Probabilistic Digital Elevation Model Generation
For Spatial Accuracy Assessment
André Jalobeanu
Centro de Geofísica de Évora, Portugal and CNRS, France

Introduction

Summary
We propose a new method for the measurement of high resolution topography from a stereo pair. The main application area is the study of planetary surfaces. Digital elevation models (DEM) computed from image pairs using state of the art algorithms lack quantitative error estimates. This can be a major issue when the result is used to measure actual physical parameters (e.g. slope or terrain roughness).

Thus, we propose to infer a dense disparity map from two images, and to estimate the spatial distribution of errors as well. We adopt a probabilistic approach, which provides a rigorous framework for parameter estimation and uncertainty evaluation. All the parameters are described in terms of random variables within a Bayesian framework. We start by defining a forward model, including an accurate resampling scheme and a spatially adaptive radiometric change map for robustness purposes. An a priori smoothness model is introduced in order to stabilize the solution. Solving the inverse problem to recover the disparity map requires to optimize a global non-convex energy function, which is difficult in practice due to multiple local optima. A deterministic optimization technique based on a multi-grid strategy, followed by a local energy analysis at the optimum, allows to recover the a posteriori probability density function (pdf) of the disparity, which encodes both the optimal solution and the related error map.

Finally, the disparity field is converted into a DEM through a geometric camera model. This camera model is either known initially, or calibrated automatically using the estimated disparity map and available measurements of the topography (existing low-resolution DEM such as MOLA for Mars and SRTM for the Earth, or ground control points if available).

Disparity Inference

Vertical disparity map estimation via nonrigid image registration using a new optical technique. The x displacements are assumed linear and are corrected beforehand. Left: resampled s1 image, right: s2 image, bottom: difference s1-s2. The ratio s1/s2 could be used for terrain roughness estimation.

Basic Ingredients

- Bayesian Inference for parameter and error estimation
- Graphical Models (Bayesian networks) for modeling
- B-Spline Interpolation Theory for accurate resampling
- Markov Random Fields for topography smoothness priors
- Loopy Belief Propagation for efficient deterministic optimization
- Computer Vision and Geometry for push-broom camera modeling

Automatic Camera Calibration, Disparity to 3D Conversion

Estimated DEM (local frame). Horizontal resolution 100m (4 pixel grid). The reconstruction was performed using a linear combination of local camera parameters estimated from the disparity map and the MOLA DEM.

Results & Conclusions

Estimated uncertainty (local frame). Same grid as the DEM. Spatial adaptive error estimates given by the standard deviation, computed by inverting the precision matrix given by a local analysis of the objective function at the optimum (numerical second derivatives): in well-textured areas the error is below 5m (<0.1 pixel) and goes above 20m over smoother areas. Empty areas exhibit the largest error, only limited by the prior smoothness.

Local Linear Reconstruction

The camera parameters (10 per area) are adjusted in order to minimize the discrepancy between the DEM reconstructed from the estimated disparity map and the reference DEM (MOLA data). We use a weak-perspective model that is only valid locally (60x60km max. area). Converting disparity to XYZ (local Cartesian frame) is straightforward and allows for uncertainty propagation.