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Simulation Modeling for Evaluation of Efficiency of Observed Ship Coordinates

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ABSTRACT: Simulation computer modeling was used to evaluate the efficiency of the vessel's observed coordinates using the mixed laws of distribution errors of the first and second type for lines of position (LOP). Simulation modeling showed good convergence of evaluation of efficiency calculated by analytical expressions and obtained by simulation. A graphical depiction of the observed points' deviation relative to the mathematical expectation in the case of distribution of LOP errors of both types according to mixed laws is obtained by the method of least squares and the method of maximum likelihood estimation.

1 INTRODUCTION

To control the position of the vessel are held the navigation parameters' measurements, based on which are calculated vessel's coordinates. For safety ship handling need to refine the methods of determining the observed coordinates and estimates of measurement and calculation errors.

If the excessive measurements of determination of a vehicle trajectory in various environments (sea, land, air, etc.) take place, coordinates calculation is usually executed by the method of least squares (LSQ) [3, 4, 17]. But LSQ is effective only when errors have distributed according to the Laplace–Gauss distribution (further – normal distribution). Studies have shown that errors of navigation measurements frequently aren't obeyed to the normal distribution, especially during critical situations, e. g. in the threat of vessels' collision, etc. [9, 10]. In such cases, the use of LSQ leads to a loss of coordinates' accuracy.

Therefore, it is necessary to analyze the possibility of vessels' coordinates calculating in the presence of excessive measurements by alternative methods. Such method is first of all a method of maximum likelihood estimation (MLE) [6, 8].

2 STATE OF THE ART

Over the past decade, the issue of increasing the accuracy of determining the vessel position has been discussed in detail in many research works [15, 16]. Results of verification of statistical hypotheses of error distribution laws navigation measurements set out in publications [5, 12]. The researchers have found that the errors of measurements of radar azimuth orientation and distances are obeyed mainly to mixed distribution laws errors of the first and second types [1]. Simulation modeling is applied for the evaluation of efficiency using the above methods, the corresponding communicative and computing costs [8].

The analysis of errors of navigation measurements' statistical data received during practical observation, set out in the work [7]. This study shows that the errors of navigation measurements are distributed at non-normal laws.

If the law of errors' distribution differs from Gaussian distribution, then using the LSQ to calculate the vessel coordinates does not provide effective evaluations. At excessive lines of position (LOP), evaluation of the efficiency of vessel's coordinates has held in the [2]. In this work is also shown that when using mixed distribution laws, the efficiency is lower «1», and with the growth of a significant parameter, it approaches the value of «1».

Results of the statistical materials' analysis of accuracy of a vessel position's definition through satellite radio navigation system has held in the [13]. It follows that the hypothesis of the random errors' distribution in determining latitude and longitude by Gaussian distribution is not correct and requires the use of other distribution laws.

Mixed error distribution laws of both types, which are an alternative to the normal law, are proposed to describe the random errors of navigation measurements proposed in the work [11]. Poisson's distribution law is considered for the same purpose in [14].

The analysis of the considered works shows that to prevent loss of accuracy of the calculated coordinates it is necessary to use methods which alternative to LSQ.

The purpose of the article is to verify the determination of the effectiveness of the ship's coordinates by simulation computer modeling in the case of distribution of measurement errors according to mixed laws of errors distribution of the first and second types.

3 METHODOLOGY

For evaluation of the efficiency of the observed coordinates, obtained at excessive LOP and calculated by LSQ, simulation computer modeling was performed. In doing so, cases were considered when LOP errors were obeyed to the normal law, as well as to mixed laws of errors distribution of the first and second type.

Simulation modeling was performed according to the following algorithm. Initially, a sample of LOP errors consisting of 1000 members was generated according to the chosen distribution law. Calculation of the each observed point's coordinates were done on 8 LOPs. Moreover, the LOP elements (transfers r_i and gradients' directions α_i) were set relatively the true vessel position. That's why, LOPs' transfers r_i equal to their errors ξ_i. During simulation modeling gradients' directions α_i were chosen equal 30°, 75°, 120°, 165°, 210°, 255°, 300° and 345°. Using the generated sample, it is possible to obtain 125 observed points. The increment of their coordinates X i Y are projections of vectorial error. This allows calculating the covariance matrix of vectorial error of observation.

The formation of 125 observed points was repeated four times, and the obtained coordinates were saved. As a result, the sample S_{500} was accumulated in vectorial error's coordinates number of 500 terms. Using the obtained sample were calculated the expected values M_X, M_Y and variances D_X, D_Y of projections X and Y of vectorial error. Simulation computer application provides the graphic depiction of the observed coordinates relative to the expected value. This allows making a visual evaluation of their deviation. It had should be take into account that a vectorial error is determined relative to the true vessel position. Then during simulation modeling for evaluation of the efficiency of the observed coordinates, it is necessary to use not variances of projections X and Y, but their second initial moments.

The computer application for simulation modeling provides calculation of observed points both LSQ and MLE. In simulation modeling standard deviation $\sqrt{\mu_2}$ of LOP error was taken as equal to "5".

First, a sample S_{500} was generated for LOPs errors distributed under normal law. The coordinates of observed points (x_t, y_t) have calculated by LSQ. In this case, the second initial moments of vectorial error's components have turned out to be equal $a_{2xG} = 24.48$ and $a_{2yG} = 0.8617$. The second initial moment of the vectorial error's module is calculated as in (1).

$$a_{2RG} = a_{2xG} + a_{2yG} = 25.86 \quad (1)$$

Fig. 1 shows the positions of observed points relative to the expected value. At that, in Fig, 1 and others maximal deviation coordinates' values equal to the standard deviation. At modeling, its value is accepted as "5".

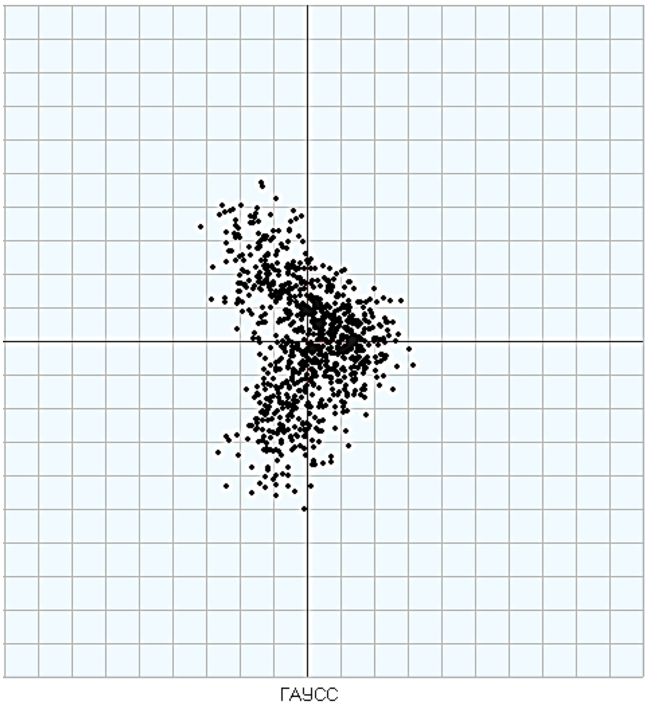

Figure 1. Distribution of observed points under normal law

The observed coordinates of vessel were calculated by LSQ. In doing so the errors of the LOP were obeyed to mixed distribution. For evaluation of efficiency of observed coordinates, the samples of LOPs' errors were generated accordance to mixed distribution.

Then the observed coordinates have been calculated by LSQ and the sample S_{500}^{LSQ} of vectorial error's coordinates was formed. At once, using the values of the same errors, the calculation of observed coordinates by MLE was performed. Then the sample S_{500}^{ML} of vectorial errors' components was formed. Based on the sample's data the expected values, variances, and the second initial moments α_{2x}^{LSQ}, α_{2y}^{LSQ} and a_{2x}^{MLE}, a_{2y}^{MLE}, components X i Y of vectorial error were calculated. Then the values of the second initial moments are calculated accordingly using LSQ as in (2), and MLE as in (3).

$$a_{2R}^{LSQ} = a_{2x}^{LSQ} + a_{2y}^{LSQ} \quad (2)$$

$$a_{2R}^{MLE} = a_{2x}^{MLE} + a_{2y}^{MLE} \quad (3)$$

Obviously, during simulation modeling (SM) efficiency of the observed coordinates e_{SM} obtained by LSQ, determined by the ratio of the second initial moments a_{2R}^{LSQ} and a_{2R}^{MLE} as in (4).

$$e_{SM} = \frac{a_{2R}^{LSQ}}{a_{2R}^{MLE}}. \quad (4)$$

The e_{SM} are compared with the corresponding efficiency's value e_T calculated theoretically by analytical expressions held in the work [2].

4 RESULTS OF SIMULATION MODELING

As a result of simulation modeling, the efficiency value $e_{SM}^{(1)}$ is obtained for the distribution of LOP's errors according to the mixed law of error distribution of the first type. They are compared with the calculated values $e_T^{(1)}$ as indicated in Table 1.

Table 1 and Fig. 2 shown dependences $e_{SM}^{(1)}$ obtained by simulation modeling, and $e_T^{(1)}$ calculated analytically, from the value of the essential parameter m.

Table 1. Efficiencies $e_T^{(1)}$ and $e_{SM}^{(1)}$ of the mixed distribution of errors of the first type

m	1	2	3	4	5	6
$e_T^{(1)}$	0.500	0.800	0.893	0.934	0.955	0.968
$e_{SM}^{(1)}$	0.507	0.636	0.710	0.792	0.800	0.888
$\delta e^{(1)}$ (%)	14.0	20.5	20.5	15.2	16.2	8.0

In Fig. 2 the values of efficiencies $e_T^{(1)}$ are depicted by blue points, and efficiencies $e_{SM}^{(1)}$ – red points. From Table 1 and Fig. 2 can be seen that the percentage discrepancy $\delta e^{(1)}$ between efficiencies $e_T^{(1)}$ and $e_{SM}^{(1)}$ does not exceed 20.5%.

During the simulation in addition to the calculated data are given graphic depiction deviation observed points relative to mathematical expectation. The variance of the vectorial error's modulus was calculated by the methods LSQ and MLE.

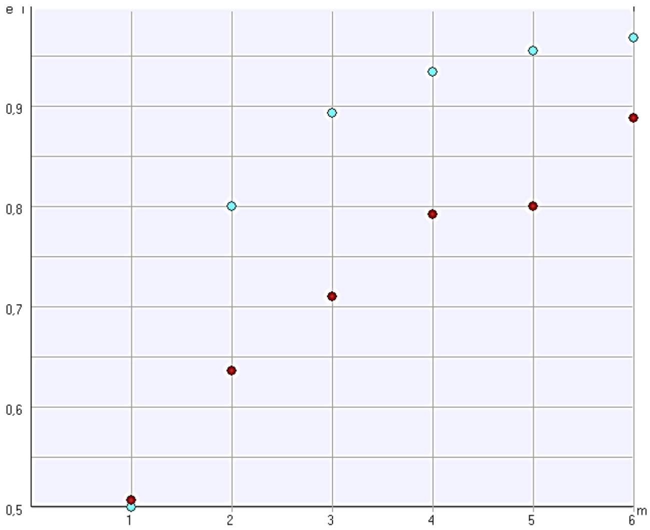

Figure 2. Dependence of efficiencies $e_T^{(1)}$ and $e_{SM}^{(1)}$ on parameter m

Fig. 3 shows a comparative characteristic of deviation of the observed points obtained by LSQ and MLE at $m = 2$ for the same LOPs.

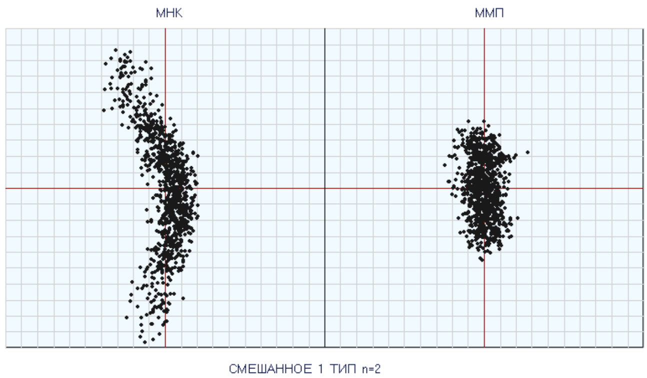

Figure 3. Comparative characteristic of points' deviation at $m = 2$

Also, results of simulation modeling were received for the case of distribution of LOPs errors according to the mixed distribution law of errors of the second type. In doing so, efficiency's value $e_{SM}^{(2)}$ obtained by simulation computer modeling were compared with the calculated values $e_T^{(2)}$ shown in Table 2 and Fig. 4, depending on the value of essential parameter m.

Table 2. Efficiencies $e_T^{(2)}$ and $e_{SM}^{(2)}$ of the mixed distribution of errors of the second type

m	1	2	3	4	5
$e_T^{(2)}$	0.700	0.857	0.917	0.945	0.962
$e_{SM}^{(2)}$	0.671	0.668	0.751	0.829	0.870
$\delta e^{(2)}$ (%)	4.1	22.0	18.1	12.3	9.6

Analyzing Table 2 and Fig. 4, can be seen that the divergence $\delta e^{(2)}$ between efficiencies $e_T^{(2)}$ and $e_{SM}^{(2)}$ in percentage less than 22.0%. The study showed good agreement between the evaluations of efficiencies calculated by analytical expressions and obtained during simulation modeling. This confirms the correctness of the analytical method of the evaluation of the efficiency of observed coordinates, calculated by LSQ.

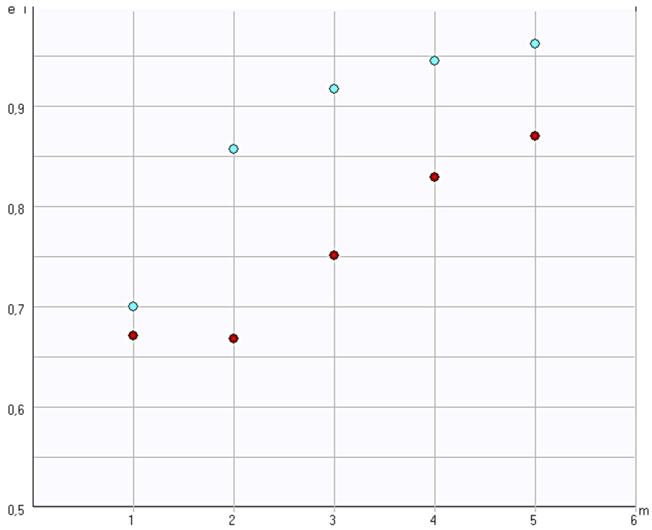

Figure 4. Dependence of efficiencies $e_T^{(2)}$ and $e_{SM}^{(2)}$ on parameter *m*

The distribution of LOPs' errors according to the mixed distribution law of errors of the second type, received at calculation by LSQ and MLE is considered. Also was obtained deviation's graphic depiction of the observed points relative to the expected value.

The comparative characteristic of deviation the observed points, coordinates of which are calculated by LSQ and MLE, shown in Fig. 5.

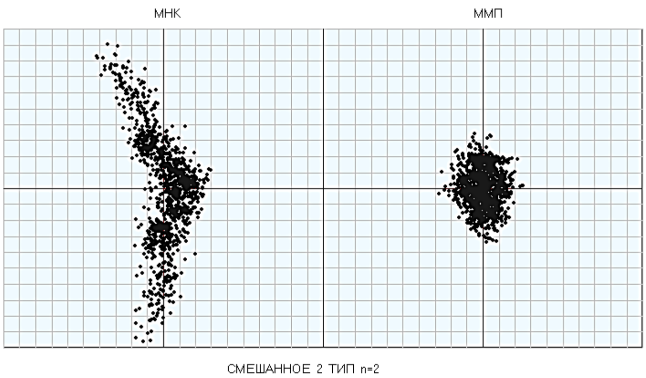

Figure 5. Deviation coordinates' values of the observed points when $m = 2$.

5 CONCLUSIONS

In the study, the methodology of simulation modeling is offered to evaluate the efficiency of the vessel's observed coordinates by mixed distribution laws of errors of the first and second type for the lines of position (LOP).

The conducted simulation modeling showed a good convergence of evaluations of efficiency, calculated by analytical expressions and obtained by simulation modeling.

According to the results of the work, a deviation graphic depiction of the observed points relative to the expected value was obtained in the case of LOP error distribution according to mixed error distribution laws of both types when using the least squares (LSQ) method and maximum likelihood estimation (MLE).

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