portion of (a) , red line is the MOLA track for the validation, lower : a detailed CTX DTM, boxed area is for the HiRISE DTM refinement)

Figure 3. The stereo DTM products in Warrego Valles



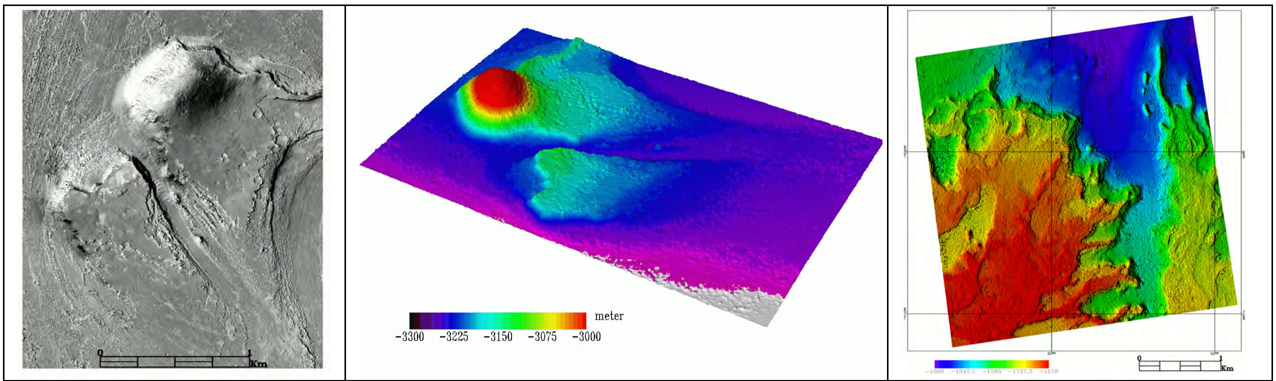
(a) MOLA track profiling with stereo DTM over Eberswalde cater (mean MOLA-CTX stereo : 9.9m , stddev : 28.8m)



(b) MOLA track profiling with stereo DTM over Warrego Valles (mean MOLA-CTX stereo : 15.4m, stddev : 32.8m)

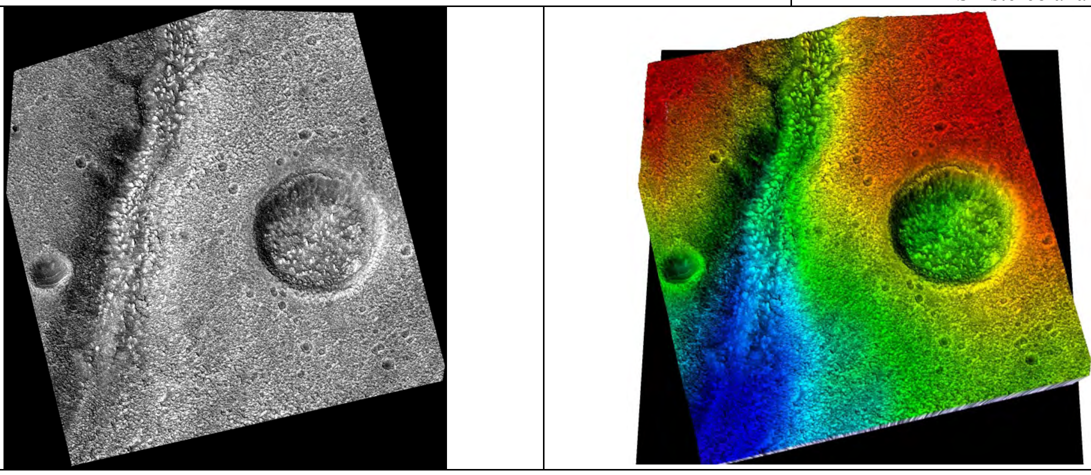
Figure 4. Stereo DTM assessments compared with MOLA spots

The other topic of stereo processing line is the maximum possible DTM resolution. Figure 5 demonstrated a few DTM products created with the maximum grid spacing in processing areas. The maximum DTM grid spacing depends on the stereo image quality but normally 0.7m-0.5m was achievable with our matching scheme. Clearly the hierarchical approach for the model based matching in our stereo implementation is capable of producing sub-meter topography with HiRISE image pair.



(a) 1m stereo DTM (left) and ortho image (right) from HiRISE stereo analysis over Athabasca Valles

(b) 0.7m stereo DTM over Eberswalde crater from HIRISE stereo analysis



(c) 0.7 m stereo DTM (left) and ortho image (right) from HiRISE stereo analysis over Warrego Valles

Figure 5. Stereo DTM products extracted from HiRISE with maximum possible resolution

5. CONCLUSION AND FUTURE WORKS

The primary outcome of this study is the prototype of unprecedented flexible and powerful stereo routines covering a variety of planetary imagery. The system proved its potential by a few sample outputs over Martian surface. The resulting CTX and HiRISE DTMs demonstrated the high geodetic accuracies as well as the blunder free topographies. Also, the test products with HiRISE showed that the maximum possible DTM resolution is up to sub meter level.

Since the planetary topographic data with medium and very high spatial resolutions provide scientific researchers a unique chance to observe and interpret three-dimensional surface, many research works s involving geological analysis will get benefits from the outputs of the processing scheme in this study. However, the current stereo scheme for planetary data employing conventional computing technology will be soon meet difficulties to manipulate the huge number and size of future planetary images such as HiSCI (High-resolution Stereo Color Imager). It should be noted that the full utilization of the stereo routines is requiring huge computing power which is only possible by the GPU/parallel computing.

In future once such conditions are satisfied, the system proposed in here will be a powerful tool to extract topographic data with advanced efficiency and highly precise geodetic control.

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