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PRo3D – a tool for remote exploration and visual analysis of multi-resolution planetary terrains

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Abstract

This paper describes a viewer called PRo3D that enables planetary scientists to explore and analyze accurate reconstructions of planetary terrains. These reconstructions, derived from 3D-processing of images obtained by rovers, landers, and satellites, provide access to the corresponding planetary surfaces on Earth in a virtual space. PRo3D allows zooming through a broad range of geometric scales to study geologic structures from far away to microscopic close-up. The viewer provides various measurement tools to derive the true dimension of surface features and let scientists place annotations in 3D space. PRo3D is a component of the *FP7-PRoViDE* tool set.

1. Introduction

An interactive viewer was necessary as user front-end to explore and analyze 3D reconstructions of planetary terrains. Already existing viewers usually focus on different application domains, such as 3DROV [4], which is used for operations planning and Rover simulation. Geological analysis has different requirements. These are:

- Study 3D representations of rock outcrops by moving around efficiently to get different perspectives
- Be able to visualize and investigate data from orbital imagery down to the magnifier-scale imagery (investigate multi-resolution data sets) for global context and spatial referencing between differently located phenomena
- Measure geological structures to determine their dimensions and other geometric features
- Mark regions and features and label them.

Meeting these requirements allows scientists to gain deeper insights from the 3D reconstruction and also supports decision making during mission operation, e.g. when choosing promising locations to send the rover to.

2. Virtual Exploration

Scientists are able to virtually fly through 3D reconstructions of Martian surfaces similar to nowadays games' experience. The crucial difference to games is the high accuracy of the reconstructions. To suffice for scientific analysis geometry and textures require a much higher resolution and a geometrically and visually correct rendering.

To handle huge amounts of geospatial data in an interactive application, PRo3D applies a technique known as Levels of Detail (LoD) [1] [3]. The appropriate level is automatically chosen for separate patches of the surface depending on the distance from the viewpoint (see Figure 1). In such a way, close-by areas are rendered at a higher detail than those further away. LoDs also allow seamless zooming within a broad range of scales so that geologists can relate large-scale structures to close-up features of rock outcrops.

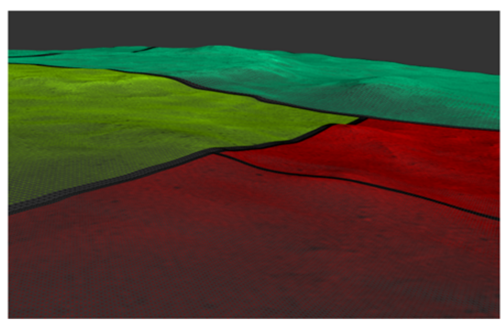

Figure 1: Color coded LODs.

3. Measurements and annotations

The viewer provides interactive tools for various types of measurements in 3D space, a feature that is essential for analysis. The following measurement tools are currently available:

- Body-fixed coordinates of selected points on planetary surface
- Distance from viewpoint to surface point
- Linear distance between two surface points
- Distance on the surface (way length) between two points
- Length of a path on the surface, described by a user-drawn polyline
- Dip and strike to calculate the inclination and orientation of sedimentary layers [2]

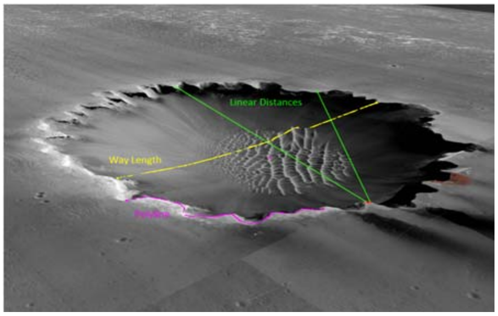

Figure 2: Demonstration of measurements types.

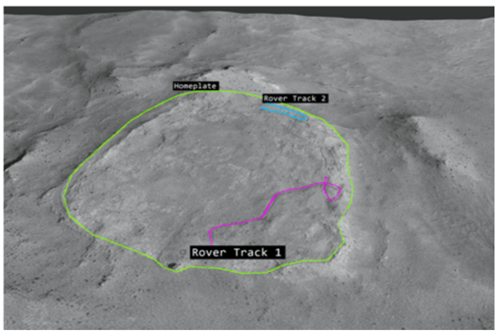

Figure 3: Annotation options (Credits: Tao and Muller, EPSC 2014)

Figure 2 shows examples of measurements. Besides measurements scientists can also place annotations in the virtual environment (Figure 3). For instance, the polyline tool allows scientists to mark and label regions of interest. These viewpoint-oriented text labels can be attached to any measurement and provide a powerful tool to annotate phenomena and insights in 3D space. All measurements can be interpreted as spatial bookmarks, which enables users to trigger a "fly-to" animation in order to locate the corresponding measurement. Intuitive viewpoint transitions offer an efficient comparison between measurements without losing the geospatial context.

4. Summary and Conclusions

We presented a tool for remote exploration and visual analysis of Martian surfaces. It immerses planetary scientist into a detailed 3D reconstruction of Martian surfaces, which is accurate enough to perform measurements and gain geological insights. Thereby it also supports decision making in ongoing and future missions.

User tests by planetary scientists have shown that the PRo3D virtual environment is an important additional method for the analysis of Martian surfaces. In future versions we will continuously improve and extend the interactive tools for measurements and annotations based on feedback from planetary scientists and the user community. Planned features further include false-color renderings of reconstructed surfaces to visualize properties such as inclination or rock materials.

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312377 "PRoViDE".

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Sharing knowledge of Planetary Datasets through the Web-Based PRoGIS

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Abstract

The large amount of raw and derived data available from various planetary surface missions (e.g. Mars and Moon in our case) has been integrated with co-registered and geocoded orbital image data to provide rover traverses and camera site locations in universal global co-ordinates [1]. This then allows an integrated GIS to use these geocoded products for scientific applications: we aim to create a web interface, PRoGIS, with minimal controls focusing on the usability and visualisation of the data, to allow planetary geologists to share annotated surface observations. These observations in a common context are shared between different tools and software (PRoGIS, Pro3D, 3D point cloud viewer). Our aim is to use only Open Source components that integrate Open Web Services for planetary data to make available an universal platform with a WebGIS interface, as well as a 3D point cloud and a Panorama viewer to explore derived data. On top of these tools we are building capabilities to make and share annotations amongst users. We use Python and Django for the server-side framework and Open Layers 3 for the WebGIS client. For good performance previewing 3D data (point clouds, pictures on the surface and panoramas) we employ ThreeJS, a WebGL Javascript library. Additionally, user and group controls allow scientists to store and share their observations. PRoGIS not only displays data but also launches sophisticated 3D vision reprocessing (PRoVIP) and an immersive 3D analysis environment (PRo3D).

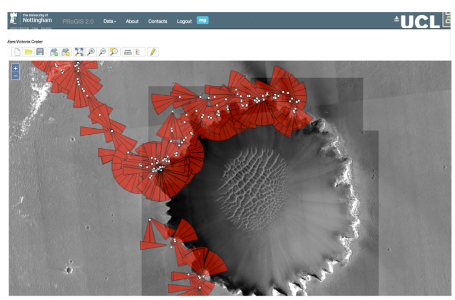

Figure 1. PRoGIS displaying camera footprints.

Acknowledgements

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Framework Programme (FP7/2007-2013) under grant agreement n° 312377 PRoViDE.

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A spatial planetary image database in the context of processing

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1. Introduction

Planetary image data is collected and archived by e.g. the European Planetary Science Archive (PSA) or its US counterpart the Planetary Data System (PDS). These archives usually organize the data according to missions and their respective instruments. Search queries can be posted to retrieve data of interest for a specific instrument data set. In the context of processing data of a number of sensors and missions this is not practical. In the scope of the EU FP7 project PRoViDE meta-data from imaging sensors were collected from PSA as well as PDS and were rearranged and restructured according to the processing needs. Exemplary image data gathered from rover and lander missions operated on the Martian surface was organized into a new unique data base. The data base is a core component of the PRoViDE processing and visualization system as it enables multi-mission and -sensor searches to fully exploit the collected data.

2. PRoViDE Project

The goal of the PRoViDE project is to collect a major portion of the imaging data gathered so far from vehicles and probes on planetary surfaces into an unique database, bringing them into a spatial context and providing access to a complete set of 3D vision products.

Excellent example data are provided by the Martian rover and lander imaging systems like the Navcam [1] and Pancam [2] on board the Mars Exploration Rovers, Phoenix Lander Surface Stereo Imager [3] , or the Curiosity Rover Mastcam [4] . Nonetheless, the PRoViDE processing and visualization system set out to also be capable to deal with historic and future landed mission data.

3. Requirements

For the PRoViDE processing chain the data base (or data catalogue) needs to deal with images ranging from orbital to microscopic scale and needs to support multiple missions as data fusion will be applied within the viewing components. Furthermore, a variety of products need to be handled and the data catalogue shall be capable to be re-usable for future mission. An additional requirement is to also keep geospatial information in the data base. While not the full record of information of considered images needs to be kept in the DB (e.g. all PDS label entries), meta-data required for processing and geospatial context need to be kept directly within the DB.

4. Existing Planetary Data Bases

PSA and PDS provide a collection of data from planetary mission with the background archiving. Hence, the focus is set on fixed standards to ensure usability for scientist from all disciplines as well as accessibility and usage in future. These objectives of data storage do not meet the needs in the context of processing and probably also other scopes.

5. Approach

The PRoViDE data catalogue is implemented as a PostgreSQL data base that will in an upcoming version also support the required spatial relation of images with respect to the global reference frame as image footprints – called fulcra. The DB is designed around two principle tables that represent the input and output of the PRoViDE processing chain. These tables are the Images and the Products table and do hold records for all images of all mission and scales considered as well as all products envisaged to be processed, respectively. Detailed property information of images or products are recorded in separate tables. The implemented schema is expected to be capable to be adapted for future missions and newly designed products if necessary.

6. Population

The DB was populated based on index files included in PDS data volumes that provide a list of data stored at this location including meta-data. The initial population with Mars rover and lander data resulted in entries listed in Table 1.

Table 1: Number of image data initially inserted in the DB.

Mission	**Sensor 1**	**Sensor 2**
MER1	Pancam 32553	Navcam 16208
MER2	Pancam 26510	Navcam 10175
MSL	Mastcam 16711	Navcam 5200
MPF		IMP 5511
PHX		SSI 3251

Products were first defined and later an estimation of how many image stereo pairs, panoramas, mosaics etc. could be hidden in the data were computed applying the collected meta-data in combination with the SPICE kernel information [5] of the respective mission.

7. Conclusion

A data base was designed and implemented that is well suited for various batch processing applications. It can hold information of orbital to microscopic scale image data. As one of the central components of PRoViDE the data catalogue it will be tested in depth during the upcoming batch processing tests having all PRoViDE components working jointly within the integrated system. Results and progress on further data catalogues developments will be presented at the meeting.

Acknowledgements

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Models of Mars based on the ESA Mars Express and NASA Mars Reconnaissance Orbiter data

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Abstract

We describe a processing system for generating multi-resolution digital terrain models (DTM) of Mars within the the iMars project of the European Seventh Framework Programme. This system is based on a non-rigorous sensor model for processing high-resolution stereoscopic images obtained from the High Resolution Imaging Science Experiment (HiRISE) camera and Context Camera (CTX) onboard the NASA Mars Reconnaissance Orbiter (MRO) spacecraft. The system includes geodetic control based on the polynomial fit of the input CTX images with respect to to a reference image obtained from the ESA Mars Express High Resolution Stereo Camera (HRSC). The input image processing is based on the Integrated Software for Images and Spectrometers (ISIS) and the NASA Ames stereo pipeline. The accuracy of the produced CTX DTM is improved by aligning it with the reference HRSC DTM and the altimetry data from the Mars Orbiter Laser Altimeter (MOLA) onboard the Mars Global Surveyor (MGS) spacecraft. The higher-resolution HiRISE imagery data are processed in the the same way, except that the reference images and DTMs are taken from the CTX results obtained during the first processing stage. A quality assessment of image photogrammetric registration is demonstrated by using data generated by the NASA Ames stereo pipeline and the BAE Socet system. Such DTMs will be produced for all available stereo-pairs and be displayed as WMS layers within the iMars Web GIS.

1. Introduction

Understanding the role of different planetary surface formation processes within our Solar System is one of the fundamental goals of planetary science research. There has been a revolution in planetary surface observations over the last 15 years, especially in 3D imaging of surface shape. This has led to the ability to be able to overlay different epochs back to the mid-1970s, examine time-varying changes (such as the recent discovery of boulder movement, tracking inter-year seasonal changes and looking for occurrences of fresh craters.

To track changes on the planet Mars it is important to compare data from different sensors and therefore address issues of varying image resolution, lighting conditions and coverage and co-registration. The goal of this work is to generate digital terrain models using the data from different Mars orbiters and use these models for making different resolution imagery data consistent with each other to improve the performance of the tools for detecting planetary surface changes.

The algorithms developed by Kim & Muller [1], [2] were further updated by employing an advanced image matcher in matching iterative window selection and improved sensor model strategy.

2 Processing chain

The initial image-processing uses the camera models for two instruments onboard the Mars Reconnaissance Orbiter (MRO CTX): the Context Camera (CTX) instrument obtains grayscale images of the Martian surface with a spatial resolution of about 6 meters per pixel over a swath that is about 30 kilometers wide. The instrument consists of a 350 mm focal length, 6 degree field of view, catadioptric Maksutov-Cassegrain telescope that images onto a 5064 pixels-wide charge coupled device (CDD) line array. The CCD detects a broad band of visible light from 500 to 800 nanometers in wavelength. The instrument includes a 256 MB DRAM buffer, so that it can acquire pictures that have downtrack lengths greater than 160 kilometers (99 miles). In other words, a typical CTX image can be as wide as 30 km and as long as 160 km.

The HiRISE camera (McEwen et al. 2007) is a detectors capable of generating images of up to 20,264 cross-scan observation pixels (exclusive of overlap pixels) and 65,000 unbinned scan lines

The processing chain co-registers the CTX images to the HRSC reference image and then the HiRISE images to the CTX image by using a feature-detection algorythm and applying a polynomial fit of the target image to the reference image.

The adaptive least-squares correlation method applied here was updated by Otto & Chau [4] using a region growing approach. The basis of this algorithm was to start with an approximate match between a single point in the left image and a point in the right (corresponding stereo pair) image. This starting point is known as a “seed-point” [5].

After stereo matching and obtaining a disparity map, a XYZ-point cloud is generated and adjusted to the DTM of reference (HRSC) by using the NASA Ames stereo pipeline tools.

3 Product quality assessment

The quality assessment of the obtained results were made by comparing the output DTMs with those produced by the NASA Ames stereo pipeline (ASP) and the BAE Socet System (SS) applyed to the same regions on Mars. For this purpose we have chosen input CTX and HiRISE images of the three most observed sites on Mars: Mars Science Laboratory (MSL Curiosity); Mars Exploration Rover A (MER-A Spirit) and Mars Exploration Rover B (MER-B Opportunity). The supporting (reference) DTMs and images were taken from the HRSC products operlapping with the CTX images.

The averaged difference between the averane HRSC, ASP and SS DTMs and our results for CTX was $+1.4 \pm 84.2$ m, -2.1 ± 84.4 m and -2.7 ± 84.9 m, respectively. The same differences for the HiRISE instrumen were -13.3 ± 19.7 m, $+4.2 \pm 19.7$ m and $+2.3 \pm 37.2$ m. The large dispersion of the differences is due to the larger number of surface features over the larger area for CTX and smaller numer of features for smaller area covered by the HiRISE instrument. The results have been considered as satisfacttory which allows using our processing for generating multi-resolution DTMs and ortho-rectified images for their further use in the surface change detection processing chain.

The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2003) under iMars grant agreement No. 607379, PRoViDE grant agreement No. 312377 and partial funding from STFC “MSSL Consolidated Grant” ST/K000977/1.

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PRoViDE: Planetary Robotics Vision Data Processing and Fusion

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Abstract

The international planetary science community has launched, landed and operated dozens of human and robotic missions to the planets and the Moon. They have collected various surface imagery that has only been partially utilized for further scientific purposes. The FP7 project PRoViDE (Planetary Robotics Vision Data Exploitation) has assembled a major portion of the imaging data gathered so far from planetary surface missions into a unique database, bringing them into a spatial context and providing access to a complete set of 3D vision products. The processing chain is exploited by a multi-resolution visualization engine that combines various levels of detail for a seamless and immersive real-time access to dynamically rendered 3D scenes. Latest results of 3D fusion between HiRISE and MER/MSL 3D stereo vision products are shown, as well as combined 3D vision processing results from multiple rover stations such as available for MER at Victoria Crater and for MSL at the Shaler site.

1. PRoViDE Scope & Components

Various planetary surface imagery has only been partially exploited for further scientific application purposes in terms of 3D data extraction, particularly the comprehensive data sets from MER's, Apollo's and Lunokhod's especially with large baselines. The PRoViDE project has collected them in an unique geospatial and temporal manner and compiled 3D vision products in order to enable a comprehensive overview of the existing data. Orbiter imagery covering these sites exist to a sufficient quality that allows a seamless embedding of the surface data. The PRoViDE major building blocks are summarized as follows:

- A **vision data catalogue** to identify candidate planetary imagery to be used for 3D vision processing, covering relevant robotic sites of recent and ongoing missions such as MER and MSL, and Lunar ground-level panoramas.
- **Comprehensive 3D vision processing** of the mentioned planetary surface missions (heritage of PRoVisG [1]), using the images identified in the vision data catalogue.
- Provision of **highest resolution & accuracy remote sensing vision data processing results** for the mentioned mission sites to embed the robotic imagery and its products into spatial planetary context including updating local-to-global transformations to enable all rover imagery to be co-registered to orbital imagery.
- **Seamless integration between orbit and ground vision data** of recent, ongoing and planned missions.
- **Added-value mechanisms** such as shape-from-shading (SFS), and the use of additional unexpected (serendipitous) image combinations (e.g. stereo pairs) leading to a better 3D description of the surface.
- Define, rehearse, execute and evaluate use cases for scientific exploitation of newly generated 3D vision products, their presentation and visualisation.
- Demonstrate the potential of existing and forthcoming planetary surface vision data by **highly realistic real-time visualisation**.
- Disseminate key data & its presentation by means of a **web-based GIS and rendering tool** in order to serve the educational, publicity and scientific objectives of Europe's planetary robotic missions.

2. Orbit-to-Ground Data Fusion

A major PRoViDE aim is the fusion between orbiter and rover image products. This is a great challenge due to the large differences in sensor footprint and ground sampling distance, as well as so far missing context for a geometrically unique presentation. To close the gap between HiRISE imaging resolution (down to 25cm for the OrthoRectified image (ORI), down to 1m for the DTM) and surface vision products, images from multiple HiRISE acquisitions are combined into a super resolution data set [2], improving the Ortho images resolution to 5cm. After texture-based co-registration with these refined orbiter 3D products, MER Pancam and Navcam as well as MSL Navcam and Mastcam 3D image products can be smoothly pasted into a multi-resolution 3D data representation. The refined registration of model height combined with the accurate rover positions based on tracks visible in the super resolution HiRISE images lead to immersive multi scale and multi sensor models. Typical results from the MER and MSL missions are presented by a dedicated real-time rendering tool which is fed by a hierarchical 3D data structure that copes with all involved scales from global planetary scale down to close-up reconstructions in the mm range.

This allows us to explore and analyze the geological characteristics of rock outcrops in larger context, based on combinations of HiRISE and rover fixed stereo base length (Figure 1) or wide base length stereo 3D products(Figure 2). The detailed geometry and internal features of sedimentary rock layers are interactively available to aid paleoenvironmental interpretation. This integrated approach enables more efficient development of geological models of Martian rock outcrops. 3D measurement tools are ready to obtain geospatial data of surface points and distances between them.

For the Lunar case, based on an LRO NAC high resolution DEM (Figure 3), data fusion and artificial 3D-modeling of Lunar surface (Figure 4) have been carried out. It is very useful for search for observation points of Lunokhod panoramic images (Figure 5), and it can be used to model a scenery simulating as being observed by a spacecraft once landed on the Moon [4].

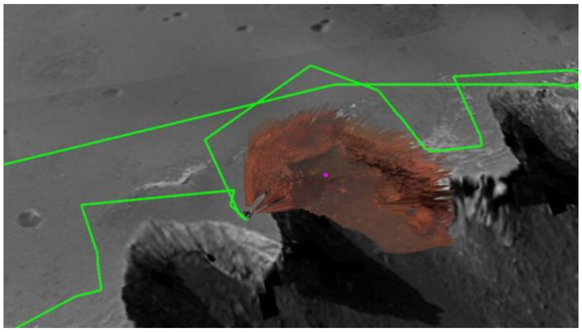

Figure 1: Fusion of HiRISE super resolution with MER fixed base length stereo-derived map

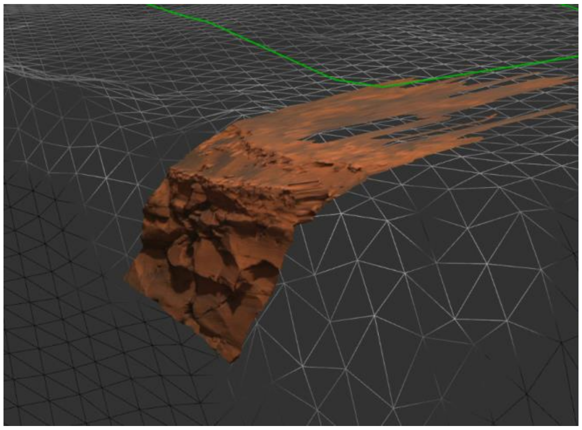

Figure 2: Fusion of HiRISE DTM with MER wide base length stereo-derived map

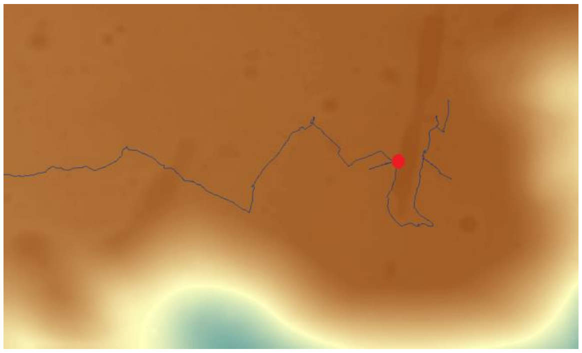

Figure 3: High-resolution DEM produced from LRO NAC photogrammetric image processing

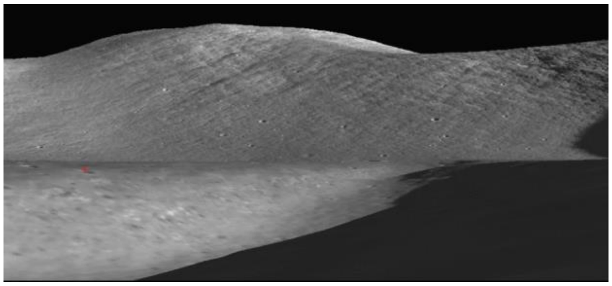

Figure 4: Result of artificial Lunar surface modeling on Lunoknod-2

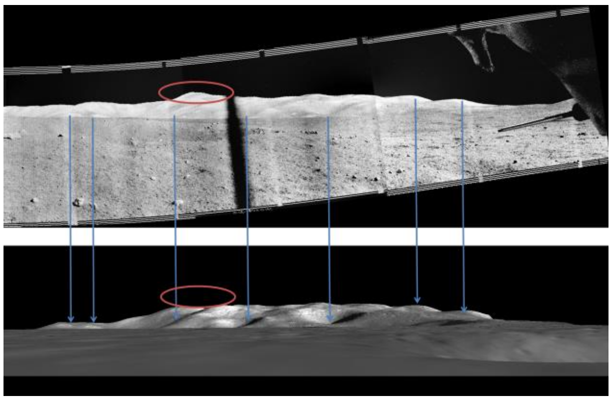

Figure 5: Comparison of the modelled image (below) with the part of processed archive panorama (above). Main features on the horizon can be easily identified. The highest peak and some hills on the left are absent on the modeled image due to the small coverage of the detailed DEM used for modeling (the peak is more than 25 km far from the landing site).

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Towards a better understanding of Martian surface processes: zooming in for a quantitative assessment of key geomorphological features from super-resolution HiRISE images in comparison to overlapping rover Navcam image

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Abstract

We have performed a quantitative study on automatically detected geomorphological features from MRO HiRISE orthorectified image st 25cm, a 5cm super-resolution resolved HiRISE image and MER-A Navcam orthorectified image to demonstrate one of the advantages of using our novel Gotcha-PDE-TV (GPT) super-resolution restoration (SRR) technique to better understand Martian surface processes.

1. Introduction

Higher spatial resolution imaging data is always desirable to the international community of planetary scientists interested in improving understanding of surface formation processes. For example, studying an area on Mars using 12m panchromatic HRSC allows you to be able to visualise the "big picture" whilst 6m CTX images allows you to see important mineralogical and geomorphological information which you can't see in HRSC and finally for a tiny percentage of the Martian surface (≈1%), 25cm HiRISE allows you to see details of surface features such as fine-scale layering. However, 25cm is not high enough resolution to be able to view individual features with diameters less than 0.75m or see the types of sedimentary features that MSL Curiosity has found in rover-based imagery.
We have developed a novel SRR algorithm/pipeline, called GPT SRR, to be able to restore rover scale images from multiple lower resolution orbital images [1]. This technique has been successfully applied to resolve 5cm-12.5cm super-resolution HiRISE images for MER-A, MER-B and MSL missions in the EU-FP7 Planetary Robotic Vision Data Exploitation (PRoViDE) project (http://provide-space.eu).

In this paper, we look into rover track and rock size distributions for several critical sites in comparison with HiRISE image, SRR image, and rover Navcam orthorectified image mosaics. Furthermore, an assessment of the potential utility of SRR products with be included for features such as RSL formation and gully movements in comparison to using HiRISE by the time of the conference.

2. Method

We use our in-house toolkit to automatically detect rocks [2] from HiRISE, SRR, and Navcam orthorectified images that cover the same area. Rock sizes and distribution are calculated from the three datasets and the differences between are analyzed.

3. Results

In this experiment, rocks have been automatically detected from the original HiRISE and SRR image for the same area around an impact crater near the MER-A traverse acquired on Sol 150 and 151. Figure (1) and Figure (2) show that in 25cm HiRISE images, rocks less than 150cm diameter are not visible and are hard to detect, whereas in 5cm SRR, rocks larger than 30cm diameter are resolved.

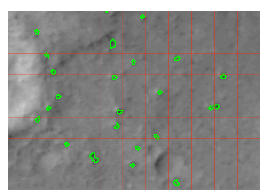

Figure 1 Automatically detected rocks (labelled green) of 25cm HiRISE image (PSP_001513_1655) (top) with 20pixel grid (5m) around an impact crater close to MER-A traverse at ~ (175.51045º, -14.58461º)

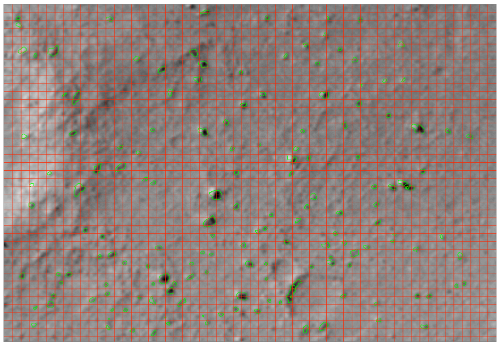

Figure 2 Automatically detected rocks (labelled green) of 5cm SRR image with 20pixel grids (1m) around the same impact crater close to MER-A traverse at ~ (175.51045º, -14.58461º).

Rock diameter (D)	Accumulated number of rocks in HiRISE	Accumulated number of rocks in SRR image
D≥150cm	22	33
D≥50cm	23	144
D≥30cm	23	153

Table 1 Accumulated number of rocks in HiRISE and SRR image.

As shown in Table (1), for rocks with diameters larger than 150cm, there are 22 detected from the original HiRISE image and only 1 rock detected in the range 50cm<diameter<150cm. On the other hand, in the SRR image, there were 33 rocks with diameter larger than 150cm, 111 rocks with 50cm<diameter<150cm, and 9 rocks with 30cm<diameter<50cm. This experiment has demonstrated that there are a large number of rocks, which are not clear enough for either automated detection/classification or manual measurement in the original HiRISE image. However, with SRR, a much greater number of rocks can be detected and therefore provide stronger evidence to support an application such as the selection of a future landing site. Example will be shown of how these rock size distributions compare against those derived form MER-A NavCam images.

6. Summary and Conclusions

We have performed a quantitative analysis on one key geomorphological feature using HiRISE, SRR and Navcam orthorectified images and compared the results to demonstrate the additional information content of using our unique SRR technique for improving understanding of Martian surface compared with using original HiRISE image. An initial comparison on rock size distribution based on HiRISE and SRR image is given in this paper.

We aim to process all available image datasets in future where we have repeat multi-view imagery starting with HiRISE first and then apply these techniques to HRSC, CTX, HiRISE, THEMIS, MOC and Viking Orbiter into geo-referenced SR mapped datasets after a porting the software onto a GPU. We also plan to apply such techniques to the retrieval of 3D heights where we have multiple stereo-pairs available. The geo-referenced SRR datasets should greatly support the geological and morphological analysis and monitoring of Martian surface processes especially change detection features in future planetary research. They can also be applied to landing site selection, which may cause difficulties for any future rover.

We believe that the GPT SRR technique developed has huge potential, not only to other Solar System solid earth targets but also to the design of future missions, which will still be severely limited by telecommunications bandwidth but also by light travel time. Transmitting back SRR derived onboard from long video sequences of LR imagery could result in substantially higher scientific returns from orbital missions. It may also be applied to space telescopic images of objects outside our Solar System such as exoplanets.

Acknowledgements

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Geological interpretation and analysis of surface based, spatially referenced planetary imagery data using PRoGIS 2.0 and Pro3D.

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Abstract

We apply the capabilities of the geospatial environment PRoGIS 2.0 and the real time rendering viewer PRo3D to geological analysis of NASA's Mars Exploration Rover-B (MER-B Opportunity rover) and Mars Science Laboratory (MSL Curiosity rover) datasets. Short baseline and serendipitous long baseline stereo Pancam rover imagery are used to create 3D point clouds which can be combined with super-resolution images derived from Mars Reconnaissance Orbiter HiRISE orbital data, and super-resolution outcrop images derived from MER Pancam, as well as hand-lens scale images for geology and outcrop characterization at all scales. Data within the PRoViDE database are presented and accessed through the PRoGIS interface. Simple geological measurement tools are implemented within the PRoGIS and PRo3D web software to accurately measure the dip and strike of bedding in outcrops, create detailed stratigraphic logs for correlation between the areas investigated, and to develop realistic 3D models for the characterization of planetary surface processes. Annotation tools are being developed to aid discussion and dissemination of the observations within the planetary science community.

1. Introduction

The FP7-SPACE PRoViDE (Planetary Robotics Vision Data Exploitation) project has been developed to exploit the wealth of orbital, probe and rover derived planetary surface imagery data taken from the dozens of missions which have successfully travelled to other planetary bodies in the Solar System. A database of processed planetary datasets has been developed [7] and PRoGIS 2.0 is the spatial entry point into which these products have been brought into a common geospatial context [2]. Access to a complete set of 3D products has been provided with additional analysis capabilities within PRo3D [6]. This paper presents methodologies used to quantitatively exploit these datasets for geological analysis on Martian test examples.

2. Geological application of PRoGIS 2.0

Orbital data is accessible through PRoGIS 2.0, in which HiRISE, CTX, HRSC and specially processed Super-Resolution HiRISE imagery [5] have been co-registered with Mars Orbiter Laser Altimeter (MOLA) data and combined with updated rover traverses. Rover Pancam, Mastcam, and Navcam imagery is accessible using the fulcra footprints of each dataset which enable the simple identification of rover imagery by location and view direction. This enables selection of specific datasets, which are relevant to geological analyses.

Images from overlapping fulcra are combined within PRoGIS 2.0 to create photomosaics and panoramas, which, together with super-resolution outcrop images, can be used for initial 2D outcrop interpretations.

3. Geological application of PRo3D

3D point clouds are created using short and long baseline rover stereo imagery, primarily from the Pancam and Mastcam sensors. Interpretations of main unit boundaries, second order stratigraphic boundaries and internal sedimentary structures are digitised directly onto the 3D point clouds. Strike and dips are calculated along bounding surfaces and bedding planes to determine sedimentary and structural geometric relationships as well as the predominant transport directions. This information is useful for determining the sediment flow directions and sediment source regions.

4. Case studies - Victoria Crater, Yellowknife Bay and Shaler

The measurement tools within Pro3D have been initially tested on outcrops around the rim of Victoria Crater, a ~ 750 m wide, moderately degraded crater located at 2.05°S, 5.50°W, in the Meridiani Planum equatorial region of Mars. It was visited by the MER-B Opportunity Rover, between Sols 952 and 1293 of operation. 100 – 150 m of erosional widening [3] has produced outcrops of pre-impact aeolian deposits < 15 m high, which form the upper dry section of a dry-wet-dry depositional sequence known as the Burns Formation [1]. Fully 3D outcrops exposed in the promontories of the crater wall show 3 – 7 m thick bedsets of large-scale cross-bedding, which have been interpreted as an ancient aeolian dune system [4]. The true 3D dimensions of these bed sets can be determined combining the dip and strike and distance measurement tools.

The tools described were also applied to analysis of data from the MSL Curiosity rover observations at Yellowknife Bay and Shaler outcrops which record evidence of fluvial and lacustrine environments on early Mars. Direct grain size measurements using the Mastcam and MAHLI instruments, as well as dip and strike measurements of bounding surfaces and cross-bedding laminations were possible within PRo3D.

5. Summary and Conclusions

PRoGIS is a highly effective tool for locating and identifying useful datasets for geological measurement and analysis. Pro3D provides the capabilities for quantitative 3D measurement of those features, allowing for a far greater understanding of layer geometries, palaeotransport directions, and temporal relationships. Regional integration of these results within PRoGIS can be used to greatly enhance the understanding of past and present surface processes on Mars.

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Improvements to Color HRSC+OMEGA Image Mosaics of Mars

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1. Introduction

The High Resolution Stereo Camera (HRSC) on the Mars Express (MEx) orbiter has acquired 3640 images (with 'preliminary level 4' processing as described in [1]) of the Martian surface since arriving in orbit in 2003, covering over 90% of the planet [2]. At resolutions that can reach 10 meters/pixel, these MEx/HRSC images [3-4] are constructed in a push-broom manner from 9 different CCD line sensors, including a panchromatic nadir-looking (Pan) channel, 4 color channels (R, G, B, IR), and 4 other panchromatic channels for stereo imaging or photometric imaging.

In [5], we discussed our first approach towards mosaicking hundreds of the MEx/HRSC RGB or Pan images together. The images were acquired under different atmospheric conditions over the entire mission and under different observation/illumination geometries. Therefore, the main challenge that we have addressed is the color (or gray-scale) matching of these images, which have varying colors (or gray scales) due to the different observing conditions. Using this first approach, our best results for a semi-global mosaic consist of adding a high-pass-filtered version of the HRSC mosaic to a low-pass-filtered version of the MEx/OMEGA [6] global mosaic.

Herein, we will present our latest results using a new, improved, second approach for mosaicking MEx/HRSC images [7], but focusing on the RGB color processing when using this new second approach. Currently, when the new second approach is applied to Pan images, we match local spatial averages of the Pan images to the local spatial averages of a mosaic made from the images acquired by the Mars Global Surveyor TES bolometer. Since these MGS/TES images have already been atmospherically-corrected, this matching allows us to bootstrap the process of mosaicking the HRSC images without actually atmospherically correcting the HRSC images. In this work, we will adapt this technique of MEx/HRSC Pan images being matched with the MGS/TES mosaic, so that instead, MEx/HRSC RGB images will be matched with specially-constructed MEx/OMEGA RGB mosaics.

2. HRSC Preprocessing

We perform a photometric correction (using a Lambertian model, by dividing by the cosine of the incidence angle). The main portion of the photometric-correction effort involves the determination of the illumination and observation angles with respect to the digital elevation model [8].

3. OMEGA Preprocessing

The MEx/OMEGA RGB mosaics have been produced as a special product by integrating the atmospherically-corrected reflectance of the narrow-band OMEGA channels over the spectral band-passes for each of the three broad-band HRSC color channels, using the measured filter functions for HRSC as weighting functions for this integration.

Based on prior experience when producing the HRSC Pan mosaic with our first approach [5], there will be additional gaps in the resulting HRSC+OMEGA RGB mosaic caused by gaps in OMEGA coverage and/or by gaps in high-quality atmospheric correction of the OMEGA data.

Acknowledgements

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(HRSC on Mars Express). We thank the HRSC experiment team at DLR Berlin and the HRSC operations team at ESOC for their successful planning, acquisition and processing of the HRSC data. Mars Express is operated by ESA/ESOC.

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ASIMUT on line radiative transfer code

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Abstract

The CROSS DRIVE project aims to develop an innovative collaborative workspace infrastructure for space missions that will allow distributed scientific and engineering teams to collectively analyse and interpret scientific data as well as execute operations of planetary spacecraft. ASIMUT will be one of the tools that will be made available to the users. Here we describe this radiative transfer code and how it will be integrated into the virtual environment developed within CROSS DRIVE.

1. Introduction

The concept of CROSS DRIVE is to join research on space engineering and science analysis. The development of the collaborative workspace will be implemented to support the following scientific data analysis:

- Share and correlate atmospheric data sets, analysis, models and simulations based on payloads of the two main Mars' satellites MEX and MRO, and future ExoMars;
- Compare and correlate satellites data for geology and geodesy;
- Benchmark satellite and ground based Mars atmospheric measurements.

The above scientific objectives will help the team to understand and develop necessary scientific algorithms and data management strategy necessary for exploiting Mars satellite and ground based data, Mars science analysis, execute Mars global circulation studies and benchmarking Mars data.

One of the key components in CROSS DRIVE is the creation of a collaborative workspace platform that provides access to remote scientists and engineers, from different disciplines, to collaborate in analysing and exploring space data in order to make scientific discoveries as well as contributing to ongoing space missions. One of the tools that will be made available to the users is a on line radiative transfer code which will be used to simulate the Martian atmosphere and to analyse Level 1 spectra of selected experiments.

2. ASIMUT on line

The IASB-BIRA ASIMUT Radiative Transfer model developed in 2006 was initially used for Earth observation missions (IASI and ACE-FTS) [2]. The code was then adapted for planetary atmospheres, in particular those of Venus [3] and Mars [1]. This code has been developed with the objective to be as general as possible, accepting different instrument types. The algorithm can simulate absorption due to molecular species but also extinction due to Rayleigh and aerosols scattering. Recently ASIMUT has been extended in order to include all scattering effects due to aerosols. ASIMUT has been chosen as the reference code for the NOMAD instrument selected to be on-board the ExoMars TGO.

ASIMUT is a modular program for radiative transfer calculations in planetary atmospheres (Figure 1). The ASIMUT software has been developed to exploit the synergy existing between the growing number of different instruments working under different geometries. The main particularities of the software are:

(i.) The possibility to retrieve columns and/or profiles of atmospheric constituents simultaneously from different spectra, which may have been recorded by different instruments or obtained under different geometries. This allows the possibility to perform combined retrieval, e.g., of a ground based measurement and a satellite-based one probing the same air mass, or from spectra recorded by different instruments on the same platform;
(ii.) The analytical derivation of the Jacobians;
(iii.) The use of the Optimal Estimation method (OEM), using diagonal or full covariance matrices;
(iv.) Its portability;

(v.) Its modularity, hence the ease to add future features.

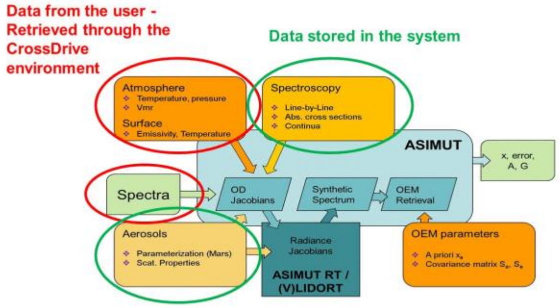

Figure 1: ASIMUT structure

Through the CROSS DRIVE Virtual environment, the user will be offered the possibility to:

- Choose a spectrum or series of spectra corresponding to given geo-temporal locations; Make use of the hi-res images available through the CROSS DRIVE Virtual environment to select the most interesting sites;
- Use the topography information available through the VO of CROSS DRIVE and corresponding to the selected area;
- Prepare the ancillary data needed for the analysis by choosing physical quantities already provided by the system: for example, the surface characteristics (albedo), the initial aerosol/dust/clouds characteristics (physical properties, loading), typical temperature and pressure profiles, initial vertical profiles of atmospheric species, etc.;
- Visualise the spectra, including change of units, saving under recognised file formats;
- Define some parameters for the analysis itself (spectral regions fitted, species to be fitted, etc.);
- Ask the system to perform the analysis;
- View the results of the analysis;
- Compare the results with existing data sets.

ASIMUT is now available on http://asimut.aeronomie.be/ to be tested before being integrated into the Virtual environment of CROSS DRIVE. For the moment data needed for the runs (simulations and retrieval) are typical values saved in the project. The next step will be to allow the user to select a location of the Martian surface through a virtual environment tool, select appropriate data and link those to ASIMUT. It is also foreseen that the retrieved atmospheric parameters will in turn be used for the radiometric correction of imaging data.

We will present the web interface and illustrate the use of ASIMUT through this on line access.

Acknowledgements

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The Multi-Temporal Database of High Resolution Stereo Camera (HRSC) and Planetary Images of Mars (MUTED): A Tool to Support the Identification of Surface Changes

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Introduction

Image data transmitted to Earth by Martian spacecraft since the 1970s, for example by Mariner and Viking, Mars Global Surveyor (MGS), Mars Express (MEx) and the Mars Reconnaissance Orbiter (MRO) showed, that the surface of Mars has changed dramatically and actually is continually changing [e.g., 1-8]. The changes are attributed to a large variety of atmospherical, geological and morphological processes, including eolian processes [9,10], mass wasting processes [11], changes of the polar caps [12] and impact cratering processes [13].
The detection of surface changes in planetary image data is closely related to the spatial and temporal availability of images in a specific region. While previews of the images are available at ESA's Planetary Science Archive (PSA), through the NASA Planetary Data System (PDS) and via other less frequently used databases, there is no possibility to quickly and conveniently see the spatial and temporal availability of HRSC images and other planetary image data in a specific region, which is important to detect the surface changes that occurred between two or more images. In addition, it is complicated to get an overview of the image quality and label information for images covering the same area. However, the investigation of surface changes represents a key element in martian research and has implications for the geologic, morphologic and climatic evolution of Mars.
In order to address these issues, we developed the "Multi-Temporal Database of High Resolution Stereo Camera (HRSC) Images" (MUTED), which represents a tool for the identification of the spatial and multi-temporal coverage of planetary image data from Mars. Scientists will be able to identify the location, number, and time range of acquisition of overlapping HRSC images. MUTED also includes images of other planetary image datasets such as those of the Context Camera (CTX), the Mars Orbiter Camera (MOC), the Thermal Emission Imaging System (THEMIS), and the High Resolution Imaging Science Experiment (HiRISE). The database supports the identification and analysis of surface changes and short-lived surface processes on Mars based on fast automatic database queries. From the multi-temporal planetary image database and the multi-temporal observations we will better understand the interactions between the surface of Mars and external forces, including the atmosphere. MUTED will be available for the scientific community via the Institut für Planetologie (IfP) Muenster.

Scientific objectives

Our objectives are (1) to study examples of surface changes based on multi-temporal HRSC ND image data caused by eolian processes, mass wasting and polar processes, as well as impact cratering processes, and (2) to document examples of surface changes through the comparison of multi-temporal HRSC ND image data with other past, current and future missions of Mars exploration, e.g., CTX and MOC, and (3) to investigate the causes of the selected examples of Martian surface changes by seeking correlations between morphologic, geologic and atmospherical processes and surface parameters such as topography, relief, elevation, thermal inertia, rock abundance, surface roughness, geologic properties and wind regimes.

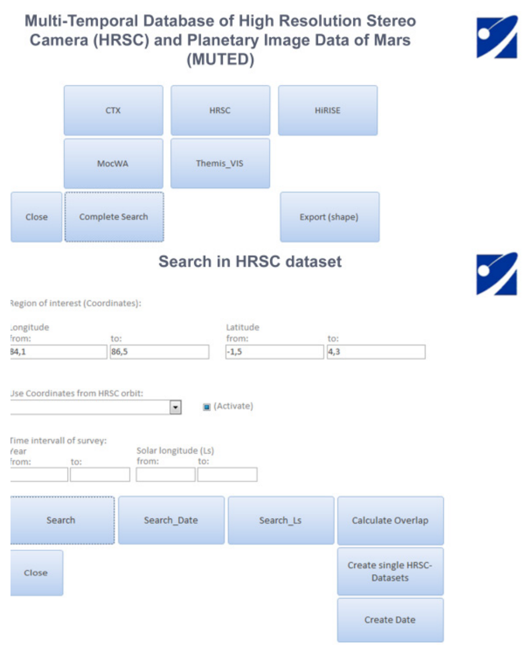

Fig. 1: User interface of the multi-temporal HRSC image database. Calculation of the overlap based on latitude/longitude of region of interest or corner coordinates of selected HRSC orbits.

Multi-temporal HRSC database

We developed an algorithm that automatically creates color-coded polygons to provide information about the location and number of overlapping HRSC ND images. The routine is based on the latitude (Lat) and longitude (Lon) coordinates of the vertices of each HRSC image and the vertices of the 100 sections each HRSC ND image consists of, respectively. In the case of an overlap of two HRSC ND images, the Lat/Lon coordinates of both images will be used to calculate the intersection, which is color-coded in the ranking. The multi-temporal HRSC database is generated by the integration of different planetary image datasets into a Microsoft Access database management system. The calculation of overlapping and the modification of the datasets are done by using VBA and SQL routines.
In the input mask, the parameters for Lat/Lon can be set freely or based on the footprints of a specific image. The compiled tables of overlapping HRSC images appear in a new mask. Additionally to the manual search of images for a requested area, the program

automatically calculates overlaps for all images and stores them along with their respective relationships. This summed number of overlapping images enables a color coded ranking.
In order to display the calculated results in GIS, a *.dbf- and *.prn-file is generated. These files are required to create GIS executable shapefiles by using free ShapeLib tools, which are based on Linux. The resulting *.shp- and *.shx-files can then be integrated into GIS. The integration into GIS will contain the development of shapefiles for each color-coded class.

GIS shapefiles

Figures 2A-D show examples of GIS shapefiles created with the multi-temporal database of HRSC images. A global view of all available HRSC images and a color-coded ranking based on the number of overlaps is shown in the GIS shapefile of Figure 2A. There are only a few gaps on the surface left (red), where only one HRSC image is available. Multi-temporal observations based on HRSC images only cannot be performed at these sites. Multi-temporal observations can be done at sites showing HRSC orbits outlined in orange, yellow or green. However, particularly for investigations of recent and short-term processes on the surface of Mars, such as dust devil movement, it is important to identify those sites that have been monitored within days, hours or minutes. This is only possible with additional planetary image data such as from the Context Camera (CTX), which are already included into the database. CTX images cover areas of an extent comparable to HRSC and also have comparable resolution. Together with HRSC, CTX images are best suited for the detection of surface changes. The addition of other planetary datasets such as CTX images will not only improve the spatial coverage of multi-temporal images, but will also extend the time period of observation. Figure 2B shows a global view of all available HRSC and CTX images and a color-coded ranking based on the number of overlaps. Although multi-temporal observations are possible using nearly all orbits, researchers that are searching for short-lived dust devils need to quickly identify those overlaps between HRSC and CTX, that have been acquired within a short time, for example within one day (Fig. 2C) or within 3 hours (Fig 2D). While there are ~60 sites on Mars that have been monitored by HRSC and CTX within one day, there are only 19 locations on Mars that have been monitored by HRSC and CTX within 3 hours. The GIS shapefiles created by the multi-temporal database of HRSC images, in particular those that show images acquired within a short timespan (hours) give researchers the option to conveniently and easily identify those sites on Mars, where investigations of recent and or short-term surface processes are possible.

Integration of additional datasets

We added additional planetary image datasets to our database. Context Camera (CTX) images, Mars Orbiter Camera (MOC) wide-angle (WA) images and Thermal Emission Imaging Instrument (THEMIS) nadir images are already included into the database. Currently we are implementing the High Resolution Imaging Science Experiment (HiRISE) dataset into the database. In particular, CTX images cover areas of an extent comparable to HRSC and also have comparable resolution. Together with HRSC, CTX images are best suited for the detection of surface changes. The addition of planetary datasets such as CTX images will not only improve the spatial coverage of multi-temporal images, but will also extend the time period of observation.

Release of MUTED

The BETA version of the multi-temporal HRSC database including the Access file and calculated shapefiles is currently available upon request via the Institut für Planetologie (IfP) (www.uni-muenster.de/planetology/ifp/). The release version of MUTED will be available via download from the webpage of the IfP. Users will have access to the database including the HRSC, CTX, THEMIS-VIS and MOC-WA datasets. In addition to the visualization of the global datasets in a GIS, users can export GIS shapefiles showing the multi-temporal coverage of images for all datasets available in database.

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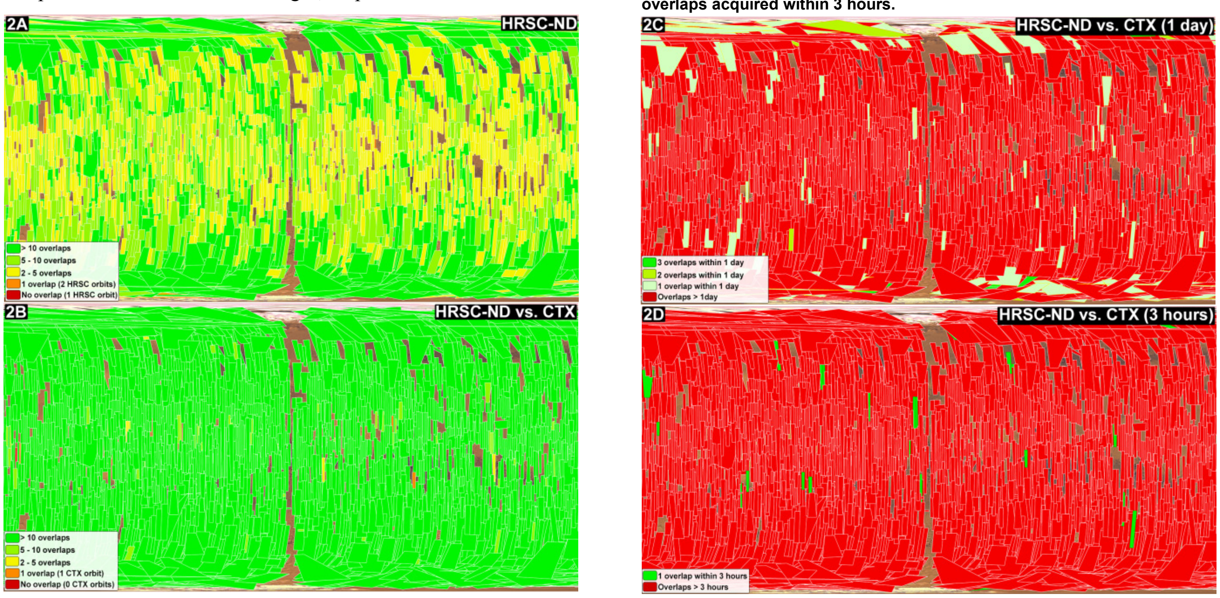
Fig. 2: Examples of GIS shapefiles created with the multi-temporal database of HRSC images. Data gap at Longitude boundary related to Beta version of the database. (A) Global view of all available HRSC images and a color-coded ranking based on the number of overlaps. (B) Global view of all available HRSC images and a color-coded ranking based on the number of overlaps with CTX images. (C) Global view of all available HRSC images and a color-coded ranking based on the number of CTX overlaps acquired within 1 day. (D) Global view of all available HRSC images and a color-coded ranking based on the number of CTX overlaps acquired within 3 hours.



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Identifying dynamic features on Mars through multi-instrument co-registration of orbital images

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Abstract

The detection and characterisation of dynamic phenomena on Mars can benefit from the systematic reconnaisance of the martian surface through high-resolution orbiter imagery. The original framework implies the straightforward detection of surface changes through the comparison of multi-temporal images acquired from a single instrument. However, up until the present-day, mainly single-instrument image pairs significantly limit the time and areal coverage range on which change detection techniques can be applied. Therefore, we have developed a pipeline that performs multi-instrument co-registration of orbital images, thus allowing the automatic detection of changes in images originating from different orbiter cameras. This work summarises the developed pipeline and shows some examples of surface changes that were detected with the help of multi-instrument co-registration.

1. Introduction

The high-resolution mapping of the Martian surface through orbital cameras started with Viking Orbiter 1 & 2 twin missions, which were launched in 1975, and was achieved between 1976 and 1980 at global medium resolution coverage of Mars, while also acquiring images with resolution as fine as 8 metres per pixel. After Viking Orbiter, four more orbiters, three from NASA and one from ESA, have been sent to Mars to image its surface with high-resolution imagery, which since 2007 reach to 25 centimetres per pixel for HiRISE images. The systematic reconnaisance of Mars with high-resolution images have allowed the identification of previously undiscovered dynamic surface phenomena and unusual surface features [1], as well as the examination of surface composition and geological history [2].

A crucial role in this analysis is played by change detection modules, in which two images acquired at different time are compared in order to try to identify surface features that have changed in the meantime, irrespective of the lighting conditions but with little or no obscuration from clouds or dust. While change detection was originally tackled in a manual and non-systematic way, the increasing imaging rate with high resolution implies the need for a fully automatic approach that would maximise the exploitation of the available data. As a result, techniques that aim at automatic surface change detection are being introduced [3], [4]. However, these few approaches tackle only the last part of a fully automatic temporal change detection pipeline, which is the change identification and classification, thus assuming the implied successfull co-registration of the input images.

Most automatic co-registration techniques are based on assumptions that limit their use in single-instrument image pairs. In order to allow the comparison of images acquired from different instruments we have developed a multi-instrument co-registration pipeline, which use HRSC orthorectified images (ORI) and digital terrain models (DTM) as a baseline so as to project all NASA images onto the same coordinate system. Subsequently, the co-registered images are examined for changes using an automatic classification scheme.

2. Method

Initially, the input images are co-registered using an HRSC ORI and DTM as a baseline. The co-registration employs SIFT points [5], which are matched through an elaborate iterative process called coupled decomposition [6], before the matched points are used to determine a camera model that projects the input image into the HRSC coordinate system.

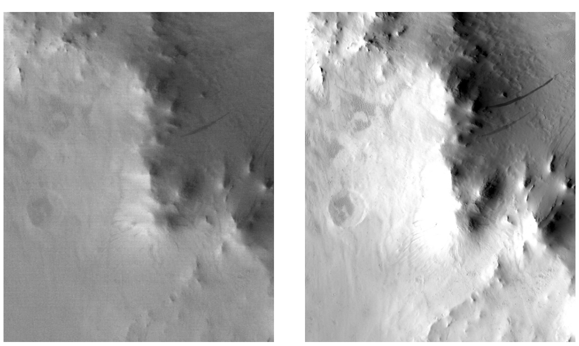
At this stage, the co-registration results may be used to indicate candidate changed regions. As a matter of fact, since the pixels of a pair of co-registered images correspond to the same location, a straightforward pixel-wise comparison (e.g. through correlation) would signify pixel-level changes. Since change detection using such correlation is rather computationally demanding when performed on the complete image strips (especially, since the latter can reach up to 10 gigapixels), we use pixel-level changes to prioritise regions-of-interest (ROIs) in the image pair. Subsequently, the change detection pipeline is executed independently in each ROI.

The latter is based on a Support Vector Machine (SVM) [7] classification scheme. More specifically, pixel features are extracted from each ROI to represent the candidate changed area. These features are the input into a SVM classifier that discriminates between actual changes and non-informative ”changes” (e.g. ”changes” triggered from different point spread functions).

3. Results

Some examples of surface changes discovered in multi-instrument high-resolution pairs are given in Figures 1 and 2. All images show an area of $9X7$ kilometres, with the North being placed at the top. The left sub-image in both examples is a HRSC orthorectified image, with resolution 12.5 metres per pixel, while the right sub-image is a CTX image (orthorectified using our co-registration pipeline), with resolution approximately 5.5 metres per pixel. Finally, the temporal distance between HRSC and CTX images is in both cases approximately 2 Martian Years. More surface changes will be shown in the EPSC presentation.

Figure 1: (a) HRSC image (b) CTX image.

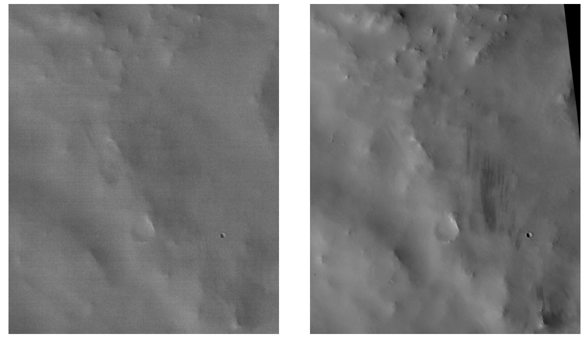


(a) (b)

Acknowledgements

The research leading to these results has received funding from the STFC “MSSL Consolidated Grant” ST/K000977/1 and partial support from the European Union’s Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement n° 607379.

Figure 2: (a) HRSC image (b) CTX image.



(a) (b)

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A 3D immersive application for real-time flythrough of planetary surfaces : The VR2Planets project

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1. Introduction

During the last two decades, a fleet of planetary probes has acquired several hundred gigabytes of images of planetary surfaces. Mars has been particularly well covered thanks to the Mars Global Surveyor, Mars Express and Mars Reconnaissance Orbiter spacecrafts. HRSC [1], CTX, HiRISE [2] instruments allowed the computation of Digital Elevation Models with a resolution from hundreds of meters up to 1 meter per pixel, and corresponding orthoimages with a resolution from few hundred of meters up to 25 centimeters per pixel. The integration of such huge data sets into a system allowing a user-friendly manipulation either for scientific use or for public outreach can represent a real challenge, which we are investigating in this study.

2. Scientific Rationale

The interpretation of geomorphologic features on planetary surfaces often relies on the quality of the acquired data, i. e. high resolution images (eventually at different wavelengths) and topographic models derived most often by laser altimetry, stereoscopic imaging, or radar interferometry. The data handling itself also plays a role in our capacity to apprehend accurately the environment which has been imaged. For example, it might be difficult to analyze a layered outcrop on a full 360° panorama rendered on a flat screen only, due to the distortions induced by the projections. On the contrary, when such a panorama is integrated into a virtual reality headset, the user can look freely by himself in any direction and apprehend the landscape as if he were simply standing in the middle of the scene, and see the nearby rocks, layered outcrops, and geological features without any distortion. Similarly, flying in real time over a 3D reconstructed landscape allows a better understanding of the stratigraphic and structural relationships between several geological units.

3. The VR2Planets project

We are investigating how innovative tools can be used to freely fly over reconstructed landscapes in real time. For this purpose, we have developed an application to immerse users in real martian landscapes reconstructed from planetary satellite data. The user can freely navigate at full spatial resolution using a game controller. The actual rendering is compatible with several visualization devices such as 3D active screen, virtual reality headsets, and a prototype of a low-cost cave system (Fig. 1), which will be shown at a public exhibit taking place in Nantes' city hall in parallel of this EPSC scientific meeting.

Figure 2: Prototype of a low-cost 3D cave environment to freely fly over martian landscapes.

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MarsSI: Martian surface data processing Information System

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Abstract

We designed a distributed information system called MarsSI to manage orbital data from martian orbiters. The application easily and rapidly allows the user to process data from these orbiters and to download scientifically ready-to-use products of Mars surface. The application also allows DTM computation from CTX and HiRISE images. This application is open to the scientific community and can be found at this address: http://emars.univ-lyon1.fr
The creation of an account is required, for that email Loïc Lozac'h : loic.lozach@univ-lyon1.fr

1. Introduction:

Geological investigations of planetary surfaces are based on the exploitation of orbital data and often acquired with different remote sensing instruments. For Mars, for instance, the number of missions and instruments and the size of the datasets are so important that even at the scale of a single scientific team, an information system to manage data is more and more required.

The creation and exploitation of a database of Mars surface is part of the e-Mars project funded by the European Research Council (ERC), the aim of which is to decipher the geological evolution of the planet from the combination of martian orbital data. We have designed a distributed information system called MarsSI to manage data from the four following Martian orbiters: Mars Global Surveyor (MGS), Mars Odyssey (ODY), Mars Express (MEX), and Mars Reconnaissance Orbiter (MRO). MarsSI allows the user to select footprints of the data from a web-GIS interface and download them to a storage server. Then the user can process raw data via automatic calibrations and finally acquire "ready-to-use" data of Mars surface. "Ready-to-use" means that the data are ready to be visualized under GIS or remote sensing softwares. An automatic stereo-restitution pipeline producing high resolution Digital Terrain Models (DTM) is also available.

2. Application architecture:

MarsSI is a 3-tiers web application based on Geomajas [1] framework. The web-tier is coded with Google Web Toolkit (GWT) [2] libraries. The services-tier is based on Spring [3] framework and provides the functionalities determined by the user's needs. It communicates with the web-tier via Geomajas command pattern, and with the data-tier via Spring's Data Access Object (DAO) pattern. The data-tier is a PostgreSQL [4] database storing the input/output entities needed in the workflow of the application's services. It also stores Mars imagery footprint's geometry and attributes thanks to PostGIS [5] functionalities.

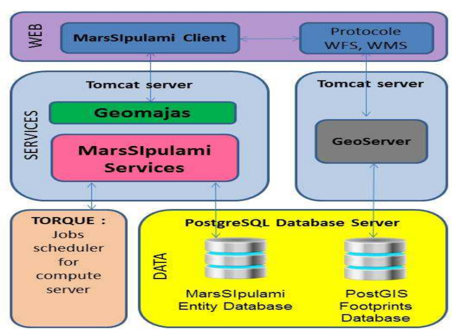

Figure 1: MarsSI architecture.

The basic workflow is the following: the footprints provided by the NASA Planetary Data System (PDS) are published in WFS protocol from the PostGIS database by GeoServer [6]. Geomajas makes them visible on screen via its web-GIS interface. The user is allowed to do searches and selections with the different GIS tools provided by Geomajas, and then the MarsSI Services creates jobs on user's demand. Those jobs scheduled are and launched by TORQUE [7] on the compute cluster. These jobs can call any software installed on the compute cluster (ISIS3, IDL/ENVI, AMES Stereo Pipelines…). Both server-side and client-side have been simultaneously developed, they are adjustable so that the application can be regularly upgraded with new instrument data or new processing pipelines.

3. Functionalities:

MarsSI is divided in two parts, a map view and a workspace view.

Data selection: The map view shows a map of Mars with the common GIS tools (zoom, identifying, measurement, selection and search), a layer view to show/hide on map the footprints available, and a table in which the user can add the selected footprints. This table shows image's information as name, geometry, status and link to its PDS on-line label file.

Data processing*:* The workspace view (Figure 2) is divided in 5 tabs: cart view, download view, calibration view, projection view and stereo-restitution view. The cart view allows the user to check the localization of the added footprints on a map, to know the status of the data that are being processed and to copy the ready-to-use data to a personal ftp account on the storage server.

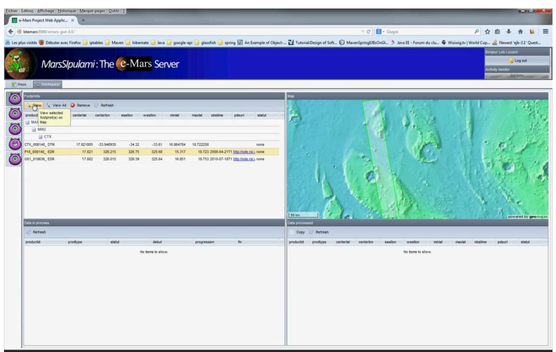

Figure 2: MarsSI user interface – workspace view

If the data are not already stored on the local server, they appear in the download view, and the user can launch the download from the PDS server. Once the download is accomplished, the data appear in the calibration view. Once the calibration is done, the data appear in the projection view. The user can now launch the map-projection of the data.

To date, MarsSI handles CTX, HiRISE and CRISM data of MRO mission, HRSC and OMEGA data of MEX mission and THEMIS data of ODY mission. CTX, HiRISE and THEMIS raw data are processed with ISIS3 functions. CRISM images are processed with the CRISM Analysis Toolkit (CAT) and OMEGA data are processed with IDL pipelines (team released pipeline).

Stereo-restitution*:* The stereo-restitution pipeline is functional for HiRISE and CTX images. CTX and HiRISE possible DTM footprints are computed, according to the following constraints: image couples with 60% width-overlapping and a minimum deviation of 10° in emission angle. It is user's responsibility to check the quality of the stereo pairs, thanks to their PDS on-line label files. Then, the user can choose one or several stereo footprints from the map view and they appear in the stereo-restitution view. If the raw image couple is not stored on the local server, MarsSI automatically adds the 2 images to the user's cart and ask him to process the data before launching the stereo-restitution application. A script inspired from Zack Moratto's blog [8] has been written. This script uses the NASA Ames Stereo Pipeline toolkit to process the stereo images and automatically obtain DTM.

4. Conclusion

The teamwork engaged under the e-Mars project has allowed the creation of an application that fully matches the needs of our team of martian geologists, allows the integration of new data processing chains, and offers standardized and distributed storage/compute resources. The application has also been designed to deal with other planetary targets. The next step of MarsSI, the martian surface database application, will be to open up to the martian community.

Acknowledgements:

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The first Quadrangle of the Mars Express HRSC Multi-Orbit Data Products (MC-11-E)

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Abstract

Panchromatic stereo and color images of the High Resolution Stereo Camera (HRSC) have been used for production of digital terrain models (DTMs) and orthoimages for the surface of Mars from single orbits since several years. We report on the characteristics of a new HRSC data product, HRSC image mosaics and multi-orbit DTMs, related methodology aspects, and the completion of the first regional product dataset.

1. Introduction

The High Resolution Stereo Camera (HRSC) of ESA's Mars Express mission [1,2] is designed to map and investigate the topography of Mars and its satellites. As a push broom scanning instrument with nine CCD line detectors mounted in parallel, its unique feature is the ability to obtain along-track stereo images and four colors during a single orbital pass. The sub-pixel accuracy of derived 3D points allows producing DTMs with grid sizes of up to 50 m and a height accuracy on the order of one pixel on the ground and better [3,4].

After more than 10 years of operation, HRSC has covered about 70% of the surface by panchromatic images at 10-20 m/pixel, and about 98% at better than 100 m/pixel. As the areas with continuous coverage by stereo data are increasingly abundant, the HRSC team has recently started a coordinated effort for the mapping of Mars by multi-orbit DTMs and image mosaics, using the complete HRSC mission data record. Such seamless, precisely co-registered data products are thought to provide valuable geodetic reference data and geological context to a variety of other datasets, bridging also between global MOLA altimetry and topography data derived from other stereo imaging instruments.

2. Methodology

Derivation of multi-orbit data products [5] is based on the same set of procedures for image rectification, matching, strip-adjustment, and calculation of 3D points applied also for the production of single-strip HRSC DTMs and orthoimages [4]. In addition, bundle block adjustment [6,7,8] and a technique for joint interpolation of multi-scale 3D point sets [9] are used. Orthoimages are photometrically corrected (Lambert model) and normalized to an external brightness standard (Thermal Emission Spectrometer albedo) prior to mosaicking [10,11]. The table below lists main characteristics of the new data product.

Table 1: Product specifications for HRSC single-strip Level-4 products and multi-orbit data products

	Single-strip DTM	*Single strip orthoimage*	*Multi-orbit DTMs*	*Orthoimage mosaics*
Production Status	40% completed	40% completed	First prototype completed (MC-11E)	First prototype completed (MC-11E)
Product Subtypes	Spheroid DTM Areoid DTM	Panchromatic (Nadir), Red, Green, Blue and Near-Infrared Channel Orthoimages	Spheroid DTM Areoid DTM	Panchromatic nadir mosaic Pan-sharpened color mosaic
Data Format	16 bit, numeric height resolution 1 m	8 bit	16 bit, numeric height resolution 1 m	16 bit
Spatial Resolution	50 / 75 / 100 m … depending on quality of image and orientation data	12.5 / 25 / 50 m … depending on ground resolution	50-100 m	depending on subtype 12.5 m (pan) max 50 m (col)
Reference Bodies for Height	Spheroid r = 3396 km and GMM3-derived equipotential surface (Areoid DTM)	n/a	Spheroid r=3396 km and GMM3-derived equipotential surface (Areoid DTM)	n/a
Reference Body for Map Projection	Spheroid r = 3396 km	Spheroid r = 3396 km	Spheroid r = 3396 km	Spheroid r = 3396 km
Map Projection	Sinusoidal (±85° latitude) Polar-Stereographic (polar areas)	Sinusoidal (±85° latitude) Polar-Stereographic (polar areas)	Equidistant Cylindrical (±57° latitude) Polar Stereographic (polar areas)	Equidistant Cylindrical (±57° latitude) Polar Stereographic (polar areas)

3. Results for quadrangle MC-11-E

The new mapping program adopts the MC-30 global mapping scheme which subdivides Mars into 30 quadrangles. For the HRSC mapping products, each quadrangle is subdivided in two to limit data volumes. MC-11 East is located at the equator and covers an E-W extension of about 1330 km (at the equator) and a N-S extension of about 1780 km. The area includes parts of Arabia Terra, Meridiani Planum and Chryse Planitia and the data products are based on 89 individual HRSC image strips. Comparison with MOLA data and analysis of residual offsets between individual HRSC strips shows that the multi-orbit data product provides the same 3D point precision and the same accuracy of co-registration with MOLA heights as the HRSC single-orbit data products, while, in addition, pixel-scale co-registration accuracy between individual HRSC image strips is achieved using bundle block adjustment, as required for producing image mosaics at the full nadir image resolution [5].

4. Summary and Outlook

The completion of the first HRSC MC-30 half-tile demonstrates that multi-orbit DTMs with grid spacing of 50 m are feasible for large surface areas in spite of the existing variation of ground pixel size based on bundle block adjustment and joint interpolation of multi-scale 3D points. Likewise, after a photometric normalization and by using an external albedo map as a brightness standard, it is possible to produce visually homogeneous image mosaics although the images (due to orbit constraints) are frequently acquired under very different illumination and atmospheric conditions. Acquisition of additional data for further improving data coverage is one of the priorities for the remaining phases of the mission.

Acknowledgements

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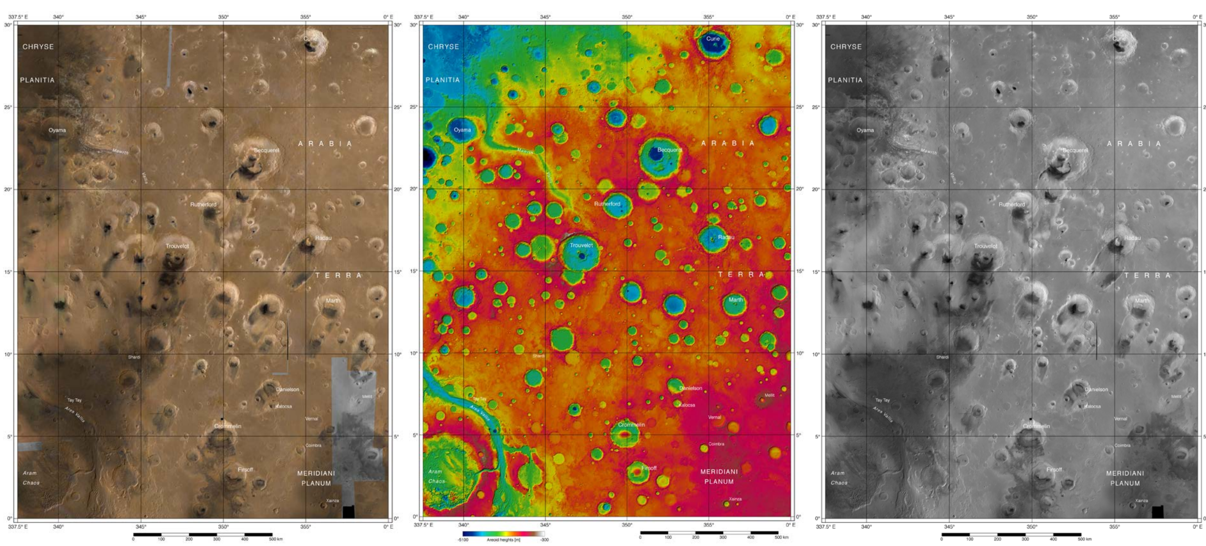

Figure 1: HRSC color mosaic, color-coded relief map, and nadir mosaic for MC-11 (East). E-W width about 1330 km (at the equator), N-S about 1780 km, resolution 12.5 m (panchromatic mosaic) and 50 m (DTM, color mosaic).

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EU-FP7-iMARS: analysis of Mars multi-resolution images using auto-coregistration, data mining and crowd source techniques: A Mid-term Report

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Abstract

Understanding the role of different solid surface formation processes within our Solar System is one of the fundamental goals of planetary science research. There has been a revolution in planetary surface observations over the last 8 years, especially in 3D imaging of surface shape (down to resolutions of 10s of cms) and subsequent terrain correction of imagery from orbiting spacecraft. This has led to the potential to be able to overlay different epochs back to the mid-1970s. Within iMars, a processing system has been developed to generate 3D Digital Terrain Models (DTMs) and corresponding OrthoRectified Images (ORIs) fully automatically from NASA MRO HiRISE and CTX stereo-pairs which are co-registered to corresponding HRSC ORI/DTMs. In parallel, iMars has developed a fully automated processing chain for co-registering level-1 (EDR) images from all previous NASA orbital missions to these HRSC ORIs and in the case of HiRISE these are further co-registered to previously co-registered CTX-to-HRSC ORIs. Examples will be shown of these multi-resolution ORIs and the application of different data mining algorithms to change detection using these co-registered images. iMars has recently launched a citizen science experiment to evaluate best practices for future citizen scientist validation of such data mining processed results. An example of the iMars website will be shown along with an embedded Version 0 prototype of a webGIS based on OGC standards.

1. Introduction

Since January 2004, the ESA Mars Express has been acquiring global data, especially HRSC stereo (12.5-25m nadir images) with 87% coverage with images ≤25m and more than 65% useful for stereo mapping (e.g. atmosphere sufficiently clear). The derived HRSC orthorectified images (ORIs) and corresponding Digital Terrain Models (DTMs) are co-registered to the global MOLA heights and have planimetric accuracy at the subgrid point level (≈9-25m RMS). This means that non-HRSC can be co-registered to HRSC ORIs to create a time layer stack of all available images of high resolution (≤100m and ≤20m). DTM/ORIs can also be retrieved for the ≈4,000 stereo-pairs from the NASA CTX and HiRISE instruments (≈1% of total). iMars has built a processing platform which can automatically co-register level-1 (EDR) data from non-HRSC images to the corresponding ORIs/DTMs and examples of this processing chain will be demonstrated in the meeting. In the second half of the iMars project these processing systems will be exercised "in anger" on all available images above a certain quality threshold to generate a time layer stack for every available image. These co-registered and orthorectified images are being used together with several different data mining approaches to try to locate and identify changes due to previously observed surface change features such as dark streaks, gullies, new impact craters, dune movement, polar pits, RSLs (Recurring Slope Linae) and avalanches. A quantitative assessment through a workshop at EGU 2014 and a corresponding online questionnaire was made of the scientific interests of European planetary scientists. This survey determined that change detection research was under-developed in Europe. In 2016, it is planned to involve geoscientists in further quantitative studies of automatically determined change features. In parallel to expert user assessments of the automatically determined change detection features, a series of citizen science assessments will be made of these auto-changed features.

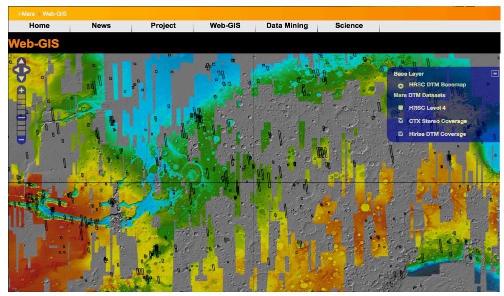

Figure 1. Example of iMars webGIS displaying all HRSC processed DTMs.

The results of the project, including DTMs (see Figure 1) will be disseminated through an OGC-compliant webGIS system based on the PRoGIS described in Giordano et al. (2015). This interface will also be employed within the citizen science assessment.

2. Methods

A number of automated stereo processing chains were assessed in a round-robin exercise within iMars. The two best, NASA Ames stereo pipeline and the

University of Seoul (UoS) were employed in a comparative quantitative assessment. The UoS system was ported by UCL staff [Yershov et al., this conference] onto a linux cluster and in parallel, UoS staff prepared the software for implementing on a parallel system in Korea.

A fully automated co-registration system described elsewhere in this conference (Sidiropoulos & Muller) has been developed to generate level-1b CTX-to-HRSC-ORI, HiRISE-to-CTX and HiRISE-to-HRSC_ORI pairs. The same system can also be applied to older (and future) image pairs form older NASA missions (e.g. MOC-to-HRSC, etc..). An example of the feature selection and auto-coregistration is shown in Figure 3 below.

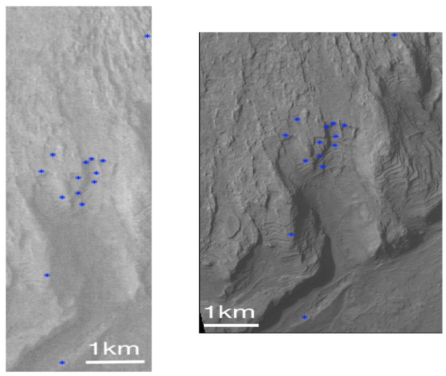

Figure 2. Automated feature points detected from HRSC ORI (left) and CTX level-1.

3. Results

An example of a multi-resolution DTM is shown in Figure 2 from UoS.

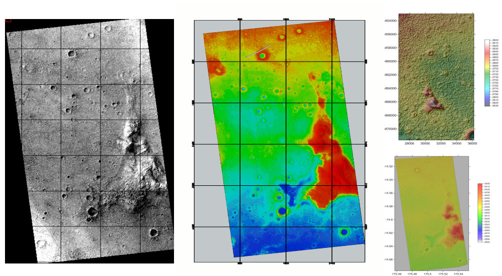

Figure 3. HiRISE ORI and DTM (leftmost panels), CTX-DTM (upper right) and HRSC-DTM of the MER-A Spirit rover site generated using the UoS processing chain.

In the next phase of the project, the DTM and auto-coregistration system will be deployed to process the ≈750k images that have been acquired to date form orbit of Mars. In addition, the automated data mining will be applied to co-registered sets of ORIs and DTMs and all of the results into the database of the webGIS. These data mining results will be assessed within a citizen science project under the aegis of the Zooniverse project. A sample screen for an initial experiment conducted by the University of Nottingham is shown in Figure 4.

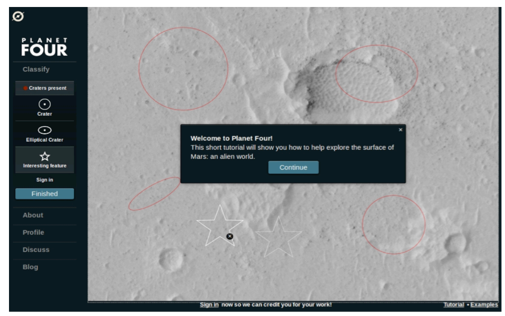

Figure 4. Example screen of a Zooniverse experiment for citizen science for Mars crater detection.

6. Summary and Conclusions

The iMars project is well into the development of the basic processing chains, which will be used in production in the next half of the project to generate a time series of almost 40 years of Mars' observations from orbit. A report will be given on how expert users are being consulted on its evaluation.

Acknowledgements

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Is that a Crater? Designing Citizen Science Platforms for the Volunteer and to Improve Results

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Abstract

Citizen science platforms allow non-scientists to take part in scientific research across a range of disciplines, and often involve the collection of volunteered scientific analysis from remotely sensed imagery. What these systems ask of volunteers varies considerably in terms of task type, level of user required and user freedom. This work studied the Zooniverse's Planet Four project and investigated the effect of task workflow design on user engagement and data outputs. Results show participants found the more guided, less-autonomous interface more frustrating, while the less complex, repetitive interface resulted in greater data coverage.

1. Introduction

The seemingly relentless advance of modern day technology has not only made the world a more connected place, but has also increased our capacity to collect and store information to an unprecedented level. This has resulted in a flood of data being produced, particularly be increasingly advanced and automated instruments carrying out large-scale surveys. Mars alone has been the subject of at least 16 NASA missions, with more planned in the future, each carrying more advanced instrumentation able to collect data in greater abundance with unprecedented levels of detail.

Citizen science, or "public participation in scientific research" [1], can be described as research conducted, in whole or in part, by amateur or nonprofessional participants often through crowd-sourcing techniques. It increasingly utilises Virtual Citizen Science (VCS) platforms [4] that gather scientific analysis from remotely sensed imagery, both of the Earth and other solar system bodies, through a website interface. Due to the abundance of data, planetary science is a prime candidate for, and adaptor of, citizen science and more specifically VCS platforms.

Despite virtual citizen science being a relatively new form of work, there has been a growing field of research considering citizen science practices in their own right, beyond the scientific problems they address. Particularly, studies involving interface HCI, platform functionality and public engagement have grown in number, contributing to a growing body of citizen science scholarship [2, 5]. However, there has been relatively little attention paid specifically to human factors issues regarding this type of data collection. This comprises a significant research gap, given that the success of a citizen science venture is directly related to its ability to attract and retain users, both to gather the large amount of data required, and to ensure the utility of the data collected [3].

In this study we make a first step in considering how virtual citizen science systems can be better designed for the needs of the volunteer, exploring whether manipulating task flow would affect both the information collected, as well as the volunteers' experience of user the interface.

2. Methodology

In order to investigate the effect of task workflow design on user experience and VCS output, a new version of the Zooniverse's Planet Four project has been developed. The new site allows users to mark craters on images of the Martian surface. A laboratory study has been carried out to both consider task workflow factors and also act as a technical test, identifying any general functionality and usability issues before a public launch.

The platform has been developed to include three different interfaces for marking craters that vary in task type, number of tasks available to the user and user freedom. They include: FULL - users have access to all the tools and can complete all crater marking tasks for each image in any chosen order, STEPPED - all tools are made available to the user and all tasks completed in a predefined order (increasing in complexity) for each image, which cannot be diverged from, and RAMPED - users have access to one tool and complete one crater marking task for a set number of images, then use another tool and complete another task (increasing in complexity) for the next set of images etc.

Thirty participants took part in the lab study between January and March 2014. There were no specific prerequisites for participation. Each participant used each interface in a random order, and afterwards completed a questionnaire asking them to share their views across themes including design & usability, tasks & tools and imagery.

3. Experimental Results

In terms of the number of crater markings per image, a statistically significant difference is shown ($F(2.656, 201.83) = 7.416$, $p < .0005$). The RAMPED (position) interface resulted in a greater number of markings (3.61 ± 4.67) compared to the FULL (2.46 ± 2.93, $p < .001$), STEPPED (2.55 ± 4.17, $p < .003$) and RAMPED (mark) (2.24 ± 2.85, $p < .001$) interfaces.

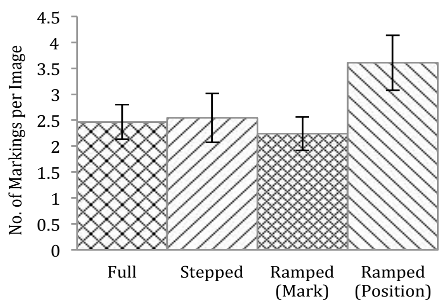

Figure 1: Crater marking results

4. Conclusions

This study found that altering the task workflow design of the interface does have an effect both on the user experience and on the resulting VCS output. When considering usability, participant comments were much greater in number for the stepped interface and predominantly negative regarding the restriction of choice, as explained by participant S19: *"I don't like to be forced to use a certain task order, and I couldn't go back or switch tools…"*

The ramped interface resulted in a much higher number of crater clusters being identified. This is an important result, as reducing the number of null returns would in turn reduce the time spent on data reduction by the science team.

When considering task workflow design, future citizen science platforms will need to perform a balancing act, weighing up the importance of user satisfaction, the data needs of the science case and the resources that can be committed both in terms of time and data reduction, more than likely on a case-by-case basis.

Acknowledgements

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MExLab Planetary Geoportal: 3D-access to planetary images and results of spatial data analysis

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Abstract

MExLab Planetary Geoportal was developed as Geodesy and Cartography Node which provide access to results of study of celestial bodies such as DEM and orthoimages, as well as basemaps, crater catalogues and derivative products: slope, roughness, crater density (http://cartsrv.mexlab.ru/geoportal). The main feature of designed Geoportal is the ability of spatial queries and access to the contents selecting from the list of available data set (Phobos, Mercury, Moon, including Lunokhod's archive data). Prior version of Geoportal has been developed using Flash technology. Now we are developing new version which will use 3D-API (OpenGL, WebGL) based on shaders not only for standard 3D-functionality, but for 2D-mapping as well. Users can obtain quantitative and qualitative characteristics of the objects in graphical, tabular and 3D-forms. It will bring the advantages of unification of code and speed of processing and provide a number of functional advantages based on GIS-tools such as:

- possibility of dynamic raster transform for needed map projection;

- effective implementation of the co-registration of planetary images by combining spatial data geometries;

- presentation in 3D-form different types of data, including planetary atmospheric measurements, sub-surface radar data, ect.

The system will be created with a new software architecture, which has a potential for development and flexibility in reconfiguration based on cross platform solution:

- an application for the three types of platforms: desktop (Windows, Linux, OSX), web platform (any HTML5 browser), and mobile application (Android, iOS);

- a single codebase shared between platforms (using cross compilation for Web);

- a new telecommunication solution to connect between modules and external system like PROVIDE WebGIS (http://www.provide-space.eu/progis/).

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Collaborative Virtual Environments for Mars Science Analysis and Rover Target Planning

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Abstract

The CROSS DRIVE project aims to develop an innovative collaborative workspace infrastructure for space missions that will allow distributed scientific and engineering teams to collectively analyse and interpret scientific data as well as execute operations of planetary spacecraft. It aims to mobilise a team of best European expertise in the field of Mars science data collection and analysis to propose and study synergic combinations of data sets and their benchmarking.

1. Introduction

CROSS DRIVE stands for "Collaborative Rover Operations and Planetary Science Analysis System based on Distributed Remote and Interactive Virtual Environments" and aims at creating the foundations for collaborative distributed virtual workspaces for European space science. Space exploration missions have produced huge data sets of potentially immense value for research as well as planning and operating future missions. However, currently expert teams, data and tools are fragmented, leaving little scope for unlocking this value through collaborative activities.

The question of how to improve data analysis and exploitation of space-based observations can be answered by providing and standardising new methods and systems for collaborative scientific visualization and data analysis, and space mission planning and operation. This will not only allow scientists to work together, with each other's data and tools, but importantly to do so between missions. The proposed collaborative workspace encompasses various advanced technological solutions to coordinate central storage, processing and 3D visualization strategies in collaborative immersive virtual environments (cf. Fig. 1), to support space data analysis.

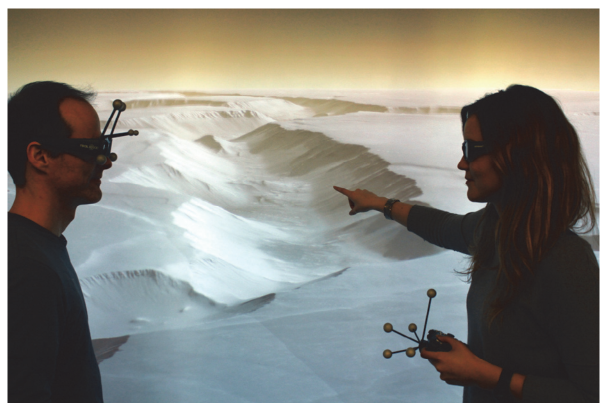

Figure 1: Interactive Mars Science Data Analysis in an immersive Virtual Environment.

Three case studies will demonstrate the utility of the workspaces for European space science: Mars atmospheric data analysis, rovers landing site characterization and rover target selection during its real-time operations. The use cases will exploit state-of-the-art science data sets and they will be constructed in view of the ESA ExoMars 2016 TGO and 2018 rover missions' scenarios.

Impact on beneficiaries will be maximised both through providing an expandable backbone infrastructure and three levels of workspace for: scientists directly engaged, other external scientists, and the public.

2. The Workspaces

The collaborative workspace platform is focused on the data analysis and operations of planetary missions (cf. [1]). Its purpose is to allow scientific and engineering teams, distributed across the world, to work together in a shared 3D space using data from past and ongoing missions, visualise scientific data and the spacecraft and rover as well as their trajectories and status information, and allow the users to freely navigate and collaboratively interact with the displayed data.

In order to allow different forms of collaboration in different contexts, three workspaces will be investigated in the CROSS DRIVE project: Core Collaboration Workspace for the core mission team, External Public Workspace for engaging selected scientists and Web Portal for broader dissemination and engagement of scientific community.

3. The Use Cases

The main target mission will be the ExoMars scenario when a Mars satellite and rover will be jointly operated. Intensive real-time science analysis processes are expected during the rover operations and in order to reduce costs, part of the science team would have to be remotely connected to the Mission Control Centre at ALTEC. To evaluate the efficiency of CROSS DRIVE's architecture as well as the foreseen data processing and analysis methods, we will perform three test use cases:

1. **Landing sites characterisation**: This use case will visualise, analyse and present relevant aspects of research in landing site selection for Mars robotic missions. Science users will be able to analyse geologic features of selected areas of Mars, apply basic GIS functionality and a selection of real-time analysis tools, and analyse the surface and subsurface structure of the terrain. Relevant sample datasets will be visualised as 3D terrain model using the Mars Cartography Virtual Reality System.

2. **Mars atmospheric data analysis and benchmarking**: Global views of Mars in order to analyse concepts related to the global circulation like geo-potential maps and time/spatial variations of selected variables will be considered. Tests will include comparisons among measured data and output of off-line complex models, among data from different payloads, and among data collected from different locations or time. Correlation and benchmarking between satellite and ground based measurements are also foreseen.

3. **Rover target selection**: This test addresses operation planning of planetary rovers and satellites by using the Collaborative Workspace. In particular the system will allow analysis of geologic features of terrain as viewed by the on-board cameras of the rover, comparison among rover images/DTM and satellites' images/DTM, analysis of the morphology of the terrain in correlation with the expected landing trajectories, provision of commands to the satellite and rover, and review of the data coming from the rover after commands execution.

4. Conclusion and Future Work

The CROSS DRIVE project will last until December 2016. During the remaining project timeframe, the three use cases will be developed and the architecture of the collaborative workspace infrastructure will be finalized and tested. The final goals of CROSS DRIVE are to deliver a virtual, collaborative and distributed workspace for space missions, in which scientific and engineering data will be visualized, analysed, interpreted and spread across scientists, engineers and the common public. A final workshop will present the results and discuss future steps with virtual reality experts and the space science community. We believe that eventually the outcome of CROSS DRIVE will advance the ExoMars planning and operation support as well as space mission data exploitation considerably.

Acknowledgements

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Interactive Webmap-Based Science Planning for BepiColombo

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Abstract

For BepiColombo, ESA's Mission to Mercury, we will build a web-based, map-based interface to the Science Planning System. This interface will allow the mission’s science teams to visually define targets for observations and interactively specify what operations will make up the given observation. This will be a radical departure from previous ESA mission planning methods. Such an interface will rely heavily on GIS technologies.

This interface will provide footprint coverage of all existing archived data for Mercury, including a set of built-in basemaps. This will allow the science teams to analyse their planned observations and operational constraints with relevant contextual information from their own instrument, other BepiColombo instruments or from previous missions. The interface will allow users to import and export data in commonly used GIS formats, such that it can be visualised together with the latest planning information (e.g. import custom basemaps) or analysed in other GIS software.

The interface will work with an *object-oriented concept of an observation* that will be a key characteristic of the overall BepiColombo science-planning concept. Observation templates or classes will be tracked right through the planning-execution-processing-archiving cycle to the final archived science products.

By using an interface that synthesises all relevant available information, the science teams will have a better understanding of the operational environment; it will enhance their ability to plan efficiently minimising or removing manual planning.

Interactive 3D visualisation of the planned, scheduled and executed observations, simulation of the viewing conditions and interactive modification of the observation parameters are also being considered.