Fusion and Visualization of HiRISE Super-Resolution, Shape-from-Shading DTM with MER Stereo 3D Reconstructions

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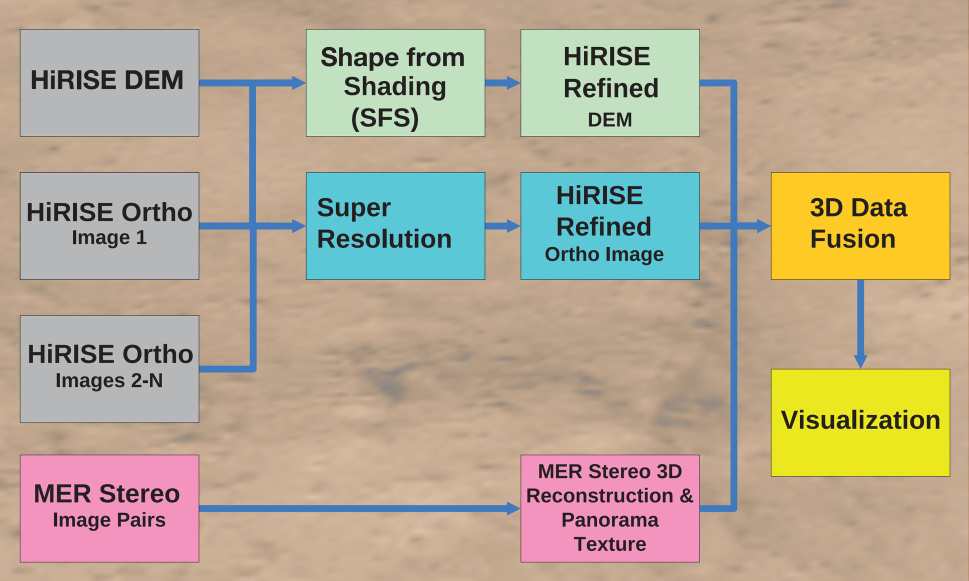
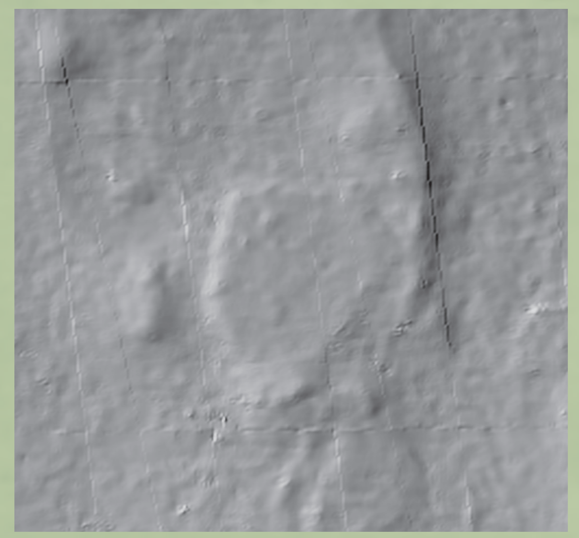
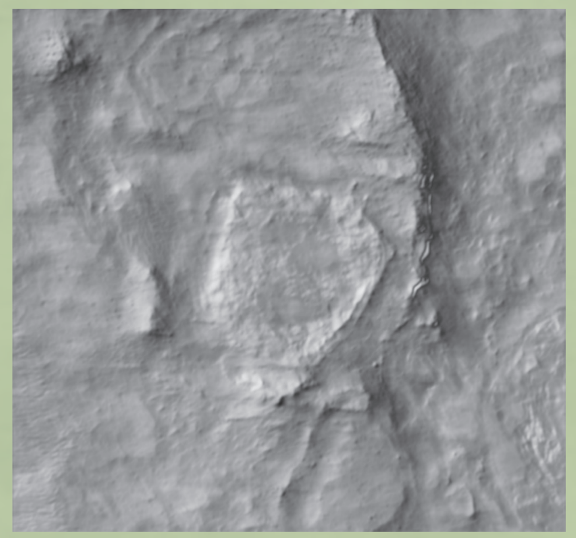


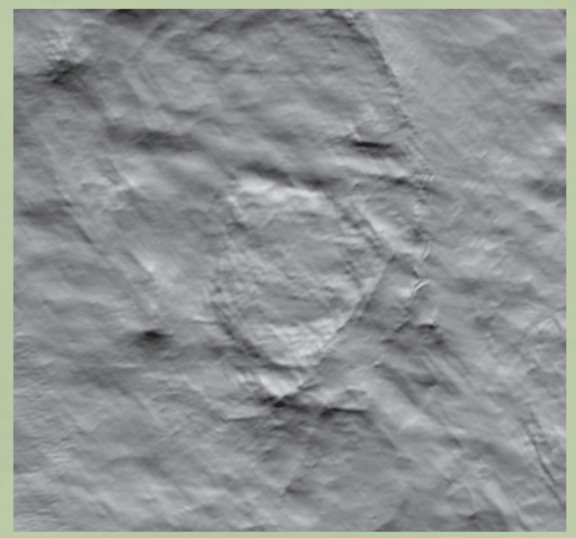
The FP7-SPACE project PRoViDE has assembled a major portion of the imaging data gathered so far from rover vehicles, landers and probes on extra-terrestrial planetary surfaces into a unique database, bringing them into a common planetary geospatial context and providing access to a complete set of 3D vision products.

One major aim of PRoViDE is the fusion between orbiter and rover image products. 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 (Tao & Muller, 2014), increasing the Ortho images resolution to 5cm. In addition, shape-from-shading is applied to one of the ORIs at its original resolution for refinement of the HiRISE DTM, leading to DTM ground resolutions of up to 25 cm. After texture-based co-registration with these refined orbiter 3D products, MER PanCam and NavCam 3D image products can be smoothly pasted into a multi-resolution 3D data representation. Typical results from the MER mission 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 to explore and analyze the geological characteristics of rock outcrops, for example the detailed geometry and internal features of sedimentary rock layers, to aid paleoenvironmental interpretation. This integrated approach enables more efficient development of geological models of martian rock outcrops. Measurement tools to obtain geospatial data of surface points and distances between them.

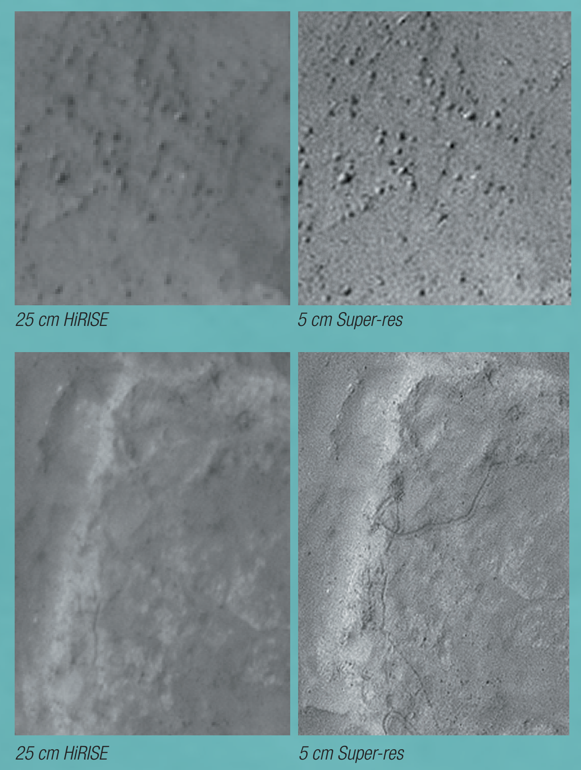
Shape from shading (SFS) uses the properties of light reflecting off surfaces to build up localised slope maps, which can subsequently be combined to extract topography. This works especially well on homogeneous surfaces and can recover fine detail. The choice of a reflectance modelling function (BRDF) and its associated parameters for the surface being analysed is a key factor in successful SFS reconstruction. Accurate knowledge of camera geometry and illumination conditions is also important. The Large Deformation Optimisation Shape From Shading (LDOSFS) algorithm shown here was developed at Aberystwyth University. It applies calculated deformations at a succession of scales to the initial surface, gradually refining the level of detail in the resulting DEM. Using an initial coarse DEM generated by stereo matching as a "seed" surface for the SFS algorithm, together with a higher-resolution image, it is possible to refine the original DEM and bring out fine surface detail. Here the SFS algorithm has been applied to an initial 1m resolution DEM of the "Home Plate" area on Mars which includes some artifacts. By combining this with a HiRISE-derived image at 25cm resolution, an enhanced detail DEM is obtained [Initial image and DEM: UCL/NASA/HiRISE]. Some reconstruction artifacts remain, and these are the subject of ongoing research.


„Home Plate" input DEM shaded (1m resolution)

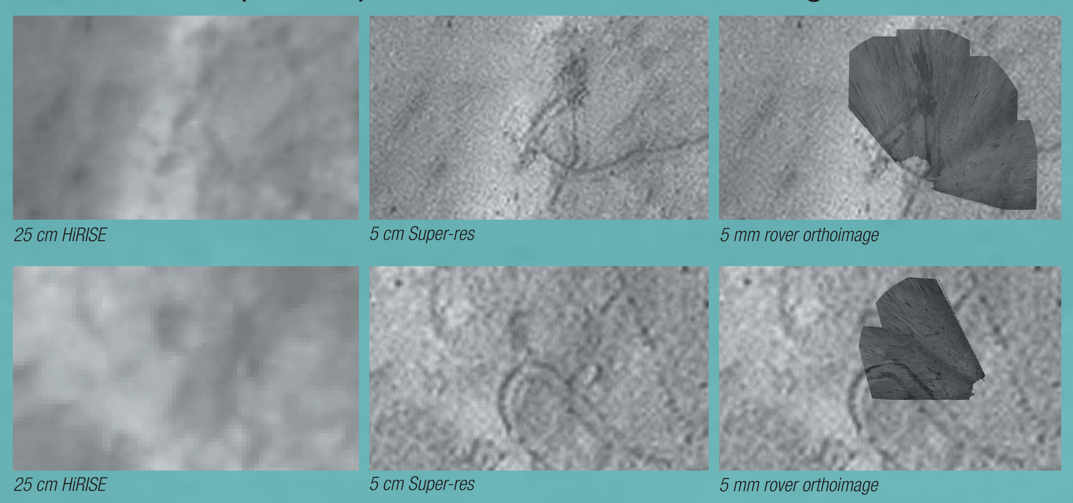

SFS-enhanced DEM shaded (25cm resolution)


SFS DEM shaded & backlit, showing some reconstruction artifacts

We have developed a novel **super-resolution algorithm** called Gotcha-PDE-TV (GPT) to be able to restore higher resolution image from the non-redundant sub-pixel information contained in multiple lower resolution raw images. The technique is demonstrated here with 8 repeat-pass 25cm HiRISE images covering the MER-A spirit rover traverse in Gusev crater to resolve a 5cm Super Resolution image of the area. The methods and their validation are described in a forthcoming publication (Tao & Muller, 2015)

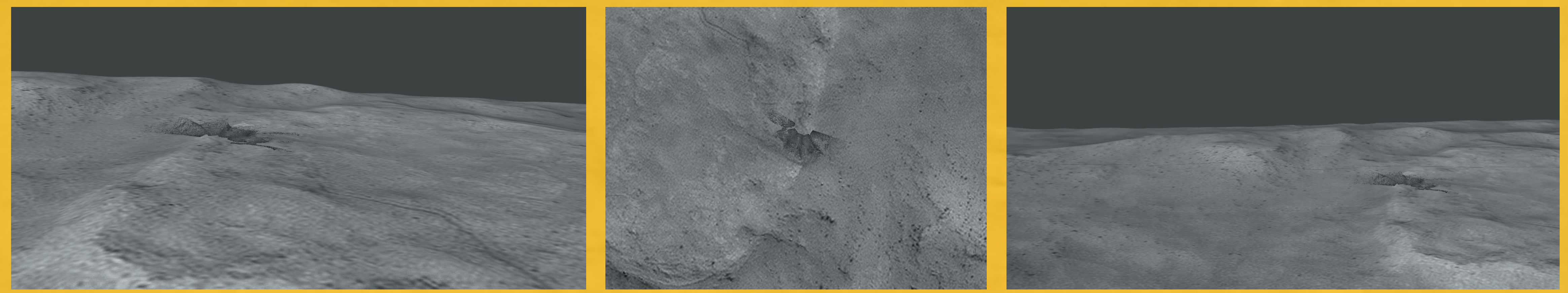


Precise co-registration of HiRISE OrthoRectified Image (ORI) and MER NavCam ORI mosaic has been achieved for several sites whichever have rich structural features (e.g. crater, cliff, hill, etc.). The Iterative Bundle Adjustment (IBA) corrected traverse is further corrected based on the co-registered rover positions. We use a morphological normalised Mutual Information based approach to co-register the wide baseline ORI from MER with HiRISE ORI, which is co-registered with CTX and HRSC v50 products via the mutual shape adapted SIFT feature matching method, both developed within the PRoVisG and PRoViDE project. Fusion between MER and HiRISE has a sub-pixel accuracy of 1cm-5cm locally and is been further improved at present via co-registration of MER and super-resolution restored HiRISE image.



Fusion between orbiter (HiRISE) and rover (MER) image products

The fusion of rover based ground imagery and orbiter data provides a great challenge due to the large differences in sensor footprint and ground sampling distance. Using high resolution HiRISE images the rover traverse could be refined precisely based on tracks visible from the orbit using an iterative bundle adjustment. These refined rover positions provide an initial prediction for the position and orientation of the calculated 3D reconstructions which remains to be adjusted mainly in its height component. This is done via the application of an ICP (iterative closest point) algorithm to refine the spatial relation between the orbiter derived model and the ground based reconstruction based on mutual structure information. 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. In a next step it is planned to project data of even higher resolution onto the reconstructions to show microscopic images or drill sites in a wide geographic context of increasing model resolution.


Verifying the fusion of a super-resolution HiRISE DEM with a MER-A Stereo panorama DEM (point cloud) in 3D view

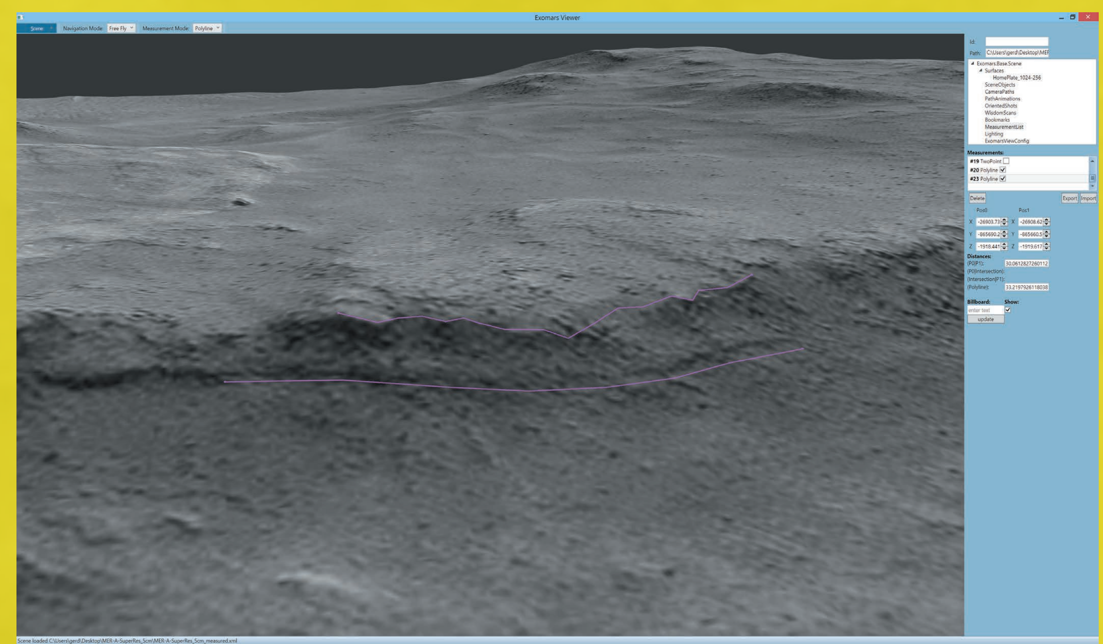
PRo3D: Planetary Robotic 3D Viewer

- Realistic real-time rendering for interactive scientific exploration of planetary surfaces
- Multi-resolution geometry supports big data sets and zooming from largearea views down to very small surface details
- Accurate measurements and annotations in 3D space for scientific analysis
- Access by remote rendering, even on mobile devices

Future Work

- Physically based rendering considering surface materials
- Skylight models to increase realism and illuminate Martian terrain with skylight from Earth


Viewer as remote rendering application on a tablet


Viewer GUI & annotation feature


Three Wall CAVE demo for immersive experiences

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