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A PROPOSED SIMPLIFIED TECHNIQUE FOR CONFIRMING HIGH PRECISION GNSS ANTENNA OFFSETS

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Abstract. The purpose of this research was to independently investigate and determine confirmatory calibration procedures for GNSS antennas. This paper focuses on the aspect of simplified techniques for confirming high precision GNSS antenna offsets. In the other words, the aim is to verify GNSS antenna offset parameters – results, which will be used to find the consequences on ground positions of orbital distortions caused by solar activity.
It is well known that the computation of GNSS observations using high precision GNSS antennas requires knowledge of the relevant antenna phase centre offsets. These offsets are the distance in three dimensions from the antenna’s physical centre to the point in space at which the antenna ‘measures’ position. The calibration processes used by manufacturers appear to vary, and, where receivers of different models are to be used together, it is essential that the calibration parameters used are all produced using the same methods and by the same authoritative sources. Meanwhile, with the growth in the use of high precision GNSS systems, the likelihood of antennas being accidentally mishandled is possibly higher than previously. Finally, it is noted that it has long been the practise for surveyors to check their instruments to ensure that they are properly calibrated. In the modern electronic age, however, it seems that this practise has been allowed to lapse as far as GNSS instrumentation is concerned.
With the above in mind, it has been decided to attempt to create a simplified procedure for calibrating high precision GNSS antennas. The aim is that it will be possible for the average surveyor to check his antenna without great effort or trouble. The objective can also be described as finding a simplified field procedure to determine whether a specific antenna’s offset parameters are within reasonable agreement with published figures.

Keywords: GNSS antenna, calibration, phase centre offsets, position.

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1. Introduction

The consistency of the phase centre offsets (PCO) of antennas is important when trying to achieve geodetic measurements, which are accurate at the millimetre level. The precise point whose position is being measured when a GNSS baseline is determined is generally assumed to be the phase centre of the GNSS antenna.

However, the phase centre of a GNSS antenna is neither a physical point nor a stable point. For any given antenna, the phase centre will change with the changing direction of the signal from the satellite. Ideally, most of this phase centre movement depends on satellite elevation (Leick 1995).

The phase centre movements affect the antenna offsets that are needed to connect GNSS measurements to physical monuments (Geo 2000). Ignoring these phase centre movements can lead to serious (up to 20 cm) vertical errors.

In addition, the phase centre is not a physical point that can be accessed with a tape measure by a user who needs to know the connection between a GNSS solution and a monument embedded in the ground. However, this kind of connection must be known if a site is ever to be occupied by different antenna types and continuity of positioning is expected. This requires that the vector between the phase centre and an external antenna reference point (ARP) on the antenna be known (Menge *et al*. 1998).

The function of antennas is to convert electromagnetic waves into electrical currents and vice versa. A GPS/GNSS position therefore refers to the phase centre of the receiver antenna. In reality the phase measurement, and as a consequence the determined signal path length depends on azimuth and elevation of the incoming signal. The purpose of antenna calibration is thus to describe these deviations from an ideal single set of offset parameters for a specific antenna.

Calibration procedures can be classified as *absolute* or *relative* and as *field* or *laboratory* procedures. Field procedures use GNSS signals from satellites in view; thus an operable navigation system is an essential condition for the calibration. Relative field calibration procedures use differential GNSS measurements to determine the calibration results of a test antenna with respect to a reference antenna. Relative calibration parameters are published and it is made clear that these are by comparison with a named antenna type and model (Mader 1999, Rothacher 2001).

Absolute antenna calibration in an anechoic chamber is a standard technique in radio-frequency engineering (Kraus *et al*. 2003). Originally, antenna calibration–to find out where satellite receiver antennas measure from – was done in the relative mode, as explained above.

With time and the arrival of new technology, it became possible to calibrate the benchmark antenna using much improved laboratory methods. At this stage, the imperfections in the benchmark itself were determined. These imperfections could then be added to the relative calibrations previously performed to develop what became known as absolute calibration. However, in a philosophical sense, there is no such thing as an absolute value for a measurable quantity. It is only possible to approach that indeterminable absolute truth by using methods that will serve to minimize residual errors (Schmid *et al*. 2003). However, as a matter of convenience, it is often comfortable to think of a measured value determined by a much better system as being absolutely accurate – even though it is not.

2. Calibration of modified theodolite

A theodolite (Wild T2) has been fitted with a spacer so that a GNSS antenna can be mounted directly onto the telescope (Figs 1, 2). The telescope can then be set horizontally or at an elevation angle to simulate incoming signals at different elevations. Naturally, the spacer itself needs to be calibrated.

Fig 1. An 'old-fashioned' theodolite fitted with a spacer

Fig 2. GNSS antenna mounted directly on the telescope

To find out the offset between the spacer bolt and the intersection of the theodolite axes, measurements were carried out using a CE Johansson AB (CEJ) Topaz 15-6-6 CNC measuring machine. This machine is programmable and can measure the actual dimensions of different geometries and is particularly labour-saving when several similar products are to be measured. This high precision measuring machine measures dimensions down to thousandths of millimetres.

At first, the spacer thickness was measured without it being fitted to the theodolite. Six points in millimetres were measured and averaged (Tab 1).

Table 1. Thickness of the spacer

Point	Thickness mm
1	34.427
2	34.407
3	34.384
4	34.461
5	34.346
6	34.584
Average	34.435

The side lengths of the spacer were got by measuring four points on each side (Tab 2).

Table 2. Side lengths of the spacer

Point	Side #1 mm	Side#2 mm
1	50.783	50669
2	50.941	50.673
3	50.896	50.647
4	50.842	50.577
Average	50.866	50.642

Figure 2 shows the GNSS antenna mounted directly on the spacer on top of the telescope so that the antenna can be rotated out of the horizontal without interfering with the body of the theodolite. Four points on the centre of the spacer were measured (Tab 3). These points were taken on diameters inside the spacer bolt and the crossing of these diameters was accepted as the centre of the spacer.

Table 3. Measurements of the spacer centre

Point	X mm	Y mm	Z mm
1	-25.352	-13.464	-24.953
2	-25.348	-13.500	-24.939
3	-25.348	-13.523	-24.950
4	-25.348	-13.544	-24.961
Average	-25.350	-13.508	-24.951

Measuring the distance between the top surface of the spacer and the intersection of the theodolite's three axes was carried out, and then the theodolite telescope was set up exactly vertically. Four points were measured at the telescope eyepiece *a* and on the cylindered surface surrounding the objective lens *b* (Fig 3, Tab 4).

Table 4. Theodolite telescope sections centres

Trial	Telescope section	
	Centre *a*	Centre *b*
1	X: -26.988 Y: +57.236 Z: +56.364	X: -24.411 Y: +57.395 Z: -84.057
2	X: -26.992 Y: +57.229 Z: +56.437	X: -24.404 Y: +57.387 Z: -84.055
3	X: -26.988 Y: +57.227 Z: +56.438	X: -24.409 Y: +57.397 Z: -84.057
4	X: -26.991 Y: +57.229 Z: +56.438	X: -24.408 Y: +57.391 Z: -84.056
Average	X: -26.990 Y: +57.230 Z: +56.419	X: -24.408 Y: +57.393 Z: -84.056

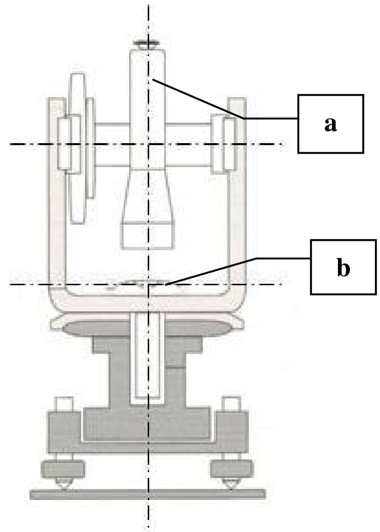

Fig 3. Measured points of telescope at eyepiece *a* and objective *b*. The theodolite telescope was set up exactly vertically. A Topaz 15-6-6 CNC measuring machine measured four times on each telescope section in free dimension coordinates system

The height of the top surface of the spacer above the centre line of the telescope was measured seven times independently (Tab 5).

Table 5. Height of the top surface of the spacer above the centre line of the telescope

Trial	Height cm
1	5.8140
2	5.8476
3	5.7440
4	5.8000
5	5.6940
6	5.8500
7	5.7000
Average	5.7785

The length of the telescope was found to be 15.178 cm. The distance from the eyepiece to the theodolite trunnion axis was measured by making measurements to both sides of the theodolite casing at both faces (Fig 4).

Additional measurements along the length of the telescope gave offsets as shown in figures 5 and 6.

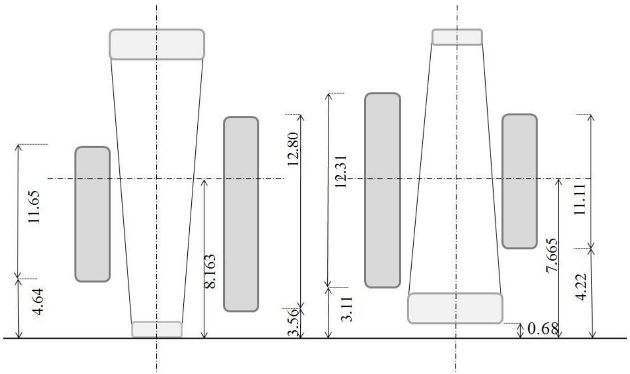

Fig 4. How the measurement of the trunnion axis of the theodolite telescope was found

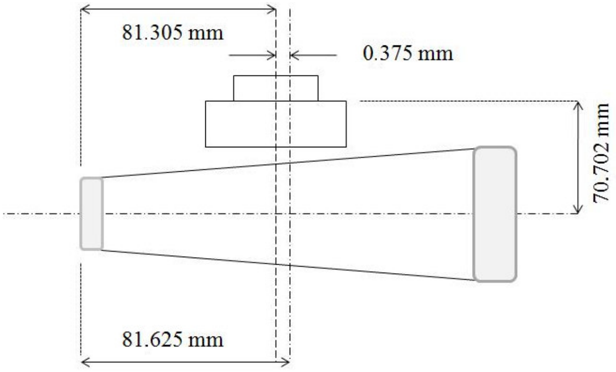

Fig 5. The difference between the centre of the spacer bolt and vertical axis of the telescope

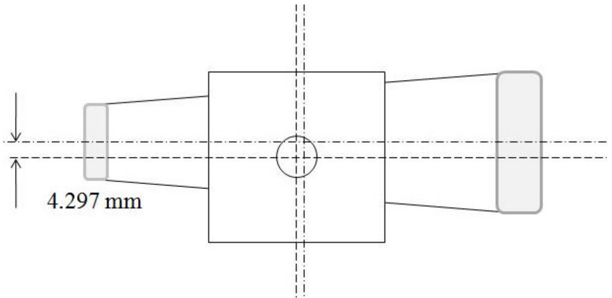

Fig 6. The difference between the centre of the spacer bolt and the intersection of the trunnion axis and vertical axis of the of the telescope

3. Field observation to determine vertical offsets

Geodetic and precise GNSS measurements require an exact knowledge of the reception characteristics of the GNSS antennas used, and therefore a calibration is necessary.

An attempt was made to independently arrive at calibration parameters, which might be compared with numbers obtained from other sources. For this purpose, having in mind that many points were inaccessible due to snow cover we decided to use the pillars marked G3, G4, G5, and Topcon (Fig 7).

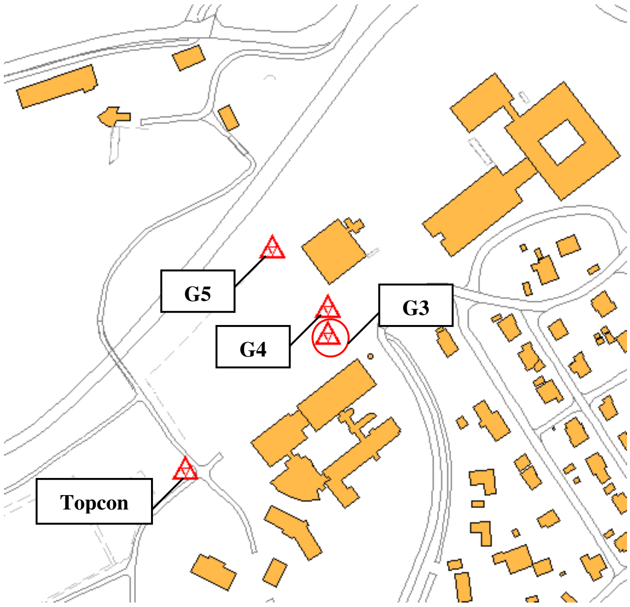

Fig 7. Scheme of the calibration base at Gjøvik University College. The reference antenna of the calibration measurements is a station called Topcon and the test antennas are G4 and G5. For helping to get vector by network adjustment, a station called G3, which was on a tripod, was used

The precise positions of these pillars have been measured and the 'true' coordinates are known (Tab 6). These coordinates were developed by network adjustment, which were computed using Leica Geo Office software, version 7. These coordinates were measured by geodetic techniques that are more precise than those used for the actual calibration methods, that is by a preplanned static GNSS campaign using both frequencies on phase measurements, with post processing of vectors and thereafter network adjustment including standard statistical analyses testing for mistakes and internal consistency in the network.

Table 6. Coordinates of points

Cartesian Coordinates			
Station	X m	Y m	Z m
G3	3066692.7092	578391.5633	5544112.9459
G4	3066690.3503	578391.2773	5544114.3169
G5	3066664.7974	578350.8902	5544132.5828
Topcon	3066794.3904	578320.0022	5544065.9730
UTM Zone 32 Coordinates			
Point	North m	East m	Height m
G3	6740481.797	591500.621	222.917
G4	6740484.538	591500.707	222.957
G5	6740520.983	591464.823	222.993
Topcon	6740381.020	591414.036	224.210

A GPS receiver calibration base can consist of several points, and their number can be varied (Skeivalas *et al.* 2006). In this case, the analysis calibration base consists of four stations. The test antennas on pillars G4 and G5 were Leica GS15 GNSS receivers, and the test antenna on pillar G3–a Leica GS15 GNSS receiver – was on a tripod. The fourth pillar, named Topcon, was chosen as the reference antenna, with parameters from the GPS antenna calibrations at the National Geodetic Survey (NGS) (Mader 1999).

4. Antenna calibration test results

As already noted, the precise point whose position is being measured by satellite techniques is generally assumed to be the phase centre of the antenna. The phase centre is, however, neither a physical point nor necessarily a stable point. For any given type of GNSS antenna, the phase position will change with the changing direction of the signal from a satellite. Ideally, most of this phase centre variation depends on the elevation of the satellite. The National Geodetic Survey (NGS) has developed a procedure for calibrating GPS antennas to allow the phase centre variation with satellite motion to be observed.

The calibration procedure normally involves placing a reference antenna in one location and the test antenna at another location close by and differencing the data to determine the phase centre offsets. This procedure is carried out under somewhat perfect circumstances. For best results, every antenna should ideally be calibrated at the site of intended use. To do this, it is necessary to have a reference antenna with characteristics.

The antenna calibration procedure uses field measurements to determine the relative phase centre position and phase centre variations of a series of test antennas with respect to a reference antenna (Schmitz, *et al.* 2002). As was mention above, for this experiment Topcon (type AT2775-42) was chosen as the reference antenna. The test antennas were Leica GS15 GNSS receivers which are set to track to an elevation mask of 15°. This test did not provide the absolute phase calibration for each antenna, but rather the relative calibrations with respect to this reference antenna. Since the reference antenna was the same for all tests, the antenna calibration for all test antennas could be used in any combination to find out the antenna phase centres.

Table 7. Calculation of phase centre measurements of frequencies L1 and L2 (North, East and Height are in UTM Zone 32 on the GRS80 Ellipsoid)

		X m	Y m	Z m	North m	East m	Height m	Ant. over point cm	Ant. over ARP cm	Phase centre cm
Frequency L1	*Station G4*									
	By vector	3066690.4708	578391.3054	5544114.5318	6740484.5350	591500.7130	223.2050			
	Network adjustment	3066690.3503	578391.2773	5544114.3169	6740484.5380	591500.7070	222.9570			
	Difference	0.1205	0.0281	0.2149	-0.0030	0.0060	0.2480	0.2320	0.1575	0.1735
	Station G5									
	By vector	3066664.9185	578350.9124	5544132.8056	6740520.850	591464.8220	223.2470			
	Network adjustment	3066664.7974	578350.8902	5544132.5828	6740520.9830	591464.8230	222.9930			
	Difference	0.1211	0.0222	0.2228	0.0020	-0.0010	0.2540	0.2345	0.1575	0.1770
Frequency L2	*Station G4*									
	By vector	3066690.4709	578391.3043	5544114.5325	6740484.5360	591500.7120	223.2050			
	Network adjustment	3066690.3503	578391.2773	5544114.3169	6740484.5380	591500.7070	222.9570			
	Difference	0.1206	0.0270	0.2156	-0.0020	0.0050	0.2480	0.2320	0.1575	0.1735
	Station G5									
	By vector	3066664.9228	578350.9207	5544132.8149	6740520.9840	591464.8290	223.2580			
	Network adjustment	3066664.7974	578350.8902	5544132.5828	6740520.9830	591464.8230	222.9930			
	Difference	0.1254	0.0305	0.2311	0.0010	0.0060	0.2650	0.2345	0.1575	0.1880

The aim of this first field trial was to test a procedure for getting the vertical antenna phase centre offset. Conditions were less than ideal due to continuing snow cover, with the result that existing pillars that were further apart than considered optimal had to be used. The actual observing procedure was simply to establish the receivers on the pillars as already noted, and then to record approximately 1 hour's worth of observations at 1 second intervals using both L1 and L2 frequencies. Great care, meanwhile, was taken to measure and record the height of the various antennas over their points. Measurements were subsequently made to connect the physical height measuring point to the conventional antenna reference point (ARP), which is the lower surface of the standard bolt at the base of all surveying antenna.

These observations were then extracted from the respective receivers, converted into RINEX format using the respective manufacturers' conversion systems, and imported to the LGO software system. The aim here was to process the observations to obtain vector positional differences between Topcon and the pillar-mounted Leica antenna.

In detail, and with the use of the menu language of LGO, all the antenna, including Topcon, were designated as unknown – in other words having zero antenna phase centre offsets. Then, at the Topcon pillar, the published offset values for L1 and L2 (Mader 2001) were used to compute the Cartesian coordinates of those phase centres. Next, using only the GPS observations, the vectors were processed, giving the Cartesian coordinates of the phase centres at the Leica antenna. Vectors were computed separately for the two frequencies.

Finally, the previously adjusted coordinates of the pillars at the Leica stations and the processed vector results were converted into UTM zone 32 coordinates based on the GRS80 Ellipsoid. The difference between these end results thus produced the desired offset estimates as listed in table 7.

5. Conclusions

1. The results of the fieldwork, which was performed under less than ideal conditions, are nevertheless within approximately 15 % of the vertical antenna offset values given in the Leica Viva GNSS controller firmware. At the time of writing, the NGS has not yet published its values on its web site. Further, it is interesting to note that, again at the time of writing, the offset parameters released by Leica (hard wired into LGO) do not include variations due to satellite elevations. These elevation values are of course available for the older Topcon antenna.

2. It therefore follows that it would be advantageous to carry out additional field tests. Intuitively, it would be better to have the test pillars much closer together, and tests need to be completed with different satellite geometry configurations as well as using both GPS and GLONASS together, and indeed separately.

3. At the same time, the relative success of the field trial thus far suggests that using the theodolite as an antenna mounting can also develop confirmatory results. However, two aspects here will need to be resolved:

For the fieldwork, it will be necessary to know the azimuth in which the telescope is pointing, so that the antenna phase centres can be adjusted with respect to the pillar coordinates.

Similarly, the geometric procedures for that 'movement' will need to be identified.

4. Meanwhile, reference is made to the use of a high precision industrial measuring device for calibrating the theodolite spacer. This was the first attempt at using this machine for any purpose at Gjøvik University College since its recent installation. The results can only be described as impressive, with measurement repeatability better than one hundredth of a millimetre. The availability of this device needs further evaluation concerning the controls that are normally expected on optical instruments.

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SUPAPRASTINTAS METODAS AUKŠTO TIKSLUMO GLOBALINĖS NAVIGACINĖS PALYDOVINĖS SISTEMOS ANTENOS NUKRYPIMAMS APROBUOTI

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S a n t r a u k a

Straipsnyje analizuojamas supaprastintas metodas, kuriuo galima aprobuoti aukšto tikslumo globalinės navigacinės palydovinės sistemos (GNPS) antenos nukrypimus. Siekiama patinkrinti GNPS antenos nukrypimo parametrus – rezultatus, kurie bus naudojami nustatant GNPS palydovo orbitos iškraipymų padarinius. Nagrinėjama procedūra, kai siekiama nustatyti, ar konkrečios GNPS antenos kalibravimo parametrai yra pagrįsti, palyginti su publikuotais duomenimis. Analizuojama problema yra aktuali, kai GNPS matavimams naudojamos aukšto tikslumo GNPS antenos ir reikalingos žinios, susijusios su antenos fazės centro nukrypimais.

Reikšminiai žodžiai: GNPS antena, kalibravimas, fazės centro nukrypimai, padėtis.