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BOOK of EXTENDED ABSTRACTS

15th Baška GNSS Conference:
Technologies, Techniques and Applications Across PNT

and

The 2nd Workshop on
Smart, Blue and Green Maritime Technologies

Under the High Auspicies of

Baška, Krk Island, Croatia

8 – 13 May 2022

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AN IMPROVED ROBUST CKF FILTERING ALGORITHM FOR GNSS/INS INTEGRATED NAVIGATION

Hao Wang, Shuguo Pan*

Abstract. *The GNSS signal received by the dynamic vehicle in the urban environment will be frequently interfered and blocked, which generates gross error affecting the positioning accuracy in the GNSS/INS integrated navigation seriously. So, this paper introduced a method for GNSS integer ambiguity resolution with INS-aided and proposed an improved robust CKF algorithm based on singular value decomposition. The algorithm overcomes the non-positive definite change of the prior covariance matrix and realizes intelligent selection of robust strategies by judging the ill-conditioned matrix. The experiment has proved that the algorithm can effectively suppress the error divergence and provide more accurate positioning results.*

Key words: *cubature kalman filter; GNSS/INS integrated navigation; robust algorithm*

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1 INTRODUCTION

GNSS/INS integrated navigation has been widely applied in high-precision positioning fields such as vehicle navigation, mobile mapping systems, aerial photogrammetry [1], and the tightly coupled strategy can provide positioning despite the lack of visible satellites [2-4]. Due to the complex observation environment, the multipath effect and gross error are crucial factors restricting the positioning performance of GNSS [5-7]. So, this paper constructed robust ambiguity resolution model for GNSS/INS tightly coupled system to overcome the outliers.

2 METHODOLOGY

The flow of the algorithm proposed in this paper is shown in **Figure 1**.

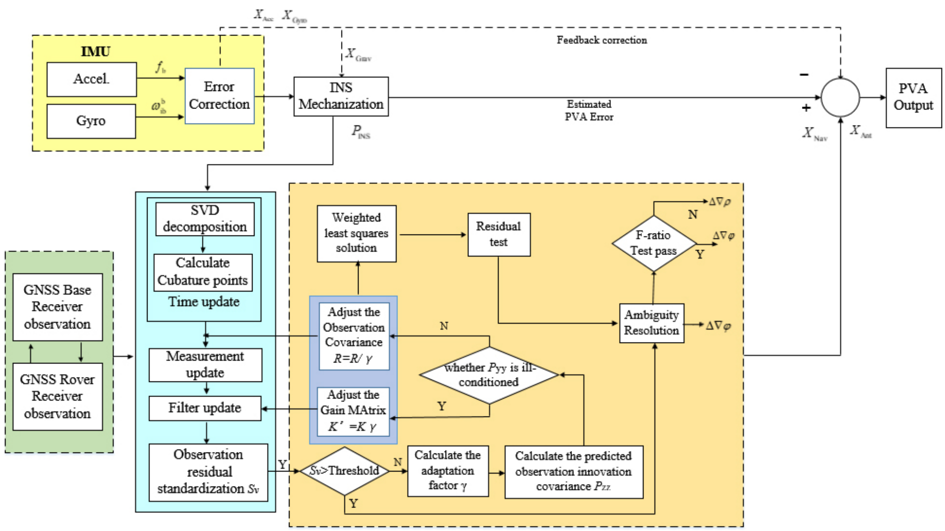

Figure 1. The flow of the improved robust CKF filtering algorithm.

We use SVD-CKF for filtering process and calculate the standardized residual. If the normalized residual is greater than the threshold, the observation is considered to be abnormal. In addition, if $cond(\bar{P}_{zz}) \geq 10$, then it can confirm that $\bar{P}_{zz}$ is ill-conditioned.

$$\bar{P}_{zz} = \sum_{i=0}^{2m} w_i^c \left(Z_{i,k|k-1} - \hat{Z}_k\right)\left(Z_{i,k|k-1} - Z_k\right)^T + R_k / r_k \tag{1}$$

$$\bar{K}_k = \begin{cases} P_{xz}\bar{P}_{zz}^{-1}, & cond\left(\bar{P}_{zz}\right) < 10^{15} \\ K_k r_k, & cond\left(\bar{P}_{zz}\right) \geq 10^{15} \end{cases} \tag{2}$$

3 RESULTS AND DISCUSSION

To verify the effectiveness of the improved robust algorithm, four kinds of observation outliers were artificially added to the observation data: single-point outliers in position, continuously increasing outliers in velocity, continuously random outliers in position and velocity, and mixed continuously random outliers in position and velocity.

Figure 2 shows the error comparison results based on the SVD-CKF algorithm and the improved robust SVD-CKF algorithm in position and velocity after adding four types of outliers.

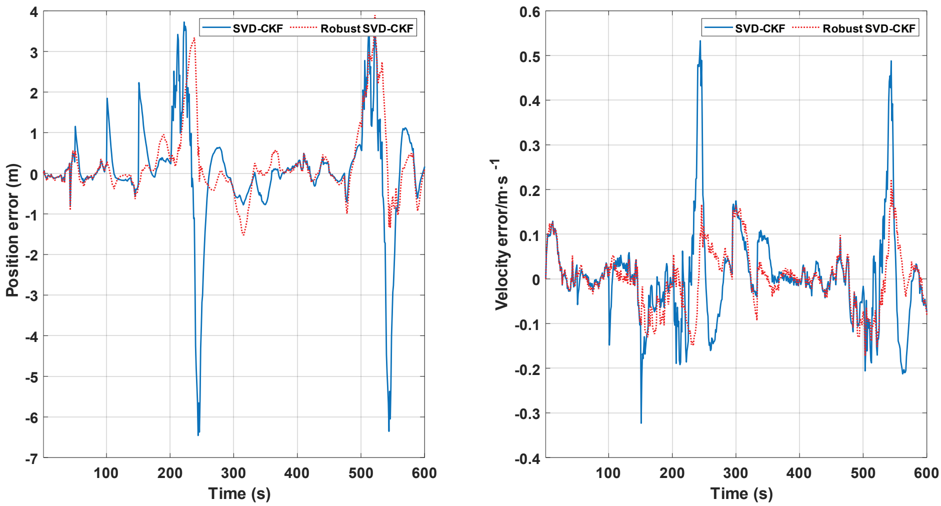

Figure 2. Error comparison results based on the two algorithms.

It can be evidently seen from **Figure 1** that the observation outliers have a greater impact on the unresilient results, while less impact on the improved robust algorithm. However, the robust results fluctuate to a certain extent at 200-250 s, 301-350 s and 500-550 s, which is due to the continuous unavailability of GNSS observation information caused by the continuous outliers at these times, resulting in the short-term drift error of the integrated navigation solution with the INS.

4 CONCLUSION

This paper constructed a CKF model based on SVD, which can suppress the non-positive definite change of the prior covariance matrix and improve the numerical stability. Combining a variety of robust strategies, the robust factor is applied to the SVD-CKF algorithm that can better reduce the disturbance effect of outliers on the GNSS/INS tightly coupled system positioning. This paper has given the corresponding calculation steps and test the positioning accuracy and robust effect of the improved algorithm by the actual measurement data.

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ANALYSIS OF TRANSFORMATION METHODS OF HYDROACOUSTIC AND OPTOELECTRONIC DATA OBTAINED USING GNSS RTK, TLS, UAV AND USV BASED ON THE TOMBOLO MEASUREMENT CAMPAIGN IN SOPOT

Oktawia Lewicka[*1], Mariusz Specht[2], Andrzej Stateczny[3], Cezary Specht[1], Czesław Dyrcz[4], Paweł Dąbrowski[1], Bartosz Szostak[3], Armin Halicki[2], Marcin Stateczny[2], Szymon Widźgowski[2]

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Abstract. *Measurements in the coastal zone are carried out using various methods, including Global Navigation Satellite Systems (GNSS), hydroacoustic and optoelectronic methods. Therefore, it is necessary to develop coordinate transformation models that will enable the conversion of data from the land and marine parts to one coordinate system. The article presents selected issues related to the integration of geodetic and hydrographic data. The aim of this publication is to present the various transformation methods and their effects that relate to the data from the tombolo measurement campaign in Sopot conducted in 2019.*

Key words: *data integration: hydroacoustic methods; optoelectronic methods; tombolo; Unmanned Aerial Vehicle (UAV); Unmanned Surface Vehicle (USV)*

1 INTRODUCTION

Undoubtedly the coordinate transformation is one of the computational tasks frequently occurring in the preparation of charts. Currently, the coordinate transformation is carried out using softwares such as: ArcGIS, CloudCompare and VDatum [1]. A coordinate transformation software made the process of data processing easier. However, they are limited by the availability of transformation methods and their possibility of modification.

2 METHODOLOGY

The article presents the transformation model of ellipsoidal coordinates into the Universal Transverse Mercator (UTM) coordinate system and two models of the 7-parameter transformation [2]. The target coordinate systems of all transformations were the Polish UTM plane system (PL-UTM) [3] and the Polish Kronstadt height system (PL-KRON86-NH).

The transformation methods and their effects that relate to the data from the tombolo measurement campaign in Sopot were conducted in 2019 [4–5]. Mathematical models have been verified for data obtained using GNSS Real Time Kinematic (RTK) measurements and Terrestrial Laser Scanning (TLS). Moreover, the models were validated by determining the standard deviation and the maximum difference of the modelled coordinates in relation to the reference coordinates (GNSS RTK).

3 RESULTS AND DISCUSSION

As a result of the accuracy analysis, it was obtained that the standard deviations of the differences between the coordinates modelled by Dąbrowski's method in relation to the reference coordinates amounted to easting, northing and height coordinates of 0.022 m, 0.040 m and 0.019 m, respectively. On the other hand, the standard deviations of the differences between the coordinates modelled by the adjustment calculus method in relation to the reference coordinates amounted to easting, northing and height coordinates of 0.009 m, 0.005 m and 0.359 m, respectively.

4 CONCLUSIONS

On the basis of the coordinate transformation methods used, it can be concluded that the adjustment calculus method obtained the best results for plane coordinates, while Dąbrowski's method obtained the best results for height coordinates. It can be assumed that the combination of these two methods of the 7-parameter transformation would give the best results. The authors plan to conduct a new measurement campaign with the use of hydroacoustic and optoelectronic systems in the future. Additionally, they are considering developing a new 7-parameter transformation method based on the synthesis of the two that have already been created.

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CURRENT AND FUTURE EGNOS PERFORMANCE STATUS IN ALGERIA

Lahouaria Tabti*[1], Salem Kahlouche[1], Belkacem Benadda[2]

Abstract. *The preliminary results of EGNOS performance in terms of precision and integrity at two sites were presented, the first is inside EGNOS service coverage in Oran and the second in Adrar is close to the border of its coverage. The results reveal that using EGNOS correction enables the improvement of precision and confirms that the integrity of APV I approach is assuring at the first site. While the integrity in Adrar was not guaranteed. Improving coverage of EGNOS system by simulation of feasibility study by setting-up of two RIMS stations in Algeria is also analysed in the second part. The results show that the performance of EGNOS in terms of availability is improved, particularly in the area between 0° and 5° in longitude and 25° in latitude. The simulation also shows that setting up of two RIMS stations will enable a good exploitation of EGNOS in Algeria for civil aviation.*

Key words: *availability; EGNOS; GPS; integrity; precision; RIMS station*

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1 INTRODUCTION

Satellite Based Augmentation System (SBAS) is a wide area differential system used to improve positioning [1] and overcome the deficiencies of GPS in terms of accuracy and integrity in real time. SBAS uses reference stations distributed over a wide region to collect raw GPS observations, elaborate corrections and broadcast to users through geostationary satellites [2]. The principal aim of this work is an experimental study of the quality of EGNOS performance (Oran and Adrar in particular) and simulation results of adding tow RIMS stations in Algeria.

2 METHODOLOGY

The real GPS data were recorded with a Trimble Net R9 geodetic receiver, which is located at two sites in July 2019 (Oran and Adrar). Analysis of the positioning performance was calculated using gLAB software [3]. During calculations, corrective EGNOS data were downloaded from the CNES site. The purpose of second section is to analyse the simulation availability of EGNOS. For that purpose, two areas have been defined to evaluate the performance of EGNOS; Oran as an operational site in latitude 35°, and three sites located between latitudes 27° and 30°. To determine the availability, we used the SBAS simulator software developed by the European Space Agency (ESA).

3 RESULTS AND DISCUSSION

The results confirm that, for Oran, EGNOS corrections offers better accuracy than GPS alone [4]. While this precision degrades in Adrar; EGNOS horizontal and vertical errors are 2.50 m and 5.56 m (95%), however, in GPS alone, horizontal error is 2.09 m and vertical is 4.22 m, which is probably due to the number of satellites excluded from the solution. The performance of EGNOS in term of integrity is also studying for these two sites; **Figures 1** and **2** present the results of integrity.

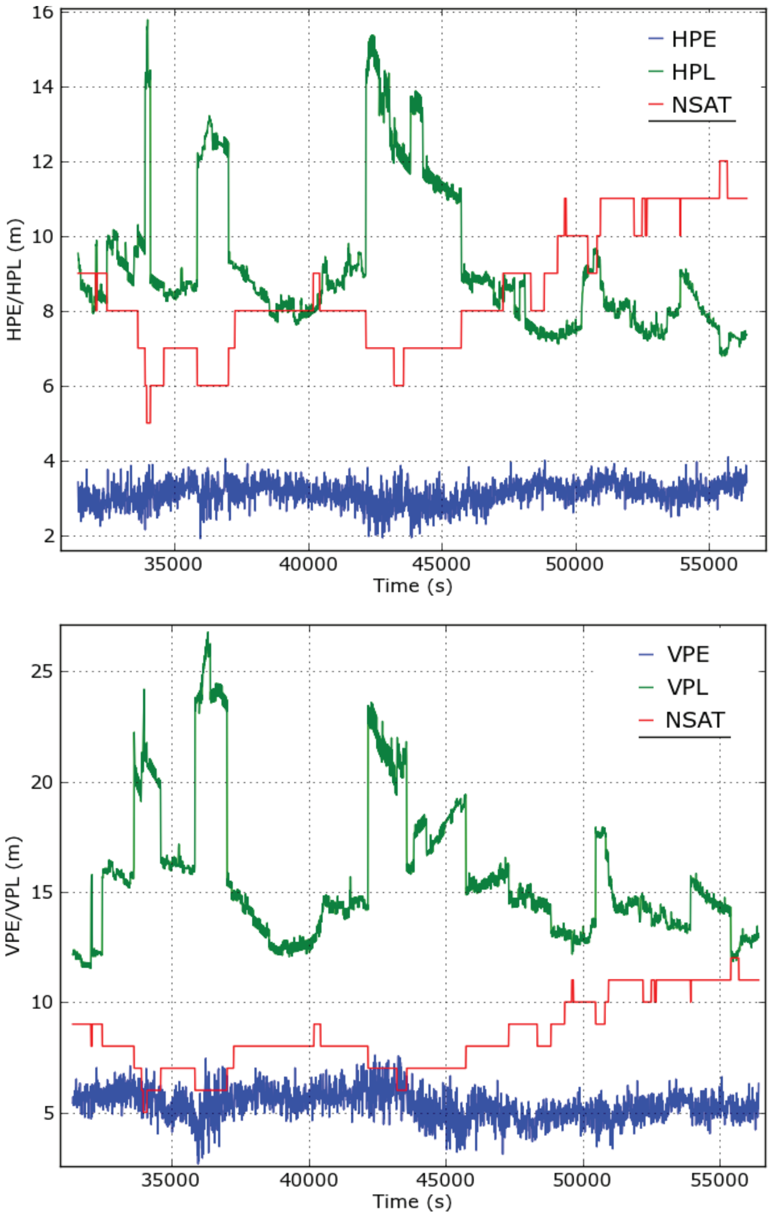

Figure 1. Position Errors (blue), protection levels (green), number of satellites used in solution (red) at Oran site.

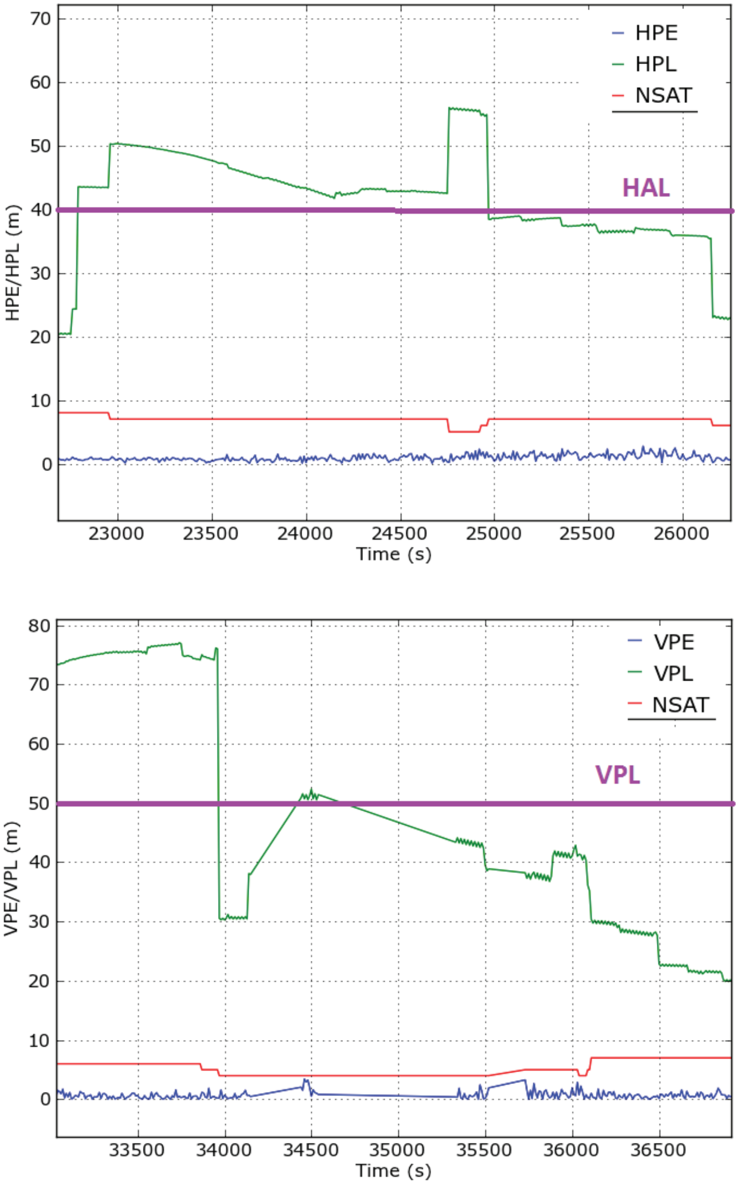

Figure 2. Position Errors (bleu), protection levels (green), against Alarm limit (purple) and number of satellites used in solution (red) at Adrar site.

In Oran, the position error is delimited by the protection level, which is lower than the alarm limit (HAL=40 m and VAL=50 m) [5]. Consequently, the system is available and integrity is ensured. For Adrar site, the position error is limited by the protection level; however the protection level is not always below the alarm limit. Therefore, the requirements of APV I approach cannot be reached, the integrity is not guaranteed and the system is considered as unavailable. The results can be certainly improving if RIMS stations will be set up in Algeria [6].

To investigate the consistency of the results, we analysed the availability of EGNOS by simulation of considering two RIMS stations in Algeria. EGNOS availability is calculated by the percentage of time when protection level is below their alarm limit. **Tables 1** and **2** provide simulation availability of two sites in Algeria for latitudes 25, 30 and 35 degrees and longitude [0° 5°].

Table 1. Horizontal availability (HPL<HAL=40 m) with 39 RIMS stations including Oran and a chosen site in %.

Sites	**ϕ : Latitude**		
	25°	**30°**	**35°**
39 stations	5.86	62.40	90.60
39 stations + Oran + Ghardaïa	48.60	96.15	100
39 stations + Oran + Adrar	54.80	99.30	100
39 stations + Oran + In Salah	62.35	100	100

Table 2. Vertical availability (VPL<VAL=50 m) with 39 RIMS stations including Oran and a chosen site in %.

Sites	**ϕ : Latitude**		
	25°	**30°**	**35°**
39 stations	6.55	68.55	98.60
39 stations + Oran + Ghardaïa	60.30	99.65	100
39stations + Oran + Adrar	65.85	99.65	100
39 stations + Oran + In Salah	71.65	99.65	100

The obtained simulation results indicate that the horizontal and vertical availability of EGNOS is improved by including two stations. It is clearly seen that the percentage of time when the best APV I availability is found in the case of Oran + In Salah and Oran + Adrar, particularly in latitude 30° and 35°.

4 CONCLUSION

EGNOS offers navigation performance in terms of accuracy and integrity; this performance degrades progressively with increasing distance from the service area. The paper can be summarised in two sections. Firstly, the accuracy and integrity for Oran and Adrar sites in Algeria are analysed; in the second, simulation of adding these two sites is also carried out. For this study, APV I approach is taken. The major conclusions reached are:

Results of EGNOS performance in Oran site confirmed the accuracy and integrity according to ICAO, which is crucial to aviation applications. Nevertheless, in Adrar site, the horizontal and vertical protection level can reach 60 m and 80 m, which are higher than the horizontal and vertical alarm limit (40 m and 50 m). This is explained by the remoteness of Adrar site from RIMS network.

Adding two RIMS stations in Algeria enables the improvement of the geographical distribution of RIMS network areas. Moreover, they could significantly expand availability performance to well outside the original reference stations.

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ANALYSIS OF THE SAASTAMOINEN TROPOSPHERIC DELAY MODEL AND ITS CONTRIBUTION TO GPS POSITIONING PERFORMANCE: A TROPICAL CYCLONE CASE STUDY

Leon Makaj*, Serdjo Kos, David Brčić, Sanjin Valčić

Abstract. *Global Positioning System (GPS) still represents one of the most widely used satellite navigation systems. However, there are certain shortcomings of the system that could affect the accuracy of the obtained position. One of such shortcomings is the impact of the troposphere on the propagation of the satellite signal, or to be more precise, calculating the tropospheric delay that occurs when the GPS signal passes through the troposphere* [1]. *This paper analyses how tropospheric delay caused by a tropical cyclone affects the GPS positioning performance.*

Key words: *global positioning system; Saastamoinen model; troposphere; tropospheric delay*

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1 INTRODUCTION

Although tropospheric delay impact is smaller than the ionospheric delay, it can reach significant effects during unstable weather conditions. In this paper, the analysis of the tropospheric delay is based on the Saastamoinen model of the tropospheric delay correction. The calculated position deviations are compared for stable weather conditions and weather conditions during a tropical cyclone. All conclusions will apply to above-mentioned cases.

2 METHODOLOGY

The analysis is based on the comparison of the position deviation caused by tropospheric delay for stable weather conditions and conditions during a tropical cyclone with and without applying the Saastamoinen model. The comparison of calculated position deviations represents the accuracy of the Saastamoinen model to calculate tropospheric delay during a tropical cyclone.

For the purpose of the study, the tropical cyclone *Mangkhut* [2] was investigated. The impact of the cyclone was analysed during 10 days (7 – 17 September 2018) at 3 different sites located in the area of the South China Sea. For the same sites, a reference, stable weather period was selected and analysed as well. Position deviations were calculated based on ground-truth data obtained from the *International GNSS Service*. Data were processed using *RTKLIB* [4] open-source software and analysed with use of *R* programming language.

3 RESULTS AND DISCUSSION

Data analyses provided insight into GPS position deviations during stable weather conditions and during a tropical cyclone, respectively. **Table 1** contains only a fraction of the gained insights; however, it provides us with interesting findings. According to the study, the average GPS position deviation was larger during a tropical cyclone than during stable weather and the same can be observed for standard deviation. Furthermore, it can also be noticed that the difference between figures with applied Saastamoinen tropospheric correction model and without any model of tropospheric correction, was not significant.

Table 1. Average positioning deviations and standard deviations of analysed data.

Values in meters		Latitude with Correction	Latitude without Correction	Longitude with Correction	Longitude without Correction	Height with Correction	Height without Correction
Stable Weather Conditions	Avg. Position Deviation	-0.2900	-0.4359	-0.4942	-0.4532	2.0219	-5.4203
Typhoon Mangkhut	Avg. Position Deviation	-0.7083	-0.8631	-0.7974	-0.7508	0.6138	-6.7380
Stable Weather Conditions	Standard Deviation	1.0123	1.0873	0.6499	0.7566	1.8203	2.1939
Typhoon Mangkhut	Standard Deviation	1.3221	1.4124	0.7344	0.8633	2.4954	2.8061

Figure 1 displays correlation values between position deviations and meteorological data during stable weather conditions and Typhoon Mangkhut. Blue indicates positive correlation while red indicates negative correlation. During stable weather, all position deviations indicate a positive correlation with relative humidity. Otherwise, negative correlation can be observed between position deviations and atmospheric pressure. During the typhoon, the correlation between position deviations and relative humidity is almost non-existent. However, a positive correlation is observed between latitude deviations and atmospheric pressure. The correlation between position deviations and temperature values is negative during both stable weather and Typhoon Mangkhut. There are no significant differences between correlation values of modelled and unmodelled positioning solutions. Correlation values provide insights into how changes in the troposphere were affecting GPS positioning accuracy [3]. Based on correlation data, there are indications that changes in atmospheric pressure might have an impact on latitude deviations and therefore with obtained GPS position accuracy.

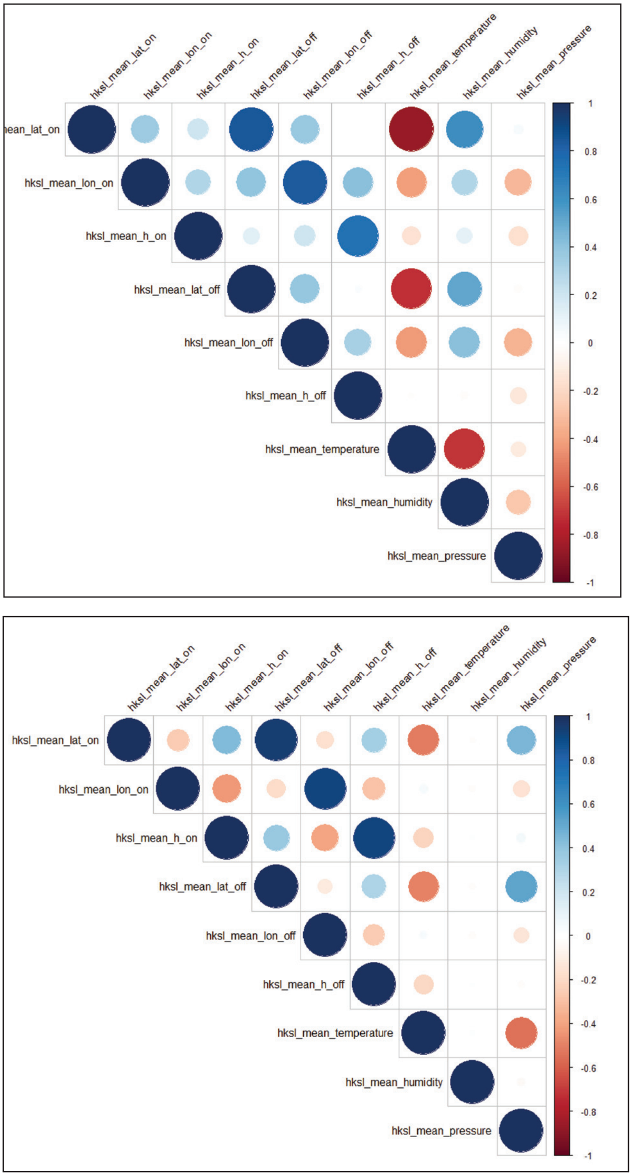

Figure 1. Correlation matrix for IGS HKSL data during stable weather conditions (24 January 2021 – left image) and during the Typhoon Mangkhut (13 September 2018 – right image).

4 CONCLUSIONS

Tropospheric delay can be significant in certain situations. No significant impact on tropospheric delay calculation was noticed when comparing results between stable weather conditions and deviations during the tropical cyclone. This indicates that the Saastamoinen model is unable to adjust in case of each meteorological activity. Even though the analysed tropospheric delay is still less significant than, for instance, the ionospheric delay, a considerable rise in tropospheric delay was observed. The investigation of the tropospheric phenomena, therefore, represents sound grounds for continuing the research.

ACKNOWLEDGMENT

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SIGNAL PATH GEOMETRIES FOR IONOSPHERIC CORRECTIONS IN SINGLE-FREQUENCY SPACE-BORNE GNSS RECEIVERS

Josip Vuković*, Tomislav Kos

Abstract. *Even though the satellites in orbits of different heights are tracked from Earth, for many applications there is a need for precise satellite positioning or timing and therefore, such satellites carry Global Navigation Satellite Systems (GNSS) receivers. Many of those are single-frequency receivers. Signals from the main and side lobes of GNSS satellites, arriving to a satellite-borne receiver from different directions, are used to calculate the position and time. To compensate for the ionospheric error, ionospheric models integrated within GNSS, intended for use on Earth, cannot be applied without modifications. For each GNSS signal arriving to the space-borne receiver, the cross-section of the path within the ionosphere must be determined and the resulting ionospheric error compensated.*

Key words: *corrections; GNSS; ionosphere; orbit; single-frequency*

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1 INTRODUCTION

The ionosphere introduces the largest error in GNSS positioning, especially if the receiver is not situated near the objects that could cause multipath. The ionosphere is situated at heights between 80 km and 2000 km, with peak electron density at 350-400 km. The Klobuchar ionospheric model used in Global Positioning System (GPS) calculates the ionospheric error at the height of 350 km above Earth's surface and presumes that the receiver is situated below that height. The NeQuickG ionospheric model used in Galileo integrates the electron density along the signal path, but it is tested only for zenith-mounted antenna and single cross-ionosphere pass [1].

2 SIGNAL PATH GEOMETRIES FOR DIFFERENT ORBITS

GNSS signals received by satellites in low Earth orbit (LEO) pass only through a fraction of ionosphere if the GNSS antenna is oriented to cover the zenith-direction hemisphere (**Figure 1**). Such antenna orientation is common as the number of GNSS satellites above LEO orbits is sufficient for position fix. In medium Earth orbit (MEO) and highly elliptical orbit (HEO) satellites, both zenith and nadir oriented GNSS antennas are needed because the number of GNSS signals received by the zenith antenna only is not sufficient for continuous position fix. **Figure 2** depicts the arrival of GNSS signals to MEO satellite from various directions. Signal paths either do not cross the ionosphere (GNSS 1 and GNSS 4), partially cross the ionosphere (GNSS 2) or even cross it twice (GNSS 3). For geostationary and geosynchronous orbits all those signal path geometries are also possible [2], while only nadir antenna is used as such satellites orbit at higher altitudes. Single-frequency GNSS receiver used in any of those orbits must be able to determine the cross-section of the signal path and the ionosphere for each satellite and calculate and compensate for the ionospheric error accordingly.

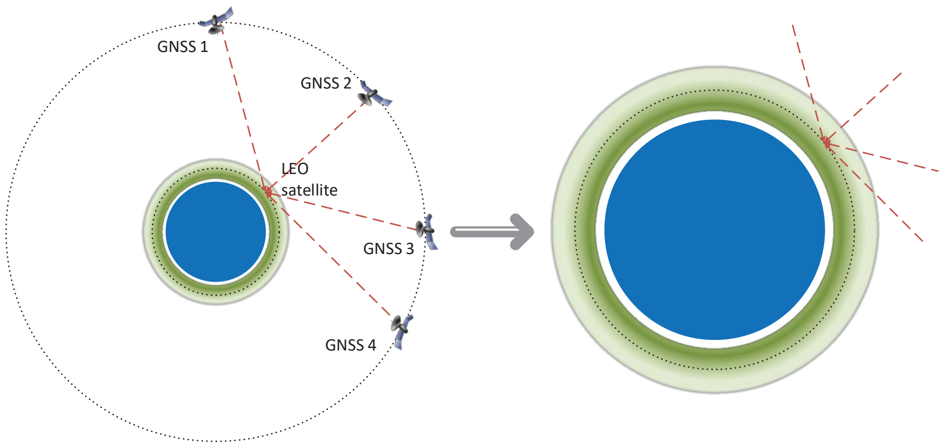

Figure 1. Geometry of ionospheric cross-sections of GNSS signals received by a LEO satellite.

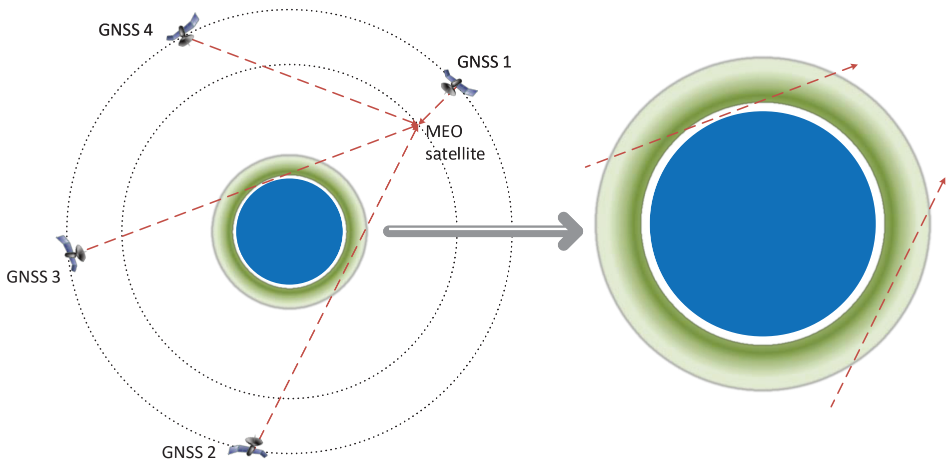

Figure 2. Geometry of ionospheric cross-sections of GNSS signals received by a MEO satellite.

ACKNOWLEDGMENT

This research has been supported by the European Regional Development Fund under the grant KK.01.1.1.01.0009 (DATACROSS).

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ENHANCEMENT OF EGNOS SERVICES IN NORTH AFRICA USING NEW RIMS STATIONS

Beldjilali Bilal

Abstract. *This article presents a preliminary study for the improvement of EGNOS services in North Africa by extending the RIMS network using new proposal stations. Based on the latest version of the EGNOS model, various parameters such as protection levels (PL), navigation system error (NSE), and ionospheric parameters (PPI location, PPI distribution, IGP statistics, GIVE calculation) are analysed for different scenarios starting with a new station to multiple stations to find the ideal number and positions of new stations used to extend the current RIMS network. The results obtained show that three (3) new stations located at (Lat: 22°, Lon: 5°), (Lat: 19°, Lon: 13°), and (Lat: 16°, Lon: -3°) can significantly improve the coverage domain of EGNOS to reach 100% in North Africa.*

Key words: *coverage area; EGNOS; RIMS stations; services enhancement*

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1 INTRODUCTION

As described in [1], North Africa is a good candidate for monitoring the performance of the EGNOS system at the border of its coverage area, more precisely in the southern part of this area. Therefore, this paper, which continues on the previous paper, presents a study for a future extension to improve the performance of EGNOS in North Africa based on the deployment of new monitoring RIMS stations. The results carried out in this paper are based on the model defined for the latest version of EGNOS to selected locations that may be potential sites for monitoring stations [2].

2 METHODOLOGY

The model used in this study contains different Macromodels for each GNSS constellation. In our case, because the study is based on GPS, the Macromodels used are the Sigma and UDRE value in addition to the Ionosphere model. Each satellite residual is expressed as [2]:

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2 + \sigma_{i,RIMS}^2 + \sigma_{system}^2 \quad (1)$$

Where:

$$\sigma_{i,air}^2 = \sigma_{i,noise}^2 + \sigma_{i,clock}^2 + \sigma_{i,orbit}^2 + \sigma_{i,multipath}^2 \quad (2)$$

$\sigma_{i,flt}^2$, $\sigma_{i,UIRE}^2$, $\sigma_{i,tropo}^2$ are the fast and long-term correction, integrity and troposphere residual, $\sigma_{i,RIMS}^2$ is the RIMS network errors, σ_{system}^2 is the GPS constellation errors.

Various parameters and initial conditions for the study are defined. In terms of satellite constellation, this work is based on the GPS constellation. A sufficient number of RIMS stations (3 at least) must monitor each GPS satellite for the whole period of the test or it will be deselected from the final solution. In addition, the elevation of the satellite is taken into consideration, only satellite with an elevation value above the mask (5°), which defines the minimum elevation of the satellite relative to the RIMS position, can be declared as monitored.

The following **Table 1** summarizes the input parameters for this study.

Table 1. Parameters used in the simulation.

Parameter	Value
Constellation	GPS
Elevation mask	5°
RIMS mask	3 stations
Aviation approach	PA
K HPL/VPL [3]	6/5.33
Alarm limit HPL/VPL [3]	40/50

The extension of the EGNOS coverage area was studied for different scenarios, starting with a single new RIMS station and continuing with several scenarios of RIMS sites. The aim of this is to find the ideal positions to ensure total coverage of EGNOS in Algeria and even in the entire North Africa.

3 RESULTS AND DISCUSSION

According to all the simulations carried out in our study, as conclusion, 3 new stations must be added to the network. The optimal locations for the new RIMS stations to ensure a significant extension and improve the theoretical coverage at the southern border are:

Table 2. Location of new RIMS stations.

Site	Latitude	Longitude
Site 1	22°	5°
Site 2	19°	13°
Site 3	16°	-3°

To validate the influence of the new RIMS stations added to the networks on the EGNOS capacity, the variation of many parameters values was analysed; a comparison between the actual statute with 40 RIMS stations and the proposed network with 43 stations is realized. The parameters taken into consideration when choosing any emplacement of new RIMS station are the protection levels which are represented by HPL (horizontal protection level) and VPL (vertical protection level), and the Navigation System Error, which are represented by HNSE (Horizontal Navigation System Error) and VNSE (Vertical Navigation System Error), in addition to the Ionospheric parameters (PPI location, PPI distribution, IGP statistics, GIVE calculation) [4][5].

The results obtained show that the new network provides 100% coverage for all North African countries (Algeria, Morocco, Western Sahara, Tunisia, Libya and Egypt) in addition to 80% coverage for North Mali and Chad.

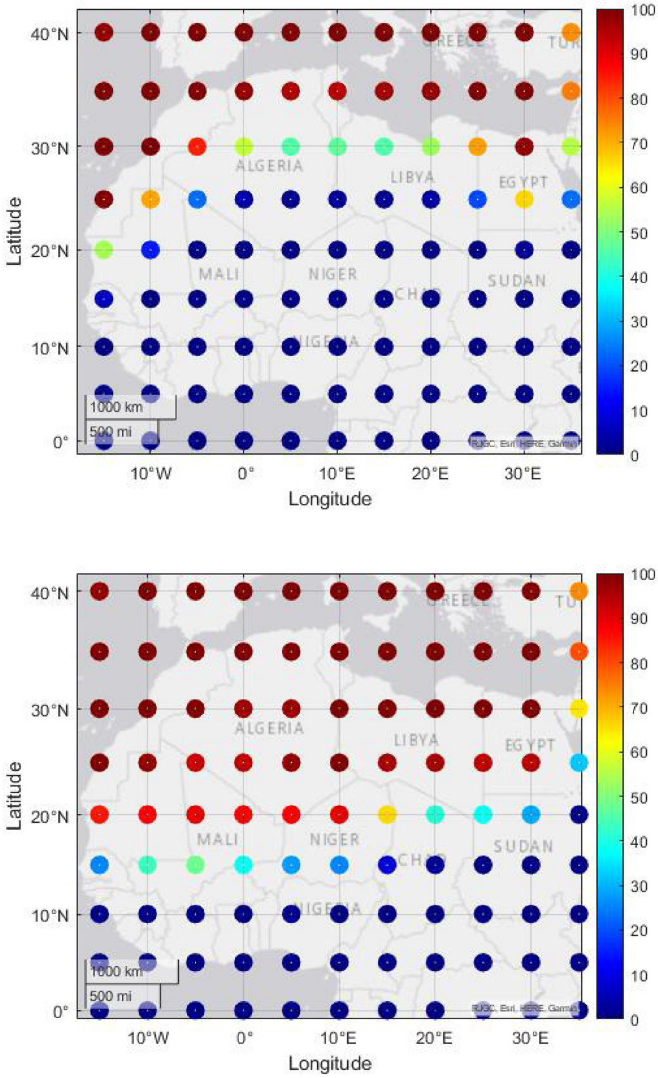

Figure 1. VPL Comparison between actual network (left) and proposed network (right).

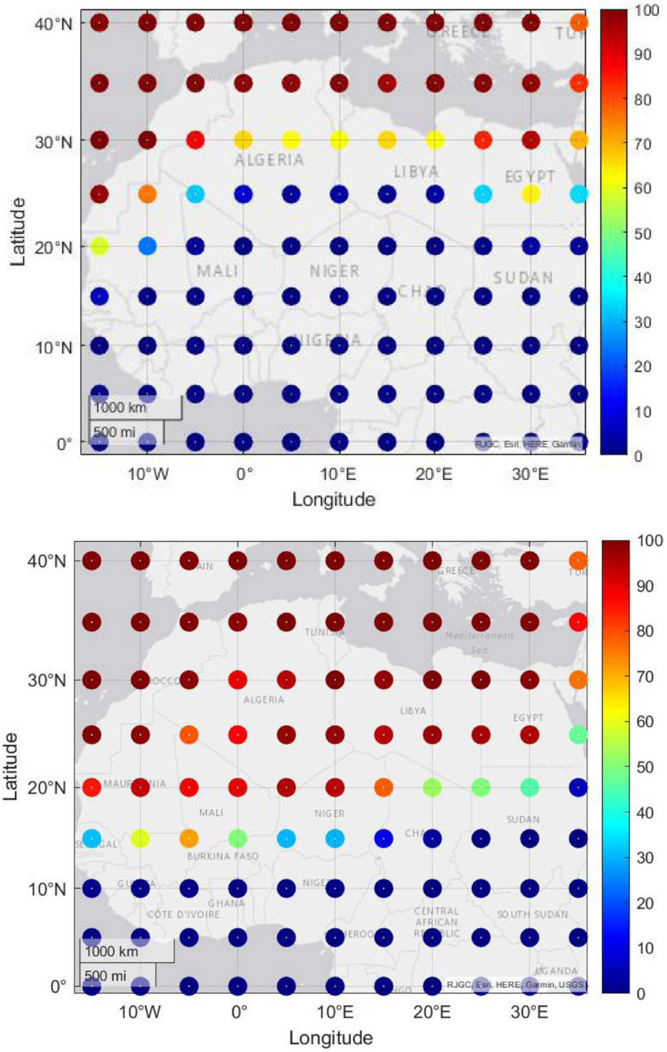

Figure 2. HPL Comparison between actual network (left) and proposed network (right).

4 CONCLUSIONS

This paper describes our simulations carried out with the aim to improve the performances of the EGNOS system by using new RIMS stations in the southern part of North Africa. A reference scenario is created for the latest version of EGNOS. The extension of the coverage area is studied for different scenarios, starting with a single RIMS station and continuing with multiple scenarios of RIMS stations. The best locations and scenarios to improve coverage at the southern border of the EGNOS service are presented and discussed in this work.

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INTEGRATING A NAVIGATION SYSTEM BASED ON VISUAL NAVIGATION

Božidar Ivanković*, Nenad Sikirica, Robert Spudić

Abstract. *Satellite navigation when integrated in vehicles and transport systems increases the mobility and safety of people and goods. Each satellite reduces the number of inconspicuous states, while visual navigation always has inconspicuous states. We propose a model that would improve the performance of the integrated navigation system based on visual navigation. We seek to understand the benefits and harms of integration in order to increase accuracy and improve the availability of a navigation solution.*

Key words: *navigation mathematics; navigation transportation services; positioning*

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1 INTRODUCTION

Case history analysis confirms the effectiveness of approach in term od completeness and allows to make suggestions on the choice of investigative technique in different scenarios. The application requires not only a navigation system that provides a continuous, accurate and reliable solution, but also reasonable cost, so it seeks to understand the advantages and disadvantages of each connection method in the context of visual navigation. The total pseudo-distance error is a convolution of independent errors.

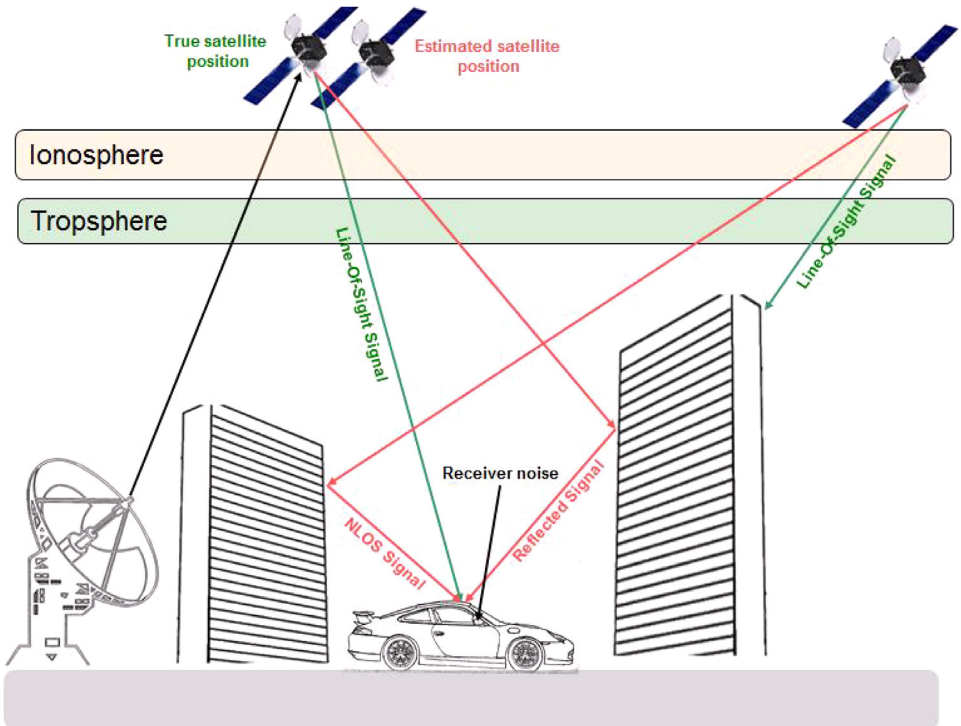

Figure 1. GNSS error sources [2]

2 METHODOLOGY

Single point positioning is challenged with receiver and satellite accuracy in changing spatial and time coordinate, because we can only detect receiving and emitting signal moments, t and t^S. Since signal speed c = 300 000 km/s is well-known, similar to [3], we define the range $\rho^S(t)$ between the receiver and the satellite at the moment t:

$$\rho^S(t) = c(t - t^S) \tag{1}$$

The range measured by (1) is not true because both signals are affected by clock offsets, Δt and Δt^S.

For the estimated satellite position (x^S, y^S, z^S), the pseudo-range provided by the S^{th} satellite during the k^{th} time reference frame is calculated in [2] as

$$\rho_k^S = \sqrt{(x_k - x_k^S)^2 + (y_k - y_k^S)^2 + (z_k - z_k^S)^2} + c(\Delta t_k - \Delta t_k^S) + \varepsilon_k^S \tag{2}$$

with geometric satellite and receiver coordinates, time offsets, and the error affecting the true satellite position due to ionosphere and troposphere, respectively.

3 RESULTS AND DISCUSSION

The satellite clock offset Δt_k^S is much less that Δt_k, being unknown [5]. If in (2) we substitute receiver clock offset as $\Delta t := \Delta t_k - \Delta t_k^S$, we obtain that true position of receiver at the moment t is represented as finding local coordinates ($x(t)$, $y(t)$, $z(t)$) such that

$$\rho^S(t) = \sqrt{(x(t) - x^S)^2 + (y(t) - y^S)^2 + (z(t) - z^S)^2} + c\Delta t + \varepsilon^S \tag{3}$$

In (3) we consider five unknowns. Enlarging the number of satellites with known positions, one ε^S appears with each new satellite contact with receiver. Due to numerous advantages of wireless networks, these errors could be calculated with differential measurement between several receivers with known reference stations. The idea is shown in **Figure 2**.

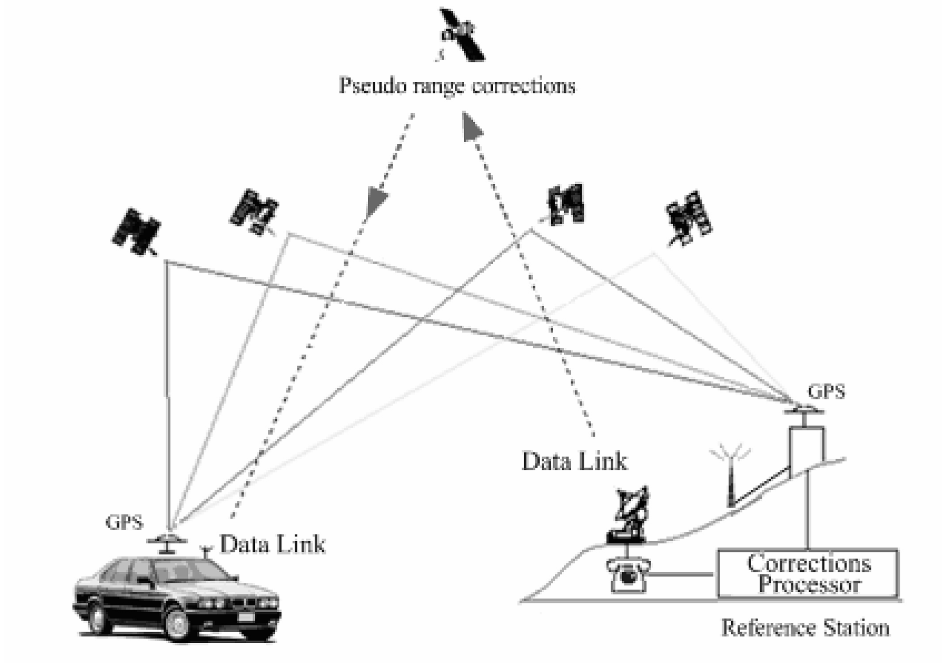

Figure 2. Differential correction [6]

The ambiguities are fixed in double differences between the receivers and the satellites. After that, in (3) there are only four unknowns that can be solved by values measured from four different satellites, obtaining a system of four equations from (3) for $S = 1, 2, 3, 4$. Solving methods are described in [1]. In this manner, pseudo-ranges given by (2) develop in range after containing known errors. According to [4], research attenuations appearing between moving and stationary receivers affects signal power, but real time positioning is not threatened.

4 CONCLUSIONS

In literature we found several ideas considering the problem of moving receiver positioning in temporary time frame. The problem is complex, since accuracy assumption presumes that errors ε^S remain their values from stationary to moving receiver if the moving receiver is nearby. We hope to contribute in developing the simple idea.

ACKNOWLEDGMENT

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THREE MONTHS OF EGNOS PERFORMANCE IN THE BALTIC SEA ON AN OIL TANKER

Rodrigo González*[1], Elisabet Lacarra[1], Manuel López-Martínez[2], Kaisu Heikonen[3]

Abstract. *The European Geostationary Navigation Overlay Service (EGNOS) augments the open public service offered by the GPS in Europe. EGNOS makes GPS suitable for safety critical applications. EGNOS provides over Europe both corrections and integrity information about the GPS system, delivering opportunities for accurate positioning improving existing applications or developing a wide range of new ones. EUSPA (the European Union Agency for the Space Programme) and ESSP (the EGNOS service provider), in the collaboration with the Finnish Transport Infrastructure Agency (Väylä) and the OSM Group AS (Norwegian Oil Transport provider), have carried out a GNSS data collection campaign of 92 days along the Baltic Sea covering the trajectory from an oil tanker vessel.This article analyses the EGNOS performance in the Baltic Sea during a long period of time in a real maritime environment with a maritime GNSS receiver. The purpose is to demonstrate the benefits of EGNOS for maritime navigation, showing that EGNOS L1 service is*

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compliant with the operational requirements defined in the IMO Res. A.1046 (27) for ocean waters, coastal waters and harbour entrances/approaches [1].

Key words: *EGNOS performance; maritime GNSS receiver*

1 INTRODUCTION

The aim of this document is to present the EGNOS performance assessment for an EGNOS Performance campaign along the Baltic Sea, on board Kiisla vessel between 1 September and 1 December 2021 using a maritime GNSS receiver.

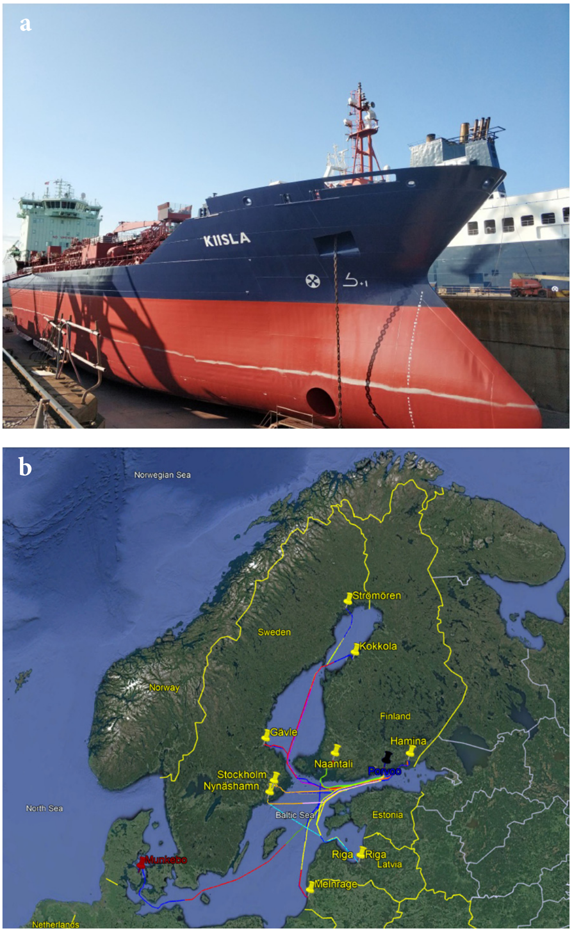

Figure 1. GNSS data collection route (*a*) and Kiisla oil tanker (*b*).

The characteristics of this GNSS data campaign in the maritime domain are the following:

- **Route:** the vessel Kiisla departed from Munkebo (Denmark) to Porvoo (Finland), going through Melnrage (Lithuania), Riga (Latvia), Nynäshamn (Sweden), Stockholm (Sweden), Gävle (Sweden), Strömören (Sweden), Kokkola (Finland), Naantali (Finland) and Hamina (Finland).
- **Time frame:** the vessel departure was on 1 September 2021 at Munkebo (Denmark) and arrived on 1 December 2021 at Porvoo (Finland).
- **Vessel:** Kiisla. This is a Finnish Aframax[1] crude oil tanker operated by Neste Shipping. This tanker distributes crude oil year-round between Neste Oil refineries in Porvoo and Naantali. Besides it calls into several Scandinavian ports. https://www.neste.com/

2 GNSS EQUIPMENT

For the GNSS data collection, the following equipment was used:

- GNSS MFMC High-end receiver with two purposes:
    - To monitor GNSS performance.
    - To compute real position of the reference path for obtaining a posterior SBAS position error during the time frame of the data campaign.

Note: The provided data was processed using PPP (Precise Point Positioning) technique in order to compute the reference trajectory, considered as the real path for the position error computation.

- SBAS capable maritime receiver to analyse EGNOS performance on-board.
- GNSS MF antenna.
- GNSS splitter.

[1] **Aframax** is a medium-sized crude tanker with a dead weight tonnage (DWT) ranging between 80,000 and 120,000. The tanker derives its name from **AFRA** which stands for Average Freight Rate Assessment. **AFRA** system was created in 1954 by Shell Oil to standardise contract terms.

3 METHODOLOGY

The GNSS performance assessment consists of three general lines:

- Real position. A GNSS MFMC receiver records GPS + SBAS + GLONASS + Galileo, to get RINEX data. These files are used to compute the precise position of the installed GNSS MF antenna with an external post-processing software suite with Precise Point Positioning (PPP) technique.
- EGNOS navigation solution. This is computed directly with the SBAS capable maritime receiver configured as SBAS mode. The computation of the performance analysis is done using internal Analysis Tools.

4 EGNOS PREFORMANCE RESULTS

This section of the report provides the results of the EGNOS performance analysis based on the PVT solution obtained with some GNSS receivers installed in the vessel: a high-end receiver and a maritime receiver.

Table 1. EGNOS position availability and HNSE obtained using EGNOS with EGNOS capable maritime receiver.

	EGNOS horizontal accuracy [m]			EGNOS position availability [%]
Period of time (DOY)	Mean	95%-percentile	Max.	--
244 – 253	0.310	0.715	1.168	100
254 – 263	0.337	0.844	2.350	100
264 – 273	0.327	0.749	1.145	100
274 – 282	0.419	0.925	1.829	99.93
283 – 293	0.351	0.826	1.447	100
294 – 303	0.359	0.881	1.730	100
304 – 313	0.360	0.955	2.068	100
314 – 320	0.387	0.920	1.617	100
321 – 335	0.399	0.939	1.466	100
TOTAL	**0.361**	**0.609**	**2.350**	**99.99**

Performance parameters analysed in the current section are the following:

- EGNOS availability: percentage of time the receiver is computing the PVT solution using EGNOS.

  EGNOS position availability is considered as the percentage of the time with EGNOS position solution in which HPE <10 m.

- EGNOS accuracy: difference between the real route (computed using PPP algorithms) and the EGNOS position solution computed by the SBAS maritime receiver.

5 CONCLUSIONS

Results from the EGNOS capable maritime receiver, during the whole EGNOS maritime data campaign, show that:

a) EGNOS position availability was 99.98% during the complete period.

The EGNOS signal-in space availability requirement at 99.8% of [1] is related to the service/signal which is fulfilled by EGNOS signal in space during the data campaign period.

b) 95th percentile of the EGNOS Horizontal Position Error was between 0.998 m and 0.589 m during the data campaign period (considering daily statistics). These values are compliant with the 10 m accuracy requirement in [1] for harbour entrances, harbour approaches and coastal waters. It is noted that the global value of 95th percentile of HPE for the data campaign is 0.609 m.

In consequence, the EGNOS performance observed on board the oil tanker Kiisla, with the maritime EGNOS capable receiver indicates that EGNOS can fully support "*Harbour entrances/approaches and coastal/ocean waters*" along the Baltic Sea according to [1], meeting the 10-meter confidence level at 95% and the signal-in-space availability requirement of 99.8%.

ACKNOWLEDGMENT

We would like to express our gratitude to OSM Group AS (Norwegian Oil Transport provider) and Väylä (Finnish Transport Infrastructure Agency) to allow ESSP to perform this GNSS data campaign in the Baltic Sea and install GNSS equipment on Kiisla vessel. Finally, the authors would like to acknowledge

the efforts done by EC and EUSPA to work at programme level for the future provision of EGNOS L1 maritime service.

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INTERACTION OF SOLAR STORMS WITH GALACTIC COSMIC RAYS: CONSEQUENCES FOR SATELLITE OPERATIONS

Luka Kramarić*[1], Mateja Dumbović[2], Krešimir Malarić[1]

Abstract. *This paper gives an overview of the terms space weather, coronal mass ejections (CMEs), galactic cosmic rays (GCRs) and their impact on satellites. To detect a CME and its counterpart interplanetary coronal mass ejection (ICME), coronagraph and instruments for measuring interplanetary plasma properties are needed, respectively. Plasma measurements used in this paper are taken from SWE and MAG instruments on the spacecraft Wind. In addition, the coronagraphs on board SOHO and STEREO-A and -B spacecraft are used to provide stereoscopic image of CMEs. This paper will explain how CMEs impact GCRs and telecommunications and will provide the interpretation of CME measurements from an event that happened on 16/06/2010.*

Key words: *coronal mass ejection; galactic cosmic rays; satellite; space weather; telecommunications*

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1 INTRODUCTION AND BACKGROUND

Coronal mass ejections (CMEs) are eruptions of plasma and magnetic field from the Sun's corona and are major drivers of space weather [1]. CMEs interact with energetic particles and cause solar energetic particles (SEPs) and Forbush decreases (FDs), sudden decreases in GCR count [3]. Solar flares accompanying CMEs cause sudden changes in electromagnetic radiation which changes the properties of ionosphere. High energy particles, such as SEPs and GCRs, may corrupt data and create noise in satellite communication. Understanding CMEs and their potentially harmful impact is extremely important for satellite operation and modern telecommunications.

2 METHODOLOGY

The geometries of observed CMEs were 3D reconstructed using Graduated Cylindrical Shell (GCS) reconstruction. GCS uses a hollow croissant as an ideal shape of a CME. Reconstruction is performed using coronagraphic images of a CME from 3 vantage points (STEREO-A, STEREO-B, and SOHO). GUI also shows hollow croissant because of GCS parameters. The GCS parameters are: 1) half angle; 2) height; 3) aspect ratio; 4) latitude; 5) longitude; 6) tilt angle.

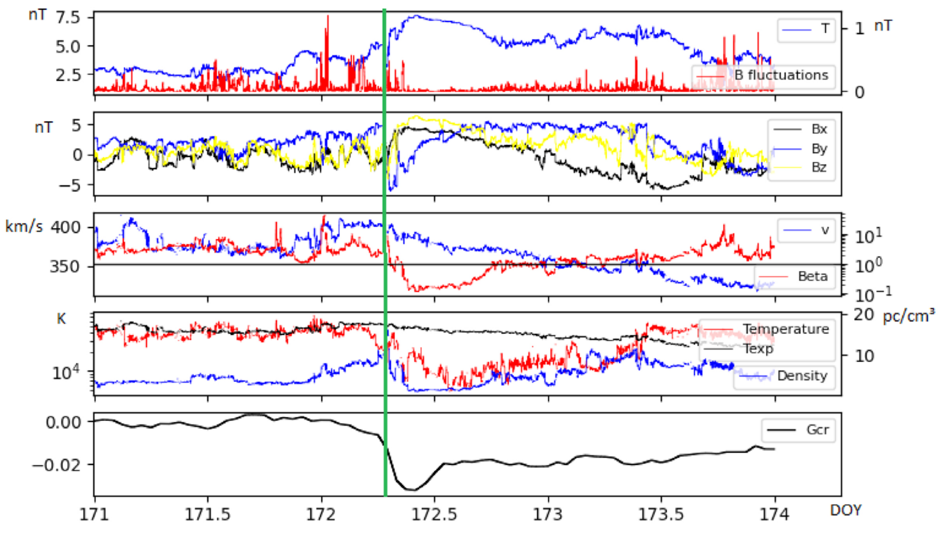

Figure 1. ICME measurement.

For observing CMEs near the Earth, we used in-situ plasma and magnetic field measurements from Wind spacecraft and GCR count data from EPHIN instrument on board the SOHO satellite. Using these measurements, we searched for correlation between CME in-situ signatures and FDs.

3 RESULTS AND DISCUSSION

Figure 1 shows in-situ measurements of an ICME that hit Wind spacecraft on 21 June 2010. The beginning of the ICME is shown by a green vertical line. It is characterised by an increased magnetic field strength and rotation of one of its components, low beta parameter, linearly decreasing speed, low plasma temperature and density. FD starts simultaneously with ICME and while it takes time for GCR count to return to normal, we can see the correlation between the two.

4 CONCLUSIONS

Long term exposures to GCRs may cause deterioration of satellites and the fewer there are, the less likely they are to cause damage. As we concluded that CMEs are corelated with FDs, CMEs increase the longevity of satellites; however, that would be a mayor oversimplification. CMEs can also create SEPs which are highly accelerated particles that produce ionizing radiation capable of destroying sensitive electronics. Researching space weather therefore remains a priority as the human species reliance on satellites increases.

ACKNOWLEDGMENT

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EGNOS ACCURACY ASSESSMENT FOR MARITIME APPLICATION IN THE ALGERIAN COAST

Derras Chahrazed*, Beldjilali Bilal

Abstract. *The goal of this work is to study the current status of EGNOS services intended for maritime applications in the coastal area of Algeria in terms of accuracy. To achieve this, an experimental study was carried out using a solution initially calculated only by DGPS, and then calculated using EGNOS corrections. The results show that a stable precision between 4 and 5m horizontally is obtained by the EGNOS solution. On the other hand, the precision deteriorates when we move away from the reference station to reach 8m horizontally for the DGNSS mode.*

Key words: *accuracy; DGNSS; EGNOS; GPS; maritime transport*

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1 INTRODUCTION

Nowadays, satellite-based augmentation systems (SBAS) are widely used for various applications such as land, air and sea transport in addition to agriculture and surveying [4]. For maritime sector, most of GNSS receivers installed on ships support SBAS signals [1]. Any type of GNSS receivers must respect requirements established by the International Maritime Organization (IMO), which define the parameters that have to be fulfilled by any radio-navigation system to be recognized [5]. In term of position precision, the accuracy which must be respected for any navigation phase is summarized in the following Table 1 [3].

Table 1. Minimum accuracy in meter requirements for maritime application.

Phase	Ocean	Coastal	Port approach	Port	Inland waterways
Horizontal accuracy	10	10	10	1	10

2 METHODOLOGY

The goal of this study is to test the degree of reception of the EGNOS signal in the coastal area of Algeria and to carry out some tests in the static mode on the quality of this signal. The data collected was processed in two different modes, DGNSS and SBAS, to be able to compare the resulting positions in terms of precision. After data acquisition, the files were processed by gLAB software in DGNSS and SBAS mode; the chosen sites are located in 4 different regions in the coastal area of Algeria.

Table 2. Approximate coordinates and lengths of the different baselines.

Site	City	Lat	Lon	Alt	Base line
AR1	Arzew	35.°85	-0.°31	67 m	110 m
MO2	Mostaganem	35.°84	0.°01	92 m	30 km
BE3	Bejaia	36.°75	5.°10	50 m	450 km
SK4	Skikda	36.°88	6.°93	48 m	600 km

One of the main advantages offered by EGNOS is the improvement in precision compared to the position calculated solely from the GPS, by the diffusion of differential corrections on the GPS ephemerides, the GPS clocks and the ionosphere whose correction equation is given by [2]:

$$lcorr\,(t) = lmes\,(t) + RCfast\,(t) - RCiono\,(t) + RCtropo\,(t) + RCclock\,(t) \qquad (1)$$

RCfast – Fast correction

RCiono – Ionospheric correction

RCtropo – Tropospheric correction

RCclock – Satellite clock correction

Differential GPS (DGPS) is an enhancement to GPS that was developed to correct errors and inaccuracies to achieve accuracy up to 10 centimetres. A receiver must be located in a precise and known place; this receiver is used as the base or reference station and the other is called a rover receiver. The base receiver calculates the difference between its position calculated by the GPS satellites and its known true position. The difference is an error correction factor, which is then transmitted to the rover receiver in order to correct its measures. For the short and medium baselines, the receiver clock error and satellite clock error are eliminated in the double-difference observation [6].

$$\Delta\nabla P_{i,j}^{\ s1sk} = \Delta\nabla \rho_{i,j}^{\ s1sk} + \Delta\nabla \varepsilon_{i,j}^{\ s1skz} \qquad (2)$$

Where $\Delta\nabla$ denotes the double-difference operator; i and j denote the reference station receiver and mobile receiver; $s1$ and sk denote the reference and non-reference satellite, respectively.

3 RESULTS AND DISCUSSION

The analysis of the SBAS and DGNSS solutions was carried out between a reference station and four points which are AR1, MO2, BE3, and SK4 distant from the latter by 110 m, 30 km, 450 km and 600 km respectively. The analysis of the impact of EGNOS corrections is carried out by comparing the error of the positions calculated in SBAS and DGNSS mode of the various points with respect to their exact positions. The following **Table 3** summarizes the results:

Table 3. Horizontal and vertical errors for DGNSS and SBAS solution.

ID point	Base Line	Error in DGNSS mode		Error in SBAS mode	
		Horizontal	Vertical	Horizontal	Vertical
AR1	110 m	±4.8m	±3.9m	±5.0m	±6.7m
MO2	30 km	±3.9m	±2.4m	±3.6m	±2.7m
BE3	450 km	±8.1m	±10.0m	±4.7m	±3.8m
SK4	600 km	±6.8m	±5.0m	±4 .0m	±3.1m

It is observed that the absolute survey improved by EGNOS gives better results compared to the DGNSS relative survey with baselines length more than 30 km and this is mainly due to the corrections transmitted by EGNOS as illustrated by the previous diagrams. According to the table and diagram, it should be noted that:

- DGNSS survey is more suitable for AR1 station because the distance between the reference station and AR1 point is very short (110 m), so DGNSS mode gives good results than SBAS.
- For the MO2 station (with 30 km baseline), the two modes give approximately the same results. Therefore, we can conclude that or getting precise results the DGNSS survey limit is about 25 km to 30 km.
- Points BE3 and SK4 are very far from the reference station, 450 km and 600 km respectively. According to the results, surveying in SBAS mode is most appropriate when the distance is large.

4 CONCLUSIONS

The main advantage offered by EGNOS is the improvement in precision compared to the position calculated solely from the GPS by the diffusion of differential corrections of the GPS ephemerides, the GPS clocks and the ionosphere. The application of these corrections significantly improves the accuracy of GPS positioning. For maritime application the precision needed for most navigation phases is 10 m, which is respected along the Algerian coast. For very precise navigation phase, in the image of navigation inside port, where the necessary precision is around 1m, SBAS alone cannot achieve this precision, so external systems are used for this phase.

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POSITION-TIME CORRELATION OF SAASTAMOINEN TROPOSPHERIC DELAY CORRECTION OF GALILEO SATELLITE NAVIGATION SIGNALS ALONG X, Y, AND Z AXES: THE PARTIAL ANALYSIS

Mario Bakota[*1], **Serdjo Kos**[2], **David Brčić**[2]

Abstract. *The paper presents the results of research on the success of the application of the Saastamoinen model of tropospheric correction in the Galileo radionavigation system. The atmospheric layer of the troposphere affects the propagation of the radionavigation signal causing a decrease in velocity and a deviation from the ideal geometric trajectory. These phenomena are commonly described by the term tropospheric delay. The atmospheric causes of tropospheric delay are hydrostatic and non-hydrostatic elements of the atmosphere, including atmospheric dry gases and water vapour in all its forms. A number of tropospheric models have been developed that determine the value of tropospheric error and correct tropospheric delay. The results presented in this paper are based on the study of the absolute deviation of the accuracy of the user position with respect to the value of tropospheric correction generated by the Saastamoinen model and its impact on the positioning accuracy.*

Key words: *Galileo radionavigation system; mapping function; Saastamoinen model; tropospheric delay; total zenith delay*

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1 INTRODUCTION

Tropospheric delay can be observed with regard to the components of the atmosphere affecting the radionavigation signal and with regard to the direction of the incoming radionavigation signal [1]. With regard to atmospheric causes, hydrostatic (dry) and non-hydrostatic (wet) causes of tropospheric delay [2]-[4] are distinguished. Due to the incoming angle of the radionavigation signal, the tropospheric delay in the zenith direction (ZTD – *Total Zenith Delay*) and delay for other incoming angles (STD – *Slant Tropospheric Delay*) [5] are distinguished. The STD is based on a mapping function that replicates the delay in the zenith direction to other angles of the incoming signal [6]-[8]. Existing models of tropospheric delay approach the determination of tropospheric delay in different ways, using different input parameters and initial assumptions. One of the most prevalent models that meets the accuracy and scope of applicability is the Saastamoinen model [9], [10] the model this research is based on.

2 METHODOLOGY

The research carried out is based on the movement of the achieved geodetic accuracy in the ECEF (*Earth Centred, Earth Fixed coordinate system*) format [11] realized by the Galileo radionavigation satellite system. The selected GNSS (Global Navigation Satellite System) stations include seven locations in the northern and southern hemispheres, with their latitudes ranging from 64.7° *S to 55.6° N. The time frame of the survey is 2021.* The initial software setting includes Saastamoinen tropospheric delay model for zenith delay modelling and Niell model for mapping function [12]. Due to the level of accuracy of the used tropospheric models, an elevation angle of the incoming radionavigation signal of 5° was determined. The software settings of ionospheric correction and ephemerides and clock correction are contained in the navigational message and are identical for all performed measurements. The key parameter of the success of the observed model is the reduction of the value of absolute deviation of the position along the coordinate axes.

3 RESULTS AND DISCUSSION

Since tropospheric delay shows a seasonal regularity, the achieved results were observed with this regard. At the same time, deviations and values of corrections on all axes were observed, as well as their mutual relations. The results are shown by a series of graphs (**Figure 1**).

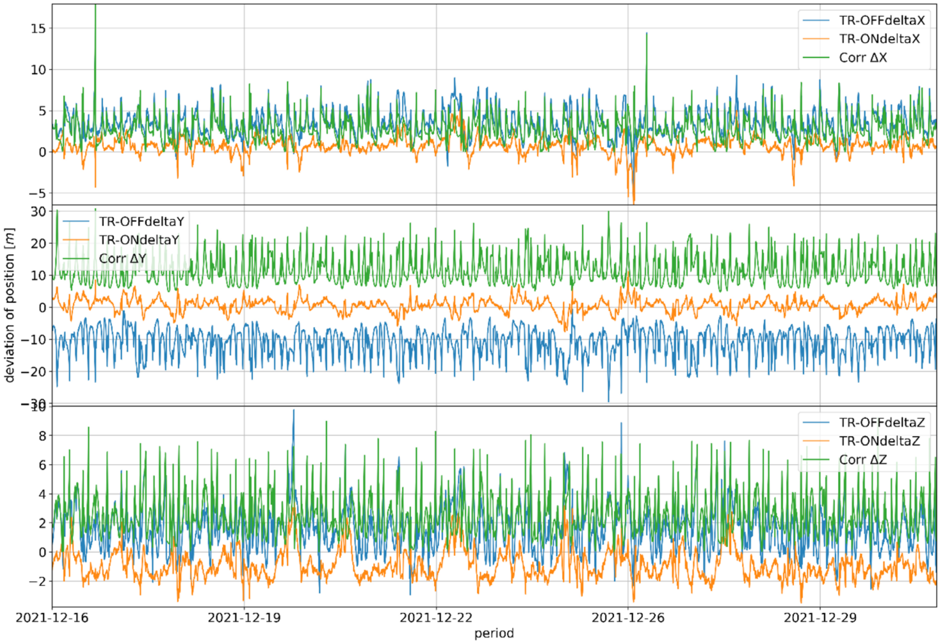

Figure 1. Trends in tropospheric correction and tropospheric error values for GNSS station at Christmas Island, Australia in the period 16 – 31 December 2021.

The results show that, although they improve the overall accuracy, there are periods of uneven accuracy, with simultaneous improvement and accuracy degradation for different coordinate axes. The research confirms the seasonal character of tropospheric error and its dependence on the geodetic position of the selected GNSS station. The reason is the diversity of climatological profiles of selected locations of the northern and southern hemispheres, which is not fully reflected in the input data of the used tropospheric models (the weather non-symmetry of the northern and southern hemispheres is predicted, not spatial).

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ADVANTAGES OF RTK FOR PRECISE VIDEO CAPTURE USING UAV

Mario Muštra[*1], Tomislav Radišić[1], Dario Petrec[2]

Abstract. *Real-Time Kinematic (RTK) positioning became very popular in recent time due to its low price and suitable accuracy for different applications, especially capturing of geo-referenced video. Comparison of accuracy in video capturing with and without the RTK upgrade on the same UAV is presented by video analysis, which served as a benchmark for the accuracy provided by each system independently. Results show that the usage of RTK significantly improves the autopilot accuracy and provides a very good upgrade to the basic Global Navigation Satellite System (GNSS) based navigation of an Unmanned Aerial Vehicle (UAV).*

Key words: *RTK; unmanned aerial vehicle; video capturing*

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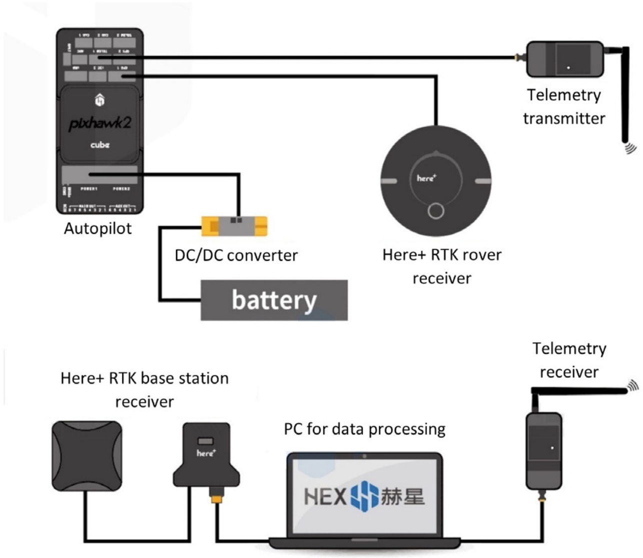
1 INTRODUCTION

Unmanned Aerial Vehicles (UAVs) became a very affordable and useful tool for different applications and especially for capturing of videos. They are increasingly used in industrial application, where it is necessary to include additional metadata in the captured video and one of the most useful is the geographical location [1]. Geo-referenced videos can be used is various scenarios, from observation to photogrammetry [2]. Navigation of UAVs is based on integration of different sensors in the autopilot Inertial Measurement Unit (IMU) with a GNSS module which provides the unit with the accurate geographical position. The expected accuracy of a GNSS system is within a couple of meters [3], which is suitable for scenarios without the requirement for the geo-referencing and stable flight is achieved by the autopilot which uses integration of sensor data through some optimisation algorithm, usually based on Kalman filter. To develop a highly accurate video capturing system, which could produce accurate georeferenced video, we built and tested a system consisting of a large UAV capable of slow and accurate following of a preprogramed flight trajectory [4]. Testing the actual accuracy of such a system is rather difficult because it is not easy to define what is the ground-truth against which it is possible to measure the performance. Defining the key points of a flight, in which UAV makes a change of its course, is also a problem, because measuring each point with a certain level of accuracy takes a lot of time. To solve that issue, we decided to create a flight pattern which follows a drawn line and measure a deviation from the optimal route.

2 PROTOTYPE OF AN UAV WITH RTK CAPABILITY

The navigation unit of the developed prototype used to test the difference in accuracy of an RTK-enabled system against standard (L1 GPS) system consists of components shown in **Figure 1** [5].

(a)



(b)

Figure 1. (a) Components of the navigation unit of the UAV with RTK system; (b) Developed UAV in flight.

To test capabilities of the RTK-based positioning against conventional positioning, relying only on L1 signal, we implemented a system which uses the captured video of a straight line to estimate the flight stability. Captured video was automatically analysed using the Scale-Invariant Feature Transform [6] and Homography using OpenCV. Flight trajectories of the desired and achieved flight are shown in **Figure 2 (a)** and **(b)** respectively, where purple colour denotes flight without RTK and yellow with RTK and it is clearly visible that the non-RTK one is a bit less smooth than the RTK one.

(a)

(b)

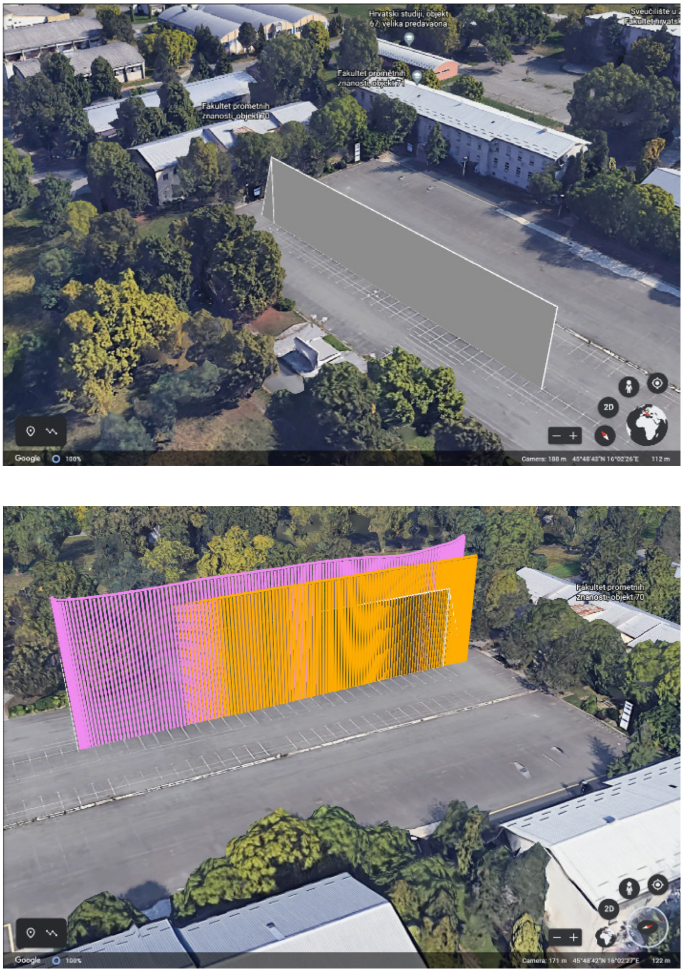


Figure 2. (a) Desired flight trajectory;
(b) Achieved flight without RTK (purple) and with RTK (yellow).

3 CONCLUSIONS

The usage of the RTK to achieve a very stable and accurate flight was tested using an UAV equipped with a high-resolution camera. Results show that RTK significantly improves flight stability over a limited perimeter, even though the autopilot of the UAV is equipped with an IMU, which should provide flight and hover stability, regardless of the input from a GNSS receiver. With the increase in the number of RTK-enabled UAVs, it can be expected that usage of this technology will become very popular in the following years.

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USING PRECISE POINT POSITIONING FOR AN AUTOMATED PASSING OF INLAND WATERWAY LOCKS

Ralf Ziebold*, Xiangdong An, Christoph Lass

Abstract. *This paper summarizes the activities of the research project SCIPPPER (2018 – 2022) in which a driver assistant function for an automatic entering of a waterway lock has been developed. A highly accurate positioning is required as one of the components of this system. Therefore, the DLR focused his activity on the development of a Precise Point Positioning algorithm with a convergence time of a few seconds.*

Key words: *automated vessels, GNSS, Inland Navigation, Precise Point Positioning*

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1 INTRODUCTION

Inland waterway transport is the transport mode with the lowest CO_2 emission per tonne-kilometre. However, there is a substantial potential for modal shift from road and rail to inland vessel transport. The increase of the grade of automation or even autonomous inland vessels could be a key enabler for this modal shift. By far the most challenging phase of inland navigation is the passing of waterway locks. Here, typically a ship with the dimension of 11.4 x 100 m has to enter a 12 m wide lock chamber, leaving just a few dm space on each side of the vessel. In order to support the automation of this manoeuvre, very accurate position, heading, turn rate and velocity information is required.

2 OVERVIEW OF THE PROJECT SCIPPPER

Within the project SCIPPPER [1] (2018 – 2022) such a driver assistant function has been developed. The idea was using the absolute Precise Point Positioning (PPP) instead of Real Time Kinematic (RTK) to achieve the required 10 cm horizontal accuracy. The reason was an expected reduction in the amount of PPP correction data and a significantly enlarged service area. Both facts would enable the correction data transmission over the VHF Data Exchange System (VDES) – the next generation of the Automatic Identification System (AIS). While a stable mobile internet connection is unfortunately not available in all inland waterways, currently AIS base stations are being operated on all main inland waterways in Germany. By upgrading the AIS base stations to VDES stations, in the future all inland vessels on the main waterways could potentially benefit from the highly accurate positioning service.

3 PPP DEVELOPMENTS/RESULTS

Besides the high accuracy, the reduction of the convergence time is one of the key challenges for the application of PPP for inland vessels. In order to shorten the PPP convergence time, we used an SSR (state space representation) correction service from a regional network including not only global corrections like satellite clock, orbit, code and phase biases but also regional ionospheric and tropospheric corrections. These corrections were provided by using the GNSS station network of SAPOS (Satelliten Positionierungsdienst der deutschen Landesvermessung). In cooperation with the Working Committee of the Surveying and Mapping

Agencies of the States of the Federal Republic of Germany (AdV) and Geo++, an SSR correction data stream has been prepared and optimised for inland vessel application. By separating the corrections into high (5s update) and low rate (30s update) corrections, an average data rate of about 0.3 kbits/s was achieved, which is a significant reduction compared to RTK correction (4-5 kbit/s).

The DLR has developed a real-time PPP algorithm using dual frequency GPS + GALIEO code and phase observations in single differenced, wide + narrow lane combination with (partly) fixing the integer ambiguities.

In **Figure 1** static positioning results are shown. Immediately after receiving all SSR correction data, a PPP fix solution is achieved yielding to an accuracy of approximately 3 cm for horizontal positioning and approximately 6 cm for vertical positioning.

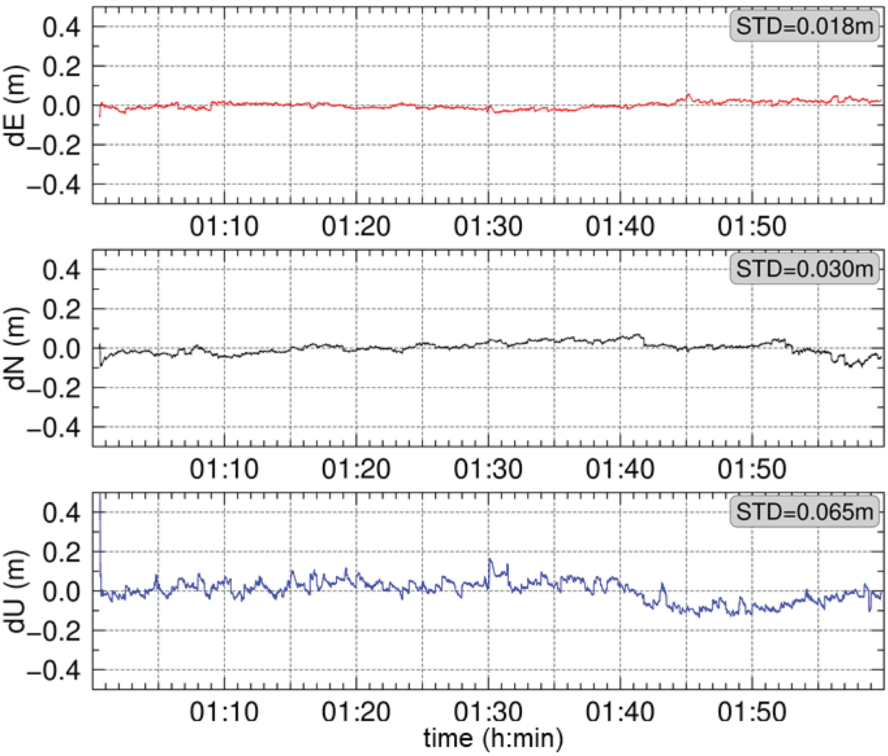

Figure 1. Static PPP positioning results

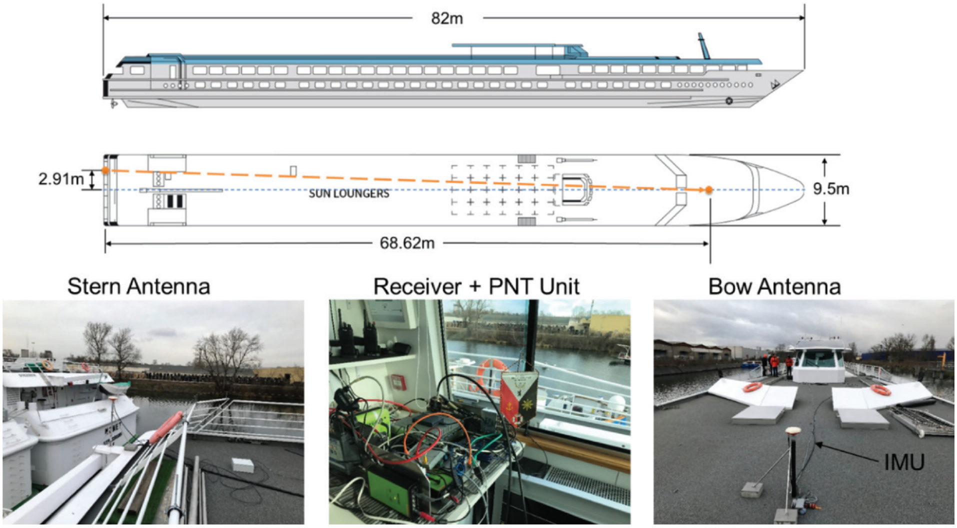

Figure 2. Experimental setup of final demonstration measurement campaign

Figure 3. Automatic entering a waterway lock with MS Victor Hugo

In the final demonstration of the SCIPPPER project, an 82 m long vessel automatically entered a waterway lock by using PPP as the main source for global positioning of the vessel (see **Figure 2**). By using a two-antenna setup **[2]**, one at the bow and one at the stern of the vessel, achieved not only very accurate positioning but also a very accurate heading determination, yielding to an accuracy of approximately 0.005°.

Figure 3 shows a photo from a drone while the MS Victor Hugo entered the waterway lock for the first time automatically.

4 SUMMARY

This paper presents the results of a real time PPP algorithm, which was used to automatically enter a waterway lock in the project SCIPPPER.

ACKNOWLEDGMENT

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TEMPORAL CORRELATION OF PROTON DENSITY AND EARTHQUAKE MAGNITUDE WITHIN THE THEORY OF SOLAR-INDUCED EARTHQUAKES: CROATIAN DECEMBER 2020 M=6.4 CASE STUDY

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Abstract. *Solar-induced earthquakes are a relatively new field of research of possible connection between events originating from the Sun and Earth's lithosphere dynamics. This is a theory that tries to explain the temporal correlation between the solar activity increase, particularly measured using proton density values, and the occurrence of the strongest earthquakes on Earth. In this paper, the case study of Croatian major earthquake in December 2020 was investigated. The increase in proton density as measured by STEREO satellite, by +4.2 standard deviations from the monthly mean value, preceding the main shock of M=6.4 by 16 hours. Such proton density increases within one day before major earthquake and agrees with the previous research where strong temporal correlation of those two events was found.*

Key words: *2020 earthquake in Petrinja; proton density; solar-induced earthquakes*

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1 INTRODUCTION

One of the emerging areas of science tries to relate space weather and Earth's crust dynamics. The focus of this research is to determine if there is a connection between increased solar activity and the occurrence of major earthquakes on Earth. Previous studies display possible correlation between increased energy released by Coronal Mass Ejections and increased likelihood of strong earthquake occurrence somewhere on Earth, following the arrival of CME energy [1-8]. We analysed the case in Croatia near the end of 2020, when the major earthquake with epicentre in Petrinja hit the area. The findings show that increased solar activity before the main earthquake shock has been detected by satellite measurements, which agrees with the stated theory of solar-induced earthquakes [1,8]. This case continues to contribute to the pool of recorded events where strong earthquakes occurred within several hours following major energy increase from the Sun.

2 METHODOLOGY

The case study of Petrinja earthquake consists of investigation of space weather preceding the main shock that occurred at 05:28 UTC, 28 December 2020 at geographical position 45.42°N, 16.22°E. The earthquake that had a magnitude of 6.4 destroyed many buildings and caused several human casualties.

The proton density (PD) dataset for December 2020 has been retrieved from NASA's public data server, obtained from the NASA's Solar TErrestrial RElations Observatory (STEREO) A satellite [9]. The earthquake data with occurrence time and respective magnitudes, within rectangular region bounded by coordinates 45.0°N-45.7°N and 15.8°-16.8°E, have been retrieved for the same period from the EMSC database [10].

3 RESULTS AND DISCUSSION

The results of data collection within the period between 23 and 31 December are presented in **Figure 1**.

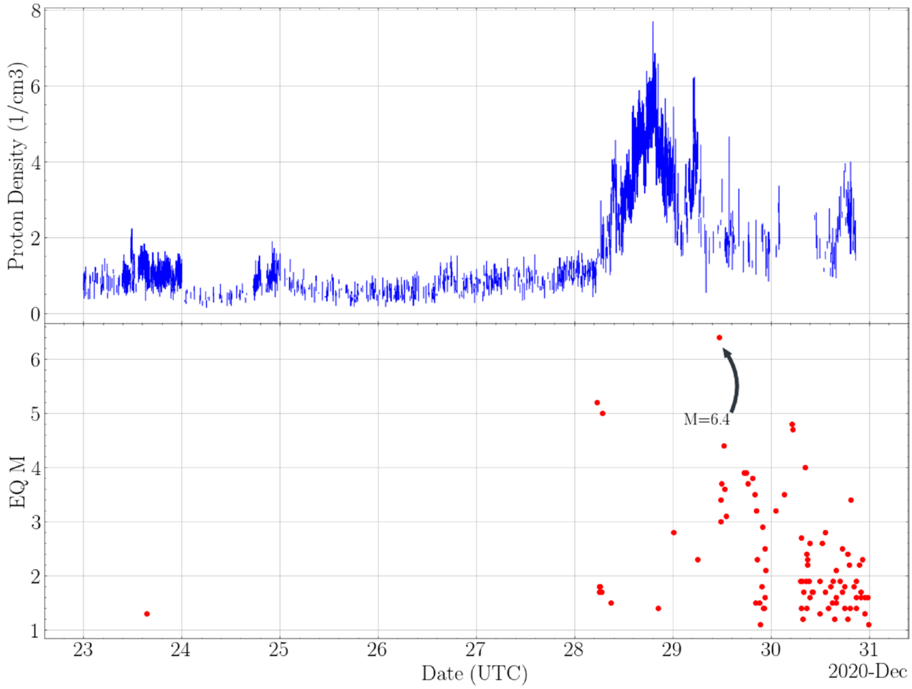

Figure 1. Proton density at STEREO satellite (blue) and earthquake magnitudes in central Croatia area. Sources: [9] and [10].

Low proton density values were found during the majority of month, with moderate increase between 10 and 13 December (not shown in **Figure 1**), which was followed by a decrease and finally monthly average baseline values. The major increase in PD has been recorded on 28 December, with peak value measured around 19:00 UTC the same day. The standard deviation of PD data within the month equals to 1.39 units, with peak value of 28 December being 7.65 units. This indicates an increase of 4.2 standard deviations from the mean monthly value (1.76). The first earthquake that hit the area occurred in the morning of 28 December, before the PD increase (consisting of two subsequent shocks with M=5.2; M=5.0). However, the main shock that occurred around midday of 29 December, followed the PD peak approximately 16 hours later (annotated with black arrow in **Figure 1**). These results agree with previous literature findings, where the PD increase before major strikes was confirmed **[1,8]**.

The main questions that can be further discussed here are the following:

1. Would the elaborated powerful M=6.4 shock occur at all, if the PD stream was quiet or lower on the previous day?
2. If it would occur, would it be exactly on that day, one day after PD peak or at some other time, perhaps later?
3. If the second earthquake would occur on 29 December, would it be that strong, if there were no PD increases on the previous day, or the energy of subsequent aftershock would steadily attenuate after the first M=5.2 strike?

4 CONCLUSIONS

The finding falls within the theory of solar-induced earthquakes. Whether the theory has any scientific validity or not, it is not known at this moment. Even more unclear is the mechanistic explanation of the possible way of triggering earthquake release by the influence of solar particles energy fluctuation. These unknowns set the theory as both intriguing and controversial, thus much more investigation is required in order to shed some light onto the matter.

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GNSS AND PNT RELATED WORK WITHIN IALA

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Abstract. *IALA is the International Association of Marine Aids to Navigation and Lighthouse Authorities, a non-profit, international technical association whose aim is improving and harmonizing aids to navigation worldwide. Several activities are currently in progress within IALA in regards to addressing the matter of the provision of sources of resilient Positioning, Navigation and Timing (PNT). Shoreside and on-board equipment/systems rely on GNSS but they remain vulnerable to internal and external intentional or non-intentional interferences. The IMO requirements and particularly the IMO e-Navigation strategy states that "e-Navigation systems should be resilient and take into account issues of data validity, plausibility and integrity for the system to be robust, reliable and dependable. Requirements for redundancy, particularly in relation to position fixing systems, should be considered". This paper aims at providing insights to the participants of the GNSS Conference with regards to the IALA scope of work within GNSS and PNT services, with a focus on gathering expertise from this forum that could contribute to this work.*

Key words: *augmentation; integrity; maritime; resilient PNT*

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1 INTRODUCTION

IALA, established in 1957, gathers together Marine Aids to Navigation (AtoN) authorities, manufacturers, consultants and scientific and training institutes from all parts of the world encouraging its members to work together in a common effort to harmonise Marine Aids to Navigation worldwide and to ensure that the movements of vessels are safe, expeditious and cost-effective while protecting the environment. Taking into account the needs of mariners, developments in technology and the requirements and constraints of aids to navigation authorities, four technical committees (ARM, ENAV, ENG and VTS) have been established bringing together experts from around the world.

The Engineering and Sustainability (ENG) Committee is composed of four working groups (WG), including the WG3 on Radionavigation services whose goal is to support and assess reliable position-fixing (with redundancy) as a fundamental requirement for navigation and e-navigation. This requirement has since been expanded to cover all aspects of PNT inputs required by both ship and shore to enable e-Navigation. The current work program 2018-2023 for ENG WG3 covers among others, the following topics:

- Resilient PNT
- R-mode (MF)
- R-mode transmitted via VHF Data Exchange System (VDES)
- Guidance on timing and synchronisation
- eRacon and Enhanced Radar Positioning System (ERPS)
- Satellite Based Augmentation System (SBAS)
- Existing Differential Global Navigation Satellite System (DGNSS) infrastructure and provision of guidance for current system
- High accuracy systems
- Cybersecurity impact for PNT data

The work in the committees is usually complemented by specialised workshops. Various PNT matters were considered on each of the following events: AtoN in the autonomous world (MASS) workshop, Cyber security workshop and Enhanced Radar Positioning System (ERPS) workshop.

2 DISCUSSION

The outcomes of various initiatives conducted by IALA express the need to:

- encourage IALA members to ensure that GNSS integrity information is provided in their area of responsibility;
- encourage IALA members to seek ways of informing mariners in a clear and timely manner that GNSS information is not unreliable; and
- identify alternative new and innovative ways of providing GNSS integrity information to mariners and find ways to speed up their development, including:
  - harmonized maritime GNSS user integrity algorithms;
  - encourage the development of Multi-System Receiver (MSR) test specification and its introduction on all vessels; and
  - the introduction of R-Mode, ERPS and other solutions for mitigating GNSS vulnerabilities.
- co-ordinate this work with other international bodies to achieve globally harmonized solutions.

Within the last few years, some progress has been made in terms of providing resilient PNT services at the disposal of the competent authorities, such as:

- The different core constellation system evolution and an increasing number of satellites on view.
- The continued work in IEC regarding standardisation of Maritime navigation and radiocommunication equipment and systems of Global navigation satellite systems (GNSS), including the standard specifying the minimum operational and performance requirements, methods of testing and required test results relative to the shipborne DGPS and DGLONASS maritime radio beacon receiver equipment.
- On-going RTCM SC104 v2.4 developments on a generic broadcast standard to allow for all GNSS signals to be corrected.
- The inclusion of augmentation systems SBAS and GBAS receivers for maritime applications, including the current developments on standardisation of an SBAS type approval receiver for SOLAS ships
- The provision of IALA guidance on different architectures to provide DGNSS corrections (classical, network, SBAS) and the different options for integrity

monitoring use, including the use of SBAS information to support the mariner through retransmission via MF radio beacons and AIS.

- Authentication as Galileo OS NMA can provide that the source of the message comes from a valid source.
- VHF Data Exchange System (VDES) is being developed, tested and operated and can provide R-mode capabilities: providing ranging measurements to an on-board navigation system so that the impact of the GNSS service outage on the ship's ability to navigate safely is minimised.

However, IALA sees that the following areas requires further development:

- Maritime Remote Autonomous Integrity Monitoring (M-RAIM) due to the fact that existing RAIM algorithms are for aviation but the IMO Res. 401 (95) on performance standards for multi-system shipborne radionavigation receiver includes RAIM as a source of integrity monitoring.
- M-RAIM standardization is poor and requires User-level integrity including new User Requirements. To understand the maritime operational environment (noise, multipath etc) which would need to be considered in the definition of a suitable algorithm.
- The test results of Advanced RAIM shows that more satellites, could provide better Horizontal Dilution of Position (HDOP) and no RAIM holes.
- Currently, RAIM algorithms are designed to identify single failed satellites, however with the move to multi-constellation receivers, a new algorithm may be needed to ensure efficient use of all available satellites and frequencies.
- A request for a RAIM test specification from the IEC.
- Need for IEC test standards for the multi-system receiver development and an organization/person to take the lead in this task.
- Implications on GNSS performances related to ionospheric changes due to solar cycle.
- Within the past years, some competent authorities have decided or plan to discontinue the DGNSS service (Japan, US, Australia, UK, Spain…). However, currently no other source of differential GNSS data is recognised by IMO. DGNSS receiver on board is type approved.
- SBAS coverage is predominately in the northern hemisphere and there are large parts of the world that currently have no integrity system.

- There is a need to ensure a coherence between the different PNT services provided by the competent authorities/AtoN providers and the market penetration in terms of number and type of ship receivers. What signal/message is the receiver capable to compute?
- The mariner still requires technology to support them but unless IMO carriage requirements are updated then most ships will not adopt the equipment.
- Training of the mariner is important since there is little awareness about the vulnerabilities of the source of PNT and a high dependence on GNSS to compute the position, navigation and timing solution. Besides, the mariner is currently unlikely to see an integrity alert on bridge equipment.
- There is no IALA guidance so far in terms in terms of timing and synchronization, the number of T&S experts attending to the committees remains very limited.

3 CONCLUSIONS

There is no one solution that fits all. IALA considers that a system of different PNT systems (dependent and independent to GNSS) could provide resilience and integrity of the data.

It is equally important to capture the follow-on work on the various system building reliance and integrity. The provision of rPNT does not only have implications on the navigation equipment but it is also a matter that encompasses cyber-security and the future Maritime Autonomous Surface Ships developments. IALA elaborates standards, recommendations and guidelines to service providers, competent authorities and manufacturers among others in regards to the provision of PNT services (Terrestrial radio navigation systems, SBAS, Loran, R-Mode, ERPS, high accuracy systems…) seeking understanding of the different solutions but also the vulnerabilities affecting these systems.

I would like to encourage GNSS and in general PNT experts to express interest to contribute to the work of the IALA technical committees and help improve the safety of navigation worldwide.

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INTEGRATION DATA MODEL OF THE BATHYMETRIC MONITORING SYSTEM FOR SHALLOW WATERBODIES USING UAV AND USV PLATFORMS

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Abstract. *The aim of this publication is to present the integration data model of the bathymetric monitoring system for shallow waterbodies using unmanned aerial vehicles (UAV) and unmanned surface vehicles (USV). As part of this model, three technology components will be created: a hydroacoustic and optoelectronic data integration component, a radiometric depth determination component based on optoelectronic data, and a coastline extraction component. Thanks to them, it will be possible to cover*

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the entire area with accurate measurements in the coastal zone, in particular between the shallow waterbody coastline and the minimum isobath recorded by the echo sounder.

Key words: *bathymetric monitoring system; data integration; hydrography; shallow waterbody; unmanned aerial vehicle (UAV); unmanned surface vehicle (USV)*

1. INTRODUCTION

The aquatic environment is one of the most dynamically changing regions on the Earth. One of the elements of these changes is the seafloor relief. Knowledge of the current waterbody depth is particularly important during: navigation in restricted areas, construction of gas pipelines, exploration of natural deposits, for the defence of the state, scientific research, etc. [1]. Changes in the seafloor relief are particularly noticeable in shallow waterbodies (at depths up to several meters), where they are of significance for human safety and environmental protection, as well as for which the highest measurement accuracy are required [2].

2. METHODOLOGY

The integration data model of the bathymetric monitoring system for shallow waterbodies using autonomous unmanned aerial and surface vehicles (INNOBAT system) will have three technology components [1]: a hydroacoustic and optoelectronic data integration component based on the method proposed by Dąbrowski et al. [3], a radiometric depth determination component based on optoelectronic data using the Support Vector Regression (SVR) [4], as well as a coastline extraction component based on the method proposed by Xiu et al. [5].

3. RESULTS AND DISCUSSION

The INNOBAT system will enable, as compared to other existing solutions, the accurate and precise measurement of the entire coastal relief based on the data acquired from UAV and USV, as well as three proposed technology components. Multisensor data fusion acquired from autonomous unmanned aerial and surface vehicles will allow to meet the requirements provided for the International Hydrographic Organization (IHO) Special Order (horizontal position error ≤ 2 m (p=0.95), vertical position error ≤ 0.25 m (p=0.95)).

4. CONCLUSIONS

Incorrect bathymetric monitoring of shallow waterbodies and those with high dynamics of hydromorphological changes can result in an adverse impact on the aquatic environment and humans. Therefore, the development of bathymetric monitoring systems seems necessary due to the fact that in recent years there has been a very rapid improvement of measurement techniques (UAV and USV) enabling the implementation of hydrographic surveys in ultra-shallow waterbodies [1], as well as computational techniques for modelling the seabed relief [3–5].

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BAYESIAN APPROACH TO CRUDE PALM OIL EXPORTS FORECASTING IN MALAYSIA AND INDONESIA

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Abstract. *Crude palm oil (CPO) is the most widely used vegetable oil, found in everything from cosmetics to food. The main producers are Indonesia and Malaysia, and nearly half of the production goes to India and the Netherlands. CPO monthly exports are usually reported by officials within 10 days of the end of the month, which is rather late for the Veg Oils market. Maritime flows of tankers carrying CPO have proved to be a good indicator of production and exports. This paper shows a CPO export model using a Bayesian approach on vessel arrivals to berth: given that a vessel arrived in ballast and has spent a certain amount of time moored (service time), the probability that this vessel departs laden within the next 1-5 days is calculated based on the distribution of service time and therefore exports are forecasted.*

Key words: *AIS; Bayesian; crude palm oil; data-driven maritime operations; stochastic modelling*

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1 INTRODUCTION

In the past, Automatic Identification System (AIS) data has been used for collision avoidance purpose, by constantly reporting vessel position and other voyage/vessel related variables to ground stations. More recently, small satellite companies have put in orbit dedicated sensors to collect AIS data in remote deep waters and/or congested waterways where ground stations are limited. Such amount of raw data has proved to be useful to create derivate products and fundamental signals of supply/demand of bulk commodities around the world.

However, to extract useful market insights from AIS raw data, robust statistical methods are required to provide the ability to create maritime routes and obtain accurate arrival/departure location and time. In this study, we aim to use Chemical Tankers activity along with Bayesian methods to forecast Crude Palm Oil exports from Malaysia, as a proxy to estimate exports and global demand for this commodity.

2 METHODOLOGY

The first stage of the research relies on AIS historical data to identify anchorage and mooring areas where chemical tankers known to carry crude palm oil have ever been in Malaysia. Those positions are then clustered and geofenced to determine our areas of interest. Next stage consists in processing AIS data to build voyages, processing both historical and streaming data to construct routes from an origin to a destination, as well as underway voyages. Using these AIS-based voyages, we determine the following events:

a) When a vessel of interest enters and leaves anchorage area, which is an indicator of waiting/queuing time.
b) When a vessel enters and leaves a mooring area, which is an indicator of service time.

Waiting/Service time is then used to fit distributions for waiting time and service time applying a Maximum Likelihood Estimation (MLE) method, we obtain a statistical model under which the observed data is most probable. We assume that waiting time in anchorage follows an exponential distribution, while time at berth (service time) follows a gamma distribution. Moreover, using these distributions, we are able to use a Naive Bayes model to estimate the probability that a vessel departs laden within the next n days, given that has been at anchorage/berth t amount time.

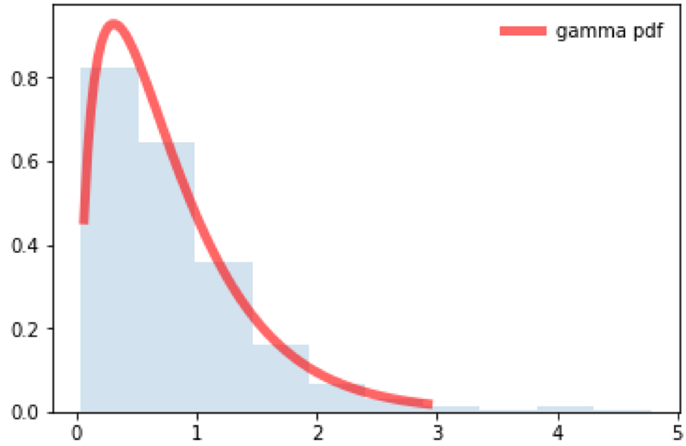

Figure 1. Histogram and fitted Gamma PDF for service time in days.

3 RESULTS

By making use of the Bayesian model, we can estimate vessel laden departures using arrivals and forecast monthly exports around day 25 of each month, beating the Malaysian Palm Oil Board (MPOB) report, which usually publish export reports around the 10th day of the following month. This gives a 15 day-ahead estimate with respect to official reports with an accuracy of 90%, which significantly improves the short-term planning scenarios for buyers.

4 CONCLUSIONS

This approach can also be used to generate export reports with more cadence, as often as weekly, which are usually only delivered by independent surveyors in ports. Furthermore, this study helps not only buyers but also economic analysis of global commodity markets beyond crude palm oil.

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METHODOLOGY FOR PERFORMING BATHYMETRIC MEASUREMENTS OF SHALLOW WATERBODIES OBTAINED USING UAVS AND THEIR PROCESSING BASED ON THE SVR ALGORITHM

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Abstract. *Currently, depth measurements of shallow waterbodies are performed with the use of a Global Navigation Satellite System (GNSS) receiver, bathymetric Light Detection And Ranging (LiDAR) or satellite imagery. However, methods based on the analysis of photos taken with the use of Unmanned Aerial Vehicles (UAV) are increasingly used.*
The aim of this publication is to present the methodology for performing bathymetric measurements of shallow waterbodies using a GNSS receiver and a photogrammetric camera mounted on the UAV. Moreover, a method of

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analysing and processing bathymetric data based on the Support Vector Regression (SVR) algorithm will be presented. The verification of the proposed model will be carried out on the basis of data obtained during GNSS Real Time Kinematic (RTK) and photogrammetric surveys on the Raduńskie Górne Lake located in Poland.

The presented methodology of creating a training set for the SVR algorithm will allow to perform bathymetric measurements with the accuracy provided for the International Hydrographic Organization (IHO) Special Order (horizontal position error ≤ 2 m (p=0.95), vertical position error ≤ 0.25 m (p=0.95)).

Key words: *hydrography; machine learning; optoelectronic methods; shallow waterbody; Support Vector Regression (SVR); Unmanned Aerial Vehicle (UAV)*

1 INTRODUCTION

The shallow waterbody is a dynamic environment, which is also heavily exploited by human activities such as biological research, coastal engineering, hydrographic surveys, etc. In addition, shallow waterbodies are unavailable for manned hydrographic vessels due to the lack of sufficient space between the hull and the seabed.

Nowadays, bathymetric measurements are usually carried out using a GNSS receiver, bathymetric LiDAR or satellite imagery. These measurement methods are inaccurate or time consuming. Therefore, there is a need to develop accurate and faster methods for determining the depth of shallow waterbodies.

This article presents the methodology for performing bathymetric measurements of shallow waterbodies using a GNSS receiver and a photogrammetric camera mounted on the UAV. Moreover, a method of analysing and processing bathymetric data based on the SVR algorithm will be presented.

2 METHODOLOGY

The proposed methodology for performing bathymetric measurements using an UAV is based on obtained results proposed by [1]. The SVR method was analysed in [2–4]. Then GNSS RTK measurements and UAV photogrammetric surveys were conducted on the Raduńskie Górne lake, located in Poland, to obtain testing and training datasets. The Structure from Motion (SfM) point cloud dataset was normalised [5] and stored in the form supported by Python's Machine Learning (ML) libraries.

3 RESULTS AND DISCUSSION

The obtained prediction function from the SVR algorithm corrects the SfM point cloud. Based on the obtained results, the proposed methodology allows to successfully perform bathymetric measurements in shallow waterbodies using a photogrammetric camera mounted on the UAV with the accuracy provided for the IHO Special Order (horizontal position error ≤ 2 m (p=0.95), vertical position error ≤ 0.25 m (p=0.95)).

4 CONCLUSIONS

The proposed methodology for performing bathymetric measurements and the data processing is designed for the autonomous unmanned aerial and surface vehicles (INNOBAT system) but it can be applied in other hydrographic surveys using an UAV. It allows for carrying out research in shallow waterbodies (at depths from 0.1 to 1 meters), where manned hydrographic vessels cannot be used.

ACKNOWLEDGMENT

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MAGNETIC TO TRUE NORTH, AVIATION CHANGE BY 2030

Bart Banning[*1], **Anthony MacKay**[2]

Abstract. *The use of the magnetic compass and magnetic North as the main reference in aircraft navigation in this era leads to avoidable costs and possible safety issues. A proposal is presented to change to GNSS based true tracks and headings, including a way forward for an internationally aligned transition strategy. Latest results of research in this field and of coordinating actions with international bodies will be presented.*

Key words: *aviation; magnetic; reference; true north; variation*

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1 INTRODUCTION

The International Association of Institutes of Navigation has taken up the initiative to transition to true tracks in aviation, as was done in the maritime world already in the previous century. Although it will take a worldwide effort to make the transition from magnetic to true reference, it is believed that this one time exercise will make aviation safer and much more efficient. At the ICAO World Conference in 2019, it was agreed that ICAO would take up this subject in its work programme. A date in the future and an accompanying roadmap for the transition to true tracks were still to be established.

An international working group was formed to bring the case forward: AHRTAG Aviation Heading Reference Transition Action Group, which has online meetings every month. The representatives are from airlines, service providers, regulating bodies and experts worldwide. The AHRTAG group reports to the International Association of Institutes of Navigation (IAIN). Its main aim is now to make the change to True North as the reference for aviation in the year 2030 in at least one country, but preferably in a larger group of countries or continent(s), with the rest following thereafter.

2 BACKGROUND

True direction can be established by measuring the spin of the Earth, offers operating accuracy of the order of one tenth of a degree and remains constant with time. By contrast, the instantaneous accuracy of a magnetic compass is probably of the order of one degree. More importantly, magnetic variation changes with location and time, necessitating constant updating of published instrument flight procedures.

Current Practice – and Exceptions. Despite its many limitations, magnetic direction is used as the datum for instructions, procedures and control in aviation, including airways tracks, approach procedure tracks and runway centrelines. When the variation alters by more than one degree, it becomes necessary to republish any printed runway and approach documentation. The other main application in which magnetic north is used as a datum are those navigation aids where the bearing information is put in at the ground station, that is: VDF, VOR and TACAN.

Having decided on this convention, by usage and custom, we then depart from it when it becomes unworkable. At latitudes above about 60° tracks and routes published on charts are given in True because of the weakness of the horizontal component of the magnetic field and because it changes so rapidly with both location and time. It is simply assumed that any aircraft operating at high and polar latitudes will be equipped with a navigation system that gives it the ability to operate in True or Grid.

3 CHANGING TO TRUE

Now let us examine how to tidy up this situation. The obvious way is to convert all directions for aviation instructions, procedures and control to True, since we have to use it near the polar regions anyway. We will have a look at the effect it would have on four different classes of aircraft that we can distinguish.

Airliners. Any airliner introduced into service less than 45 years ago uses an inertial navigation gyro-based system for navigation. Two, or sometimes 3, inertial reference systems determine True heading by measuring the direction of the Earth's spin. In the modern Flight Management System, all the navigation computations of spherical trigonometry to calculate desired tracks and all the computations of position data in latitude and longitude are carried out in True, so, for purely navigational purposes, there is no requirement for magnetic direction. Therefore, no magnetic sensor is incorporated into the system.

However, for compatibility with Air Traffic Control procedures, the aircraft have to be capable of operating in Magnetic. Thus, the Inertial Reference System contains a database with values of variation against latitude and longitude. The problem is that variation changes with time. The database is calculated for the half decade in which the IRS was built. Unless the database is updated, the information goes out of date. Unfortunately, updating is expensive and there is no strong incentive for the airline to carry it out.

Aircraft with a gyro-magnetic compass. Let's now turn to those aircraft that use a traditional gyro-magnetic compass, in other words, one with a flux valve, such as might be found in an air-taxi aircraft. In fact, this problem of operating gyro-magnetic compasses in True has been dealt with before. During the '50s and '60s, compasses were magnetic, but automatic dead reckoning systems using Doppler needed their input to be in True to be compatible with a latitude and longitude graticule. Most compasses for large aircraft of that period had a facility for manual entry of variation to give a true read-out to the navigation equipment and, in many cases, to the actual compass dial, so that the pilot could fly true headings off the compass.

This facility tended to die out in gyro-magnetic compasses produced after about 1970 because the Doppler Ground Position Indicators had become digital by then and it was simpler to adjust the variation in the display computer itself, rather than in the compass. However, if we switched to True, the demand would revive, and it would be an easy matter for manufacturers to reinstate a well-established fifty-year old technology into modern gyro-magnetic compasses.

Aircraft with Directional Gyro Indicators (DGI). We now turn to those aircraft using a combination of Direct Reading Magnetic Compass and a Direction Gyro Indicator. These present the least problem of all. The DGI has no direct magnetic input and is simply set by the pilot to whatever datum is required. Normally, this is magnetic direction. All that would be required would be that the pilot would have to apply the local variation every time that he reset the DGI, which is normally every fifteen minutes or so. The light aircraft community has nothing at all to fear from such a change.

Aircraft with a Direct Reading Compass only. For aircraft that have nothing but a magnetic compass, which is mainly the microlight community, the only real option would be to mentally apply variation. Generally, these aircraft tend not to fly much more than, say, 100 miles from their home bases and it is a simple matter to remember just one value of variation and apply it every time.

4 THE CASE FOR CONVERTING

The case for converting to True as the datum for aviation instructions, procedures and control is clear, and the only problems would be those of practically implementing it. Whilst it would be a huge and costly undertaking, it would also be a one-off operation which, once completed, would be final, unlike the present situation which is also costly, but is constantly with us.

The biggest single problem in trying to implement this change worldwide would be inertia – the large number of countries involved and the difficulty of finding the will to all change at once. Some of these countries do not have a sophisticated aviation environment that could deal with this easily, and in others, the change might meet opposition from a conservative general aviation lobby. A foreseeable way that it could happen would be if a single country were to file a difference with ICAO and change unilaterally. Once they had proved that it worked without problems, we might then expect others to follow progressively.

IAIN takes the view that the case for converting to True North as the datum for aviation instructions, procedures and control is clear. The only problems would be the practical ones involved in implementing such a change. While it would be a huge and costly undertaking, it would also be a one-off operation, which, once completed, would be final, unlike the present situation, which is also costly, but is constantly with us.

Several Air Navigation Service Providers have conducted studies in the previous years. Those have also included live test flights. The results have all been in favour of the change.

5 CONCLUSION

The air navigation service provider of Canada has recently decided to make the change to True tracks in the year 2030. The associated Concept of Operations will be made available. Coordination efforts are underway in the Americas, Europe and elsewhere to implement the same changes.

Modern aircraft, surveillance systems and instrument flight procedures are all designed using True tracks. The practice of converting them to Magnetic all the time for no practical reason will be a thing of the past.

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EVOLVING ECDIS: GNSS PNT-BASED CONCEPTS TOWARDS SAFE AND AUTOMATED MARITIME NAVIGATION VENTURE

David Brčić*, **Srđan Žuškin, Serdjo Kos, Sanjin Valčić**

Abstract. *The study discusses the information- and task-centred concepts and possibilities of Electronic Chart Display and Information System (ECDIS), which may facilitate the navigation venture and ease the workload of the Officer of the Watch (OOW). The concepts refer to the development of Global Navigation Satellite System (GNSS) Positioning, Navigation and Timing (PNT) (basic) services relating to main navigational tasks the system is used for or relies on. The proposals represent potential design and foundations for future outlooks of the system, in line with emerging maritime concepts such as digital vessels, cloud-based technologies and e-Navigation, always in the function of safety of navigation improvement.*

Key words: *decision support systems; ECDIS eho; electronic chart display and information system; GNSS PNT services; maritime navigation*

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1 INTRODUCTION AND BACKGROUND

The genesis of ECDIS resulted from the need for real-time tracking of vessels [3]. In the past four decades, the system developed to a complex, integrated navigational system accepted as primary navigational means. It represents synergy in the form of available navigational and non-navigational data integration and various supporting tools, automating current manual or semi-automated tasks **[1]**. It refers to the reduction of OOWs' workload in terms of safety of navigation, route planning and optimization, Electronic Navigational Charts (ENCs) purchase and updating, implementation of maritime-venture regulations, assisted services, additional data, and other navigational assistance means. It also applies to real-time positioning as one of the system's main features, Global Positioning System (GPS) being still the most common primary positioning source.

2 ECDIS CONCEPTS: NEW MARITIME NAVIGATION AND ROOM FOR IMPROVEMENT

Recent advancements in maritime navigation can be reflected, among other things, in integration and data fusion, task automation, voyage optimization, development of navigational data, sensor-based environment presentation and cloud-based navigation, to name a few. All these developments are leading towards new navigation concepts, with some features already present and some emerging. The GNSS PNT services act as a reliable and inviolable element for the further development of any critical application, especially considering the advanced PNT methods, as well as recent multi-constellations (**Figure 1**) **[6, 8]**. At the same time, the GNSS vulnerabilities – natural causes and especially intentional threats – must be particularly addressed.

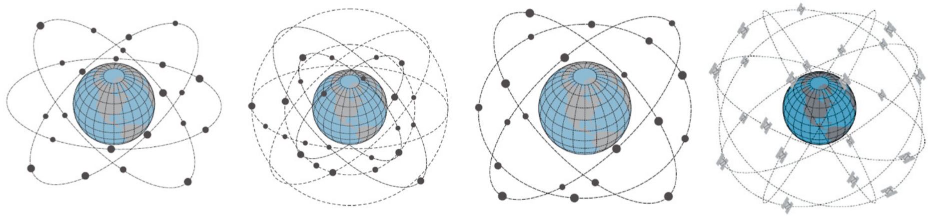

Figure 1. GNSS constellations (*from left to right*):
Galileo, BeiDou, GLONASS and GPS [8].

The aim of e-Navigation is to make maritime navigation and communications more reliable and user friendly, with the overall goal to improve safety of navigation and to reduce errors. The key points of e-Navigation are [4, 2]: *i)* improved, harmonized and user-friendly bridge design; *ii)* means for standardized and automated reporting; *iii)* improved communication of VTS Service Portfolio; *iv)* improved reliability, resilience and integrity of bridge equipment and navigation information; and *v)* integration and presentation of available information in graphical displays received via communication equipment. The mentioned initiatives and activities represent, to a certain extent, the path towards fully digital vessels and autonomous navigation.

However, there is a certain amount of points which represent challenges towards autonomy, sensor fusion, control algorithms, communication and connectivity and cyber security [7]. Regarding the e-Navigation concept, the emerging risks can be generally classified as lack of standardization on board and ashore, incompatibility between vessels, an increased and unnecessary level of complexity and security threats [4, 5].

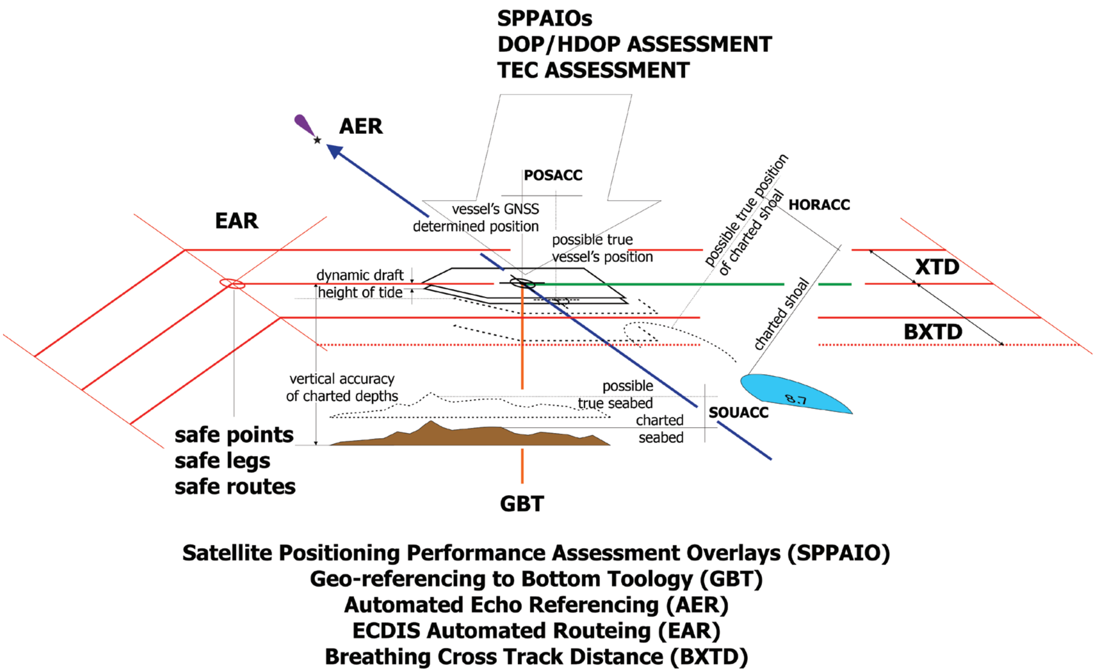

Figure 2. Concepts and possibilities of additional ECDIS presentation features.

In the midst of the mentioned development, the OOW is still considered as the ultimate decision-maker. This brings, or rather *keeps* the ECDIS system to the fore, given it represents the primary navigational means on-board vessels and beyond; the emerging features make it a decision support tool and the trademark of the forthcoming changes. Regarding the previously mentioned new navigational key points, specifically those related to navigational information and graphical presentation, the system improvements can be achieved in several directions. Conceptual features overlaying the ENCs are presented in **Figure 2**.

The features can be named as Automated Echo Referencing (AER); Geo-referencing to bottom topology (GBT); ECDIS Automated Routeing (EAR); Satellite Positioning Performance Assessment Information Overlays (SPPAIOs); Space Weather Information Overlays (SWIOs); Breathing Cross Track Distance (BXTD).

3 DISCUSSION AND CONCLUSION

All presented features, except from GBT, can be derived from basic PNT services and GNSS performance and they can be presented as a constant feed, forecast, additional data layer, etc. Here, the GNSS PNT performance is considered as crucial, providing essential information, and at the same time, the same performance is observed as a matter of additional care. The resulting loop, by development and usage of proposed concepts, contributes to OOW's situational awareness and timely and proper actions during the navigation venture.

ACKNOWLEDGMENT

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UNCERTAINTY ANALYSIS OF WEATHER SIMULATION MODELLING DURING NAVIGATION

Ivan Sulovsky*[1], Jasna Prpić-Oršić[1] , Kenji Sasa[2], Chen Chen[3]

Abstract. *Nowadays, the aspect of environmental protection is becoming increasingly important, as the community is putting strong pressure on those who have the potential to reduce pollution by reducing greenhouse gases (GHG) emissions. One of the most important factors in maritime transport is the weather, but the assessment of weather conditions is not clearly defined. They directly affect the motions and loads of the ship in rough seas, as well as ship speed and fuel consumption. This paper presents a six-year investigation (2010-2016) and a comprehensive measurement campaign on a 28000 DWT class bulk carrier.*

Key words: *decision support systems, ship navigation, uncertainty analysis, wind and waves*

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1 INTRODUCTION AND BACKGROUND

The ship, known as the "tramper" had no fixed route and sailed frequently in the Southern Hemisphere for six years. Throughout the whole period, navigational parameters such as weather data, wave data, engine data, voyage data, and motion data were measured. Chen et al. [1] performed a comparative analysis with WRF numerical models using measured data. To evaluate the accuracy of the given results, a statistical analysis is presented using conventional statistical measures such as standard deviation, root mean square error, etc. Also, spectral density peak factor is proposed as a quick quantitative measure of wind and waves using fast Fourier transforms.

2 METHODOLOGY

Statistical parameters are introduced to indicate the relevance of the calculated data in relation to the measured ones, such as the mean deviation, variance, standard deviation and correlation coefficient, shown in **Figure 1**.

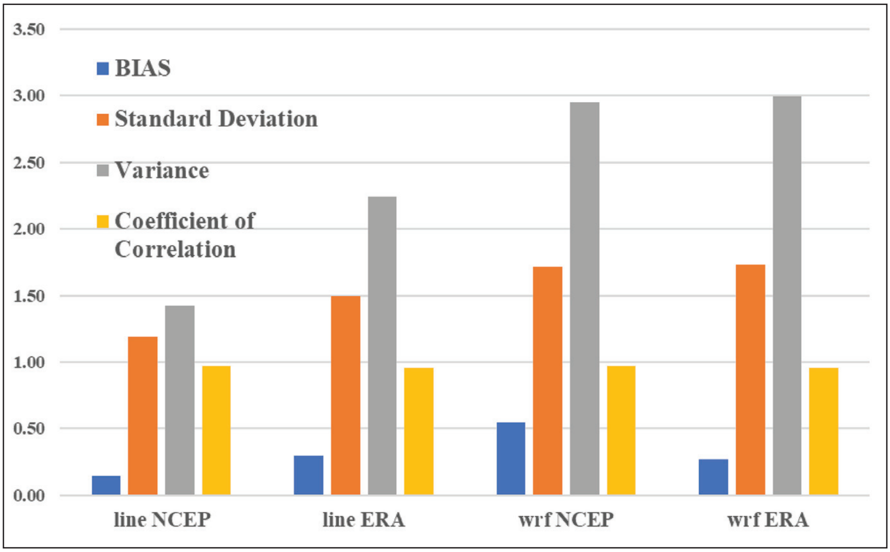

Figure 1. Statistical parameters for wind numerical models.

Furthermore, an uncertainty analysis was performed using Fast Fourier transforms, to analyse the peaks of the spectral density plots of wind and waves. Their dissipation over the ordinate axis gives an overview of the similarity and, where possible, the accuracy compared to the measured data.

3 RESULTS AND DISCUSSION

For wind speed and wave heights, statistical analysis showed satisfactory accuracy. However, for the direction wind and waves direction, the data are somewhat more scattered.

4 CONCLUSIONS

The main value of this work is to provide a better insight into the uncertainties in the development of on-board decision support systems. In this paper, measures for evaluating the uncertainty of weather predictions are given. The most important feature of the proposed measures is the efficiency and speed of computation, which is a key feature in decision-making process on a ship's bridge.

ACKNOWLEDGMENT

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ACCIDENTAL MARINE POLLUTION PREPAREDNESS AND RESPONSE AT SEA

Đani Šabalja, Marko Đorđević*, Marko Strabić

Abstract. *According to the intervention plan, proper action of the operational staff will accelerate the actions of removing oil from the sea surface. By presenting significant maritime accidents throughout history, lessons are adopted that enable us to rehabilitate oil from the sea surface in the future successfully. The number of maritime accidents is declining today compared to the previous twenty years. However, maritime accidents occur daily, resulting in marine pollution, and pollution prevention is paramount. By inserting meteorological and external factors variables into the specialized program ADIOS, the properties of oil are graphically shown in real-time, which facilitates the development of an intervention plan for a possible maritime accident. Creating an intervention plan in this way raises the factor of protection of the marine environment.*

Key words: *accidental pollution; Adriatic Sea; maritime traffic; weathering processes*

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1 INTRODUCTION

Today, the transport of goods and cargo by sea is the most economical transport branch [1]. Some types of cargo require special attention during transport and handling during loading and unloading of cargo in ports [2]. In world transport by the sea, we encounter various types of cargo with different properties. Each pollution affects flora and fauna differently. Pollution of the sea with oils from liquid cargo ships has the most significant effect of damage to flora and fauna [3]. For this reason, it is imperative to assess the possible dangers of spilling oil on the sea surface. The transport of liquid cargo is increasing every day. With more oil transported by sea, the risk of pollution also increases. Liquid cargo tankers have significantly influenced marine ecology in the course of history. Oil transported by tankers can have far-reaching consequences on a country's economy [4]. Preventing the spread of oil when moving on the sea surface is crucial.

2 METHODOLOGY

The research aims is to present the dangers of accidental marine pollution from liquid cargo ships. Using the ADIOS program, the model shows the main properties of oil over time (weathering processes) which provides an optimal solution to reduce the risk of handling a particular type of oil. Furthermore, the GNOME software tool was used to simulate the movement of oil on the sea surface. Knowing the movement of oil on the sea surface is very important when installing specialized equipment [5]. The risk is a function of the probability of an adverse event and the consequences that that event will cause. From this follows a mathematical representation of risk [6].

$$R = f(p,C) \tag{1}$$

From the formula, the notation p indicates the probability of occurrence of a specific event, while the notation C implies the consequence caused by accident. Numbers between 0 and 1 express the numerical representation of the probability of a specific event, i.e., the probability of any event that will occur is between 0% and 100%. For mutually exclusive events, the probability that any event will occur is the sum of the probabilities of the individual events. From this follows a mathematical representation [7].

$$P(E_1 \cup E_2) = P(E_1) + P(E_2) \tag{2}$$

The probability of a collision between two ships is also determined by the traffic density in a specific area [8].

3. RESULTS AND DISCUSSION

It can be seen from **Figure 1** that a quick reaction to non-persistent oils is not necessary because oil evaporates quickly. In contrast, intervention is mandatory for persistent oils. **Figure 2** shows a model of predicting the movement of oil pollution on the sea surface. Predicting the movement of oil using the GNOME program is as follows: surface currents affect the movement of the oil slick up to 97% in the direction of the current, and if the wind acts simultaneously (3%), the oil moves in the direction of the resultant of these forces. The first steps of intervention in the event of accidental sea pollution are crucial. Reaction rates with equipment are vital to prevent the further spread of contamination.

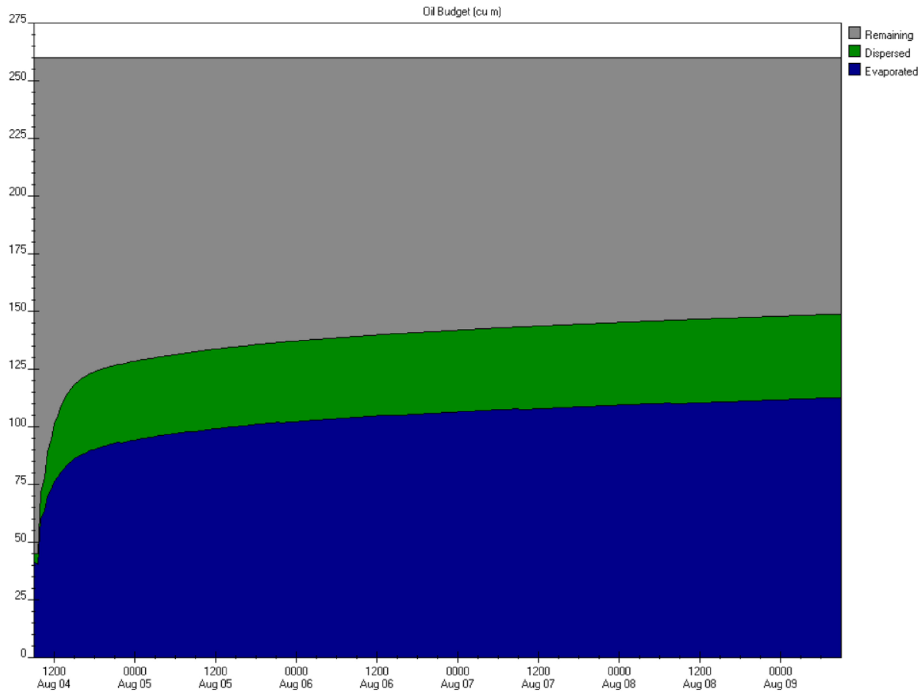

Figure 1. Fate of a typical crude oil – Arabian Light

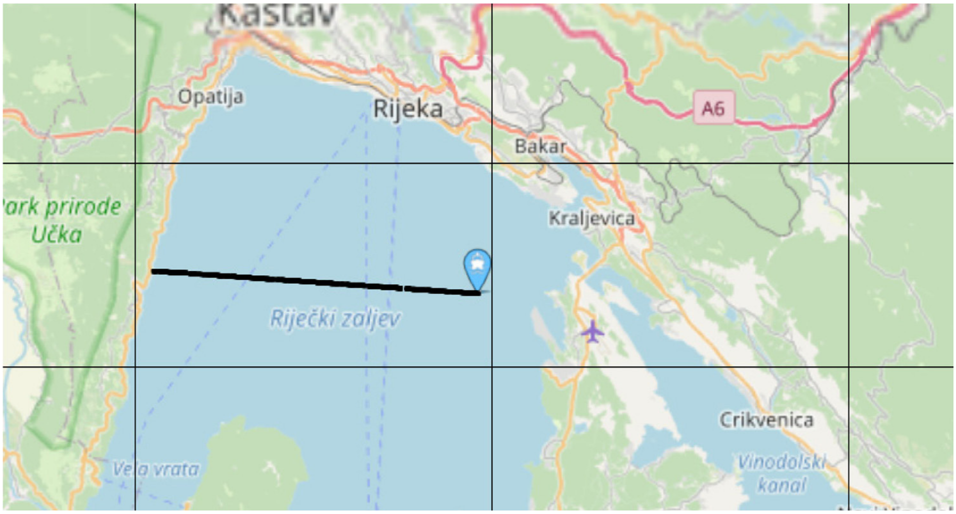

Figure 2. Simulate oil movement using the GNOME program

Also, boom for prevention of pollution cannot retain oil at higher speeds of sea currents of 0.6 knots. This means that the boom, in this case, will not give results and will not be used. Due to the proximity of ecologically significant resources also chemical dispersants are excluded as an option to respond to marine pollution.

4 CONCLUSIONS

Rapid intervention in case of marine pollution and proper equipment accelerates the spread of oil by sea. Maritime accidents occur daily and the risk of pollution is always present. In the research, the first weathering process shows us the main features of spilled oil in real-time such as evaporation, dispersion, viscosity, and all the above parameters help in deciding on the selection of appropriate specialized equipment to respond to marine pollution, in this example, the Rijeka Bay. Also, the model presented in the paper most closely calculates the oil movements that can reach the sensitive area of Mošćenička Draga with beaches that are important for tourism in the Republic of Croatia. Following that, the disadvantages and advantages of the available equipment are stated, and on that basis, the proposal of the optimal equipment for pollution prevention is given. The research conducted and presented in the paper can be of crucial importance in deciding how to prevent pollution and serve in the development of the National Plan for Intervention of Marine Pollution.

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BALLAST WATER ALTERNATIVES

Nina Kostović*, Mate Barić, Luka Grbić

Abstract. *To eliminate the introduction of foreign marine species which are nowadays the main concern and reason for the introduction of ballast treatment systems, a new concept in ship design was developed as an alternative. Most of them are still more theoretical than practical, except one concept. Scientist at the University of Michigan created "continuous flow" method as a replacement for the classic ship ballast. This concept is designed to replace double bottom tanks with the network of trunks running from bow to stern, below the waterline. The opening at the bow and stern allows water to pass through these channels which reduces ship buoyancy, instead of weighing it down.*

Key words: *ballast water; continuous flow; invasive marine species; trunks*

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1 INTRODUCTION

In order to maintain the stability and safe operation of the ship, ballast water is used to trim the vessel and obtain a predetermined draft. To eliminate the introduction of invasive marine species in ballast tanks and the disadvantages of ballast water treatment system, many manufacturers, researches and professionals are seeking alternatives to existing systems. Alternative concepts can be classified according to the operation method in two main groups:

- no ballast or zero discharge methods,
- continuous flow method.

Most research has been conducted in the area of the latter one.

2 METHODOLOGY

The analysis of current work on the topic of alternative ballast system and the level of probability of their application in real conditions have been used in this study together with the information gathered on websites about naval engineering and innovations in shipping industry.

3 RESULTS AND DISCUSSION

All ballast water alternatives have one benefit in common, they avoid all costs of Ballast Water Treatment. Most of them include new hull designs (monomaran hull, tri-hull concept, V-hull concept) or changes in the existing ballast water tanks (use of smaller tanks to control trim and stability, use of potable water). One concept suggests the use of solid ballast (25-ton TEU containers). However, the suggested methods are costly and many vessels would require a major hull reconstruction to accommodate them. Continuous flow method replaces double bottom tanks with a set of longitudinal tanks or trunks. Water is flowing in trunks, fully exchanging water in them every 1 – 2 hours when a ship is in motion. The difference in pressures between the bow and stern is used to drive water through the trunks without pumping. This concept is more suitable for ships that operate either in loaded or ballast condition (bulk carriers, tankers).

4 CONCLUSION

Ballast free vessels would have extended service life without the threat of corrosion caused by sediment build-up in ballast tanks. Course-keeping capabilities would be improved, negative impact on ship's stability (without free-surface) would be avoided and DW increased. The major problem is lack of regulatory pressure and strong conservatism in the shipping industry are holding back ballast-free shipping. Operators are not encouraged to introduce these major changes due to concern about ship seaworthiness. Introduction of ballast – free water systems is still postponed; however, their usage may change in the future. Nevertheless, creation of ballast-free ship far exceeds the disadvantages.

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WAVELET TRANSFORM NEURAL NETWORK CLASSIFIER FOR ELECTRICAL FERRY POWER DISTURBANCE CLASSIFICATION

Luka Draščić, Aleksandar Cuculić, Ivan Panić*, Jasmin Ćelić

Abstract. *Hybridization and electrification of ferry-based transport aims to reduce environmental impact caused by conventional power generation methods used on conventional ferries. Diversification of ship's power generation and distribution systems, use of alternative power sources, energy storage solutions and voltage and frequency converters can have a negative impact on electrical power quality and complicate detection and identification of electrical faults. This paper proposes the method for identification and classification of such faults based on wavelet transform decomposition and neural network classifier.*

Key words: *electrical ferry; fault classification; neural network; wavelet transform*

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1 INTRODUCTION

One of the primary activities of blue economy in Europe is focused on social and economic aspects of maritime transport. Ferry-based transport of passengers, vehicles and other goods in Europe makes up over 70% of the entire global ferry traffic [1]. Increase in ferry transport can improve economic growth, but it is also accompanied by increased environmental impact and air pollution [3]. Primary means of propulsion and electrical power generation and distribution on-board conventional ferries are static frequency converters powered by marine diesel engine driven synchronous generators. This method of on-board power generation is robust and enables stable and frequent navigation scheduling, but it also poses challenges with respect to environmental considerations, regulations and standards [2]. Increase in environmental demands has encouraged research in ferry propulsion system and power generation system electrification and hybridization with focus on renewable power sources and energy storage solutions [5-7]. Conventional ferry power system is well known with established electrical protection schemes and power management system. Hybrid and fully electrical ferry power topologies are significantly more complex and require development and additional research of new solutions for supervision, control and protection of diversified power system during islanding, cold ironing, or shore charging. In order to ensure correct power flow, these topologies often use multiple voltage and frequency converters that can have significant impact on power quality [4]. One of the primary issues in improving power quality of the ship power grids is detection and identification of electrical faults. Correct classification of electrical signals depends on the identification and selection of relevant features that can serve as an input to the classifier. Best known methods for signal decomposition are Fourier transform and short-time Fourier transform that decompose the signal in the frequency domain. These can provide good results [8, 9] but cannot describe the signal in both frequency and time domain simultaneously. Wavelet transform decomposition enables signal analysis in systems with non-uniform bandwidth and allows access to localized signal information both in time and frequency domain.

2 METHODOLOGY

This paper considers following three-phase disturbances: voltage sag, oscillatory transient, harmonic distortion, and voltage notches. Over 200 signal samples were artificially generated for each disturbance type. All signals were decomposed using *db1, db4* and *db6* wavelet transform with five detail coefficients and one approximation coefficient. Standard deviation, entropy and skewness were calculated. Shallow neural network with 18 input neurons, 3 hidden and 6 output neurons was used as a classifier.

3 RESULTS

Neural network classifier based on db6 wavelet transform signal decomposition gave the best results with clear differentiation of signal categories. Voltage notch classification is the most improved disturbance category when compared to *db1* and *db4* decomposition neural network classifier. Example of oscillatory signal wavelet *db6* decomposition and neural network confusion matrix are presented in **Figure 1**.

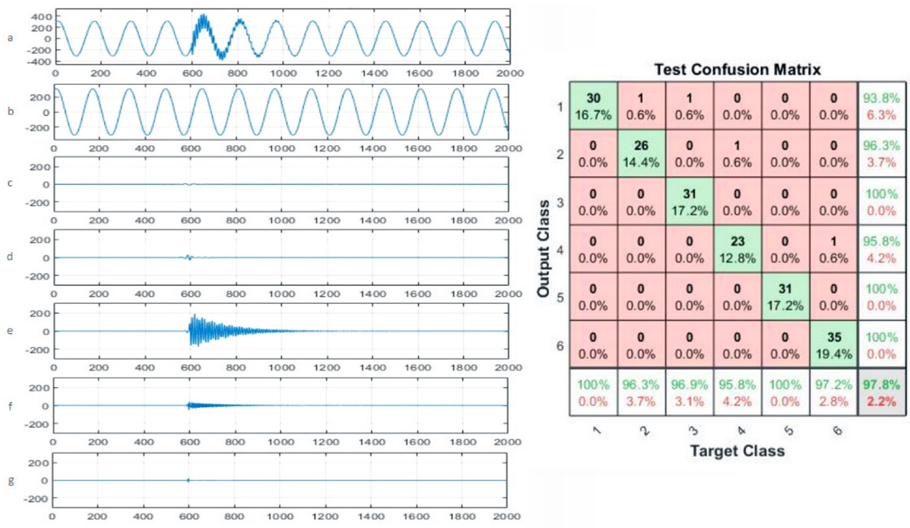

Figure 1. Oscillatory signal decomposition using *db6* wavelet transform (left); Neural network *db6* wavelet transform classifier confusion matrix (right).

4 CONCLUSION

This paper presented the methodology for identification and classification of three phase disturbances for the use in hybrid and electric ferry power systems. Wavelet transform signal decomposition based neural network classifier was developed and evaluated as it can analyse non-uniform bandwidth signals simultaneously in time and frequency domain. Best performance was measured on *db6* based classifier with clear differentiation of all disturbance categories.

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VERTICAL MOTIONS RMS PREDICTION FOR SMALL CRUISES CONCEPT DESIGN

Samuele Utzeri[1], Luca Braidotti[*1], Jasna Prpić-Oršić[2]

Abstract. *During the concept design of a cruise vessel, the assessment of vertical motions is of the utmost importance to assure sufficient passenger comfort. However, this task is not straightforward since, usually, the hull forms are unknown at the very beginning of the design process. Here, a method is proposed to predict the vertical motions from a set of relevant dimensions and coefficients defining a small cruise ship. The method employs the Multiple Linear Regression (MLR) methodology to assess the RMS of the motions exploiting a database of small cruise vessels in the full-load condition.*

Key words: *concept design; multiple linear regression; RMS; seakeeping*

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1 INTRODUCTION

Due to the complexity of the ship design [1], Multi-Attribute Decision-Making (MADM) techniques can be used during the concept design to select the best possible design [2]. The core of these systems is a mathematical model mapping the variable space into the attribute space. Usually, the main geometrical parameters of a ship are taken as variables, whereas the attributes are representative of the key performances for quality assessment and ranking of the design alternatives. Considering a small cruise ship, seakeeping capabilities shall be considered to assure passenger comfort. The present work aims at building a metamodel to assess the seakeeping performances of a ship (RMS of pitch and heave) based on main non-dimensional geometric characteristics.

2 METHODOLOGY

The metamodel has been developed using a database of small cruise ships including 58 ships defined according to the Design of Experiments (DoE) with different L/B, B/T, CX and CP. These ships are supposed to operate in the North Sea, i.e. in areas 4 and 11 as defined in [3]. To properly cover the annual diagrams, 7 zero-crossing periods Tz were selected ranging from 4.5 s to 10.5 s with 1 s increment. Three ship speeds were examined in the full load condition: 10, 15, 20 kn. Then, RMS values of heave and pitch were calculated for head sea employing the strip theory (Frank method) and the Pierson-Moskowitz wave spectrum assuming unitary significant wave height. The results were used to develop the seakeeping metamodel employing the Multiple Linear Regression (MLR) methodology. The following non-dimensional independent variables xi were considered: L/∇1/3, L/B, B/T, CP, CWP, CVP, BM/B, BML/B, (LCB–LCF)/L, and Fn. The heave RMS has been made non-dimensional by dividing by L. All the variables from the database were normalised in the interval [–1,1]. The following full second-order model has been adopted:

$$y' = \beta_0 + \sum_{i=1}^{k} \beta_i x_i' + \sum_{i=1}^{k} \beta_i x_i'^2 + \sum_{i=1}^{k} \sum_{j=1, j\neq i}^{k} \beta_{ij} x_i' x_j' \quad (1)$$

Where the ′ stands for normalised variables. The coefficients β were selected using the stepwise selection and assessed through the least-squares method [4, 5].

3 RESULTS AND DISCUSSION

The methodology has been applied, obtaining very good results (R2adj ranging from 0.74 to 0.99). To validate the metamodel, a test vessel was chosen outside the database used for regression analysis but inside the design space covered by the database. **Table 1** shows the comparison between the RMSs values combuted with strip theory (obj) and the ones estimated with the metamodel (est) for V=10 kn. The obtained errors are always below 10% and are usually greater at low periods, where the RMS absolute value is smaller.

Table 1. RMS heave and pitch absolute motions, V=10kn

T_z (s)	Heave			Pitch		
	RMS_{est} (m)	RMS_{obj} (m)	error (%)	RMS_{est} (m)	RMS_{obj} (m)	error (%)
4.5	0.020	0.021	-6.63	0.047	0.050	-4.57
5.5	0.047	0.050	-7.05	0.114	0.120	-4.80
6.5	0.080	0.084	-5.16	0.180	0.186	-3.01
7.5	0.108	0.115	-6.22	0.226	0.223	1.25
8.5	0.132	0.140	-5.32	0.237	0.234	1.29
9.5	0.155	0.160	-3.07	0.241	0.230	4.75
10.5	0.174	0.175	-0.93	0.227	0.216	5.32

4 CONCLUSIONS

In conclusion, the results and their accuracy are satisfactory for the concept design stage where uncertainty of 10% is widely considered acceptable. Thus, the developed metamodel can be used to assess and compare vertical motions of small cruise ships within MADM methods. In future works, the proposed methodology could be extended by considering relative motions RMSs or by building regressions of the transfer functions.

ACKNOWLEDGEMENT

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IMPROVING THE SHIP PROPULSION EFFICIENCY BY PROPELLER MODIFICATION AD OPTIMIZATION PROCEDURES

Josip Orović*, **Marko Valčić, Josip Mijatov, Mladen Čirjak**

Abstract. *Decarbonisation and energy efficiency measures, which aim to reduce greenhouse gas emissions in the upcoming years, are now more than ever in the focus of the maritime industry. Scientific researches recognise the relation between the propeller shape/class, fuel oil consumption, vibration intensity and ship's speed, but it is still not completely analysed. The project "Improving the ship propulsion efficiency by propeller optimization" aims to research possible fuel savings, vibration and exhaust gas emissions reduction as well as other positive impacts on the ship's propulsion system by optimizing her propeller(s). The final aim of the project is the development of the computer program for the ship's propulsion system condition diagnosis and predicting the amount of savings that can be achieved by optimizing the propeller with respect to the desired class.*

Key words: *exhaust gas emissions; fuel oil consumption; propeller modification; propeller optimisation; propulsion efficiency; vibration analysis*

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1 INTRODUCTION

Ship propellers are manufactured mainly by casting. This is the cheapest way of manufacturing, but the mechanical properties of the materials obtained by this technique are not ideal. Air pockets, micro cracks, non-homogeneity, different cooling methods and other factors contribute to the fact that the properties of such propellers are sub-optimal [1]. Another way to manufacture propellers is by using the CNC machine to cut the metal into the desired shape. This is a much more expensive and slower technique but also not the perfect one [1]. The results is that the new propeller, which has just been mounted on the propeller shaft and has never been at sea, is not so perfect. There are deviations from the ideal axes and tolerances that do not correspond to the manufactured ones. The existing propeller classes arranged in descending order are S, 1, 2 and 3, where S denotes the best propeller class and 3 the worst one [2]. The differences in the classes are in the manufacturing accuracy, i.e. the tolerance and the deviation of the propeller pitch from the theoretical one. The purpose of the project "Improving the ship propulsion efficiency by propeller optimization" is to research and further explain how propeller optimisation procedures, aiming to obtain a better class, can reduce fuel oil consumption, greenhouse gas emissions, ship vibrations and improve the overall propulsion efficiency of the ship.

2 METHODOLOGY

The research activities on the project will last for about 30 months and will be carried out on different types of ships. Project realization can be divided in several steps. The first step is to measure the ship's parameters in the current state at different engine loads before the dry-dock. With the Testo 350 Maritime exhaust gas analyser (**Figure 1**) [3], Falcon (**Figure 2**) [4] and Recovib Tiny [5] portable vibration analysers/instruments, portable or ship's fuel oil consumption sensors and position/speed instruments the data will be measured and analysed. Next step is to remove the propeller and perform a 3D scan (**Figure 3**) and numerical analysis [2]. Subsequently, the optimisation of the propeller shape in order to modify it to the desired class will be performed (**Figure 4**). After the propeller shape modification to the desired class and the on-site installation, the measurement of the ship's parameters with the optimized propeller can be performed. The final step is to analyse the measured parameters before and after the propeller optimization and modification process in order to see how this process contributes to the improvement of the measured parameters. As an upgrade to the mentioned process, it is also planned to develop a new service. In addition to class optimization, research will be conducted using CFD software and equipment that will redraw the 3D model to the smallest details. The aim is to analyse how the propeller shape, number of blades, diameter, pitch ratio, rake, skew and other factors will influence the propulsion efficiency [6], [7].

Figure 1. Testo 350 Maritime flue gas analyser.

Figure 2. Acoem's Falcon vibration analyser.

Figure 3. 3D propeller scaning.

Figure 4. Propeller shape modification.

3 RESULTS

Research studies on propeller optimisation are very limited so data obtained by this research will help in creating more relevant database and offer the possibility to enhance the propulsion efficiency. The research results will give insight into ship speed gain and fuel oil consumption and vibration reduction due to propeller optimisation and modification. The project results will serve as a base for the future research on the above-mentioned topic, help creating a larger database of ships with optimised propellers and could significantly contribute to greenhouse gas emission reduction. In addition, the development of appropriate computer program for this purpose will give a customer a unique service and a great decision support tool. This service will be a novelty in the global market because it will offer customers an information on propeller condition before and after the modification, as well as on the fuel oil consumption before and after the optimisation procedures.

4 CONCLUSION

The project results will show how propeller design and manufacturing processes are significant to ship's speed, fuel oil consumption and ship vibrations. Furthermore, this data could be used for various propeller optimisation procedures. The results of the research could be of interest to shipowners, ship operators, ship engine and/or ship propeller manufacturers, environmentalists and all other interested parties in the process of reducing the fuel oil consumption, ship vibrations and emissions of greenhouse and harmful exhaust gases into the atmosphere.

ACKNOWLEDGMENT

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APPLICATION OF ADVANCED DIGITAL TECHNOLOGIES FOR AIS DATA UTILIZATION

Nikola Lopac*[1,2], Irena Jurdana[1], Nobukazu Wakabayashi[3], Hongze Liu[3]

Abstract. *The Automatic Identification System (AIS) uses Very High Frequency (VHF) to communicate navigational information among vessels and between vessels and shore. This work presents recent research on the application of advanced digital technologies for additional utilization of AIS data in support of navigation, including microservices architecture-based platform for providing maritime data, a novel data compression method for use in transmission of large quantities of shipboard data required in future autonomous vessel operation and the possibilities of the application of some more advanced computational methods, such as machine learning, in AIS data analysis.*

Key words: *Automatic Identification System (AIS); digital technology; e-navigation; maritime communication system; maritime transport*

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1 INTRODUCTION AND BACKGROUND

The Automatic Identification System (AIS) is a communication system that allows vessels equipped with receivers within a defined communication range to communicate vessel identification and navigational information [1, 2]. Its operation is based on the Very High Frequency (VHF) band and Self Organizing Time Division Multiple Access (SOTDMA) transmission protocol [1, 2].

2 METHODOLOGY

The primary purposes of the AIS include simplified information exchange and vessel identification, as well as assistance in target tracking, situation awareness and search and rescue operations [1]. The information transmitted by shipborne AIS includes dynamic, static and voyage-related information [1, 2]. Thus, the AIS has contributed to increased navigation safety and improved surveillance from land.

This work addresses some recent studies on expanding the application of the AIS and even better utilization of available data.

3 RESULTS AND DISCUSSION

The mandatory use of AIS has been regulated by the International Convention for the Safety of Life at Sea (SOLAS) since 2008 [3]. However, not all vessels are required to carry AIS, which prevents them from receiving other vessels' navigational information and makes it difficult to detect them using passive systems due to their smaller size. Therefore, in [4], a lower-cost, sustainable platform for providing AIS and additional maritime information was developed. The platform was based on the microservices architecture and consisted of data centers and vessel and land stations. It was able to function independently with different types of existing AIS onboard equipment, as well as via the Internet connection to land stations collecting and storing AIS data to data centers.

Moreover, the increased digitalization and development of autonomous vessels, particularly in their sustainable operation [5], significantly increases the amount of maritime data [6] required to be transmitted in real-time via maritime communications, still characterized by slower communication speeds. In [7], a shipboard data compression technique based on differential binary encoding was proposed and experimentally validated on actual vessel data, significantly reducing the required data transmission rate.

Finally, the rapid development of machine learning techniques in recent years opens up the possibility of applying these advanced computational methods to AIS data, with several recently conducted studies addressing a range of diverse applications [8, 9].

4 CONCLUSIONS

This work presented recent research on the application of some advanced digital technologies for improved AIS data utilization in support of safe and efficient maritime transport. Moreover, the potential of applying some machine learning-based techniques combined with the available data is also pointed out.

ACKNOWLEDGMENT

This work was supported by the University of Rijeka, Faculty of Maritime Studies, under the project "Advanced Computer Methods for Digital Signal Processing and Object Detection".

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ROLE OF HYDROGEN IN DECARBONIZATION OF MARITIME SHIPPING

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Abstract. *This analysis performed by Hydrogen Europe assesses the long-term viability of various hydrogen-based solutions for the full decarbonization of maritime shipping. The goal was to see what role can hydrogen produced from renewable energy sources play in reducing the greenhouse gas (GHG) footprint of international shipping, which solutions work best for which ship types and applications and what are the techno-economic barriers for wide adoption of hydrogen as a marine fuel.*

Key words: *carbon tax; decarbonization; hydrogen; hydrogen-based fuels (ammonia)*

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1 INTRODUCTION

Hydrogen and hydrogen-based fuels (such as ammonia) offer tremendous potential for the decarbonisation of the worldwide maritime fleet. This analysis shows that, depending on the ship type, for the CO_2 price to provide a sufficient incentive to switch from fossil fuel oils to zero-emission fuels, it would have to be between 100 EUR/tCO_2 to 250 EUR/tCO_2 as shown in **Figure 1**.

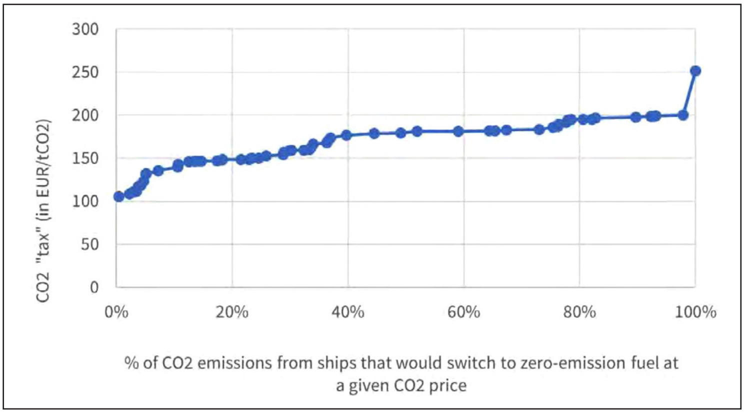

Figure 1. Shipping CO_2 emission savings as a function of the carbon tax [1].

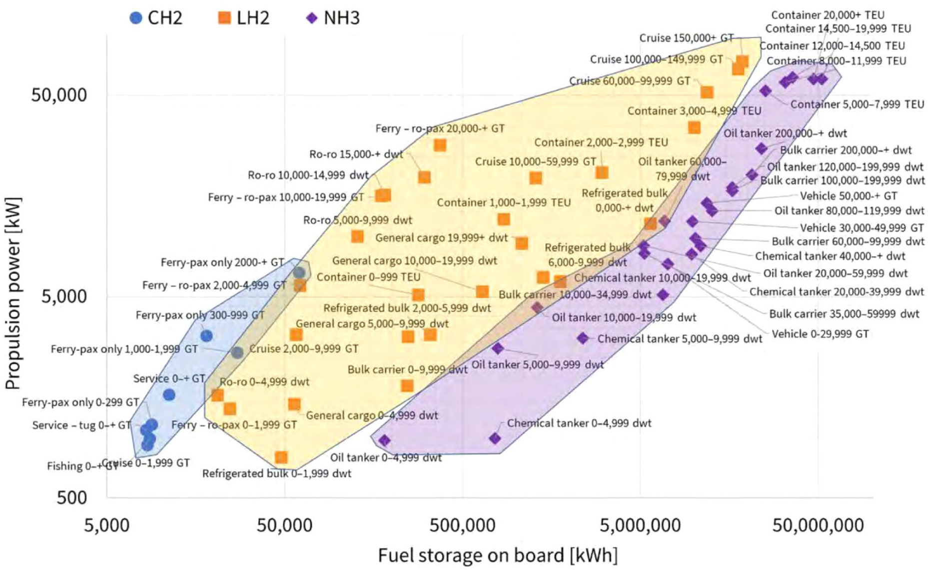

Figure 2. Optimum zero-emission propulsion option for various ship types [1].

In order for hydrogen to be competitive, even at a relatively low price of 2.4 EUR/kg, foreseen for 2030, a carbon price of 180 EUR/tCO_2 would mean extra fuel costs of around 560 EUR/t.

2 ANALYSIS

The analysis [1] took into consideration the size and operational profile of the ships, the costs of fuel, the costs of the required onboard equipment and the cost associated with the loss of cargo space due to the size of fuel storage. The three options that came out as the most cost-efficient are:

- Compressed hydrogen with PEM FC (proton-exchange membrane fuel cells) for relatively small ships with an operational profile that allows for frequent refuelling,
- Ammonia with SOFC (solid oxide fuel cell) for deep-sea shipping applications or smaller vessels with high-value cargo (e.g., chemical tankers),
- Liquefied hydrogen with PEM FC for every ship in between.

While liquid hydrogen seems to be the optimal solution for most ships, in terms of total energy demand, 91.4% of all fuels would be used by ships using e-ammonia, liquid hydrogen share would be 8.6% and compressed hydrogen below 0.1%.

3 CONCLUSIONS

Hydrogen and hydrogen-based fuels (such as ammonia) indeed offer tremendous potential for the decarbonisation of the worldwide maritime fleet, providing a significant carbon tax is imposed. Hydrogen has a much broader role in the decarbonization of the economy than just as a zero-emission fuel. It is the only sufficiently available and scalable technology enabling deep decarbonization across all sectors of the economy, which without hydrogen would be improbable and prohibitively expensive.

ACKNOWLEDGMENT

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ANALYSIS OF SIMULATED EXHAUST GAS EMISSIONS AND EMISSIONS MEASURED ON-BOARD RO-PAX VESSELS

Vlatko Knežević*, Josip Orović, Marko Valčić, Zoran Pavin

Abstract. *Quantification of exhaust gas emissions presents a great challenge due to diversity of engine and marine fuel types, various operation modes and new stringent environmental regulations. Onboard measurements are necessary for developing the emission database, but there is also a need for validation of simulated values. This paper presents an analysis of measured emissions on three RO-Pax vessels sailing in the Adriatic Sea and simulated exhaust gas emissions that were obtained using the Wärtsilä-Transas simulator model of the RO-Pax vessel during the joint operation of the engine room and navigation bridge simulators.*

Key words: *engine room simulator; exhaust gas emissions; marine diesel fuel; measurements; navigational simulator; onboard ship; RO-PAX vessel*

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1 INTRODUCTION

European Union has approved the new Regulation 2015/757 on the monitoring, reporting and verification of CO_2 emissions from maritime transport [1]. The Regulation includes monitoring and reporting exhaust gas emissions in the European Economic Area (EEA), especially CO_2 as greenhouse gas. International Maritime Organization (IMO) approved this example with a similar amendment – IMO Data Collection System, which requires ships larger than 5000 GT to report and record fuel oil consumption [2]. This emissions database was used in [3] for analysing emissions in 2018 from Ro-Pax vessels calling at European ports. The mentioned regulations and quantifications of emitted exhaust gases provides the first step for developing new strategies in terms of reducing shipping emissions.

2 METHODOLOGY

Testo 350 exhaust gas analyser [3] was used in this research for monitoring exhaust gas temperature and concentrations of CO_2 and O_2 as a percentage in a volume of dry exhaust gas, as well as CO, NO_x, SO_x in ppm in the dry exhaust gas. It operates in accordance with ISO 8178-4:2020, MARPOL Annex VI and NO_x Technical Code 2008 [4]. The onboard measuring process was carried out during the cruising phase of the voyages and the measuring equipment sampling point was located after the turbine wheel, in the exhaust duct. In **Figure 1**, the probe hole (small ball valve) for measuring equipment is presented and it is located approximately 0.2 m downstream from the turbocharger.

The scheme of the exhaust gas analyser setup for the main engine is shown in **Figure 2**. The measured raw data files are saved onto a device with an option to transfer it via Bluetooth or cable (wired) to the computer. All other relevant engine and vessel parameters for this research were also collected directly from instruments in the engine control room and navigational bridge during the measuring processes.

Three RO-Pax vessels were selected for the measuring process with similar main engine and propulsion plant parameters such as four-stroke main engines connected through reduction gearboxes to controllable pitch propellers (CPP). The emission data were collected during multiple voyages between the ports of Croatia, Italy and Montenegro and simulated emission data were recorded during voyages under different weather and engine conditions that are common for the Adriatic Sea.

Figure 1. Sampling point for measuring exhaust gases.

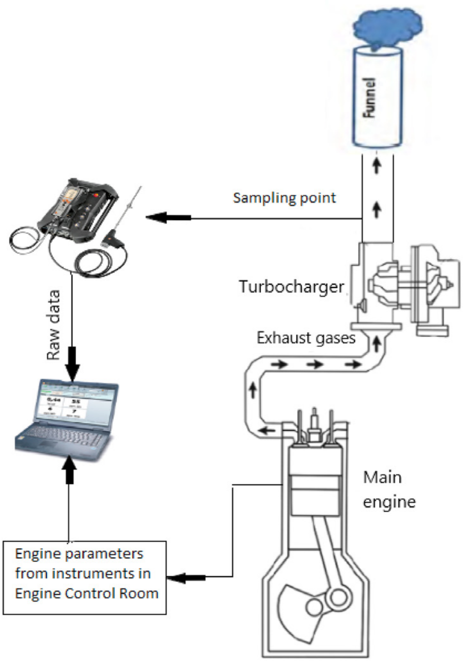

Figure 2. Scheme of the measuring equipment setup.

The simulated emission data were obtained using the Wärtsilä-Transas simulator model of the RO-Pax vessel, which is similar in engine parameters and other ship particulars with respect to previously mentioned vessels.

3 RESULTS

The obtained results and analysis of measured exhaust gas values and simulated emission data are presented in **Table 1**, with the goal to compare the emission data in order to detect similar emission data patterns.

Table 1. Comparison of emission data and engine parameters between Vessel 1, Vessel 2 and simulated vessel.

Vessel/Engine	% of MCR	CO_2d (%)	O_2d (%)	NO_xd (ppm)	COd (ppm)	t_{Ex} (°C)	SFOC (g/kWh)	λ
Vessel 1/Engine 1P	80	5.20	13.46	866	167	376.44	213	2.891
Vessel 1/Engine 1S	80	5.45	13.10	1114	135	391.54	213	2.761
Simulator/Engine	80	5.97	13.01	980	95	341.28	191	2.526
Vessel 1/Engine 2 P	74	5.67	12.87	1006	184	404.29	216	2.657
Vessel 1/Engine 2 S	74	5.79	12.70	789	198	411.22	216	2.603
Simulator/Engine	74	5.90	13.10	955	99	331.92	191	2.555
Vessel 2/Engine P	67	5.65	13.15	1218	166	331.32	205	2.666
Simulator/Engine	67	6.66	12.09	855	99	404.12	193	2.271
Vessel 2/Engine S	77	5.83	12.59	1314	165	356.58	203	2.585
Simulator Engine	77	5.93	13.07	968	97	335.43	191	2.543

The results were analysed under the same engine load for onboard measured values and in simulated scenarios. It can be noticed that almost all measured emission values are similar to the simulated ones, except during the lower engine loads (< 70% of MCR). This is due to lower turbocharger efficiency at lower loads and it directly influences on CO_2 and O_2 percentage in exhaust gases.

4 CONCLUSION

The results obtained during the onboard measurements and from the simulation process, with the same engine loads, are similar and can be used for further validation and development of quantitative models for exhaust gas emission estimation. In both scenarios, the exhaust emissions, i.e. the output variables, depend on the engine load, used fuel and environmental conditions. The results from one source could be used to validate another source in order to provide a relevant emission database and to plan new strategies for reducing the amount of exhaust emissions. Moreover, the results could be helpful for creating an additional emission database and improved estimation of exhaust gasses under various marine engine conditions.

ACKNOWLEDGMENT

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LESSONS LEARNT DURING COVID-19 CRISIS MANAGEMENT IN SEAFARING: A SRI LANKAN PERSPECTIVE

Samadhi Medawela Disanayaka[*1], Rohini Widyalankara[2], Prasanna Sedrick[1], Charith Tharaka[1], Harindra Perera[1], and Peshala Medagama[1]

Abstract. *This study is conducted during the period when the threat of the Covid-19 pandemic is diminishing. The physical well-being and mental health of 63 seafarers who have returned to Sri Lanka after being onboard a ship undergo a synchronic investigation in this study. The questionnaire collected data on basic demographic characteristics and the personal vaccination process, health and safety onboard, mental, physical and social well-being. The analysed results show that Covid-19 crisis management in the seafaring industry, as perceived by Sri Lankan seafarers, is satisfactory. However, resolutions to the crew change procedures on board and the repatriation process need attention.*

Key words: *Covid-19; experience on board; Sri Lankan seafarers; work conditions*

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1 INTRODUCTION

Though the intensity of Covid-19 is declining, lessons learnt during the global pandemic will create better awareness on the management of future maritime crisis situations. The seafaring industry is a demanding, high risk vocation. UN Secretary-General Guterres (2021) has stated "unable to go to shore, repatriate and change crews, and without access to medical care, seafarers face a humanitarian crisis that jeopardizes the safety and the future of shipping". United Nations too commends the work of two million seafarers in "extraordinarily challenging times" [3]. The Covid-19 pandemic, as stated in [2], has led the shipping industry and seaborne trade undergo a negative trend.

2 METHODOLOGY

Sampling: Nonprobability purposive cum convenience sampling where members of the target population were shortlisted based on easy accessibility, geographical proximity and availability. The total sample consisted of 63 seafarers recently employed in the shipping sector. They required CDCs and were following courses at CINEC Campus¸ Malabe, Sri Lanka. They were off board after their signoff. The ranks of the respondents included Masters, Chief Officers, 2nd Officers, Chief Engineers, 2nd Engineers, 3rd Engineers, Able seamen, Deck Hands, Oilers. Nationality of the population included Sri Lankans (n = 61), Filipino (n = 1), Ukrainian (n = 1). Mean value of contract period was 12.5 months.

Instrument: The questionnaire had 25 questions and received 63 responses. The respondents had served on 28 vessels including APL Columbus, African Goshawk, Berlin Bridge, CALA Piccola, Caledoni, Erisort, GFS Genesis, J U Parahahsn, KOTA Cabar, LM Nilwala.

The first section of the questionnaire, in *Google Docs*, contained basic demographic characteristics. The second section targeted obtaining information on work-related questions after embarkation.

3 RESULTS AND DISCUSSION

In line with [1], this study targeted multiple maritime areas for analysis. Question 21 was: 'Was health and safety being balanced adequately during operational demands on board?'. Responding to the question, only 28.6% of the respondents stated that health and safety were *Always* balanced adequately. It is disheartening to note that while the pandemic was spreading, more than 25% of the population did not maintain social distancing and did not wear masks while moving onboard. As indicated by Figure 1 below, approximately 50% of the respondents *Frequently/Very Frequently* carried extra workloads.

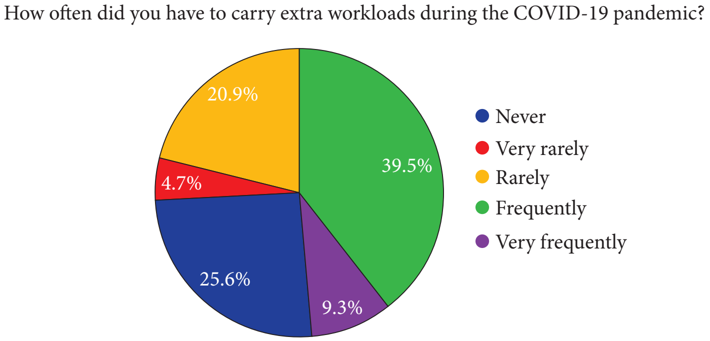

Figure 1. Frequency of carrying extra workloads.

The analysis in Figure 2 shows that 77.3% of the respondents claim that their expectation for repatriation was *Strong/Very Strong/Extremely Strong.*

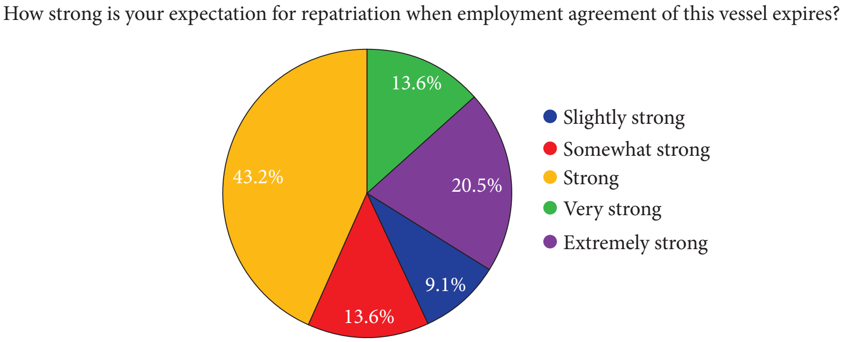

Figure 2. Expectation for repatriation.

4 CONCLUSIONS

It could be concluded, based on the findings of this study, that Sri Lankan seafarers claim that the industry handled the situation satisfactorily. Based on their information, feasible resolutions to the crew change procedures on board and streamlining the repatriation process are areas which need attention in future. Though the findings state that the shipping industry had handled the situation satisfactorily in view of Sri Lankan participants, it cannot be generalized to reflect the performance of the entire maritime industry nor the perception of the total population of international seafarers.

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DO BIOMETRIC MEASUREMENTS OF NAVIGATORS ON THE SHIP'S BRIDGE DURING A SIMULATED PORT APPROACH INCREASE SAFETY?

Dejan Žagar*, Blaž Luin, Franc Dimc

Abstract. *The paper presents an experimental study of navigators' biometric readings during a port approach manoeuvre. The aim was to determine a biometric response during a cognitively demanding phase. While participants were controlling a simulated ship entering a narrow channel, data were collected using wireless biometric wrist sensors and processed in order to analyse time delay and rate of change of participants' biometric responses. The results confirm statistically significant differences of biometric data before and during the manoeuvres.*

Key words: *biometrical readings; e-solutions; human computer interactions; human factor; safe navigation; VTS*

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1 INTRODUCTION

According to the reports of collisions which include human error actions [1], most incidents/accidents are due to the high cognitive load of ships' crew and/or their lack of situational awareness, despite all the modern navigational aids and instruments on the ship's bridge. This paper therefore presents an experimental study of a navigator's biometric response during a simulated navigation task measured with biometric sensors. The specific body response indicates the state of the process in working memory and can influence the participant's decision-making process.

2 METHODOLOGY

The aim of the experiment is to analyse the reaction time and the rate of change of the participants' body response in the demanding cognitive phase, which includes 15 seconds before entering the narrow channel and 15 seconds after entering the channel. The task consists of entering the port of Koper on a large container ship with a draft of 14 meters. The task is to navigate in a narrow channel, which is also dredged to 15 meters, so there is not much room for error. Six experienced captains, who have been at sea for an average of 11.7 years (std 4.7), volunteered for the experiment. They are all locals and familiar with local environmental conditions, including the port approach.

3 RESULTS AND DISCUSSION

Participants' normalized BVP values, indicating current relative blood flow during sessions, were recorded at the channel entrance for ± 15 seconds around time "zero" when the virtual line between initialization buoys was crossed. The average amplitude of the normalized BVP signals from all participants is 29.1. The peak amplitude, averaging 204.9, is measured in average of 10.8 seconds before time zero, indicating saturation of participants' working memory.

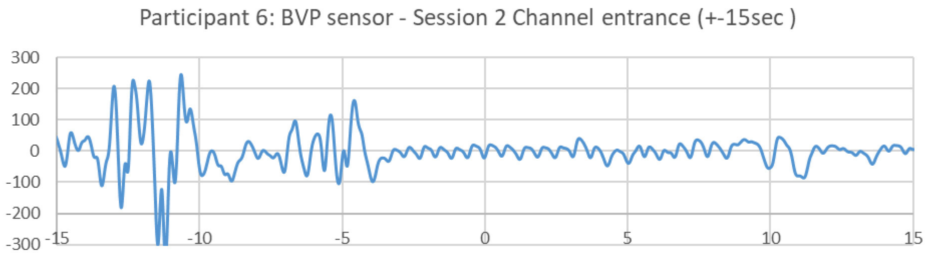

Figure 1. Normalized sequence of participants' BVP values during a 30-second sailing through a narrow channel. The readings show that participants exhibit a high response during the sequence, lasting an average of 6.2 seconds. The mean point of high response occurs 10.8 seconds before entering the channel, indicating the period of workload saturation.

4 CONCLUSION

While writing this paper, we submitted several proposals to the authorities of the port of Koper. These have been accepted and are already being implemented. For example, manoeuvres with these ships start a mile earlier so that pilots can prepare for entry, which reduces stress and increases safety. In addition, approach speeds are now limited to 6 knots. Our research shows that biometric data helps us identify the anomalies of typical human reactions on the ship's bridge during simulation, which has at least an indirect impact on maritime safety.

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IMPACT OF ENVIRONMENTAL LOADS ON SHIP SPEED BASED ON SIMULATED DATA

Zoran Pavin*, Marko Valčić, Josip Orović, Vlatko Knežević

Abstract. *In recent years, particular attention has been given to improve the efficiency of maritime transport and to reduce exhaust emissions into the ship's environment. Although the impact of environmental loads on ship speed has been extensively researched so far, this area should be given even greater importance. This is precisely the reason for choosing the topic of the impact of environmental loads on ship speed as the goal of the research in this paper. For the purpose of this research simulating of various conditions of external disturbances were performed with analysis of their impact on ship navigation parameters. Moreover, the analysis and discussion of the collected data were performed, and one practical example of a possible application related to the real-world ship economy analysis is given.*

Key words: *environmental loads; ship resistance; ship speed; simulation*

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1 INTRODUCTION

Environmental loads, i.e. disturbances that act on the vessel are caused primarily by the action of wind, waves and sea currents, but also by other unmodelled parts of the system dynamics [1]. Ship operational performance has to be evaluated in actual sea conditions where waves and wind exist as is stated in recent issues of the International Maritime Organization (IMO) regulation. Because of this, the weather factor fw, which represents the reduction in ship speed due to environmental loads, is incorporated in the energy efficiency design index (EEDI) regulation [2]. In order to calculate the added resistance of a vessel, i.e. the consequent involuntary speed loss in a seaway due to wind and waves, it is necessary to perform one of common experimental approach based on a model testing [2]. Another approach to this issue could be using a simulator model based on an actual vessel such as the one used in this research.

2 METHODOLOGY

Wärtsilä Navi-Trainer Professional 5000 (Wärtsilä NTPRO 5000) navigational simulator and Wärtsilä ERS-LCHS 5000 TechSim engine room simulator, owned by the Maritime Department of the University of Zadar, were used for the purposes of this research in joint operational mode. The modelled vessel is a RoPax ferry with twin four stroke medium speed non-reversible MAN B&W 8L32/40 diesel engines and controllable pitch propellers [3]. The ship model particulars are shown in **Figure 1**.

Area of navigation chosen for the simulations is the Adriatic Sea where the value of significant wave height was chosen as Hs = 3 m [4]. In order to cover the potential and more intense environmental loads, the simulated maximum significant wave height of Hs = 4 m was also taken into account. Along with the wave height, an equivalent wind speed was determined according to relations defined in existing literature [4] as shown in **Table 1** [5]. Analysed encounter angles of wind and waves, shown in **Figure 2**, were chosen from the following set $\gamma = \{0°, 20°, 35°, 120°, 150°, 180°\}$.

Table 1. Significant wave height and true wind speed relation based on [**Farkas et al., 2016**]

H_s (m)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
V_{wind} (kn)	11.8	16.8	20.7	24.0	26.9	29.5	31.9	34.1

	▪ Length, overall – 125 m ▪ Breadth, molded – 23.4 m ▪ Designed draft, molded – 5.3 m ▪ Service speed – approx. 19 knots
Propulsion: ▪ 2 x MAN 8L32/40 Four stroke, medium speed, turbocharged, non-reversible main diesel engine, MCR 4,000 kW at 750 RPM ▪ 2 x Controllable Pitch Propeller (CPP) ▪ CPP Bow Thruster 1000 kW ▪ 2 x Fin Stabilizers	
Electric Plant: ▪ 3 x Diesel Generator 600 kW, 450V AC, 60 Hz, 3 ph (diesel engine – CAT 3508B) ▪ 1 x Shaft Generator (PTO) 1160 kW, 450V AC, 60 Hz ▪ Emergency Diesel Generator 260 kW, 450V AC, 60 Hz	

Figure 1. RoPax ship model particulars

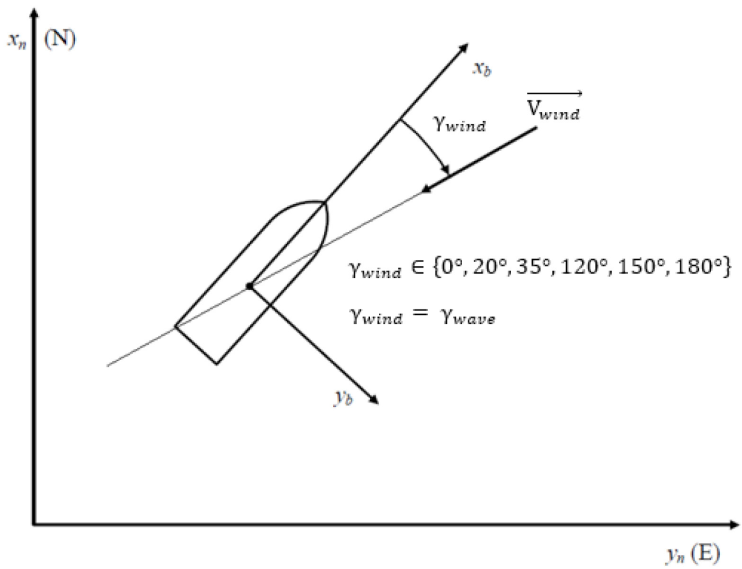

Figure 2. Encounter angles of environmental loads shown in ship coordinate system $\{b\}$ with respect to NED coordinate system $\{n\}$

Main engine load was set at 90% of maximum continuous rate (MCR). The recorded vessel speed parameter was speed through water (STW). In this research, the sea current parameters were ignored and set to zero values, thus the recorded vessel speed can also be viewed as a speed over ground (SOG).

3 RESULTS

The purpose of this research was to gain insight into ship speed loss due to environmental loads within the frame of conditions defined in the previous chapter. Therefore, the results of the research are presented exclusively through the reduction in ship speed expressed in knots. The acquired simulation data is shown in **Table 2**. Ship speed reduction was analysed with respect to the reference ship speed obtained in calm sea conditions with no wind or waves. For this particular ship, her reference speed in calm sea conditions was determined to be equal 17.28 kn under the 90% of MCR engine load.

Table 2. Vessel speed reduction due to environmental loads

Environmental loads		Vessel speed (kn)					
V_{wind} (kn)	H_s (m)						
0.00	0.00	17.28	17.28	17.28	17.28	17.28	17.28
11.80	0.50	16.56	16.54	16.56	16.93	16.99	17.01
16.80	1.00	16.15	16.11	16.13	16.72	16.79	16.80
20.70	1.50	15.21	15.14	15.28	16.29	16.33	16.35
24.00	2.00	13.43	13.52	13.74	15.66	15.78	15.63
26.90	2.50	11.64	11.92	12.38	14.97	15.15	15.39
29.50	3.00	9.89	10.17	10.63	14.06	14.45	14.68
31.90	3.50	8.66	8.94	9.44	13.34	13.96	14.30
34.10	4.00	8.63	8.90	9.40	13.55	14.01	14.40
Encounter angle $\gamma_{wind} = \gamma_{wave}$		0°	20°	35°	120°	150°	180°

Besides the data shown in **Table 2**, additional parameters such as specific fuel oil consumption (SFOC) and engine shaft power were collected from the engine room simulator. If one were to use this data to calculate fuel consumption per hour and vessel voyage time for several different scenarios it would be possible to analyse the impact of environmental loads on the vessel exploitation economic efficacy. For example, the difference between calm sea conditions and maximum environmental loads at 0° encounter angle is approximately double the voyage time and thus double the fuel consumption per voyage.

4 CONCLUSION

The results of this research were consistent in proving that increasing environmental loads lead to increasing vessel speed loss. Such data can be extremely useful when analysing vessels economic efficiency and other respective implications such as greenhouse emissions. The previously mentioned example shows how significant the impact of ship speed loss actually is with respect to important factors such as voyage time, fuel consumption and respective greenhouse and other harmful exhaust gas emissions. Furthermore, this data could be used for route optimization procedures.

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