Adjustment of the Densification Network in the Czech Republic

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Key words: densification network, adjustment, reference frame, GPS

SUMMARY

Since the beginning of the nineties, a formation of a unified reference frame for Europe has been in progress, under the International Association of Geodesy (IAG) umbrella. The Czech Republic (the Czechoslovakia at that time) joined this project in 1991 when the first international campaign EUREF-CS/H-91 was launched. Since 1996 two independent observation campaigns has been carried in the Czech Republic resulting in 3094 trigonometric points with coordinates based on GPS technology and about 30 thousands of densification points. These observation results are going to be a subject of a new sequential adjustment based constrained to coordinates of the CZEPOS permanent stations with known coordinates in ETRS89. For the adjustment of the given sets of densification GPS vectors with given variance-covariance matrices has been selected a free software project GNU Gama. Preliminary adjustment results of the densification network are presented. The final adjustment results will be used to define corrections between the traditional Czech national reference system (S-JTSK) to the new coordinate system S-JTSK/50 based on ETRS89.

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1. Towards S-JTSK/05

The Czech Cadastral System S-JTSK, based on Krovak oblique conic conformal projection, was designed for prewar Czechoslovakia and in the Czech Republic it has been maintained and is in successful use until today. With the introduction of a multipurpose positioning system for the Czech Republic, CZEPOS, there is a strong need for updating the traditional S-JTSK coordinate system to satisfy the present state of art in surveying, namely to speed up and economize precise geodetic measurements.

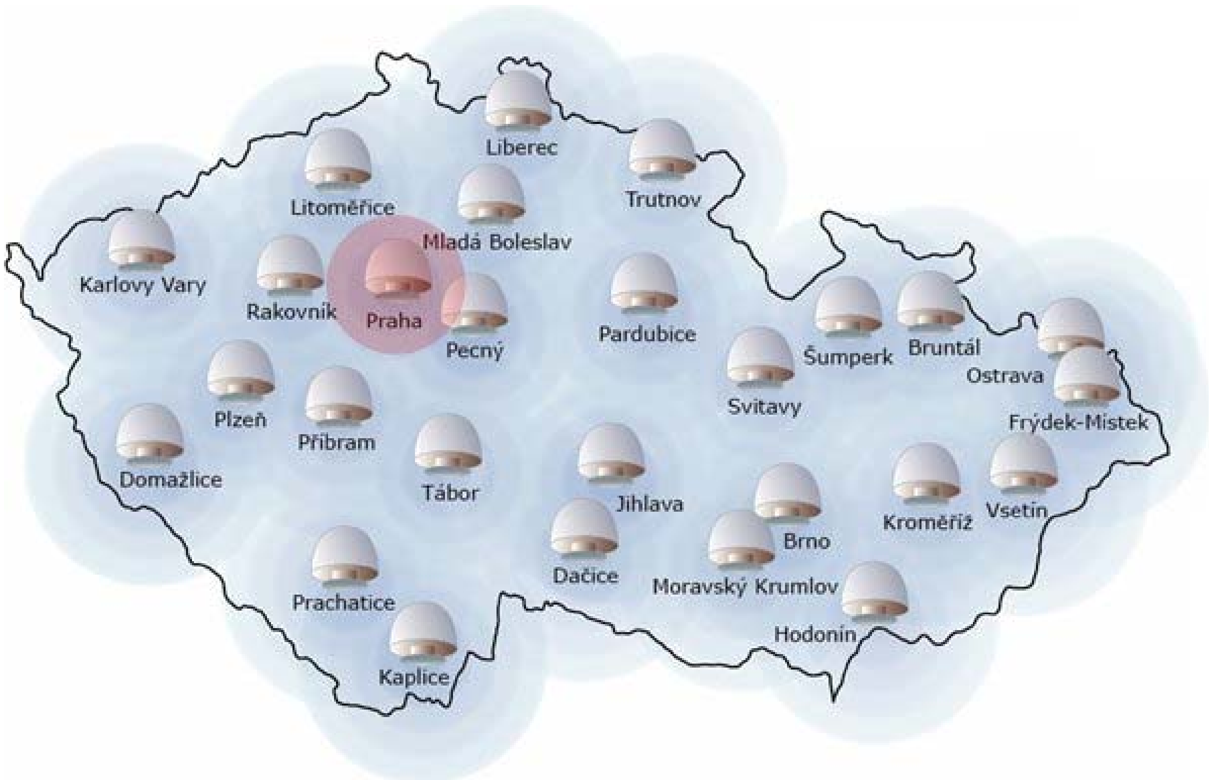

Fig. 1. CZEPOS **-** an active network of permanent GNSS stations in the Czech Republic

A new coordinate system, denoted as S-JTSK/05, is being developed to integrate the new coordinate system with observations in the ETRS89, based on exact mathematical transformation formula. Coordinate differences between new system S-JTSK/05 and the old S-JTSK are going to be just in few centimeters and thus acceptable for majority of practical observations, like cadastral boundaries, GIS applications etc. These corrections between both systems will be tabulated in fixed step tables and transformation from the old system to the new one will be nothing more than a cubic interpolation. The S-JTSK/05 coordinate system should than replace the old one for all new surveying and cadastral measurements and spatial geoinformation applications.

Since early nineties, a formation of a unified reference frame for Europe has been in progress, under the International Association of Geodesy (IAG) umbrella based on techniques of spatial geodesy. The Czech Republic (the Czechoslovakia at that time) joined this project in 1991 when the first international campaign EUREF-CS/H-91 was launched and first 6 points were observed in the ETRS89 coordinate system with GPS technology. Also it was decided at that time, that on the territory of CZ and SK these techniques will be used to build improved geodetic control, fully integrated with the European reference frame.

Since 1996 two independent observation campaigns have been carried in the Czech Republic: *selective maintenance* with 3094 trigonometric points with new GPS observed coordinates and *densification campaign* in which regional cadastral offices carried out GPS measurements of about 30 thousand of densification trigonometric points. Thus for all of these trigonometric points we know both ETRS89 coordinates and the S-JTSK coordinates. These densification observation, GPS vectors, are going to be the subject of a new sequential adjustment constrained to coordinates of the CZEPOS permanent stations and other stations with known coordinates in ETRS89 (the national reference frame DOPNUL). This adjustment of the densification network will be used to define corrections between the traditional Czech national reference system (S-JTSK) and the new coordinate system S-JTSK/50 based on ETRS89.

For the adjustment of the given sets of GPS vectors with known variance-covariance matrices has been selected free software GNU Gama. Network adjustment of GPS vector is defined as a mathematical model of adjustment on ellipsoid, numerical solution of the sparse matrix of normal equations is implemented using a simple *envelope* memory model.

2. GNU Gama

GNU Gama is a software project for adjustment of geodetic networks, that has been presented to the FIG community on several occasions, so we need not to go into details introducing it. The project is released under GNU GPL license and it was designed to be a tool to demonstrate some alternative numerical methods of adjustment of geodetic observations, that minimize weighted sum of residuals without a need of explicit build of normal equations (Gama can operate directly on the linearized *project equations*) and as a tool that could be used for independent check of the adjustment results from other software tools used in practical surveying.

The academic project GNU Gama has claimed not to be another *black box* tool, but to be an open source software (free software to be precise) that might be used by our students to study implementation of numerical methods used in the project. The project is written in C++ language and we also use it to show students practical usage of object oriented programming and in several courses dealing with practical adjustment of observations. In 2001, Gama was dubbed the GNU software, after fulfilling relatively strict formal demands needed for a project to be included into the GNU project.

Least squares adjustment in Gama has been formulated to enable processing of correlated observations, i.e. observations with generally non-diagonal (banded or full) covariance matrix. Observations are organized into groups (*clusters*) with common banded symmetric covariance matrix. This way, both correlated and uncorrelated observations can be handled easily.

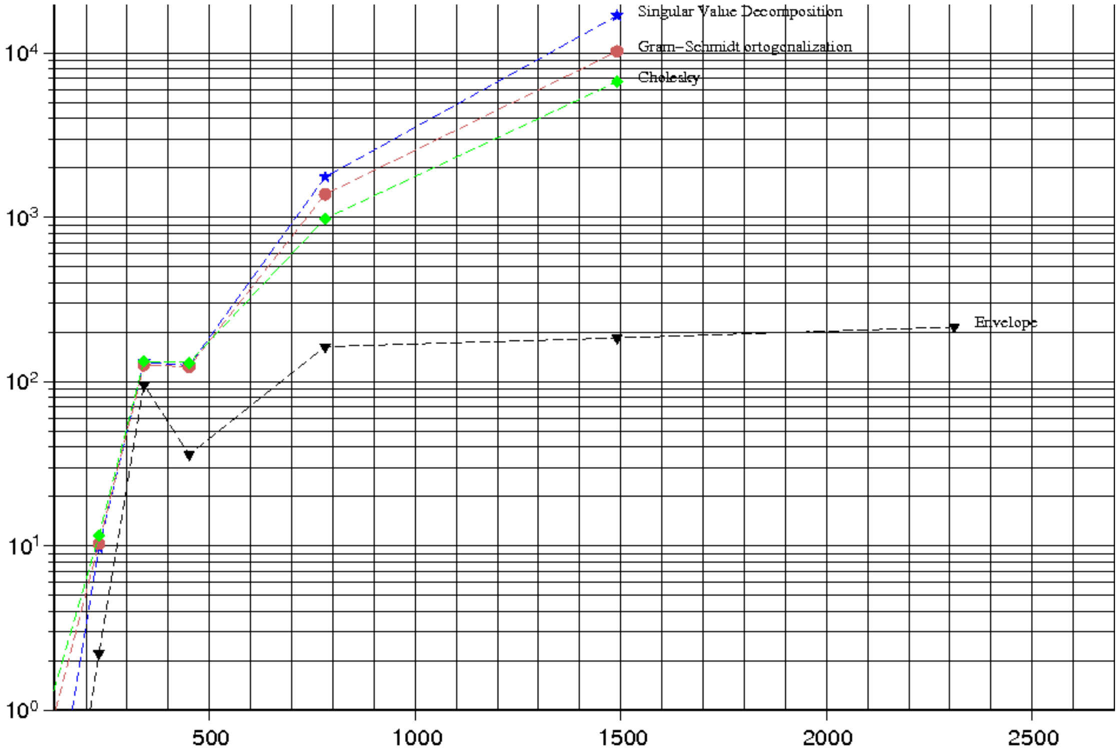

Fig. 2. A sample graph of solution time in seconds for dense and sparse algorithms and number of unknown parameters.

Observation objects are created dynamically and organized into lists, rooted in their corresponding clusters, the list of all clusters represents the main observation container. Observation objects are designed to be maximally general, they are derived from a template virtual observation class with only two attributes (a pointer to its cluster and its index in the cluster observation list) and two abstract methods (observation dimension and *accept* method one parameter, a pointer to *ObservationVisitor*, needed to implement *acyclic observation visitor pattern*). Observation dimension defines how many project equations are derived during linearization.

For the adjustment of densification network (of GPS vectors) we use a program gama-g3 for adjustment of 3D networks with both input and output data in XML format. Apart from least squares adjustment in dense matrices (algorithms based on SVD, GSO and Cholesky decomposition) gama-g3 also implements Cholesky decomposition of the sparse matrix of normal equations using a simple scheme of minimizing the size of decomposed matrix *envelope* (minimizing local bandwidth of individual rows/columns).

Technically, there is not much interesting to say about the sparse adjustment solution implemented in gama-g3, we would only like to mention here that the program can also solve so called *free networks*, i.e. networks without fixed points regularized, by declaring selected points to be constrained, free networks never distort observations as is the case of networks with fixed points (solution time is about five times slower for free networks because of the more complicated way of computing selected elements of full covariance matrix of adjusted unknown parameters).

3. Preliminary Testing Solutions

Results of the first adjustment, as shown at figure 3, were far from being optimistic.

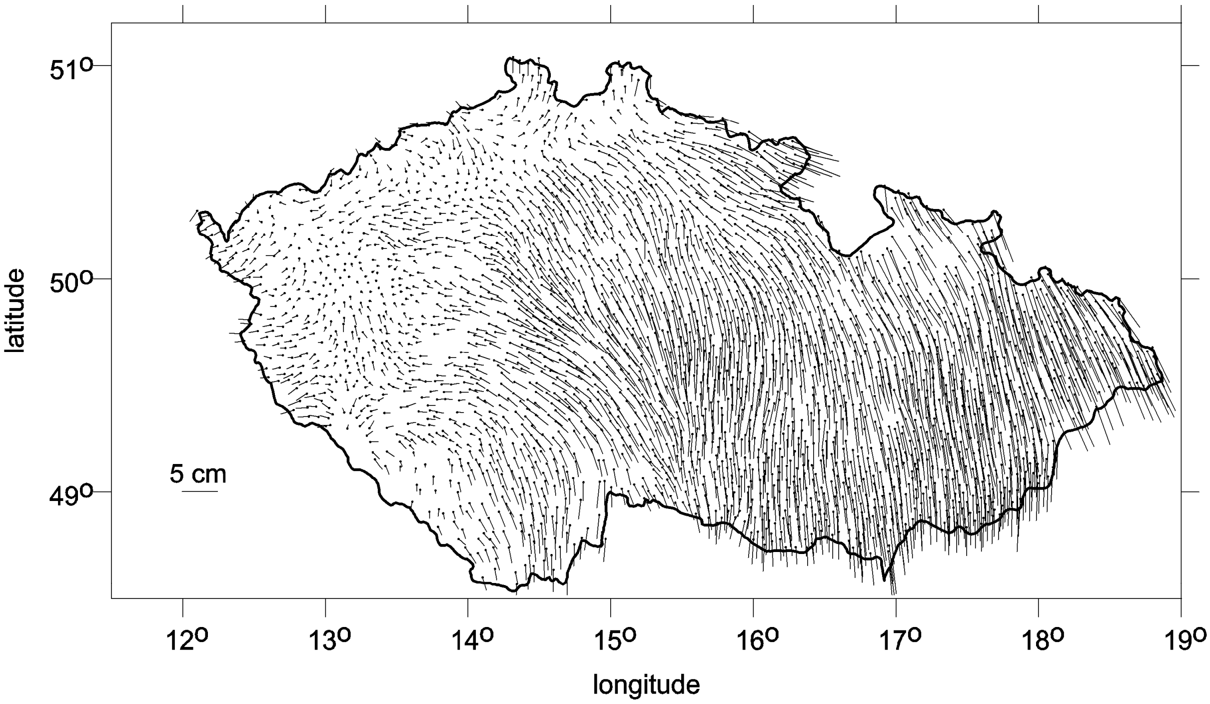

Fig. 3. Adjustment result distorted by erroneous station coordinates.

Fortunately, soon it proved that the problem stemmed from blunders in the input data, as we used outdated station coordinates of the national reference frame DOPNUL (some point monuments were moved).

For checking adjusted station coordinates we used an older result of adjustment of the DOPNUL stations (by M. Skala, software GPSurvey 2.35 and TRIMNET Plus 92.11c and height transformation by WGJT2ZU).

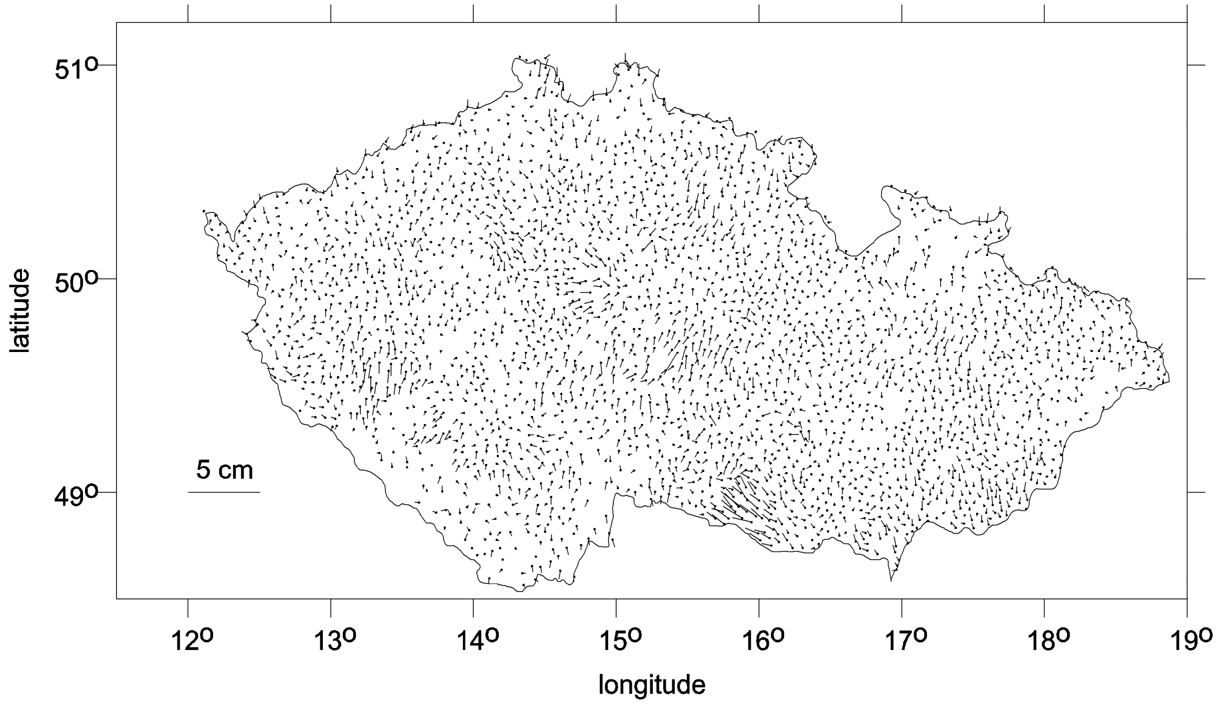

Fig. 4. Positional differences of coordinates of stations in the projection plane

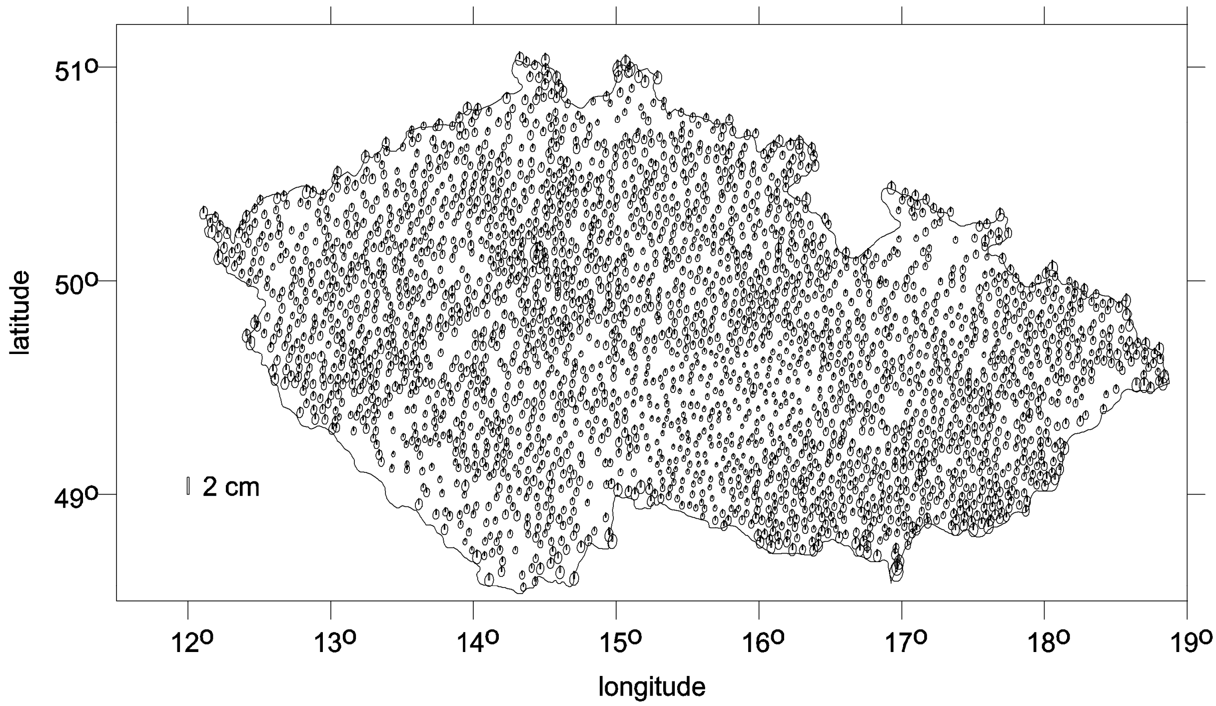

Fig. 5. Standard error ellipses of adjusted coordinates in the projection plane

Basic parameters of our solution are

Unknown parameters	8,775
Project equations	28,626

with user solution time about 32 seconds. Coordinate corrections in directions NEU were in millimeters, as in the example following (error ellipses typically oriented in the North-South direction)

<point> <id> 06050250 </id>
<n-free/> <dn> 6.692 </dn> <ind>1</ind>
<e-free/> <de> -0.369 </de> <ind>2</ind>
<u-free/> <du> -4.067 </du> <ind>3</ind>

Height differences in the first preliminary adjustment of the DOPNUL station coordinates are mostly below two centimeters. Some anomalies in the adjusted shifts, clearly visible from fig. 4, and some outlying coordinate corrections indicate that there are still some errors in input data.

Data observation and clean-up is going to be the most difficult task we are facing this year. Namely we have to adjust vectors observed by regional cadastre offices for about 30 thousand densification network trigonometric points that will be used to determine the areal differences between old system S-JTSK and new updated system S-JTSK/05.

The research project of the new update coordinate system S-JTSK/05 for the Czech Republic is to be finished next year. We plan a workshop to present the final report in 2009. We would like to take this opportunity to invite in advance all FIG colleagues, who are interested, to our workshop.

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BIOGRAPHICAL NOTES

Jan Pytel is a PhD student of Ales Cepek. His research is focussed on geodetic observations and data processing, databases and web services. Jan Pytel published several papers and intensively works in the field of Free Software development.

Jan Kostelecky is professor of geodesy from 1997, working at the Department of Advanced geodesy, Faculty of Civil Engineering,Czech Technical University in Prague. Since 1970 research worker at Research Institute of Geodesy, Topography and Cartography, Zdiby, at present vice director of the Institute. He is working in geodetical astronomy, space geodesy, geodynamics and geodetic control. Author of more then 150 scientific papers, co-author of the two Space Geodesy monographies.

Ales Cepek is a professor of geodesy from 2003, working at the Department of Mapping and Cartography, Faculty of Civil Engineering, Czech Technical University, Prague, Czech Republic (since 1992). Started his professional career at the Research Institute of Geodesy, Topography and Cartography (VUGTK), Zdiby (from 1980 to 1991) where worked on research projects, programming, analysis and implementation of data structures for cadastral programs, co-author of programs for adjustment and analysis of geodetic networks; later at geodetic observatory observations with circumzenithal (astrolab), project for estimation of parameters of local quasigeoid. At present conducting research in the field of adjustment and object-oriented processing of geodetic data.

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