ABSOLUTE ROBOT-BASED GNSS ANTENNA CALIBRATION

– FEATURES AND FINDINGS –

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INTRODUCTION

It is generally assumed that all measurements taken with a GNSS antenna refer with sufficient accuracy to one specific point of the antenna. The location and stability of such a point directly affects the accuracy of the GNSS positioning and consequently of the estimated coordinates.

Actually, the electrical property of a tracked GNSS signal varies with elevation and also with azimuth of the satellite. This fact is termed as phase center offsets and variations (PCV) of a GNSS antenna. The PCV depend on the frequency of the observable and are therefore different for the GPS L1 and L2 signal. It becomes even more complex in the case of different frequencies in use for GLONASS satellites.

Therefore a calibration of a GNSS antenna is required to provide corrections to account for the variations of the phase measurements and to exactly relate the GNSS measurements to one single point at the antenna, the so-called antenna reference point (ARP).

For a long time, GNSS antennas were calibrated relative to a second so-called reference antenna. This was due to the fact, that it is difficult to separate the errors of the two involved sites in precise DGNSS. However, the reference antenna itself does have phase variations.

Absolute chamber calibrations revealed the PCV for the commonly used reference antenna AOADM/T, but corrections failed in applications, because the PCV of the transmitting satellite antenna has to be considered as well in global applications.

The development of a robot-based absolute GNSS antenna calibration field procedure by Geo++ in cooperation with the Institut für Erdmessung, Universität Hannover, proved the absolute PCV completely independent. The system provides a sophisticated method for even more analysis of the complex antenna and station errors. The operational system has been extended in functionality by Geo++ since 2000.

A brief overview of the robot-based calibration systems, results and research topics are presented in the following.

ABSOLUTE ROBOT-BASED GNSS ANTENNA CALIBRATION

The Geo++ Absolute Field Calibration with a robot 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 and independent from the reference antenna. This is achieved with a precisely calibrated and fast moving robot, which is frequently 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° 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.

A robot-based absolute antenna calibration provides PCV for the L1 and L2 observables with an accuracy better than 1 mm.

ABSOLUTE VERSUS RELATIVE PCV CORRECTIONS

From theory it is obvious, that relative PCV corrections introduce systematic into the GNSS processing in different instances. Absolute PCV corrections produce an ideal isotropic, absolute antenna (NULLANTENNA) relating the GNSS measurements to a single point (ARP).

Relative PCV corrections convert the antenna PCV pattern to the pattern of the reference antenna. The generally used reference antenna AOADM/T, however, has elevation dependent PCV in the order of 1 to 2 cm. Satellites are seen under different elevations and with increasing distance errors remain due to imperfect corrections.

In November 2006 the International GNSS Service (IGS) performed the transition from relative to absolute PCV corrections together with the introduction of a new reference frame ITRF05. For several applications and products, the absolute corrections improved performance, because the separation of errors is enhanced and systematic biases are removed from modeling.

Hence, it is of advantage for every application from local RTK to global ones to use absolute PCV.

INSIGHT THROUGH SERIES OF GNSS ANTENNA CALIBRATIONS

Since 2000, the robot-based system at Geo++ calibrated over 150 antenna types, 1200 individual antennas in over 4100 calibrations. The large number of individual calibrations of same type enables detailed insight into repeatability within a model series. The assembling precision for the manufacturing can be verified, or slight changes in design or components altering the antenna model can be detected.

The analysis of model series showed e.g. assembling errors (reception elements differently oriented up to 180°), changes in the design of antennas (height shifts of reception element) and effects coming probably from the assembled sample of reception elements.

Among others, it could be demonstrated that DM-type (Dorne Margolin) antennas, which are one of the best geodetic types, do have outliers and show production changes over serial numbers for every manufacturer.

Furthermore, antenna radomes were often considered to have negligible impact, but significant changes of PCV have been detected with the calibration system.

The consequence is, that applications with highest accuracy requirement must rely on individual antenna calibration.

ROBOT-BASED SYSTEM FOR FURTHER EXPERIMENTAL INVESTIGATIONS

The absolute antenna calibration system with robot turned out to be an excellent instrument to investigate in general antenna, receiver or station errors. Conducted experiments were expanded to investigate other issues besides pure PCV.

MULTIPATH FOR A SINGLE STATION

Precise DGNSS always involves two stations, which makes the separation of station dependent errors awkward. One such problem is the determination of multipath for one single station. The GNSS processing initially provide only the lump-sum of multipath of both stations. Hence, one station has to be free of multipath to separate it from a second station.

The robot can be used to obtain such a multipath free station. A continuous but (pseudo-) random motion of an antenna on the robot in all directions from a center position removes the systematic multipath effects on that particular station. A quite simple terming for this approach is that the moving robot’s purpose is to randomize or noisify multipath on the robot station.

A complete station calibration using such a procedure with the robot is possible, but problems with spatial coverage (satellite constellation), changing site 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 findings new approaches are under development to enable station calibrations.

NEAR-FIELD AND FAR-FIELD MULTIPATH

Systematic biases due to reflections in the close vicinity of an GNSS antenna site (pillar, tri-brach, etc.) were known by theory before. With the robot-based absolute antenna calibration such near-field effects on antenna's PCV were determined and investigated in detail.

A particular antenna setup mounted on the robot is constantly rotated and tilted in the calibration procedure, but the geometry between received satellite signals and setup does not change. Due to the very long-periodic multipath in the close vicinity and electro-magnetic interaction of the antenna, the phase variation pattern changes. Therefore, the near-field effect of the antenna can be determined and investigated. The far-field effects are still eliminated by the procedure of the robot antenna calibration.

The difference between a standard calibration and a calibration with a representative mock-up (setup and mounting) will give the impact of the near-field on PCV.

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.

Especially for the height, the understanding and correction of near-field effects is essential.

DETERMINATION OF CARRIER-TO-NOISE PATTERN

GNSS receivers provide regularly signal-to-noise or carrier-to noise (CN0) values of the phase observable. The CN0 values are observable, which carry additional information of the GNSS measurements. Inference on multipath are possible.

The CN0 are used in the robot-based calibration to determine decrease functions, which mainly contain antenna characteristics, but also some receiver dependencies. In general, one can account for the major influences affecting the CN0 readings of an antenna/receiver system. However, a standardization is required to allows the simultaneous use of CN0 decrease functions from different antenna/receiver combination in GNSS applications. A weighting of observations based on standardized CN0 is feasible.

Generally, the L1 CN0 values from all receiver types can be used due to comparable tracking modes based on the C/A code. The L2 values, however, differ and are often not consistent with the actual L2 measurements. Therefore standardization efforts are currently hampered. For the future better and comparable CN0 values are anticipated from the new civilian codes on all frequencies.

GLONASS PCV

GLONASS PCV are estimated considering the individual frequency of each GLONASS satellite. Instead of an arbitrary mixture of tracked GLONASS frequencies, the change of PCV with frequency is used to generate a Delta PCV with units of m/25MHz. Hence, the PCV for every individual GLONASS frequency can be computed using the GPS PCV and interpolating for the required GLONASS frequency. The GLONASS PCV are later provided as metric PCV for the frequency channel number k=0.

This approach enables GLONASS PCV from field calibration and reveals differences to GPS PCV and even differences between the individual GLONASS frequencies.

Experiences of the interaction of small PCV differences with tropospheric modeling and amplification using the ionospheric free linear combination (L0) suggest to consider GLONASS PCV. They represent an improvement of modeling, which should not be neglected in the attempt to improve precision of GNSS applications.

Therefore, GLO PCV should be frequency dependent estimated and applied. For the future, Delta PCV may also be used for Galileo until a sufficient constellation for absolute field calibration is achieved.

SUSCEPTIBILITY OF ANTENNAS TO RAIN

Multipath effects depend on the reflective properties of the environment and thus depend on weather conditions. With changing weather conditions a change in the position domain must theoretically be expected, if the acting errors are not effectively eliminated by the observation procedure or corrected in a sufficient way.

For example, the reception characteristic of a chokering antenna with and without radome are different when it rains. The radome covers the antenna and the chokerings, so that among others no water can accumulate in the chokerings. However, the moisture on the radome interacts with the antenna completely different and causes as well changes.

Effects on PCV have been proved while executing antenna calibration under completely dry weather conditions and under controlled sprinkling of the antenna during robot-based calibration. Actually a wet radome shows a change in PCV for the analyzed type.

The findings open a new field of analysis and may explain e.g. remaining effects in time series.

GNSS ANTENNA'S GROUP-DELAY VARIATIONS

The impact of the antenna on GNSS measurements is not limited to the phase. Recent investigations with the robot-based calibration systems indicated also group delay variations (GDV) of the code measurements.

It is curious, that until now mostly civilian avionic GPS applications have investigated the antenna influence on L1 GPS GDV. Although geodetic applications are based on precise phase measurements, they rely severely on code observable. Code applications range from code carrier comparisons up to precise time transfer.

The robot-based GDV calibration is under investigation, but the magnitude of several dm GDV even for elevation over 20° is noteworthy. For the ionospheric free linear combination the magnitude is in the order of up to 1 m for elevations below 30°. The GDV is currently lacking high individual repeatability, but a type mean reveals similar antenna susceptibility for geodetic antennas as detected for avionic antennas in chamber calibrations.

GDV will be an important topic in future research.

CALIBRATION OF GNSS SATELLITE ANTENNA

Already radome and near-field constructions amounted to weights definitely heavier than the initially anticipated maximum of the robot design. Special investigations and tuning of the robot made heavier weight possible.

An absolute PCV field calibration of a GPS BLOCK II/IIA satellite antenna has been successfully performed with the robot. The weight of over 14 kg and the small 15° reception cone required enhanced robot guidance concepts. Elevation and azimuth dependent PCV for the original L1, L2 observable and consequently for L0 have been determined. Estimation of satellite PCV from global networks are mostly elevation dependent and limited to L0.

The results show, that the azimuthal variations of the transmitting antenna are significantly larger than the pure elevation dependent PCV pattern. The currently applied elevation dependent corrections account only for 10% of the effect. Hence, there is potential for improvement in precise GPS application, if nadir and azimuth dependent PCV are used.

DISCUSSION AND SUMMARY

The features of the absolute robot-based GNSS Antenna Calibration and its use for general antenna, receiver and station analysis have been briefly discussed. The system can provide GNSS antenna's PCV, GDV and CN0 pattern in standard calibration.

Absolute PCV are today a prerequisite for precise GNSS applications. Standardized CN0 pattern are expected to become important in future as well as GDV.

The extensive use of the robot as a flexible method extended the features of the system more and more. The findings from the robot-based measurements provided besides PCV aspects also insight into near- and far-field multipath.

The robot served as a method to determine absolute multipath in station calibrations, which is not operationally but a very exact reference system. The robot-based system moved especially investigations of near-field effects on GNSS antennas forward.

The high precision of the calibration system shows, that one is facing a general problem of the uncertainty principle or the observer effect known from physics or other sciences. The interaction of the GNSS antenna during calibration and later on site is a complex matter and may change the validity of the estimated parameters and corrections.

The separation and correction of PCV and/or near-field as well as the far-field components are therefore the conclusion from our current finding with the robot-based calibration system. The different constituents have different properties, which must be differently accounted for. There is need for PCV corrections considering near-field, but also station calibrations for remaining near-field changes and far-field multipath in general.

Nevertheless, the complex matter underlines, that the precision in GNSS positioning is steadily increasing and new aspects have to be added to GNSS errors and models to operationally obtain the utmost accuracy.

REFERENCES

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