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Adjustment of MOLA Laser Altimeter Tracks to HRSC Photogrammetric Stereo DTMs Using Evolution Strategy

Konrad Willner, Klaus Gwinner, Alexander Stark, Stephan Elgner, and Hauke Hussmann
German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany (konrad.willner@dlr.de)

Introduction: The laser altimeter data of Mars Global Surveyors (MGS) Mars Orbiter Laser Altimeter (MOLA) [1] instrument provide a global network of laser shots with unprecedented height precision for planet Mars. The determination of planetary radii (i.e. 3D coordinates of points at the surface), requires knowledge of spacecraft trajectory and the instrument's orientation in space that is often limited, leading to inconsistencies between the nominal ground profiles obtained, as is observed in the original (not adjusted) MOLA mission data record at cross-over points. This occasionally leads to substantially offset outlier profiles. In the final mission data products such discrepancies are reduced by applying adjustment techniques to minimize cross-over residuals [2]. When compared to digital terrain models (DTM) of similar resolution such as HRSC Mars quadrangle DTMs [3], single MOLA tracks still show considerable variability in terms of height differences after co-registration.

We present a method to effectively and accurately co-register MOLA profiles to existing Mars half-quadrangle DTMs which allows to increase the accuracy of the co-registration of the single laser tracks while providing similar internal a-posteriori cross-over accuracies as the archived MOLA data record. The method allows to derive improvements to the extrinsic observation parameters directly and applies Evolution Strategy (ES) techniques for parameter optimization.

The High Resolution Stereo Camera (HRSC) on ESA's Mars Express (MEX) [4] spacecraft provides a unique data set to derive a global Mars DTM through stereo photogrammetry [3], at improved spatial resolution. As the HRSC DEM is already aligned with the MOLA DTM through a photogrammetric bundle adjustment using MOLA height control data, height differences between the two datasets are already small at the beginning of the ES process and largely related to additional detail represented in the HRSC DTM and the uncertainty of position associated with the MOLA tracks, generally estimated as about 100 m horizontally and one to few meters in height.

Methods: We apply Evolution Strategy (ES) techniques [5,6] that have their strengths in solving large parameter vectors for a given problem. The problem is reduced to implementing the observational equations for each data source, and to formulating a suitable quality function that includes dependencies of all unknown parameters. Here we model a parameter vector comprising the bore-sight vector of MOLA and an orbital shift in along-track, across-track and in height for each laser segment. Segments are defined as continuous sections of the laser data that reach from North Pole to South Pole. Segments are co-registered to DTM half-quadrangles at the equator while laser data points of one segment outside the DTM area will still inherit the parameter optimization. Potential errors increase with increasing distance to that reference DTM region.

The ES randomly creates a number of parameter vectors and tests the quality of all these child vectors based on the defined quality function. Here we derive the root-mean square of all height differences at the shifted (according to the parameter vector) laser shot locations and the DTM heights. The child vector with the lowest RMS determined is the seed for new random child vectors. We apply an ES-CMA [4] procedure in our implementation as this variant has the capability to self-adjust the search distances applied and thus provides reliable convergence properties.

Results: ES-based adjustment of MOLA tracks was applied using an equatorial HRSC DTM half-quadrangle (MC-13E) and the laser track segments intersecting this quadrangle. The quality of the adjustment was evaluated by visual inspection of gridded DTM data products (Fig. 1) and by analyzing the consistency of the results in terms of height residuals at cross-over points. The corresponding values were also derived for the original MOLA profiles and MEGDR data set. Gridded DTM products mainly show the outlier tracks (see Fig. 1). We note that these quite do occur in the original MOLA, but also still appear in the crossover adjusted version. The ES adjustment, apparently allows for the most reliable integration of outlier tracks, although they cannot be eliminated completely over the full reference DTM. Height residuals at cross-over points amount to ±3.52 m initially, i.e. before any corrections to the nominal profile solutions while an average residual height difference of only ±0.70 m is achieved with ES-adjusted profiles. Considering outlier-tracks by applying a global 3s-blunder elimination to the height differences, the corresponding values then are to ±2.72 m (nominal case), and ±0.41 m (ES-adjusted).

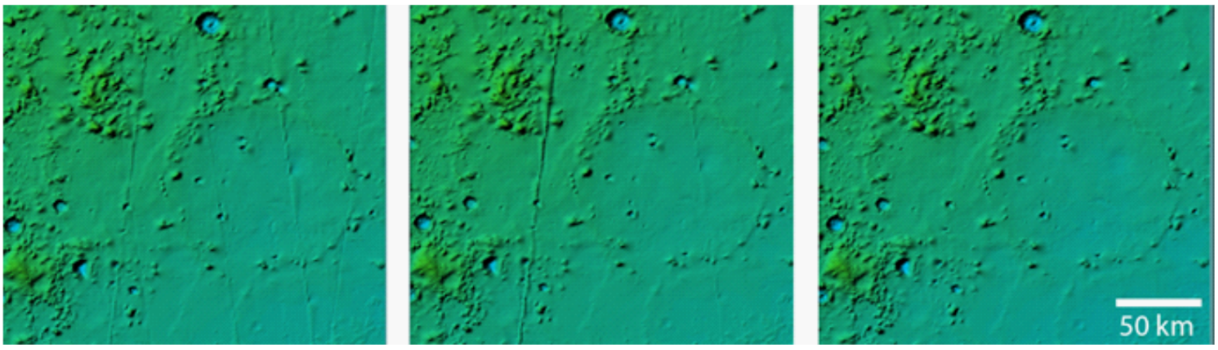

Figure 1: *Color-coded and shaded display of gridded digital terrain model from MOLA profiles of different processing levels (subset of DTM at 463 m/post resolution covering quadrangle MC-13). Left: original MOLA tracks with nominal orientation data. Center: cross-over corrected profiles [2]. Right: MOLA tracks adjusted to HRSC DTM using the Evolution Strategy method. Note different contribution of outlier tracks. For fine-scale differences concerning height accuracy please refer to text.*

From these encouraging results, we conclude that the ES-method performs very well with respect to the reliability and the accuracy of the parameter optimization. As the method establishes a high-quality co-registration between MOLA and the reference DTM, the results are considered very promising with respect to a future revision of the global MOLA data product and joint HRSC/MOLA DTMs.

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