Methodology for classifying types of underlying surfaces using radar frames in a spatially distributed system of small-sized radar stations

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***Abstract* — A methodology is being developed for classifying types of underlying surfaces based on radar frames (RF) of the flow in the forward viewing area of small-sized airborne radar stations of a multi-position system. Direct and inverse classification problems are solved to determine new reference models in order to construct maps of underlying surface zones based on statistical characteristics without the use of optical location visual information.**

To construct standards, it is necessary to solve the inverse problem, in which the initial data is the data from the combination of the optical and radar layers of the frame. The solution to the inverse problem depends on the quality of the result of solving the direct problem. When implementing the direct task, radar and optical images are combined. A radar flow is formed from reflected signals from the underlying surface based on a modification of the method of radar synthesis of the antenna aperture with a frequency comparable to the video frequency. The optical image can, for example, be a digital terrain map pre-loaded into the aircraft's memory, or an optical image recorded in an optical location system. As a result of this combination, a complex location image is formed, which is the input data for solving the inverse problem.

The purpose of this research is to develop a methodology for classifying territories according to radar flow for constructing an appropriate (classification) map of the area based on segmentation methods, combining heterogeneous images, methods of remote sensing of the Earth, methods of mapping the earth's surface and searching for reference mathematical (statistical) models of echo signals, which are basis for classification of small-sized airborne radars in spatially distributed systems.

The practical significance of these studies lies in the fact that a new methodology for classifying territories is proposed, implemented in the equipment of multi-position systems on small aircraft for solving problems of environmental monitoring, as well as assessing vegetation cover and land use, in particular forestry, agriculture, as well as coastal, aquatic and marshy areas. boundaries of divisions of various zones to unlock the potential of using territories.

Keywords — classification of territories by type, underlying surface, high-resolution radar images, remote sensing of the earth, image segmentation, small-sized airborne radars, direct and inverse tasks, formation of a complex location image, mapping of the earth's surface, multi-position systems.

I. INTRODUCTION

Currently, multi-position onboard systems for mapping the earth's surface using remote sensing methods are increasingly being used. For a number of reasons, these systems are based on small aircraft (SA). Firstly, the tactical and technical characteristics of SAs allow the use of increasingly larger payloads in terms of mass and dimensions. Secondly, the onboard location systems themselves are reduced in their weight and size characteristics. Thirdly, the flight time of SAs, both aircraft and helicopter types, increases to carry out long-term mapping of the earth's surface. However, for the purposes of 1) operational mapping of the Earth's surface using remote sensing methods, 2) increasing information content and 3) timely notification of emergencies and other environmental disasters, it is advisable to use multi-position systems consisting of several spatially distributed systems (SDS) of small-sized airborne radars (SSAR), based on SA.

A comparative analysis of single-position location modes showed the significant complexity of using known methods of observing the Earth's surface using radar methods to implement the goals of operational surveillance with SSAR, since it is quite difficult to simultaneously cover all the requirements of this type of task using known mapping methods. These requirements include:

1) Implementation of a review of the observed areas, with the detection of objects of interest and their subsequent tracking, including people, in a minimum period of time;

2) Increasing the resolution of “range-azimuth” coordinates in real time;

3) Ensuring a high probability of correct detection with a fixed value of the probability of a false alarm against the background of noise and interference.

The last requirement, in turn, dictates the condition for the signal-to-noise ratio, which should be potentially the maximum possible [1]. These requirements lead to the need to improve the modes of operational mapping of the earth's surface from the boards of SA.

Selecting a multi-position viewing mode allows you to significantly reduce search time, which is one of the key factors in solving problems of operational mapping of the earth's surface. To fulfill the first and third requirements mentioned above, it is necessary to carry out a review in the front zone along the SA course of movement. This approach allows us to minimize the time spent searching for physical objects of interest when conducting search and rescue operations of an operational nature [2-4].

An important aspect is the fact that when performing these operations in the forward viewing area along the course of movement of the small aircraft (SA) carrying on-board equipment, its trajectory can be easily adjusted upon approach before the observed area is identified as a disaster or environmental disaster zone. This fact allows you to save time when approaching the corresponding area, compared to the side-scan mapping method, in which it is necessary to make a turn, accompanied by additional time costs. In addition, when correcting the movement of approach to a disaster or environmental disaster zone, the range to it decreases and the signal-to-noise ratio increases, which means the third requirement is met.

The ability to provide high resolution in azimuth and range in the forward viewing area is also the main characteristic when performing operational mapping tasks, which must be increased when forming a radar flow in the forward viewing area of the SSAR [5-7]. These arguments justify the expediency of choosing small-sized multi-position onboard radar systems in relation to the implementation of onboard operational mapping systems.

For these reasons, today the urgent task is 1) the development of the theory of integrating location information in radar multi-position onboard systems, and also 2) the implementation of practical methods of operational mapping on their basis. They are trying to solve this urgent problem within the framework of automated multi-position on-board monitoring based on complex processing of the flow of radar frames and technical vision methods. Therefore, this work is devoted to the research and development of an approach for combining location data obtained from several heterogeneous sources, ensuring the formation of heterogeneous frames with SA. Based on the combination of heterogeneous data [8-10], a complex location frame (CLF) is formed, which is used to determine the space of information features for classification and typification of the underlying surface from various observation angles in a multi-position mode of observation of the territory in the interests of determining the type of underlying surface: vegetation, arable land, wetland, farmland, forest cover, etc.

There are known methods for classifying territories according to one, two or several information characteristics. Some other signs are also possible: geometric, polarization, etc. [11, 12].

However, for the classification of types of observed territories, the most promising is to determine the density law of the distribution law (LD) of the amplitudes of reflected signals with the determination and analysis of its statistical parameters (mathematical expectation, dispersion, coefficient of variation, etc.) in the dynamics of classification according to the generated RLC flow in order to determine inter-frame stable criteria for determining and expanding the space of classification information features.

Thus, the following scientific task is posed: to develop a methodology for determining the space of information features by which it is possible to classify the types of underlying surfaces that are consistent with experimental data. And also develop an appropriate methodology for classifying territories.

II. A TECHNIQUE FOR DETERMINING THE SPACE OF INFORMATION FEATURES FOR CLASSIFYING UNDERLYING SURFACES

In the direct problem of classifying zones in images of underlying surfaces, the initial frame and the control factor are known. The initial frame is the CLF, consisting of an optical layer (OL) (for example, a fragment of a digital terrain map (DTM)) and a radar layer (RL). The controlling factor is the well-known classification of zones on the OL. The unknown unknown is the classification of the underlying surface zones on the RL. The direct problem is solved by finding a correspondence of the classified zone on the OL layer corresponding to the zone of the underlying surface on the PC. Solving the direct problem by finding correspondence between zones on different layers is necessary in order to solve the inverse problem of searching for data corresponding to the control factor (the decision rule or criterion by which further classification will be carried out).

The solution to the classification problem is to experimentally confirm the ability to reliably determine the types of underlying surfaces with SSARs during autonomous monitoring of the earth's surface, including from SAs, in particular in multi-position mode. The task is to find statistical equivalents - the laws of distribution of echo signals for radar classification of various types of underlying surfaces according to the statistical dependencies between the reflections of echo signals, according to which the flow radars are formed, as well as according to the inter-frame parameters determined in dynamics and the dependencies between the radars, which are built according to the radar flow.

To classify the types of observed territories, the most promising is to determine the LD fluctuations of the amplitudes of the echo signal, expressed by the distribution density. To describe the LD, its statistical parameters must be determined and analyzed (mathematical expectation - MS(A), dispersion - DS(A), coefficient of variation - KS(A), etc.).

Thus, it is necessary to determine the space of information features by which it is possible to classify the types of underlying surfaces that are consistent with experimental data. And also to develop an appropriate methodology for classifying territories.

The scheme for determining the space of information features for classifying underlying surfaces is presented in Fig. 1.

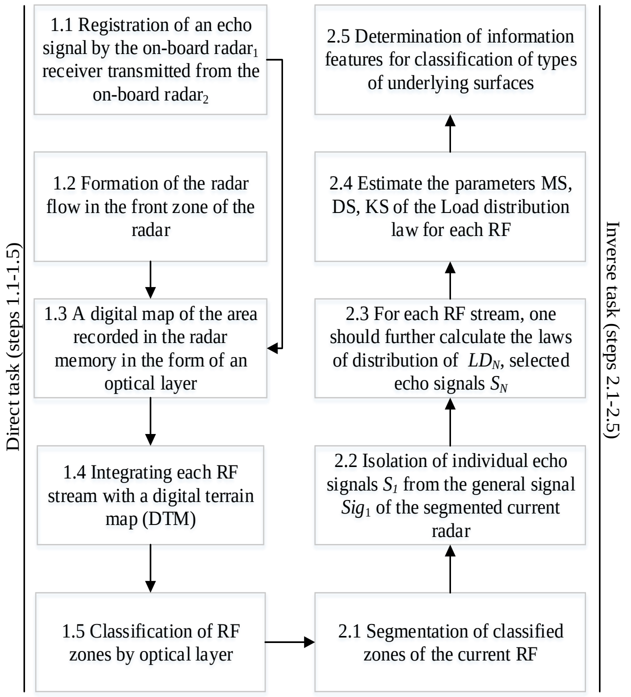

Fig. 1. Scheme for determining the space of information features for classifying underlying surfaces by type

The direct recognition task (classification) is presented in Fig. 1 by clauses 1.1-1.5.

1.1 Registration of an echo signal by the radar1 receiving device transmitted from radar2, which provides illumination of the front zone of radar1 in the anterolateral viewing mode.

1.2 Formation of the radar flow in the front zone of the radar1.

1.3 A digital map of the area recorded in the radar memory in the form of an optical layer with a classification of zones by type of earth surface.

1.4 Integrating each RF stream with a digital terrain map (DTM) computer using segmentation methods.

1.5 Classification of RF zones by optical layer.

First, the echo signal is registered (clause 1.1), from which the RF is formed (clause 1.2). At the same time, in the memory of SSAR1 there is a recorded DTM in the form of an OL with a classification of zones of the Earth's surface of the same surface (clause 1.3), according to which the radar was generated during the flight. It is capable of producing fragments of the digital computer in the form of OL from various angles. Next, the segmentation procedure [13-18] is simultaneously applied to the RF and the DTM fragment in the form of OL, having previously concatenated the images into a single composition. The pixel clustering methods applied to the studied radar and operating system identify characteristic areas, based on the analysis of which the subsequent combination of the studied images of various natures into a single complex image takes place (section 1.4). On the generated complex image, the task of classifying the RL according to the superimposed OS is implemented (clause 1.5). The processes of the direct problem are described in [9, 10, 15].

Next, the inverse problem is solved (clauses 2.1-2.5 of the diagram in Fig. 1).

2.1 Segmentation of classified zones of the current RF.

2.2 Isolation of individual echo signals S1 from the general signal Sig1 of the segmented current radar corresponding to individual types of classified areas.

2.3 For each RF stream, one should further calculate the laws of distribution of LD_1, LD_2, ..., LD_N, selected echo signals S_1, S_2, ..., S_N, individual segmented areas corresponding to one type.

2.4 Estimate the parameters MS, DS, KS of the LD distribution law for each RF to collect interframe parameters $S_q = \{(MS_1, DS_1, KS_1), (MS_2, DS_2, KS_2), ..., (MS_N, DS_N, KS_N)\}$ with the aim determination of mathematical standards.

2.5 Determination of information features for classification of types of underlying surfaces observed from different angles based on the analysis of inter-frame parameters S_q.

Here, based on the CLF flow with already classified zones of the Earth’s surface by type, it is necessary to determine the space of information features, that is, to find a mathematical model in the form of a statistical equivalent determined from a set of inter-frame parameters of the LD.

To solve the inverse problem, it is necessary to select areas (segments) on the radar with classification using the existing CLF with already classified ones on each frame for subsequent selection of the echo signal from the radar layer of the CLF, corresponding to individual previously classified areas. To do this, segmentation of the radar (clause 2.1) layer of the CLF is implemented while preserving the classification of zones according to the optical layer of the CLF. Next, the separation (division of the total Sig of the registered echo signal, from which the current RF was generated in clauses 1.2 of the scheme) of the echo signal corresponding to individual segments, which in turn correspond to specific types of classified areas (clause 2.2), is carried out.

After the division of the registered echo signal into clusters has been carried out, which correspond to individual segmented zones with the classification of zones of the underlying surface according to the optical layer of the CLF, it is necessary to determine the laws of distribution of these selected individual echo signals corresponding to the segmented areas with classification into specific types of the underlying surface (clause 2.3).

Having calculated the density of the LD, previously separated echo signal from the total received signal for the formation of the radar, it is necessary to determine which LD it belongs to. To do this, it is necessary to evaluate the consistency of the obtained distribution laws (clause 2.3) to determine mathematical standards - statistical equivalents (clause 2.4) for solving the direct classification problem without using OL.

It is also necessary to additionally determine the space of information features (statistical parameters of the LD - mathematical expectation, dispersion, coefficient of variation, etc.) for classifying the underlying surface from different observation angles (clause 2.5) to increase the reliability of recognition of the observed territory in the SSAR.

The following clearly shows the sequence of actions for solving the inverse problem of clauses 2.2-25 for one specific segment (see Fig. 2).

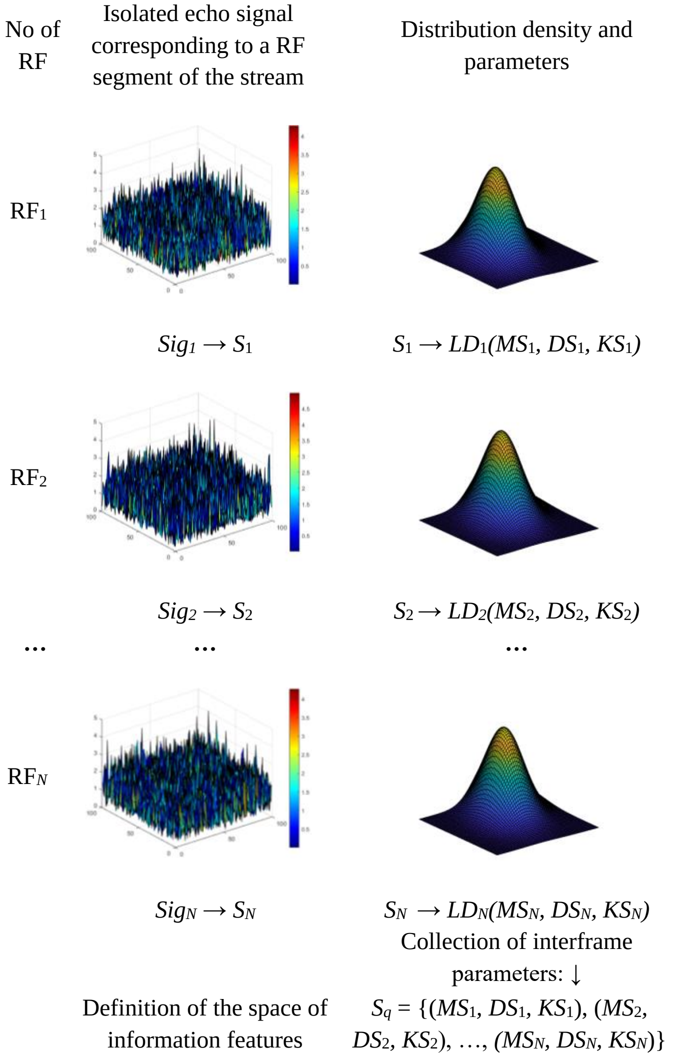

Fig. 2. Scheme for solving the inverse task

Thus, an approach is presented for searching for information signs of statistical equivalents for radar classification of observed territories and constructing corresponding classification maps) based on methods of airborne radar, statistical analysis, segmentation and complex processing of optical location and radar frames of flows.

After the space of information features consistent with experimental data for the classification of territories has been determined. Further, it becomes possible to implement a methodology for constructing a classification map of types of underlying surfaces according to RF without the use of OL CLF, that is, without the use of optical devices that have limitations when operating in difficult weather and seasonal conditions.

III. CONCLUSION

To solve the problem of classifying earth surfaces, MBRs were used. For this purpose, the corresponding parameters of the echo signals of the space of information features were determined, analyzed and generated. A block diagram for determining information features is presented. At the same time, the most informative classification parameters were identified. The selected parameters of echo signals are stable under the influence of various destructive influences on the signal during its propagation.

A methodology for classifying territories on formed radars has been developed. The classification technique is based on a high-speed image segmentation algorithm, on the basis of which the echo signal is separated from individual selected areas of the underlying surface.

The work has developed a classification technique based on certain information characteristics. The exclusion of the optical layer in the classification methodology and the use of purely on-board radar equipment that classifies underlying surfaces makes it possible to classify territories regardless of weather, daily and seasonal conditions. In this case, the reliability of the classification technique depends on the intrinsic fluctuations of the evaluated characteristics of the echo signals.

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