MULTI-MISSION LASER ALTIMETER DATA PROCESSING AND CO-REGISTRATION OF IMAGE AND LASER DATA AT DLR.

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Introduction: The Institute of Planetary Research (IPR) at DLR has a long tradition in the processing, analysis, and archiving of planetary mapping data. In the past years, we also have become interested in laser altimeter datasets from various planetary missions. Consequently, IPR has joined forces with Technical University of Berlin to develop a system for the processing and storage of laser altimeter datasets, which are typically very large. The system is based on a Linux server and uses PostgreSQL and PostGIS as database software. The system currently contains all data from the MOLA (Mars Global Surveyor), LALT (Lunar Kaguya mission), MLA (MESSENGER), and LOLA (Lunar Reconnaissance Orbiter) instruments. The main purpose of the system is a fast search for laser altimeter data points in a specified area on the surface of the planetary body. Additional functions for recovery of housekeeping data, as well as the calculation of physical parameters like slope and roughness are also implemented. It is planned to use this laser data processing system also for the planning and optimizing of the operations of upcoming instruments like BELA (BepiColombo) and GALA (JUICE).

Furthermore, laser altimeter data can be combined with digital terrain models based on stereo images (stereo DTMs). Through the co-registration the individual advantages of these complementary topographic datasets can be combined, while the disadvantages are avoided [1]. Typically, laser altimeter data provide high topographic accuracy but it suffers from large gaps in the coverage. For stereo DTMs typically the opposite applies, they provide extensive coverage but less accurate height information. Consequently the combination of both data sets leads to internally consistent topographic products and can be used for quality assessment. Moreover, the temporal coverage of the data sets can be used for measurement of the rotation and tidal deformation of the planetary object [2].

Data Ingestion: All laser altimeter data from previous missions (LALT, MOLA, and MLA) and from the currently running mission (LOLA) were downloaded from the Planetary Data System (PDS) nodes and ingested into the databases carefully looking for the quality of the different laser shots. The datasets were indexed and clustered using the PostgreSQL commands to allow very fast access to the data. Data from instruments on missions close to launch (BELA) and in preparation (GALA) were simulated using an instrument performance model by taking into account the individual instrument characteristics and operation scenarios [3].

Data Analysis: A set of PostgreSQL routines was developed to allow the analysis of the laser databases. Scripts for the calculation of e.g. topography, slope, and roughness were developed to allow the calculation using the fast algorithms which are inherent to PostgreSQL and PostGIS. One example of a roughness calculation from return pulse spreading is shown in Fig.1. The developed scripts can be used for various missions since the catalog structures were designed very similar. Recently, a Python interface to the database was established and allows a more convenient access to the databases.

Fig.1: Roughness plot of Candor Chasma calculated from MOLA data. White areas correspond to high roughness, while black areas indicate regions which are smooth. The baseline for the roughness measurements is 75 m, i.e. the diameter of the MOLA footprint.

Co-registration of laser and stereo image data: Due to limitation in knowledge of the spacecraft orbit and attitude the topographic datasets (laser profiles or stereo DTMs) can have offsets with respect to each other. With the help of the co-registration such offsets can be determined and both datasets can be brought to an agreement within their respective uncertainties [4].

Co-registration would be straightforward in the case one could easily identify conjugate points, i.e. measurements which correspond to the same feature on the surface. Due to the heterogeneity in the coverage of the laser profiles compared to stereo DTMs the identification of conjugate is very hard to establish. Thus, our approach consists of both finding conjugate points and determining the transformation of the co-registration.

Co-registration formalism: In particular our approach is to co-register points in 3-D to a quasi-continuous representation of the planetary surface. Thereby the former points are the laser altimeter measurements and the latter is given by the gridded stereo DTM with applied sub-pixel interpolation. Having a continuous representation of the surface has the advantage that the gradients for computation of partial derivatives can be easily obtained. Thus, the co-registration can be performed through a non-linear least-squares adjustment. The functional model g is formed by the radial differences of the DTM radius r^{i}_{DTM} and the i-th laser altimeter measurement $\boldsymbol{r}^{i}_{\mathrm{LA}}$

$$g^{\boldsymbol{i}}(\boldsymbol{p}) = r^{i}_{\mathrm{DTM}}(\boldsymbol{p}) - \left|\boldsymbol{r}^{i}_{\mathrm{LA}}(\boldsymbol{p})\right|, \tag{1}$$

where $\boldsymbol{p}$ is a vector of co-registration parameters. The stereo DTM $r_{\mathrm{DTM}} = r_{\mathrm{DTM}}(l, s)$ is represented by a structured grid of lines l and samples s obtained from spherical or Cartesian coordinates with the help of a map projection. The parameters of the co-registration can be any parameterizable type of a 3-D manipulation, e.g. a similarity transformation with parameters for translation, rotation and scaling. Furthermore, the co-registration parameters can be related to dynamical process, like rotation of the planetary object [1,2].

With the help of the surface gradients the partial derivatives $\partial g^{\boldsymbol{i}}(\boldsymbol{p})/\partial \boldsymbol{p}$ can be computed and combined in form of a design matrix $\boldsymbol{A}$. The best-fit parameters are then obtained through an iterative solution of the normal equation

$$\boldsymbol{p}_{k+1} = \boldsymbol{p}_{k} - (\boldsymbol{A}_k^T \boldsymbol{A}_k)^{-1} \boldsymbol{A}_k^T \, \boldsymbol{g}(\boldsymbol{p}_k) \,, \tag{2}$$

where k denotes the iteration number. Typically after five iterations the estimates for the parameters converged and their formal uncertainty can be computed by

$$\boldsymbol{\Sigma}_p = \sigma_g^2 (\boldsymbol{A}^T \boldsymbol{A})^{-1} \,, \tag{3}$$

where $\boldsymbol{\Sigma}_p$ is the parameter covariance matrix and σ_g^2 is the variance of the final radial differences (Eq. 1). When applicable the observations can be weighted according to the accuracy of the laser altimeter measurement or the stereo DTM height uncertainty. With the help of the interpolation of the DTM the co-registration parameters can be determined accurate to the sub-pixel level for profiles with more than 100 data points on a rough terrain.

Fig. 2 shows a portion of the MOLA profile together with the stereo DTM based on images from the MarsExpress High Resolution Stereo Camera (HRSC) [5]. The co-registration revealed that to match the stereo DTM the MOLA profile required a shift by 23.8±5.9 m and 152.1±6.5 m in latitude and longitude directions, respectively. The radial offset is only 2.1±0.6 m.

Through the general construction of the code the co-registration method can be easily applied to laser altimeter data obtained from different instruments and DTMs with different resolution and coverage. The code is written in Python and includes a VICAR (Video Image Communication And Retrieval) Python interface for reading and saving DTM data. As outlined above the laser altimeter data is conveniently accessed through a connection to the PostgreSQL database. The co-registered data products can be linked with data from other instruments, e.g. spectrometers, and allow further investigations of the surface properties [6].

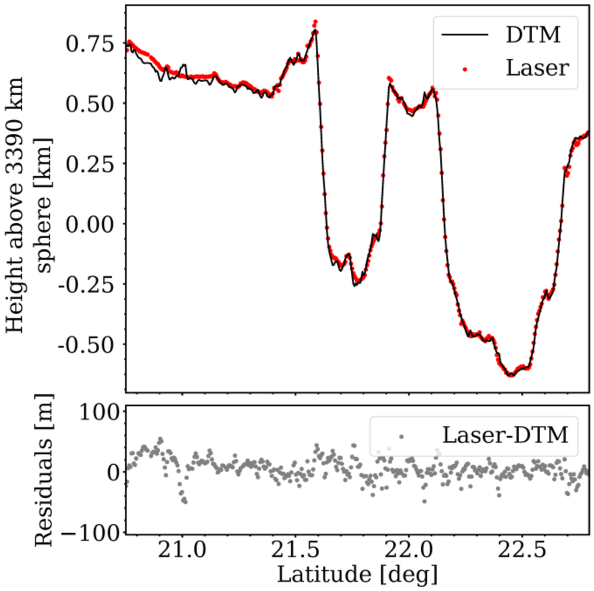

Fig. 2: MOLA profile (red dots) and HRSC stereo DTM (black line) located in the MC11 quadrangle [5] of Mars after co-registration. The residuals, which have a standard deviation of about 35 m, are shown in the bottom panel.

References:

[1] Stark, A., et al., 2015a. *PSS*, 117, 64-72. [2] Stark, A., et al. 2015b, *GRL*, 42, 7881-7889 [3] Steinbrügge, G., et al., 2015. *PSS* 117, 184-191. [4] Gläser, P., et al., 2013. *PSS*, 89, 111-117. [5] Gwinner, K., et al., *PSS*, 2016. 126, 93-138. [6] Naß, A. & D'Amore, M., 2018, this issue.