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ON GNSS IN-SITU STATION CALIBRATION OF NEAR-FIELD MULTIPATH

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INTRODUCTION

Near-field multipath is increasingly of interest and importance in GNSS applications. There are often problems in GNSS applications present, which are due to but not associated with the near-field issues. The near-field effect depends on several parameters and affects the range measurement, but also other model components (e.g. the troposphere). Hence the complexity and interaction of near-field effects generally hide the actual cause. The theoretical existence of near-field multipath was described and discussed e.g. in 1995 (Elosegui et al. 1995). The experimental verification of near-field effects for GNSS antennas has been demonstrated by Geo++ in 2003 (Wübbena et al. 2003). Since then several experiences regarding near-field impact have been reported. They are from antenna calibrations, RTK networks (Wübbena et al. 2006a), coordinate changes after antenna change, height determination (Hirt et al. 2010) and attitude determination with GNSS (Wübbena et al. 2006b).

Systematic investigations of the near-field effect are still necessary, but most important is to develop strategies for the determination and concepts to take the effect into account. The benefits of such station calibration are obvious: an improvement of accuracy and reliability for a variety of GNSS applications. The most pressing application are currently permanent GNSS reference stations in real-time applications and precise height determination. In consequence, in-situ station calibration methods are required for operational use.

NEAR-FIELD MULTIPATH

Near-field multipath is caused by the close vicinity around a GNSS antenna. The GNSS signals are affected due to signal diffraction and reflection, but also by not directly accessible effects like imaging and electromagnetic interaction. In addition the antenna near-field impact depends on antenna type (e.g. dimensions, radome construction), mount/setup (e.g. tribrach, adapter, tripod), site (e.g. pillar, roof), weather condition (e.g. reflecting coefficient, snow). Basically any matter or change in the near-field around the antenna may change the reception characteristic and consequently affects the tracked GNSS signals.

The theoretical impact of near-field multipath can be analyzed and computed with a simplified model assumption of one single horizontal reflector. In real life the conditions are much more complex. However, one primary horizontal reflector corresponds well to a standard geodetic antenna station setup on a pillar/pier. Input into such computation is the antenna height above the reflector, which gives the multipath impact on a signal as a function of elevation (refer to e.g. Elosegui et al. 1995 , Wübbena et al. 2006a). The result is, that the multipath for small antenna heights (up to several decimeter) has very low frequencies and has even in high elevations a systematic influence. Moreover, the integral of the multipath curves is not zero. Hence, the average of near-field effects is not zero and there is no reduction through long observation time. A systematic and complex error remains in the coordinates.

The complexity is manifold. There is an amplification of the near-field impact in the position domain. The actual differences in range may be some millimeter, but the coordinate bias reach centimeters. The range errors caused by near-field multipath drive the troposphere model into not predictable model errors, which result mainly in height errors. An increase by a factor of three is present for the ionospheric free linear combination (L0). The satellite constellation and elevation mask influence the positioning, which give a time and spacial dependency. For details refer to Dilßner et al. (2008).

IMPACT OF NEAR-FILED MULTIPATH

The robot-based absolute GNSS antenna calibration (Wübbena et al. 2000) is also an excellent tool to investigate other issues of GNSS antenna and receiver characteristics. The phase center variations (PCV) are commonly determined with a standard deviation 0.2 to 0.4 mm using the calibration system. This corresponds to the common repeatability of 1 mm, except close to horizon.

Generally only a GNSS antenna is placed on top of the robot for calibration, but any near-field setup can be added. There is an restriction to safely operate the robot, which limits maximum dimensions and weight of such near-field constructions. The geometry between antenna and the near-field is constant despite the actual movements of the antenna with the robot. This fact allows to use a representative near-field setup during an antenna calibration to estimate the actual near-field impact. Hence, a calibration provides PCV plus multipath near-field influence. The separation of PCV and near-field multipath is obtained through the difference of calibrations with and without near-field environment.

The near-field multipath impact has been demonstrated for a DM-type choke ring antenna (Wübbena 2003), which are still considered the most effective antenna type against multipath. The choke ring antenna is calibrated with a reconstruction of different pillar heads together with different setups (tribrach). The difference in L0 PCV compared to a regular calibration varies between setups, affected elevation range and magnitude. The PCV differences are in the elevation range 10-30° ca. 2 mm up to a maximum of 7 mm and for 40-70° elevation the mean difference is ca. 2 mm up to a maximum 5 mm. The impact in the range domain shows, that even for sophisticated multipath mitigation there are still remaining impacts from the near-field of the antenna.

Moreover, very critical gradients – large PCV changes over small elevation ranges – have been detected for other antenna types. The impact in the position domain can reach up to 10 cm due to the complex interaction of the near-field with other parameters, which has been

	Error	Characteristic	Treatment
Antenna	PCV	elevation and azimuth dependent PCV	calibration of PCV using robot
Multipath	$MP_{near-field}$	long-periodic, systematic effect, bias	calibration of near-field effects using robot/in-situ station calibration
	$MP_{far-field}$	short-periodic, systematic effect	averaging over time,absolute station calibration or weighting (CN0)
Station Uncertainty		stable underground, setup, monumentation	analysis of time series

Tab. 1: Treatment of station dependent errors

Fig. 1: Near-field free setup (left), which is a a optimized copy of top of robot with mount (right)

investigated for a receptive antenna/setup combination in a real-time RTK network (Lesparre 2006, Wübbena et al. 2006a).

HOW TO TACKLE NEAR-FIELD EFFECTS

This knowledge on near-field effects causes a different look at station dependent errors and requires new strategy for dealing with it. The general Geo++ philosophy is the separation of individual error components. The most important station dependent errors dS are PCV and multipath MP, but multipath is further separated into near-field and far-field multipath:

$$dS = PCV + MP_{near\text{-}field} + MP_{far\text{-}field}$$

Near-field and far-field multipath do have different properties, which allows different strategies to account for it.

In Tab. 1 station dependent errors are listed with their basic characteristic and treatment. The stability of a site is also included for completeness, but will not be discussed here any further.

Far-field multipath is generally canceled out through longer observation times. Referring back to the theoretical analysis, multipath induced for a standard tripod height (e.g 1.7 m) shows high frequencies and comparable magnitude over all elevations with an average of zero. This is even more valid for remote reflectors. Nevertheless, for real-time applications far-field multipath is still a problem. Single site calibration using a robot have been tested (Böder et al. 2006), but effort and costs complicate this technique to become an operational procedure. Weighting schemes for the observable are currently the most practicable approach.

PCV and Near-field multipath can be calibrated using the absolute GNSS antenna calibration. However, the near-field calibration with a robot is often an approximation of the actual site setup (e.g. Schmitz et al. 2008). It is generally not possible to resemble the site setup in all its complexity and a procedure for already existing stations is required. Therefore a demand for in-situ station calibration exists.

IN-SITU STATION CALIBRATION: BASIC PRINCIPLE

In-situ calibrations of PCV and multipath have been investigates by several researchers (e.g. Hurst, Bar Sever 1998, Iwabuchi et al. 2004, van der Marel 2006, Granström, Johansson 2007). Generally the phase residuals from a data processing are used to derive combined PCV/multipath maps. Several days of data can be combined through so-called residual stacking.

The central task is the separation of effects of one single station without any correlation to a second one and to obtain results for the original observable instead of a linear combination (i.e. L0). Therefore the Geo++ approach for in-situ station calibration comprises of a combination of different methods.

Special near-field free equipment is required to collect in-situ GNSS observation to account for the complete and complex site dependencies.

The GNSS data allows the analysis of the site's near-field multipath and the actual determination of single station near-field multipath. With this information it is possible to derive for GNSS applications both, near-field multipath corrections and weighting schemes. The correction and weighting are obtained for the original phase and code GNSS observable as a function of elevation and azimuth. Hence, correction/weighting maps similar to the PCV correction tables are feasible.

IN-SITU STATION CALIBRATION: EQUIPMENT AND SETUP

One key issue for an in-situ station calibration is a near-field free station, which is operated for the site analysis on a short baseline. A near-field free station requires optimal control of near-field effects and PCV. This is achieved using as an antenna mount of the near-field free station an optimized copy of the robot top and its setup, which is used during individual absolute GNSS antenna calibration. This gives the best approximation of near-field multipath and PCV (Fig. 1).

Fig. 2: Near-field free stations on poles and GNSS reference stations (on pillar in front, on roof partly obstructed)

In addition a high and slight setup (Fig. 2) on a pole

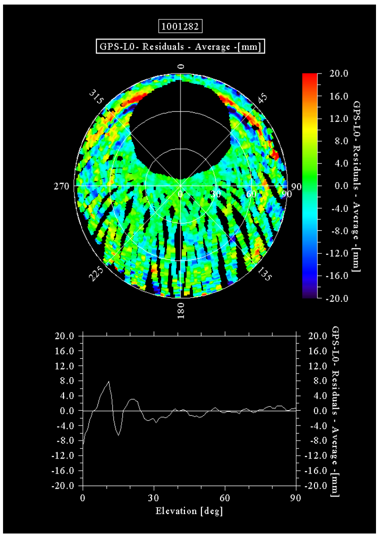

Fig. 3: Reference station 1000/1001 view from East and GPS L0 phase residuals (doy 282-283, 2009)

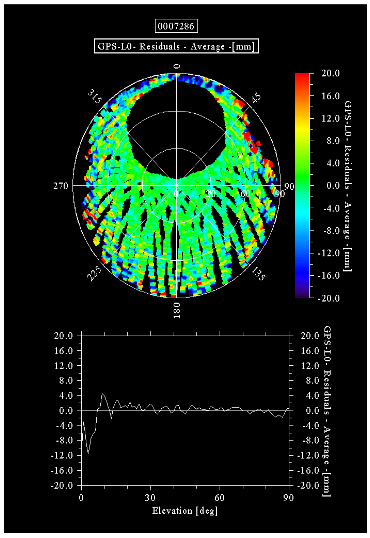

Fig. 4: Reference station 0007 view from SW and GPS L0 phase residuals (doy 286-287, 2009)

(~ 3 m) is used to reduce any far-field multipath beforehand. Over short distances no impact from atmospheric or orbit errors is anticipated.

A redundant setup with three near-field free stations (or more) is chosen, which covers the complete GNSS visibility of the reference station. In addition sophisticated GNSS receivers with optional coupled clocks are used. In case, the original receiver of the reference station is substituted through an in-situ calibration receiver using an antenna splitter to access the coupled clock. Common data parameters are 1 Hz data rate, 0° cut-off and at least 24 h data. The complete setup and system design is transportable, flexible, scalable and easy to use.

EXPERIMENT

An in-situ calibration experiment was executed on the Geo++ roof (Fig. 2) over ten days. The Geo++ reference station on the roof top (1000) was used as one station. It faces close objects, several flat reflectors and in addition remote reflectors (Fig. 3). The second reference station (0007) is a standard setup consisting of a pillar with the top pier acting as primary horizontal reflector and some remote reflectors.

Both reference stations do have near-field influences, which the residual analysis clearly shows.

IN-SITU STATION CALIBRATION: RESIDUAL ANALYSIS

The residual analysis for the reference stations uses the original phase and code observable as well as carrier-to-noise observable (CN0) for GPS and GLONASS as input. The system is extendable to all future signals and GNSS systems. The residuals are processed as function of azimuth and elevation. The analysis software derives range corrections and a weighting scheme for the the observable. With the residual analysis basically an iterative approach is possible, which can therefore be used as a verification.

The in-situ calibration residual analysis uses 24 h data for the reference station on the roof top (1000). Although the residuals of the original signals are obtained, the GPS L0 residuals are shown in Fig. 3. There are basically no obstructions, but a prominent band in the North (280°-80°) up to ~10°-15° elevation. Up to 4 cm residual changes over small elevation range are visible. For the second reference station again 24 h of data from different days were analyzed on pillar 0007. The GPS L0 residuals in Fig. 4 show an obstructions in the western hemisphere (building) and in the NE region (45°-90°, tree). Alternating pattern are present, which reach up to 30° elevation over the complete azimuth range and up to 2-4 cm over small elevation ranges.

IN-SITU STATION CALIBRATION: RESULTS

To verify the in-situ calibration, the correction and weighting pattern are applied to a data set in a GPS processing. The data set is from a different time period compared to the in-situ station calibration data (Fig. 5). The static baseline processing (between the in-situ calibrated stations) uses an arbitrary 4 h data set with 1 Hz data rate and 5° cut-off angle. The positioning is based on the ionospheric free linear combination L0 with troposphere estimation for two cases, with and without in-situ correction/weighting applied. The differences to reference coordinates (horizontal GNSS, leveled height*) are displayed in Fig. 5.

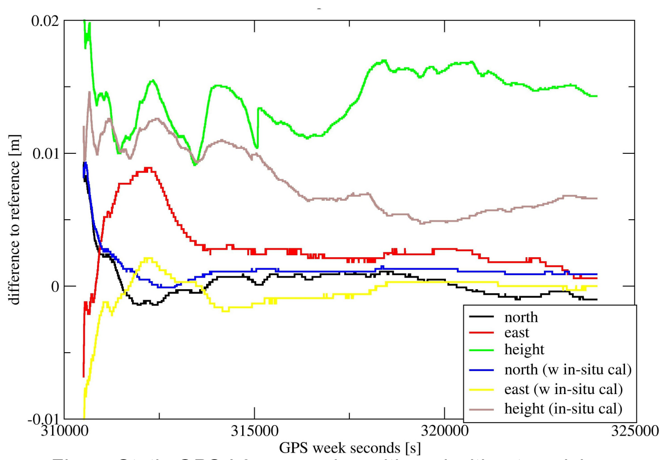

Fig. 5: Static GPS L0 processing with and without applying in-situ correction/weighting (doy 287, 2009)

* Leveled height has to be verified.

Obvious systematic errors through near-field multipath can be recognized in the positioning. Applying correction/weighting from the in-situ station calibration gives small coordinate changes in plane coordinates (2 -3 mm), but larger changes in the height component of up to 1 cm. There is an improvement in coordinates and also in the general performance (jumps due to ambiguity resets, convergence time) for the processing applying the correction/weighting.

Further and detailed analysis of the data set are necessary, which investigates also coupled clocks, and GLONASS correction/weighting. Finally evaluations considering actual reference stations/RTK networking and and absolute height (comparison with leveling) are of interest.

SUMMARY AND DISCUSSION

Near-field multipath has an significant impact on GNSS applications and is of importance for the separation of error components, performance of sophisticated modeling, reliability and accuracy of applications. Especially flat and horizontal reflectors are critical, which are often present on today's reference station setups.

There are systematic errors through near-field multipath clearly present in positioning. Looking at the mainly affected component height, raises the general question how to determine GNSS height without any systematic error. Hence, the need for taking near-field multipath into account for GNSS processing becomes obvious.

An in-situ station calibration approach has been developed, which is based on a combination of several strategies to separate the near-field multipath for a single station to the best. Calibrated, near-field free stations allow for an easy setup at a reference station site and operation over short distances to access the original GNSS observable. In addition the approach is scalable and uses redundancy to obtain e.g. the complete GNSS visibility of the reference station.

From observations at the reference site GNSS phase and code corrections as well as weighting schemes of near-field multipath are derived. The application of the correction and weighting in a GPS processing gives very promising results. Further analysis and experiences of the in-situ station calibration are still necessary, for example environmental changes (e.g. weather condition).

A general recommendation is also to perform more analysis and assessment of station dependent errors and avoiding near-field multipath already in the beginning while setting up new GNSS stations.

The system will be further developed into a complete in-situ station calibration equipment and analysis software.

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