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EQUATIONS SYSTEM PARAMETERIZATION FOR THE RADIO EMISSION SOURCES COORDINATES DETERMINATION

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Abstract—*The problem of determining the location of radio emission sources by means of the time difference of arrival method is considered. The advantages and disadvantages of this method are analyzed. When solving equation systems, it is used Newton's iterative method. In this case, there are cases where Newton's method diverges, and the solution cannot be found. Jacobean is close to zero, if the radio emission source coordinates are located on the segment connecting the observation stations. The method of parameterization of the calculation system for increasing the convergence of the Newton method is considered. The efficiency of the proposed parameterization with different mutual arrangement of the passive radar system and the source of radio emission is analyzed, and proved for greater accuracy calculations should be chosen that hyperboloid, the angle at the top of which is the smallest. It was shown the conditions by that the hyperboloid parameterization allows object coordinates determining with rather high accuracy.*

Index Terms—Passive radiolocation; equations system parameterization; Newton method convergence; hyperboloid; direction finding; time difference of arrival method; radio emission source.

I. INTRODUCTION

Coordinates determination of the radio emission source (RES) by the multi-position complexes of a passive location is based on the time differential and range-metering method, which in foreign literature is called in abbreviated form as TDOA method (Time Difference of Arrival). The main measured information for this task solution is measurements of delays time of the signals receipt at the station. Determination of the observed RES coordinates is based on a solution of the hyperbolic equations on the central place of acceptance. For n of points of observation (one of them is a central station of reception) the $n-1$ system of the nonlinear hyperbolic equations is necessary to solve. In this case, the system of mathematical equations expressing the distances and geometry structure of the stations and RES relative positioning consists of the unknown coordinates set at the minimum quantity of measurements, and the equations should not be linearly dependent. Generally, analytical methods of the solution of the nonlinear equations systems guaranteeing receiving an acceptable result does not exist, therefore systems of equations are solved by approximate iterative methods. The most widespread method of a solution of similar systems is Newton's method. On condition of the certain requirements execution to the nonlinear equations properties Newton's method is as well the most effective method of the solution. However, its practical application is complicated by the following difficulties [1]:

– formal application of the computing routine of a method does not guarantee convergence of an algorithm which existence is defined by properties of the nonlinear equations;

– bad conditionality of the partial derivatives matrixes lowers the coordinates finding accuracy, reduces the convergence speed and finally can create basic difficulties at a solution of tasks.

Basis of radar detection and determination of RES coordinates is the radio signal re-emitted or radiated by subjects to observation. In an active radar-location the source of electromagnetic oscillations is the sending device of radar station. The main characteristics of radar station depend on the look and parameters of the probing signal (energy, carrier frequency, range duration and width): distance, accuracy of determination of coordinates and speeds of objects, resolution capability, that is information which can be received when processing a radar signal.

The most perspective is use of the passive radar-location systems in which the receivers system connected with each other is used. Using the receiving stations (RS) carried in space, the complex provides finding of the geometrical values characterizing RES location. The passive location system should consist not less than of two RS.

The most common coordinates determination method in the passive location systems is the measurement of relative signal delays. In a passive radar-location the frequency of the coming radiation is in advance unknown therefore the review of a radio signal is made in frequency domain. As positions are carried in space, the signal from the source will come to each of them not at the same time. The signal arrival time differences for each position can rather just be measured in a case of pulse radiation on delay factor of any set time point. The first attempts of the passive systems use came down to use of direction finding channels of radar station with the subsequent combination of information in the central station. This method of determination of coordinates received the name triangular (direction finding, goniometric). As the only method of determination of coordinates the triangular method was not widely adopted. Nevertheless, interest in researches in the field of passive radar complexes was rather high that caused search of new solutions for RES detection and coordinates determination [2].

The time difference of arrival method for the first time was applied in the sixties the 20th centuries. Its essence consists in measurement by several RS, being at some distance from each other, the temporary arrival difference of the signal radiated by the source.

II. Problem Statement

Generally, the operation principle of the passive location multi-position systems on the basis of TDOA method is based on use of four accepting stations: L_1, L_2, L_3, and C (Fig. 1), where C is a central station of reception.

Basic data are observation stations coordinates, speed c and signal passing time τ_i from the object to the observation station, where i is a number of the observation station. Location of the central station of reception is accepted as the coordinate's origin of the three-dimensional space.

Signal delay period is defined τ_1, τ_2, τ_3 on the known coordinates of stations and time of receiving signal:

$$\tau_i = \frac{1}{c}\left(\overline{OL_i} + \overline{CL_i} - \overline{OC}\right), \quad (1)$$

where τ_i is the signal arrival time delays of i – RES signal on station C from stations L_i; OL_i is the distances between RES and stations; CL_i is the distances between the side and central stations; OC is the distance between RES and the central station.

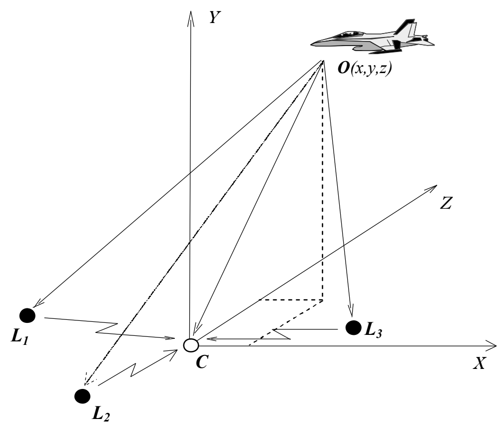

Fig. 1. Operation principle of the RES coordinates determination by the passive system

Ratios (1) connect RES signal arrival times with the distances between stations L_i and a central station C, with distances between all stations and RES and also with a speed c of the RES signal distribution speed in the atmosphere.

Having expressed ratios (1) in the coordinate system of the stations position and RES, we will receive the system of the nonlinear equations in which all values except coordinates of provision of RES are known (x, y, z):

$$F_i(\vec{s}) = \frac{1}{c}\left(\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} + D_i - \sqrt{x^2+y^2+z^2}\right) - \tau_i = 0, \quad D_i = \overline{CL_i}, \quad i = 1, 2, 3. \quad (2)$$

By the software development for the passive location complexes the problem of the computing operations volume reduction, increasing accuracy of the received solutions and also receiving reliability of the accepted result in the conditions of the limited temporary resource of the real-time system is very important.

It will be offered a number of approaches for the mathematical and algorithmic apparatus improvement for the main objective solution of the passive location complexes – RES coordinates obtaining [3].

By the coordinates and route task solution the following can reach reduction of computing operations in the ways:

– modified Newton method use connected with partial derivatives matrix recalculation number reduction;

– algorithmic organization improvement. Coordinates determination acceleration with the help of an exception of one of the equations of the system (2) from the iterative process, if one of coordinates of RES does not change (for example, flight altitude), and also at the stabilization achievement of the any of RES coordinates in iterative process. At the same time the equations having the greatest sensitivity to the error of the coordinate calculation to errors in basic data [4];

– direct exception of one of the equations by development and application of analytical conversions of initial system (2). One of such methods, namely a parameterization method, will be stated below in this work.

In the considered area $\Omega \in R^3$ three-dimensional space R^3 vector function $F(s) = (F_1(s), F_2(s), F_3(s))$ has all partial derivatives of the 1st order. The computing procedure of the Newton method can be received easily from decomposition in a row of Taylor in point x^* systems of equations

$$F(s^*) = F(s_k) + F'(s_k)(s^* - s_k) + R(s^* - s_k). \quad (3)$$

Assuming s^* is a system solution, the right part (3) will be equated to zero, and, neglecting the residual member $R(s^* - s_k)$, it will be received the Newton's scheme:

$$F(s_k) + F'(s_k)(s^* - s_k) = 0. \quad (4)$$

Resolving the equation (4) in rather new approach s_{k+1}, it will be gained a classical form of the method:

$$s_{k+1} = s_k - F'(s_k)^{-1} F(s_k). \quad (5)$$

For the Newton method implementation it is necessary to receive the analytical expressions for the partial derivatives matrix calculation that allows saving time.

Iterations (5) are possible if a matrix of partial derivatives $F'(s_k)$ – no degenerate as only in this case there is an inverse matrix $F'(s_k)^{-1}$. Newton's method not with guarantee meets this condition even in case of one variable.

The task is to research the complex of the interconnected problems like convergence, resistance to errors of measurements, tasks solution time expenses by Newton's method and its modifications.

III. Hyperboloid Construction and Parameterization

The equations (2) define the locus, the difference of distances from which to these focuses is equal to some value, $2r$. In three-dimensional space this surface is called a hyperboloid. The hyperboloid equation can be written in simpler look if focuses are on one coordinate axis. By means of turn conversion it is possible to solve the problem in the new coordinate system. For determinacy it will be accepted as focuses the basic and side stations – C and L_2, at the same time it will be arranged the focus L_2 on an axis y (Fig. 2). In this case, coordinates of focuses will be $(0;0;0)$ and $(0;D_2;0)$, respectively. It is possible to select any other receiving station and any coordinate axis, the solution will be executed similarly. The hyperboloid equation in a new coordinate system has an appearance:

$$\frac{\left(y_p - (D_2/2)\right)^2}{r^2} - \frac{x_p^2}{q^2} - \frac{z_p^2}{q^2} = 1, \quad (6)$$

where $q = \sqrt{(D_2^2/4) - r^2}$, the lower index p means the coordinates received by transformation of the initial coordinate system.

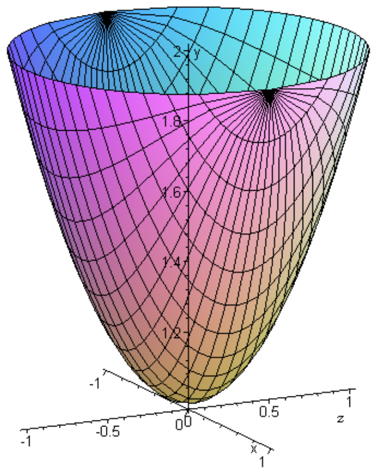

Fig. 2. Hyperboloid corresponds to the equation $F_2 = 0$

To transform the hyperboloid equation to the canonical form, it will be executed turn of the coordinate system. Conversion is a combination of turns around an axis y on an angle φ_1 and around axis z on an angle φ_2 (Fig. 3). Angles are from ratios

$$\begin{cases} \varphi_1 = -\operatorname{arctg}\dfrac{z_2}{x_2}, \quad \varphi_2 = -\operatorname{arctg}\dfrac{\sqrt{z_2^2 + x_2^2}}{y_2}. \end{cases} \quad (7)$$

The turn matrix has an appearance

$$P^+ = \begin{pmatrix} \cos\varphi_2 \cos\varphi_1 & -\sin\varphi_2 & -\cos\varphi_2 \sin\varphi_1 \\ \sin\varphi_2 \cos\varphi_1 & \cos\varphi_2 & -\sin\varphi_2 \sin\varphi_1 \\ \sin\varphi_1 & 0 & \cos\varphi_1 \end{pmatrix}. \quad (8)$$

Inverse matrix

$$P^{-}=\begin{pmatrix}\cos\varphi_2\cos\varphi_1 & \sin\varphi_2\cos\varphi_1 & \sin\varphi_1\\ -\sin\varphi_2 & \cos\varphi_2 & 0\\ -\cos\varphi_2\sin\varphi_1 & -\sin\varphi_2\sin\varphi_1 & \cos\varphi_1\end{pmatrix}. \quad (9)$$

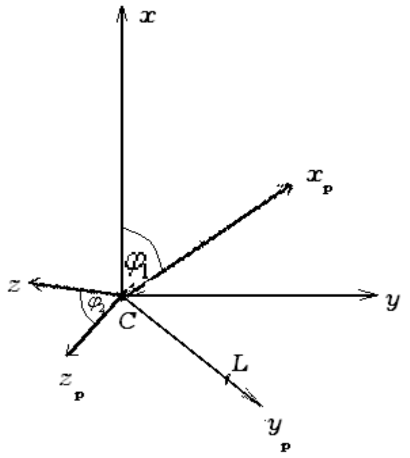

Fig. 3. Coordinate system turn

Hyperboloid (6) can be written in a look

$$\begin{cases} x_p = q\,\mathrm{sh}\,t\cos\varphi,\\ y_p = \dfrac{D_2}{2} + r\,\mathrm{sgn}\left(D_2 - \tau_2\cdot c\right)\mathrm{ch}\,t,\\ z_p = q\,\mathrm{sh}\,t\sin\varphi. \end{cases} \quad (10)$$

Values t and φ are the hyperboloid parameters. At such parameterization (10) the second equation of an initial system (2) is satisfied identically.

It is known that asymptotes of a hyperbole are straight lines. The canonical surface formed by rotation of an asymptote around the real axis is called an asymptotic cone of a double-band hyperboloid. The slope angle β an asymptotic cone is defined as $\mathrm{tg}\beta = r/q$. By the task solution it is necessary to select that hyperboloid for which the slope angle is closer to zero.

The system of equations (2) comes down to two equations with two unknown variables:

$$F_1 = \frac{1}{c}\left(\sqrt{\left(q\,\mathrm{sh}\,t\cos\varphi - x_{1p}\right)^2 + \left(\frac{D_2}{2} + r\,\mathrm{sgn}\left(D_2-\tau_2 c\right)\mathrm{ch}\,t - y_{1p}\right)^2 + \left(q\,\mathrm{sh}\,t\sin\varphi - z_{1p}\right)^2}\right.$$
$$\left. + D_1 - \sqrt{\left(q\,\mathrm{sh}\,t\cos\varphi\right)^2 + \left(\frac{D_2}{2} + r\,\mathrm{sgn}\left(D_2-\tau_2 c\right)\mathrm{ch}\,t\right)^2 + \left(q\,\mathrm{sh}\,t\sin\varphi\right)^2}\right) - \tau_1 = 0,$$
$$F_3 = \frac{1}{c}\left(\sqrt{\left(q\,\mathrm{sh}\,t\cos\varphi - x_{3p}\right)^2 + \left(\frac{D_2}{2} + r\,\mathrm{sgn}\left(D_2-\tau_2 c\right)\mathrm{ch}\,t - y_{3p}\right)^2 + \left(q\,\mathrm{sh}\,t\sin\varphi - z_{3p}\right)^2}\right.$$
$$\left. + D_3 - \sqrt{\left(q\,\mathrm{sh}\,t\cos\varphi\right)^2 + \left(\frac{D_2}{2} + r\,\mathrm{sgn}\left(D_2-\tau_2 c\right)\mathrm{ch}\,t\right)^2 + \left(q\,\mathrm{sh}\,t\sin\varphi\right)^2}\right) - \tau_3 = 0. \quad (11)$$

The system (11) is solved by the Newton's method. For the general case

$$\begin{cases} F_1(t,\varphi) = 0,\\ F_3(t,\varphi) = 0, \end{cases}$$

initial approach is selected (t_0, φ_0). Further the matrix of derivatives is built

$$L = \begin{pmatrix} \dfrac{\partial F_1}{\partial t} & \dfrac{\partial F_1}{\partial \varphi}\\ \dfrac{\partial F_3}{\partial t} & \dfrac{\partial F_3}{\partial \varphi} \end{pmatrix}. \quad (12)$$

Following value of variables t and φ is defined from the recurrence matrix relation:

$$\begin{pmatrix} t_{n+1}\\ \varphi_{n+1}\end{pmatrix} = \begin{pmatrix} t_n\\ \varphi_n\end{pmatrix} - L^{-1}\begin{pmatrix} F_1\\ F_3\end{pmatrix} \quad (13)$$

where L^{-1} is the inverse matrix.

There are parameters t and φ, then by means of representations (10) and (6) RES coordinates in the new coordinate system are defined. By multiplication of the matrix P^{-} on the received vector, it will be received the answer: object coordinates in the initial coordinate system.

IV. MATHEMATICAL MODELING

Cartesian coordinates of the RES that is situated relatively to the base station were determined by preset delay times. The calculation was made in the Maple software package in two ways. In the first way, the system of the hyperbolic equations (3) was solved directly by Newton's method. In the second way, hyperboloid parameterization was used. Results of calculations are presented in Table I.

TABLE I. CALCULATION RESULTS

No	Preset delay times, μs		Solution, m		Iterations 1. Way	Iterations 2. way
1	τ_1	41.4451	x,	50000	18	18
	τ_2	123.403	y	40000		
	τ_3	34.634	z	1000		
2	τ_1	45.992	x	40000	17	14
	τ_2	124.777	y	30000		
	τ_3	35.305	z	800		
3	τ_1	36.198	x	400000	27	22
	τ_2	118.681	y	300000		
	τ_3	28.373	z	21800		
4	τ_1	72.033	x	300000	32	25
	τ_2	120.382	y	100000		
	τ_3	9.5007	z	2800		

Newton's process meets also a limit vector $s^* = \lim\limits_{p\to\infty} s^{(p)}$ is a system solution at execution of the following conditions:

1) Jacobean's matrix $W(s)$ at $s = xs^{(0)}$ has an inverse matrix of $G_0 = W^{-1}(s^{(0)})$ where $||G_0|| \le A_0$,

2) $||G_0 f(s^{(0)})|| \le B_0 \le M/2$,

3) $\left|\frac{\partial^2 f_i(s)}{\partial x \partial y}\right| + \left|\frac{\partial^2 f_i(s)}{\partial y \partial z}\right| + \left|\frac{\partial^2 f_i(s)}{\partial z \partial x}\right| \le C$,

4) constants of A_0, B_0, C_0 satisfy to inequality: $\mu_0 = 2nA_0B_0C_0 \le 1$.

Analytical formulas for definition μ_0 in this case are very bulky, therefore the numerical research of this value depending on distance between coordinates of an object and a point $x^{(0)}$, taken for zero approach, was made by means of the Maple software package.

Example. Reception stations coordinates:

Central station: (0,0,0). Side stations: (4.00; -0.27; 0.05); (2.78; -3.13; 0.15) (1.15; 2.09; 0.85). RES coordinates (19.1; 0.7; 0.9). Signal delay time $1.15\cdot10^{-7}$ s, $6.64\cdot10^{-6}$ s, $9.08\cdot10^{-6}$ s respectively.

After five iterations it will be received RES coordinates with the accuracy up to 1 km. Further the error of calculations does not decrease, and remains in the same limits.

At calculations by Newton's method without parameterization the result was not received, the method divergences.

The dependence of mean value μ_0 from distance to the RES (coordinates (19.1; 0.7; 0.9)) is given in the Fig. 2. For definition of mean value μ_0, 20 points, which are evenly distributed on the sphere of radius of S with the center in a point undertook (19.1; 0.7; 0.9), parameter in each point was calculated and there was a mean value. A deviation between values μ_0 in points of the sphere did not exceed 10% of its mean value.

The dependence of 1 Fig. 4 shows that at small distances of initial approach to RES the parameter of convergence is small, and Newton's method quickly convergences. At the distance more than 3 km from the RES, value μ_0 quickly grows and the convergence is not guaranteed.

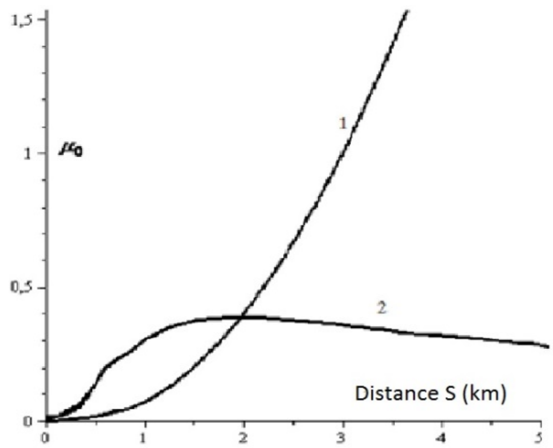

Fig. 4. Dependence of mean value μ_0 from distance of initial approach $x^{(0)}$ to an object (1) is the by application of the direct Newton method; (2) is the by parameterization in combination with the Newton's method

V. CONCLUSIONS

Parameterization at small distances to an object does not improve calculations. The value of the parameter μ_0 there will be always less than one. At distance about 1.5 km the parameter of convergence reaches the maximum value then begins to approach zero: the more the distance to the RES, the parameter is less. Thus, judging by the diagram, parameterization allows to reduce quickly the RES search, when it is at far distance.

If the RES is in the pyramid formed by observation stations, then the accuracy of calculations worsens, position error will make up to 2.5 km, and this error does not decrease with the subsequent iterations. So, hyperboloid parametrization use allows to determine object coordinates, if it is out of the pyramid formed by reception stations with rather high accuracy.

REFERENCES

[1] A. I. Kanashenkov, V. I. Merkulov, and O. F. Samarin, *Current state of the perspective radiolocation systems. Opportunities and restrictions*. Moscow, 2002, 176 p. (in Russian)

[2] V. N. Tkachenko, R. I. Manuilenko, T. S. Khashan, and R. L. Pantyeyev, "Research of space-temporal models of passive direction finding of the radio emission source," *Works of the East Ukrainian university*. vol. 2, pp. 52–59, 2012. (in Russian)

[3] O. M. Rybytska, D. M. Bilonoga, and P. I. Kalenyuk, *Linear algebra and analytical geometry: teaching book*. Publishing house of Lviv Polytechnica, 2011, 124 p. (in Ukrainian)

[4] L. Yang, J. Cao, & W. Yang, "TDOA location based on modified Newton method," *2016 IEEE 13th International Conference on Signal Processing (ICSP)*. doi:10.1109/icsp.2016.7878079.

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Р. І. Мануйленко, Р. Л. Пантєєв, А. П. Козлов, Ю. А.Опанасюк. Параметризація системи рівнянь для розв'язання задачі визначення координат джерел радіовипромінювання

Розглянуто проблему визначення місця розташування джерел радіовипромінювання за допомогою різницево-далекомірного методу. Проаналізовано переваги та недоліки цього методу. Для розв'язання системи рівнянь використовується ітеративний метод Ньютона. При цьому бувають випадки, коли метод Ньютона розходиться і, як наслідок, рішення знайти неможливо. Якобіан близький до нуля, якщо координати джерела радіовипромінювання розташовані на прямій, що з'єднує станції радіомоніторингу. Розглянуто метод параметризації системи рівнянь для покращення збіжності методу Ньютона. Проаналізовано ефективність запропонованої параметризації з урахуванням різного взаємного розташування пасивної системи радіомоніторингу та джерела радіовипромінювання, доведено, що для більшої точності обчислень слід

вибирати той гіперболоїд, кут у вершині асимптотичного конусу якого є найменшим. Показано умови, за яких параметризація гіперболоїдів дозволяє визначати координати об'єктів з досить високою точністю.
Ключові слова: Пасивна радіолокація; параметризація системи рівнянь; збіжність методу Ньютона; гіперболоїд; визначення напрямку; різницево-далекомірний метод; джерело радіовипромінювання.

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Р. И. Мануйленко, Р. Л. Пантеев, А. П. Козлов, Ю. А.Опанасюк. Параметризация системы уравнения для решения задачи определения координат источников радиоизлучения

Рассмотрена проблема определения местоположения источников радиоизлучения с помощью разностно-дальномерного метода. Проанализированы преимущества и недостатки этого метода. При решении системы уравнений используется итеративный метод Ньютона. При этом бывают случаи, когда метод Ньютона расходится и, как следствие, решение найти нельзя. Якобиан близок к нулю, если координаты источника радиоизлучения расположены на прямой, соединяющей станции радиомониторинга. Рассмотрен метод параметризации системы уравнений для увеличения конвергенции метода Ньютона. Проанализирована эффективность предложенной параметризации с учетом различного взаимного расположения пассивной системы радиомониторинга и источником радиоизлучения и доказано, что для большей точности вычислений следует выбирать тот гиперболоид, угол в вершине асимптотического конуса которого является наименьшим. Показаны условия, при которых параметризация гиперболоидов позволяет определять координаты объектов с достаточно высокой точностью.
Ключевые слова: пассивная радиолокация; параметризация системы уравнений; сходимость метода Ньютона; гиперболоид; определение направления; разностно-дальномерный метод; источник радиоизлучения.

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