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Implementation of a Self-Consistent Stereo Processing Chain for 3D Stereo Reconstruction of the Lunar Landing Sites

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1. Introduction

The department for Planetary Geodesy at TU Berlin is developing routines for photogrammetric processing of planetary image data to derive 3D representations of planetary surfaces. The ISIS software [1], developed by USGS, Flagstaff, is readily available, open source, and very well documented. Hence, ISIS was chosen as a prime processing platform and tool kit. However, ISIS does not provide a full photogrammetric stereo processing chain. Several components like image matching, bundle block adjustment (until recently) or digital terrain model (DTM) interpolation from 3D object points are missing. Our group aims to complete this photogrammetric stereo processing chain by implementing the missing components, taking advantage of already existing ISIS classes and functionality. With this abstract we would like to report on the development of our stereo processing chain and its first application on the Lunar Apollo landing sites.

2. Stereo Processing Chain

To compute accurate 3D models and subsequently ortho-image maps several methods and software were developed. The processing chain contains several different steps namely dense image matching, object point estimation and DTM interpolation. The general workflow and components needed to derive DTMs and ortho-images is displayed in Figure 1.

2.1. Matching Software

The matching software is optimized for both orbital and close-ranged planetary images and compatible with ISIS formats as well as other common formats like Vicar, TIFF, PNG or JPEG. It supports multi-threading in order to increase the performance and to handle large images, such as Lunar Reconnaissance Orbiter Camera (LROC) data, efficiently. The matcher integrates different matching algorithms like a feature based (FB) and an area-based (AB) matching algorithm. With the help of Speeded Up Robust Features (SURF) the geometrical relations of the input images are determined and the differences are minimized. AB matching techniques like normalized cross-correlation (NCC) and least-squares matching (LSM) are used to perform a dense matching. NCC delivers an approximate value of the disparity value and is used as an input for the LSM. The latter is applied in order to refine the result to sub-pixel accuracy. Due to the FB capability, the software can handle uncompressed, radiometrically corrected and non-rectified images. Thus a pre-rectification and an existing DTM of the study area are not necessary.

2.2. Object Point Calculation

A software which is capable of calculating the object points from the matching results is being developed. It uses the camera models which are already existing within the ISIS frame. SPICE kernels provide the camera interior and exterior orientations and by applying the collinearity equations the object points are estimated in an iterative manner. A first implementation is finalized and needs further testing. It is also envisaged to integrate a bundle adjustment module within this tool to minimise the uncertainties of camera orientations and avoid the possible offsets and distortion between the derived surface model and the absolute frame.

2.3. Interpolation Tool

Large clouds of 3D object point coordinates are used as input data for the DTM interpolation. The coordinates are map-projected into a pre-defined cube file, which serves as a target container. The input data can be provided in non-sequential order and there are no specific requirements in terms of spatial distribution or homogeneity of the distribution of the points. Furthermore, it is possible that several object points define only one pixel of the target projection. Different interpolation methods like mean, median, inverse distance weighting (IDW), nearest neighbor (NN), intersection accuracy weighting (IAW) are implemented to determine exactly one value for the resulting pixel. Furthermore the interpolator has a gap filling feature.

3. Tests

The stereo chain was tested with the Apollo 11, 14 and 15 landing sites. We used LROC images with the ground resolution of 0.49 to 0.55 meters per pixel. The image pairs were matched to provide DTMs covering parts of the corresponding landing site areas. Table 1 shows the statistical summary of the image matching and triangulation results for each landing site.

3.1. Co-Registration to the LOLA Reference

While the DTMs benefit from the very good internal consistency, small offsets and possible distortion between the derived surface models remain. The models are also not referenced to a common reference frame as uncertainties in the spacecraft attitude, position, or instrument mounting on the spacecraft are present. While a bundle block approach to correct for these small misalignments is currently under development, we have studied a different approach using Lunar Orbiter Laser Altimeter (LOLA) data as a common reference. The resulting DTMs are co-registered to LOLA tracks that intersect the study area. During this process a grid search is performed looking for a best fit between the LOLA profile and the DTM heights on pixel accuracy level [2]. This is followed by a least squares fit of the track with respect to the DTM to obtain sub-pixel accuracy for the fit. Results of the fit between DTMs and LOLA tracks are shown in Table 2.

References

[1] Anderson, J. A., Sides, S. C., Soltesz, D. L., Sucharski, T. L. and Becker, K. J.: Modernization of the Integrated Software for Imagers and Spectrometers, Lunar and Planetary Institute Science Conference Abstracts, 35, p. 2039, 2000.

[2] Gläser, P., Haase, I., Oberst, J. and Neumann, G. A.: Co-registration of laser altimeter tracks with digital terrain models and applications in planetary science. Planetary and Space Science, 89, pp. 111-117, 2013.

Landing Site	♯ of matches	♯ of overlapping pixels	♯ of object points	Avr. tri. error
Apollo 11	73,917,578	74,000,000	73,917,545	+/- 0.32
Apollo 14	91,983,984	92,000,000	91,983,496	+/- 0.71
Apollo 15	83,454,803	84,500,000	83,545,720	+/- 0.47

Table 1: Statistical summary of the image matching results.

DTMs	Lateral Shift (m)		Height Shift (m)
	Sample	Line	
Apollo 11	-36.65	-1.02	9.332
Apollo 14	8.84	33.47	-3.814
Apollo 15	65.97	-2.02	11.278

Table 2: The shift values of the DTMs with respect to LOLA tracks

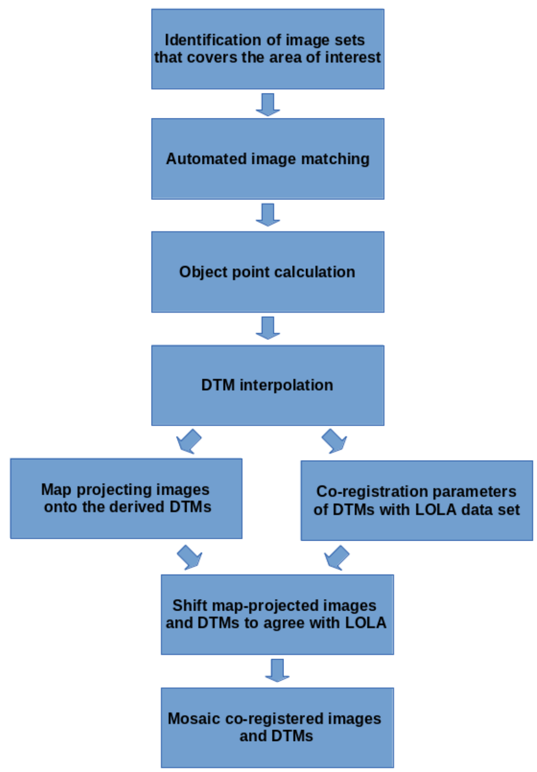

Figure 1: Stereo processing flowchart

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