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MONITORING OF FOREST FIRES USING SATELLITE IMAGES WITH MEDIUM SPATIAL RESOLUTION (THE EXAMPLE OF ARIZONA, USA)

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Statement of the problem and analysis of recent research and publications relating to resolve problem

Forest fires are the second global factor in the destruction of forest areas, after cutting. Despite the consistent prevention work, aimed at protecting forests, thousands of hectares of forestland are annually damaged and destroyed as a result of fires.

Forest fire is the spontaneous spread of fire within the forest fund. The object of burning in the forest is forest combustible materials with spatial structure and characteristic vertical layers: underlayment in thickness of 2 - 5 cm; moss, lichens and fallen leaves in thickness of 6 - 8 cm; herbaceous plants; bushes up to 2 m; a set of young trees (growth) up to 6 m; a set of adult trees higher than 6 m. Combustibility of forest materials depends on such factors as time of year, time of day, weather conditions. The composition of each layer depends on the soil-climatic conditions in the region. [10]

The fire danger of forest areas is estimated taking into account the specific parameters of the forest: the type of forest, type of woodland, age, completeness, closeness of crowns, etc. Fire danger is influenced by the clutter of the forest massif. Together with the presence of bushes, growths and low-down branches of trees, this leads to the burning of other layers of forest during the burning of the surface layer and the occurrence of fire at the crowns of the trees. Under favorable conditions, the speed of spread in the vertical direction is 6-10 times higher than the horizontal. [10]

The average value of the fire load in the forests over large forest fires varies in the range of 5 - 10 kg/m^2. In conditions of dry and prolonged weather and high temperatures, the surface layer dries up and reaches a critical humidity level at which the spread of combustion is carried out. [10]

Weather is a factor that promotes or prevents occurrence and spread of fire. Frequent rains, rainy weather prevent forest fires and vice versa, after prolonged heat in the absence of rain, summer thunderstorms may be the cause of a fire. Blizzards to the ground in the presence of dry grass or dry wind cause fire. Especially dangerous are so-called "dry thunderstorms", during which discharges of atmospheric electricity between the clouds and the earth are not accompanied by the fall of the rain. The occurrence of fires is largely due to drought, which can be considered as a complex of atmospheric processes, when precipitation for more than 20 days is no more than 30% of the average monthly norm for the forest district. Warm autumn and cold winter with little snow, and in summer there is a high temperature, critically low relative humidity, the presence of moderate or strong winds and low rainfall precede the season with an increased risk of forest fire. [8]

Monitoring of forest fire is a system of monitoring and control of fire danger in forest, weather conditions, the state of forest combustible materials, sources of fire and forest fires with the purpose of timely development and taking action for preventing forest fires and reduce losses from them. [1]

There are some ways to monitor forest fires:

- satellite monitoring - observing the development of forest fires by satellite images, detecting large fires by analyzing satellite data, predicting the occurrence of forest fires in a certain area;
- aviation monitoring - review of forest areas, detection of fires with aviation;
- terrestrial monitoring - land-based detection of fires. [12, 14]

Remote sensing data is an important source for obtaining thematic information about types of land use and terrestrial cover at various scale levels. The process of obtaining thematic information according to the data of remote sensing with the use of automated methods for processing them is called the automatic thematic classification. [7, 15]

In remote sensing are used two mathematical models of classification of objects: the method of uncontrolled classification, which is based on a special mathematical instrument of multivariate analysis of data - cluster analysis, and a controlled classification method based on statistical characteristics. [4, 9]

An uncontrolled classification consists in the distribution of all pixels of the image in relatively homogeneous classes, based only on the proximity of their spectral characteristics in a multidimensional space of spectral features.

A controlled classification involves assigning a pixel of the image to a known class of objects to which corresponds pre-determined spectral image in a multidimensional space of spectral features. To obtain this spectral image, reference areas of the image (standards) are used, which represent certain thematic classes. The pixel values of the standards are used as

training samples for setting up the recognition algorithm. In the process of recognition, each pixel of a picture is consistently compared with the standards and refers to this or that class. [7, 11]

Standards are determined from field observation data, which ideally should be carried out on the day of surveying. If this is not possible, then surveying and field observations must be carried out on the same time of year. In addition, sources for selecting the standards may be thematic maps, images of higher resolution, reporting materials, etc. Standards determine the quality of the training sample and, as a consequence, the accuracy of the controlled classification. [6]

Presentation of main material and research results

Technological scheme of research. The task of the reserch is to determine the areas of damaged vegetation due to forest fires on the basis of satellite images with the medium spatial resolution using methods of uncontrolled and controlled classifications. The technological scheme of research is given in fig. 1.

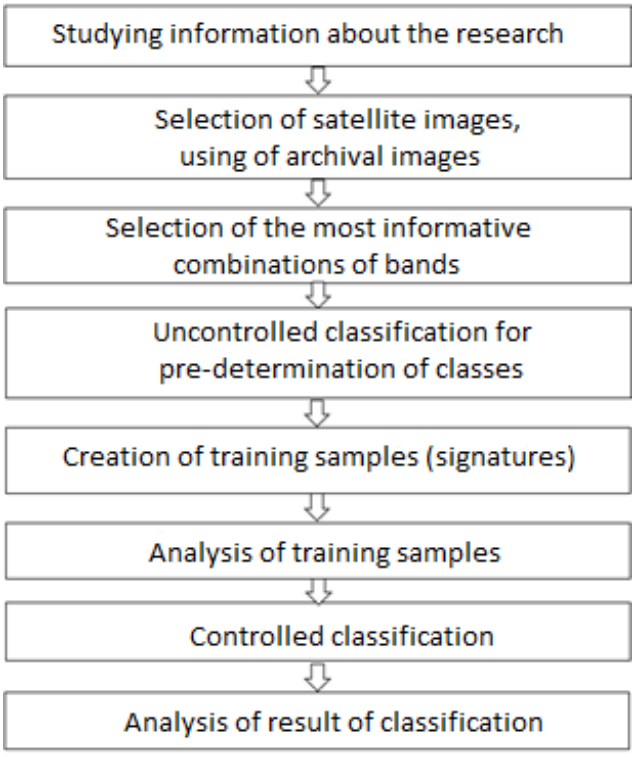


Fig. 1. Technological scheme of research

Input data. The input data for this research were three pairs of satellite images obtained by optoelectronic cameras from satellites: Landsat-5 (May 30, 2011, June 15, 2011), Landsat-7 (June 7, 2011) for the forest area in Arizona State (USA). Satellite systems Landsat 5 and Landsat 7 provide images in seven and eight spectral bands. The resolution of the Landsat 7 is 30 m in spectral bands and 15 m in panchromatic band, Landsat 5 - 30 m in spectral bands. Images were uploaded from the USGS site in system WGS_1984_UTM_Zone_12N.

Pre-processing. Previous processing of image involves the synthesis of spectral bands in such a way as to obtain the most qualitative information about the research object.

For the creation of one existing set of raster data in the ArcGIS 10.4.1 software environment, the Mosaik tool was used (fig. 2).

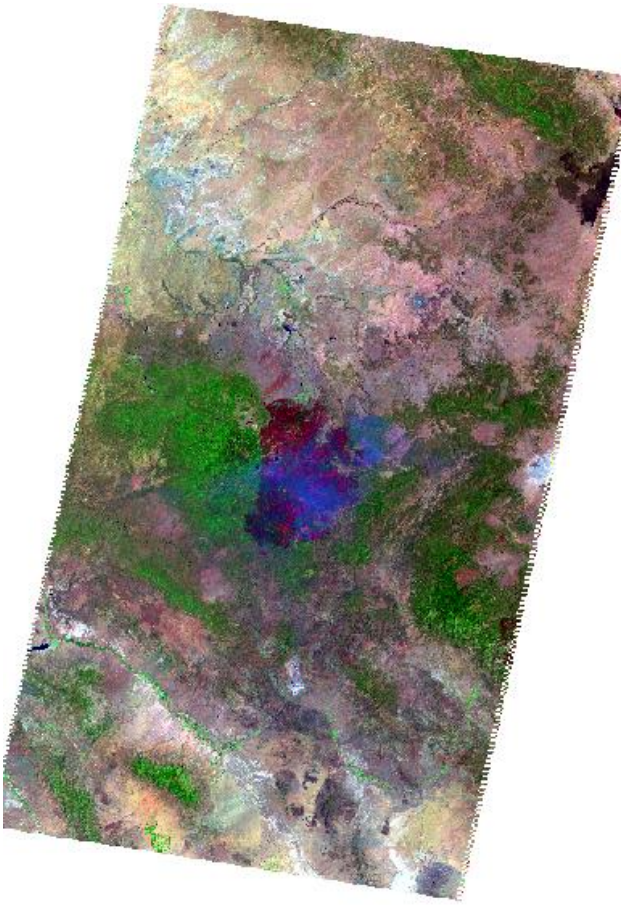


Fig. 2. The result of using "the Mosaik tool" to a pair of images taken from Landsat 5 (June 15, 2011)

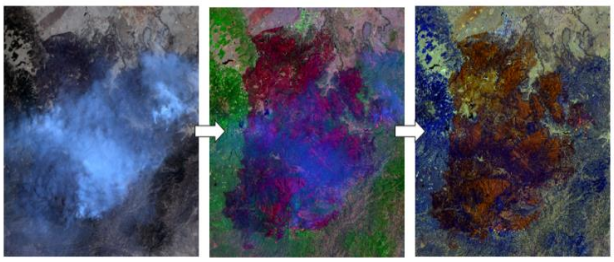
The correct combination of spectral bands has a great importance for synthesis. After all, the maximum contrast between the burned area and the undamaged surface is main in interpreting the change of forest cover, as a result of forest fires.

The combination of 7-4-2 bands (fig. 3) allows to interpret state and types of vegetation in the image, as well as analyze state of the atmosphere and smoke. However, the presence of smoke in the image is an undesirable phenomenon in the application of controlled classification.

Therefore, it is expedient to use a combination of 7-5-4 bands (fig. 4), which does not include any bands from the visible range. This combination of bands allows completely remove the smoke in the image, making it more informative.

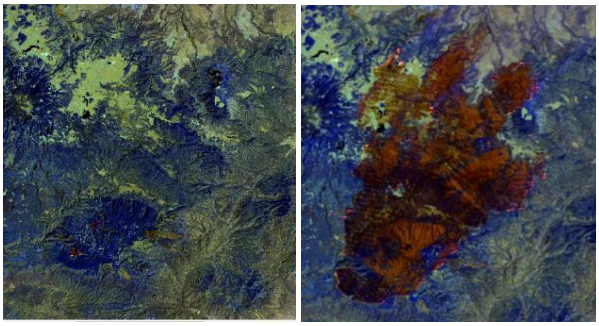
The visual decryption of the images was carried out and the following basic classes were determined: burned

vegetation, damaged and healthy vegetation, damaged and undamaged area, places of active burning.

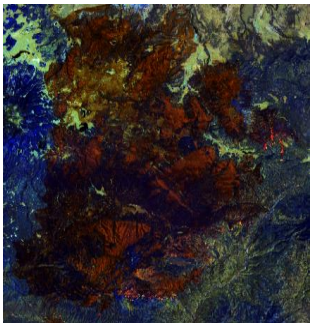


a *b* *c*

Fig. 3. Analysis of the results of synthesizing images from Landsat 5 (June, 15, 2011):
a - 3-2-1; b - 7-4-2; c - 7-5-4



a *b*



c

Fig. 4. Synthesized images for the territory of research with a combination of bands 7-5-4:
a - Landsat 5- 30.05.11;
b - Landsat 7 - 07/06/11; c - Landsat 5 - 15/06/11

Uncontrolled classification. To create a thematically defined set of classes, an uncontrolled classification is used. Important in the method of uncontrolled classification are boundary procedures, which determine the number of classes, the criteria for assigning the pixel to a particular class, and also specify the number of iterations. [16]

An uncontrolled classification by ISODATA algorithm is based on the use of the formula of minimum spectral distances [3]:

$$SD_{xyl} = \sqrt{\sum_{l=1}^{L}(\mu_{li} - X_{xyl})^2} \qquad (1)$$

where L – quantity of band ;

l – number of band;

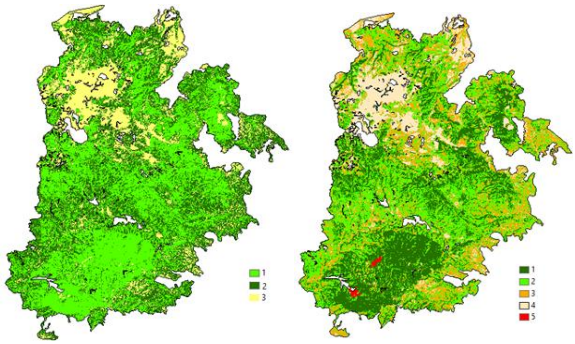
μ_{li} – average value of class i in band l;

i – number of class;

X_{xyl} – value of pixel for band l;

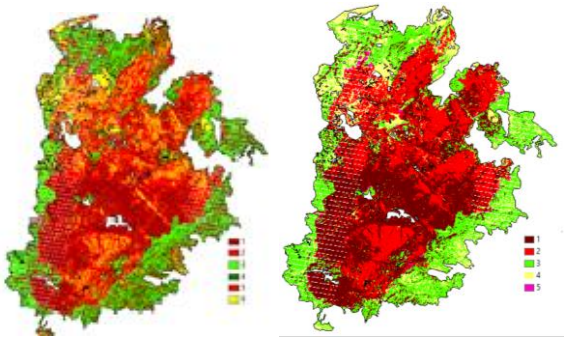
SD_{xyl} – spectral distance of the pixel at the point with coordinate x, y.

The process of classification was carried out in several stages - iterations. The results of uncontrolled classification are shown on fig. 5, 6 and 7.



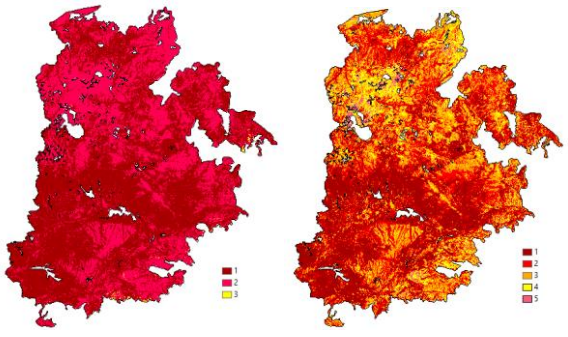
a *b*

Fig. 5. Classified satellite image from satellite Landsat 5 (May 30, 2011) with division into:
a - 3 classes; B - 5 classes



a *b*

Fig. 6. Classified satellite image from satellite Landsat 7 (07.06.2011) with division into:
a –5 classes; b –6 classes



a *b*

Fig. 7. Classified satellite image from satellite Landsat 5 (30.05.2011) with division into:
a – 3 classes; b – 5 classes

According to the results of the uncontrolled classification, the optimal number of classes for each image is determined by the visual method, namely: 4 classes for image from satellite Landsat-5 (30.05.2011),

six classes for image from satellite Landsat-7 (07.06.2011) and 5 classes for image from the satellite Landsat-5 (15.06.2011).

Controlled classification. Based on the results of an uncontrolled classification, we create training samples for conducting controlled classification. Formation of training samples is an important stage in the controlled classification. [4, 13] For better identification of objects in reserach area, a satellite image downloaded from the virtual software SAS.Planet was used. The spatial resolution of this image is 5 m. A polygonal method for adding standards to the training samples was used (fig. 8).

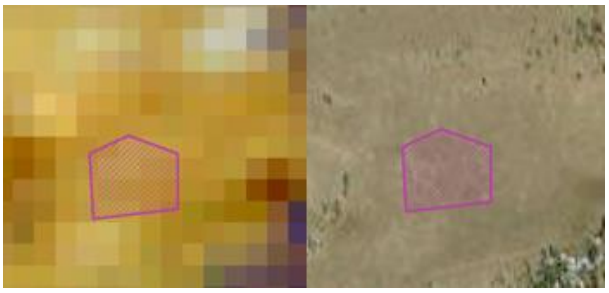


Fig. 8. The process of forming a training sample in ArcGIS

According to the results of researchs [2, 12], the most accurate results for the classification of forests are obtained using the method of maximum probability. The method of maximum probability is based on the probability of the relation of a particular pixel to a certain class. The basic equation assumes that these probabilities are the same for all classes and have a normal law of distribution of data. It is possible to take into account the different probability for all classes through the introduction of the so-called weight factor. This variant of method of maximum probability is known as the Bayes method [3]. However, if there is no a priori knowledge of probability, there is no need to indicate a weight factor. In this case, for all classes, it is equal to 1.0 in the base equation.

The equation for classification by method of maximum probability has the next form [3]:

$$D = \ln(a_m) - [0.5 \ln(|K_m|)] - \\ -[0.5(X - M_m)^T (K_m^{-1})(X - M_m)] \qquad (2)$$

where

D – weight distance (probability);

a_m - percentage of the probability of belonging the classified pixel to the class m (equal to 1.0 or entered on the basis of a priori data);

$|K_m|$ - determinant of the matrix Km.

The pixel belongs to the class m, if the calculated D for it is minimal.

Results of classification by method of maximum probability are given in fig. 9, 10 and 11.

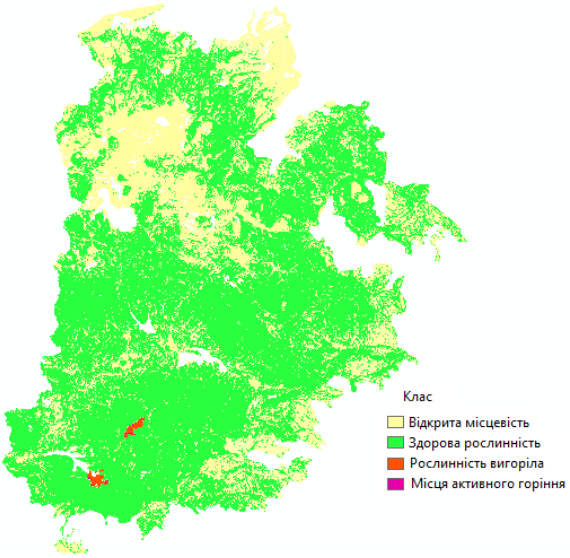


Fig. 9. Classified satellite image from satellite Landsat 5 (30.05.2011) with division into 4 classes

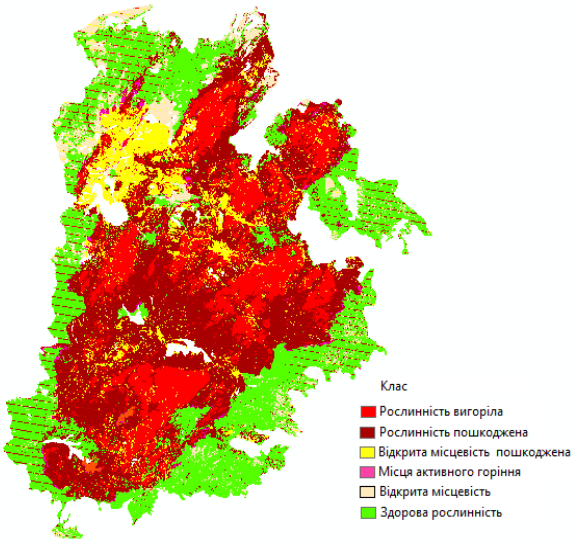


Fig. 10. Classified satellite image from satellite Landsat 7 (07.06.2011) with division into 6 classes

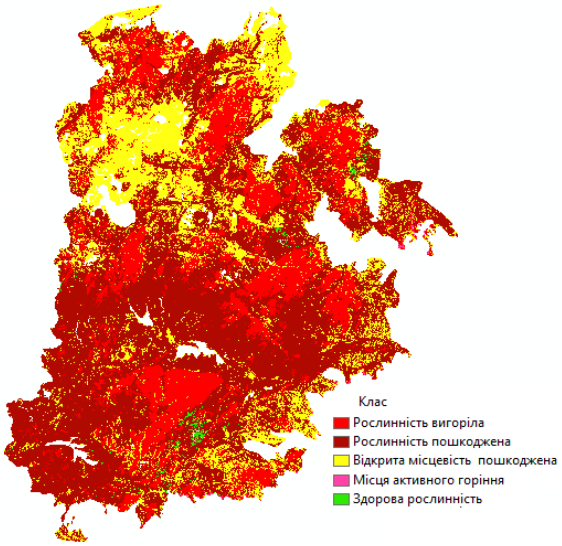


Fig. 11. Classified satellite image from satellite Landsat 5 (15.06.2011) with division into 5 classes

As a result of classification of images, the following classes were obtained :

1) Landsat-5 (30.05.2011) with division into 4 classes: burned and healthy vegetation, undamaged area and places of active burning;

2) Landsat-7 (07.06.2011) with division into 6 classes: burned vegetation, damaged and healthy vegetation, damaged and undamaged area, places of active burning;

3) Landsat-5 (15.06.2011) with division into 5 classes: burned vegetation, damaged and healty vegetation, damaged area, places of active burning.

Tables 1, 2, 3 show the calculated area of determined classes.

Table 1

Areas, calculated on the basis of controlled classification

Class	Area (km²)
Burned vegetation	4
Healthy vegetation	1497
Undamaged area	407
Places of active burning	1
Total	**1909**
Area of fire	**4,43**

Table 2

Areas, calculated on the basis of controlled classification

Class	Area (km²)
Burned vegetation	350
Damaged vegetation	649
Damaged area	151
Undamaged area	126
Places of active burning	14
Healthy vegetation	549
Total	**1839**
Area of fire	**1164**

Table 3

Areas, calculated on the basis of controlled classification

Class	Area (km²)
Burned vegetation	444
Damaged vegetation	1010
Damaged area	444
Healthy vegetation	8
Places of active burning	2
Total	**1908**
Area of fire	**1900**

Table 4 shows area of fire and its changes that occurred for the period 30.05. - 15.06.2011.

Table 4

Areas of fire in different time

Date	Area of forest fire (km^2)
30.05.2011	4
07.06.2011	1164
15.06.2011	1900

The average squared error of the area determination is calculated by the formula [3] :

$$m_S = m_t\sqrt{S}\sqrt{\frac{1+K^2}{2K}} \qquad (3)$$

$$m_t = m_x\sqrt{2} \qquad (4)$$

where

m_t – average squared error of distance determination;

K – number of turning points.

The average squared error of the area is 0.74%. According to the national report of the Interagency and Coordination Center of the United States, area covered by the fire is 1969 km^2.

Consequently, the results of the study suggest that it can be possible to identify forest fires, determine the time of fires and determine their area by satellite images with medium spatial resolution.

Conclusions

1. It is established that the use of satellite images with medium spatial resolution is an effective approach to monitoring forest fires.
2. It is important to select bands to exclude smoke. The combination of the seventh, fifth and fourth bands of the image is determined as optimal for identifying the objects.
3. An uncontrolled classification using the ISODATA algorithm was used to determine the optimal number of classes.
4. A controlled classification was applied for the specified classes by the method of maximum probability.
5. According to the classification, the area covered by a forest fire is 1900 km^2.
6. An average squared error of the determination of area based on satellite images is determined to be 0.74%.

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Monitoring of forest fires using satellite images with medium spatial resolution (the example of Arizona, USA)

A study of forest fires in Arizona, USA with using satellite images was conducted. Images taken from satellites Landsat 5 (May 30, 2011, June 15, 2011) and Landsat 7 (June 7, 2011) for the selected forest area in Arizona were used. Methods of unsupervised and supervised classification are used to determine the area of the fire and its changes for the period May, 30 - June 15, 2011.