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Availability of the GNSS Geodetic Networks Position during the Hydrographic Surveys in the Ports

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ABSTRACT: Geodetic network GNSS receivers are more commonly associated with positioning systems used in maritime hydrography. In terms of positioning accuracy when no terrain obstacles are present, they meet international hydrographic surveys standards (S-44) fully. Those standards are defined as 1m (0.95) for Exclusive Order and 2m (0.95) for Special Order. It is equally as important to ensure access to position which error is not higher than above mentioned maximum values. This is most often determined by the density of port infrastructure.

This article presents the results of analysis of availability of hydrographic system that operates based on geodetic GNSS networks. Hydrographic surveys in question were undertaken in inner basins with diverse infrastructure. Three representative types of ports were selected for this reason: fishing type (Hel), medium sized, modern commercial type (Gdynia) and highly congested, narrow canal type (Gdansk – Motlawa). A non-public, geodetic GNSS network was used for all surveys. It is worth mentioning that the above network is at the moment the only available network that provides both GPS and GLONASS corrections.

The surveys provided evidence that geodetic GNSS networks can be successfully utilised to determine position of hydrographic vessel in low and moderately developed ports as well as in Exclusive and Special Orders. In highly congested ports however, the availability of the above mentioned method of measurement can be insufficient to realise a survey.

1 INTRODUCTION

Document IHO S-44 [IHO 2008] determines strict minimum standards for hydrographic surveys for special order for harbours, berthing areas, and associated critical channels with minimum under-keel clearances. Also Canadian Hydrographic Service [CHS 2003] determined an additional standard for hydrographic surveys: exclusive one for shallow water in harbours, berthing areas, and associated critical channels with minimum under-keel clearances. Horizontal accuracy (95% confidence level) is [IHO 2008, CHS 2003, MoD 2018] 1m for Exclusive Order and 2m for Special Order. It should be emphasized that the reliability of bathymetric data is an important element of the e-Navigation concept developed today in the maritime navigation [Weintrit A., 2018; Urbański J. et al. 2008], especially in the ECDIS [Weintrit, A. 2009].

Although there are other local [Kelner J. et al. 2016; Sadowski J., Stefański J., 2017] or long range [Czaplewski K., 2018] positioning system solutions available on the sea other than GNSS, but maritime DGPS is the main system that is used in hydrography due to its range (100-200 km), accuracy 1-2m (p=0.95) [Dziewicki M., Specht C. 2009] and integrity. It can be used for positioning in Special Order areas. For

Exclusive one it is insufficient and e.g. real time geodetic network should be used instead [Specht C. et al 2017].

It should be noted that availability of precise, actualised seabed data is crucial for maritime safety [Neumann T. 2018], especially for dangerous cargo [Guze et. al. 2017].

The main issue for measurements utilising GNSS is the availability of satellite signal in urbanised areas. Bathymetric surveys undertaken in port basins, the following factors determine the accuracy of measurement: the type and height of port infrastructure, its density and number of satellite systems used by the geodetic GNSS receiver [Czaplewski K., Goward D. 2016].

In order to determine the influence of density of port infrastructure on availability of selected value of positioning error of the geodetic GNSS receiver, a percentage of time when its measurements meet all conditions of Exclusive order (1m) and Special Order (2m) was defined.

Three representative types of basins were used as described in Fig. 1, 2 and 3.

Figure 1. Hydrographic vessel's trajectory in fishing port (Hel)

Figure 2. Hydrographic vessel's trajectory in medium sized, modern commercial port (Gdynia)

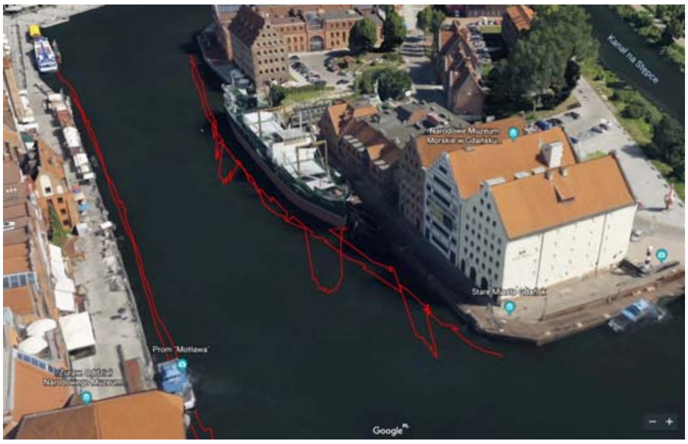

Figure 3. Hydrographic vessel's trajectory in highly congested, narrow canal area (Gdansk – Motlawa)

2 MODEL OF THE AVAILABILITY OF THE CERTAIN VALUE OF POSITION ERROR

The new approach which joins the accuracy and one of the reliability criterions is the term – availability of the certain value of position error. Let's define the availability of certain value of position error – as a probability that in any moment of time (t) the position error of determining coordinates (δ_n) is lower or equal then the arbitrary acceptable value (U), which mean than $\delta_n \leq U$, $n = 1,2,...$ (Fig. 4.). The suggested approach treats the lifetimes and the times of failure as the random variables being in relation in the fixed value of the position error and also it introduces the measures which making the reliability estimation possible.

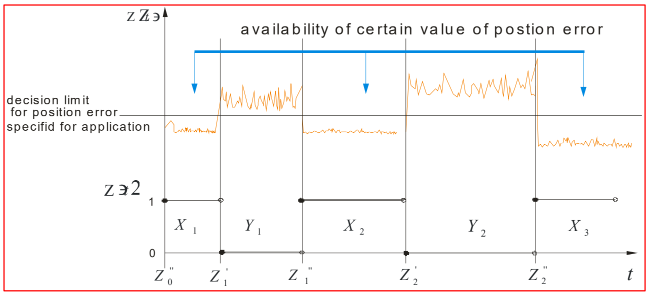

Figure 4. Idea of availability of the certain value of position error.

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 $\alpha(t)$ be the binary interpretation of the reliability state of the process as:

$$\alpha(t) = \begin{cases} 1, & Z_n^{"} \leq t < Z_{n+1}^{'} \\ 0, & Z_{n+1}^{'} \leq t < Z_{n+1}^{"} \end{cases} \quad \text{for} \quad n = 0,1,... \tag{1}$$

The state $\alpha(t) = 1$ 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.

Then we can recognize two states: the working one – the state where the error $\delta_n \leq U$ for $n = 1,2,...$

and the state of failure where $\delta_n > U$. Let $X_1, X_2,...$ be the working times while $Y_1, Y_2,...$ are the times of failures. Hence the moments: $Z'_n = X_1 + Y_1 + X_2 + Y_2 + ... + Y_{n-1} + X_n$, $n = 1,2,...,$ are the moments of failures and $Z''_n = Z'_n + Y_n$, are the moments of renewal. Assume also that the random variables X_i, Y_i, $i = 1,2,...$ are independent and the working failure times have the same distributions.

Let's define the analytical form of the distributions of the variables X_n and Y_n as

$$P(X_i \le x) = F(y), \tag{2}$$

$$P(Y_i \le y) = G(y) \quad \text{for} \quad i = 1,2,..., \tag{3}$$

where: $F(x)$, $G(y)$ means the distribution functions of X_n and Y_n.

Then the availability of a certain value of position error will be denoted as [Specht C., 2003]

$$D(t) = P[\delta(t) \le U]. \tag{4}$$

According to [Specht C. 2003] final form for availability of the certain value of position error as follows

$$D(t) = 1 - F(t) + \int_0^t [1 - F(t - x)] dH_\Phi(x), \tag{5}$$

where

$$H_\Phi(x) = \sum_{n=1}^{\infty} \Phi_n(x) \tag{6}$$

is a renewal function of stream made of the renewal moments.

Typical realizations of the operating time in navigational systems are characterized by the exponential distributions of the lifetime and the time of failures due to the property called the "memoryless" property. Let define the exponential process where the distribution functions as

$$F(t) = \begin{cases} 1 - e^{-\lambda t} & \text{for} \quad t > 0 \\ 0 & \text{for} \quad t \le 0 \end{cases}, \tag{7}$$

$$G(t) = \begin{cases} 1 - e^{-\mu t} & \text{for} \quad t > 0 \\ 0 & \text{for} \quad t \le 0 \end{cases}, \tag{8}$$

where λ, μ are failure and renewal rates.

$$\begin{aligned} D_{\exp}(t) &= 1 - F(t) + \int_0^t [1 - F(t - x)] dH_\Phi(x) = \\ &= e^{-\lambda t} + \int_0^t \left[1 - \left(1 - e^{-\lambda(t-x)}\right)\right] dH_\Phi(x), \end{aligned} \tag{9}$$

where $D_{\exp}(t)$ denotes the availability of the certain value of position error in the navigational system in the case of the exponential life and failure times distributions. After few simple transformations [Specht C., 2003] finally form could be find as

$$D_{\exp}(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-(\lambda + \mu)t} \tag{10}$$

and availability factor (limiting value) of certain value of position error - $A_{\exp}$ can be calculated as

$$A_{\exp} = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda} + \frac{1}{\mu}} = \frac{\mu}{\mu + \lambda}. \tag{11}$$

3 EXPERIMENT

Dual frequency phase receiver working in real time in GNSS geodetic TPI NETpro network was tested on board a hydrographic motorboat Homar-1 during sonar surveys (Gdynia, President's Basin) and bathymetric one (Hel, the harbour). The motorboat was equipped with an interferometric echosounder and a towed sonar. For dynamic tests geodetic satellite receiver Topcon HyPer II with 10 Hz positioning frequency has been used. The data, recorded in Sokkia SHC25 controller, has been postprocessed in TopconLink application, which allows to select geometrical rates HDOP, VDOP and accuracy one: horizontal and vertical precisions. The receiver's antenna has been located on board the motorboat, which have not influenced on satellites visibility or covering upper hemisphere [Makar, 2018a,b].

The TPI NETpro GNSS network provides 5 types of fixes (DGNSS, NET RTCM 2.3, NET RTCM 3.0, RTK RTCM 2.3 and RTK RTCM 3.0) that differ in generation mode and obtained accuracy. Irrespective of the type of fixes, before the measurements are taken, the network user connects to a control center called the NTRIP server and sends one's approximate position using the NMEA GGA message. For the NET RTCM 2.3 or 3.0 correction, the system generates a virtual reference station for it, usually within 5 km of the receiver, pointing towards the nearest actual reference station [Specht C. Specht M 2018].

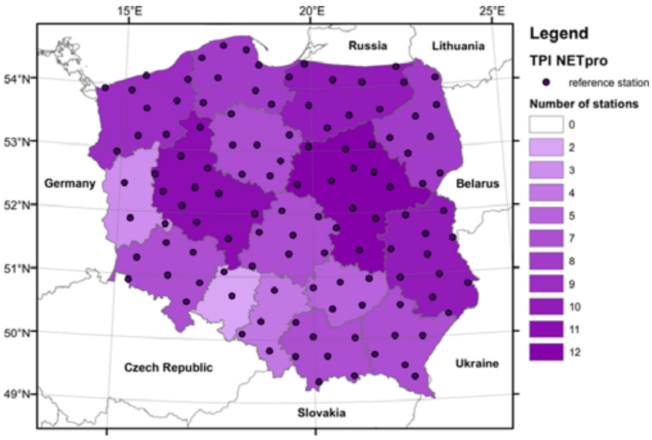

Figure 2. TPI NETpro GNSS geodetic network.

4 RESULTS

Surveys recorded the following number of points: Gdynia– 19023 points, Hel – 30116 points and Gdansk – 2353 points. The above were analised based on relationships presented in chapter 2. The calculations utilised data registered by GNSS receivers and Mathcad 15. The benchmark of positioning error has been assumed as its horizontal orientation, essential during hydrographic surveys. Collective results of the analyses of position's availability with defined positioning error (1cm, 2cm, 5cm, 10cm, 1m, 2m) are presented in Tab 1.

Table 1. Availability factors for positioning errors: 1cm, 2cm, 5cm, 10cm, 1m, 2m – Gdańsk, Gdynia and Hel ports

Port	Availability factors [%]					
	1 cm	2 cm	5 cm	10 cm	1 m	2 m
Gdansk	8.23	74.41	82.81	82,95	83.12	88.74
Gdynia	47.04	97.10	98.37	98.80	99.34	99.81
Hel	64.69	85.67	100 %	100 %	100 %	100 %

Figures below present examples of functions and availability factors for positioning error defined as 10cm, 1m, 2m – determined for measurements in Gdynia.

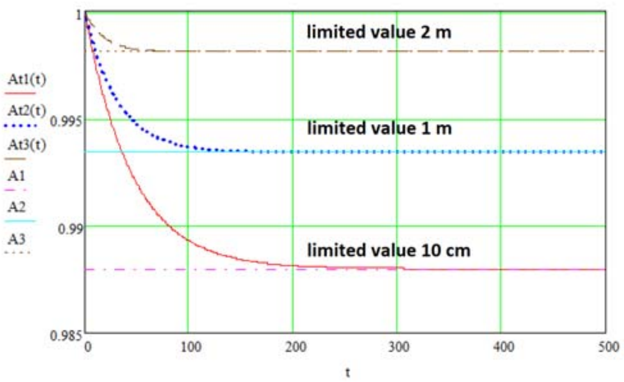

Figure 3. Examples of availability functions and availability factors for positioning error defined as 10cm, 1m, 2m – determined for measurements in Gdynia

5 CONCLUSIONS

This article presents the mathematical model of availability of certain values of positioning error calculations.

Hydroacoustic surveys realised in both Gdynia and Hel ports indicated that Geodetic GNSS networks can successfully be used in maritime hydrographic surveys in port areas. They also proved high availability of positions, exceeding 95%, which in turn proves that the methodology in question can be used for positioning in maritime hydrography. It can be observed, that terrain obstacles in Port of Gdynia did not have meaningful influence on decrease of accuracy of determining position. The main limitation of geodetic GNSS networks is the coverage of mobile networks.

Gdańsk case is an exception as measurements were undertaken in close vicinity to high density infrastructure and vessels moored to the bearth. The research proved, that in order to achieve positions availability of 1m and 2m error values requires additional planning of observations campaign that minimises the value of DOP coefficients.

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