Fusion Radar and Optical Information in Multi-Position on-Board Location Systems

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***Abstract* — The article deals with the issues of combining information in a two-position small-size radar system to improve the system's resolution when mapping the underlying surfaces in the front side view area. This radar system also serves to improve the accuracy of azimuthal coordinates of physical objects and information sensors detected in the view area. This information is used in the optical two-position system, located on the same small UAVs on which the small-size on-board radars are based, which allows the positioning of cameras on detected objects with high accuracy. The high precision positioning of the cameras allows the combination of the two-position optical system information and radar information. The result of this combination allows to clarify the coordinates of the edges of the underlying surfaces, in particular the coastal zone, as well as to improve the reliability of the classification of underlying surfaces and detected physical objects.**

Keywords — *multi-position small-size radar system, optical and locating system, fusion information, underlying surface, classification.*

I. Introduction

Radar methods are now widely used to collect and analyze information in areas such as underlying surface mapping in the front side view area, detection and determination of coordinates of physical objects and information sensors in given observation areas, as well as for classification of surfaces and physical objects. These radar system capabilities are widely used in areas such as digital terrain mapping, coastline definition, glacier delineation, geological exploration, environmental monitoring, collection of information from sensors informing about the status of man-made objects, detection of people in areas of environmental disasters and catastrophes, etc.

To solve the above tasks, unmanned aircraft vehicles (UAVs) equipped with small-size on-board radars (OBRs) are usually used. These UAVs perform the flight in automatic or automated mode according to specified trajectories. Due to the limited load capacity of the UAV, resources of small-size radars are also limited. This leads to the fact that with limited resources the accuracy of mapping and determining the coordinates of detected physical objects and information sensors may be insufficient. The situation is even worse with the classification of surfaces and detected objects, as the resolution of small-size OBRs is insufficient, especially on the angular coordinates. However, radar methods for the decision of considered problems are still used as these methods possess a number of essential advantages in comparison with others. The main such advantages include, in particular, all-weather capability and long range.

Different approaches are used to overcome traditional shortcomings of radar methods, most often single-position ones. One such approach is the transition from single-position systems to multi-position systems. Multi-position systems make it possible to improve both the accuracy of mapping and the accuracy of determining the coordinates of detected objects when processing the information received from the UAVs spaced out in space together. They also increase the probability of correct classification of underlying surfaces and physical objects.

Another approach is the use of optical systems [1, 2] that have a number of advantages over radar methods to solve the above mentioned problems. Especially this advantage manifests itself in the case of classification of detected objects the sizes of which are commensurate with the resolution capacity of multi-position OBRs, so they are visible on the radar "picture" simply as illuminated spots. However, the short range of optical systems compared to radar systems and the dependence on weather conditions significantly limit their area of application. Similar disadvantages, in particular limited range, are inherent in other approaches, such as the use of infrared range, etc.

The most promising areas of research aimed at overcoming the shortcomings of the approaches used to solve the above problems are the study of the possibility of combining information obtained from sources based on different physical principles [3-5]. However, this area is so vast that its review cannot be presented in one or even a series of articles on this topic. Therefore, in this paper we investigate the possibility of implementing the ideas of combining when using a two-position small-size OBRs as the main information source, and as an additional source of optical cameras located on the same UAV as the OBRs.

II. Two-Position System of Small On-Board Radars for Detection of Physical Objects in a Joint Review Area

Let's consider possibilities of two-position small-size OBRs at the review of a joint zone of search of physical objects. This mode of operation of two-position OBRs is presented in Fig.1, which shows a joint view area and two OBRs located on two

UAVs, carrying out a search of physical objects in this area. The UAVs are moving at parallel courses with the same speeds V, the maximums of the antenna patterns, width $\Delta\varphi$, directed to the center of the view area *C*, located at distances *L* from each UAV. Fig. 1 shows the range tracks with dashed lines. Since the height of the UAV's flight is much higher than *L*, we can limit ourselves to looking at the planimetric picture, which is reflected in Fig. 1.

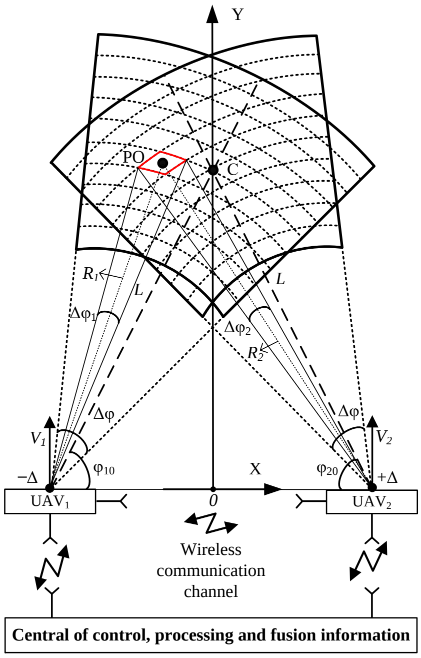

Fig. 1. Resolution elements of a two-position small OBRs

Let the joint view area detect a physical object (PO), the distances to which from the UAV_1 and UAV_2 are equal to R_1 and R_2, respectively. Consider the fact that the antennas of small-size UAVs are small, which leads to a fairly wide beam of the directional pattern and the width of the directional pattern determines mainly the angular resolution of the UAV. Due to this, the angular coordinates of the detected object, namely, the azimuthal coordinates φ_1 and φ_2 coincide with the directions of the maximum directional diagrams of the UAV_1 and UAV_2 antenna systems, respectively, and the accuracy of determining the coordinates is actually equal to $\Delta\varphi/2$. R_1 and R_2 range coordinates are determined by corresponding range tracks, whose width $c\tau_c/2$ and determine the range resolution capability, the accuracy of distance determination is equal accordingly to $c\tau_c/4$, c - light speed, τ_c - duration of the probing pulse (or compressed complex probing signal).

These resolution capabilities and accuracy correspond to the situation when both OBRs operate independently of each other. It should be noted that in this autonomous mode it is possible to achieve an acceptable accuracy of determining the range coordinates of detected objects by reducing τs, but the accuracy of determining angular azimuthal coordinates in small-size OBRs may be unacceptable for the reason mentioned above.

The paper [6] presents the structure and analyzes the accuracy characteristics of a two-position OBRs, consisting of two OBRs, with each UAV has a high-speed communication channel equipment, through which OBRs exchange information about the physical objects detected in the joint view area and can transmit information to the central ground control station. Additional opportunities for information exchange are reflected in the same Fig. 1. This information exchange allows at the same apertures of antenna devices to increase by an order and more an estimation of angular coordinates of the found objects [7] that is qualitatively visible also in Fig.1.

Indeed, in the exchange of information between the OBR_1 and OBR_2, the OBR_1 equipment that detected a physical object on the *i*-th range track has information about the detection of the object by the OBR_2 station on the *j*-th range track. This allows us to calculate the dimensions of the resolution element, which is equal to the intersection of the range tracks of two, spaced in the radar space. This resolution element of the two-position OBR system is shown in Fig. 1.

The center of the selected resolution element determines the distance coordinates of the detected physical element R_1 and R_2, and the angular sizes of the element determine the resolution of OBR_1 and OBR_2 by angular azimuthal coordinates $\Delta\varphi_1$ and $\Delta\varphi_2$. It is possible to calculate the angular coordinates of the resolution element center, which are the azimuthal coordinates of the detected object. It is clear that $\Delta\varphi_1 << \Delta\varphi$ and $\Delta\varphi_2 << \Delta\varphi$, and therefore the direction to the object is determined with rather high accuracy, despite the wide size of the directional diagrams of the antenna systems of small-size OBRs.

Analytical expressions calculating coordinates of the physical objects R_1, R_2, $\Delta\varphi_1$ and $\Delta\varphi_2$ detected in the joint view area depending on the flight modes are given in [8], where it is shown that the linear dimensions of the resolution elements by angular coordinates at the corresponding choice of flight parameters are commensurate with the dimensions of the resolution elements by distance.

III. Two-Position System of Small Onboard Radars for Mapping of Laying Surfaces in the Front-Side Area

The two-position OBR system described above is the simplest system. This system is designed to detect physical objects and sensors in a given area, informing about the environmental condition of the underlying surfaces and the functioning of man-made objects. More complex equipment is required for mapping and digital mapping tasks. This equipment can also be located on small UAVs. In [7, 9-11] structural schemes and algorithms of functioning of similar two-position systems of small-size OBRs are presented. Feature of these systems is the ability to carry out mapping not only in the front-side view zones, using methods of synthesis of the aperture of antenna systems [12-15], but also in the front zones. In the front areas, as is known, in the case of single-position location is not implemented mode of synthesis of the antenna aperture. In case of two-position system such a mode can be realized. In the second case, a high degree of resolution is achieved for the front zone, as well as in the front side areas.

Below the principles of operation of such a two-station OBR system and its possibilities are considered.

Two UAVs, as in the previous case, fly parallel courses and exchange information among themselves and with the control center. This situation is illustrated in Fig. 2.

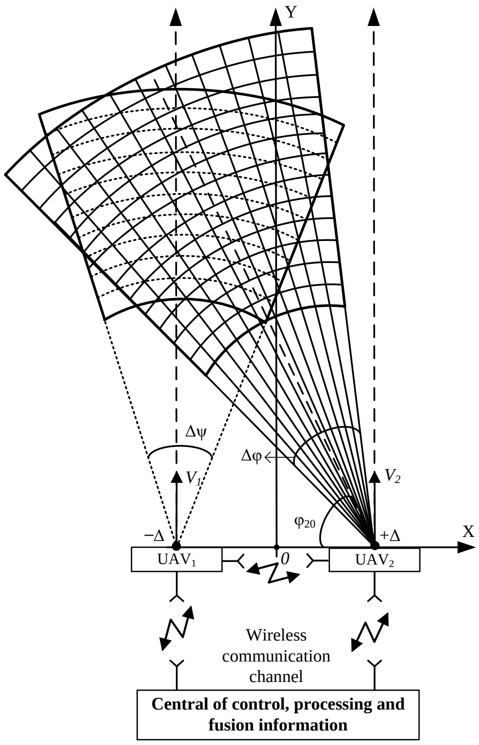

Fig. 2. Front-area mapping with a two-position small OBRs

In contrast to the previous case, each OBR has a two-beam antenna system - one antenna is directed forward, at the course of the UAV, the width of the antenna pattern is equal to $\Delta\psi$, and the second, as well as in Fig. 1 is shifted to the corner φ_{20} and its width of the directional pattern - $\Delta\varphi$. Fig. 2 shows the UAV_1 front view antenna and the UAV_2 side view antenna, as well as the combined view area "covered" by these two antennas. The same illustration is valid for the UAV_2 front view and the UAV_1 side view antennas, which form the combined front view area of the UAV_2 (mirroring in relation to the Y axis).

Just as in the first case, OBRs have fairly wide directional patterns of antenna systems, both front (front view) and front-side view antennas. However, if we consider the joint viewing area shown in Fig. 2, which is the intersection of the "illumination" areas of the front OBR_1 antenna and the "side" OBR_2 antenna, then the detection of physical objects in this joint viewing area occurs using the same algorithms as in the above case. This means that we can significantly increase the resolution of angular (azimuthal) coordinates and, accordingly, improve the accuracy of determining the angular coordinates of detected objects. In this case, the capabilities for detecting and determining the coordinates of these two-position radar stations are almost identical [6-10].

In contrast to the previous case, this more complex two-position system has additional features. Namely, in the front-side view of the joint zone on OBR_2, an aperture synthesis mode can be implemented, in which the field of view of the OBR_2 side antenna is divided by angular coordinates into resolution elements, the size of which is determined by the bandwidth of Doppler filters, as shown in Fig. 2 [7, 10]. Over a high-speed communication channel, this detailed picture of the underlying surface obtained by the OBR_2 equipment is transmitted to OBR_1, forming a picture of the underlying surface in the forward viewing area of OBR_1 [9, 10]. The operation of such a more complex two-position radar system is explained by the function diagram shown in Fig. 3.

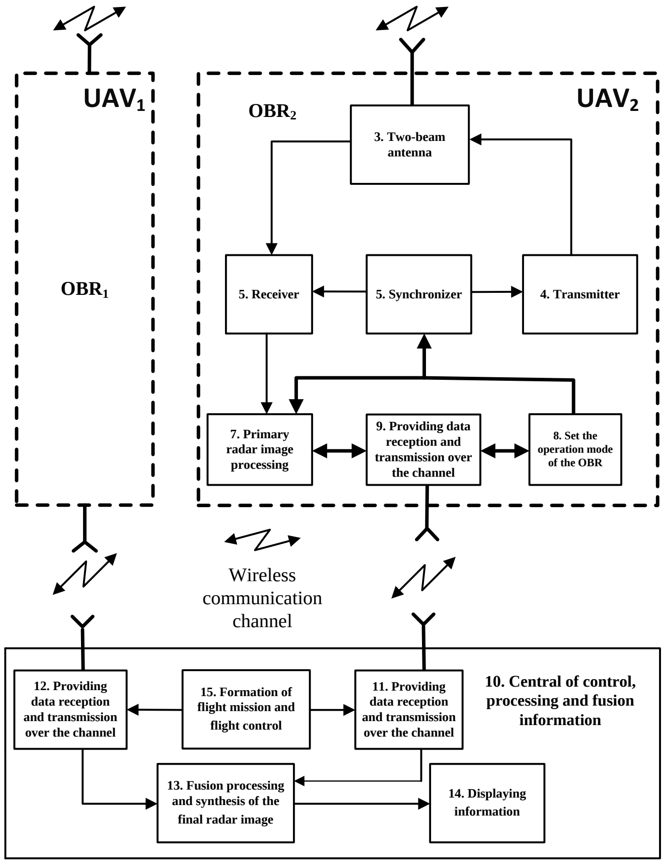

Fig. 3. Function diagram of two-position system small OBRs for mapping of laying surfaces in the front-side area

The purpose of the blocks shown in Fig. 3 is clear from their names and does not require special explanations. In this scheme, great importance is attached to the high-speed communication channel, through which the image of the anterior-lateral viewing area of OBR_2 is transmitted to the OBR_1 equipment, since this transmission contains a sufficiently large amount of information. Passed the matrix of the coordinates of the centers of the elements of the resolution of the radar image in a polar coordinate system connected with OBR_2, matrix, brightness and some other parameters generated by the instrument OBR_2 image of the underlying surface of the anterolateral zones review OBR_2 coincident with the front area OBR_1.

The OBR_1 hardware recalculates the obtained coordinates of the centers of resolution elements and brightness of the anterior-lateral viewing zone of OBR_2 to the anterior viewing zone of OBR_1. Basically, this is a conversion of coordinates from a single polar coordinate system associated with OBR_2 to a polar coordinate system associated with OBR_1, and a conversion of the brightness matrix of the centers of resolution elements with brightness adjustments, in accordance with the change in the distances of the centers of resolution elements to OBR_1. Thus, the image of the underlying surface of the front viewing area of OBR_1 is formed [9].

In addition to the above-mentioned features of the two-position small-size OBRs, it is possible to compensate for the effect of migration of moving physical objects that occurs when the radar is formed by the OBR_2 equipment, by using information about the coordinates of detected physical objects received by OBR_2 from the OBR_1 equipment [7].

IV. Fusion Information Algorithms Used In The Multi-Position Radio-Optical Complex

The two-position small-sized OBRs discussed above have great practical advantages. The main of these advantages are all-weather, long range, sufficiently high accuracy in determining the coordinates of detected physical objects and the outlines of the edges of underlying surfaces, etc. However, they are inherent and disadvantages associated with the problems of classification of detected objects and types of underlying surfaces. These shortcomings are due to the fact that detected objects in radar pictures, especially those that are smaller than the resolution element of the radar system, are visible simply in the form of bright illuminated spots, devoid of any classification features.

Classification issues are quite successfully resolved by modern optical-location systems. Existing optical location systems as well as radar systems are not without drawbacks, in particular, they depend on weather conditions and have a not very long range. However, these systems, with the precise guidance and focusing of optical systems on physical objects, make it possible to solve the classification of physical objects and determine the types of underlying surfaces, which are extremely difficult to classify by the electromagnetic characteristics of the reflected radar signals.

In multi-position optical-location systems for solving classification problems, it is necessary to identify the object, that is, make sure that the same physical object is observed, bring the images of the object of interest to one scale, rotate it and thereby bring the object in the image to a joint coordinate system, after which you can use classification algorithms. The solution of these problems, as noted earlier, requires solving the issues of pointing the cameras at the object, implementing the corresponding focuses, image rotation, etc.

The two-position OBRs considered above allow detecting objects, determining their angular coordinates and calculating the distance to detected objects. This, in essence, is the solution of problems of optical-location systems: object detection - solution of the identification problem, determination of angular coordinates - solution of the problem of pointing the optical system to the object, determination of the distance to the object - solution of the focusing problem, determination of viewing angles of the object with respect to OBR - solving the problem of the corresponding turns, etc. Naturally, these problems are solved in multi-position radar OBRs, possibly with insufficient accuracy for optical-location systems, but, nevertheless, it is clear that the information received from multi-position OBRs greatly facilitates the solution of problems of optical-location systems. Therefore, the idea naturally arises of combining information from multi-position radar systems with information from optical-location systems.

The integration algorithm that implements the ideas described above is presented in Fig. 4.

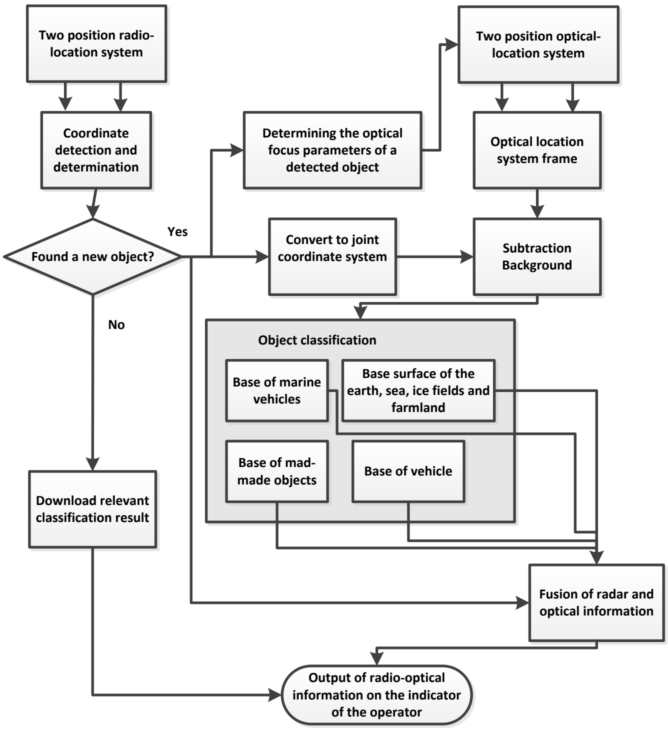

Fig. 4. The block diagram of the algorithm for information fusion

The operation of the algorithm is understandable from the names of the corresponding blocks that carry out the operations described in sufficient detail in the relevant literature on multi-position radar and optical systems [16-20]. However, one of the possibilities of implementing the idea of combining information received from sources based on different physical media is shown here.

In our case, the optical-location system is located on the same UAVs on which small-sized radars are located, that is, each UAV is a video camera carrier and, therefore, the two-position OBRs system is rigidly connected to the optical-location system. On each UAV, using information from a neighboring OBR, the angular coordinates of the detected object are determined, which allows you to accurately direct the cameras to the detected object. Since the coordinates of the distance to the object are determined on each UAV, this information can be used to focus cameras. In this case, not only the coordinates of the detected object, but also its clear video image from two different angles will be transmitted to the central control panel, which will increase the likelihood of its correct classification. Thus, in the situation under consideration, the tasks of detecting a physical object, determining its coordinates, pointing and focusing cameras are assigned to a two-position small-sized radar system, and the classification task to an optical one. At the central control point, electromagnetic classification features can also be used to classify objects, but they, in our case, play a secondary role.

V. CONCLUSION

The use of small-sized OBRs for the detection of physical objects allows one to achieve high accuracy in determining the angular coordinates of detected objects only when these OBRs are combined into one multi-position radar, in which a high-speed information exchange between individual radars that are part of a multi-position system occurs.

To solve the problems of mapping, you can use small-sized multi-position radar with a limited aperture of antenna devices, but the complexity of the equipment is necessary. In particular, it is possible to use two-beam antenna systems, which makes it possible to implement aperture synthesis modes on separate OBRs, while there are possibilities to correct migration effects due to the movement of physical objects in the mapping zone.

When the UAV is equipped with cameras, simultaneously with the OBRs multi-position system, an optical-location system is implemented in which, due to radar information, the cameras are searched, identified, guided and focused on the detected objects, which makes it possible to correctly classify them.

VI. ACKNOWLEDGMENTS

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