CLASSIFICATION OF THE EARTH'S COVER BY RADAR IMAGES

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Results of investigations into thematic interpretation of orbital images recorded with the SIR–C/X–SAR radar with synthetic aperture in the L- and C-bands for HH, VV, and HV polarization states are given. Problems of recognition of characteristics of forest and agricultural vegetation, erosion processes of soil on the regional scale on the plain and foothill territories of the Altay Krai are examined. Influence of filtration of the speckle noise is studied and images are classified by the kernels in the contrast – mean intensity space. Results of classification have been compared with the ground-based data and orbital scanning and photographic images obtained in the optical range.

INTRODUCTION

Joint examination of orbital images of the Earth's territories in the visual, IR, and radiowave ranges allows one to take full advantage of methods of thematic interpretation as applied to problems of analysis of natural resources.

The methods for orbital data thematic interpretation have been developed at the Altay Subsatellite Experimental Station of the Scientific-Research Institute of Ecological Monitoring at the Altay State University since 1988. In this time experience on interpretation of the Earth's cover images on the regional scale has been gained, large volume of the thematic information has been accumulated on the basis of images obtained in the optical range of spectrum, and the ground-based data base has been compiled. With the advent of images in the radiowave range with the same resolution as in optical range, it becomes possible to compare the optical and microwave images and to use the methods of image interpretation developed for the optical and near-IR spectral ranges to the images recorded by a radar with synthetic aperture (RSA-images) as well as to perform joint interpretation of the data in the optical and microwave ranges.

The aim of this work is the development of procedures for estimation of the state of soil-vegetative cover on the basis of classification of the orbital radar images recorded with the SID–C/X–SAR radar with the synthetic aperture (RSA) and a comparison of the results with the ground-based data, scanner imaging by the MCU–E camera, and photographic images recorded from onboard the RESURS–F1M aerophotographic satellites.

PRELIMINARY INTERPRETATION AND CLASSIFICATION OF RADAR IMAGES

The examined territory is located between the Pre-Altai plane and outskirts of the Kolyvan and Bashchelak mountain ridges of Mountainous Altai. Images were recorded from onboard the SHUTTLE on October 7, 1994, with the SIR–C/X–SAR radar at wavelengths of 23.5 (*L*-band) and 5.6 cm (*C*-band) with a resolution on the Earth's surface of ~10 m. Signals with the HH, HV, and VV polarization states as well as images with full energy of signals were interpreted. Absolute calibration of data was lacking. Preliminary signal processing included its redigitization for the number of intensity gradations $K = 256$. The minimum intensity of the backscattered radar signal from an object was taken as the first gradation. In the examined case, this object was the open even water surface of a lake. The data for the same region obtained with the MCU–E and from onboard the RESURS–F1M as well as the ground-based data were used for comparison.

The first stage of an analysis of radar images was the filtration of speckle noise caused by coherence of the signal forming the RSA image. For its suppression we tested well-known averaging, median, sigma, and Lie filters.[1] The noise was smoothed by subsequent application of the filters to one and the same fragment of radar image (RI). An averaging window had the dimensions 3×3 pixels. Further interpretation showed that the classification quality was highest for the Lie filter.

Most simple and widespread approach to the natural object classification by radar images is the use of only one characteristic – the intensity of scattered signal I that depends on roughness and dielectric properties of objects. In this case, the mean value of this characteristic averaged over the window with dimensions $M \times N$

$$\bar{I} = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} I_{mn}, \qquad (1)$$

was used, where I_{mn} is the intensity of a single pixel.

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In addition, the feasibility of application of the characteristics of statistical texture analysis, which was most close to the visual perception of the object by a person, was analyzed. In the paper, the method of adjacency matrices was used. Elements of these matrices are frequencies with which the pairs of points (one with the brightness i and the other with the brightness j spaced at distance r in the direction θ) are encountered in the image. For the analysis, windows of different dimensions were used, the distance $r = 1$, and $\theta = 0$, 45, 90, and 135° (see Refs. 2 and 3). Adjacency matrices were constructed in the vicinity of each point of the initial image. After the adjacency matrix determination for different θ, the averaging was performed over the angles of the corresponding matrix elements.

Knowledge of the adjacency matrix elements allowed us to proceed to the image texture characteristics. Among them were the contrast C, the entropy E, the degree of homogeneity U, and the inverse moment[2] IM, defined as follows:

$$C = \sum_{i=1}^{K} \sum_{j=1}^{K} (i - j)^2 P_{ij} \text{ is the contrast,}$$

$$E = \sum_{i=1}^{K} \sum_{j=1}^{K} P_{ij} \log P_{ij} \text{ is the entropy,}$$

$$U = \sum_{i=1}^{K} \sum_{j=1}^{K} P_{ij}^2 \text{ is the degree of homogeneity, and}$$

$$IM = \sum_{i=1}^{K} \sum_{j=1}^{K} P_{ij}/(1 + |i - j|) \text{ is the inverse moment.} \quad (2)$$

To compare the efficiency of application of the characteristics and feasibility of the object recognition in the images, several structures were examined among them fields and forest areas with different species of trees for which their texture characteristics were calculated for all states of radiation polarization. Our analysis has shown that for the problem of vegetation classification with the given number of signal digitization levels $K = 256$ it is expedient to select only two characteristics – the contrast and the average intensity level for all states of polarization.

Further image interpretation includes classification based on the description of classes by the kernels in the coordinates C and $\bar{I}$. In so doing the window sizes were varied from 2×2 to 20×20 along with the signal polarization. The problem of recognition was to divide all examined set of points in the space $(C, \bar{I})$ into the comparatively small number (not necessary known *a priori*) of homogeneous, in a definite sense, groups or classes.

For this classification, heuristic algorithms were chosen based directly on the formalization of the problem of the selection of groups of compact points[4] in multidimensional space. They were named heuristic because the notion of the compact group of points cannot be rigorously formalized. These algorithms can be implemented sufficiently simply and have high rates of calculations. This was the deciding factor for their choice. The Forel', Pulsar, and k-mean algorithms[4] were implemented. As the input parameters of classification block, a set of characteristic vectors was applied. As a result of its operation, the points were divided into groups.[5]

CLASSIFICATION RESULTS

The first simplest variant of classification was implemented for only one characteristic – C or $\bar{I}$. The result showed the feasibility of recognition of the forest vegetation from the field one through the LHV channel in this way. However, classification by the mean intensity showed a large spread of classes for agricultural fields. The classification by one characteristic in the CHV channel did not allow us to recognize the forest and field vegetation.

In case of classification by two characteristics, the basic types of the Earth's resources were recognized for all states of polarization in the L-band that had the smooth surface (water and smooth soil without vegetation), scanty vegetation on fields, tracts of forests, and populated places.

The next step comprises the selection of structurally different groups from each class. It was found that the frequency bands have different capabilities. Thus, the L-band can be used to select tracts of forests from low bushes and grass whereas this is impossible in the C-band. In the images recorded in L-bands for the HH and VV polarization states the tracts of coniferous, deciduous, and mixed forests are well recognized. The darkest background in the image corresponds to the coniferous forest (pine trees) and slightly lighter background corresponds to fir and aspen thickets. Still lighter fragments correspond to pine and birch thickets and to tracts of birch. Within the track of forest, open glades can be easily recognized. The same can be distinguished for the cross-polarized component in the L-band. These fragments of the Earth's cover are also well recognized according to classification of scanner photographs of the MCU–E recorded from onboard the Kosmos–1939 satellite and reliably interpreted in panchromatic orbital photographs. All results of interpretation of the orbital images were tested by the data of ground-based expeditions.

A road network is well recognized in all RI, regardless of the wavelength and polarization. Power transmission lines are imaged only on the photographs taken in the L-band for the HV polarization in the form of bright straight-line bands with point-like images of supports. Agricultural fields of cultivated land are more clearly imaged in the L-band for the HV polarization. As a whole, comparative analysis of the

RI recorded at different wavelengths for different polarization states showed the advantage of images obtained in the *L*-band of radiowaves for vegetative cover recognition. The *C*-band turned out to be inapplicable for the selection and recognition of the vegetation type.

CONCLUSIONS

Our investigations gave the following results:

1. The algorithm of filtration of speckle noise for the problem of classification of natural objects by the radar images has been selected. The quality of classification is found to be highest with the use of the Lie filter.

2. Applicability of the texture characteristics to the interpretation of radar images has been investigated. As a result, classification algorithms have been constructed in the space contrast – mean intensity for 256 gradations of the initial image intensity.

3. As a result of classification, forests and fields with different heights of vegetation as well as forests of different types were identified. With the help of the automatic classification only, forests, lakes, populated places, and fields have been recognized. Comparison of output classes with the ground-based data and optical images has been made. Tracts of forests of different types (thickets of pine, birch, fir, and aspen) are reliably interpreted.

4. The program complex that allows one to analyze the radar images and includes the blocks of filtration and classification has been created.

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