Near-field Effects on GNSS Sites: Analysis using Absolute Robot Calibrations and Procedures to Determine Corrections

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The phase center and variations (PCV) of a GNSS antenna can be precisely determined using the Geo++® Absolute Field Calibration with a Robot. The PCV are determined free or significantly reduced of any multipath effects depending on the antenna type. However, there are remaining multipath effects caused by the actual setup and the environment on the GNSS site, which can significantly modify the phase variations.

The site multipath influence itself can be separated into near-field and far-field effects, which do have different properties. Near-field effects cause a systematic bias especially in the coordinate height component. Far-field effects can be averaged out by sufficient length of observation data.

The absolute antenna calibration with the robot is an excellent instrument to investigate near-field effects on phase variations. A particular antenna setup mounted on the robot will be constantly rotated and tilted by the calibration procedure, but the geometry between received satellite signals and setup will not change. Due to the very long-periodic multipath in the close vicinity and electro-magnetic interaction of the antenna, the phase variation pattern change. Therefore, the near-field effect of the antenna can be determined and investigated.

Investigations on near-field effects using a robot, the separation of site dependent error components and feasible approaches to determine GNSS site near-field effects are discussed.

Introduction

The Geo++® Absolute Field Calibration with a Robot (Wübbena et al. 2000) precisely determines phase center and variations (PCV) of a GNSS antenna. It is fundamental to calibrate the antenna using a procedure which is free of multipath influences or with significant reduction of multipath effects. This is achieved with a precisely calibrated and fast moving robot, which is tilting and rotating the tested antenna. Fast changing antenna orientations are essential for the calibration, because time difference between consecutive epochs amount to just a few seconds. Therefore the environmental multipath error in consecutive epochs is highly correlated and can be well described as a stochastic process within a Kalman filter. To avoid any potential multipath not eliminated by mathematical modeling, a high elevation mask of 18 deg is used, which is dynamically adopted for tilted orientations. Further error components such as ionospheric, tropospheric and orbit biases cancel out using a very close-by reference station. Due to this observation procedure, it is possible to obtain ultimately a clear PCV signal free of residual systematic effects.

Fig. 1: near-field calibration of a TPSPG_A1 antenna on a special mount/mast

However, there are remaining multipath effects caused by the actual setup and the close environment around the GNSS antenna, which can significantly change the actual phase variations. The site multipath influence itself can be separated into near-field and far-field effects, which do have different properties. Near-field effects cause a systematic bias especially in the coordinate height

component. Far-field effects may be averaged out by sufficient length of observation data.

The absolute antenna calibration with the robot has been used to investigate the near-field effects on antenna phase variations. Instead of just calibrating an antenna the additional setup like tripod or mock-ups of pillars are mounted on the robot. The geometry between received satellite signals and the particular setup will not change while constantly rotated and tilted by the calibration procedure. Due to the very long-periodic multipath of the close vicinity and electro-magnetic interaction of the antenna with the setup, the phase variation pattern change. Therefore, the near-field effect of the antenna can be determined and investigated. The far-field effects are eliminated by the procedures of the robot antenna calibration.

Theory

Antenna near-field effects are mainly caused by multipath interferences induced by reflectors located in the close vicinity of the antenna as well as other electromagnetic phenomena like diffraction and antenna imaging effects. It is known that near-field effects are usually caused by surfaces of pillars or special adaptations where the antennas are mounted on (Elosequi et al. 1995, Wübbena et al. 2003).

There are different reasons why multipath effects coming from the close vicinity can cause more severe problems compared to multipath induced by reflectors which are located further away from the antenna. Due to the short distance between the reflector and the antenna phase center, the reflected signals tend to be much stronger than signals coming from more distant objects because they experience less spreading loss. Hence, the amplitude of these multipath errors is larger.

Furthermore, the antenna near-field multipath has a very long-periodic behavior, especially with increasing satellite elevation angles. Depending on the height of the antenna above the reflecting horizontal surface, the multipath periods of oscillation can reach several hours.

For an isotropic antenna (point form) and an unlimited horizontal reflector the near-field effect is a function of mainly satellite elevation, detour path resp. height, reflection coefficient and signal frequency. The near-field effects are caused by the antenna setup, e.g. pillar, tripod, tribrach, adaption, etc. The signal is consequently influenced by diffraction, reflection, imaging and electro-magnetic coupling.

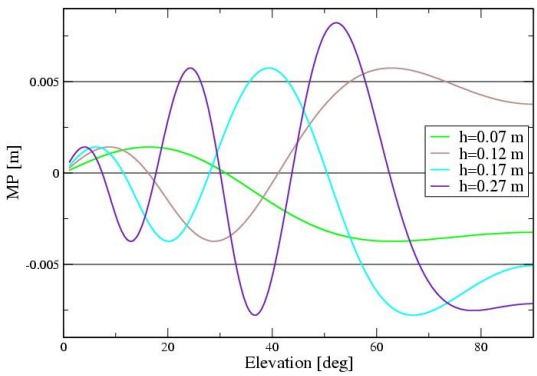

Fig. 2: theoretical L0 multipath on a „pillar“ for different antenna heights up tp 0.27 m

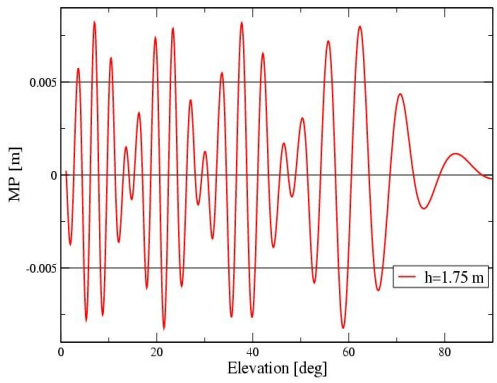

Fig. 3: theoretical L0 multipath for a „tripod“ with an antenna height of 1.75 m

The near-field multipath has been computed for different scenarios. The first one is a pillar setup with different antenna heights from 7 cm up to 27 cm. The multipath residuals have been computed for the ionospheric free linear combination L0. The L0 linear combination is the signal which is used in regional and global coordinate estimation. Fig. 2 shows functions of low frequency with significant effect even in high elevations. This corresponds to a systematic influence (bias) of especially the height component, which does not average out over long observation time. Although only elevation dependent effects have been shown, there are also azimuth dependent influences for non-symmetric setups.

The second scenario is a tripod setup, which is depicted in . The increased antenna height above the theoretical reflector shows high frequencies and correspondingly a „smaller“ influence on the position estimation. It can be considered as a transition of the multipath influences of the reflector into the far-field effect. Therefore an averaging effect can be expected for an appropriate observation time.

Calibration of the Near-field Effect

In order to verify the appearance and to reveal the magnitude of antenna near-field effects, the Automated Absolute Field Calibration has already proven to be a well suitable technique (Wübbena et al. 2003, Schmitz et al. 2004, Dillßner et al. 2006). For this type of investigation, the antenna has to be mounted on the robot together with a representative model of the actual antenna environment. The mock-up of the close environment causes multipath interferences for the antenna during the calibration procedure, because the geometric relationship is constant. Reflections coming from the same direction with respect to the antenna coordinate system, induce the same near-field multipath signal. Therefore, the antenna near-field effect is not eliminated by the calibration observation procedure. Instead, an additional signal pattern caused by the near-field multipath superimposes the PCV signal. Comparing the measured pattern with the PCV results of an isolated antenna calibration, the influence of the near-field can be determined and analyzed.

The robot is limited in weight and dimension of the tested antenna setup. However, small and light re-construction of the near-field causing setup, which are still representative are generally possible to calibrate.

The near-field effect can be generally described like antenna PCV by a spherical harmonic expansion during the real time calibration or with tabulated values for later use. For the constant geometry between antenna and near-field causing environment (pillar mock-up, tribrach, etc.) the estimated PCV include the sum of both errors.

At first, the repeatability of two calibrations with the robot and the same setup are demonstrated. Fig. 6 shows PCV differences of the ionospheric-free linear combination L0 for the same Dorne Margoline type antenna (ASH700936D_M). The repeatability is generally better than 2 mm, except for the horizon (0 deg elevation).

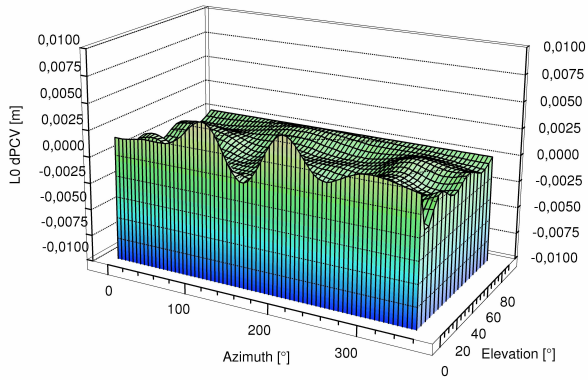

Fig. 4: L0 dPCV of two calibrations with the same setup

Two common geodetic setups with a tribrach on a quadratic and a round pillar reconstruction were selected to show up the influence of the near-field on a high quality Dorne Margoline choke ring antenna. Fig. 6 and Fig. 5 show the setups during the calibration on the robot.

The L0 near-field influence of the tribrach and the quadratic pillar re-construction (edges of 30 cm) are depicted in Fig. 8 and correspondingly for the tribrach and the round pillar re-construction (diameter of 20 cm) in Fig. 7. The PCV difference of the near-field setup and a regular calibration is shown. The influence of the near-field has a magnitude of up to 7.5 mm in low elevations and even 5 mm for 10 deg elevation. For some azimuthal regions at the horizon the effects is even larger.

Moreover, a large gradient in high elevation as especially seen for the round pillar, will severely affect the position estimation. The differences are in addition amplified by any tropospheric scaling factor estimated in the positioning, because the differences to the actual PCV pattern are interpreted as tropospheric variations.

The near-field multipath will differ for another antenna type and modifications of the general setup. This is probably the reason, why even for individually and absolute calibrated GNSS antennas height changes are observed for some sites, when the antenna (type) is changed.

Fig. 6: quadatic pillar reconstuction with a Dorne Margolin choke ring antenna on the robot, edges 30 cm

Fig. 5: round pillar reconstuction with a Dorne Margolin choke ring antenna on the robot, diameter 20 cm

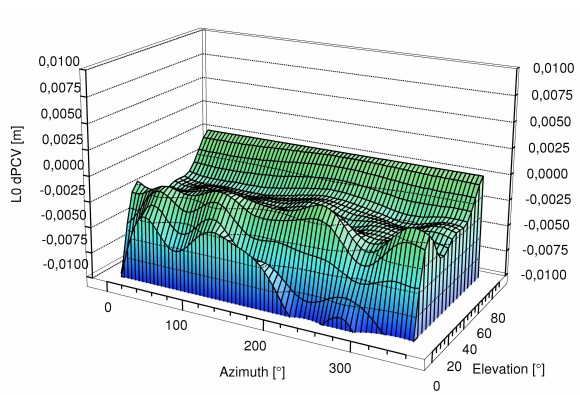

Fig. 7: L0 dPCV showing near-field influence of tribrach/round pillar

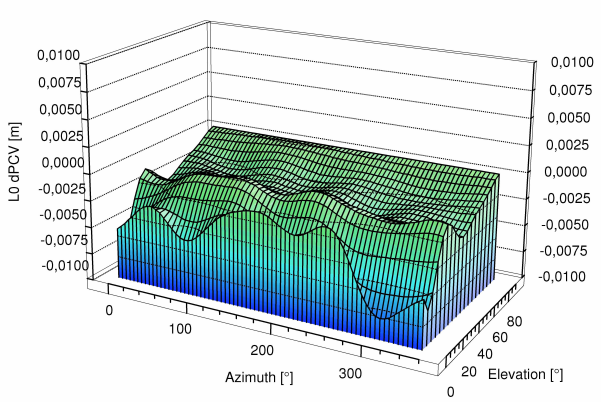

Fig. 8: L0 dPCV showing near-field influence of tribrach/quadratic pillar

Station Dependent Errors

PCV and multipath MP are the most important errors constituents of the site dependent error δS. Other site dependent errors are e.g. the monument stability, which is omitted in the following simplified formulas:

$$\delta S = \delta PCV + \delta MP$$

The PCV error components can be precisely calibrated and also used to separate PCV and multipath. A complete station calibration using a procedure with a robot is generally possible (Böder et al. 2001), but problems with spatial coverage (satellite constellation), changing environment, weather influences (reflection coefficient) as well as effort and costs complicate this technique to become an operational procedure. Nevertheless, it is an ideal reference system to determinate the complete absolute multipath effects of one particular station.

From the technical point of view, it is therefore convenient to divide multipath MP in a near-field and a far-field component, which leads to

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

The benefits are many fold. The near-field effect of multipath acts basically like a bias on the positioning results. However, it can be determined by means of two separate calibration on the robot. Hence, PCV and near-field influences on the positioning can be corrected. Especially for precise height determination it is important to investigate the near-field affecting the GNSS height determination. It is currently difficult to separate or estimate the near-field multipath component with another technique or to determine the magnitude of the height biases without external information.

The far-field multipath has complete different physical properties, which allows for different modeling or treating in GNSS applications. In static GNSS observations the effect will cancel out with sufficient observation time. Even for kinematic application adequate techniques are feasible to apply weighting schemes for the far-field multipath components (Wübbena et al. 2006a).

	constituent	***characteristic***	***handling***
antenna	PCV	elevation and azimuth dependent PCV	calibration of PCV with robot
multipath	near-field	long-periodic, systematic effect, bias	calibration of near-field effect using robot and re-construction of antenna setup
	far-field	short-periodic, systematic effect	averages out over time or station calibration
site stability		stable monument, antenna site	analysis of time series

Tab. 1: site dependent errors and their treatment

The site stability has to be analyzed using time series, but this may be affected by PCV and near-field multipath without adequate corrections.

The site dependent error components, their characteristics and their proposed handling in the evaluation of a GNSS application are summarized in Tab. 1.

Experience from a RTK Network

The Kadaster in the Netherlands build up a RTK network called NETPOS for governmental authorities. NETPOS consists of 31 reference stations. All reference stations are equipped with the same Topcon PG-A1 antenna setup.

The TPSPG_A1 antenna, a small rover antenna without ground plane and choke rings, is mounted on a steel pipe mast (Fig. 9). The near-field effect has a significant influence for such an antenna setup causing especially height errors in positioning. A calibration of the antenna including (the upper part of) the mast was executed with the robot to determine the near-field effect together with the antenna's PCV due to height errors observed in RTK positioning.

Fig. 9: NETPOS antenna and mast

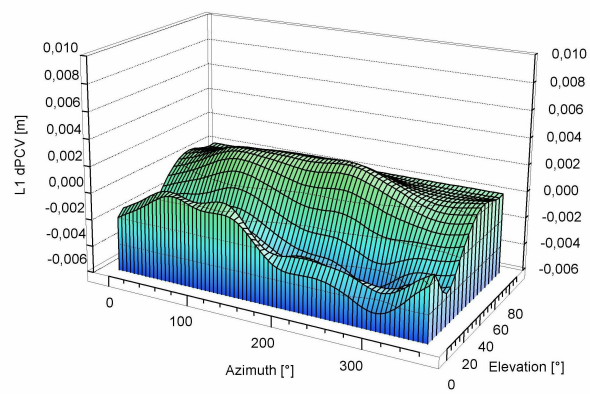

Fig. 11: L1 dPCV: TPSPG_A1 vs. TPSPG_A1+M

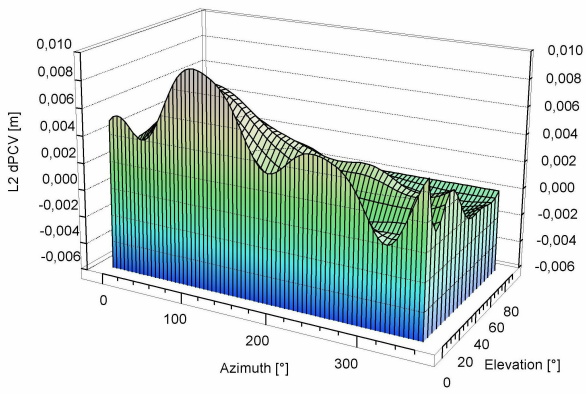

Fig. 10: L2 dPCV: TPSPG_A1 vs. TPSPG_A1+M

The differences between the antenna calibration with and without the mount re-construction (TPSPG_A1+M) reach a magnitude of several mm for L1 and L2. For L0 the differences amplify and are close to 2 cm. The differences depicted in Fig. 11 and Fig. 10 are computed from a type mean considering more than five individual antenna.

The elevation dependent graphs in Fig. 12 show differences of the five individually calibrated antenna with mount compared to the type mean of the antenna without mount for the ionospheric-free linear combination L0. The repeatability of the mount influence is in the order of 4 mm, however, some differences might be attributed to the individual antenna. The near-field effect itself is up to 18 mm.

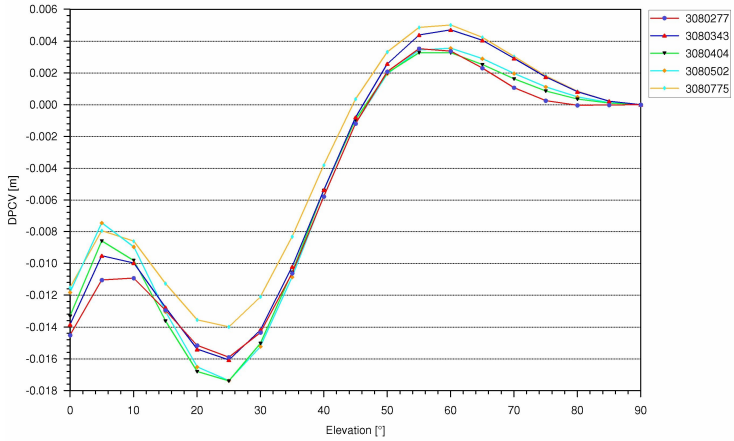

Fig. 12: L0-dPCV:TPSPG_A1 vs. TPSPG_A1+M

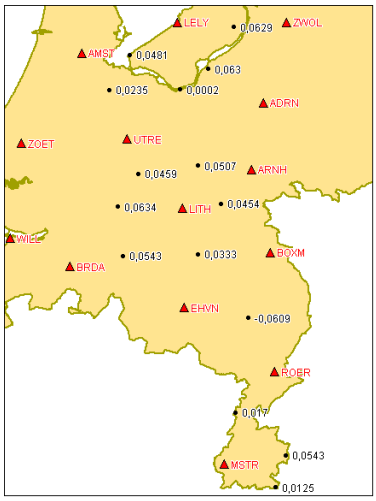

Fig. 13: RTK positioning height errors observed in NETPOS causedby antenna near-field effects

Of more interest are the effects of the near-field multipath in the position domain. To validate the quality of NETPOS RTK measurements were executed on 81 well-known reference points, part of the Netherlands base net. A systematic height offset with a mean value of 32 mm and constellation dependent variations appeared, see for a partial overview and individual differences Fig. 13.

Cause of these errors are the near-field effects of the reference antennas. The effect in RTK positioning is increasing compared to the actual near-field effect seen in the PCV due to tropospheric modeling and satellite constellation. The errors are changing with time, satellite constellation, geographic location and are therefore not repeatable.

After introducing the PCV corrections with the re-construction of the steel mast, the RTK height components are free of systematic biases and have a precision of better than 19 mm.

Summary

The systematic bias caused by near-field multipath effects can be calibrated with a representative re-construction together with the antenna's PCV on the robot. The difference with a regular antenna calibration reveals the actual near-field influences.

A separation of near-field and far-field multipath is proposed to correct for these two differently acting error components. Several advantages in adequate modeling and correction will give improvements in accuracy.

The application of near-field corrections in an operational RTK network demonstrated the significant improvement in RTK coordinate estimation.

The capabilities of the robot concerning size and weight of the antenna as well as a representative mock-up of the GNSS antenna site setup are limited. Investigations are on the way to estimate the near-field antenna effects on a site with a special observation procedure in addition to the robot calibration.

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