Formation of a Method for Estimating the Error of Determining the Coordinates of the Source of a Sound Anomaly

Aleksandr Trunov [1], Zhan O. Byelozyorov [1], Serhii I. Maltsev[1], Maksym Skoroid[1]

[1] *Petro Mohyla Black Sea National University, Mykolaiv, Ukraine, 68 Desantnikov, 10, Mykolaiv 54000, Ukraine.*

Abstract

The methods of determining the coordinates of the source of a sound anomaly are considered. Improving the quality of the equipment of the computerized systems of microphones for registration of intensity of noise was done by the method of Monte-Carlo simulation. The computing for different components and parameters of the system and evaluation of error for comparison of the efficiency of four algorithms was done. As a result, consideration set a task conduct simulation of random processes that form a random component of error into computer systems of microphones and movable unmanned aerial or ground vehicles as a source of a dynamic error. To experimental study the propagation of the front of SA wave, the nature of its attenuation, and physical modeling of the random position of the point of the source SA, it was proposed to use a rotary platform on thrust bearings driven by a stepper motor. The model of rotation control of platform in Matlab by using especially a hybrid two-phase stepper motor model is considered. The comparative analysis of estimates of the maximum possible error of algorithms for symmetric and asymmetric echograms was provided. On the bases of analyzing the algorithms for recognizing and determining the momentum of input time of complex echograms was done The recommendation for conditions and advantages for algorithm application was formulated.

Keywords

Sound Anomaly, coordinates, random simulation, estimating error, static, dynamic

1. Introduction

The strategy of offensive and defensive actions demonstrates the success of the use of unmanned aerial vehicles and anti-tank systems. These results show that the paradigm of success is dominated by the number of personnel and tanks with artillery successfully changing the paradigm of automation and implementation of computer-integrated technologies, which aims to maximize the preservation of personnel [1-3]. However, its further development and practical application require the development of small-sized means of determining the coordinates of the sound anomaly (SA) [4-5] and ensuring the assessment of the maximum possible error [6-9]. This task is becoming especially important and relevant for devices installed on mobile devices such as unmanned aerial vehicles (UAVs) or ground unmanned vehicles (GUVs) or ground unmanned combat vehicles (GUCVs) [1-3]. In addition to these, the possible use of small-scale means of determining the coordinates for further improvement of monitoring systems for civilian use [4-5] requires the development of methods for estimating the maximum possible error and the formation of measures to reduce it.

2. Analysis of recent publications

The work [1] reveals the advantages of using UAVs for compatible video and audio

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EMAIL: trunovalexandr@gmail.com (A. Trunov); zhan.byelozyorov.@gmail.com (Z. Byelozyorov); mserg92@gmail.com (S. Maltsev); hahido71@gmail.com (M. Skoroid)
ORCID: 0000-0002-8524-7840 (A. Trunov); 0000-0002-3216-8153 (Z. Byelozyorov); 0000-0001-9094-5259 (S. Maltsev); 0000-0003-1641-9124 (M. Skoroid)

reconnaissance, which complement each other in information and allows you to enter this information in the electronic fire card of the department. However, despite the advantages of such implementation of computer-integrated technologies, the complication of effective use of metrological measurement scheme used in this article is the lack of binding of coordinates of the carrier and device for determining the coordinates of the source SA to one basic coordinate system. In addition, it is unreasonably assumed that the error of the coordinates of the center of gravity of the UAV, as determined by GPS, is zero, and its relative orientation does not contribute to the magnitude on the error. In work [2] the necessity is highlighted and the reality of NBR application is demonstrated. However, during the operation of the GUAV there will also be a problem of determining the coordinates and its spatial orientation. In [3] there is also the problem of estimating the error and its impact on the result of reliable data entry into the electronic card of the fire department. Thus, the development of acoustic means of detecting a shot from a small weapon, their classification and formation of design requirements are presented in [4]. However, these issues of choosing a metrological scheme and determining the error were not raised and resolved. The development of devices for wireless monitoring and recording the coordinates of the shot as one of the examples of SA [5] opens up new opportunities for further improvement of equipment. Thus, [6] forms a method for estimating the error of measuring the angle directly to the target by a distributed system of sound artillery reconnaissance. However, the error of determining the coordinates of SA is ignored. The methodical error of direction-finding target by sound artillery reconnaissance system [7] is not taking into account the motion of computer system of microphones.

Peculiarities of the application of the sound metric complex in the deployment at short distances with simulation as a combat application, which determines the priority tasks of data reliability and accuracy of the coordinates of the source SA [8]. The proposed method of the evaluation value is applied for Polish aviation in the SBAS APV landing procedure [8]. The experience and results of its implementation into Position Dilution of Precision are demonstrated and compared for the two air tests in Dęblin and Chełm [8].

Analysis of the reasons and factors for the formation of error in the processes of sound reconnaissance or other types of SA shows that further expansion of the scope of application with the use of mobile vehicles will only increase the maximum possible error [9]. The article shows preliminary results of EGNOS Safety of Life service performance in Dęblin in comparison to the results obtained in Olsztyn [9]. The main parameters characterizing a navigational system i.e. accuracy, integrity, continuity, and availability were analyzed in detail [9]. The experience can have to consider as a basis to assess the possibility of implementing the EGNOS APV approach and landing procedures in Dęblin and Olsztyn [9].

The useful contribution to the formation of causes and quantification of error is presented in [10] for a multilevel learning approach based on B-splines for the localization of sound sources. In [11] the algorithm and the process of automatic determination of microphone coordinates are presented. The quality of the created hardware, which shows the tendency to miniaturize and integrate single-chip single-board computers, leads to the spread of examples of use in the rehabilitation of the military, working in high-noise areas [12]. The second success is the use in flexible robotic systems [13]. A special role was played by successes in the development of elements of the CS in the robotic systems of navigation units and positioning of production elements of flexible systems [14].

Enhancement of methods and modernization of means of study opportunities to improve the accuracy and reliability especially in-flight due to geometric calibration of the spacecraft imaging complex using known and unknown landmarks are demonstrated in works [15]. The constructing dynamic scenarios in the work of navigation geographic information systems based on the principles of sound location is also improved based on the development of CS elements [15] and requires comprehensive accounting and modeling of all components that form the error of the device as a whole.

Thus, the search for the causes of methodological and random errors in mobile monitoring systems by UAV, GUV and GUCV has emerged as an unsolved problem, due to growing needs for accuracy assessment and application requirements.

Thus, the availability of innovative hardware [5], which has been created recently, will contribute to the formulation and solution of the problem of developing a perfect metrological scheme and method of correctly estimating the maximum possible error.

3. Purpose and objectives of the study

The aim of the work is to improve the quality of the equipment of the CS of microphones of registration of SA, by simulation, accounting for components that form the error of its evaluation and the introduction of algorithms that reduce it.

To achieve this goal, the following tasks were set:

- Set a task and conduct simulation of random processes that form a random component of error;
- Carry out a comparative analysis of estimates of the maximum possible error of algorithms for symmetric and asymmetric echograms;
- To analyze the algorithms for recognizing and determining the time of complex echograms.

4. Statement of the problem of modeling and research of the influence of the algorithm on the value of the random component of the maximum possible error.

The echogram recordings that formed sound simulators were used as a source of data material [5]. The methods of error estimation theory, probability theory, normal distribution, Monte - Carlo, recurrent approximation and simulation in Matlab methods were used to solve the research problems.

4.1 Statement of the problem of simulation modeling of random processes that form a random component of error.

The CS consisting from four microphones was considered, each of which is located at the vertices of an equilateral pyramid with an equilateral triangle at the base [5]. A connected Cartesian coordinate system is chosen. Its starting point O is taken so that it coincides with the point of intersection of the three bisectors of the triangle base AKD. In some cases, it was assumed that the fourth microphone is turned off, then the pyramid degenerates into a triangle. The scheme of arrangement of microphones as point and stationary receivers is presented in fig. 1.

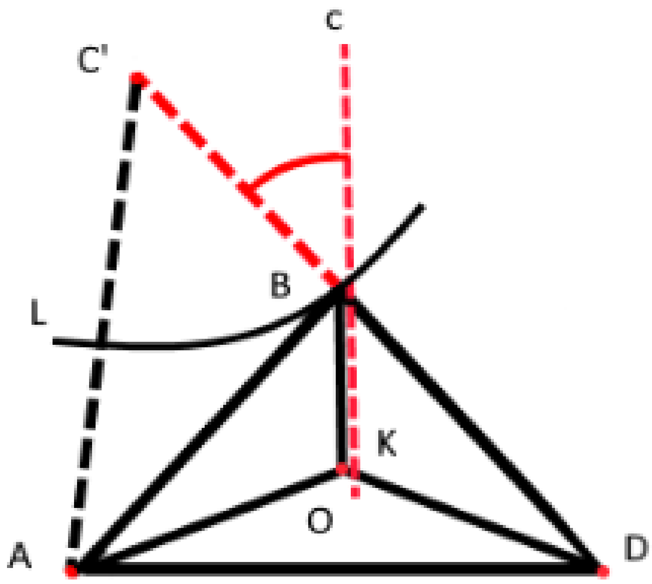

Figure 1: Scheme of four microphones location as point receivers

Next, we assume that SA are point and stationary sources. Let us denote by the letter C the point where the source SA is located. When the source is shifted to the point C', the rays CB and C'B form an angle CBC', which changes randomly, which is described by the normal law of Gaussian density. Under these conditions, as indicated, the range of change of the angle CBC' will be a limited interval [-5 / 6π, 5 / 6π]. In the simulation, the intermediate value of the angle CBC' was calculated from this range by the expression:

$$\angle CBC' = \alpha - \Delta\alpha + 2\Delta\alpha k_i, \tag{1}$$

where k_i - is a random number evenly distributed in the interval [0, 1].

The angle ABC' is calculated by eq. (1) as a random variable and forms the elements of the sample:

$$\angle ABC' = 180 - \angle CBC' - 30 = 150 - \angle CBC'. \tag{2}$$

The distance from the wave front to the microphone will also be a random variable and will be equal to:

$$AL = \sqrt{r^2 - 2ra\cos\angle ABC' + a^2} - r. \tag{3}$$

In [5-9] it was assumed that the front of the acoustic wave during propagation did not change the amplitude, and hence the intensity of the wave. This assumption led to the formation of an error in determining the coordinate SA. t was mainly supposed in recent works that the amplitude of the intensity of the wave is inversely proportional to the square of the distance between the sound source and receiver. As a result of this assumption, the intensity of the wave recorded by the first microphone will change its values when fixed by subsequent microphones depending on the distance to the source of SA. As a result of such attenuation, the amplitude of intensity of the wave will change by:

$$\Delta i = I_{\max}\left[\frac{1}{(r+AL)^2} - \frac{1}{r^2}\right]. \tag{4}$$

For scientifically based choice of equipment for experimentally studying the propagation of the SA wave, the nature of its attenuation and modeling the random position of the point of origin of the source SA, it was proposed to use a rotary platform on thrust bearings driven by a stepper motor to position determine by eq. (1)-(4). The Matlab's model of stepper motor control is implemented using specially a hybrid two-phase model.

The input data as a specified parameter was changed in the dialog box in accordance experiment program as selected from the specific data. Each of the motor phases can be powered by two PWM converters on H-bridge MOS transistors. The auxiliary DC source is generated by a DC voltage drop in range from 12 to 28 V. Two not connected controllers independently measure and control currents by comparators. The MOSFET drives signal also are referenced by these controllers. The current pulsation is controlled by the hysteresis band of the comparators. In the formation of frequency-modulated output signals, their variable is selected depending on the parameters of the engine and generated by the simulation algorithm.

The single-phase excitation scheme, the formation of a rectangular voltage drop pulse with the specified parameters of amplitude and time length according to the values specified in the dialog box makes such a scheme convenient and easy to conduct experimental simulations based on Monte Carlo simulation. The motion and rotation position of the stepper motor rotor is controlled by STEP and DIR input modulated DC voltage from the output Signal Builder unit. In accordance with values from the range, 0 to 2 A and 0 to 500 steps/s in correspondence value are chosen in dialog mask will be selected current amplitude and step speed. In the fig. 2 are shown an example STEP and DIR input and on fig. 3 is shown the oscillogram of shaft rotation. This oscillogram demonstrates the possibility to modulate the area of growth, of the constancy and of the fall.

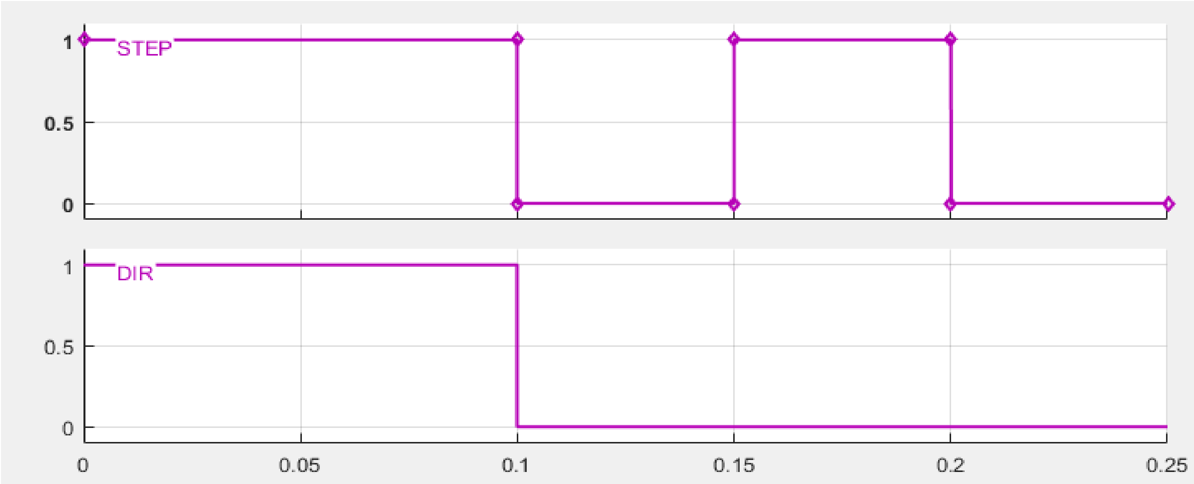

Figure 2: Appearance of signals for stepper motor control

The cover of the oscillogram fig.2 as time function is shown how a set of values 0 and 1 in STEP and DIR output from the Signal Builder effected on the character of the output signal: 1.0 a positive value initiates the rotation of the motor; a zero value stops the rotation. The DIR generally controls the direction of rotation. A positive value (1.0) imposes a positive direction, and a zero value initiates the opposite rotation. The operation of the stepper motor drive is illustrated by the main characteristics of the signals: voltage drop, current, torque, angular position, speed, and time decrement. Each of these characteristics a function of time displayed on the Scope unit.

For simulation was performed fixed decrement of time 1 µs. As was determined by the analysis of the results of the experiments this value is quite good enough because provides acceptable accuracy for PWM. To distinguish higher PWM accuracy is required, a decreased decrement of time, but for this case, the simulation will be so slower. The one type of realized signal applied to the engine are shown in Fig. 2. The process of rotation of the rotor by a stepper motor in Matlab is displayed as an oscillogram: the angle defined in degrees as a function of time. An example showing the reaction to random numbers of the angle of rotation of the platform is presented in Fig. 3. The engine from the initial position begins to rotate the rotor clockwise to a time of 0.105 ms, then fixed its position for 0.05 ms, and 0.155 ms changes the direction of rotation counterclockwise to 0.205 ms, and then fixed again..

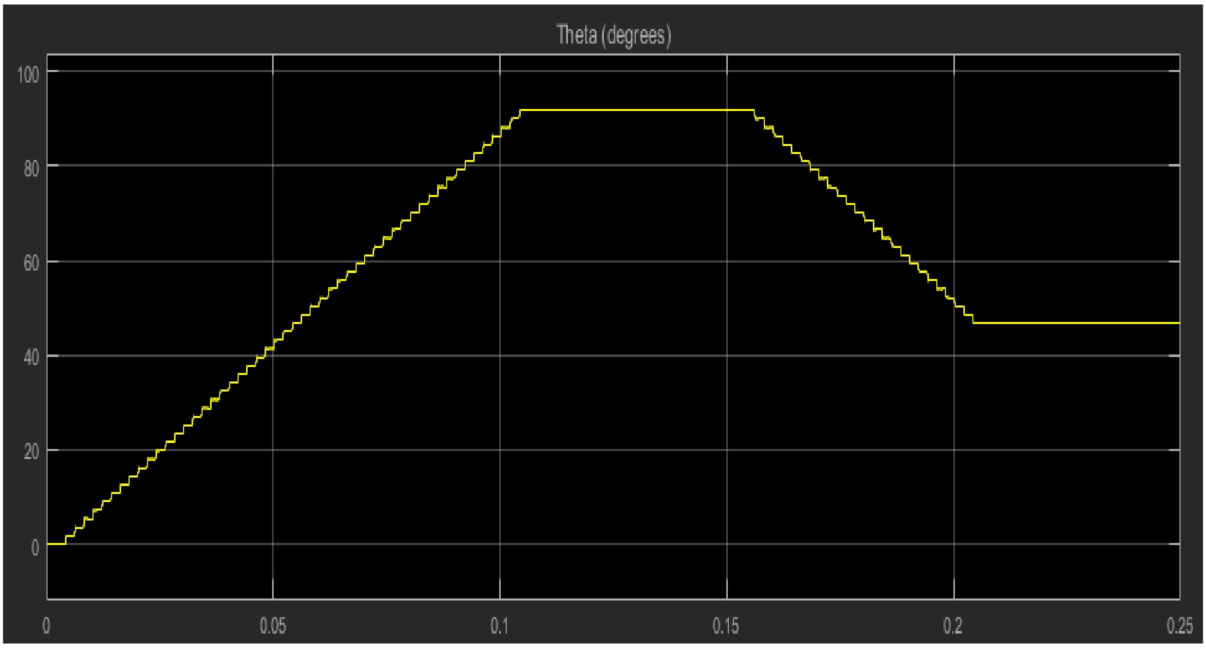

Figure 3: Oscillogram of shaft rotation

Such fragments of the presented movements correspond to a random set of numbers generated by simulation. Thus, the simulation of the rotational movements of the platform confirms the suitability of the system, which is proposed for physical modelingThus, the error resulting from the hypothesis of intensity constancy, causes an error in determining the time according to the echogram:

$$\Delta t = \left. \frac{\Delta i}{\nabla i} \right|_{i=a} \tag{5}$$

However, if the CS of the microphones is located on the UAV, the coordinates of which are determined by the GPS with an error, then due to the movement there are additional components that should be considered together with the static error.

Consider the case of monitoring and control UAV when the physical field wave intensity is scalar and inhomogeneous. In this case, the error of its measurement is determined in the first approximation by field fluctuations and sensor properties:

$$\Delta i = \left|\overline{gradi}\right| \left(\frac{\Delta r}{2} + \frac{\Delta r_g}{2} + v_i t_{np} \right) + \left(\Delta F_{CT} \right) = \sqrt{\frac{3}{2}} \left| \frac{\partial i}{\partial l} \right|_{\max} \left[\left|\Delta l\right|_{\max} + \Delta l_g + \overline{v}_i t_{np} \right] + \left|\Delta i_{CT}\right|, \tag{6}$$

where r – generalized coordinate, l – coordinate in the direction of greatest intensity increase, Δl_g – maximum size of the measuring part of the microphone in this direction, v_i – UAV speed, t_{np} - signal conversion time, Δi_{CT} – static sensor intensity error.

The last expression shows that the error of determining the intensity field using sensors located on the UAV depends not only on the static error $\left|\Delta i_{CT}\right|$, the value sensor, but also on the time constant, the error of the speed sensors, and hence the acceleration. The latest shows that inflated requirements for static error of sensors are not always justified. In addition, it is possible to reduce this component of the error by reducing the size of the sensor as an averaging zone. Despite the increase in error, the advantage of this system is that due to its installation on an inexpensive UAV, it is relatively inexpensive and maneuverable and durable. The latter allows you to read data at different heights. This fact allows us to obtain information bypassing the natural terrain and other obstacles, such as trees, buildings, etc., while the UAVs themselves can be at a safe distance and height and even in the rear, both outside the affected area and over enemy positions.

4.2. Comparative analysis of estimates of the maximum possible error of algorithms for symmetric and asymmetric echograms

The formation of the algorithm for determining the time of the phases of echograms according to the sound time series, which are registered by different microphones, is the main source of errors [5-9] as a static component. In this regard, it was determined to develop a key element of the general algorithm of the module program [5]. The task of the module is to establish conditions that ensure the uniqueness and uniformity of fixation of the identical moment of time in different echograms of one SA. Consideration of SA, in the form of a long-term function of intensity change, leads to the hypothesis of phase invariance of any of its points during propagation. Based on the above, it was assumed that such an echogram point was found, and there is an unambiguous relationship to determine it. Based on one of the conclusions of [5] on the calibration procedure, as a tool to expand the functions and capabilities of the monitoring CS, a four-point schedule using the method of recurrent approximation (MPA) was used. According to the expression of the analytical series of MPA [5], the approximate value of the time of entry of the acoustic wave is calculated. In the case where the discrepancy between two consecutive moments of time does not satisfy the required accuracy, the approximation is repeated until the required convergence is reached.

Thus, the introduction of the intensity of the SA as a continuous function that is integrated with the square, the norm of which allows several ways to determine the characteristic phase according to the calibration of multipliers $\lambda_{\omega i}$, as one that uniquely determines the time of registration. Analysis of the results of comparing the amplitude of the wave and the norm, the center of gravity or the relative location of the point of length as an unambiguous criterion on which to base the algorithm for fixing SA is set as one of the most important tasks to minimize error.

To establish practical recommendations for the choice of the algorithm for fixing the time of entry of the same phase of the wave into the microphone, simulation modeling was used, in particular the Monte-Carlo method. When placing the microphones at the vertices of an equilateral triangle at a distance of 0.6 m and a distance of 100 m from the event, the magnitude of the error was analyzed. A simple SA, represented by the triangular law of intensity distribution, with symmetric and asymmetric law of change of intensity in time and their composition, was considered. The distributions and intensity parameters of several examples are given for symmetric dependence in table 1 for asymmetric in table 2, and for the composition in table 3.

Table 1

Dependences of intensity distribution on time for symmetric SA

№	Relative time, calculated from the beginning of SA, t, s	Relative intensity			
		Example 1	Example 2	Example 3	Example 4
1	0	0	0	0	0
2	0,1	0,2	0,2	0,4	0,5
3	0,2	0,4	0,6	0,8	0,7
4	0,3	0,6	0,8	0,9	0,8
5	0,4	0,8	0,9	1	0,9
6	0,5	1	1	1	1
7	0,6	0,8	0,9	1	0,9
8	0,7	0,6	0,8	0,9	0,8
9	0,8	0,4	0,6	0,8	0,7
10	0,9	0,2	0,2	0,4	0,5
11	1	0	0	0	0

Table 2

Dependences of intensity distribution on time for asymmetric SA

№	Relative time, calculated from the beginning of SA, t, s	Relative intensity			
		Example 1	Example 2	Example 3	Example 4
1	0	0	0	0	0
2	0,1	0,3	0,6	0,8	0,35
3	0,2	0,6	0,9	0,9	0,7
4	0,3	0,8	1	1	1
5	0,4	1	0,9	0,8	0,9
6	0,5	0,9	1	0,9	0, 8
7	0,6	0,6	0,9	0,7	0,5
8	0,7	0,4	0,8	0,5	0,4
9	0,8	0,3	0,6	0,4	0,3
10	0,9	0,2	0,2	0,2	0,1
11	1	0	0	0	0

Table 3

Dependences of intensity distribution on time for the composition SA

№	Relative time, calculated from the beginning of SA, t, s	Relative intensity			
		Example 1	Example 2	Example 3	Examp le 4
1	0	0	0	0	0
2	0,1	0,3	0,6	0,8	0,2
3	0,2	0,6	0,9	0,9	0,7
4	0,3	0,8	1	1	1
5	0,4	1	0,7	0,8	0,7
6	0,5	0,8	1	0,9	0, 8
7	0,6	0,6	0,7	0,7	0,5
8	0,7	0,7	0,6	0,5	0,7
9	0,8	0,4	0,5	0,4	0,5
10	0,9	0,2	0,3	0,2	0,1
11	1	0	0	0	0

The results of calculations showing the effect of influences of distance from microphon to the source of the SA on the error are presented in table 4.

Table 4

Analysis of the influence of intensities and parameters of SA on the magnitude of the error

Example SA	Distance to SA, r, m	Maximum intensity error	Absolute time error Δt,s	Relative coordinate error,%
1	25	7,41E-05	1,74121E-05	0,0689
1	50	9,43E-06	1,0943E-05	0,0538
1	75	2,81E-06	1,02811E-05	0,0532
1	100	1,19E-06	1,01189E-05	0,0531
2	25	7,41E-05	1,37061E-05	0,0789
2	50	9,43E-06	1,04715E-05	0,054
2	75	2,81E-06	1,01405E-05	0,0532
2	100	1,19E-06	1,00595E-05	0,0531
3	25	7,41E-05	1,37061E-05	0,1719
3	50	9,43E-06	1,04715E-05	0,0343
3	75	2,81E-06	1,01405E-05	0,0273
3	100	1,19E-06	1,00595E-05	0,0267
4	25	7,41E-05	2,48242E-05	0,0327
4	50	9,43E-06	1,1886E-05	0,0215
4	75	2,81E-06	1,05621E-05	0,0213
4	100	1,19E-06	1,02379E-05	0,0212

As evidenced by the analysis of the calculation results (see table 4) for symmetric SA (examples of table 1), the distance to SA has a significant effect on the magnitude of the error. Thus, when recording the intensity, it is assumed that the maximum value of the intensity of the wave coming to each of the microphones was assumed to be constant. The latter assumption also makes a significant contribution to the magnitude of the overall methodological error, as the intensity decreases as the wave propagates from the first microphone to the next. It is known that almost all [5] algorithms do not take this fact into account. In addition, the time used by the system is synchronized with the time of reading information from the microphones, and therefore, as a second factor, introduces a time error equal to half the sample time of reading. Thus, in the simulation, simulating the changes in intensity, the value of the maximum possible error of the maximum intensity, the absolute error of the time and the relative error of the coordinate SA are estimated. The results of the analysis show that for the selected four examples of symmetric distributions of intensity SA, the same regular changes in the dependence of the maximum possible error are observed. Increasing the distance between the microphones increases the amount of error, but it should be noted that this impairs the mobile quality of the system. Data demonstrating the grounds for such conclusions are presented in table 5 for example 4 of the symmetric variant of echograms. Thus, with increasing distance between the microphones, significantly increases the maximum possible error and, as a consequence, the relative error of determining the coordinates.

Table 5

Analysis of the influence of the distance between the microphones on the error? algorithm 5

№	The distance between mic-rophones *a*, m	Distance to SA, r, m	Maximum intensity error	Absolute time error Δt, s	Relative coordinate error, %
1	0,2	25	2,53E-05	1,10118E-05	0,0145362
2	0,6	25	1,29648E-05	7,41E-05	0,0206952
3	1,0	25	0,000121	1,48284E-05	0,0287785
4	1,4	25	0,000165	1,66079E-05	0,0372271

To select the algorithm for determining the time, the simulation and comparison of processes by the criterion of the magnitude of the relative error, the number of operations and the time required to fully calculate the time of entry of the wave into the microphone. In [5-9] the authors established that the determining factor of the three criteria is the accuracy of coordinate determination. Its value is determined by the error of fixing the time of entry of the wave to each of the microphones. In this regard, four algorithms were considered.

Algorithm 1.

The calculated time is the arithmetic mean time between the moment of time at which the value of 0.5 of the maximum intensity in the jump phase is reached and the time at which the intensity decreases to 0.5 of the maximum intensity.

Algorithm 2.

The calculated time is the time of the center of gravity of the echogram at ten points, and its countdown is from the point in time at which the value of 0, 5 maximum intensity is reached.

Algorithm 3.

The calculated time is the time of the arithmetic mean between the time of the jump phase from 0, 2 values of maximum intensity and level to 0.2 of its decrease in maximum intensity.

Algorithm 4.

The estimated time is according to the recurrent algorithm according to MPA [5] for which the estimated time is as the time of equivalent areas, according to the recurrent relation.

First of all, their work was studied and the influence of factors on the error for each of the four algorithms was studied. The properties of these algorithms were studied. The general conclusion of this analysis is that the generalized first and third algorithms are the simplest and most effective for symmetric intensity distributions. The use of a given value of the constant from 0.2 to 0.5 in the formal essence of the algorithm does not change. However, it leads to unified values of zero and one. In addition, the choice of a constant value of 0.2 significantly reduces the total calculation time, which is critical for specific applications. Algorithm 4 is efficient in terms of action and accuracy, but requires the organization of complex calculations. The accuracy of algorithm 4 is justified for complex non-symmetric intensity distributions, and for symmetric simple SA it is advisable to use algorithm 1.

4.3. Analysis of algorithms for recognizing and determining the time of complex echograms

On the basis of the conducted analysis the generalized algorithm of definition of time of occurrence of a sound wave of difficult structure ON as follows was formulated.

Algorithm 5. The calculated time is the arithmetic mean time between the time of the jump time from 0.2 to the value of the maximum intensity and the first subsequent maximum. To analyze the advantages and disadvantages of Algorithm 4, we analyze the effect of the distance between the microphones on the amount of error when using Algorithm 4.

Table 6

Analysis of the influence of distance between the microphones on the error value using algorithm 4

№	The distance between microphones *a*, m	Distance to SA, *r*, m	Maximum error intensity, Δi	Absolute error of time Δt, c	Relative error of the coordinates of its decline, %,	Total calculation time Δt_{Min}, s
1	0,2	25	2,53E-05	1,253E-05	0,000143128	0,20002265
2	0,6	25	7,41E-05	1,741E-05	0,000182726	0,20004716
3	1,0	25	0,000121	2,207E-05	0,023603	0,20007036
4	1,4	25	0,000165	2,652E-05	0,029351	0,20009259

To confirm this conclusion, we present the calculations by algorithm 4 (see Table 6). Thus, the calculations of the variant of table 5 show a significant reduction in error due to the choice of algorithm 5. However, the calculation of time costs shows that in the case when the origin is unknown and to be determined, the simple algorithm 5 prevails because it has a millisecond time.

Thus, when the accuracy of determining the value of the coordinate by algorithm 5 is sufficient, and the time of determining the coordinate is critical, the advantage over algorithm 4 is algorithm 5. In addition, it should be noted that for MES, military, with an error of centimeters, time is decisive, and for other purposes there is an accuracy of coordinates of a source SA.

5. Conclusions

1. The task of simulation modeling and estimation of the magnitude of the components of the maximum possible error that occurs when determining the coordinates of SA is set and carried out. Comparative analysis of the simulation results shows that the distance to the source SA and the relative position and distance between the microphones of the CS significantly affects the amount of static error. Thus, when increasing the relative distance from 41.66 to 82.33, the error decreases from 0.0689% to 0.0538%, and then almost unchanged for the case of symmetric echograms.

2. The choice of the algorithm does not significantly affect the estimation of the static maximum possible error in determining the coordinates SA for symmetric echograms, however for asymmetric echograms the choice of the algorithm significantly recognizes its value.

3. The algorithm for determining the moment of time of the identical phase of the occurrence of the wave front is determined by the required accuracy or the required calculation time. For critical accuracy, more preferable is the MPA algorithm 4, and at critical time, acquires algorithm 5.

6. References

[1] Trunov, A., Byelozyorov, Z. (2020). Forming a method for determining the coordinates of sound anomalies based on data from a computerized microphone system. Eastern-European Journal of Enterprise Technologies, 2 (4 (104)), 38–50. doi: http://doi.org/10.15587/1729-4061.2020.201103

[2] The Pentagon received at its disposal the first robot mule, 2022. URL: https://phys.org/news/2012-12-legged-squad-ls3-darpa-four-legged.html

[3] A. Trunov, P. Kazan, V. Alieksieiev, O. Korolova, O. Sliusarenko, I. Dronyuk, Functioning Model of The Ground Robotic Complex, in: Proceedings of The International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT'21), IEEE, 2, p. 128–131. 2021, doi: 10.1109/CSIT52700.2021.9648595.

[4] Axel Michelsen and Ole Næsbye Larsen. Pressure difference receiving ears. Topical review. IOP publishing. bioinspiration & biomimetics Bioinsp. Biomim. 3 (2008) 011001 (18pp) doi:10.1088/1748-3182/3/1/011001

[5] Zh.Byelozyorov, A. Trunov, Increasing quality of the wireless module for monitoring and supervision of sound series of the expanded purpose, Eastern-European Journal of Enterprise Technologies, vol. 6/5 (114) (2021), 28–40. DOI: https://doi.org/10.15587/1724061.2021.247658

[6] R. Kochan, O. Kochan, B. Trembach, P. Falat, K. Warwas. Theoretical Error of Bearing Method in Artillery Sound Ranging Proceedings of the 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2019, 2019, 2, стр. 615–619, 8924450

[7] R. Kochan, B. Trembach, O. Kochan. Methodical error of targets bearing by sound artillery intelligence system ISTCMTM. Scientific journal "Measuring Equipment and Metrology. Lviv 2019; Volume 80(3) : pp.10-14. https://doi.org/10.23939/istcmtm2019.03.010

[8] Kamil Krasuski, Damian Wierzbicki. Monitoring Aircraft Position Using EGNOS Data for the SBAS APV Approach to the Landing Procedure. Journal Sensors 20(7):1945. March 2020 DOI:10.3390/s20071945

[9] Ciećko, A.; Grunwald, G. The comparison of EGNOS performance at the airports located in eastern Poland, Technical Sciences 2017, 20(2), pp. 181–198

[10] L. Nguyen, J. Valls, X. Qiu: Multilevel B-Splines-Based Learning Approach for Sound Source Localization, IEEE Sensors Journal (2019). doi:10.1109/ JSEN.2019.2895854

[11] D. Döbler, G. Heilmann, M. Ohm, Automatic detection of microphone coordinates, 3rd Berlin Beamforming Conference, 2010. URL: http://www.bebec.eu/Downloads/BeBeC2010/Papers/BeBeC-2010-15.pdf

[12] J. Suern Yong, D.Y. Wang, Impact of noise on hearing in the military, PMCID, PMC4455974. PMID: 26045968 (2015). URL: https://mmrjournal.biomedcentral.com/articles/10.1186/s40779-015-0034-5.

[13] C. Rascon, I. Meza, Localization of sound sources in robotics: A review, Elsevier Masson SAS, 2017. URL: https://doi.org/10.1016/j.robot.2017.07.011

[14] X. Yang, H. Xing, X. Ji: Sound Source Omnidirectional Positioning Calibration Method Based on Microphone Observation Angle, Complexity JOUR, vol. 04. 2018. October. DOI: 10.1155/2018/2317853

[15] A. I. Tkachenko "Fuzzy" Estimating of the In-Flight Geometric Calibration Parameters.Том 51, Выпуск 3, 2019, pp. 48-55. DOI: 10.1615/JAutomatInfScien