

METHOD OF DETERMINING THREE ACOUSTIC SENSORS FOR REGISTRATION THE BALLISTIC WAVE OF AN ARTILLERY SHOT**V. E. Demydenko¹, S. S. Retsenko², M. M. Maksymov²**¹ Odesa Polytechnic National University² National University "Odesa Maritime Academy Institute of the Naval Forces

Abstract. The paper is dedicated to the development of the method of identifying acoustic sensors for registering ballistic and muzzle waves of an artillery shot. The proposed method allows solving the problem of selecting three acoustic meters from the existing set in the firing zone, which are the most suitable for implementing effective registration of ballistic and muzzle waves of a shot, taking into account their location, measurement error, and the probability of failure-free operation.

Keywords: artillery shooting, verification of shots, ballistic wave, method of identifying acoustic sensors

Introduction

Currently, barrel field artillery serves as the main force for performing fire missions in ground combat operations [1]. Recent conflicts, including those in the 21st century and the ongoing war between Ukraine and Russia, have revealed that to be effective, artillery must be utilized with innovative tactical approaches and methods. In 2022, the Ukrainian Armed Forces reportedly fired between 4,000 and 7,000 artillery rounds daily, while the Russian occupation forces fired several times (sometimes up to ten times) more [2]. Achieving high accuracy in artillery strikes allows for accomplishing fire missions with significantly fewer rounds.

Moreover, the traditional approach to counter-battery operations [3] has shifted toward a "shoot and scoot" tactic [4]. To ensure the continued combat effectiveness of artillery units, it is critical to reduce the time required to engage targets [5]. Each artillery shot gives the enemy a chance to locate the firing unit and launch counterattacks. In this regard, the development of innovative effective techniques of firing that allow for the destruction of targets with the least number of rounds and minimal exposure time on the firing line is of critical importance.

1. Statement of the problem

In the present day, utilizing advanced methods and modern information technologies is recommended to enhance shooting precision. For example, calculating projectile flight paths with

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sophisticated ballistic models relies on specialized techniques for rapid assessment and accuracy prediction under field conditions [6, 7].

Additionally, specialized tools [8] and geographic information systems [9, 10] are now employed to develop firing tables and produce map-tablets for artillery units' commanders.

Enhancing shooting accuracy and minimizing time spent at firing positions can be achieved by refining the process of verifying shot results, specifically confirming whether the projectile has hit the target or determining its deviation from the aiming point [11]. This technological approach involves creating an information feedback loop between successive shots from an artillery piece [12, 13]. After each shot, the initial firing settings are adjusted for the next round. As outlined in [13], there are two categories of information feedback procedures: "shoot-look-shoot" for targets visible from the firing position, and "shoot-adjust-shoot" for concealed positions. Both approaches require the assessment of the projectile's burst coordinates, which adds complexity and time to the verification process.

In order to significantly increase the efficiency of verification of artillery shots under conditions of various disturbances, a method has been developed in [14, 15] that allows verification of a shot before the projectile lands and explodes. This method is based on the registration of ballistic and sound waves generated by a projectile flying along a trajectory, using a system of acoustic sensors distributed in space. Implementation of the given method allows to significantly limit the time of fire implementation of weapons and reduce the consumption of shells when compensating for random disturbances compared to traditional sighting. Full-scale field testing has fully confirmed the correctness of the main scientific and technical concepts underlying this method [15].

To implement the method of verification of an artillery shot with random disturbances, discussed above, it is necessary to have a specialized

measuring system consisting of a weather station, at least three acoustic sensors, a calculation unit and other auxiliary elements. Moreover, the efficiency of using this method and the considered system for determining the coordinate of the collision of an artillery shell with a surface mainly depends on the accuracy of recording the ballistic wave shot using the three acoustic measuring devices given above. In turn, the accuracy of recording the ballistic wave and the success of the subsequent parabolic approximation are affected by a number of factors, including the measurement error and the probability of the working state of the acoustic sensors, their location in relation to the line of fire direction, etc.

Since the acoustic measuring devices are placed in the firing zone in advance, and the positions of the artillery guns and the coordinates of the targets to be hit may change during firing depending on the received fire missions, the main task that must be solved before each shot is the selection of three measuring devices from the existing set that would be best suited for recording the ballistic wave. To solve this complex problem, it is advisable to use a method for determining three acoustic sensors for recording the ballistic wave of an artillery shot, the development of which is the subject of this study.

Thus, the main goal of this work is to develop a method for determining three acoustic sensors for registration the ballistic wave of an artillery shot.

2. Basic aspects of the method for determining three acoustic sensors for registration the ballistic wave of an artillery shot

The proposed method allows for the determination of three acoustic sensors that would be best suited for registering a ballistic wave during the verification of artillery shots, based on known values of the current target coordinates, the artillery mount itself, and all functioning acoustic sensors distributed in the firing zone. The target coordinates are received from the fire control unit depending on the received fire mission. The current coordinates of the artillery mount and each of the functioning acoustic sensors located in the firing zone are determined using their built-in navigation systems.

At the initial stage, based on the received coordinates of the target and the artillery cannon, the required firing range L_{fr} and the angle α between the firing direction line and the Oy axis are determined. Also the equation of the line of the firing direction for the current shot is drawn up. In turn, the firing range and angle α are calculated on the basis of dependencies (1) and (2), and the equation of the firing direction line in the form of a general equation of a straight line on a plane is written in the form of expression (3) [16, 17]:

$$L_{fr} = \sqrt{(x_{tr} - x_{ARC})^2 + (y_{tr} - y_{ARC})^2}; \quad (1)$$

$$\alpha = \arcsin\left(\frac{x_{tr} - x_{ARC}}{L_{fr}}\right); \quad (2)$$

$$a_{fr}x + b_{fr}y + c_{fr} = 0, \quad (3)$$

where x_{tr} , y_{tr} are the target coordinates; x_{ARC} , y_{ARC} are the coordinates of the artillery cannon; a_{fr} , b_{fr} , c_{fr} are the coefficients of the equation of the firing direction line. At the same time, in this case, the angle α can take values only from -90° to 90° , and increases in the clockwise direction. The coefficients of the equation of the straight line on the plane (3) a_{fr} , b_{fr} , and c_{fr} are found using certain expressions of analytical geometry [16] or using the method of least squares based on the known coordinates of the target and the artillery cannon [18].

To significantly reduce the volume of calculations in the process of selecting the three most suitable acoustic sensors at the initial stage, it is advisable to sort out of the total number of all functioning sensors of the system only those that are in the zone of possible registration of ballistic and acoustic waves of the current artillery shot. In turn, this zone is limited by the conventional parallelogram ABCD. It is advisable to set the AD width of this zone depending on the accuracy of registration of ballistic and acoustic waves by sensors (in most cases, no more than 100 m). The length AB is determined as the length of the projectile flight section with a supersonic speed L_{ss} using the projectile flight model [19, 20] based on the firing range L_{fr} previously calculated by formula (1).

To determine the zone of possible registration of ballistic and sound waves of an artillery shot and the subsequent selection of sensors located in it, it is necessary to first find the coordinates of points A, B, C, D, as well as determine the equations of four straight lines passing through these points.

The coordinates of points A and D are based on the current coordinates of the artillery cannon using expressions (4) and (5), respectively:

$$x_A = x_{ARC} - \frac{L_{AD}}{2}; y_A = y_{ARC}; \quad (4)$$

$$x_D = x_{ARC} + \frac{L_{AD}}{2}; y_D = y_{ARC}, \quad (5)$$

where L_{AD} is the length of segment AD.

The coordinates of points B and C are found based on the coordinates of the point on the line of firing direction in which the projectile loses supersonic speed, using expressions (6) and (7), respectively:

$$x_B = x_{ls} - \frac{L_{BC}}{2}; y_B = y_{ls}; \quad (6)$$

$$x_C = x_{ls} + \frac{L_{BC}}{2}; y_C = y_{ls}, \quad (7)$$

where x_{ls} , y_{ls} are the coordinates of the point on the line of firing direction in which the projectile loses its supersonic speed; L_{BC} is the length of segment BC ($L_{BC} = L_{AD}$).

In turn, the coordinates of the point on the line of the firing direction, in which the projectile loses its supersonic speed, are calculated based on the determined length of the flight section of the projectile with a supersonic speed L_{ss} , the angle α and the current coordinates of the artillery cannon using expressions (8) and (9), respectively:

$$x_{ls} = x_{ARC} + L_{ss} \sin \alpha; \quad (8)$$

$$y_{ls} = y_{ARC} + L_{ss} \cos \alpha. \quad (9)$$

Next, the equations of four straight lines passing through the following points are determined: 1) A and B; 2) D and C; 3) A and D; 4) B and C. To simplify the calculations of the equation of these lines, it is advisable to present them in the form of equations of lines with angular coefficients:

$$y = a_{AB}x + b_{AB}; \quad (10)$$

$$y = a_{DC}x + b_{DC}; \quad (11)$$

$$y = a_{AD}x + b_{AD}; \quad (12)$$

$$y = a_{BC}x + b_{BC}, \quad (13)$$

where a_{AB} , b_{AB} , a_{DC} , b_{DC} , a_{AD} , b_{AD} , a_{BC} , b_{BC} are the coefficients of the equations of straight lines. These coefficients are found using certain expressions of analytical geometry [16] or using the method of least squares based on the coordinates of points A, B, C and D [18].

After that, on the basis of the equations of lines (10)-(13) and their determined coefficients, conditions (14) are formed, for the fulfillment of which, a sequential check of all functioning acoustic sensors of the system is carried out according to their coordinates. In turn, where x_i , y_i are the coordinates of the i -th acoustic sensor of the system.

$$\begin{cases} x_i \geq \frac{y_i - b_{AB}}{a_{AB}}; \\ x_i \leq \frac{y_i - b_{DC}}{a_{DC}}; \\ y_i \geq a_{AD}x_i + b_{AD}; \\ y_i \leq a_{BC}x_i + b_{BC}, \end{cases} \quad (14)$$

If the coordinates of the i -th sensor satisfy the conditions (14), then it enters the zone of possible registration of ballistic and sound waves of an artillery shot and can be selected as one of the three most suitable sensors.

After carrying out this sorting, all sensors that have passed the test for the fulfillment of conditions (14) with a positive result are numbered in order and selected for further calculations aimed at finding the three most suitable meters for registering ballistic and sound waves. All other acoustic sensors that are not included in the zone limited by the parallelogram ABCD are not used in the following stages of the method.

At the next calculation stages of the proposed method, only three meters are determined among the set of selected sensors, which are the most suitable for registering ballistic and sound waves. To select these three acoustic sensors, all selected sensors are evaluated according to the following parameters.

The first parameter that significantly affects the suitability of an acoustic sensor for high-quality registration of ballistic and sound waves is its position along the line of firing direction, which is determined by the distance d_i from the artillery cannon to the point on the line of firing direction, as close as possible to this sensor.

In turn, for more accurate verification of artillery shots, it is advisable to register ballistic and muzzle waves in the second half of the projectile flight section with supersonic speed and as close as possible to its end [14, 15]. In addition, all three acoustic sensors must be placed evenly along the firing line to ensure proper capture of the ballistic and muzzle waves at three different points. Also, the last third sensor cannot be installed too close to the point with coordinates x_{ls} , y_{ls} , in which the projectile loses supersonic speed, because this point is determined with a certain error, and a situation may arise when the third sensor will be outside the flight zone of the projectile with supersonic speed. Therefore, as optimal distances from the artillery cannon to the first, second and third sensors along the line of the firing direction, it is advisable to pre-set the following values: $d_{1opt} = 0.5L_{ss}$; $d_{2opt} = 0.7L_{ss}$; $d_{3opt} = 0.9L_{ss}$, where L_{ss} is the length of the projectile

flight section with supersonic speed for the current shot.

Thus, when choosing the most suitable first, second or third acoustic sensors, it is necessary for each i -th sensor located in the zone of possible registration of ballistic and muzzle waves (ABCD), to calculate the parameter d_{li} and compare its value with the corresponding preset optimal value d_{l1opt} , d_{l2opt} or d_{l3opt} .

In turn, the distance d_{li} for the i -th acoustic sensor is calculated based on the coordinates of this sensor and the obtained general equation of the line of firing direction (3) as follows. First, the coordinates x_{pi} , y_{pi} of the point on the line of the firing direction closest to this sensor are determined using expressions (15) and (16) [16, 17]:

$$x_{pi} = \frac{b_{fr}(b_{fr}x_i - a_{fr}y_i) - a_{fr}c_{fr}}{a_{fr}^2 + b_{fr}^2}, \quad (15)$$

$$y_{pi} = \frac{a_{fr}(a_{fr}y_i - b_{fr}x_i) - b_{fr}c_{fr}}{a_{fr}^2 + b_{fr}^2}, \quad (16)$$

where x_i , y_i are the coordinates of the i -th acoustic sensor; a_{fr} , b_{fr} , c_{fr} are the coefficients of the equation of the firing direction line.

After that, based on the received coordinates x_{pi} , y_{pi} and the known coordinates of the artillery cannon x_{ARC} , y_{ARC} , the value of the distance d_{li} is calculated directly using the formula (17)

$$d_{li} = \sqrt{(x_{pi} - x_{ARC})^2 + (y_{pi} - y_{ARC})^2}. \quad (17)$$

The second no less important parameter by which the most suitable acoustic sensors are selected is the distance d_{ti} from the sensor to the nearest point on the line of the firing direction, which is determined by the length of the perpendicular drawn from the point where the sensor is located to the line of the firing direction. The smaller the value of this distance, the higher the accuracy of recording the ballistic and muzzle waves of a shot, and, accordingly, the more suitable this sensor is considered to be. Therefore, the optimal option for all acoustic sensors (first, second and third) used for shot verification is their location directly on the line of the shooting direction ($d_{l1opt} = d_{l2opt} = d_{l3opt} = 0$).

The value of the given distance d_{ti} for the i -th acoustic sensor can be calculated based on the coordinates of this sensor x_i , y_i and the resulting equation of the line of firing direction (3) in general form using expression (18) [16, 17]

$$d_{ti} = \frac{|a_{fr}x_i + b_{fr}y_i + c_{fr}|}{\sqrt{a_{fr}^2 + b_{fr}^2}}. \quad (18)$$

For clarity, the process of determining the distances d_{li} and d_{ti} for the i -th acoustic sensor in the zone of possible registration of ballistic and muzzle waves (ABCD) for the case when the line of the firing direction passes at an angle α to the axis Oy is shown in Fig. 1. In turn, the following notations are accepted in Fig. 1: 1 is the artillery cannon, 2 is the target, 3 is the i -th acoustic sensor. The zone of possible registration of ballistic and muzzle waves ABCD is outlined by bold dashed lines. All acoustic sensors located in this zone are marked in gray.

The third parameter, which must also be taken into account when choosing the three most suitable acoustic sensors, is the value of their probability of failure-free operation $P(t)$. Even if the i -th sensor has a fairly good location (according to the d_{li} and d_{ti} parameters) in the ABCD zone, and the value of its probability of failure-free operation is not high, then choosing it for the registration of ballistic and muzzle waves will be inappropriate, since there is a rather high risk of its failure and subsequent failure to complete the entire verification procedure of the current shot.

In practice, the reliability of any element is determined by two components: the probability of sudden failures $P_r(t)$ and the probability of wear failures $P_u(t)$ [21].

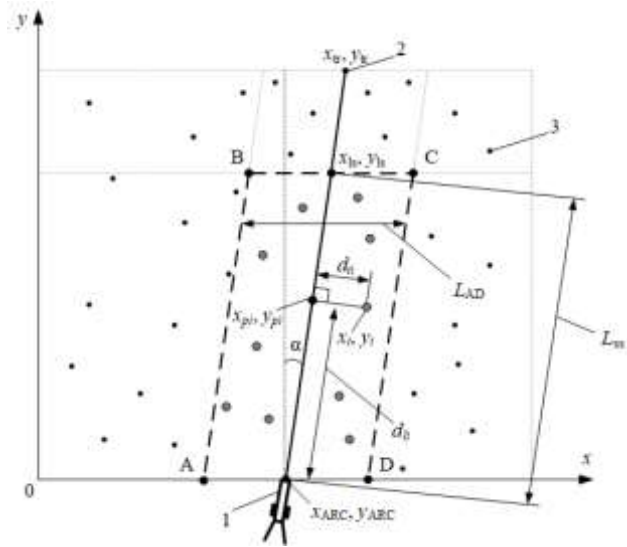


Fig. 1. - Determination of d_{li} and d_{ti} distances for the i -th acoustic sensor in the zone of possible registration of ballistic waves.

Random failures are described by an exponential law, in which the reliability or probability of failure-free operation $P_r(t)$ is determined by the expression:

$$P_r(t) = e^{-\lambda t}, \quad (19)$$

where λ is the intensity of sudden failures.

During the normal operation of the equipment, the failure rate is a constant value for the exponential law. When wear occurs, the failure rate begins to increase and wear failures are added to random failures, which are usually described by the normal distribution law:

$$P_u(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{\infty} e^{-(t-M)^2/2\sigma^2} dt, \quad (20)$$

where M is the average value of the durability of the element, taking into account the wear; σ is the standard deviation from the average durability, which is defined as

$$\sigma = \sqrt{\frac{\sum (t-M)^2}{N}}, \quad (21)$$

where N is the number of failures during time t .

In turn, the joint probability of failure-free operation of the element taking into account sudden and wear failures in the period from $t = 0$ (when the element is new) to time t is calculated as

$$P(t) = e^{-\lambda t} P_u(t). \quad (22)$$

Thus, in the process of selecting the most suitable sensors for recording the ballistic and muzzle waves of a shot, the probability of failure-free operation $P(t)$ for each i -th acoustic sensor is determined using the expression (22) depending on the time of operation t based on the known values of λ_i , M_i and N_i .

For a comprehensive assessment of the suitability of acoustic sensors for recording ballistic and muzzle waves of a shot, it is advisable to draw up a complex dimensionless criterion of suitability J , which will take into account properly all three considered sensor parameters (d_{li} , d_{ii} and P_i). In turn, the suitability criterion J_i for each i -th sensor

$$J_i = f(d_{li}, d_{ii}, P_i). \quad (23)$$

In turn, dependence (23) can be represented as a linear function with pre-selected weighting coefficients, as well as more complicated functions, including those calculated using fuzzy logic, neural network or neuro-fuzzy models.

Moreover, for the convenience of calculations, it is advisable to assume that the criterion of suitability of acoustic sensors J can vary in the range from 0 to 1. The more the calculated value of the criterion J_i approaches 1, the more suitable the i -th sensor is considered.

Since the three most suitable sensors must be selected for registering the ballistic and muzzle waves of each shot, the criterion J_i for each i -th sensor must be calculated 3 times (J_{i1} , J_{i2} , J_{i3}) taking

into account as which sensor (first, second or third) it will be used. Next, the largest of the obtained values (J_{i1} , J_{i2} or J_{i3}) will determine the final suitability of this sensor J_{if} with fixation as exactly which sensor (first, second or third). In turn,

$$J_{if} = \max\{J_{i1}, J_{i2}, J_{i3}\}. \quad (24)$$

After that, according to the value of the final suitability J_{if} , this i -th acoustic sensor will be assigned to one of three groups: potential first, second or third sensors. For example, for the i -th acoustic sensor, the following values of the suitability criterion as the first, second, and third sensors were calculated: $J_{i1} = 0.791$; $J_{i2} = 0.215$; $J_{i3} = 0.42$. Since the value of J_{i1} is the largest among the calculated ones, this sensor will be pre-selected to the group of potential first sensors with the corresponding suitability $J_{if} = 0.791$.

Thus, for all sensors included in the zone of possible registration of ballistic and muzzle waves ABCD, the suitability criterion J is calculated three times, after which they are divided into three groups according to the obtained best J_f values.

At the last stage of the method, in the formed groups of potential first, second and third sensors, the corresponding best first, second and third sensors will be selected according to the maximum suitability values of J_{best1} , J_{best2} , J_{best3} . These acoustic sensors will be three sensors that will be used to register the ballistic and muzzle waves of the current artillery shot.

Based on all of the above, we will form the main steps of the proposed method of determining three acoustic sensors for registering ballistic and muzzle waves of an artillery shot.

3. Main steps of the method for determining three acoustic sensors for registering ballistic wave of an artillery shot

The proposed method has a graphical representation shown in Fig. 2 and consists of the following sequential steps.

Step 1. Method initialization. At this stage, all initial data necessary for the verification of artillery shots is obtained or determined. In particular, the number and coordinates of all functioning acoustic sensors distributed in the area of artillery firing are determined and recorded. The fixed values of all parameters used in the calculations of the method are pre-selected, including: the width of the zone of possible registration of ballistic and muzzle waves L_{AD} ; optimal distances from the artillery cannon to the first, second and third sensors along the line of firing direction d_{1opt} , d_{2opt} , d_{3opt} ; current values of the probability of failure-free operation of each

sensor $P(t)$. In turn, it is advisable to set the width of the AD zone L_{AD} depending on the accuracy of registration of ballistic and muzzle waves by sensors (in most cases, $L_{AD} = 100$ m). It is advisable to set the optimal distances from the cannon to the sensors along the line of the firing direction by the following dependences on the length of the flight section of the projectile with a supersonic speed L_{ss} for the current shot: $d_{1opt} = 0.5L_{ss}$; $d_{2opt} = 0.7L_{ss}$; $d_{3opt} = 0.9L_{ss}$. Current reliability values $P(t)$ for sensors are calculated based on their known values of sudden failure intensity λ , durability M , number of failures N , and operating time t . Also, immediately before starting the calculations, the current coordinates of the target x_{tr} , y_{tr} and the artillery cannon x_{ARC} , y_{ARC} are obtained.

Step 2. Implementation of initial calculations. Based on the coordinates of the target x_{tr} , y_{tr} and the artillery cannon x_{ARC} , y_{ARC} , the required firing range L_{fr} , the angle α and the length of the projectile flight section with a supersonic speed L_{ss} are determined.

In addition, the equation of the firing direction line for the current shot is drawn up and its coefficients a_{fr} , b_{fr} , c_{fr} are determined. In turn, the firing range and angle α are calculated based on dependencies (1) and (2), respectively, and the length of the projectile flight section with supersonic speed L_{ss} is calculated using the projectile flight model [19, 20]. The general equation of the line of the firing direction is written in the form of expression (3), and its coefficients a_{fr} , b_{fr} , c_{fr} are found using expressions of analytical geometry or the method of least squares based on the known coordinates of the target and the artillery cannon.

Step 3. Determination of the zone ABCD of possible registration of ballistic and sound waves of the current artillery shot. At this step, the coordinates of points A, B, C, D, as well as the equations of four straight lines passing through these points are determined. In turn, the coordinates of points A, B, C and D are found using expressions (4)-(7), respectively. At the same time, formulas (8) and (9) are used to find the coordinates x_{ls} , y_{ls} of the point on the line of the firing direction in which the projectile loses its supersonic speed. The equations of the four straight lines passing through the points A, B, C and D are written in the form of equations (10)-(13), respectively, and their coefficients are calculated using the expressions of analytical geometry or the method of least squares based on the coordinates of the points A, B, C and D.

Step 4. Sorting of sensors included in the ABCD zone. From the total number of all functioning sensors of the system, only those that are in the zone ABCD of possible registration of ballistic and muzzle waves of the current artillery

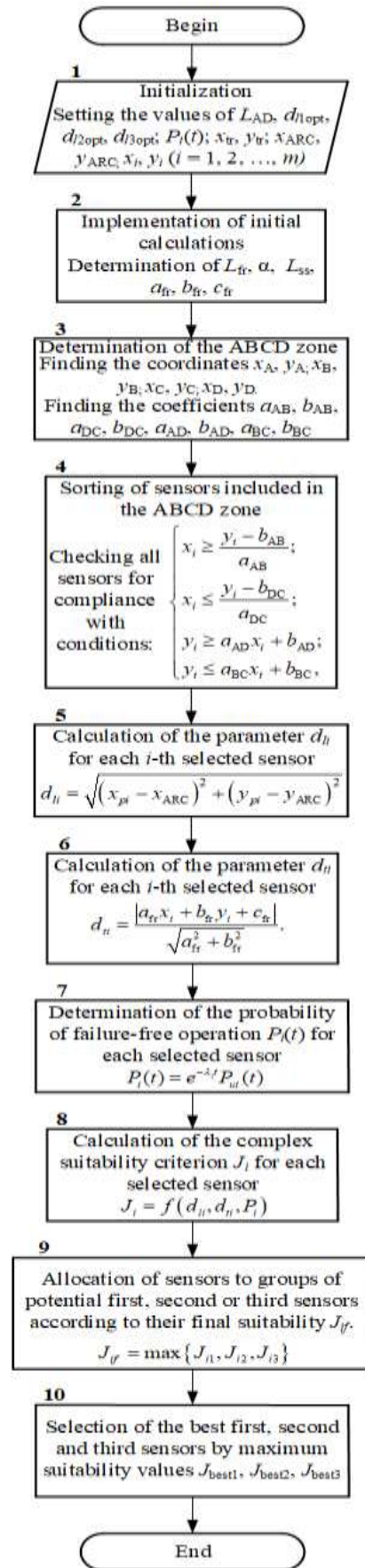


Fig. 2. Block diagram of the method for determining three acoustic sensors for registering ballistic wave of an artillery shot

shot are sorted. Based on the complex conditions (14), a sequential check of all functioning acoustic sensors of the system is carried out according to their coordinates. If the coordinates of the i -th sensor x_i, y_i satisfy the conditions (14), then it is selected for further calculations. All other sensors (which did not pass the selection) are discarded and not used in the next steps of the method.

Step 5. Calculation of the parameter d_{li} for each i -th selected sensor. For each i -th sensor located in the ABCD zone, the distance d_{li} from the artillery cannon to the point on the line of firing direction, as close as possible to this sensor, is calculated. This distance is calculated using dependence (17), and the coordinates x_{pi}, y_{pi} of the point on the line of the firing direction closest to the i -th sensor are found using expressions (15) and (16), respectively.

Step 6. Calculation of the parameter d_{li} for each i -th selected sensor. The distance d_{li} from the sensor to the nearest point on the line of the firing direction is calculated for each i -th sensor located in the ABCD zone. This distance is calculated using formula (18).

Step 7. Determination of the parameter $P_i(t)$ for each i -th selected sensor. For each i -th acoustic sensor located in the ABCD zone, the probability of failure-free operation $P_i(t)$ is calculated using expression (22).

Step 8. Calculation of the complex suitability criterion J_i for each i -th selected sensor. At this stage, based on the predefined parameters d_{li}, d_{li} and $P_i(t)$ for each i -th sensor, the complex suitability criterion is calculated 3 times (J_{i1}, J_{i2}, J_{i3}) using expression (23) taking into account as which sensor (first, second or third) it will be used. In turn, the function (23) must be previously defined with pre-set values of its coefficients.

Step 9. Allocation of all sensors to groups of potential first, second or third sensors according to their final suitability value J_{if} . At this step, for each i -th sensor, the final suitability J_{if} is determined using expression (24) with a fixation as which sensor (first, second or third). Next, 3 groups of potential sensors (first, second and third) are formed, by which all available sensors are distributed.

Step 10. Selection of the best first, second and third sensors by maximum suitability values. At this stage, in each of the three groups of potential sensors formed in the previous step, one best sensor is selected according to the maximum suitability values of $J_{best1}, J_{best2}, J_{best3}$. These acoustic sensors will be the three (first, second and third) sensors, which will be used to register the ballistic and muzzle waves of the current artillery shot.

After implementation of the last 10th step of the proposed method, the search for the best acoustic

sensors is considered complete, and the selected three sensors can be used to verify the current artillery shot and registration of the coordinates of the projectile's collision with the surface.

Conclusions

In this study, the method of identifying three acoustic sensors for registering ballistic and muzzle waves of an artillery shot is developed. The proposed method makes it possible to solve the problem of selecting three acoustic meters from the existing set in the firing zone, which allow to implement effective registration of ballistic and muzzle waves of a shot, taking into account their location in relation to the line of the firing direction, measurement error, and the probability of failure-free operation.

Implementation of the given method allows to perform subsequently verification of a shot before the projectile lands and explodes, which significantly limit the time of fire implementation of weapons and reduce the consumption of shells when compensating for random disturbances.

In further studies, it is planned to consider various dependencies for calculating the complex dimensionless suitability criterion of acoustic sensors, including those calculated using fuzzy logic, neural network or neuro-fuzzy models. Also it is planned to conduct a series of computational experiments on specific examples of various shots in different conditions to evaluate the accuracy of the method.

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МЕТОД ВИЗНАЧЕННЯ ТРЬОХ АКУСТИЧНИХ СЕНСОРІВ ДЛЯ РЕЄСТРАЦІЇ БАЛІСТИЧНОЇ ХВИЛІ АРТИЛЕРІЙСЬКОГО ПОСТРІЛУ

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Анотація. Стаття присвячена розробці методу ідентифікації акустичних сенсорів для реєстрації балістичних і дульних хвиль артилерійського пострілу. Запропонований метод дозволяє вирішити задачу вибору трьох акустичних вимірювачів із наявного набору в зоні стрільби, найбільш придатних для здійснення ефективної реєстрації балістичних і дульних хвиль пострілу з урахуванням їх розташування, похибки вимірювання та ймовірності безвідмовної роботи.

Ключові слова: артилерійська стрільба, верифікація пострілів, балістична хвиля, метод ідентифікації акустичних сенсорів

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