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DEVELOPMENT OF THE PRINCIPLE OF REJECTING THE OBJECT FALSE COORDINATES FOR RADIO ENGINEERING LOCATING SYSTEMS

The paper further develops the principle of validating the method for identification of the object coordinates. The method is based on the relationship between the object location relative to the sensors and the signs as well as the absolute values of the differences between distances.

Key words: *coordinate identification principle, rejection of false coordinates.*

Analysis of the latest research and publications. While solving the problem of object coordinate identification using the method of differential distance measurements, which forms the basis of the methods for precise identification of the object coordinates, along with the true coordinates other solutions are also obtained. However, in the literature on radio engineering radio-navigation systems the issue of choosing the solution from several options, the one that corresponds to the actual object location, has not received adequate attention [1-3]. The majority of authors point to the need of additional information (a priori or on other systems about possible location of the object, while allowing for low accuracy). Solution of a similar problem in seismological systems regarding identification of the object coordinates using three receivers is reduced to consideration of eight equiprobable combinations of signs of signal delays [4; 5]. It is argued that even the absence of systematic measurement error is not the evidence of precise identification of the coordinates, and the probability of identifying the coordinates does not depend on the dispersion of errors and the type of their distribution probability as well as on the topology of location finders.

Problem statement. Taking the above mentioned into account as well as the results of the research on the development of radio engineering seismological control systems, it can be stated that the task of rejecting false coordinates and reduction of the ambiguity of coordinate measuring problem has not lost its **relevance**.

Therefore, the paper aims at studying the causes for the occurrence of false coordinates during coordinate measurement implementation using three omnidirectional receivers as well as at further development of the principle for validation of the method for object coordinate identification.

Main content of the work. The task of identifying the object coordinates on the plane from the set of measured values of the differences in distances relative to several pairs of signal receivers, that are located at the fixed points, can be reduced to a mathematical formulation. Let there be a set of fixed points given by their coordinates in a corresponding coordinate system. Relative to the point, the coordinates of which are to be determined, the distances from it to the points where the receivers are located are known. The described general algorithm for coordinate identification allows for finding the roots of the nonlinear equation system that link the initial data with the coordinates of the object to be located. Solution of the nonlinear equation system is a complex mathematical problem that has no general solution. Depending on the method of obtaining analytical solution, several solutions (at least two) can arise. The cause for the occurrence of false roots is incorrectness of the model elaboration in accordance with the problem of identifying the object coordinates. The causes are explained in the works of O. G. Sibel [6-8]. The equation that links the value of the difference in distances with the coordinates of the object and of the sensors-receivers has the form of

$$\Delta r_{AB} = \sqrt{(a+x)^2 + y^2} - \sqrt{(a-x)^2 + y^2}. \tag{1}$$

After squaring the left and right sides of the equation we obtain

$$\Delta r_{AB}^2 = 2\left(a^2 + x^2 + y^2 - \sqrt{(a+x)^2 + y^2}\sqrt{(a-x)^2 + y^2} \right),$$

where from

$$\left((a+x)^2+y^2\right)\left((a-x)^2+y^2\right)=\left(a^2+x^2+y^2-\Delta r_{AB}^2/2\right)^2 .$$

Simplification gives

$$\frac{4x^2}{\Delta r_{AB}^2}-\frac{4y^2}{4a^2-\Delta r_{AB}^2}=1, \qquad (2)$$

i.e. equation (1) has the form of canonic equation of hyperbola

$$\frac{x^2}{a_1^2}-\frac{y^2}{b_1^2}=1, \qquad (3)$$

where $a_1=\Delta r_{AB}/2$; $b_1=\sqrt{4a^2-\Delta r_{AB}^2}/2$.

From the presented analytical transformations it follows that the location point of target object D is on the line described by equation (3). However, it should be taken into account that while squaring equation (1) the sign of the value of the difference in distances Δr_{AB} was lost. Actually, point D could belong only to one of the hyperbola branches in accordance with system of conditions

$$\begin{cases}\dfrac{4x^2}{\Delta r_{AB}^2}-\dfrac{4y^2}{4a^2-\Delta r_{AB}^2}=1;\\ \Delta r_{AB}\cdot x>0.\end{cases} \qquad (4)$$

In this regard let us consider the approach for selecting false roots while solving the system of equations of hyperbole, which is based on the analysis of the relation between locations of the object, sensors and values of the differences between distances that link them.

Let there be two sensors that are located at points *A* and *B*. It is also determined that difference of distances $\Delta \mathrm{r_{AB}}$ from the object to the sensors [6-8] is

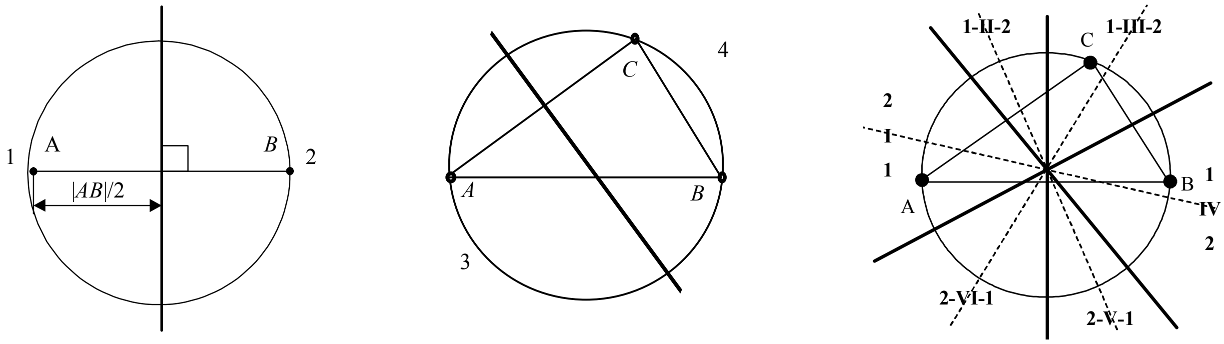
$$\Delta \mathrm{r_{AB}}=r_A-r_B,$$

where r_A, r_B are distances from points *A* and *B* to the object.

Then, if the plane is divided into two sectors by the line perpendicular to the segment AB that passes through its midpoint (Fig.1a), we obtain the following conditions:

if the object is located in sector 1, the condition $\Delta r_{AB}<0$ is satisfied;

if the object is located in sector 2, the condition $\Delta r_{AB}>0.$ is satisfied.



A

b

c

Fig. 1. Sectors of the object location

If three sensors are given in sectors *A*, *B* and *C* and differences of distances Δr_{AB}, Δr_{AC}, Δr_{BC}

are determined, then we can make similar conclusions for each pair of sensors. E. g., for the pair of sensors $\{A, C\}$ we obtain the following conditions (Fig. 1 b):

if the object is located in sector 3, the condition $\Delta r_{AC} < 0$ is satisfied;

if the object is located in sector 4, the condition $\Delta r_{AC} > 0.$ is satisfied.

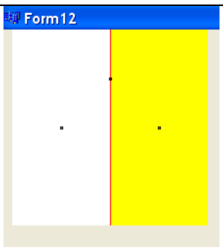
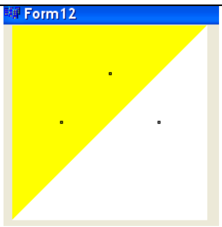
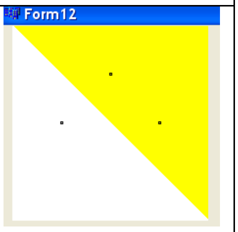
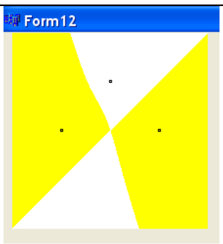
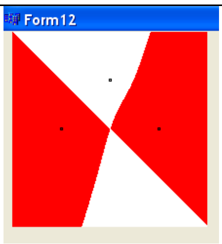
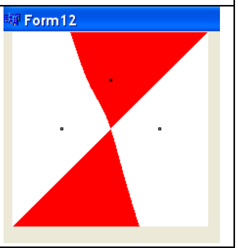
Since it is known that in each triangle three perpendiculars to its sides that pass through the midpoints of these sides intersect at the center of the circumscribed circle, then three lines perpendicular to the sides of triangle ΔABC pass through their midpoints and divide the area into six sectors (Fig.1 c). For each sector a system of inequalities, that links the object location relative to the sensors with the values of the differences between distances, is set up and the known regularities are obtained (Table 1, row 1).

Table 1

Regularities of identifying the coordinates of the object using a triad of sensors

Sector of the object location			**I (1, 2)**	**II (1, 2)**	**III (1, 2)**	**IV (1, 2)**	**V (1, 2)**	**VI (1, 2)**
Condition of the object location In the sector	**according to the signs of the differences between distances**		$\begin{cases}\Delta r_{AB} < 0;\\ \Delta r_{AC} < 0;\\ \Delta r_{BC} > 0.\end{cases}$	$\begin{cases}\Delta r_{AB} < 0;\\ \Delta r_{AC} > 0;\\ \Delta r_{BC} > 0.\end{cases}$	$\begin{cases}\Delta r_{AB} > 0;\\ \Delta r_{AC} > 0;\\ \Delta r_{BC} > 0.\end{cases}$	$\begin{cases}\Delta r_{AB} > 0;\\ \Delta r_{AC} > 0;\\ \Delta r_{BC} < 0.\end{cases}$	$\begin{cases}\Delta r_{AB} > 0;\\ \Delta r_{AC} < 0;\\ \Delta r_{BC} < 0.\end{cases}$	$\begin{cases}\Delta r_{AB} < 0;\\ \Delta r_{AC} < 0;\\ \Delta r_{BC} < 0.\end{cases}$
	according to the values of the differences between distances	**1**	$\lvert\Delta r_{AC}\rvert > \lvert\Delta r_{BC}\rvert$	$\lvert\Delta r_{AC}\rvert < \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{BC}\rvert > \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{AC}\rvert > \lvert\Delta r_{BC}\rvert$	$\lvert\Delta r_{AC}\rvert < \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{BC}\rvert > \lvert\Delta r_{AB}\rvert$
		2	$\lvert\Delta r_{AC}\rvert < \lvert\Delta r_{BC}\rvert$	$\lvert\Delta r_{AC}\rvert > \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{BC}\rvert < \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{AC}\rvert < \lvert\Delta r_{BC}\rvert$	$\lvert\Delta r_{AC}\rvert > \lvert\Delta r_{AB}\rvert$	$\lvert\Delta r_{BC}\rvert < \lvert\Delta r_{AB}\rvert$

The novelty of the principle is the revealed relationship between the object location in the sector and the values of the differences between distances to the places where the sensors are located. I.e., absolute values of the differences between distances are additionally considered (Fig. 2).

$\lvert AB\rvert > 0$	$\lvert BC\rvert > 0$	$\lvert AC\rvert > 0$
		
$\lvert\Delta r_{AB}\rvert > \lvert\Delta r_{AC}\rvert$	$\lvert\Delta r_{AB}\rvert > \lvert\Delta r_{BC}\rvert$	$\lvert\Delta r_{AC}\rvert > \lvert\Delta r_{AB}\rvert$
		

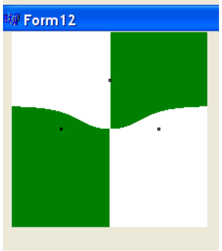
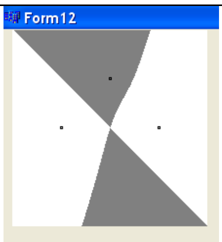
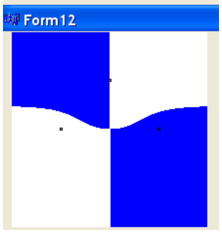
$\left\|\Delta r_{AC}\right\| > \left\|\Delta r_{BC}\right\|$	$\left\|\Delta r_{BC}\right\| > \left\|\Delta r_{AB}\right\|$	$\left\|\Delta r_{BC}\right\| > \left\|\Delta r_{AC}\right\|$
		

Fig. 2. Sectors of the object location taking into account absolute values of the differences in distances that are measured by the triad of sensors

In accordance with the data of Fig. 2, a non-linearity feature of the sector division line, especially evident in the near zone, is determined. This is explained by the division line being a hyperbole. The above-mentioned should be taken into account in the procedure of implementing the principle of rejecting false coordinates of the object. The established regularity (lines 2, 3 of Table1) complements the known regularity based on the signs of the differences in distances.

In accordance with the data of Table 1, number of the object location sectors is doubled as compared with the case when only the signs of the differences in distances are taken into account (Fig. 3).

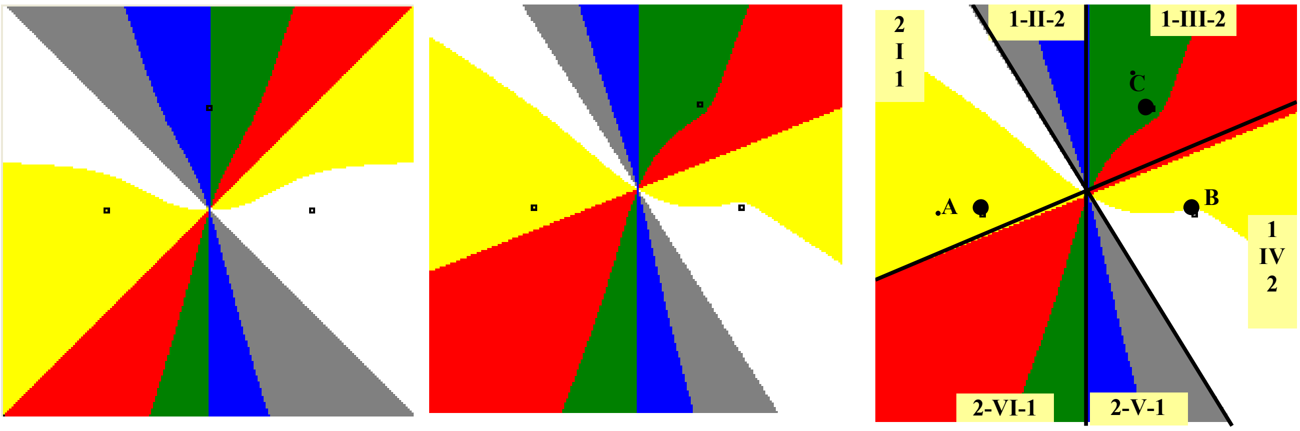


Fig. 3. Regularities of the object coordinate identification taking into account absolute values of the differences in distances

This enables double reduction of the probability to obtain a false coordinate of the object location. The obtained relationships between the object location and signs as well as the values of differences between distances Δr can be used for validation of the method for identifying the object coordinates.

The developed principle is implemented using the following procedure:

1. In accordance with the signs of the differences in distances, using the systems of inequalities, sectors I-VI of the object location are determined with reference to the area (row 1, Table 1).
2. Division of the determined sectors I – VI into two subsectors 1, 2 is performed in accordance with the absolute values of the differences in distances using the inequalities (rows 2, 3,Table 1).
3. The sector that corresponds to the object coordinates is determined.
4. From the signs and absolute values of the differences in distances for given coordinates the location sector is also determined.
5. When sectors determined in accordance with 3 and 4 coincide, actual coordinates of the object location are determined.

Conclusion. Thus, the principle has been developed for validating the method of identifying the object coordinates (the principle of rejecting false coordinates) based on the relationship between the object location relative to the sensors and signs as well as absolute values of differences between distances. This has enabled double reduction of the probability to obtain a false coordinate of the object location.

Further research will be directed towards development of the method for identification of the object coordinates.

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