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# CORRELATION OF THE ERRORS IN CALCULATED AND MEASURED NAVIGATIONAL PARAMETERS IN INTEGRATED BRIDGE NAVIGATION SYSTEM

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**KÖPRÜÜSTÜ BİLEŞİK SEYİR SİSTEMİNDE HESAPLANAN VE ÖLÇÜLEN SEYİR HATALARI ARASINDAKİ İLİŞKİ**

**ÖZET**

Bileşik Köprüüstü seyir sistemi seyir araçlarının en kapsamlı ifadesidir. Verileri güvenli seyir için geniş kapsamlı olarak kullanılır. Ey Yakın Yaklaşma Noktası kısıtlı görüşte ve yoğun trafikte gemimiz küçük hedeflerin arasında seyir yaptığında çok önemli bir parametredir. Bu sebeple zabit, Bileşik Köprüüstü Seyir Sistemi ile hesaplanan En Yakın Yaklaşma Noktası hatalarının özelliklerini, bu hatayı oluşturan sebepleri ve bunlar arasındaki ilişkiyi bilmelidir.
Bu makale Doğu Çin Denizinde bir Konteyner gemisinde yapılan deney ölçümlerini sunmaktadır. Bileşik Köprüüstü Seyir sisteminde gemi rotası ve hız sensörleri arasındaki farklı hatalar ve Ey Yakın Yaklaşma Noktası analiz edildi. Veriler gemi rotasının 'izleme durumu' ve 'Pruva durumu' halinde elde edildi. Veri işleme için iki değişken değer (X, Y) algoritması kullanıldı.
**Anahtar Sözcükler:** Hatalar ilişkisi, Bileşik Köprüüstü Seyir Sistemi

**ABSTRACT**

Integrated bridge navigation system is the state-of-the-art navigational equipment. Its data is wide use especially for safe passing ships. Closest point of approach is great important parameter when our ship sales around small targets, in heavy traffic and in condition of restricted visibility. Because of this the navigator shell knows the character of errors in the calculated closest point of approach by integrated bridge navigation system, the reasons that create this errors and the correlation between them.
This article presents some experiments carried out in the East China Sea on board of container ship. The correlation between different errors from the ship's course and speed sensors in the integrated bridge navigation system and closest point of approach is analyzed. The data are obtained in "track mode" and in "heading mode" of ship's course control. An algorithm for two random values (X,Y) is used for data processing.
**Keywords:** Correlation of errors, Integrated bridge navigation system

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## 1. INTRODUCTION

Integrated Bridge and Navigation System (IBNS) in respect of steering the vessel is a system combined navigation data from several aids to navigation – GPS receiver, Electronic Chart Display and information System (ECDIS), Radar ARPA, Gyrocompass and Autopilot. The IBNS finds growing application in modern navigation. Its wide scope navigational capabilities facilitate navigation, especially when sailing in regions with heavy traffic, close to dangers to navigation, in narrow waters, etc. As any other instrumental system, IBNS produces the data of measured and calculated navigational parameters with certain errors, which are subject to many analyses and publications [2, 3]. But these publications do not analyze how the ship's drift calculated by IBNS affect the ARPA calculations for closest point of approach with moving targets.

The present article deals with the dependence of the error in the calculated by the IBNS distance of own ship to a moving target on the measured navigational parameters in different ship control modes on a preset course. Analysis is made based

## 2. COURSE CONTROL MODE IN IBNS

The integrated bridge navigation system ensures fully automated control of the speed and the course of the ship [5]. The following two modes are used for course control:
- automated control in track mode – ship sailing following preliminary drawn track in the ECDIS, which input in the ARPA;
- automated control in heading mode ship sailing following given gyro compass course.

Fig. 1 shows the principle scheme of the IBNS configuration. When steering the ship the data from the radar, the electronic chart and the computerized track pilot system are of paramount importance.

When approaching moving targets, different data sources for the own ship course are used in the two modes of ship control in IBNS. The components of the target movement and the components of the situation are calculated using the formulas [2]:

$$
\begin{aligned}
TC_T &= arctg\left(\frac{V_R.cos\,C_R + V_{OS'}\, sin\,TC_{OS}}{V_R.sin\,C_R + V_{OS'}\ \ cos\,TC_{OS}}\right)\\
V_T &= \sqrt{(V_R.sin\,C_R + V_{OS}\ sin\,TC_{OS})^2 + (V_R.cos\,C_R + V_{OS}\ cos\,TC_{OS})^2}\\
CPA &= D.sin|C_R - TB|\\
TCPA &= \frac{D.cos|C_R - TB|}{V_T}
\end{aligned}
\qquad (1)
$$

where $TC_{OS}$ is the own ship's course and $TB$ is the bearing to the acquired target.

In the track mode, the own ship's course of movement is entered by the GPS, i.e. the ship's course over ground. The speed is also calculated over ground, the speed data are calculated on the basis of the DOLOG measurements which are ground stabilized due to small depth. It is important to note that for the experiment purposes ship's speed data is used for calculation the own ship drift only. It is well known fact that own ship's speed affect ARPA calculation also. But this data is more precise and accurate and speed errors are relatively small compared with course errors [3].

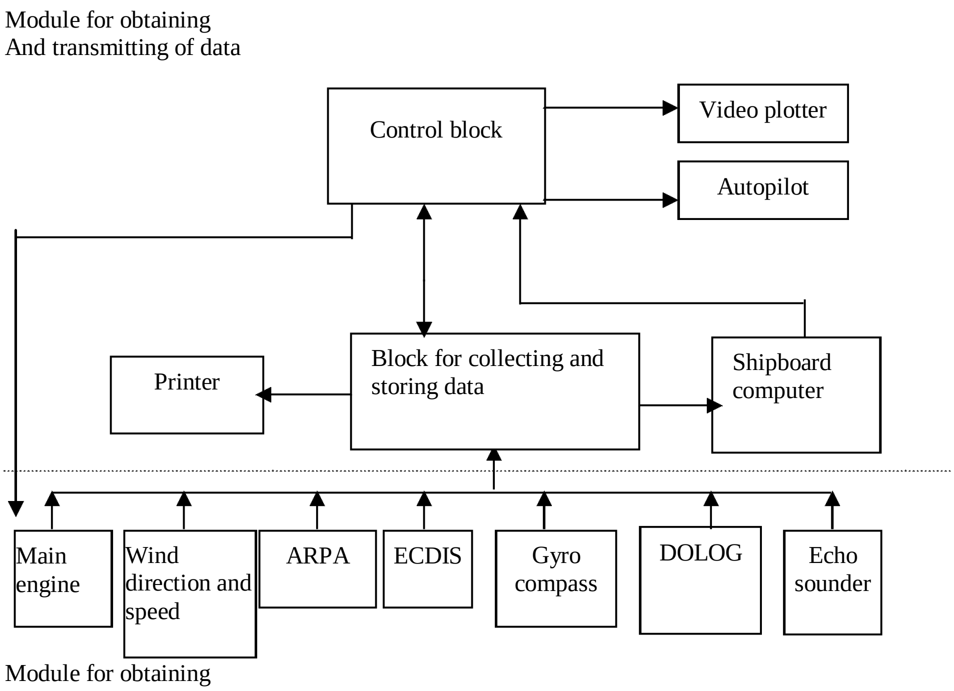


**Figure 1.** IBNS structural scheme

When in the "heading mode", the ship gyrocompass course is used for the first and second formula of the equations (1). To keep this course, the "track pilot" system sends control signals to the rudder, which aim at compensating for the influence of possible drift. Such control signals are produced in both control modes, the drift angle data measured by the DOLOG being used to compensate for the drift. It is important for the process of passing ships that in track mode the influence of the drift on own ship and on the moving targets is different, which has its impact on the components of their relative movement – relative course and relative speed. It should be noted, however, that in "heading mode" the ambient factors have the same impact on own ship and the targets around her. This fact determines the nature of the errors in the components of the situation of passing ships.

## 3. CORRELATION OF THE ERRORS IN THE CALCULATED CLOSEST POINT OF APPROACH AND THE OWN SHIP COURSE DATA

The problem of the reasons, leading to the errors in the calculated Closest Point of Approach (CPA) acquires particularly great importance when sailing around small targets, in heavy traffic and in conditions of restricted visibility. The idea suggested by [6], which describes the error aggregate in IBNS when approaching can be further developed in the context of the above, said as follows:

$$r^T = \left(Dd, Dy_{a_i}, DV_{a_i}, Dy_{a_j}, DV_{a_j}, Dy_b, DV_b, DD_i, DP_i, DC_i\right) \qquad (2)$$

where $r^T$ is vector of the errors measured and calculated by the IBNS navigational parameters in the process of passing ships;

*Dd* - error in the rudder deflection angle;

$Dy_{a_i}, DV_{a_i}$ - an error in the own ship's course and speed over ground, as measured by a GPS receiver or calculated by the IBNS;

$\Delta\psi_{a_j}$ - error in the ship's course according to gyrocompass readings;

$DV_{a_j}$ - ship speed error in the fore and aft line;

$Dy_b, DV_b$ - errors in the speed and course in the traced target;

$DD_i, DP_i$ - errors in the measured bearing and distance to the target;

$DC_i$ - error in the ship's drift angle, calculated by the IBNS.

Some experiments were carried out in the East Chinese Sea in order to analyze the correlation between the different errors from the ship's course sensor and calculated drift in the IBNS and the calculated closest point of approach. Some of the results are shown in table 1 and table 2. The configuration of the IBNS were used was of the type shown in figure 1. The data in table 1 were obtained in "track mode" of ship's course control, and those in table 2 - in "heading mode" of ship's course control. Measurements were taken every 30 seconds.

**Table1.**

| Gyro compass [deg] | Drift angle [deg] | Course relative to the ground [deg] | CPA [mile] | Distance to the target [mile] | Gyro compass [deg] | Drift angle [deg] | Course relative to the ground [deg] | CPA [mile] | Distance to the target [mile] |
|---|---|---|---|---|---|---|---|---|---|
| 17.3 | 0.7 | 15.7 | 1.60 | 14.88 | 18.9 | 0.8 | 16.2 | 1.47 | 6.95 |
| 17.7 | 0.8 | 16.4 | 1.08 | 14.46 | 19.3 | 1.2 | 16.4 | 1.42 | 6.69 |
| 18.1 | 0.9 | 16.2 | 1.24 | 14.12 | 19.4 | 1.5 | 16.6 | 1.46 | 6.36 |
| 18.7 | 1.3 | 16.6 | 1.42 | 13.78 | 19.7 | 1.3 | 17.1 | 1.49 | 5.98 |
| 18.8 | 1.2 | 16.2 | 1.48 | 13.44 | 19.8 | 0.9 | 17.5 | 1.55 | 5.67 |
| 19.2 | 1.5 | 16.5 | 1.34 | 13.12 | 18.8 | 0.6 | 16.9 | 1.45 | 5.37 |
| 19.3 | 1.6 | 16.6 | 1.31 | 12.82 | 18.3 | 0.8 | 16.1 | 1.44 | 5.07 |
| 19.1 | 1.1 | 16.6 | 1.54 | 12.46 | 18.5 | 1.0 | 15.7 | 1.46 | 4.75 |
| 18.9 | 0.9 | 17.0 | 1.68 | 12.09 | 18.9 | 1.5 | 15.6 | 1.52 | 4.47 |
| 18.3 | 0.6 | 16.6 | 1.56 | 11.78 | 19.5 | 1.4 | 16.7 | 1.49 | 4.17 |
| 17.5 | 0.6 | 16.6 | 1.49 | 11.47 | 19.8 | 1.9 | 17.6 | 1.46 | 3.85 |
| 17.6 | 1.1 | 15.3 | 1.33 | 11.12 | 20.2 | 1.7 | 17.6 | 1.54 | 3.54 |
| 18.6 | 1.0 | 15.7 | 1.60 | 10.81 | 20.3 | 2.0 | 18.1 | 1.55 | 3.24 |
| 19.5 | 1.1 | 16.9 | 1.44 | 10.49 | 19.3 | 1.5 | 17.4 | 1.53 | 2.88 |
| 19.3 | 1.0 | 17.0 | 1.73 | 10.20 | 19.0 | 1.5 | 16.6 | 1.51 | 2.62 |
| 19.3 | 1.3 | 17.8 | 1.74 | 9.85 | 18.6 | 1.6 | 15.7 | 1.55 | 2.41 |
| 19.1 | 1.5 | 17.2 | 1.50 | 9.57 | 19.0 | 1.2 | 15.9 | 1.56 | 2.11 |
| 19.1 | 1.9 | 17.1 | 1.50 | 9.18 | 19.4 | 1.6 | 16.6 | 1.55 | 1.99 |
| 19.4 | 1.6 | 17.6 | 1.55 | 8.94 | 19.5 | 1.8 | 15.7 | 1.56 | 1.82 |
| 19.1 | 1.8 | 17.2 | 1.54 | 8.53 | 20.2 | 2.3 | 16.1 | 1.55 | 1.72 |
| 19.2 | 1.1 | 17.2 | 1.60 | 8.22 | 20.8 | 2.2 | 17.0 | 1.56 | 1.65 |
| 18.5 | 0.9 | 16.6 | 1.58 | 7.93 | 20.4 | 1.5 | 17.2 | 1.56 | 1.58 |
| 17.8 | 0.5 | 16.0 | 1.44 | 7.57 | 20.3 | 1.7 | 17.2 | 1.56 | 1.56 |
| 18.2 | 1.2 | 15.7 | 1.42 | 7.26 | | | | | |

Note: Ship's course in "track mode" – 016.6°

An algorithm for two random values *(X, Y)* [1] was used for data processing, where *X* is the CPA deviation, and *Y* is the readings of the ship's course sensor or the calculated ship's drift. The content of the algorithm is the following:

**Table 2.**

| Gyro compass [deg] | Drift angle [deg] | Course relative to the ground [deg] | CPA [mile] | Distance to the target [mile] | Gyro compass [deg] | Drift angle [deg] | Course relative to the ground [deg] | CPA [mile] | Distance to the target [mile] |
|---|---|---|---|---|---|---|---|---|---|
| 46.9 | 2.0 | 42.5 | 1.10 | 5.40 | 47.4 | 2.3 | 43.3 | 0.97 | 3.46 |
| 46.8 | 2.0 | 43.5 | 1.07 | 5.31 | 46.7 | 2.2 | 43.4 | 1.01 | 3.39 |
| 47.1 | 2.0 | 43.5 | 0.94 | 5.20 | 47.0 | 2.1 | 43.9 | 0.95 | 3.39 |
| 47.3 | 1.8 | 43.7 | 0.98 | 5.11 | 46.7 | 2.2 | 43.8 | 0.88 | 3.28 |
| 47.0 | 1.8 | 44.2 | 0.99 | 5.00 | 47.0 | 2.0 | 43.3 | 0.96 | 3.28 |
| 46.9 | 2.1 | 43.6 | 1.05 | 4.89 | 47.1 | 1.7 | 44.0 | 0.83 | 3.16 |
| 47.2 | 2.2 | 43.4 | 0.99 | 4.79 | 47.1 | 2.0 | 43.2 | 0.97 | 3.16 |
| 47.0 | 2.0 | 44.1 | 0.94 | 4.67 | 47.1 | 1.6 | 43.6 | 0.86 | 3.04 |
| 47.2 | 2.0 | 44.2 | 1.00 | 4.56 | 47.0 | 2.0 | 44.0 | 0.96 | 3.04 |
| 46.8 | 2.0 | 43.7 | 1.04 | 4.44 | 47.4 | 1.6 | 43.9 | 0.85 | 2.92 |
| 46.5 | 1.9 | 43.5 | 1.01 | 4.34 | 47.1 | 1.7 | 43.8 | 0.96 | 2.92 |
| 47.1 | 1.9 | 43.1 | 0.97 | 4.25 | 47.3 | 1.4 | 43.8 | 0.96 | 2.82 |
| 47.5 | 2.2 | 44.0 | 0.99 | 4.12 | 47.0 | 1.6 | 43.4 | 0.92 | 2.58 |
| 47.7 | 2.4 | 43.7 | 1.00 | 3.97 | 47.2 | 1.9 | 43.9 | 0.92 | 2.14 |
| 47.3 | 2.5 | 42.8 | 1.03 | 3.87 | 47.3 | 1.8 | 43.9 | 0.90 | 2.03 |
| 47.2 | 2.5 | 43.8 | 0.79 | 3.75 | 47.1 | 1.9 | 43.7 | 0.97 | 1.88 |
| 47.2 | 2.4 | 43.4 | 0.87 | 3.63 | 47.7 | 2.2 | 44.0 | 0.92 | 1.88 |

Note: Ship's course in "heading mode" – 047.0°

- the estimation for the mathematical expectation of values $X$ and $Y$ is calculated :

$$m_x = \frac{\sum_1^n X_i}{n}; \quad m_y = \frac{\sum_1^n Y_i}{n} \tag{3}$$

- the statistical second initial moments are calculated:

$$a_2^*(X) = \frac{\sum_1^n X_i^2}{n}; \quad a_2^*(Y) = \frac{\sum_1^n Y_i^2}{n} \tag{4}$$

- the statistical variances are calculated:

$$D_x = \frac{\sum_1^n (X_i - m_x)^2}{n-1}; \quad D_y = \frac{\sum_1^n (Y_i - m_y)^2}{n-1} \tag{5}$$

- the mean square deviations are calculated:

$$s_x = \sqrt{D_x}; \quad s_y = \sqrt{D_y} \tag{6}$$

- the statistical central moment is calculated:

$$a_{1,1}^*[X;Y] = \frac{\sum_1^n X_i.Y_i}{n} \tag{7}$$

- the statistical correlation moment is calculated:

$$K_{X,Y}^* = a_{1,1}^*[X;Y] - m_x.m_y \tag{8}$$

- the correlation coefficient is calculated:

$$r_{XY} = \frac{\frac{K^*_{XY}}{n-1}}{s_x . s_y} \qquad (9)$$

In navigation a correlation coefficient of $r > 0,2$ is a clear indicator of the presence of a substantial relation between the values being analyzed [4].

The calculations in "track mode" showed comparatively weak dependence of the deviation from the closest point of approach on the value of the drift angle

* $m_X = 77,49$ *deg*; $m_Y = 0,06$ *deg*;
* $D_X = 675,2$ *deg*$^2$; $D_Y = 0,012$*deg*$^2$;
* $a^*_{1,1}[X;Y] = 4,213$ *deg*$^2$;
* $K^*_{X,Y} = 0,45$

where $X$ is the CPA deviation random value and $Y$ is the drift angle random value in "track mode".

The correlation coefficient in this case is $r_{XY} = 0,16$ . The value is close to the limit $0,2$ and can be said that the dependence is not so significant.

The correlation coefficient between the CPA deviation and the ship's course over ground is $r_{XY} = 0,31$, which shows a great interdependence between the two values. The calculations show

* $m_X = 0,06$ *deg*; $m_Y = 2,04$ *deg*;
* $D_X = 0,012$ *deg*$^2$; $D_Y = 1572,14$ *deg*$^2$;
* $a^*_{1,1}[X;Y] = 1,23$ *deg*$^2$;
* $K^*_{X,Y} = 1,35$

where $X$ is the CPA deviation random value and $Y$ is the ship's course over ground random value in "track mode".

The following results were obtained in "heading mode":

- in case of research the dependence between the CPA deviation and the ship's course over ground the results are

* $m_X = 0,04$ *deg*; $m_Y = 201,88$ *deg*;
* $D_X = 0,008$ *deg*$^2$; $D_Y = 504,67$*deg*$^2$;
* $a^*_{1,1}[X;Y] = 8,15$ *deg*$^2$;
* $K^*_{X,Y} = 0,07$

where $X$ is the CPA deviation random value and $Y$ is the ship's course over ground random value in "heading mode".

The correlation coefficients between the CPA deviation and the ship's course over ground is $r_{XY} = 0,04$ . It is mean that the dependence is very weak.

- the results concerning the dependence between the CPA deviation and the ship's drift angle are

* $m_X = 119,82$ *deg*; $m_Y = 0,04$ *deg*;
* $D_X = 245,37$ *deg*$^2$; $D_Y = 0,008$*deg*$^2$;
* $a^*_{1,1}[X;Y] = 4,61$ *deg*$^2$;
* $K^*_{X,Y} = 0,18$

where $X$ is the CPA deviation random value and $Y$ is the drift angle random value in "heading mode".
and the correlation coefficients between the CPA deviation and the ship's the drift angle is $r_{XY} = 0{,}13$. The dependence is also weak.

The analysis of the results shows that in "track mode" the CPA deviations are mainly due to errors and fluctuations from the ship's course over ground. Since this course is determined by the data from the GPS receiver, the errors in the system have a direct or indirect impact mostly on the fluctuations of the calculated CPA.

In "heading mode" the gyrocompass course accuracy is of paramount importance to the CPA calculations - correlation coefficients between the CPA deviation and the ship's gyrocompass course is $r_{XY} = 0{,}43$. The insignificant dependence on the drift angle is due to the same influence of the ambient factors on the movement components of both the own ship and the targets.

## 4. CONCLUSION

The results from the analyses show the influence of the data from different IBNS sensors on the calculations of certain navigational parameters. The CPA is doubtlessly the most important element of the navigational safety. The accuracy of the calculated CPA is also influenced by the accuracy of the measured distance and bearing to the targets. In the above analyses, however, the errors in these parameters are considered to be instrumental ones and of constant nature. The analysis paid greater attentions to those parameters, leading to random errors, since they have a greater influence on the values, calculated by the IBNS.

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