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RECOGNITION OF NATURAL OBJECTS ALONG A TRACE OF EARTH'S SURFACE BY SPECTRAL REFLECTANCE CHARACTERISTICS AND PHOTOIMAGES

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ABSTRACT
On the basis of remote sensing data of reflected by natural formations solar radiation in the visible and near infrared (NIR) ranges of the electromagnetic spectrum and accompanying photographic images, there are recognised the classes of objects, which are located along ~ 20 km long trace of the Earth's surface passing through the mountain of Sarnena Sredna Gora. The measurements are made onboard the manned space station 'MIR' with the help of the multichannel spectrometric system 'Spectrum 256' developed in STIL-B.A.S. The spectral reflectance characteristics (SRC) of the natural formations are obtained in the spectral range 450 ÷ 830 nm using the spectrometric system in the 128 spectral channel mode of operation. The SRC are linked to the underlie cover by means of accompanying photo images made with the built in the system photographic camera as well as with additional topographic data. Statistical methods are applied to verify the reliability of the main classes of objects and their subclasses delimited by the spectral methods.

INTRODUCTION

Among the main objectives of remote sensing of Earth from Space in the visible and near infrared (NIR) spectral ranges is to verify the adequacy of the different types of natural formations and their states with the information based upon the reflected by them electromagnetic radiation. Such investigations are of great scientific interest because of providing description of the objects through objective physical characteristics reflecting changes in their physical and chemical, and biological parameters.

To the research related with studies of spectral reflectance characteristics (SRC) of natural objects and phenomena it was assigned a significant part in the Scientific Research Program developed in connection with the flight of the second Bulgarian cosmonaut onboard the manned space station 'MIR'. A number of remote sensing experiments were carried out with the help of the multichannel spectrometric system 'Spectrum 256' developed by scientists and specialists of STIL – BAS and being operated for more than 12 years onboard the orbital station 'MIR' (Mishev, 1988). They were directed mainly to investigation of the various types of natural formations and their states by means of their spectral reflectance characteristics, the dynamics of their colour coordinates, the influence of the conditions in carrying the experiments out (atmospheric conditions, zenith angle of Sun, and others) on the reflection power of the objects, the optical properties, structure and dynamics of Earth's atmosphere (Mishev *et al*., 1989; Mishev *et al*., 1999; Krezhova *et al*., 1998).

The amount of information that is obtained by multichannel spectrometers and scanners mounted on aerospace carriers is increasing continuously but the data accumulated are of practical importance only in case of being quickly and effectively converted into information necessary for decision making or developing a strategy of behaviour. The modern methods, through the machine interpretation of data, ensure completely automated treatment and analysis of data in real time. In the practice a wide range of application and development find the qualitative methods for treatment of aerospace data among which is the method for recognition of natural formations by their spectral reflectance characteristics. The essentials of this method are in relating (classification) the SRC of the studied object to one of the classes of objects determined on the basis of accumulated databases of SCR (Swain and Davis, 1983). Therefore, it is necessary to know in depth the spectral characteristics of the classes of natural formations and the factors that exert influence upon them because they are a basic means of the remote sensing methods for recognition of natural formations on the Earth's surface.

In interpreting images obtained from Space the spatial indications are often very important in identifying the objects but in applying the algorithms for image recognition they are of no so effective use as the spectral indications.

The present paper is aimed to report on results from recognition of natural objects along a land trace of the Earth's surface by means of their SRC and accompanying photo images acquired under space conditions by means of 'Spectrum 256'. A priori information about the reflection power of the main classes of objects accumulated under ground conditions (field and laboratory measurements) in the visible and NIR ranges of the electromagnetic spectrum, and topographic data are used. The efficiency of the used instrumentation and method for carrying out continuous monitoring of natural formations is also shown.

EXPERIMENT AND DATA

In accomplishing the program for remote sensing utilising the system 'Spectrum 256' onboard the manned station 'MIR' there was obtained a large amount of spectral data and linked to them accompanying photo images taken with the built in the system photographic camera operating in automated mode. The measurements with 'Spectrum 256' were carried out through the MIR' station illuminators 'by fixing it by means of a special console. The latter is a mechanical device of circular design with graduated scales (nonius) for reading of the angle of rotation and positioning of the spectrometric system with respect to the illuminator, which allows for three-dimensional orientation of the direction of measurements. By means of the viewfinder of the photo camera the spectrometer is directed to the object selected for observation.

In our present study we used the spectral data accumulated during the passage of the 'MIR' station in one of its orbits above the territory of Bulgaria. The trace of the Earth's surface subjected to spectrometry is with a length of ~420 km in Southwest - Northwest orientation and crosses the towns of Razlog, Pazardzhik, Targovishte, and Tervel. The system 'Spectrum 256' has been operated in an operational mode with 128 spectral channels, each of 3nm halfwidth and spatial resolution 70x170 m at the 'MIR' station altitude of ~300 km.

The data are recorded within he spectral range 450 ÷ 830 nm in digital form (codes of the analogue to digital converter). For each session of recording (of about of 2 minutes duration) in the 128 channel operational mode of the system there is generated a set of data containing 2048 SRCs. In the course of each one of the registration sessions the corresponding dark current is recorded as well.

By applying a specialised program package the recorded spectral data are subjected to a preliminary treatment that includes the extraction of a given number of spectra with the possibility for printing and saving of a particular file, averaging and elimination of the dark current, and radiometric linkage. In the essence of the radiometric linkage is to account for the sensitivity of every one of the spectral channels by means of the calibration factors determined while carrying out the calibration of the system 'Spectrum 256' on absolute scale. After eliminating the dark current followed by performing the radiometric linkage, the real data for the radiance *L* of natural formations is obtained in absolute units [μW/cm^2 sr nm].

The radiance *L* of a particular natural formation at a given wavelength λ, i.e. the flux emitted into a unit solid angle by a non point – like source in a given direction from a unit projected area of this source in the same direction, is dependent of the flux density of incident radiation $E_0(\lambda)$ and the reflection properties of the object $r(\lambda)$ (Mishev, 1985)

$$L(\lambda_i, \theta, \varphi) = f[E_0(\lambda_i, \theta_0, \varphi_0), r(\lambda)], \qquad (1)$$

where: θ_0 и φ_0 – zenith and azimuth angles of Sun, which condition the illumination of the natural formation; λ_i – wavelength; θ, φ - direction of the reflected radiation.

The radiance L recorded by means of the spectrometric block of the system 'Spectrum 256' is determined by (Mishev, 1985)

$$L(\lambda) = \frac{1}{\pi} \sin h \int_{\lambda_{\min}}^{\lambda_{\max}} E_h(\lambda) P_h(\lambda, H) P(H) r(\lambda) R(\lambda) d\lambda, \qquad (2)$$

where: $P(H)$ - atmospheric transfer coefficient in direction to the sensor; $R(\lambda)$ - spectral characteristic of a given channel of the spectrometric system, $r(\lambda)$ - reflection power of the object under study, $E_0(\lambda, \theta_0, \varphi_0)$ - spectral density of the flux of solar radiation incident on the upper borders of the atmosphere; $P_h(\lambda, H)$ - transfer coefficient of the atmosphere at a wavelength λ, dependent of the Sun's height and its corresponding air mass *H.*

By means of a specialised software package the spectral reflectance characteristics in absolute units are subjected to a preliminary analysis. It includes: visualisation of the spectral reflectance characteristics obtained after the radiometric calibration; histogram and 3D analyses; diagrams of the data on channels along the whole measured trace or for particular sections of it.

METHOD AND RESULTS

The recognition of natural formations on the basis of the spectral data and accompanying photo images has been carried out by several steps.

First, on the photo frames representing sectors from earth surface with a size of 25 x 25 km it was determined the location of the river Struma. By using the reference marks printed on each photo frame the line of the spectrally measured trace was laid, and the Struma River has been taken as reference. On a map of Bulgaria drawn to a scale of 1: 500 000 the whole trace subjected to spectrometry was also protracted. On the Bulgarian territory the starting point was chosen at the village of Mikrevo, which is a few kilometres Southwest from the Struma River, and the town of Tervel was taken as the last point. The measurements with the spectrometric system 'Spectrum 256' along this trace have been carried out in the beginning of June and low clouds are observed to obscure some sections of the land trace. Therefore, after reviewing the photo images with taking into account the meteorological conditions along the particular land trace it was selected a section of it situated in the Mountain of Sarnena Sredna Gora. On the topographic map used, the chart K-9-37, 38 drawn to a scale of 1:100 000, the corresponding part of the land trace was protracted. From the photo images and the accurate topographic chart used it was determined the distance of the chosen section (southest with respect to the trace, at 1km far from the village of Ivan Vazovo and 157, 5 km far from the Struma River.

The topographic symbols on charts K–9-37,38 (A, B, C, D) drawn to a scale of 1:50 000 define the types of objects spread on this part 20.8 km long of the trace to be pieces of land with gardens planted with fruit trees, meadows, arable lands (fields), and forests of broad-leaved trees.

After reviewing the spectral data and their spatial link to the photo images the spectral characteristics corresponding to the Struma River was identified on the basis of the typical features of spectral reflectance characteristics of watery objects. (Cracknel, 1984).

The next step is by the spectral reflectance characteristics to carry out the recognition the objects specified from the topographic data to be located along the studied section of the trace. On the basis of SRC features the whole set of SRC data was decomposed into subsets. Then, the types of objects determined from SRC and topographic data were linked one to another with taking into account the spatial resolution of 'Spectrum 256' (one SRC corresponds to 170 m of land trace) and the photo images (one SRC per 1,1 mm of the photo frame).

Using the spectral data there were delimited three regions of Sredna Gora Mountain occupied with deciduous forests. Their distance with respect to the starting point of the studied section (Ivan Vazovo village), the number of corresponding SRC, and the change in altitude within the boundaries of one region, are presented in Table 1. The averaged SRC of these sets of data are shown in Figure 1.

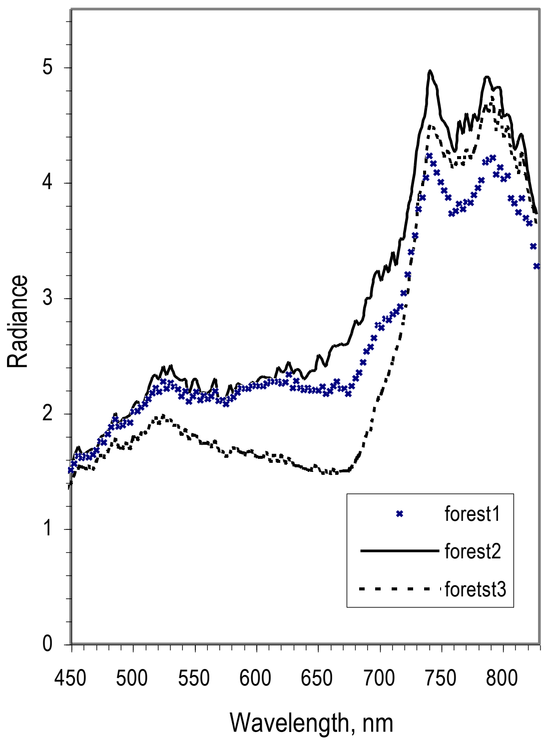

Figure 1. Averaged SRC of the three forest canopies

More substantial differences of the three types of spectral reflectance characteristics are observed in the NIR spectral range (741 ÷ 820 nm) wherein the reflection power of green vegetation is the highest and in the region of about 650 nm (maximum absorption of solar radiation. They are reasoned by the diversity of types of broad-leaves trees falling within one pixel, the possibility of presence of a mixed spectral class in one pixel, and difference in altitude.

By spectrometric data there were delimited also four sectors of arable land located as follows. The first one of 1,5 km in length is in the beginning of the section of the land race, in the region of Ivan Vazovo. The second sector with a length of 1.2 km is at a distance of about 2.4 km far from the starting point, and the third and fourth ones are located at a distance of 4,2 km and 12.3 km and are 2 km and 1.9 km long, respectively. Figure 2 shows the averaged SRC of these sectors of land. There are observed strongly pronounced differences in the values of SRC mainly in the visible range of the spectrum (450 ÷ 700 nm). This is due to the diversity of cultures grown and presence of mixed spectral classes within the boundaries of one pixel.

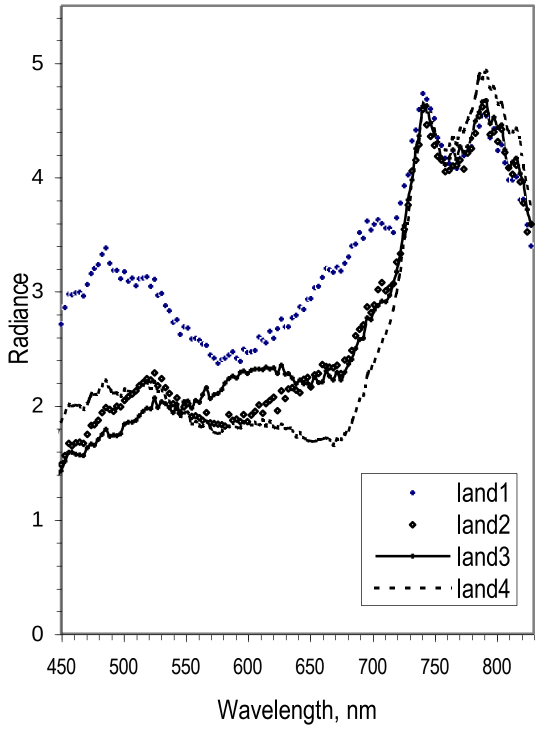

Figure 2. Averaged SRC of the four fields

Based on their spectral reflectance characteristics in these sectors of land there were delimited by several types of sub-regions with different green plantations. In Figure 3 are displayed the averaged spectral reflectance characteristics of the subclasses of objects, which form the averaged SRC of the first sector of arable lands. The course of SRC indicates the presence of two mixed spectral classes (subclass 1 and subclass 2). The SRC of the latter are significantly different from the typical spectral characteristics of green vegetation in the spectral range studied.

In the process of recognition of natural formations it was established the presence of another two classes of objects. The first one is orchards and occupies a sector with a length of 900 m, which is located at a distance of 1.6 km far from the Ivan Vazovo village. The other one is meadows (1.5 km long along the trace) at a distance of 5 km from the village. Figure 4 shows that the spectral reflectance of meadows is smaller throughout the whole spectral range studied.

Table 1. Distance, height above sea level, and ordinal number of SRC of the three forest canopies

Object	Distance, km		Height above sea level, m		SRC, №	
	from	to	from	to	from	to
Forest 1	3.6	4.30	300	320	946	949
Forest 2	7.6	11.3	423.7	495.4	970	995
Forest 3	14.3	20.8	466	654	1008	1045

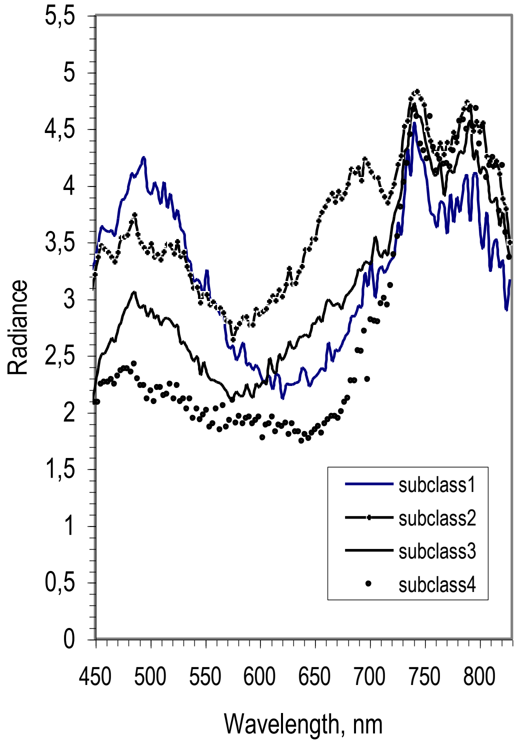

Figure 3. Averaged SRC of the subclasses of arable land 1

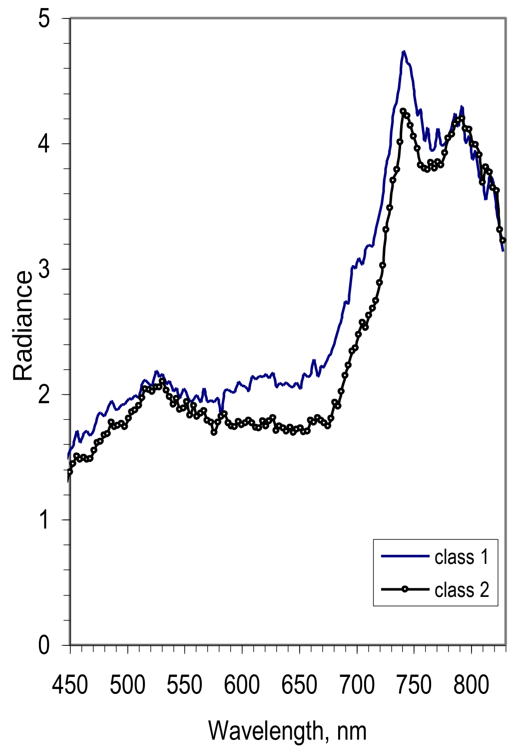

Figure 4. Averaged SRC of the two pieces of land – orchards (class 1) and meadows (class 2)

To confirm the likeness or unlikeness of the types and subclasses of objects determined by SRC it was applied a cluster analysis of the spectral data for the characteristic wavelengths λ_1 = 525 nm and λ_2 = 744 nm at which SRC reaches its maximum in the visible and near-infrared spectral regions, respectively. Figure 5 illustrates the results for the distribution of the reflection power at λ_1 with respect to the reflection power at λ_2 for the three broad-leaves forests. The spectral data of the three broad-leaves forest canopies are distinctly grouped into three clearly pronounced clusters.

The results presented show that the multichannel spectrometric system 'Spectrum 256' and the method developed and implemented for recognition of natural objects by spectral data, photo images and additional topographic data allow for the operative monitoring of natural formations by spectral indications.

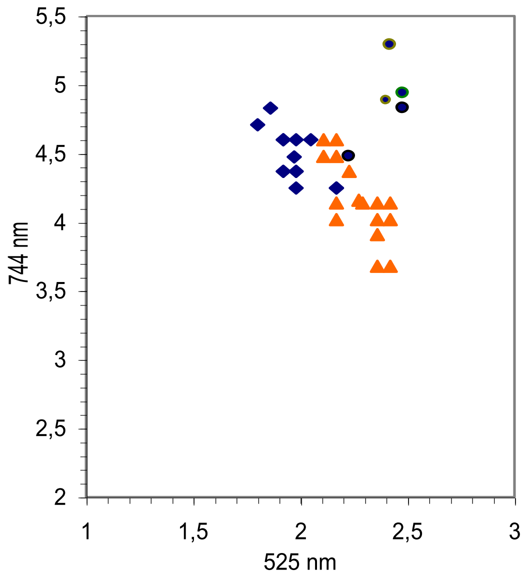

Figure 5. Cluster analysis of the SRC of 3 deciduous forests

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