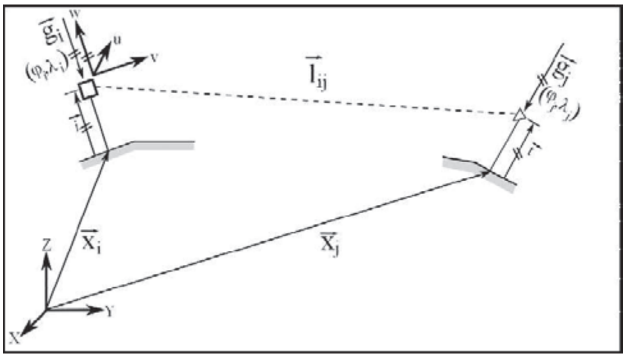
Theory and Software Development on 3D Integrated Adjustment including Videotachymetry Observations for the Geomonitoring System GOCA

Introduction

In order to prevent people and constructions from hazards caused by ground movements or movements of building structures geomonitoring tools are used. For providing a reference frame for the monitored object points a two-stepped adjustment is carried out. This adjustment is normally accomplished by a split up in 2D/1D (plane and height). This thesis deals with the implementation of a quasi-integrated 3D approach, which uses a gravitational model (EGM2008) and the vertical directions for connecting the position and the physical height system. This enables geomonitoring applications using large GNSS networks or laser-scanner data. Furthermore the adjustment tool was extended by additional integration of camera observations next to common observations such as GNSS and TPS observations.



Geocentric Cartesian System and LAV Systems of TPS [Heck 1995]

Quasi-Integrated 3D Adjustment

With φ, λ being the astronomical vertical directions (astronomical latitude and longitude), B and L ellipsoidal latitude and longitude and ζ, η the Deflections of the Vertical (DOV)

$$\phi = B + \xi;\quad \lambda = L + \frac{\eta}{\cos B}$$

the rotation matrix D_i and D_{ij} can be set up with

$$D_e^{LAV,i} = \begin{bmatrix} -\sin\phi_i\cos\lambda_i & -\sin\phi_i\sin\lambda_i & \cos\phi_i \\ -\sin\lambda_i & \cos\lambda_i & 0 \\ \cos\phi_i\cos\lambda_i & \cos\phi_i\sin\lambda_i & \sin\phi_i \end{bmatrix},\quad D_{LAV,i}^{LAV,j} = D_e^{LAV,i}\cdot D_e^{LAV,j^T}$$

and can be used to rotate between the geocentric right handed system X, Y and Z to the left handed Local Astronomical Vertical system (LAV) u,v and w, as shown in the figure above.

This enables the contemplation of GNSS and TPS observations in one system, considering both, the plane and the height.

TPS and GNSS Observations

Based on the before given rotation matrices the observation vector given by TPS with *i* and *t* being instrumental and reflector heights can be expressed by

$$\begin{bmatrix}\Delta u\\ \Delta v\\ \Delta w\end{bmatrix}_{ij}^{LAV,i} = De^{LAV,i}\cdot\begin{bmatrix}\Delta x\\ \Delta y\\ \Delta z\end{bmatrix}^{e} - \begin{bmatrix}0\\ 0\\ i\end{bmatrix}^{LAV,i} + D_{LAV,j}^{LAV,i}\cdot\begin{bmatrix}0\\ 0\\ t\end{bmatrix}^{LAV,j}$$

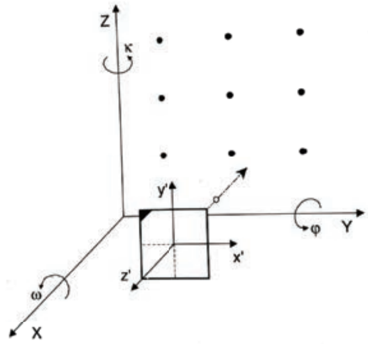
and for the GNSS baselines given by a baseline between rover *i* and base *j* by

$$\begin{bmatrix}\Delta X\\ \Delta Y\\ \Delta Z\end{bmatrix}_{ij}^{e} = \begin{bmatrix}x_j - x_i\\ y_j - y_i\\ z_j - z_i\end{bmatrix}^{e} - D_{LAV,i}^{e}\cdot\begin{bmatrix}0\\ 0\\ i\end{bmatrix}^{LAV,i} + D_{LAV,j}^{e}\cdot\begin{bmatrix}0\\ 0\\ t\end{bmatrix}^{LAV,j}.$$

This leads to the functional model which is used in the Gauß-Markov-Model (GMM) with

$$dl + v = A(x_0)\,d\hat{x},\quad \hat{x} = (A^T PA)^{-1} A^T Pdl.$$

For the first adjustment step, the initialization, a free network adjustment is computed, the second step (georeferencing) a hierarchical network adjustment, based on the stable points from step 1. Both adjustments are based on L2 norm.



Recording setup with reversed order of rotation [Luhmann 2003]

Integration of Image Observations

The integrations of image observations into the adjustment software can be divided into two steps:

1. Marker recognition in photographs by means of the SURF algorithm provided by OpenCV and matching methods, furthermore projective transformations (homography) in order to receive 2D image coordinates
2. Using bundle adjustment and collinearity equations from photogrammetry for the functional model in the adjustment for estimating 3D object coordinates of those markers

1. SURF Algorithm

The SURF (Speeded Up Robust Features) algorithm consists of two steps, first of all the computation the feature detection of characteristic points of the marker, in this thesis for the SURF algorithm optimized markers were used (see figure below). SURF uses box filters for approximations of second derivations of Gauss functions, which are shown in the figure on the right.
Second step is the determination of feature descriptors by means of a 64-dimensional descriptor vector, for this a local area around the feature divided into 4x4 sub-regions is considered. Using 4 different Haar-wavelets for the horizontal and vertical directions the 4x4x4=64 dimensions are set up.
By matching these descriptor vectors homologous points in two pictures can be detected. Therefor algorithms such as Brute Force are used.
Projective transformations (homographies) are then used to determine 2D image coordinates of specified points of the markers.

2. Bundle Adjustment and Collinearity Equations

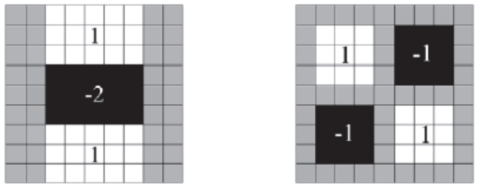
The derived 2D image coordinates from step 1 are then introduced to the adjustment as new observation types.
The collinearity equations given by

$$x'=x'_0+z'\left(\frac{r_{11}(X-X_0)+r_{21}(Y-Y_0)+r_{31}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}\right)+\Delta x'$$

$$y'=y'_0+z'\left(\frac{r_{12}(X-X_0)+r_{22}(Y-Y_0)+r_{32}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}\right)+\Delta y'$$

provide the connection between those 2D coordinates and the demanded 3D object coordinates. The figure on the previous page shows the recording setup that is assumed during the shootings, by means of reversed order of rotations of the angles of the exterior orientation in order to avoid singularities.

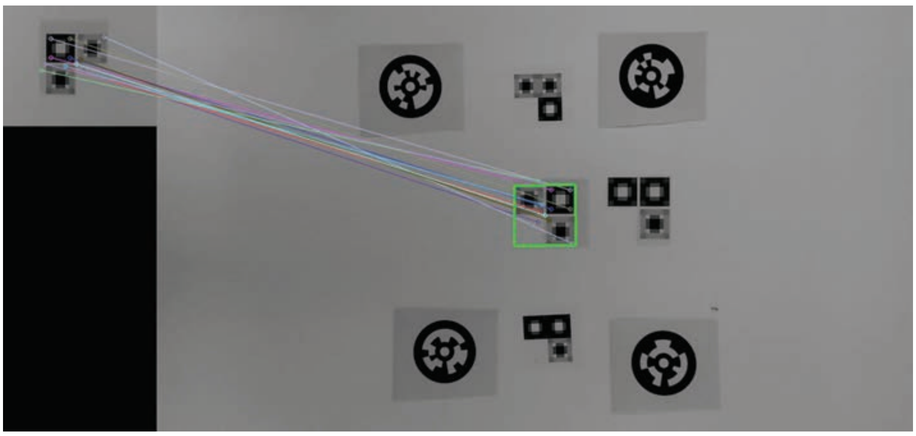
By a bundle adjustment, under consideration of control points for solving the datum defect and also computing a self-calibration by estimating the parameters of the interior orientation the integration of image observations was implemented.



Box filters as approximations of 2nd order derivations of Gauss function [Bay 2006]

Conclusion

The successful implementation of a two-stepped quasi-integrated 3D adjustment tool enables combined and separate computations for GNSS and TPS observations. In addition to that data snooping methods and result protocols were included. Several tests that were ran showed reliable, good results for the first initialization step and the second step, the georeferencing.
Based on the object-oriented approach the adjustment tool is easily extensible by further observation types, such as laser-scanner observations for example.
Furthermore the integration of camera observations was accomplished, so later-on observations from video-tachymeters can flow into the adjustment.



Marker recognition based on SURF algorithm and homograpy

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