Optimized Technology for GPS Height Determination

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SUMMARY

On ground of accuracy analysis of long term experimental measurements in a testing network and other localities an optimized measuring technology for GPS height differences determination was designed and succsessfully tested. Goals are the economical gains and reduction of observation time. Another goal is improvement of vertical GPS accuracy including the appropriate geoid modeling.

A reduced observation scheme which can substitute the long sessions with mimimal loss of accuracy is presented together with some practical exemplifications. The technology was successfully applied by determination of detailed quasigeoidal section of 100 km length along the first order levelling lines at south-eastern Moravia. The technology was also tested in long term geodynamic monitoring of mountain areas.

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1. INTRODUCTION

Nowadays the GPS technology is widely used for many kinds of geodetic surveys, for various purposes. It is possible to reach millimeter horizontal relative accuracy levels over tens, or even hundreds of kilometers. However, from well-known reasons, the vertical GPS accuracy is not so easily obtained - baseline vertical component is more sensitive to many influencing factors than the horizontal components, especially in mountain areas with considerable height differences between stations, and therefore the achievement of planned accuracy is more problematic, and often time consuming.
The heights determined by GPS are related to the WGS-84 ellipsoid, while levelling heights (orthometric, normal) are related to given vertical datum, which is defined physically. Limiting for GPS absolute height accuracy is the exact knowledge of the local (quasi)geoid. Relative GPS heighting is influenced also by many factors. Reduced scheme of observation in triplets may be used to mitigate some periodical noise components in measured height differences. The scheme was practically tested in the campaign focused on determination of the quasigeoidal section from the differences of GPS and levelling heights. Further the scheme was applied by measurements of levelling sections in Sněžník network. Relative GPS height differences were measured effectively and with improved accuracy here.

2. DETERMINATION OF HEIGHTS BY GPS

GPS heighting is considered as an alternative to classical terrestrial height measuring methods in present time. From methodological point of view the determination of height with help of GPS is more complicated than by classical terrestrial methods. From well known reasons the GPS measures vertical component less accurately than the horizontal ones. These reasons are:
- satellite visibility (no satellites under horizon),
- satellite associated errors (orbits, clock bias),
- signal propagation errors (ionospheric/tropospheric delay),
- receiver associated errors (clock bias, antenna phase centre offsets/variations),
- station associated errors (surroundings, centring, signal multipath and diffraction),
- secondary effects (solid earth tides, ocean and atmospheric loading etc.),
- uncertainties in alignment to reference frames.

GPS is 3D positioning method which determines coordinates in global geocentric orthogonal system (WGS-84). From practical reasons the global coordinates X, Y, Z are transformed into ellipsoidal coordinates φ, λ, h and eventually into local horizontal coordinates n, e, u. Finally, the ellipsoidal heights are transformed to orthometric or (quasi)geoidal heights. For this step the knowledge of (quasi)geoid undulations N_i is necessary, which are defined by

$$h_i = H_i + N_i \quad ,$$

where *h* is ellipsoidal height, *H* is orthometric height, and *N* is geoidal undulation.
The undulations can be determined in several ways using either absolute or relative methods. Geoidal surface is irregular and it is practically impossible to represent it by exact mathematical modeling function. Convenient is often an approximation through spherical harmonics expansion. Satellite (quasi)geoid can be modeled by a set of harmonic coefficients describing an Earth's gravity potential (Teunissen, Kleusberg 1998)

$$W_0 = \frac{G \cdot M_E}{r \cdot} \; (1 + \sum_{n=2}^{n'} \left(\frac{a_e}{r} \right)^n \sum_{m=0}^{n} P_{nm} (\sin \varphi) \left(C_{nm} \cos m\lambda + S_{nm} \sin m\lambda \right) + \frac{\omega^2 r^2}{2} \cos^2 \varphi$$

from which the (quasi)geoid heights can be derived.
GPS height surveying is based on the determination of ellipsoidal heights, with subsequent reduction to given height system. It presumes application of an appropriate gravity field model which enables determination of (quasi)geoid undulations in respect to a conventional reference datum. The undulations must be determined in grid of sufficient density covering the survey area, and must be of sufficient quality, to allow for retaining of an appropriate height accuracy level.

Apart from global/regional networks, most of the practical GPS surveying applications are of extent of few kilometers, or tens of kilometers. In such cases is often used another procedure based on transformation with help of common points in both height systems (so called identical points). Appropriate types of transformations can be applied.

For achievement of desired accuracies the relative GPS positioning with phase observations is used for the purposes of height determinations. Observation modes include static, rapid static, kinematic, and pseudokinematic techniques. In last years the progress of real time technologies (RTK, or DGPS) can provide accuracies comparable with those of the classical techniques based on post-processing (Hofmann-Wellenhof, et.al. 2000).

Further accuracy improvement is possible by applying the advanced techniques for measurement optimization, detection of error sources, and sophisticated modeling and mitigation of effects of all the relevant influencing factors. In last decade there have been introduced many improvements and modifications which may help to reduce the effects of some disturbing influences on propagation of satellite signals, of error sources connected with station setup (surrounding conditions, GPS hardware, offsets/variations of antenna phase center, etc.). Examples are i.e. efficient ambiguity resolution techniques, precise absoulte field antenna calibrations with robots, and use of elevation or SNR (Signal to Noise Ratio) dependent weighting of the observations by processing.

3. REDUCED GPS OBSERVATION SCHEME

It is well known that the fundamental way to improve the accuracy of GPS surveys is to prolong the observation (session) times. If we assume 1 cm accuracy comparison level in vertical component, global GPS surveys working with baselines up to several hundreds of kilometers need several days sessions, regional surveys baselines within range from 20 to 100

km need appropriate session intervals about 48 hours, while most of practical local GPS surveys of an extent below 20 km can hardly be shortened under 8 hours.
Such long observation times are demanding on organization and costs. It was the main reason for proposition of a special measuring procedure which is based on the combination of data observed in shorter sessions, separated by constant time intervals, with minimized loss of accuracy (Švábenský, Karský, 1999). It is convenient to combine two (dyada), or better three (triplet) shorter sessions of 60-90 minutes duration, measured in separation of six to eight hours after each other.

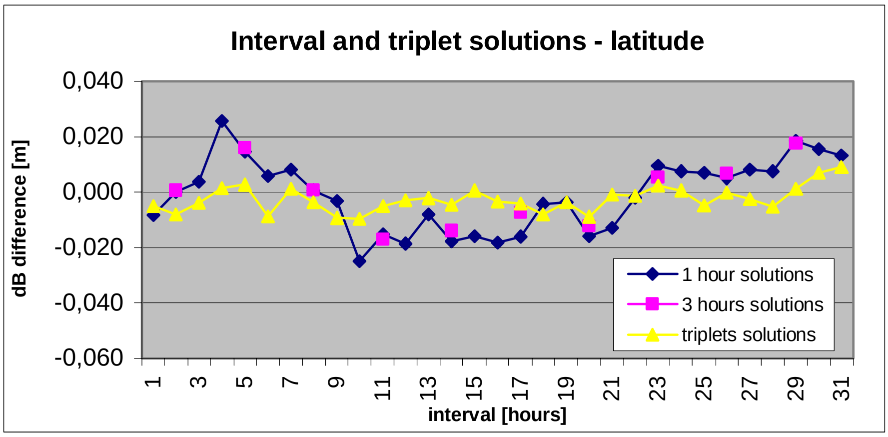
First ideas of benefits from combination of shorter observation intervals took shape in course of processing analyses of long-time sessions observed during the Sněžník network campaigns. Local experimental geodynamic Sněžník network was established twelve years ago (1992), in Czech-Polish cooperation. The network is situated along the Czech - Polish frontier in Králický Sněžník mountain region, in northern Moravia. Originally it was designed as testing local satellite network for monitoring and analyses of deformations in the upper layer of litosphere. Since 1992 yearly campaigns of GPS, EDM, levelling, gravimetric, astronomical and other measurements had been carried out here within several research projects. Brno University of Technology had organized observation activities and carried out the measurements and processing of all campaigns in czech part of the network since 1994.

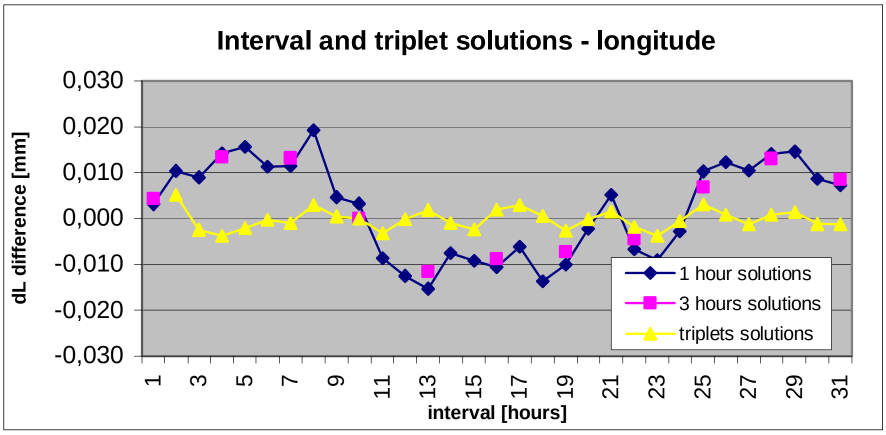
GPS data were observed mostly with dual-frequency receivers Leica, Ashtech, and Trimble. The measurements included wide range of GPS baselines with observation intervals varying from half of an hour to several days sessions, with baseline lengths varying between 0,5-15 km. Various experiments were concentrated on GPS accuracy investigations, combination of different GPS receivers/antennas, relations of the baselines measured in sessions of different duration as well as comparison of results obtained with help of standard Leica SKI-Pro and scientific Bernese software.

Among others also the problems of optimized GPS height determination were investigated here, in cooperation of TU Brno and Research Institute of Geodesy, Topography and Cartography Zdiby - Geodetic Observatory Pecný (Švábenský, Karský 1999), (Švábenský, Weigel, 2002b).
For typical baseline VYHL – VESE (6,2 km length) from Sněžník network the comparison of variations of single triplets and their variations in relation to triplet separation intervals over 72 hours observation interval indicated again an optimal separation interval of 8 hours. The differences between minimal and maximal values of one hour solutions were up to 4 cm in course of 24 hours. In combinations of three one-hour solutions with eight hours separation interval the differences were four times smaller. (Švábenský, Weigel 2002a).

In Fig. 1 the examples of single components series for another baseline VYHL – BRAD (14 km length) in northern Moravia geodynamic network are shown. The differences between single interval and combined (triplet) interval results for horizontal and vertical baseline components are clearly illustrated here. In the graphs three different solutions are shown. The first is the solution of single 1 hour intervals, second is the solution of single 3 hours intervals, and third is the triplet solution computed as adjustment of three single one hour interval solutions separated by 8 hours.

The reduced observing scheme was further applied by repeated measurements of levelling sections in Sněžník network. Relative GPS height differences were measured more effectively, with less elaborateness, and with improved accuracy here.





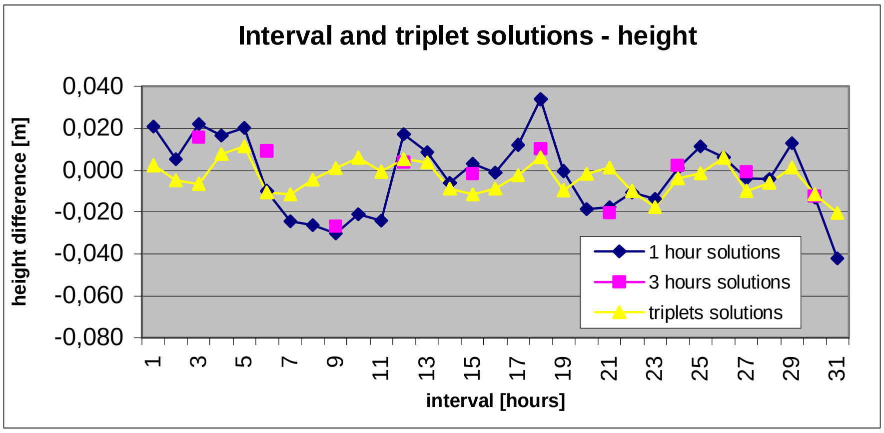


Fig. 1: Comparison of interval and triplet solutions (latitude, longitude, and height)

4. GPS LEVELLING USED FOR QUASIGEOID TESTING

The reduced observing scheme for GPS heighting had been for the first time systematically used for the purpose of quasigeoid testing. Selected quasigeoidal section in direction of its maximal gradient in south-eastern part of Czech Republic was measured by GPS profile going along the state leveling lines of the first order – see Fig.2. Quasigeiodal slope in direction of the measured profile is about 2,5 m over 102 km (Kostelecký, et.al. 2002).
The profile was divided into four individual segments and measured by GPS method in the years 1999 – 2001 (campaign PROFILE). For GPS stations the levelling benchmarks with good observation conditions were chosen, or eccentric stations in near vicinity of the benchmarks were established.

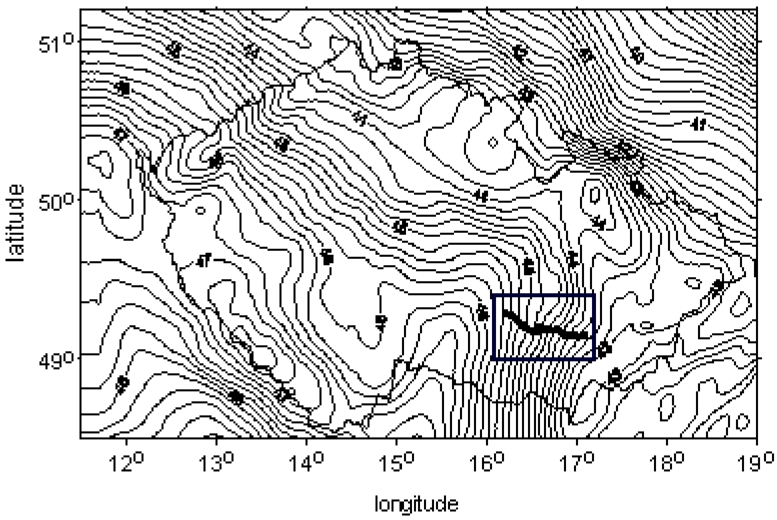


Fig. 2: Quasigeoid of the Czech Territory and the Measured Profile

Distances between single stations varied between 2 and 3 km. One segment of total length about 30 km had been measured within 24 hours, and average single session lasted about 1,5 hour. GPS observing scheme was designed so that each station was measured 3 times during 24 hours. Station in the middle of each section observed continually all 24 hours, stations in one and three quarters of section observed 12 hours (3 times 4 hours). The control reference station TUBO observed also 24 hours continually. Measurement of the complete profile with 6 receivers (102 km, 50 stations) took 96 hours. Session lengths 90 min allowed the reliable ambiguity solution even in worse observation conditions.

The measured data were processed using the BERNESE ver. 4.2 (4.0) scientific software system. Processing of complete profile yielded mean standard deviation of a triplet height difference solution (computed from all segments) lower than 5 mm.

5. CONCLUSIONS

Although the GPS heighting is rather complicated procedure because it combines several methods of positioning and gravity field determination (GPS, levelling, geoid modelling), it becames a currently used technique. When the accuracy has to be comparable with that of the lower order levelling, the observation times must be prolonged, in relation to baseline length.
The designed reduced observing scheme for GPS heighting based on combination of shorter sessions with optimized separation intervals offers an alternative to long static observations. It is demanding as to precise timing and organisation, but the final results indicate substantial productivity increase in GPS height determination. If single sessions of 1 - 1,5 hours duration are observed, it is possible to measure 4 - 5 stations in 24 hours using 2 receivers, and 15 – 20 stations using 5 receivers. In normal conditions the achieved accuracies of height differences are under 5 mm for baselines up to 5 km, and under 8 mm for baselines up to 15 km. In this way the reduced scheme of observation in dyads/triplets offers significant advantages over the usual standard observing scenarios. So as the session duration is comparatively short, the importance of reliable ambiguity resolution is emphasized, and desirable is also the detection and mitigation of multipath or diffraction effects, f.e. with help of residuals analysis, and proper weighting of observations.
Important for GPS absolute heights determination is the exact knowledge of the local (quasi)geoid, especially in mountain areas.

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BIOGRAPHICAL NOTES

Otakar Švábenský. graduated in 1971 at Czech Technical University in Prague, under the faculty of Civil Engineering. He worked for a short period as a surveyor. Since 1975 he has been lecturing at Brno University of Technology, Department of Geodesy. First scientific degree (CSc.) in 1987 . Associate Professor since 1993. Czech national delegate for FIG Commission 6. His interests are: satellite geodesy and engineering surveys.

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