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# IMPROVING THE SYSTEM OF MOBILE DEVICES FOR DETERMINING THE COORDINATES OF SOUND ANOMALIES

Byelozyorov Zh. O.

Petro Mohyla Black Sea National University, Mykolaiv, Ukraine

E-mail: zhan.byelozyorov@gmail.com

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**Abstract.** The simulation of the operation of devices for determining the coordinates of sound anomalies, which is located on board mobile devices of monitoring systems, is considered. The calculation based on the data of the coordinates of sound anomalies, which were measured in the connected coordinate system of a separate device, coordinates in a single basic system, is substantiated. The model of the error calculation process was built and modeled taking into account the influence of the angular velocity of the carrier device for a separate device. It is proposed based on the results of modeling the hardware and software parts of the device.

This study is devoted to the modeling of devices embedded in mobile monitoring systems designed to detect sound anomalies. These devices play a crucial role in identifying and tracking the coordinates of such anomalies. The research focuses on elucidating the computational methods used to transform the coordinates of sound anomalies, originally measured in a linked coordinate system of individual devices, into coordinates within a single reference system.

An important aspect of this study is the construction of a model to estimate the error accumulation process. This model takes into account the influence of the angular velocity of the carrier on individual components. By simulating various scenarios, the study aims to accurately quantify and understand the sources of errors inherent in the system.

In addition, the study offers recommendations for improving the hardware and software components of the device based on the information obtained during the simulation process. These recommendations include hardware additions and strategic reallocation of software components to mitigate errors and improve the overall efficiency and accuracy of audio anomaly detection systems.

**Анотація.** Розглянуто моделювання роботи пристроїв визначення координат звукових аномалій, які розташовані на борту мобільних пристроїв систем моніторингу. Обґрунтовано розрахунок за даними координат звукових аномалій, вимірних у зв'язаній системі координат окремого приладу, координат в єдиній базовій системі. Побудовано та змодельовано модель процесу розрахунку похибки з урахуванням впливу кутової швидкості несучого пристрою для окремого пристрою. Запропоновано за результатами моделювання апаратної та програмної частин пристрою.

Це дослідження присвячене моделюванню пристроїв, вбудованих у мобільні системи моніторингу, призначених для виявлення звукових аномалій. Ці пристрої відіграють вирішальну роль у ідентифікації та відстеженні координат таких аномалій. Дослідження зосереджено на з'ясуванні обчислювальних методів, які використовуються для перетворення координат звукових аномалій, спочатку вимірних у пов'язаній системі координат окремих пристроїв, у координати в одній системі відліку.

Важливим аспектом цього дослідження є побудова моделі для оцінки процесу накопичення помилок. Ця модель враховує вплив кутової швидкості носія на окремі компоненти. Шляхом моделювання різних сценаріїв дослідження спрямоване на точне кількісне визначення та розуміння джерел помилок, притаманних системі.

Крім того, дослідження пропонує рекомендації щодо вдосконалення апаратних і програмних компонентів пристрою на основі інформації, отриманої в процесі моделювання. Ці рекомендації включають доповнення до апаратного забезпечення та стратегічне перерозподіл програмних компонентів для зменшення помилок і підвищення загальної ефективності та точності систем виявлення звукових аномалій.

**Keywords:** modeling, device on board, sound anomaly, coordinate error, addition of hardware, redistribution of parts of programs.

**Ключові слова:** моделювання, пристрій на борту, звукова аномалія, помилка координат, додавання апаратного забезпечення, перерозподіл частин програм.



## INTRODUCTION

Supplementing the composition of traditional information flows with data on the characteristics of sound events in the environment and on sound anomalies (SA) expands the capabilities of surveillance and monitoring systems [1, 5]. Especially as a result of the analytical solution of the problem of SA coordinates [6] based on the data of four microphones and the creation of small-sized microprocessor devices, which are managed in a wireless network by web applications of Android smartphones, created innovative opportunities for their development as computerized systems (CS) [7]. Joint use of CS for systems determining coordinates of the SA (SDCSA) and autonomous robots significantly expands their functional capabilities [8]. In this regard, despite the works that theoretically justify the calculation of methodological error [9, 10], an additional problem arises related to the need to simultaneously use several devices for SDCSA. It is due to the fact that the devices with SDCSA in their own connected, and not in the basic coordinate system (BCS).

The last reason is an additional source of error in the practical application of several devices placed on mobile autonomous robots of various types, which was studied comprehensively in the connected coordinate system [11], and into the single basic one still requires its setting and solution.

### 1. TRENDS IN THE DEVELOPMENT OF DEVICES FOR DETERMINING THE COORDINATES OF SOUND ANOMALIES ACCORDING TO THE LATEST WORKS

In the works of recent years, attempts have been made to create small-sized CS, suitable for determining coordinates with a system of four microphones for automated experiments and installation on mobile autonomous devices. One of the works, which theoretically substantiated the reduction of the number of microphones, analytically solved the system of nonlinear equations, laid the foundations for creating effective algorithms for four microphones [6]. The numerical modeling and process convergence research carried out in it only confirmed new possibilities for expanding the functions of the device when using small-sized controllers [6]. An example of an effective implementation of such an idea for experimental study and practical creation of CS by wireless control of recording by a system of microphones of sound arrays and SDCSA is work [7]. The experimental results demonstrated the possibility of creating small-sized autonomous monitoring devices for SA with wireless Wi-Fi communication channels controlled by Android smartphones [7]. However, the work [7] also showed that an important obstacle to its application is the methodical error caused by the design features of the CS structure and the conditions of its location. Studies of theoretical aspects of error formation according to the Bearing Method in Artillery Sound Ranging [8] will obviously find their application. However, the attempt to separate from the value of the general error of methodical targeting for artillery systems is common for control and measurement systems for various metrological schemes [9]. In this regard, as an extension and continuation of previous works, modeling was set up and carried out to study the influence of metrological scheme factors and mode parameters on the error value [10]. The developed method for estimating the error of SDCSA source determined the problem of phase identification for different microphones and allowed to choose algorithms for their processing according to the given value of their error [10]. At the same time, the development of mobile robotics has demonstrated new capabilities that fundamentally change functions as a result of joint use [11]. The second example studying the possibilities of joint application of the unmovable device for SDCSA is the work [12]. The paper analyzes the features of the interaction between one UAV and the device for SDCSA is installed significantly affects on the total error [13]. The difficulty of determining the additional error component depends on the quality of the device dynamics model [13]. The use of the hand of anthropomorphic robots reduces the error component, but the drive error also contributes and needs to be taken into account [14]. The work [15] is devoted to the study of the influence of disturbances on the dynamics and the study of the structure of the controller for the formation of the stepper motor driver as part of the drive. Its addition is the work [16], which estimates tolerances for setting parameters based on experimental data. The algorithm of parallel calculations in the tasks of determining the tolerance of parameters is solved on the basis of the ellipsoid estimation method [17]. They will be especially acute during the operation for SDCSA located on mobile surveillance systems. Thus, one of the main unsolved problems that hinder physical modeling and further improvement of SDCSA is the lack of methods that allow taking into account the variability of coordinates and orientation of devices.

### 2. THE PURPOSE AND OBJECTIVES OF THE RESEARCH

The goal of the study is to increase the efficiency of the system of devices for SDCSA, which are located from the of mobile devices as the part of the monitoring system.

To achieve this goal, the following tasks were set:

- develop algorithms for recalculating coordinates in the linked system of the device to a BCS;
- form the recommendations on improving the structure and composition of the software and its physical redistribution between the single-board controller and the Android smartphone;
- carry out modeling and establish the nature of the arrangement of devices in the monitoring system.

### 3. PROBLEMS OF COMBINING INFORMATION ABOUT SOUND ANOMALIES BASED ON THE DATA OF VARIOUS MOBILE COORDINATE DETERMINATION DEVICES

In research firstly were considered  $N$  mobile devices that are part of the monitoring and surveillance system [6]. Suppose that a separate  $i$ -th mobile device, on board of which is placed the  $i$ -th device for determining the coordinates SA moves in the BCS  $O_oX_oY_oZ_o$ . A semi-connected coordinate system  $O'_iX'_iY'_iZ'_i$  and a rigidly connected coordinate system  $O_iX_iY_iZ_i$  were also introduced, for which one point  $O_i$  was chosen as the reference point, which is the center of mass of the apparatus. The axes of the semi-connected coordinate system are oriented parallel to the axes of the same name in the BCS  $O_oX_oY_oZ_o$ . We denote the speed with which point  $O_i$  moves:



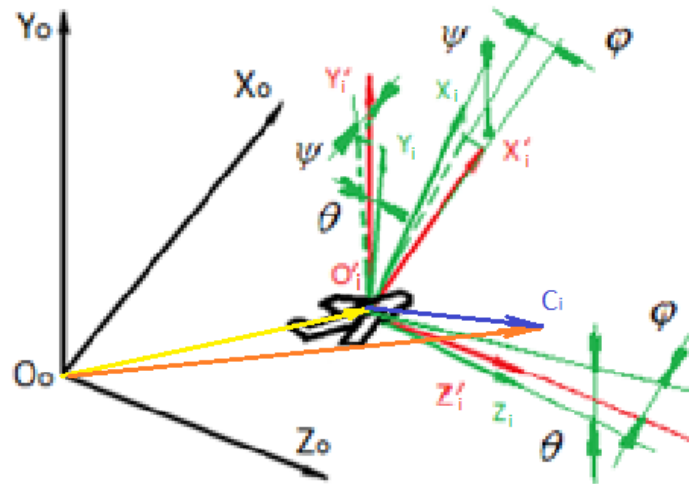
$$\bar{V} = \bar{i}V_x + \bar{j}V_y + \bar{k}V_z \tag{1}$$

Apparatus *i* and the rigidly connected coordinate system  $O_i X_i Y_i Z_i$  rotates with angular velocity  $\bar{\Omega}$  around the center of mass, which will be presented through projections:

$$\bar{\Omega} = \bar{i}\omega_x + \bar{j}\omega_y + \bar{k}\omega_z \tag{2}$$

where  $\bar{i}, \bar{j}, \bar{k}$  - are the unit vectors of the axes of the connected coordinate system,  $V_x, V_y, V_z, \omega_x, \omega_y, \omega_z$  - projections of velocities on the corresponding coordinate axes and instantaneous positions of the center of mass  $x(t), y(t), z(t)$  with the angular orientation of the object in space at three angles  $\theta(t), \varphi(t), \psi(t)$ .

For the further presentation of the material, three consecutive rotations of the coordinate system  $O_i X_i Y_i Z_i$  around the vertical axis  $O'_i Y'_i$  to the drift angle  $\varphi$ , followed by a rotation around the axis  $O'_i Z'_i$  to the trim angle (pitch)  $\psi$ , and then a rotation around the axis  $O'_i X'_i$  to the roll angle  $\theta$  were considered. SA was accelerated as a point source, the coordinates of which are determined by the device located on board the mobile device. The position of SA in the space of the bound coordinate system is conventionally denoted by the point  $C_i$  or vectors: relatively to the rigidly connected  $O_i X_i Y_i Z_i$  coordinate system by the vector  $\bar{R}_{oici}$  and relatively to the BCS  $O_o X_o Y_o Z_o$  is the vector  $\bar{R}_{oci}$  specifying the position of the center of mass apparatus in the BCS. Under these notations and the conditions of the projection of the angular velocity vector (2), we write down the derivatives of the Euler angles of drift  $\bar{R}_{oci}$ , trim  $\psi$ , and roll  $\theta$  [13]:



**Fig. 1 – Movement of the apparatus in the BCS  $O_o X_o Y_o Z_o$  semi-connected**  
**Рис. 1 – Рух апарату в БКС  $O_o X_o Y_o Z_o$  напівзв'язаний**

$O'_i X'_i Y'_i Z'_i$  and rigidly connected  $O_i X_i Y_i Z_i$

$$\begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = \begin{bmatrix} \dot{\theta} + \dot{\varphi} \sin \psi \\ \dot{\varphi} \cos \theta \cos \psi + \dot{\psi} \sin \theta \\ -\dot{\varphi} \sin \theta \cos \psi + \dot{\psi} \cos \theta \end{bmatrix} \tag{3}$$

Using the notation of the radius of the formation vector SA relative to the connected coordinate system by the vector  $\bar{R}_{oici}$  and the origin as reference point of the connected system  $\bar{R}_{ooi}$  its coordinate will find as the vector  $\bar{R}_{oci}$  by angle of rotation  $\bar{\alpha}$ :

$$\bar{R}_{oci} = \bar{R}_{ooi} + \bar{\alpha} \times \bar{R}_{oici} \tag{4}$$

Thus, the error of determining the SA *i* - coordinate with that device is

$$\Delta \bar{R}_{oci} = \Delta \bar{R}_{ooi} + \Delta \bar{\alpha} \times \bar{R}_{oici} + \bar{\alpha} \times \Delta \bar{R}_{oici} \tag{5}$$

If the error of the position of the center of mass is determined by GPS properties and the placement of the receiver on the device relative to the center of mass, then angular velocity sensors must be installed to determine the error of the



angular velocity vector. The error of determining the SA coordinate is determined by the method used in the  $i$ -th device on board the  $i$ -th apparatus. Thus, to model the error of the SA coordinate, which will be formed as a result of the simultaneous use of several ( $N$ ) devices, it is enough to find the average value of the vector as the average of the vector sum of all vectors for one SA in the BCS.

#### 4. ANALYSIS AND IMPROVEMENT OF THE STRUCTURE OF THE CS AND THE COMPOSITION OF THE SOFTWARE AND ITS PHYSICAL REDISTRIBUTION BETWEEN THE SINGLE-BOARD CONTROLLER AND THE ANDROID SMARTPHONE

The basis for the analysis was the CS of the SA registration device, which consists of a receiving module (RM) based on an ARDUINO board and a data processing module (DPM) based on a smartphone [7]. As a result of solving the problem of the minimal structure, the RM included microphones with amplification and signal matching boards, an ARDUINO UNO WIFI REV2 board with digital and analog input-output channels and an integrated Wi-Fi module. When using the RM as a module of a separate device for determining the SA coordinate, the principle of operation of the CS consisted in the fact that the microphones of the RM recorded a stable sound wave signal, determined the arrival time of one of its phases and transmitted its array in digital format for processing by software (SW), which physically was previously installed on the ARDUINO board. As a result of ARDUINO UNO WIFI REV2 SW operation, after forming an array of fixed time of arrival of one phase of the sound wave to each of the microphones. After forming an array with information for all microphones, Arduino turns on Wi-Fi and the RM access point of module. Turning on the access point in surveillance mode is waiting for the RM and only after it is turned on, a connection is established between them specifically for receiving the array about the fixed time of the sound wave entering the microphones. The SW installed on the DPM [12], based on the received data, calculates the coordinates of the SA and visualizes them on the smartphone screen both automatically and on request.

The transition to the use of devices on board mobile devices, which are part of the surveillance system, fundamentally expands the functions of the devices. However, as shown by the consideration of the movement process of a separate device and their system with devices on board, to ensure metrological quality, it is necessary to place GPS receivers that determine the coordinates of the device and sensors of accelerations and angular position and orientation in space. The latest requirements also make changes to the structure of the CS and software, respectively. In order to improve the structure and composition of the software and choose the physical redistribution between the single-board controller and the Android smartphone, the RM should be supplemented with a NEO-7M GPS module. With the help of the latter, the RM software should form an array of the coordinates of the receiver center and an array with data on the positioning of the RM in the form of values of Euler angles in a three-dimensional format with subsequent transmission to the DPM.

This data set will allow the DPM software to synchronize the positioning of both the microphones of a single RM and several RMs both in stationary mode and during the movement of the latter. Such an improvement will bring together the data of the devices on the time of registration of one phase of one SA in a single BCS. Such an improvement will bring together the data of the devices on the time of registration of one phase of one SA in rigidly connected coordinate system. For hardware, it is necessary to use the NEO-7m module, which is a continuation of the GPS module series from uBlox and which replaces the NEO-6m. This module supports several navigation systems (GPS, GLONASS) and provides a low level of energy consumption with high positioning quality.

Thus, the hardware addition will include the NEO-7m module, tilt angle acceleration sensors and a gyroscope. The software will complement the Arduino software that can be installed from a smartphone, as well as the software for requesting and transmitting two data streams of coordinates from the NEO-7m and accelerations and angles with a gyroscope. Upon request, three data streams are now transmitted to the DPM via Wi-Fi module of Arduino. The DPM software is additionally supplemented with software for processing two new streams and presenting coordinates in one BCS.

#### 5. MODELING AND COMPARISON OF DATA ON THE OCCURRENCE OF A SOUND ANOMALY ACCORDING TO THREE DEVICES

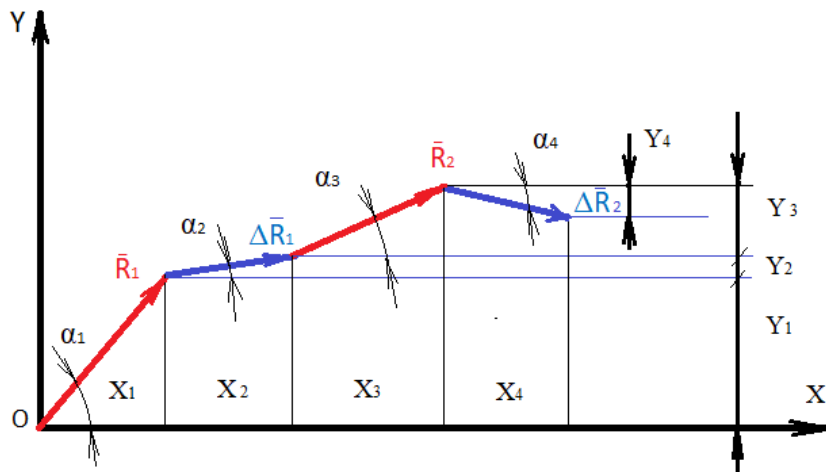
To simulate the process of determining coordinates by  $N$  devices installed on  $N$  mobile devices, first of all, we will enter the system time. Its value relative to the step number during the course of the process will be determined by the length of the interval  $\Delta$ . As a norm, we will take the length of the observation interval, which is assigned and divided by the number of intervals. The number of intervals  $k$ , as in all cases of analysis of samples of random variables, is recommended to be calculated using the Sturges number. Let's assume that two vectors  $\bar{R}_1$  and  $\bar{R}_2$  (Fig. 2), which are marked in red, are fixed at the beginning of the simulation, which determine the coordinates of the center of mass of the device and SA.

Vectors displaying probable error values  $\Delta\bar{R}_1$  and  $\Delta\bar{R}_2$  are marked and in blue in Figure 2. Under these conditions, setting the error vectors as random variables in which both the modulus and the direction have a uniform distribution. The module and direction of the device position error changes in a limited interval. The module is from zero to the maximum error of determining the GPS coordinate, and the direction is from  $-180$  to  $+180$  degrees. Also, the error vector for determining the coordinates of the device changes to the maximum error determined by the accuracy class of the device, and the direction is from  $-180$  to  $+180$  degrees.

The normal error distribution law was adopted for the modules and the direction of the error vectors. We will conduct the simulation for the SA fixation vector for three devices, and define the SA position as the average. The simulation



results are presented in Table 1. In Table 1, column 2 presents the relative radius, columns 3 and 4 present the angle that determines the direction of the resulting vector and its modulus, respectively.



**Fig. 2 – Schematic presentation of the formation of the SA coordinate error as a result of the device error and the device error**

**Рис. 2 – Схематичне зображення формування похибки координат СА внаслідок помилки приладу та помилки приладу**

The simulation was carried out with different modules of the position vector of the bound coordinate system R1 and R2, which determines the position of the formation point SA in the bound coordinate system. As evidenced by the data analysis, random changes in the error vectors for determining the starting coordinate of the connected coordinate system slightly change this vector in terms of magnitude and direction in the static mode for one device:

$$\left\{ \begin{aligned} X_{aver} &= \sum_{i=1}^3 \sum_{j=1}^4 \frac{X_{ij}}{3}, Y_{aver} = \sum_{i=1}^3 \sum_{j=1}^4 \frac{Y_{ij}}{3}, Z_{aver} = \sum_{i=1}^3 \sum_{j=1}^4 \frac{Z_{ij}}{3}. \end{aligned} \right.$$

Table 1. Modeling of the error formation process

№	ΔR1,m	R1=500m R2=500m		R1=300m R2=300m	
		<i>αрез</i>	<i>Rрез, m</i>	<i>αрез</i>	<i>Rрез, m</i>
1	0	44,99739	1414,281	44,99563	848,5959
2	1,25	44,99196	1414,421	44,98658	848,7367
3	2,5	44,98478	1414,609	44,97464	848,9263
5	3,75	44,98024	1414,728	44,96712	849,0481
6	5	44,97659	1414,825	44,96106	849,1473

However, the use of several devices for its measurement will obviously change the picture. To study this effect, three devices were considered and simulations were carried out. Devices are located on the line and at the vertices of an equilateral triangle. In the case of the scheme, when the devices are located on the line under the same conditions, the error increased at sharp angles in relation to the direction of the radius of the formation vector SA and those approaching 180 degrees. In the case when the devices were located according to the scheme of an equilateral triangle, the error distribution became more uniform. Thus, the simulation demonstrated the influence of the metrological parameters of the systems, which determine the features of the SDCSA carrier, on the increase of the error. The modeling also demonstrates that the division of tasks by the nature of SA into classes: a separate sound that does not repeat with a certain nature of changes, a repeating sound, the duration of which is an order of magnitude longer than the processing time, and a non-permanent sound of a periodic nature. The nature of the modernization and addition of other principles of measurement and improvement of the algorithm for accounting for the influence of the moving medium is a way of further research into the development of SDCSA for practical application of several devices placed on mobile autonomous robots.

### CONCLUSIONS

The model of the apparatus movement in space, as an absolutely rigid body allows to development of algorithms for recalculating coordinates SA are determined in connected system of the device to a single basic coordinate system if the coordinates of the origin of the connected coordinate system are known in it.

The minimum structure of a mobile wireless device for installation on board a mobile device requires improvement of the structure and composition of the software and its physical redistribution between the single-board controller and the Android smartphone.

Modeling the process of the simultaneous influence of the error in determining the coordinates of the origin of the connected coordinates system and the error in determining the coordinates in them allows to calculation of the coordinates



of SA in a single basic coordinates system to the algorithm for determining the mathematical expectation and dispersion.

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