sciendo

DOI: 10.1515/aon-2018-0005

MATEUSZ BILEWSKI, PAWEŁ ZALEWSKI
Maritime University of Szczecin, Poland

ASSESSMENT OF GNSS POSITION INTEGRITY WITH THE USE OF POST-PROCESSED EGNOS DATA IN THE AREA OF SZCZECIN-ŚWINOUJŚCIE WATERWAY

ABSTRACT

GNSS measurements can be supplemented by the information available in EGNOS system even if one has only GNSS receiver that is not processing Satellite-Based Augmentation Systems data. The article describes how to obtain the variances of ranges to the satellites used for positioning when the final antenna position and satellites' elevation and azimuths values are recorded. To verify how the resultant estimates of position error correspond to real errors the research based on GPS receiver was conducted.

Keywords:
EGNOS, SBAS, integrity data, SISNET parser, CRC-24Q

1. INTRODUCTION

Receivers recording GNSS data and integrity data from the EGNOS system are much more expensive, less popular and mostly less accessible, except in aviation, than the ones recording GNSS data without augmentation data. Data from the EGNOS system are freely available on the Sisnet website [SISNeT, 2016]. Possibility to verify the GNSS position integrity with the use of post processed data from the EGNOS system in the area of Szczecin-Świnoujście waterway was examined. It was assumed that the receiver used GNSS signal without differential corrections from SBAS or ground-based systems (GBAS - Ground-Based Augmentation System). Static measurements lasted for 67 days.

2. THE PROCEDURE OF SATELLITES' RANGE VARIANCES CALCULATION

A range variance σ_i^2 [m^2] for each of satellites is composed of 4 components which can be estimated based on EGNOS integrity data:

- $\sigma_{i,flt}^2$ - ephemeris corrections,
- $\sigma_{i,UIRE}^2$ - full degraded ionospheric correction,
- $\sigma_{i,mr}^2$ - contribution from the shipborne (marine) receiver,
- $\sigma_{i,tropo}^2$ - tropospheric model correction.

Their dependency is represented by the formula (1).

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,mr}^2 + \sigma_{i,tropo}^2 \qquad \ldots(1)$$

The components of (1) can be calculated in accordance to the algorithms set for airborne receivers [RTCA, 2013] and modified for marine use [Zalewski et al., 2015]. The Message Type from the EGNOS system which contains the parameters used in these algorithms is referred in the further part of the article in braces, for example {MT 10} means Message Type 10. $\sigma_{i,flt}^2$, depending on the root-sum-square flag RSS_{UDRE} {MT 10}, is calculated by the formula (2).

$$\sigma_{i,flt}^2 = \begin{cases} (\sigma_{UDRE}\delta_{UDRE} + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er})^2, if\ RSS_{UDRE} = 0 \\ \sigma^2{}_{UDRE}\delta_{UDRE}^2 + \varepsilon^2{}_{fc} + \varepsilon^2{}_{rrc} + \varepsilon^2{}_{ltc} + \varepsilon^2{}_{er}, if\ RSS_{UDRE} = 1 \end{cases} \qquad (2)$$

In the formula:

- σ_{UDRE} is the user differential range error, read out from the table based on the {MT 2,3,4,5,24};
- δ_{UDRE} is an additional factor depending on user position, if defined in {MT 27,28}, otherwise equals 1;

- ε_{fc} is a fast correction degradation parameter, calculated by the formula (3) {MT 7,25};
- ε_{rrc} is a range rate correction degradation parameter, calculated by the formula (4) depending on IODF mask (if IODF=3 the other formulas as set in [RTCA, 2013] should be used, but this is extremely rarely encountered);
- ε_{ltc} is a long-term degradation parameter, calculated by one of the formula variants (5), (6) depending on received {MT 25} version (v0 or v1) and the reception time {MT 2,3,4,5,6,7,10,25}.
- Last component ε_{er} is an "en route" degradation parameter, used only when system misses some of fast and slow correction messages (7).

$$\varepsilon_{fc} = a\frac{(t-t_u+t_{lat})^2}{2} \qquad ...(3)$$

$$\varepsilon_{rrc} = \begin{cases} 0, if\ (IODF_{current} - IODF_{previous})_{mod3} = 1 \\ (\frac{aI_{fc}}{4} + \frac{B_{rrc}}{\Delta t})(t - t_{of}), if\ (IODF_{current} - IODF_{previous})_{mod3} \neq 1 \end{cases} \qquad ...(4)$$

$$\varepsilon_{ltc,v0} = C_{ltc,v0} floor\left(\frac{t-t_{ltc}}{I_{ltc,v0}}\right) \qquad ...(5)$$

$$\varepsilon_{ltc,v1} = \begin{cases} 0, if\ t_0 < t < t_0 + I_{ltc\_v1} \\ C_{lts\_lsb} + C_{lts\_v1}\max\{0, t_0 - t, t - t_0 - I_{ltc\_v1}\}, otherwise \end{cases} \qquad ...(6)$$

$$\varepsilon_{er} = \begin{cases} 0, if\ neither\ fast\ nor\ long\ term\ corrections\ have\ time\ out \\ C_{er}, otherwise \end{cases} \qquad ...(7)$$

The above components do not depend on the particular satellite, whereas $\sigma^2_{i,UIRE}$ is calculated separately for each of satellite according to the following relationship (8):

$$\sigma^2_{i,UIRE} = F^2_{i,pp}\sigma^2_{i,UIVE} \qquad ...(8)$$

$F_{i,pp}^2$ is the obliquity factor dependent on the satellite elevation E_i, calculated by the formula (9). $\sigma_{i,UIVE}^2$ is user ionospheric vertical error, calculated from N nearest points (N=3 or N=4) (10,11,12) {MT 10,26}, described in detail in [RTCA, 2013].

Considering the satellite and user positions, the user must first determine the location of the ionospheric pierce point of the signal path from the satellite. The location of an ionospheric pierce point is defined to be the intersection of the line segment from the receiver to the satellite and an ellipsoid with constant height of 350km above the WGS84 ellipsoid [RTCA, 2013].

$$F_{i,pp}^2 = \left[1 - \left(\frac{R_e cosE_i}{R_e + h_I}\right)^2\right]^{-\frac{1}{2}} \qquad \ldots(9)$$

$$\sigma_{i,UIVE}^2 = \sum_{n=1}^{N} W_n(x_{pp}, y_{pp})\sigma_{n,ionogrid}^2 \qquad \ldots(10)$$

$$\sigma_{ionogrid}^2 = \begin{cases} (\sigma_{GIVE} + \varepsilon_{iono})^1, if\ RSS_{iono} = 0 \\ \sigma_{GIVE}^2 + \varepsilon_{iono}^2, if\ RSS_{iono} = 1 \end{cases} \qquad \ldots(11)$$

$$\varepsilon_{iono} = C_{iono\_step} floor\left(\frac{t - t_{iono}}{I_{iono}}\right) + C_{iono\_ramp}(t - t_{iono}) \ldots(12)$$

Tropospheric refraction is a local phenomenon based on tabular values related with region. Therefore $\sigma_{i,tropo}^2$ takes constant value during measurements in small area. $\sigma_{i,mr}^2$ is the estimated variance of marine (shipborne) receiver error depending on the receiver's properties and site-specific GNSS signal propagation effects like multipath, which should be locally evaluated (this alone variance cannot be derived from the SBAS message). At this stage of the research this variance was not accounted in calculations, though its effect on final integrity estimations cannot be assumed as negligible.

3. DESCRIPTON OF THE PARSED EGNOS MESSAGES

The process of EGNOS messages parsing consists of several stages. Data block format of the EGNOS message frame is presented in the Fig. 1 [RTCA, 2013].

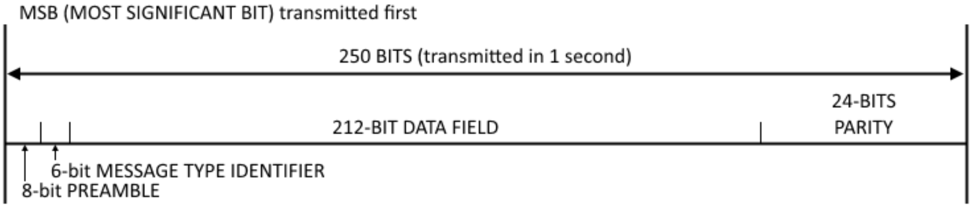

Figure 1. Data block format. Source: RTCA, 2013.

The beginning of the message frames received from the satellite can be recognized by the cyclic prefix: $53_{(16)}$, $9A_{(16)}$ and $C6_{(16)}$, but when data are received as ".ems" file (in post processing) each frame is preceded by an additional satellite number, date and time of registration [SISNeT, 2016].

CRC-24Q is Cyclic Redundancy Check parity in the 24 bit version developed by Qualcomm Corporation. After receiving a frame the checksum calculated by CRC-24Q algorithm should be checked. Subsequently calculating the checksum, quick method based on the hash table can be used [CRC24, 2016]. In the case of an invalid checksum, message is rejected. In the next step messages necessary to parse are checked whether they were previously received according to the tree presented in the Fig. 2. The arrows in the Fig. 2 indicate the flow of information. Messages required are marked by continuous arrows and preferred to parse are marked by dashed arrows

Afterwards the data is stored in a database to enable intuitive access. Separate process is designed for readout from this database if data were obtained and their age is valid.

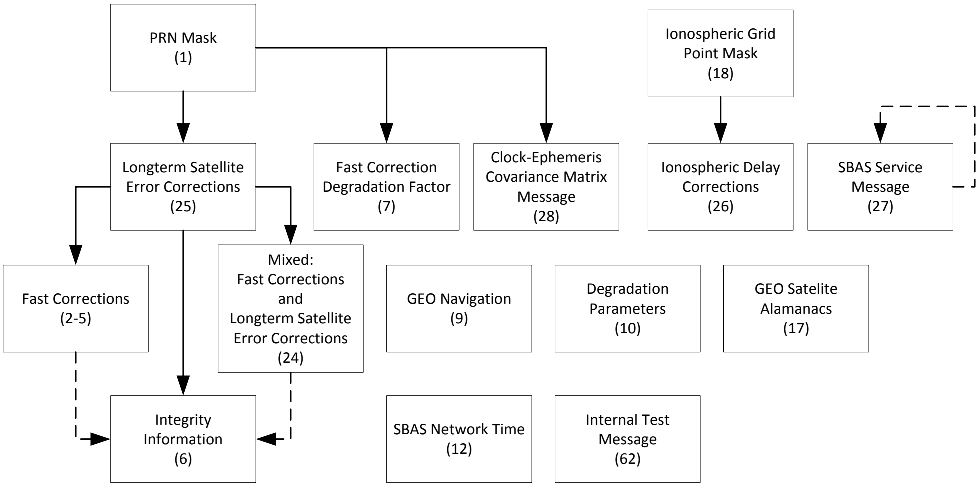

Figure 2. Messages and relationship between message types in EGNOS. Source: CRC24, 2016.

A dedicated program “parser_egnos” was written in C# to extract specific data from “.ems” files on the .Net platform 4.5. Classes grouping the related data were designed to store individual data series. Fig. 3 shows the relationship between these classes.

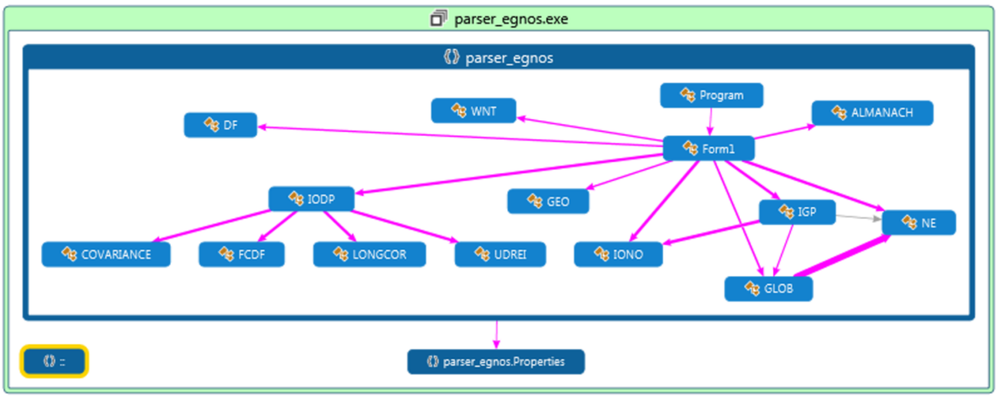

Figure 3. The code map of “parser_egnos”. Source: Authors.

4. ARCHITECTURE OF MEASURING EQUIPMENT

Contemporary GNSS receivers are able to send the raw and processed measurement data by network, serial connection or directly to local storage like an SD card. The standard industry connection via COM port to logging computer was selected in the examined system. An application recording messages in NMEA0183 format was written in C#. This application was additionally designed to send the log file to the predefined e-mail address enabling external saving of the resultant data every midnight. Two frequently used WAAS/EGNOS/MSAS capable GPS marine receivers were preliminary chosen for the research: 6-channel Leica MK10 and the 12-channel Garmin 2010C. Finally, after comparison of the number of satellites with integrity data in SISNeT ".ems" files, the Garmin 2010C (Fig. 4) was selected for logging, due to the higher number of tracked satellites which were also present in the ".ems" files (10 to 11). A program written in C#, to extract specific data from ".ems" EGNOS files, was modified to extract only data necessary to calculations related to present antenna's position.

Figure 4. The Garmin 2010C EGNOS capable GPS receiver. Source: Garmin Ltd.

5. MEASUREMENT RESULTS

The position error estimated from logged positions was calculated as a difference between each obtained position and the average of all obtained positions, which was treated as a reference (the Vincenty's formulae were used to calculate the distance between these two points [Vincenty, 1975]). Integrity parameters were assembled from the SISNeT database for the corresponding period. The results of the comparison between:

- errors estimated from logged EGNOS augmented GPS positions, and
- errors estimated from EGNOS integrity data as HPLs

are presented in the Fig. 5. The methodology of HPL estimation from EGNOS integrity data followed the one presented in [Zalewski et al., 2015].

The input quantities derived from the GNSS and SBAS messages for the integrity algorithm on the user side were:

1) The geometry between GNSS satellites and user derived position from observations of the GNSS satellites (the geometry matrix G of size $n\times4$):

$$G = \begin{bmatrix} -\cos E_1 \sin Az_1 & -\cos E_1 \cos Az_1 & -\sin E_1 & 1 \\ -\cos E_2 \sin Az_2 & -\cos E_2 \cos Az_2 & -\sin E_2 & 1 \\ \ldots & \ldots & \ldots & \ldots \\ -\cos E_n \sin Az_n & -\cos E_n \cos Az_n & -\sin E_n & 1 \end{bmatrix} \quad \ldots(13)$$

where E_i and Az_i are the elevation and azimuth angles between the receiver antenna and the i^{th} satellite (i=1,2,...,n), and n is the number of visible satellites, respectively.

2) The weight matrix W built under assumption of uncorrelated, EGNOS corrected, measurements characterized by the inverse variances σ_i^2 (1) of the distances to the observed satellites:

$$W = \begin{bmatrix} \frac{1}{\sigma_1^2} & 0 & \ldots & 0 \\ 0 & \frac{1}{\sigma_2^2} & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \ldots & \frac{1}{\sigma_n^2} \end{bmatrix} \quad \ldots(14)$$

Based on (13) and (14) the covariance matrix was found:

$$\begin{bmatrix} s_E^2 & s_{EN} & s_{EU} & s_{ET} \\ s_{EN} & s_N^2 & s_{NU} & s_{NT} \\ s_{EU} & s_{NU} & s_U^2 & s_{UT} \\ s_{ET} & s_{NT} & s_{UT} & s_T^2 \end{bmatrix} = \left(G^T WG\right)^{-1} \qquad \text{…(15)}$$

where:

s^2_E is the variance of the receiver's antenna Easting measurement in the local reference frame centered on the GNSS antenna (East, North, Up, ENU) [m^2];

s^2_N is the variance of the receiver's antenna Northing measurement in the local reference frame (ENU) [m^2];

s^2_U is the variance of the receiver's antenna vertical measurement [m^2];

s^2_T is the variance of the receiver's time correction measurement multiplied by the speed of light [m^2]; and, finally, the mixed terms (e.g. s_{EN} etc.) are the co-variances of the respective measurements [m^2].

And finally the circular assessment of the point positioning integrity on the user side was calculated as a length of the protection circle radius, named horizontal protection level (HPL):

$$HPL = k\sqrt{\frac{s_E^2 + s_N^2}{2} + \sqrt{\left(\frac{s_E^2 - s_N^2}{2}\right)^2 + s_{EN}^2}} \qquad \text{…(16)}$$

where k is a coverage factor coming from the assumption of uncertainty's normal distribution in both the North and the East directions of position coordinates.

For further analysis the measurements were grouped into 12 classes of HPL with step of 0.1m. The Fig. 5 presents the dependence of errors estimated from logged EGNOS augmented GPS positions and HPLs calculated from the EGNOS integrity data with k =1. There is a significant correlation between these two visible as a rising trend in the Fig. 5.

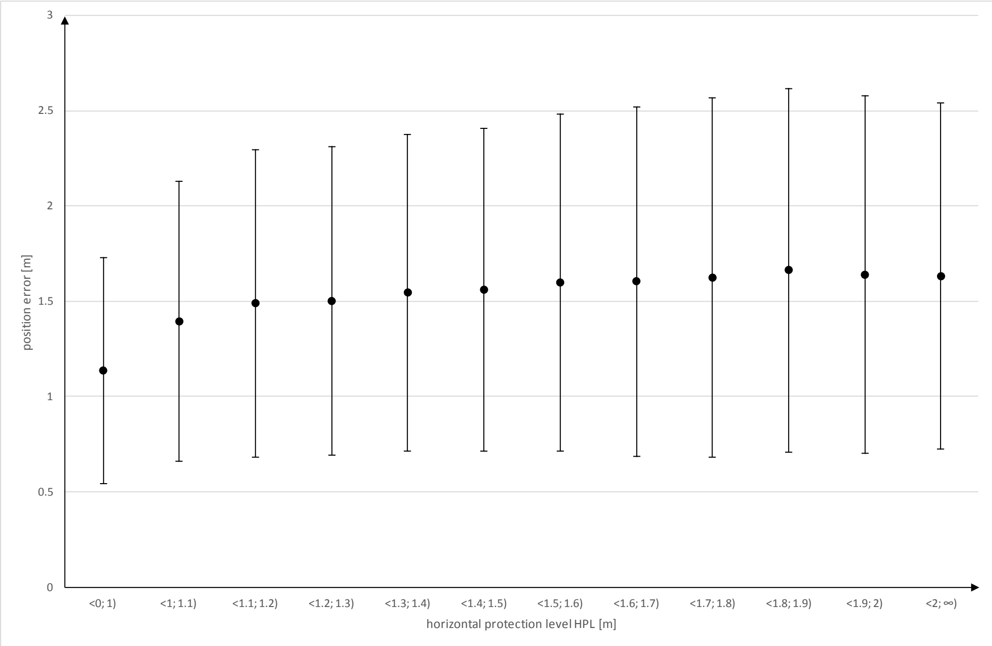

Figure 5. Dependency between HPL and estimated position error. Source: Authors.

CONCLUSIONS

GNSS measurements can be supplemented by the information available in EGNOS system even if one has only GNSS receiver that is not processing SBAS (Satellite-Based Augmentation Systems) data. The HPLs estimation follows quite closely the statistical estimation of position error even if one does not use high accuracy reference like geodetic survey or RTK. This allows for assumption that the usage of live EGNOS signals, implementation of tropospheric and marine receiver error estimation and finally the geodetic reference should improve the correlation between EGNOS HPL and real error even further. Such research will follow, but even these preliminary results presented in the paper lead to conclusions that usage of EGNOS integrity data in marine environment is quite promising and useful.

REFERENCES

[1] CRC24, http://ask.okbase.net/topic/2014010716_13100_390688008.htm, Accessed: 17 July 2016.

[2] RTCA, Inc. SC-159, RTCA DO-229D Minimum Operational Performance Standards (MOPS) for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment, 2006, Change 1, 2013.

[3] SISNeT, http://www.egnos-pro.esa.int/sisnet/, Accessed: 17 July 2016.

[4] Vincenty, T. Direct and Inverse Solutions of Geodesics on the Ellipsoid with application of nested equations. Survey Review. XXIII (misprinted as XXII) (176): 88–93, April 1975.

[5] Zalewski P., Gucma L., Born A., Urbańska K., Schlueter S., Born A., Poretta M. Assumptions of Full Mission Ship Bridge Simulation Including EGNOS. Conference Proceedings of 2015 International Association of Institutes of Navigation World Congress, Prague, Czech Republic, 20–23 October 2015.

Received November 2016
Reviewed June 2018
Accepted July 2018

MATEUSZ BILEWSKI
Maritime University of Szczecin
Wały Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: m.bilewski@am.szczecin.pl

PAWEŁ ZALEWSKI
Maritime University of Szczecin
Wały Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: p.zalewski@am.szczecin.pl

STRESZCZENIE

Pomiary GNSS mogą być wspomagane informacją dostępną w systemie EGNOS nawet, gdy wykorzystuje się odbiornik GNSS, który nie jest zdolny do przetwarzania danych z system SBAS. W artykule opisano, w jaki sposób można uzyskać informację o wariancji pomierzonych odległości do satelitów, jeśli znane są pozycja anteny oraz azymuty i wysokości satelitów ponad horyzontem. Dla zweryfikowania, w jakim stosunku pozostają estymowane błędy pozycji względem rzeczywistych błędów przedstawiono wyniki badań przeprowadzonych z użyciem odbiornika GPS.