APPLICATION OF THE POLISH ACTIVE GNSS GEODETIC NETWORK FOR SURVEYING AND DESIGN OF THE RAILROAD

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Abstract

One of the main problems related to railroad surveying design, and its maintenance is the necessity to operate in local geodetic reference systems caused by the long rail sections with straight lines and curvatures of the running edge. Due to that reason the geodetic railroad classical surveying method requires to divide entire track for a short measurement sections and that caused additional errors. At the end of last century, development of the Global Navigational Satellite Systems (GNSS) positioning methods operating in the standardized World Geodetic System (WGS-84) jointed with incrementation of its precision allowed verification of capability of utilization GPS measurements for railroad surveying. The trials with single GPS reference station using Real Time Kinematic method with VHF emission have shown the strong impact of the spatial decorrelation the pseudorange corrections (PRC's) on the base station and survey receiver. This problem has been resolved after the evaluation of the active geodetic networks in different countries which used Virtual Reference Station (VRS) idea, General Packet Radio Service (GPRS) transmission method and Networked Transport of RTCM via Internet Protocol (NTRIP) defined in 2004 by The Radio Technical Commission for Maritime Services (RTCM). In 2008 project of a reference station system (Active Geodetic Network) designed for Poland, was carried out by the polish authority for geodesy – Head Office of Geodesy and Cartography. The precise GNSS satellite positioning network ASG-EUPOS is also a part of the European Position Determination System (EUPOS), which has prepared the standards for reference systems for countries in Central and Eastern Europe, in order to establish a unified infrastructure for positioning services.
The article presents surveying results of the measurement campaign realized in march 2008 on the 40-km long railroad in Poland. Four GPS (L1, L2) receivers were placed on the moving rail platform and their positions were fixed in real time kinematic mode (every 20cm), based on the national active geodetic network (ASG-EUPOS). The accuracy analyzes and results of the implementation of results in railroad design process are discussed.

Keywords: railway track, geometrical layout, satellite surveying GPS, ASGEUPOS network, coordinates determining, error correction

1 Introduction

One of the main problems connected with geometrical forming systems of a railway track is the lack of detection range of the whole system activity. This is connected with line sections and curves on a railway area which are very often so large that visual evaluation of their shape is impossible. Conventional geodesy requires division of the railway route into smaller examined separately parts. It becomes an additional errors source and a total appraisal of particular geometrical system is difficult. Development of geodetic satellite techniques combined with improving precision of measure GPS (Global Positioning System) induces geodesists to make an attempt to apply GPS technique for the purpose of making inventory of railway tracks. Accessible to researchers at the beginning of the 21 century measurement techniques and development of the RTK (Real Time Kinematics) methods have allowed researchers to obtain measuring accuracy of one centimetre at 1÷5 Hz frequencies with necessity of additional altitude measurement reduction.

Satellite surveying will enable in future the actual state inventory as well as updated rough route marking out. Action towards creation the implementation base of a new measurement technique for railway should be undertaken. Presented work describes development of the main electricity measurement techniques and measuring accuracy of railway satellite surveying on the ground of experimental research. Research relied on taking a few dozen kilometre railway detour by a motor truck WM 15 with four satellite aerials installed on its platform [2]. The initiator of experimental research was The initiator of experimental research was Gdansk University of Technology – Department of Railway Engineering and Chair of Geodesy; Polish Naval Academy in Gdynia – Faculty of Navigation and Naval Weapons was a participant. Technical support was given by Polish Railway Lines Company in Gdansk (with its seat in Gdynia) and measuring apparatuses were given by Leica Geosystems GA.

The set consisted of four Leica receivers of 1200 Smart Rover system which contained Smart Antenna ATX1230GG type and RX 1250 controllers (fig. 1). The antenna phase centre position towards railway track axis was made with traditional geodesy methods pursuant to the tachymetry measurements.

Figure 1 Position of receiver antennas GNSS Leica system 1200 (A, B, C, D) on the motor car platform WM 15

The measurements used Polish ASG-EUPOS network which has been working since 2008 year [3]. The Polish part of the system ASG-EUPOS has consisted of 98 reference stations evenly located over country. Except for the new starting up stations, the system has adapted also existing stations managed by universities, research and development centres, state administration and private firms. The complex measure tests of all real-time and post-process services and obtained results analysis were made. Additional compatibility correction tests were also carrying out; test territories are numbered National Management Centres, called also Counting Centres are the second segment of ASG-EUPOS system. Central Office is situated in Warszawa and its branches are situated in Katowice. They have a task of controlling and managing stations network, correction generating of made observations and making satellite surveying available to the recipients. All interferences were signalled and analysed; if necessary countermeasures have been undertaken.

2 Availability of the certain value of the possition error during the measurements

Let's define the reliability process in which the relation between the single measurement error δ_n and the parameter *U* decide about its state (work or failure). Let *a(t)* be the binary interpretation of the reliability state of the process. The state *a(t)=1* means that in the moment *t* the error of the single measurement is less or equal than *U*. In the opposite case for $\delta_n > U$, the system is in the state of failure. The availability of a certain value of position error will be denoted as

$$D(t) = P[\delta(t) \le U] \tag{1}$$

The final form of the availability was presented as [4, 5]

$$D(t) = 1 - F(t) + \int_0^t [1 - F(t - x)] dH_\Phi(x) \tag{2}$$

where:
F(x) – distribution functions of working states,

$H_\Phi(x) = \sum_{n=1}^{\infty} \Phi_n(x)$ – a renewal function of a stream made of the renewal moments.

For referred measurements, the limited *U* values was established as 10 cm. The figure 2 presents the availability functions and its limited values of the certain value of position error calculated for all (*A, B, C, D*) GPS receivers.

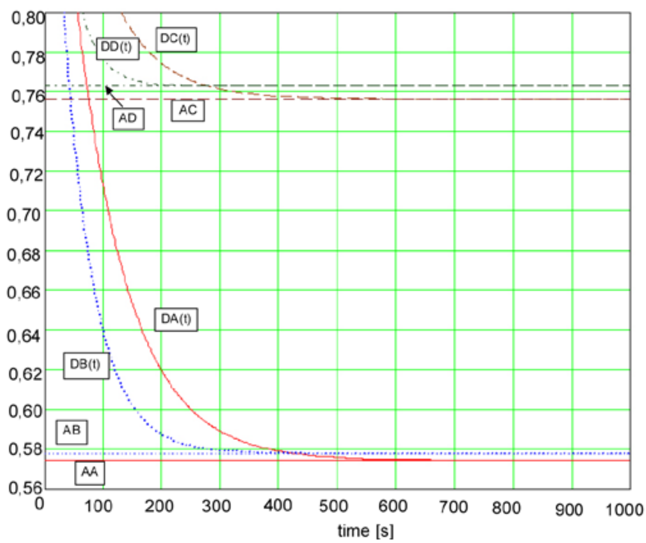

Figure 2 Availability functions: *DA(t)*, *DB(t)*, *DC(t)*, *DD(t)* and its limited values (*AA, AB, AC, AD*), of the certain value of position error functions for U = 10 cm

Analysis shown in figure 2 indicates strong connection between GNSS receiver location and accuracy of position determination. Results for receivers which are located nearby the motor truck cabin are considerably worse than results for far away located receivers. The horizon obstruction was the reason of accuracy deterioration. Low values of the availability determined by receivers located nearby the cabin results in carefully GPS campaign planning, based on the specialised software and including the terrain obstructions.

3 Practical applications of the results

On the basis of the obtained results it was possible to define the main direction of the whole railway route and its segments. These are basic data to design a railway geometric system. For that purpose, a particular run of the route was examined on railway segments. The final measurement was conducted in ellipsoidal GPS coordinates and transformed into Gauss-Kruger (X,Y) conformal coordinates. This procedure allows confronting two main issues:

- possibility to establish the railway route and turning angle determination for the design purpose,
- determination of the railway route (arcs and transition curves) for the modernisation purpose.

3.1 Determination of the main railway route and turning angle

The analysis is presented on the example of geometric lines (fig. 3) where two, relatively long, straight railway tracks. The graph below is prepared on the basis of positions obtained from GPS receiver *A*.

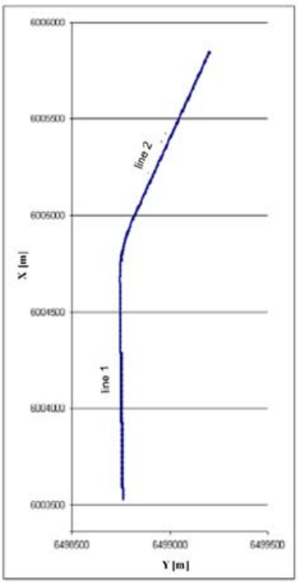

Figure 3 Two rail tracks as coordinate system

We define the strait line in the parametrical form as time functions: *X(t)* and *Y(t)*, where measured errors impacted on dependent values: *X* and *Y*. For calculating the equation the method of least square has been applied. As the result in case of line 1 (fig. 3) we obtain:

$$X = 5997482{,}803 + 2.87311\ t, \tag{3}$$

$$Y = 6498829{,}206 - 0.03388\ t, \tag{4}$$

where: $t = 2151.00 \div 2493.20$ s.

The equations (3), (4), can be written in a Cartesian coordinate system (Y, X) as:

$$X = 557114695.89386 - 84.80253837\ Y. \tag{5}$$

The directional coefficients *b* of the line ($b = \text{tg}\ \varphi$) were calculated for other three GPS receivers; the final form is presented below:

- for receiver B $\quad X = 557268029.52202 - 84.82609979\ Y \quad (6)$
- for receiver C $\quad X = 556946536.77392 - 84.77663027\ Y \quad (7)$
- for receiver D $\quad X = 557114696.09606 - 84.80135773\ Y \quad (8)$

In our case, the particular segment of the route was calculated on the basis of 1713 measurements obtained from GPS receivers. Presented results proved small difference between directional coefficients *b* estimated for GPS receivers and confirmed the high usefulness of the proposed method.

The next step was to calculate the turning angle. For GPS receiver *A* directional coefficient was equal –84.80253837. The value corresponds to the angle $\varphi_1 = 90.6756°$. The equation of line 2 is done as:

$$X = -8405165.30199 + 2.21735165\,Y \tag{9}$$

For line 2, tg $\varphi_2 = 2.217352$, thus $\varphi_2 = 65.7252°$. The module of the turning angle can be presented as $|\alpha| = |\varphi_2 - \varphi_1| = 24.950°$. Table 1 presents α values for all GPS receivers.

Table 1 Values of the turning angle for all GPS receivers calculation

GPS receiver no	A	B	C	D
tgφ_1	-84,80253837	-84,82609979	-84,77663027	-84,80135773
φ_1 [rad]	1,58258788	1,582584605	1,582591483	1,582588044
φ_1 [deg]	90,6756	90,6754	90,6758	90,6756
tgφ_2	2,217352	2,218354	2,218013	2,217988
φ_2 [rad]	1,147120762	1,147290051	1,147232453	1,14722823
φ_2 [deg]	65,7252	65,7349	67,7316	65,7313
$\|\alpha\|$ [rad]	0,435467118	0,435294554	0,43535903	0,435359815
$\|\alpha\|$ [deg]	24,950	24,941	24,944	24,944

3.2 Determination of railway route change direction area

The area where the route changes direction can be determined in relatively a simple way when the coordinates of the route are transformed into the symmetrical position as presented in figure 4.

The new transformed coordinates can be calculated as the following equations:

$$x = (Y - Y_0)\cos\beta + (X - X_0)\sin\beta \tag{10}$$

$$y = -(Y - Y_0)\sin\beta + (X - X_0)\cos\beta \tag{11}$$

where rotation angle β has a form:

$$\beta = \varphi_1 - \frac{\alpha}{2} = \frac{1}{2}(\varphi_1 + \varphi_2) \tag{12}$$

For GPS receiver *A*, calculated angle rotation β was established as 1.36485432 rad.

The Gauss-Kruger conformal coordinates:

$$Y_0 = 6498745.04911\text{m},\ X_0 = 6004519{,}50986\text{ m}$$

were applied as functional values.

Figure 4 presents the railway route change direction area with approximated lines defined by functions:

$$y_1 = 0{,}221241\,x \tag{13}$$

$$y_2 = 91{,}89349 - 0{,}221241\,x \tag{14}$$

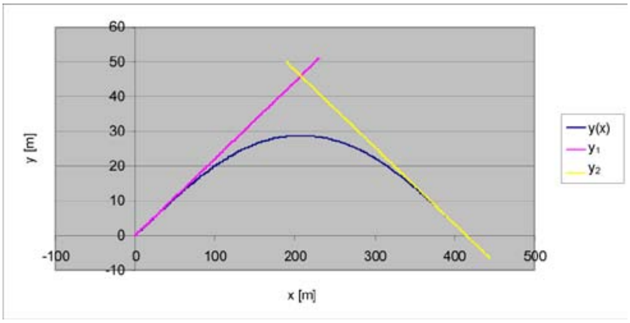

Figure 4 Considered part of the railway route in the local coordinate system (β = 1.36485432 rad, Y_0 = 6498745.04911m, X_0 = 6004519.50986 m)

In conclusion, the coordinates of the railway route position could be estimated within 56cm span. It allows assessing the route axis placed in curves, as well as for defining appropriate design works in the local coordinate system. The process allows for assessing the route's axis placed in curves as well as for defining appropriate design works in the local coordinate (x, y).

4 Final remarks

Presented research is a result of a general report obtained from measurement campaign and focuses on establishing GPS active geodetic network capabilities in railway route determination. The future analyses and trials will enable to explore the estimation methods further, especially in the aspect of the railway route regulation.

The analysis indicated strong connection between location of GNSS receiver and accuracy of position determination. Results obtained from receivers located nearby the motor truck cabin are considerably worse than those obtained from located away. The horizon obstruction deteriorated accuracy. Low values of the availability determined by receivers located nearby the cabin (50 %) impacts the precise GPS planning process, based on the specialised software and analysis of the terrain obstructions. At the present stage, it can be stated that implemented measuring technique opens a whole new perspective on applied research. As proved, it enables very precise determination of basic data definition for railway line modernization design.

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