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Dynamic Global Navigation Satellite System antenna position verification using raw pseudorange information

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Abstract

This article presents a method of obtaining relative and global coordinates using the Global Navigation Satellite System (GNSS). Four GNSS antennas have been compared in this research. The GNSS antennas have been utilized by the Veripos and Septentrio Systems. Global Positioning System (GPS) pseudorange observations are used to obtain relative position of the GPS antennas. Relative positions are based on calculations made by the RTKLIB software. Lever arm range and bearing are used to assess accuracy of the true antenna location relative to the vessel Navigation Reference Point (NRP). The article deals with the problem of assessing the quality of real-time positioning equipment. Comparing results of the raw position calculation with the physical measurements shows the usefulness of the real – time position monitoring.

Introduction

Precise vessel positioning requires proper knowledge of the ship perimeter. Local coordinates are referenced to the vessel reference point (VRP), which is the origin of the coordinate system of the ship reference frame (Nardez, Krueger & Vargas, 2011). Correctly surveyed VRP is crucial for proper track planning, precise maneuver execution, etc. Each of the reference systems need to be properly referenced by the lever arms calculations. Specialized survey vessels transiting between projects need onboard positioning equipment calibration (Report, 2011), particularly when changing any of the vessel antennas, relocating them or modifying structures around. Such activity can affect the performance of the antennas performance. Due to short transit times, it is necessary to prove the location of antennas and the quality of positioning data, to assure enough accuracy during any precise positioning projects (Vint, 2010).

In a preceding article, a relative positioning method has used pseudorange data to compare Global Positioning System (GPS) antenna positions. Calculations were performed by using RINEX data, which was collected by different GPS receivers and processed using RTKLIB software.

Rinex format and RTKLIB as a processing medium

Rinex is an acronym for Receiver Independent Exchange Format. The receiver collects the raw GNSS data. Rinex is a standard form that allows both usage of measurements generated in the receiver and further analysis of those measurements (disturbances and position degradation identification) (Gurtner, 2007).

For post processing of pseudorange data, RTKLIB software has been utilized. It is an open source program package for standard and precise positioning with the Global Navigation Satellite

System (GNSS). RTKLIB consists of a portable program library and several APs (application/programs) which use the library. The features of RTKLIB are as follows:

1. Supports standard and precise positioning algorithms with: GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS;
2. Supports various positioning modes with GNSS for both real-time- and post-processing.
3. Supports many standard formats and protocols for GNSS;
4. Supports several GNSS receivers' proprietary messages;
5. Supports external communication via Serial, TCP/IP, NTRIP, local log file (record and playback) and FTP/HTTP (automatic download);
6. Provides many library functions and API's (application program interfaces), including: Satellite and navigation system functions, matrix and vector functions, time and string functions, coordinates transformation, input and output functions, debug trace functions, platform dependent functions, positioning models, atmosphere models, antenna models, earth tides models, geoids models, datum transformation, RINEX functions, ephemeris and clock functions, precise ephemeris and clock functions, receiver raw data functions, RTCM functions, solution functions, Google Earth KML converter, SBAS functions, options functions, stream data input and output functions, integer ambiguity resolution, standard positioning, precise positioning, post-processing positioning, stream server functions, RTK server functions, downloader functions (Takasu, 2007–2013).

Obtaining receiver absolute and relative position

Absolute positioning involves the use of only a single passive receiver at one station location. It collects data from multiple satellites in order to determine the station's location (Nguyen, 2007).

In relative positioning, two or more GPS receivers simultaneously receive signals from the same set of satellites. These signals are then processed to obtain the components of the base line vectors between observing stations.

Antennas within relatively short distance of one another, experience the same type of errors. Those errors include ionospheric and tropospheric delays, ephemeris errors, satellite altitude, atmospheric loading, ocean loading and residual satellite clock errors. Two antennas of the same producer should perform within the limits provided by the manufacturer (Nguyen, 2007).

When a GPS receiver performs a navigation solution, only the approximate range or "pseudorange" to selected satellites is measured. The pseudorange is determined by correlation of both the transmitted code and reference code created by the receiver. Measurements do not contain the correction for synchronization errors between the two clocks – satellite and receiver. Velocity of the transmitted signal is affected by the atmosphere. This pseudorange concept is presented in Figure 1.

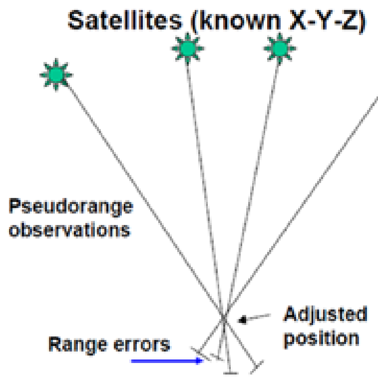

Figure 1. Pseudorange measurement (NAVSTAR, 2003)

Pseudorange can be described by the equation:

$$R = p^s + c(\Delta t) + d \tag{1}$$

where:

R – observed pseudorange;
p^s – true range to satellite (which is unknown);
c – velocity of propagation;
Δt – clock biases, including receiver and satellite;
d – propagation delays caused by atmospheric conditions.

At a given measurement period, the GPS receiver generates a set of n pseudorange equations (where n is the number of satellites visible to the receiver). The pseudorange equation (1) can be rewritten as:

$$R_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + c(\Delta t) + d_u \tag{2}$$

(x_u, y_u, z_u) = ECEF position coordinates of the user (m);
(x_i, y_i, z_i) = ECEF position coordinates of the i-th satellite (m).

When four pseudoranges are observed (for 3-D position), four equations are formed from Equation 2.

$$(R_1 - c(\Delta t) - d_1)^2 = (x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2 \tag{3}$$

$$\left(R_2 - c(\Delta t) - d_2\right)^2 = \left(x_2 - x_u\right)^2 + \left(y_2 - y_u\right)^2 + \left(z_2 - z_u\right)^2 \tag{4}$$

$$\left(R_3 - c(\Delta t) - d_3\right)^2 = \left(x_3 - x_u\right)^2 + \left(y_3 - y_u\right)^2 + \left(z_3 - z_u\right)^2 \tag{5}$$

$$\left(R_4 - c(\Delta t) - d_4\right)^2 = \left(x_4 - x_u\right)^2 + \left(y_4 - y_u\right)^2 + \left(z_4 - z_u\right)^2 \tag{6}$$

In these equations, the only unknowns are x^u, y^u, z^u and Δt. Solving those four equations yields the 3-D position solution. These geocentric coordinates can be transformed to any reference datum. Calculation steps can be found in Bowring (1976).

Sets of antenna coordinates are produced based on the pseudorange observations. Coordinates are calculated using data from RINEX observation and navigation files. For the purpose of research, WGS-84 is used as a reference ellipsoid (Blewitt, 1997).

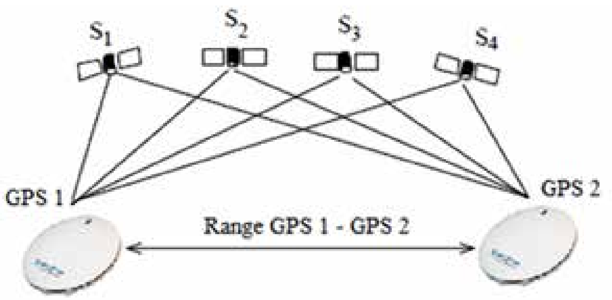

Figure 2. Relative position of the GPS antennas

In the relative technique, positions of the two different receivers are compared. Absolute positions of the antennas are calculated, and then direct range calculation is performed.

For the 3-D positioning, direct range computation, for the two different antennas are calculated as follows:

$$(3\text{D})_{1-2} = \sqrt{\left(A_1 - A_2\right)^2 + \left(B_1 - B_2\right)^2 + \left(C_1 - C_2\right)^2} \tag{7}$$

where: $A_{1(2)}$, $B_{1(2)}$, $C_{1(2)}$ – Cartesian coordinates of the respective antennas.

Data collection and analysis

Data was collected on August 31, 2014, on board the seismic survey vessel *Polar Duchess*, during a seven hour period, while the vessel was underway. The vessel was following a trackline given from the navigation system called "Orca". Pseudorange data was acquired every one second. Observations were gathered in two data files designated as navigation and observation files (.O and .N) (Takasu, 2007–2013).

For the purpose of the research, two types of antenna have been used: Fugro AD410 and Septentrio PolarNt*GG. Fugro antennas were strictly used for positioning mediums; Septentrio antennas served as a baseline for Gyro – GPS.

Figure 3. Fugro AD410 antenna (left) and Septentrio PolarNt*GG GPS/GLONASS-antenna (right)

Table 1. Surveyed nominal offsets of the antennas in relation to VRP

NRP	Navigation reference point	STBD / PORT (*X*) [m]	FORE / AFT (*Y*) [m]	UP / DOWN (*Z*) [m]
1	Septentrio GPS Antenna Starboard (aux)	5.64	–1.11	21.07
2	Septentrio Gyro GPS Antenna Port (main)	–5.64	–1.08	21.05
3	Veripos Port GPS Antenna	–4.37	0.57	27.13
4	Veripos Starboard GPS Antenna	3.94	0.56	27.12

Initial values of the antenna offsets have been presented in Table 1. These values were set by surveyors during initial deployment of the vessel.

Antennas were mounted on the Navigation mast above all the other instruments. There were no zones of data that deteriorated due to obstruction. Antennas were mounted well above the deck on the masts so that the multipath effect would be considered negligible in further analysis.

Figure 4 shows horizontal distribution of the antennas. The positive *Y*-axis indicates direction of the vessel's bow; the positive *X*-axis refers to the starboard of the ship while the negative *X*-axis refers to the port of the ship, respectively. Two aft antennas belong to Septentrio system; while the fore antennas belong to Veripos system.

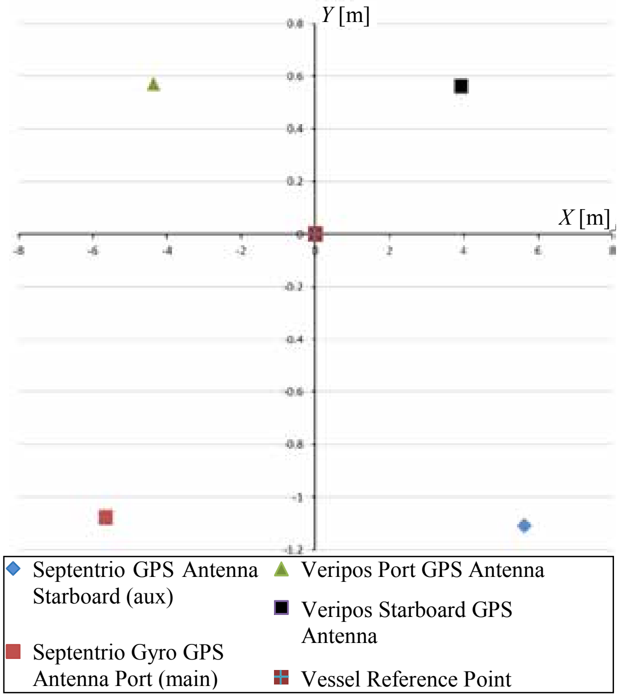

Figure 4. Nominal antenna offsets on the main mast in the *XY* plane

Figure 5 indicates the location of the antennas in the vertical plane. The *Z*-axis represents direction perpendicular to the center and beam line pointing away from keel, and the positive *X*-axis shows starboard direction, as in Figure 4.

Nominal 3D/2D offsets based on the surveyed antennas position were calculated and the results are displayed in the Table 2 (descriptions for the numbers are given in Table 1).

Data was acquired from all directions to get all the possible antenna relations to the satellites. Positions were then differentiated against each other to obtain direct range measurement. Results are presented in Figures 7–12.

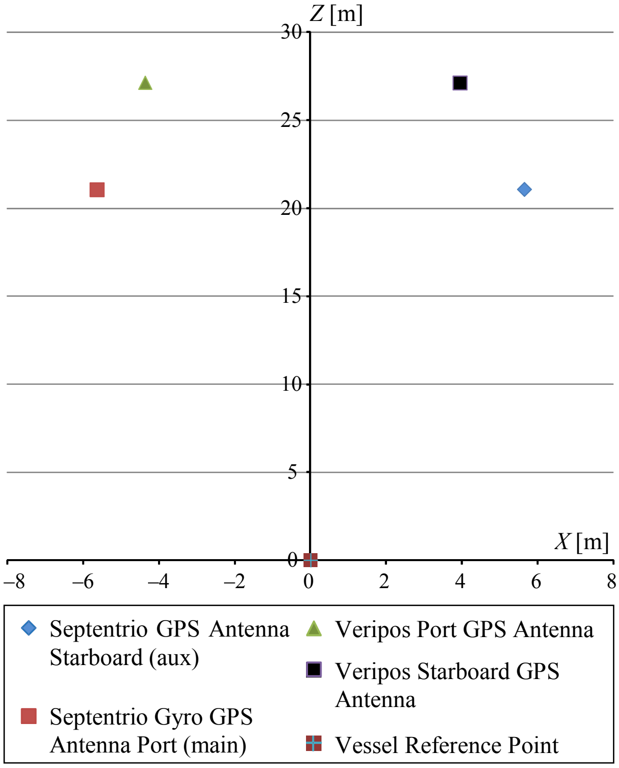

Figure 5. Nominal antenna offsets on the main mast in the *XZ* plane

Table 2. Calculated range between antennas

	3D range [m]	2D range [m]
1–2	11.28	11.28
3–4	8.31	8.31
1–3	11.82	10.15
1–4	6.50	2.38
2–3	6.43	2.08
2–4	11.46	9.72

Using RTKLIB software, raw GPS positions of the antennas were calculated based on WGS-84 datum.

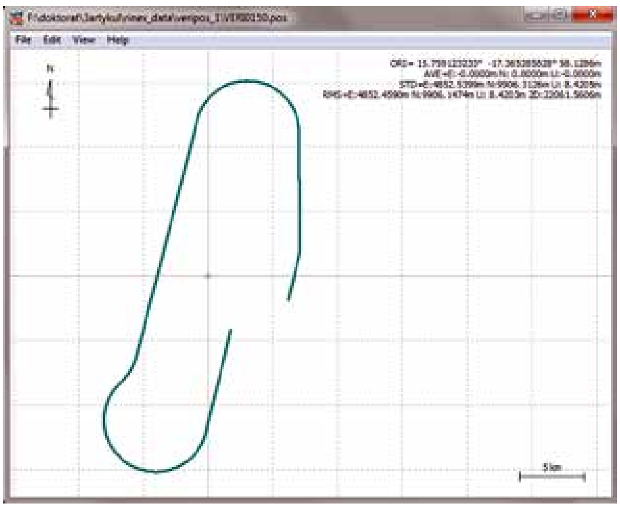

Figure 6. Example of a track of the GPS uncorrected positions of one of the antennas

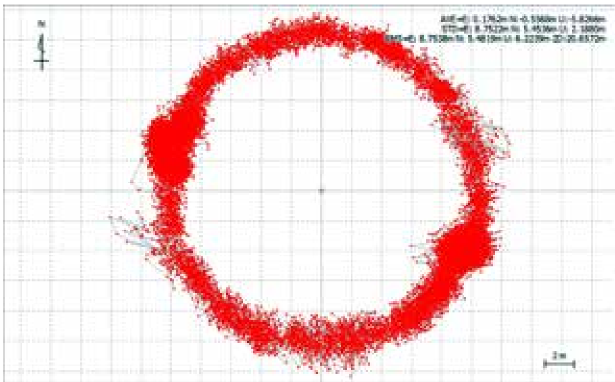

Figure 7. 2-D position differences between the Septentrio Aux antennas and Veripos 1 antenna

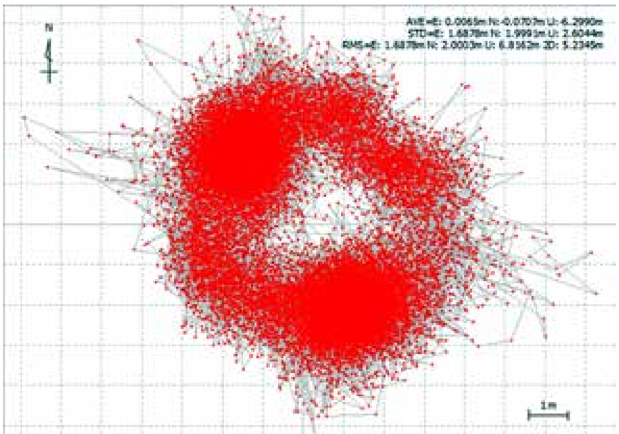

Figure 8. 2-D position differences between the Septentrio Aux antennas and Veripos 2 antenna

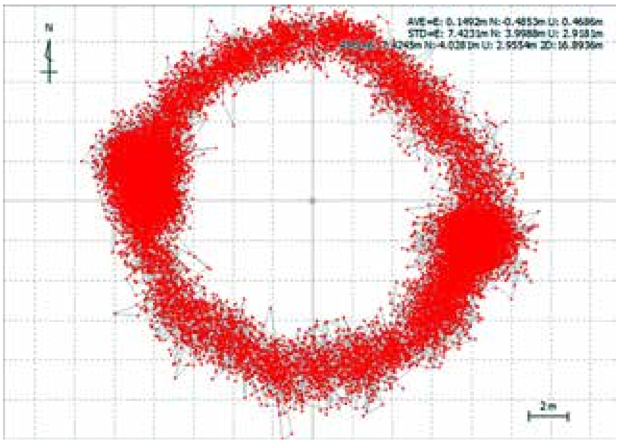

Figure 9. 2D position differences between the Septentrio antennas

The 2D and 3D ranges were obtained using only raw positions. Antennas are described by the data presented in Table 3.

The results shown above are the mean distances calculated over the whole period of data collection, including straight lines, as well as turns (see Figure 6).

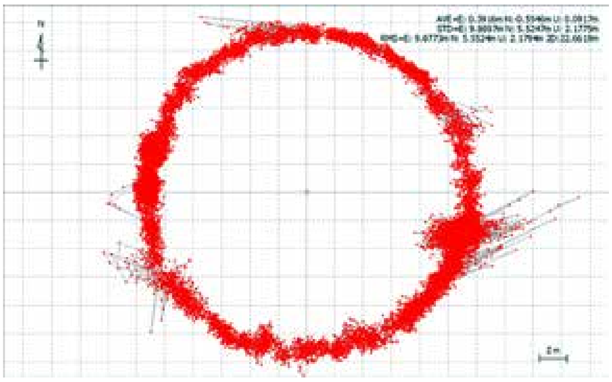

Figure 10. 2D position differences between the Veripos antennas

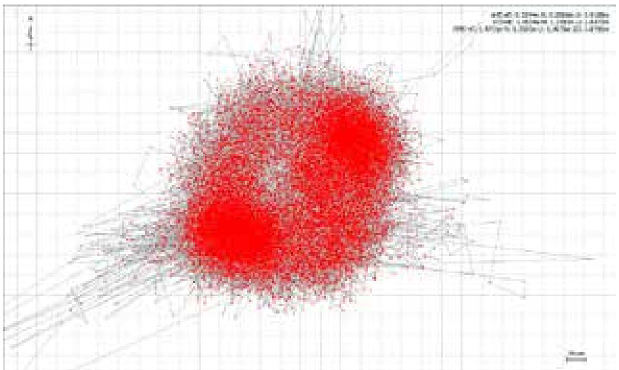

Figure 11. 2-D position difference between the Septentrio Main antenna and Veripos 1 antenna

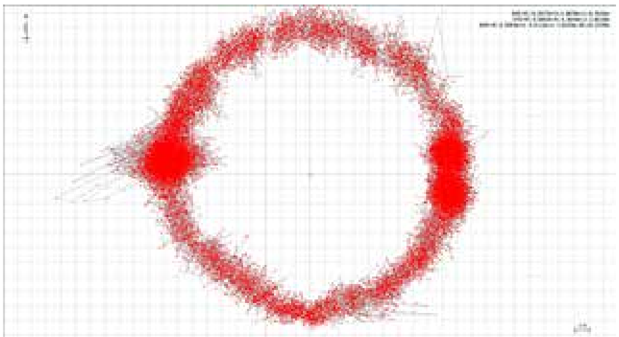

Figure 12. 2D position differences between the Septentrio Main antenna and Veripos 2 antenna

Table 3. Results of the calculated antenna offsets

	3D range [m]	2D range [m]
1-2	11.54	11.31
3-4	8.95	8.43
1-3	12.06	10.31
1-4	7.30	2.62
2-3	6.75	1.92
2-4	11.93	9.64

Data obtained was compared with range values derived from initial antennas offset measurements. Results are presented in Table 4.

Table 4. Calculated raw distance between antennas

	Difference	
	3D [m]	2D [m]
1-2	–0.26	–0.03
3-4	–0.64	–0.12
1-3	–0.24	–0.16
1-4	–0.80	–0.23
2-3	–0.32	0.16
2-4	–0.48	0.08

Conclusions

Data presented reveals only centimeter distance differences between antenna locations. Results are more clearly seen in the 2-D plane. In general, 3-D positioning is less accurate than 2-D[Navstar]. The lowest distance difference was measured between Septentrio antennas. It can be assumed that the same grade of antennas, located at the same height shows better results in their relative positioning. In general, all comparisons fell within one meter. While collecting data, stability of the data could be seen as well. This could allow monitoring position quality during operation and rejecting underperforming solution.

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