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Features of information processing in the onboard two-position small-sized radar based on UAVs

Vadim A. Nenashev[a], Alexander F. Kryachko[a], Alexander P. Shepeta[a], Dmitry A. Burylev[a]
[a]State University of Aerospace Instrumentation
67, Bolshaya Morskaia str., Saint-Petersburg, 190000, RUSSIA

ABSTRACT

Currently, small aircraft, including UAVs are widely used for civilian purposes to obtain high-precision maps of the terrain, determining the edge of the land-sea, assessing the state of farmland, classification of observed surfaces, environmental monitoring, and also to detect physical objects and sensors that inform about the state of man-made objects. Onboard small radar located on a small aircraft must provide high resolution as coordinate range so as azimuth coordinate when solving these tasks. However, due to their small size and, consequently, the small aperture of the airborne radar antenna, the provision of high resolution azimuth is problematic, especially in the front viewing area, where it is impossible to use SAR methods.

The paper considers with the problem of front and front side view of the earth's surface by a group consisting of two onboard small-size radar station combined into a single information and telecommunication distributed system. Information is exchanged between the equipment of the respective small aircraft via a high-speed radio frequency communication channel. Such a two-position small-sized radar, with appropriate integration of information obtained by spaced sources, allows to overcome the limitations of single-position systems. The paper presents algorithms of information processing in the described two position small radar system, that significantly improves resolution in the azimuthal coordinate in the front and front side zones of review at rather small apertures of the receiving antennas. Shown the requirements for the characteristics of airborne radar and trajectories of small aircraft, allowing to achieve the specified dimensions of the resolution elements on the coordinates of the range-azimuth and, accordingly, to improve the accuracy of the coordinates of the detected physical objects.

Keywords: two-position system, onboard small-sized radar station, front and front side view area, high resolution element, information integration, UAV, antenna aperture, SAR.

1. INTRODUCTION

Considering the problem of improving the estimation of the azimuthal coordinate of radiocontrast objects detected in the joint area review with help of a two-position system onboard small radar. Due to the fact that the range at which the detection is almost always much greater than the altitude, we will limit ourselves to the consideration of the problem for the flat area, the transition to the stereo metric picture does not cause much difficulty, but complicates the already cumbersome formulas obtained by using the planimetric model.

2. PROBLEM STATEMENT

So, two aircraft that carry a small on-board radar stations – ARS1 and ARS2, carry out a flight at the same altitude at a distance of $D=2\Delta$ from each other. Both ARS autonomously search and detect physical objects in the joint survey area. The joint viewing area is shown in Figure 1, which shows the "illumination" of the irradiated underlying surface (ground or sea) diagrams of antenna systems and the range of two small-sized radar located on the X0Y plane at the coordinates $(-\Delta, 0)$ - ARS1 and $(+\Delta, 0)$ – ARS2.

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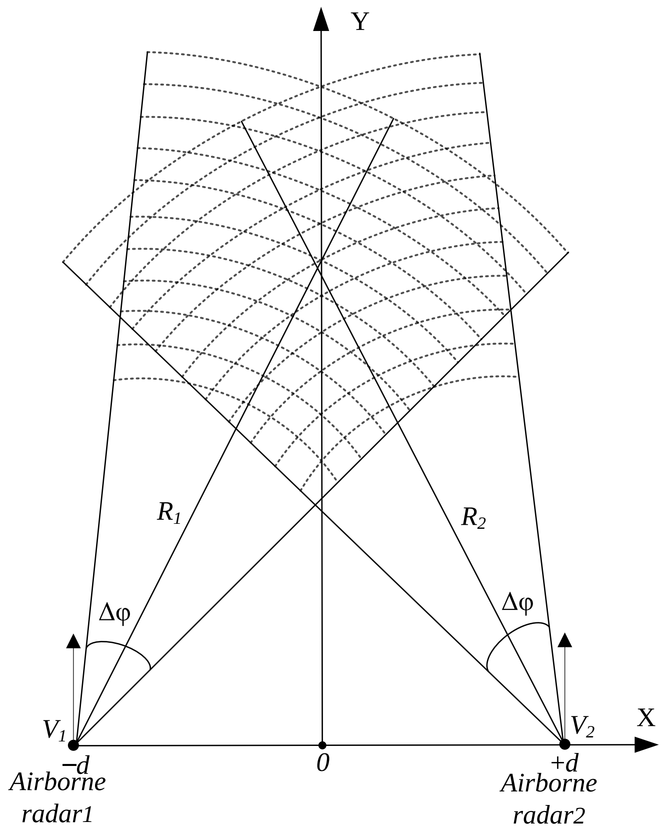

Figure 1. Joint area of view of two-position system of small onboard radar station

Each radar determines the coordinates of the detected object in azimuth and range, the distance to the object is uniquely identified by the number corresponding track range and azimuth, with the beam width $\Delta\varphi$, due to the small aperture antenna system (small radar station), actually coincides with the direction of the maximum of the graph. These features of the small-sized two-position onboard radar system are reflected in Figure 1 - the accuracy of determining the range of the radio contrast object depends on the width of the $2d$ range path, and the azimuth for each ARS coincides with the direction of the maximum radiation of the antenna. In this case, the resolution of each ARS range is determined by the width of the range track, and azimuth – with the width of the antenna on azimuth, that is, in practice, the resolution of the angular coordinate is actually absent.

The described situation corresponds to the autonomous operation of the ARS, when each ARS searches and detects the object independently. This lack of autonomous operation can be significantly compensated by combining the two ARS into a single two-position system, which just implies the exchange of information about the coordinates of the detected objects. This case is considered in this paper, namely, when a physical object is detected, information about the coordinates of the object is exchanged between the ARS, which can significantly improve the accuracy of determining their azimuthal coordinates.

Figure 1 illustrates the situation of the front side view, but all of the above applies to the front view areas. The method of calculating the resolution of two-position system for front side view, that shown below, can be easily extended to the review of the front zones, but in this case it is necessary to use two-beam multi-position systems described, for example, in [1-10]. This generalization goes beyond the issues addressed in this paper.

3. ESTIMATION OF AZIMUTHAL COORDINATES OF DETECTED OBJECTS IN TWO-POSITION SYSTEM OF SMALL ONBOARD RADAR STATION

Suppose a radio-contrast physical object was detected in the joint area of view of the two-position system of small-sized ARS. This object is detected by ARS1 on the range track, the center of which is at a distance R_1 from the location of ARS1, defined by the coordinates (-Δ, 0) on the X0Y plane. ARS2 detects the same object on a range path whose center is at distance R_2 from the ARS2 location defined by the coordinates (+Δ, 0) on the x0y plane. Considering the object to be point, which does not reduce the generality of consideration, we denote the coordinates of the detected object in the Cartesian system as (x_0, y_0). This detect situation is illustrated in figure 2.

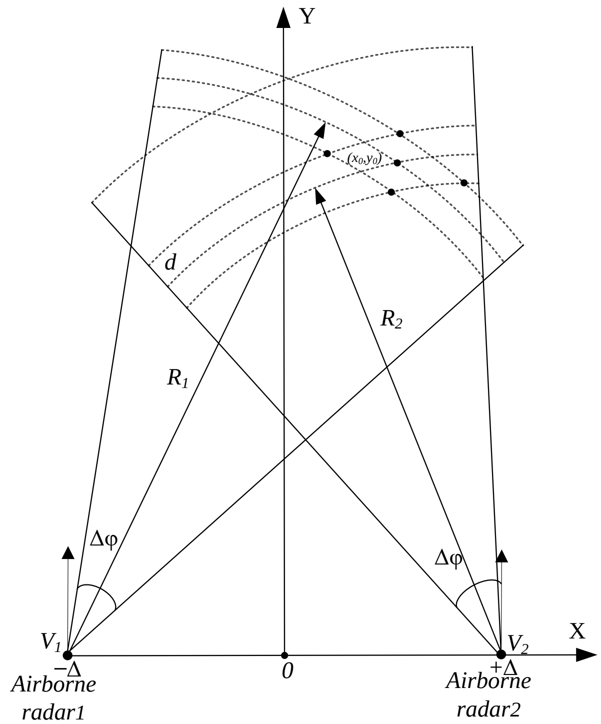

Figure 2 – Determination of the coordinates of the center of the detected object in the observed joint survey area

Let`s find the coordinates of center of detected object (x_0, y_0), in the resolution element, expressing them to known for two-position system distances to the object R_1, R_2, distance between ARS D=2Δ and the width of the track range equal to $2d=\tau_и c/2$, where $\tau_и$ – the duration of the probing signal (if the signal is too complex, then after its compression), and c – speed of light. The point with coordinates (x_0, y_0) is at the intersection of two circles and, as it follows directly from figure 2, determined from a system of equations:

$$\begin{cases} (x-\Delta)^2 + y^2 = R_2^2, \\ (x+\Delta)^2 + y^2 = R_1^2, \end{cases} \tag{1}$$

solving which, we get:

$$\begin{aligned} x_0 &= \frac{R_1^2 - R_2^2}{2D} = \frac{(R_1 - R_2)(R_1 + R_2)}{2D}, \\ y_0 &= \frac{1}{2D}\sqrt{\left[D^2 - (R_1 - R_2)^2\right]\left[(R_1 + R_2)^2 - D^2\right]}. \end{aligned} \tag{2}$$

The question of the existence of a real solution of the system (1) is not discussed here, since for the real values of the quantities included in the expression (2), the values x_0 and y_0 are always valid.

Expressions allow you to evaluate the directions to the detected object as the directions to the point (x0, y0), which can be calculated in different ways. In particular, using the arctangent function, the directions φ_{01} and φ_{02}, as directly follows from Figure 3, defined by expressions $\varphi_{01}=\mathrm{arctg}(y_0/(\Delta+x_0))$, and $\varphi_{02}=\mathrm{arctg}(y_0/(\Delta-x_0))$.
These formulas allow us to recalculate the azimuthal coordinates of the detected object by each ARS.

4. EVALUATION OF THE RESOLUTION OF THE TWO-POSITION SYSTEM OF SMALL AIRBORNE RADAR STATION BY AZIMUTH

To estimate the resolution of the two-position ARS system is necessary to find the coordinates of the points (x_1, y_1) and (x_2, y_2).

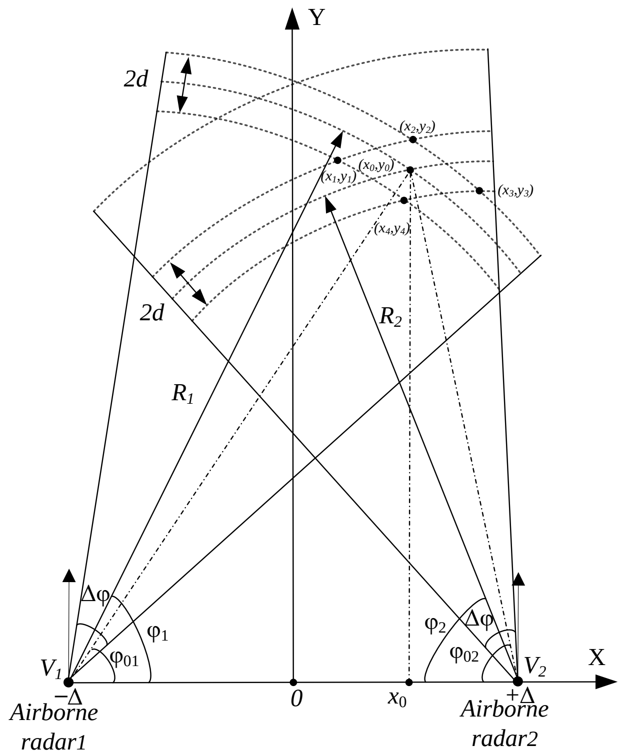

Figure 3. Determination of resolution in the observed joint survey area

As directly follows from figure 3, the coordinates (x_1, y_1) are determined from the system as:

$$\begin{cases} (x-\Delta)^2 + y^2 = (R_2+d)^2, \\ (x+\Delta)^2 + y^2 = (R_1-d)^2, \end{cases} \tag{3}$$

solving which, we get:

$$x_1 = x_0 - \frac{d}{D}(R_1+R_2),$$
$$y_1 = y_0\sqrt{\left[1+\frac{d_0}{D-(R_1-R_2)}\right]\left[1-\frac{d_0}{D+(R_1-R_2)}\right]}. \tag{4}$$

And coordinates (x_2, y_2) – from system:

$$\begin{cases}(x-\Delta)^2+y^2=(R_2-d)^2, \\ (x+\Delta)^2+y^2=(R_1+d)^2,\end{cases} \tag{5}$$

Solving system (5), we get:

$$x_2=x_0+\frac{d}{D}(R_1+R_2),$$
$$y_2=y_0\sqrt{\left[1-\frac{d_0}{D-(R_1-R_2)}\right]\left[1+\frac{d_0}{D+(R_1-R_2)}\right]}. \tag{6}$$

From expressions (4) and (6) for ARS1 we get directions to points (x_1, y_1) and (x_2, y_2) from point (-Δ, 0), which are defined by the expressions φ_{11}=arctg(y_1/(Δ+x_1)), and φ_{21}=arctg(y_2/(Δ+x_2)), respectively, hence the angular size of the resolution element Δφ1, in which the object is detected

$$\Delta\varphi_1=arctg\left(tg\left(\varphi_{11}-\varphi_{21}\right)\right)=arctg\frac{tg\varphi_{11}-tg\varphi_{21}}{1+tg\varphi_{11}\cdot tg\varphi_{21}}=arctg\frac{y_1\left(\Delta+x_2\right)-y_2\left(\Delta+x_1\right)}{y_1y_2+\left(\Delta+x_1\right)\left(\Delta+x_2\right)}. \tag{7}$$

A similar expression is obtained for ARS2. We get directions to points (x_1, y_1) and (x_2, y_2) from point (+Δ, 0) are defined by the expressions φ_{12}=arctg(y_1/(Δ-x_1)) and φ_{22}=arctg(y_2/(Δ- x_2)), respectively. The angular size of the resolution element $\Delta\varphi_2$ for ARS2 is:

$$\Delta\varphi_2=arctg\left(tg\left(\varphi_{22}-\varphi_{12}\right)\right)=arctg\frac{tg\varphi_{22}-tg\varphi_{12}}{1+tg\varphi_{12}\cdot tg\varphi_{22}}=arctg\frac{y_2\left(\Delta-x_1\right)-y_1\left(\Delta-x_2\right)}{y_1y_2+\left(\Delta-x_1\right)\left(\Delta-x_2\right)}. \tag{8}$$

From expressions (7) and (8) follow the formulas of calculation of increase of resolving power on angular (azimuthal) coordinates for ARS1 and ARS2, namely, the angular dimensions of the resolution elements are reduced by Δφ/Δφ1 and Δφ/Δφ2 times for ARS1 и ARS2, where Δφ is the width of the ARS antenna radiation pattern in power at level 0.5 of the radiation maximum, respectively.

It should be noted that the «gain» in azimuth resolution for ARS1 and ARS2 is different and depends on the point (x0, y0) - the location of the detected object in the joint viewing area.

5. COORDINATES OF POINTS (X_3, Y_3) AND (X_4, Y_4) OF RESOLUTION ELEMENT OF TWO-POSITION SYSTEM OF SMALL ONBOARD RADAR STATIONS

When determining the area of the resolution element of a two-position system, the value of which may be needed when calculating the statistical characteristics of point estimates of azimuthal coordinates of detected objects, expressions are required that determine the coordinates of points (x_3, y_3) and (x_4, y_4) through the values of R_1, R_2, D=2Δ and d_0=2d.

As shown in figure 2, the coordinates (x_3, y_3) are determined from the system

$$\begin{cases}(x-\Delta)^2+y^2=(R_2+d)^2, \\ (x+\Delta)^2+y^2=(R_1+d)^2,\end{cases} \tag{9}$$

solving which, we get:

$$x_3=x_0+\frac{d}{D}(R_1-R_2),$$
$$y_3=y_0\sqrt{\left[1+\frac{d_0}{(R_1+R_2)-D}\right]\left[1+\frac{d_0}{(R_1+R_2)+D}\right]}. \tag{10}$$

Coordinates (x_4, y_4) are determined from the system:

$$\begin{cases}(x-\Delta)^2+y^2=(R_2-d)^2, \\ (x+\Delta)^2+y^2=(R_1-d)^2,\end{cases} \tag{11}$$

solving system (11), we get:

$$\begin{aligned} x_4 &= x_0-\frac{d}{D}(R_1-R_2), \\ y_4 &= y_0\sqrt{\left[1-\frac{d_0}{(R_1+R_2)-D}\right]\left[1-\frac{d_0}{(R_1+R_2)+D}\right]}. \end{aligned} \tag{12}$$

Now, after determining the coordinates of the points (x_1, y_1), (x_2, y_2), (x_3, y_3) and (x_4, y_4), setup a two-dimensional distribution of the location of the detected object in the resolution element, it is possible to estimate the statistical characteristics of the azimuthal coordinates estimation.

6. CONCLUSION

In this paper were obtained analytical relations to calculate the resolution of the two-position on-Board small radar in the azimuthal coordinate. The presented analytical relations allow us to choose the characteristics of the flight path of ARS carrier aircraft, the characteristics of ARS and the dimensions of the joint front-side review zone in such a way as to provide the required resolution of the two-position system in azimuthal coordinates.

Expressions are obtained for the front side view can be used to calculate the characteristics of two-position small radar system in the case of the front view, which gives the possibility to use a mode of synthetic aperture radar each member system.

The presented algorithm of information aggregation in a two-position system is useful when using such systems to search for people in disaster zones, as well as when taking information from sensors that collect information for monitoring the environmental situation and assessing the state of man-made objects, especially in remote and dangerous places.

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