DEVELOPMENT OF A RANGEFINDING METHOD FOR DETERMINING THE COORDINATES OF TARGETS BY A NETWORK OF RADAR STATIONS IN COUNTER-BATTERY WARFARE

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Abstract

The increase in the accuracy of determining the coordinates of targets is explained by the use of a network of counter-battery radar stations and the rangefinding method for determining the coordinates of targets. The main advantage of using the rangefinding method for determining the coordinates of targets in a network of counter-battery radar stations is to ensure the required accuracy

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in determining the coordinates of targets without using accurate measurement of angular coordinates. The minimum geometry of the system, which ensures the use of the rangefinding method for determining coordinates, is given. The method of determining the coordinates of targets by a network of counter-battery radar stations has been improved. In contrast to the known ones, information about the range to the target is additionally used in a spatially distributed network of radar stations for counter-battery combat. The boundaries of the working zones of the network of two and three counter-battery radar stations are calculated. The features of creating a continuous strip using the rangefinding method for determining the coordinates of the target are considered. Statistical modeling of the rangefinding method for determining the plane coordinates of the target has been carried out.

It has been established that the use of the rangefinding method ensures the determination of the planar coordinates of the target in a sector of at least 120°. The targets are at a distance of direct radio visibility in relation to the counter-battery radar. The root-mean-square error in determining the target range in this case is no more than 50 m. It has been established that the creation of continuous bands of a low-altitude radar field at a certain height is possible by arranging radar stations in a line. In this case, the distance between the counter-battery radar stations should be no more than half the target detection range at this height.

Keywords: rangefinding method, determination of coordinates, target, radar station, counter-battery warfare.

1. Introduction

In modern conditions, one of the main countermeasures against terrorist attacks using mortars (including nomadic mortars) is counter-battery warfare (CBW) [1]. In order to conduct high-quality CBW, the leading countries of the world developed the concept of Counter – Rockets, Artillery and Mortar (C-RAM) [2]. The main part of the C-RAM are the CBW radar stations (RS) (for example, AN/TPQ-48A and AN/TPQ-49) [2]. Such CBW RSs are small-sized and easily portable. The small size of the CBW RS causes fairly wide beams of the antenna pattern (BAP). Thus, the azimuth width of the BAP CBW RS at a level of 3 dB is about 19° [3]. This width of the bottom is the equivalent of the board of other advantages of the CBW RS. Such advantages: small size, light weight, ease of transportation, electronic circular scanning and the use of the decimeter wavelength range (L-band, 23 cm). Such advantages provide high reliability of the CBW RS and ease of combat use.

The presence of wide BAP beams in the azimuthal plane necessitates the use of a single-pulse (sum-difference) method for determining the azimuth. This leads to well-known problems [4–6]:

– deterioration of resolution in angular coordinates;

– distortion of the direction-finding characteristic of a monopulse system;

– an increase in the errors of angular measurements in the presence of two or more targets in the main beam of the BAP.

Wide BAP beams significantly increase the probability of hitting other targets and local objects in the main BAP beam. This leads to significant errors in measuring the azimuth of the target being followed and a deterioration in the accuracy of determining the coordinates of the mortar firing position.

Therefore, it is relevant to develop a method for determining the coordinates of targets of the CBW RS with high resolution in angular coordinates.

The aim of the article is to increase the resolution when determining the coordinates of the CBW RS targets.

To achieve the aim, the following objectives were set:

– to develop a method for determining the coordinates of the CBW RS targets;

– to perform simulation modeling of the method for determining the coordinates of the CBW RS targets.

RS resolution is determined by technological, technical limitations and physical processes (diffraction phenomena, beam width, bandwidth, observation time). Such restrictions are formulated in [7]. In [8], it was taken into account that the distinctive RS range in terms of range is determined by the width of the spectrum of the probing signal. Therefore, in [8] it is proposed to use broadband signals in the RS. But the use of broadband signals greatly complicates the RS design, complicates the electromagnetic compatibility and reduces the RS noise immunity.

In [9], to increase the RS resolution, it is proposed to increase the coherent accumulation time. However, the time of coherent accumulation is limited by the RS total time resource

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and the finite interval of coherence of signals reflected from the target. These factors limit the use of the coherent accumulation time.

In [10], the superresolution method is proposed. Method [10] is based on the maximum likelihood method. In [10], it is found that the RS resolution depends on the method of signal processing. Difference indicators are obtained by means of conditional probabilities of correct detection and false alarm for signal amplitude estimates. It is established that these indicators depend on the signal/noise and the uncertainty function. The discrimination method [10] by comparing signal amplitudes at the moment of maximum likelihood of estimates of unknown signal parameters is currently used in superresolution algorithms in the statistical approach. However, the use of [10] in the CBW RS requires significant design changes and complication of information processing methods.

In [11], a statistical approach to signal resolution is proposed, which is based on the Bayesian method. The disadvantages of [11] are: a significant amount of a priori information on the distribution of signal and noise parameters, the uncertainty of the loss function, etc.

In [12], a non-Bayesian resolution enhancement method is proposed. The method assumes the difference of an unknown number of quasi-deterministic signals. In this case, the signals should have constant parameter values over a finite time interval against the background of Gaussian noise. The main disadvantage [12] is the need to use a priori information on the distribution of signal and noise parameters.

In [13], further development of statistical methods for increasing the RS resolution is proposed. The method [13] is based on the Petrov-Galerkin transformation and uses the Helstrom resolution strategy. The Petrov-Galerkin transformation is used to solve operator equations. Helstrom strategy implies comparison with a threshold of signal amplitudes at the time of maximum likelihood estimates of the unknown parameters of these signals. The disadvantages of the method are the computational complexity and the availability of a priori information on the scattering characteristics of the target.

In [14], a method is proposed for increasing the RS resolution by increasing the number of range gates, their location, and optimal processing of the amplitudes of the reflected signals. The disadvantage [14] is a significant increase in signal processing time and the need to use additional information regarding the parameters of the reflected signals.

In [15], an inverse filtering method is proposed to improve the RS resolution. The method makes it possible to determine the coordinates of the target with an accuracy up to the sampling interval of the analog-to-digital converter. The disadvantage [15] is the low resistance of the processing results to the noise effects.

In [16], to improve the RS resolution, a parametric method of digital analysis is proposed, which is similar to the Capon method. Method [16] is difficult to implement. Therefore, the Multiple Signal Classification (MUSIC) method [17] and Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) [18] have been proposed. The disadvantages [17, 18] are the increased requirements for the RS element base and the high computational complexity of signal processing. In addition, the quality of the methods [17, 18] depends on the number of targets, the presence of correlated sources, the principle of forming the data matrix, etc.

Known methods for increasing the RS resolution in angular coordinates are to increase the dimensions of the antennas or switch to the range of shorter wavelengths [19, 20]. In the case of CBW RS with electronic scanning, the methods [19, 20] are inappropriate. An increase in the size of the antenna leaves the CBW RS with such advantages as small size, lightness and ease of transportation. The transition to the shorter wavelength range leaves the CBW RS with such advantages as reliability in operation and ease of adjustment after transportation.

An alternative way to increase the resolution in angular coordinates is the use of system effects in the joint processing of RS information from several spatially separated CBW RS. In [21], the methods of N-polynomials and N-bearings were proposed. In this case, only angular coordinates are used in [21].

In [22, 23], the use of phase-frequency information from two receivers using the direction finder of Saibel is proposed. Methods [22, 23] have certain limitations. The main of these limitations is the possibility of using for passive systems to determine the coordinates of targets.

In [24], an increase in RS resolution was proposed by creating low-base multiradar RS. A method for joint processing of signals from two radar stations with mechanical rotation is considered. In [25], a method for coherent processing of RS information in a multiradar system of two RSs is considered. The main drawback [24, 25] is the application of the proposed methods for a multiradar RS with mechanical rotation.

In [26], a multiradar RS is considered. Each station measures only the distance to an air object. The objective function of the optimization problem of determining the target coordinate is determined by the criterion of maximum entropy. The main drawback [26] is the ambiguity in determining the angular coordinates of an air object in the RS.

In [27], a distributed gradient method is proposed for determining the coordinates of an object. To determine the initial approximation of the gradient, the particle swarm method is used [28]. It is determined that the use of the particle swarm method significantly increases the efficiency of the method. The disadvantage [27] is the presence of significant errors and the ambiguity in determining the coordinates of the object.

In [29], a method is proposed for measuring the signal phase to determine the distance in RS with linear frequency modulation. The disadvantage [29] is the possibility of using the method in RS of the meter range (wavelength is 5.2 m).

In [30], it is proposed to take into account the cross-sectional plane when determining the coordinates of an object. An expression for determining the accuracy of measuring the coordinates of an object is given. But the results of [30] can be used when using the Swerling model to describe an object.

In [31], a method is proposed to improve the accuracy of determining the coordinates of objects by using the Dempster-Shafer proof theory. A new metric for measuring the distance to an object and a system that implements the proposed method are proposed. The disadvantage of [31] is the possibility of using the method at short distances.

In [32], the RS construction based on a genetic algorithm is proposed. It has been established that the genetic algorithm makes it possible to build a high-quality RS. But in [32], the RSs operate autonomously; the RS operation as part of a multi-position system is not considered.

In [33], a method is developed for determining the coordinates of the firing positions of nomadic mortars using the CBW RS network. The method involves processing information by the CBW RS network and measuring the coordinates of mines. At the same time, the measurement of mine coordinates is coordinated in space and time. But in [33], the issue of increasing the CBW RS resolution is not considered.

To conduct further research in order to increase the resolution in determining the coordinates of the CBW RS targets, let's set the task of developing a method for determining the coordinates of the CBW RS targets with high resolution in angular coordinates.

2. Materials and methods for the study of determining the coordinates of targets by a network of counter-battery warfare radar stations

The following are used in the study:
– mathematical apparatus of the theory of matrices;
– methods of probability theory;
– methods of mathematical statistics;
– methods of system analysis;
– methods of differential calculus;
– methods of statistical radio engineering;
– iterative methods;
– methods of the theory of radar;
– methods of optimization theory;
– methods of multiposition radar;
– methods of mathematical modeling.

During the experimental calculations, the Monte Carlo method of statistical tests was used. Validation of the proposed solutions was carried out using analytical and empirical methods of comparative research.

When carrying out experimental calculations, the following restrictions and assumptions were adopted:

– nomadic mortars of 82 mm and 120 mm calibers are being considered;

– the term «target» meant mines 82 mm and 120 mm;

– AN/TPQ-49 CBW RS was adopted as a means of CBW RS;

– it was considered that the conditions for the coordinated inspection of the airspace over the CBW RS network were met;

– it was considered that the conditions for time synchronization of the CBW RS in the network were met;

– it was believed that there was only one target in the field of view of the CBW RS network;

– corrections for meteorological conditions during firing were considered to be carried out (the state of the atmosphere in the firing plane (wind, pressure, air temperature));

– it was believed that the target's flight path was ballistic.

3. Results of the development of a rangefinding method for determining the coordinates of targets

When the CBW RS network operates in the mode of autonomous reception and synchronous survey of space, let's use the rangefinding method for determining targets. The main advantage of using the rangefinding method for determining the coordinates of targets in the CBW RS network is the ability to provide the required accuracy in determining the coordinates of targets without using accurate measurement of angular coordinates in the CBW RS. This makes it possible to reduce the requirements for the bottom width and antenna dimensions.

The possibility of determining the coordinates of targets in the CBW RS network by measuring only ranges without using angular measurements is explained in **Fig. 1**.
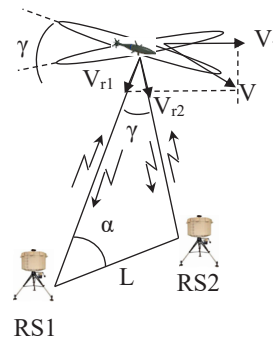

Fig. 1. Improving the accuracy of determining the coordinates of targets in the network of two radar stations for counter-battery warfare with autonomous reception

Fig. 1 shows that the error ellipse is significantly flattened in range. This is explained by the fact that the accuracy of determining the azimuth of targets in the CBW RS is even worse than the accuracy of determining the range of targets. In the joint processing of information from two CBW RS, the body of errors corresponds to the intersection of the error bodies for each CBW RS. Due to this, the accuracy of determining the coordinates of targets can be significantly improved. This is equivalent to improving azimuth accuracy by measuring ranges.

When implementing the rangefinding method for determining the coordinates of targets in a two-position system (**Fig. 1**), the root-mean-square error (MSE) of determining the target azimuth is estimated by expression (1) (when the condition $D > (2–3)L$ [34] is met):

$$\sigma_\alpha = \frac{\sigma_D \sqrt{2}}{L \sin(\alpha)}, \tag{1}$$

where σ_α – MSE determination of the target azimuth by measuring two target ranges; D – distance from the CBW RS to the target; L – base between the CBW RSs; σ_D – MSE for determining the range of the target in the CBW RS; α – azimuth of the target in relation to the CBW RS.

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In general, if the number of primary measurements (ranges, angles) in the CBW RS network exceeds the minimum required number necessary to determine the coordinates of targets, then redundant measurements can be used to improve the accuracy of determining the coordinates of targets.

The CBW RS network, which implements the rangefinding method for determining the coordinates of targets, belongs to active multi-position systems. The minimum geometry of the system, which ensures the use of the rangefinding method for determining coordinates, is shown in **Fig. 2**.
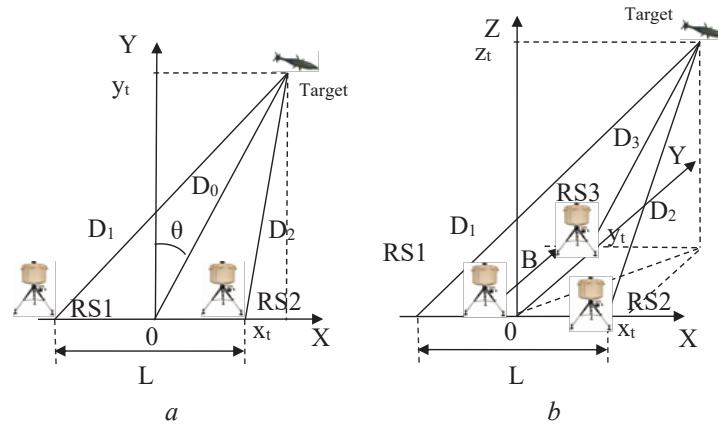
Fig. 2. The minimum required geometry of the network of counter-battery radar stations for the implementation of the rangefinding method for determining the coordinates of the target: *a* – on plane; *b* – in space

Assuming that the locations of the CBW RSs are known accurately, the primary target parameters that are measured by the CBS RSs and used to determine the targets are the ranges to the targets relative to the corresponding CBW RSs (D_1, D_2, D_3). The connection between the primary parameters and the target coordinates in a network of two CBW RSs (**Fig. 2, *a***) is determined by expressions (2), (3) [19]:

$$x_t = \frac{1}{2L}(D_1^2 - D_2^2),\tag{2}$$

$$y_t = \frac{1}{2L}\sqrt{(2D_1^2L^2 + 2D_2^2L^2 + 2D_1^2D_2^2 - D_1^4 - D_2^4 - L^4)}.\tag{3}$$

For a three-position system (**Fig. 2, *b***), the relationship between the primary parameters and the spatial coordinates of the target is determined by expressions (4)–(6) [19]:

$$x_t = \frac{1}{2L}(D_1^2 - D_2^2),\tag{4}$$

$$y_t = \frac{(D_1^2 + D_2^2 - 2D_3^2 + 2\left(B^2 - \dfrac{L^2}{4}\right)}{4B},\tag{5}$$

$$z_t = \sqrt{D_1^2 - \left(x_t + \frac{L}{2}\right)^2 - y_t^2},\tag{6}$$

where x_t, y_t, z_t – target coordinates; D_1, D_2, D_3 – range to the target in relation to *RS*1, *RS*2, *RS*3, respectively; L – distance between RS1 and RS2; B – distance between RS3 and base L (when the CBW RS is located at the corners of an equilateral triangle).

Target location error in the CBW RS network shown in **Fig. 2, *a***, and provided that the CBW RSs have the same MES, the range determination is determined by expression (7) [19]:

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$$\sigma_{xy} = \frac{\sigma_D \sqrt{2}}{\sin(\gamma)}, \tag{7}$$

where σ_{xy} – MES of the target location on the plane; σ_D – MES for determining the range in the CBW RS; γ – angle of intersection of the position lines (circles corresponding to the range of the target relative to $RS1$ and $RS2$, respectively), determined by expression (8) [19]:

$$\gamma = \operatorname{arctg}\left(\frac{\frac{L}{2} - D_0}{\frac{L}{2} + D_0} \operatorname{ctg}\left(\frac{\theta}{2} + \frac{\pi}{4}\right)\right) + \operatorname{arctg}\left(\frac{\frac{L}{2} - D_0}{\frac{L}{2} + D_0} \operatorname{ctg}\left(\frac{\pi}{4} - \frac{\theta}{2}\right)\right) + \frac{\pi}{2}, \tag{8}$$

where the quantities L, D_0, θ are indicated in **Fig. 2, *a***.

Expressions (7), (8) can be used to calculate the boundaries of the working zones of the system shown in **Fig. 2, *a***. Within the working area, UPC, the MSE of target location does not exceed the specified value. The working zones of the location of the rangefinding two-position system are shown in **Fig. 3**. In **Fig. 3** it can be seen that at a distance of up to two base sizes in the direction perpendicular to the base, MSE of positioning can be provided no more than $3\sigma_D$. It should be taken into account that the indicated working areas can only be implemented with simultaneous target detection in two CBW RSs (providing overlapping of the detection zones of the CBW RS). Taking into account the curvature of the Earth, the possibility of simultaneously detecting a target in two spatially separated CBW RSs depends on the ratio of the target detection range at a certain flight altitude and at the distance between the CBW RSs (base size). The target detection range at a certain height is limited both by the energy potential and noise immunity of the CBW RS, and by the range of direct radio visibility.
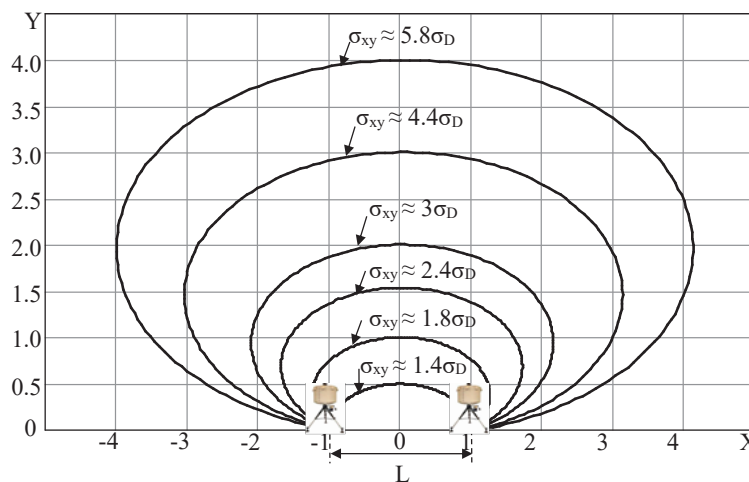

Fig. 3. Working areas of target location by a network of two counter-battery radar stations

Fig. 4 shows the overlay of target detection zones at different heights on the working zones of the rangefinding system. The use of the rangefinding method for determining the coordinates of the target is possible only in areas formed by the intersections of two corresponding circles. **Fig. 4** shows that with a target detection range equal to the size of the base L, the possibility of using the rangefinding method is provided only in the area indicated by number 1. In area 1, target location is provided with a SCP of no more than 1.8 σ_D. With a target detection range equal to two base sizes ($2L$), the possibility of using the rangefinding method is provided in the area indicated by number 2. Area 2 is significantly larger than area 1, but has large values of the target location MES.

In **Fig. 4** it can be seen that in area 2 the target location MES value is provided only in a certain sector. Features of creating a continuous strip using the rangefinding method for determining coordinates are shown in **Fig. 5**. In **Fig. 5** it can be seen that the use of the rangefinding method is

possible only if the target detection range is twice the distance between the CBW RSs. Area 2 in **Fig. 2** corresponds to this condition in **Fig. 5**. According to the analysis of **Fig. 5** it follows that the use of the rangefinding method at a certain flight altitude is possible when the distance between the CBW RSs does not exceed half the target detection range at this altitude.
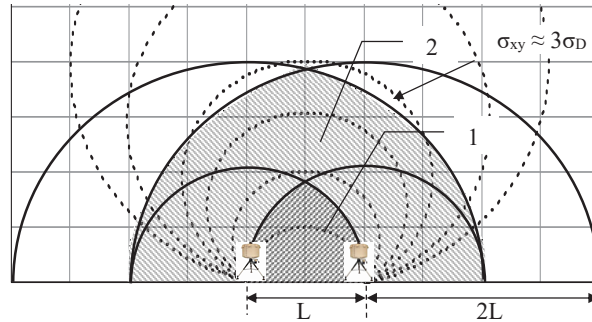

Fig. 4. Superposition of detection zones of radar stations for different target heights and working zones of the rangefinding system
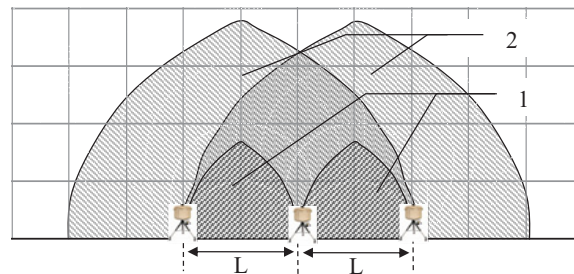

Fig. 5. Creation of continuous bands, where it is possible to use the rangefinding method for determining the coordinates of the target for different heights

The results of statistical modeling of the rangefinding method for determining the plane coordinates of the target are shown in **Fig. 6, 7** in the form of an error field for the MES of determining the target range in the CBW RS $\sigma_D = 100$ m and $\sigma_D = 50$ m.

From the analysis of **Fig. 6** it can be seen that the results of statistical modeling correspond to the working zones calculated theoretically by expressions (7), (8) and shown in **Fig. 3**. The results of statistical modeling confirm the possibility of using the rangefinding method for determining the plane coordinates of the target in a two-position system. In **Fig. 6** it can be seen that the on-off system provides the required accuracy in determining the in-plane coordinates of the target by the range-finding method only in a certain sector, which is less than 180°. The use of a three-position system (**Fig. 7**) ensures the determination of the planar coordinates of the target by the rangefinding method practically in the 180° sector.
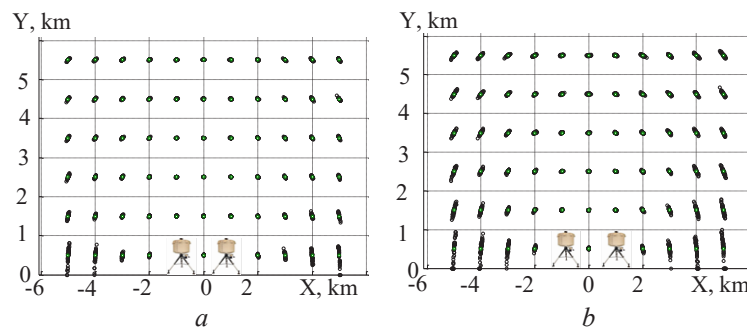

Fig. 6. Results of statistical modeling of the rangefinding method error field in a two-position system at: $a - \sigma_D = 100$ m; $b - \sigma_D = 50$ m
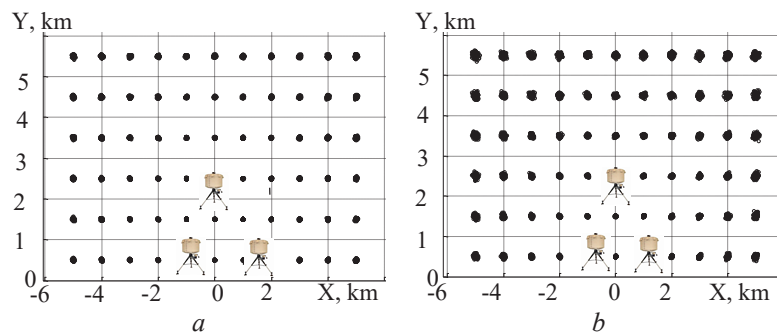
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Fig. 7. Results of statistical modeling of the field of errors in determining the plane coordinates of the target by the rangefinding method in a three-position system at: $a - \sigma_D = 100$ m; $b - \sigma_D = 50$ m

According to the results of statistical modeling in **Fig. 8** shows error ellipses corresponding to two-position and three-position systems. From the analysis of **Fig. 8, a**, it can be seen that the two-position system generates a biased estimate of the coordinates. The center of the error ellipse does not match the actual position of the target. This is due to the lack of consideration of the target's flight altitude when determining plane coordinates. The greater the height of the target, the greater the estimate bias will be. The three-position system forms an unbiased estimate of the target coordinates (**Fig. 8, b**), although it has a larger error ellipse.
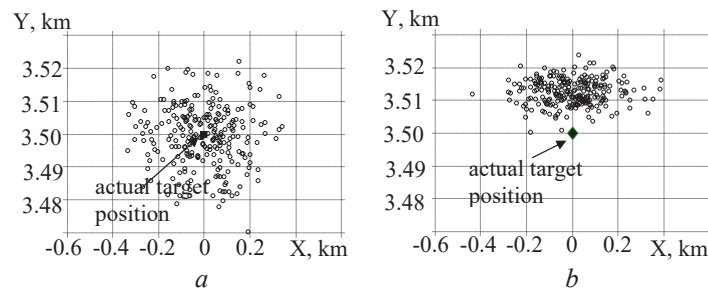

Fig. 8. Scatter diagram of coordinate estimates (error ellipses) and actual target positions when using the ranging method: a – two-position system; b – three-position system

Thus, based on the results of the analysis of the features of using the rangefinding method to determine the coordinates of a target in the CBW RS network, the following conclusions can be drawn:

– the use of a range-finding method for determining the coordinates of a target in a network of two CBW RSs ensures the determination of the in-plane coordinates of the target. The targets are at a distance of direct radio visibility with respect to the RS in a sector of at least 120°. MES for determining the target range in the CBW RS is within 50 m;

– it is possible to create continuous bands of a low-altitude radar field at a certain height, where the use of the rangefinding method is ensured. In this case, the CBW RSs are placed in line. The distance between the CBW RSs should be no more than half the target detection range at this height. This creates a continuous band at a distance relative to the base line up to 75 % of the target detection range at this height;

– it is advisable to use the rangefinding method in a network of three CBW RSs under consideration to expand the sector for determining the in-plane coordinates of targets.

4. Discussion of the results of the study of determining the coordinates of targets by a network of counter-battery radar stations

The increase in the accuracy of determining the coordinates of targets is explained by the use of the CBW RS and the rangefinding method for determining the coordinates of targets. The main advantage of using the rangefinding method for determining the coordinates of targets in

the CBW RS network is the ability to provide the required accuracy in determining the coordinates of targets without using accurate measurement of angular coordinates in the CBW RS. The possibility of determining the coordinates of targets in the CBW RS network by measuring only ranges without using angular measurements is explained in **Fig. 1**. The minimum geometry of the system, which ensures the use of the rangefinding method for determining coordinates, is shown in **Fig. 2**.

Using expressions (7), (8), the boundaries of the working zones of the system shown in **Fig. 2, a**. The working zones of the location of the rangefinding two-position system are shown in **Fig. 3**. In **Fig. 3** it can be seen that at a distance of up to two base sizes in the direction perpendicular to the base, a positioning MES of no more than $3\sigma_D$ can be provided.

Fig. 4 shows the superposition of target detection zones at different heights on the working zones of the rangefinding system. The use of the rangefinding method for determining the coordinates of the target is possible only in areas formed by the intersections of two corresponding circles.

Features of creating a continuous strip using the rangefinding method for determining coordinates are shown in **Fig. 5**. In **Fig. 5** it can be seen that the use of the rangefinding method is possible only if the target detection range is twice the distance between the CBW RSs.

The results of statistical modeling of the rangefinding method for determining the plane coordinates of the target are shown in **Fig. 6, 7** in the form of a field of errors in the MES determination of the target range in the CBW RS $\sigma_D = 100$ m and $\sigma_D = 50$ m. From the analysis of **Fig. 6** it can be seen that the results of statistical modeling correspond to the working zones calculated theoretically by expressions (7), (8) and shown in **Fig. 3**. The results of statistical modeling confirm the possibility of using the rangefinding method for determining the plane coordinates of the target in a two-position system. The use of a three-position system (**Fig. 7**) ensures the determination of the planar coordinates of the target by the range-finding method practically in the 180º sector.

According to the results of statistical modeling in **Fig. 8** shows error ellipses corresponding to two-position and three-position systems. From the analysis of **Fig. 8, a**, it can be seen that the two-position system generates a biased estimate of the coordinates. The center of the error ellipse does not match the actual position of the target. This is due to the lack of consideration of the target's flight altitude when determining plane coordinates. The greater the height of the target, the greater the estimate bias will be. The three-position system forms an unbiased estimate of the target coordinates (**Fig. 8, b**), although it has a larger error ellipse.

When carrying out experimental calculations, the following restrictions and assumptions were adopted:

– nomadic mortars of 82 mm and 120 mm calibers are being considered;

– the term «target» meant mines 82 mm and 120 mm;

– AN / TPQ-49 CBW RS was adopted as a means of CBW RS;

– it was considered that the conditions for the coordinated inspection of the airspace over the CBW RS network were met;

– it was considered that the conditions for time synchronization of the CBW RS in the network were met;

– it was believed that there was only one target in the field of view of CBW RS network;

– corrections for meteorological conditions during firing were considered to be carried out (the state of the atmosphere in the firing plane (wind, pressure, air temperature));

– it was believed that the target's flight path was ballistic.

During the study, it was believed that there was only one target in the inspection zone of the CBW RS network. In carrying out further research, it is necessary to develop a method for determining the coordinates of several targets of counter-battery radar stations.

5. Conclusions

The method of determining the coordinates of targets by the CBW RS network has been improved. In contrast to the known ones, information about the range to the target is additionally used in the spatially distributed CBW RS network. The boundaries of the working areas of the network of two and three CBW RSs are calculated. The features of creating a continuous strip using the rangefinding method for determining the coordinates of the target have been considered.

Statistical modeling of the rangefinding method for determining the plane coordinates of the target has been carried out. It has been established that the use of the rangefinding method for determining the coordinates of a target in a network of two CBW RSs ensures the determination of the plane coordinates of the target. The targets are at a distance of direct radio visibility with respect to the RS in a sector of at least 120°. MES for determining the target range in the CBW RS is within 50 m.

It has been established that the creation of continuous bands of a low-altitude field at a certain height, where it is possible to use the rangefinding method, is possible by placing the CBW RSs in a line. The distance between the CBW RSs should be no more than half the target detection range at this height. This creates a continuous band at a distance relative to the base line up to 75 % of the target detection range at this height. It is expedient to use the rangefinding method in a network of three considered CBW RSs to expand the sector for determining the in-plane coordinates of targets.

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