# Optimization the Size of the Search Area for Moving Physical Objects Based on Preliminary Target Designation Data

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***Abstract* — Carrying out rescue operations in case of shipwrecks implies the need to solve the problems of detecting ships in distress and floating equipment used to rescue people. In this case, the crucial task is minimizing the search time in a given area when detecting false alarms and a high probability of detecting physical objects. Such tasks can be solved in automatic or automated mode using unmanned aerial vehicles equipped with small optical radar stations. The search time is minimized by choosing the appropriate coverage area of the detected physical object with a given probability and organizing the scanning mode of this area in accordance with the probabilistic digital map of the object's location in the resolution elements of the onboard small-sized radar. This work is devoted to this issue.**

**Keywords — search area, coverage probability, distribution law, resolution element, view mode, sea surface, false alarm probability, detection probability.**

## I. Introduction

When carrying out rescue operations caused by shipwrecks, one of the most important indicators is the time of detection of a ship in distress, lifeboats and watercraft in the disaster zone. Maritime disasters can occur in maritime areas that are far enough from continents and islands where adequate means are available to rescue people in distress. Therefore, the task of saving people can consist of the following main stages:

- determination of the preliminary coordinates of the ship in distress;
- sending the aircraft (AC) to the place of the alleged disaster using the specified preliminary coordinates;
- upon reaching a certain distance to the center of the alleged catastrophe, the calculation of the search zone in which the ship in distress or rescue craft should be located;
- turning on the aircraft onboard locators and searching for physical objects in the calculated search area [1].

With this formulation of the aim, the minimization of the search time is possible by “optimizing” the size of the search zone in azimuth coordinate and in range, while it is necessary to ensure a sufficiently high probability of “covering” the detected objects by the zone. This optimization depends on many parameters:

- the accuracy of the preliminary indication of the coordinates of the alleged crash site,
- errors of the autonomous control system (ACS),
- flight range to the point where the search mode is turned on,
- characteristics of the on-board location complex,
- zone scanning algorithm,
- sea currents and wind in the disaster zone, leading to the shifting of those in distress from the center of the disaster, etc. [2].

In this work, based on the expressions obtained in paper [1], the probabilities of finding objects in distress in the search zone are calculated, which, in turn, is determined by the capabilities of the onboard complex and the zone scanning algorithm. The formulation of the problem and the conditions under which the zone is calculated, fully correspond to the formulation of the problem and the search conditions described in [1].

## II. Determining the Size of the Search Area

Let us briefly describe the formulation of the problem and the derivation of the relations obtained in [1].

So, the coordinates of a sea vessel in distress, or the coordinates of the center of a presumed catastrophe, are transmitted to the ACS system of the aircraft, which begins an autonomous flight to the point determined by these coordinates. The coordinates of the center entered into the ACS are determined with some errors, and the ACS system during the flight time $t$ to the point where the search mode is turned on introduces additional errors [3]. Considering, as usual, the total coordinate errors as independent normally distributed random variables, the distribution density of coordinates $f_0(x_0, y_0)$ of a stationary object in distress at the moment the search mode is turned on is written in the form [1].

$$f_0(x_0, y_0) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left( -\frac{(x_0 - L)^2}{2\sigma_x^2} - \frac{y_0^2}{2\sigma_y^2} \right), \quad (1)$$

where $\sigma_x^2$ and $\sigma_y^2$ are the despersions of the object coordinates errors in the search zone, and $L$ is the distance to the center of the zone at the moment of turning on the search mode, Fig. 1.

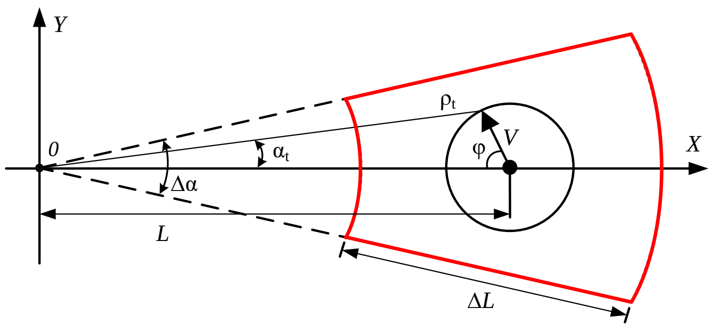


Fig. 1. Search area

In the case when the detected object moves in the zone with a speed $V$ in the direction of φ, at the moment of turning on the search mode, the conditional density of distribution of its coordinates $f_t(x_t, y_t/V, \varphi)$ is written in the form

$$f_t(x_t, y_t / V, \varphi) = \frac{1}{2\pi\sigma_x\sigma_y} \cdot \exp\left( -\frac{(x_t - L - Vt\cos\varphi)^2}{2\sigma_x^2} - \frac{(y_t - Vt\sin\varphi)^2}{2\sigma_y^2} \right). \quad (2)$$

When calculating the size of the search zone, the requirement for a high probability of covering the detected object leads to the condition for calculating the maximum zone, which is determined when distributed evenly in the interval (-π, +π) and at the maximum movement speed of the detected $V = V_{max}$. In this case, averaging expression (2) over $V$ and φ, taking into account that the distribution density is

$$f(V, \varphi) = f(V)\, f(\varphi) = \frac{1}{2\pi}\delta\left(V - V_{max}\right), \quad (3)$$

and also setting $\sigma_x^2 = \sigma_y^2 = \sigma^2$, we obtain

$$f_t(x_t, y_t) = \frac{1}{2\pi\sigma^2} \exp\left( -\frac{(x_t - L)^2 + y_t^2 + \left(V_{max}t\right)^2}{2\sigma^2} \right) \cdot I_0\left( \frac{V_{max}t\sqrt{(x_t - L)^2 + y_t^2}}{\sigma^2} \right), \quad (4)$$

where $I_0(.)$ – is the zero-order Bessel function of the imaginary argument, the modified Bessel function [4].

The search mode is carried out when the zone is scanned with an electromagnetic beam, while the size of the zone (Δ$L$, Δα) and the coordinates of the detected object ($\rho_t$, $\alpha_t$) are determined in the polar coordinate system. Passing to polar coordinates, we obtain the expression

$$f_t(\rho_t, \alpha_t) = \frac{\rho_t}{2\pi\sigma^2} \exp\left( -\frac{\rho_t^{\,2} - 2\rho_t L\cos\alpha_t + L^2 + \left(V_{max}t\right)^2}{2\sigma^2} \right) \cdot I_0\left( \frac{V_{max}t\sqrt{\rho_t^{\,2} - 2\rho_t L\cos\alpha_t + L^2}}{\sigma^2} \right), \quad (4)$$

from which follows the formula that determines the probability of covering $P_{\text{nakr}}$ by the zone (Δ$L$, Δα) of the detected object [1]

$$P_{\text{nakr}} = 2\int_{L-\frac{\Delta L}{2}}^{L+\frac{\Delta L}{2}} \int_{0}^{\Delta\alpha/2} f_t(\rho_t, \alpha_t)\, d\rho_t\, d\alpha_t \quad (6)$$

it should be borne in mind that there are many pairs (Δ$L$, Δα) that satisfy expression (6).

## III. Probabilistic Map Of The Object's Location In The Resolution Elements Of The Search Area

The probabilistic map of the location of a physical object in the search zone is understood as the probability of the presence of an object in the resolution elements determined by the characteristics of the onboard radar, namely, the width of the electromagnetic antenna beam Δφ and the width of the distance track Δ$l$, the minimum size of which is determined by the duration of the sounding pulse min (Δ$l$) = $c\tau_c/2$, where $c$ is the speed of light, $\tau_c$ is the duration of the souding pulse (the duration of a compressed complex sounding signal [5, 6]), Fig. 2.

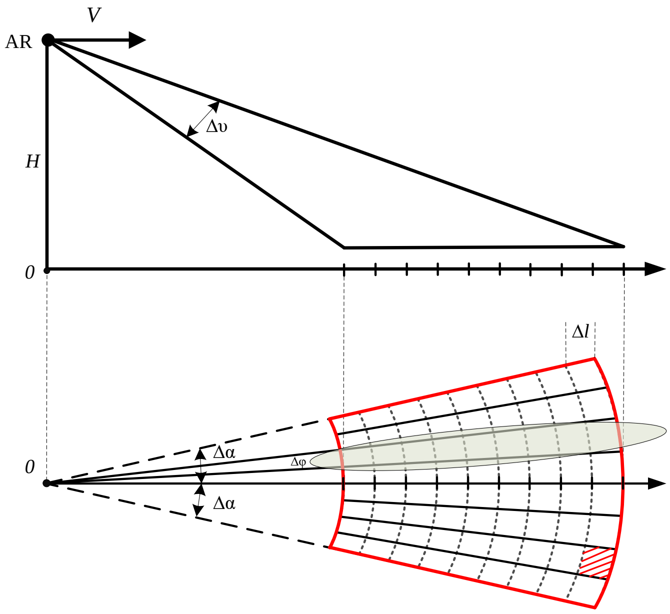


Fig. 2. Search area with permission items

The calculation of a probability map, in fact, is reduced to the calculation of the elements of a rectangular matrix of probabilities

$$\mathbf{M}_{n,m} = \begin{pmatrix} p_{1,1} & p_{1,2} & \vdots & p_{1,m} \\ p_{2,1} & p_{2,2} & \vdots & p_{2,m} \\ p_{3,1} & p_{3,2} & \vdots & p_{3,m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n,1} & p_{n,2} & \vdots & p_{n,m} \end{pmatrix}, \quad (7)$$

where $p_{i,j}$ is the probability of finding the object of detection in the $i$,$j$-th resolution element, calculated by the integral over the surface of the $i$,$j$-th element $\Delta S_{i,j}$

$$p_{i,j} = \iint\limits_{\Delta S_{i,j}} f_t(\rho_t, \varphi_t) d\rho_t d\varphi_t \quad (8)$$

In this case, the probability of covering the detected object by the scanning zone is

$$P_{\text{nakr}} = 2 \int\limits_{L-\frac{\Delta L}{2}}^{L+\frac{\Delta L}{2}} \int\limits_{0}^{\Delta\alpha/2} f_t(\rho_t, \alpha_t) d\rho_t d\alpha_t = \sum_{i=1}^{n} \sum_{j=1}^{m} p_{i,j} \quad (9)$$

When passing from the Cartesian coordinate system to the polar one, in which the elements of the probabilistic map of the search zone are calculated, the symmetry of the functional form of distributions (1) and (2) presented in the Cartesian coordinate system is completely violated. To illustrate this, we present two distributions used to calculate the elements of the probability matrix $\mathbf{M}_{n,m}$, for two cases - a stationary object with $V = 0$, distributions (1) and (3), Fig. 3, and one moving with a speed $V$, distribution (2) and (3), Fig.4.

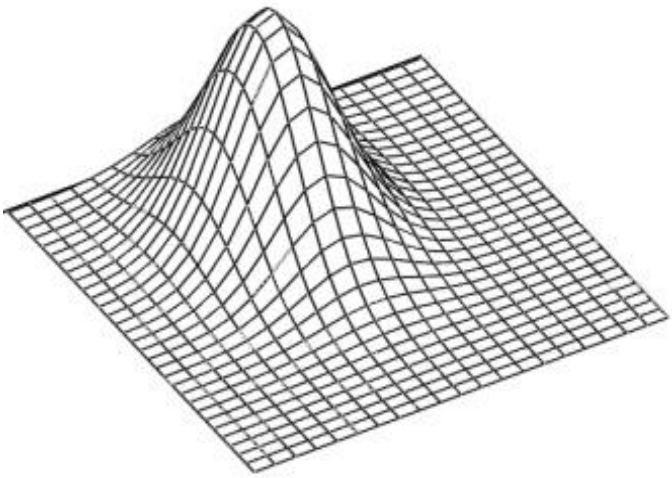

Fig. 3. Distribution (1) in the polar coordinate system

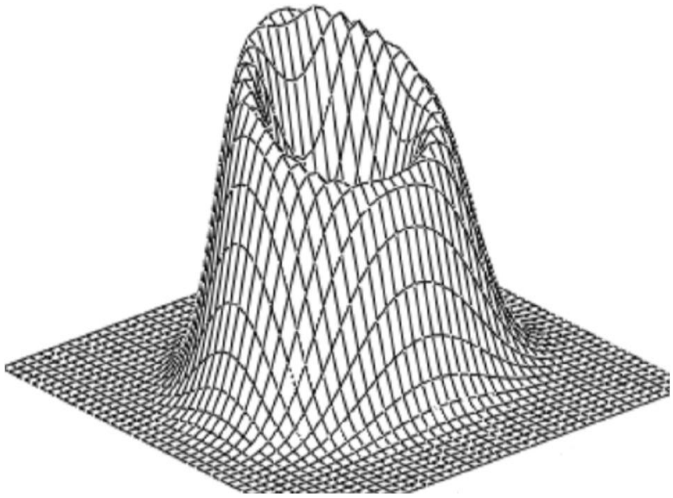

Fig. 4. Distribution (2) in the polar coordinate system

Figures 3 and 4 clearly show “distortions” of the visual representation of distributions when recalculating the probability map from the Cartesian coordinate system to the polar one. In addition, these figures clearly show the possibility of reducing the search time with an appropriate algorithm for viewing the resolution elements of the onboard radar.

## IV. ORGANIZATION OF THE VIEW OF PERMISSION ITEMS IN THE SEARCH AREA

Organization of the search area scanning mode is one of the main methods of reducing the average time of detecting a physical object. Within the issues considered in this work, scanning the zone, or viewing the resolution elements of the search zone, is possible in two ways - scanning with a cosecant electromagnetic beam and scanning with a point beam [5].

The first scanning method is illustrated in Fig. 1. Its advantage is that the area is scanned quickly enough, since the detection of an object along the distance tracks occurs in parallel, then the main scanning time is determined by scanning along the angular coordinate. In particular, if the burst of echo signals, along which the detection occurs, consists of $N$ pulses, and the repetition period of the probing signals is $T_{rls}$, then the time of "fixation" of the electromagnetic beam in a certain direction is equal to $NT_{\text{rls}}$. In this case, for a single viewing of the entire zone, it will take time equal to $M\ N\ T_{rls}$, where $M$ is the number of corner viewing sectors equal to

$$m = E(\Delta\alpha/\Delta\varphi + 0.5), \quad (10)$$

where $E$ (.) is the Antje function [3].

The disadvantage of this method is that the energy of the electromagnetic beam is distributed over the entire length of the range search zone, that is, it is distributed over the range, length $\Delta L$, which naturally reduces the signal-to-noise ratio.

For this scanning mode, the probability matrix is recalculated into a vector line $\Phi_m = (P_1, P_2, \ldots P_m)$, the elements of which are determined by the expression

$$P_j = \sum_{i=1}^{n} p_{i,j}. \quad (11)$$

Minimization of the average search time $T$ in this mode is possible by organizing the viewing mode by the resolution elements of the corner sectors, which correspond to the maximum values $\mathbf{M}_{n,m}$ of the elements of the row vector $\Phi_m$.

The second method of scanning the search area with a needle electromagnetic beam is illustrated in Fig. 5.

The advantage of this method is an increase in the signal-to-noise ratio by $n$ times in relation to the first scanning mode, and the disadvantage is an increase in the time of a single full scan of the zone by $n_\theta$ times compared to the first method, where $n_\theta$ is the ratio of the width of the cosecant pattern of the electromagnetic beam in the vertical plane to the width in the vertical plane of the needle radiation pattern. When it is implemented, the matrix elements $\mathbf{M}_{n\theta,m}$ are ranked and the viewing is performed by resolution elements for which the probabilities of finding the detected object in them are maximum.

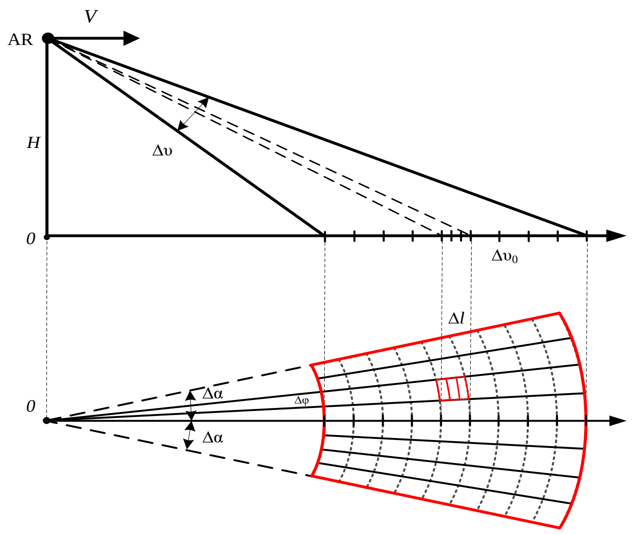


Fig. 5. Scanning the search area with a needle electromagnetic beam

These modes, if it is possible to control the electromagnetic beam, will reduce the search time. In this case, however, it should be borne in mind that the search time will be influenced by the characteristics of the detectors of echo signals of physical objects, which are not enough to be calculated by the known standard methods [7, 8], since when fixing false alarms of detectors when observing echoes of the sea surface, it is necessary to take into account the correlation both in spatial coordinates, and in time [9]. If frequency tuning is used to increase the efficiency of detectors, as it is done in [10], then there will be no temporal correlation, but the spatial correlation is necessary. The calculation of the real search time and comparison of various algorithms for scanning the search area is possible only when determining the characteristics of the detectors, therefore, this article is not considered, since the discussion of issues related to the effectiveness of detectors is beyond the scope of the issues considered in this work.

## V. Conclusion

When carrying out rescue operations of ships in distress, and when rescuing people on board ships after a shipwreck, one of the crucial factors in the provision of timely assistance is the factor of minimizing the search time for ships and people in distress.

The minimization of the search for victims is possible by optimizing the search area, taking into account a priori information about the possible movements of ships and watercraft in the disaster area. It is also possible by calculating a probabilistic digital map that estimates the probability of finding those in distress in the resolution elements of on-board radar systems performing a search, which, in turn, makes it possible to optimize the scanning modes of the search area.

The analytical ratios, calculations and algorithms presented in the work make it possible to solve these urgent and vital tasks.

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