GNSS Multi−Station Adjustment for Permanent Deformation Analysis Networks

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***Abstract**: With the new multi−station RTK software GNNET it is possible to combine the advantages of a rigorous multi−station adjustment with the requirements of real time processing. Local area networks of some hundred meters, or large networks with several tens of kilometers inter station distance may be processed. Even high dynamic processes can be monitored with an observation rate of up to ten Hertz or more. On the other hand, reasonable results may be obtained even with low cost single frequency GPS receivers.*

1 Introduction

GNSS like GPS or GLONASS are well suited as an observation technique for permanently monitoring of deformation objects. Monitoring an area with a couple of object points is often typical for these applications. Due to the deformation analysis algorithms, the full and correctly estimated covariance matrix of all object points is required. For many objects an instantaneous detection of possible deformations is important.

However, currently available processing techniques do their job either as a baseline approach with RTK techniques with the lack of the full covariance information, and/or do it in post−processing with the lack of instantaneous results.

To eliminate the disadvantages of common processing, Geo++ developed the new GNSS multi−station real time adjustment package GNNET.

2 GNSS Multi−Station RTK Software GNNET

2.1 Basic Principles

For a multi−station adjustment of GPS observations it is hard to work with double differenced observations due to the complexity of correlations. This is well known from the post−processing approaches over the last 10 years and leads to sub−optimal solutions. To get an optimal result with unbiased estimates and covariance information, the observables in GNNET are undiffer−enced code and carrier phases.

The observations may be introduced as direct measurements from connected receivers. To re−duce the required bandwidth on the data links it is also possible to preprocess the observations of a station to get reduced observations formatted as RTCM phase corrections. So observations or corrections in RTCM format from remote stations may be used.

To process GPS and GLONASS observations simultaneously, the software is able to take care for the different time and coordinate frames of GPS and GLONASS. Due to the internal use of undifferenced carrier phases the ambiguities of GLONASS phase measurements are solved si−multaneously with the GPS ambiguities.

In a multi−station environment it often is not necessary or adequate to sample all stations with the same input data rate. Stable control points need a lower sample rate than high dynamic object points. To fulfill these requirements, different input rates for different stations are possi−ble. Together with the ability to predict phase corrections for stable reference stations, this allows a very flexible organization of the data collection.

Although the main goal is to get the coordinate results in real time, it is sometimes necessary to do a postprocessing, i.e. if an online data link failed and all observations are available some−times later. Thus all data may be processed in a postprocessing session, using the same input formats as in real time, or with RINEX observations as an additional input format.

All available observations are processed to estimate the parameters of a state vector and its covariance matrix. The most important estimable parameters are:

- coordinates with static, kinematic or stochastic motion model,
- satellite orbit model,
- ionospheric model,
- tropospheric model and
- other nuisance parameters (among them ambiguities).

Not all parameters are appropriate under all circumstances. Orbit and ionospheric parameters are generally omitted in smaller networks, while they are required in larger ones.

To get high accuracies, the ambiguities of the phase observations have to be resolved. For permanent observations normally the ambiguities of the most satellites can be assumed as al−ready fixed, because of the continuously observation process. For the first initialization and to recover from loss of lock, fast and reliable ambiguity search algorithms are implemented. The ambiguty search may be performed with different elevation masks, independently from the state vector estimation.

The most interesting parameters in a deformation analysis network are of course the coordi−nates. Depending on the stability of the station, static, kinematic or stochastic motion models may be used. In the static model the coordinates are assumed constant over the the whole obser−

vation period. In the kinematic model new coordinates are estimated independently for every new epoch, while in the stochastic model the coordinates are stochastically coupled to the former epoch. This allows to reduce any remaining influence of systematic, time correlated errors like multipath or antenna inhomogenities.

2.2 Sub−Millimeter Accuracy Enhancements

Under special circumstances an additional reduction of systematic errors is possible. Assuming that antenna phase center inhomogenities can be eleminated by calibration [4] and other error influences like orbit and atmosphere are eliminated either by modelling or are neglectable in very small networks, the most important remaining error source is multipath. The multipath influence is in the order of some millimeters and up to more than one centimeter in the height component.

Assuming further that multipath influence is the same when the multipath geometry between satellite and receiver is the same, we can try to find a constellation where the satellites in the inertial space and the receivers on the rotating earth are in the same relative position. After a siderial day the earth is in the same position relative to the inertial space. Due to the orbit design of the GPS space segment the satellites have a period of almost exactly two revolutions per siderial day. Although this varies for some individual satellites, it is sufficient to assume an identical geometry in the satellite/receiver constellation. Of course the multipath relevant reflectors in the environment have to be identical.

Now in the difference of the observations between two successive siderial days the multipath influence is dropped out. With this difference of observations we can estimate the coordinate difference between two successive days with an accuracy of less than one millimeter [7].

The method of siderial day differences fails if the multipath geometry changes significantly between two days. This may occur due to building, removing or obstruction some reflecting areas in the station environment. Due to the different orbital parameters the GLONASS satellites do not reappear after one siderial day, so GLONASS is currently not suitable for siderial day differences.

2.3 Communication Requirements

Real time processing requires simultaneous availability of all observables at the processing place. With GNNET it is possible to have different input rates for different stations. This allows sharing of radio link frequencies to transmit the observations of more than one station over one single radio frequency using time slicing techniques.

The transmission of all the necessary observation data requires the following link capacity for an all−in−view satellite constellation of 12 GPS satellites (24 for GPS/GLONASS):

Observation Type	Data Format		
	raw data[1]	RTCM−2.2	RTCM++
GPS L1	9600 bps	4800 bps	1200 bps

1 amount of data varies with receiver manufacturer and type

Observation Type	Data Format		
	raw data	RTCM−2.2	RTCM++
GPS L1+L2	19200 bps	9600 bps	2400 bps
GPS/GLONASS L1	19200 bps	9600 bps	2400 bps
GPS/GLONASS L1+L2	38400 bps	19200 bps	4800 bps

Tab. 1: Required Link Capacity for All−In−View Satellites with 1 Hz Update Rate

The format RTCM++ has been developed by Geo++ to improve the compactness and the flexibility of the RTCM format [5]. RTCM++ avoids some wasted space in the message types 20 and 21 (phase corrections) and allows additional information, i.e. moving reference station coordinates, to be transmitted. RTCM++ is fully compatible with standard RTCM because it uses the message type 59 which is available for proprietary information exchange.

For higher update rates an adequate higher bandwidth is required. Since often the data age is to be minimized, the highest possible data rate is chosen. RTCM++ allows a lower data age than all other corresponding formats.

To cover all possible applications it is required to support as many different communication links as possible. GNNET allows communication over

- serial lines,
- computer networks (TCP/IP, NetBIOS),
- radio link,
- leased lines or
- mobile phone (GSM).

Duplex connections may be used as well as one way communication channels.

3 Applications

3.1 Deformation Monitoring

The most important application covered by this paper is the automated monitoring of deformations. Whenever the view to the sky is possible, there is a good chance that the desired deformation information can be obtained with GNSS. The possible deformation tasks are among others:

Deformations on engineering buildings

dams
towers
etc.

Observation of earth surface deformations

local geodynamic processes,
landslides,
monitoring of subsidence

3.2 Other Applications

Permanent Reference Station Networks

A very important application of a rigorous multi–station RTK adjustment is in a network of permanent reference stations. Permanent reference stations [2] are transmitting code and phase corrections to an unlimited number of mobile stations to allow them a position determination within an accuracy of some centimeters in real time. A stand alone reference station cannot determine the systematic errors in orbits or atmosphere. The accuracy and the maximum distance are limited due to these unmodelled systematic errors. The errors can only be determined in a multi–station network solution and require a real time software like GNNET [3]. The multi–station adjustment may either be computed on the mobile site, which requires to collect the corrections from all reference stations. Another approach is to convert the complex error models of GNNET into a more simple error model which describes the systematic errors as a function of the position. The parameters of this simple model (Flächen–Korrektur–Parameter FKP) are transmitted to the mobile station where they are combined with its actual position to a set of phase corrections without the systematic errors.

Enhanced Positioning and Navigation of Vehicles

Some applications in positioning terrestial, marine or airborne vehicles often require an accuracy, reliability and availability that cannot be obtained from a single GPS equipment. Introducing additional receivers on the base station allow to enhance the accuracy of the positioning due to the reduction of systematic errors and the availbility due to multiple reference stations. A second or third receiver on the mobile station enhances the availability because with multiple antennas the risk for obstructions is lower. With a true multi–station adjustment there is no significant jump in the derived coordinates when switching between the antennas. [6]

Attitude Determination and Machine Guidance

If a platform is equipped with more than one receiver, the attitude of the platform may be computed from the difference of the antenna positions. With two receivers one can get the heading, with three receivers also roll and pitch. Using four or more receivers allows a redundant determination. To get the attitude directions with a reasonable accuracy, the ambiguities have to be resolved. The known inner geometry of the platforms antenna positions may help to speed up the ambiguity resolution. An unbiased estimation of the coordinates as is obtained from GNNET is required to get an unbiased attitude. The availability in real time allow the online guidance of machines in civil and other engineering.

4 Examples and Results

In the last two month a typical example of a deformation measurement was performed at the "Eidersperrwerk" in northern Germany. The building blocks the marine tides from the inner part of the Eider river. Five GPS single frequency receivers were installed on the building. One re–

ceivers was placed on land in some hundred meters distance. The receivers of type Ashtech G12 performed measurements with 5 Hz sample rate. All receivers were connected to a computer running GNNET. The antennas were calibrated for offsets and elevation dependent phase inhomogenities.

The results show the high potential of the new techniques. After eliminating the multipath influence, the height coordinate could be reproduced with an accuracy of less than one millimeter.

5 References

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