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ADVANCED THEMATIC MAPPING APPROACH FOR FORECASTING LANDSCAPE CHANGE USING GIS

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1. INTRODUCTION

Recently application of data obtained by remote sensing (RS) methods is becoming more intensive. New opportunities of RS data application for solving problems of efficient natural resources management appear. It is connected with decrease of RS data cost alongside with improvement of spatial, spectral and temporal resolution of RS sensors. Moreover, owing to intensive use of RS systems last years large amount of time series RS image data obtained for the same land area has been acquired. These images can be applied for solving problems of forecasting natural and anthropogenic ecosystems changes.

Efficient solving of forecasting problems becomes possible with joint application of landscape thematic mapping technologies making use of aerospace imagery, modern geographical information systems (GIS) providing advanced means for spatial information storing and analyses as well as automated forecasting and decision making support facilities.

In the paper the new software package providing facilities of forecasting landscape ecosystem changes with use of time series aerospace images is considered. The software package is implemented as an additional component (forecast subsystem - FS) for the self-organizing vector-raster GIS (SOVR GIS) developed in Tomsk Polytechnic University [1]. The SOVR GIS supports functions of automated interpretation of time series aerospace images and landscape thematic mapping by means of the adaptive classification procedure (ACP). The produced thematic maps are further used for automated generation of forecast maps indicated landscape features changes. Forecasting map design is implemented by FS which employs several forecasting models, based on Markov chains, regression analysis and neural network analysis [2]. These advanced forecast facilities allow to choose the best model and provide efficient decision-making support based upon the forecast results. Moreover in the paper the results of SOVR GIS and FS application are discussed. The application example shows the forecasting results, obtained with use of satellite RESURS-O1 time series images of Uymon steppe area (Altay Region, Russia).

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2. BASIC METHODOLOGY OF FORECASTING LANDSCAPE CHANGE IN SOVR GIS

The general functional scheme of the forecast procedure using time series aerospace images, high-performance ACP and several forecast models is shown in fig.1.

Several time series images, acquired for the interested area with certain time intervals, are classified by means of the ACP. Then the produced thematic maps, corresponding to initial aerospace images are processed with the FS. In the FS the most efficient forecast model is selected and the forecast is made resulting in a new thematic map for the step tn + 1. In case when a longer term forecast is necessary, the designed thematic map is put to the input of the FS (fig. 1). Thus, the forecasting map for the step tn + 2 is produced and so on. The forecast results indicated in the designed forecasting maps jointly with other well-known GIS facilities can be used for efficient decision making. For instance the forecast results can be applied for detecting a tendency of change of a landscape class square.

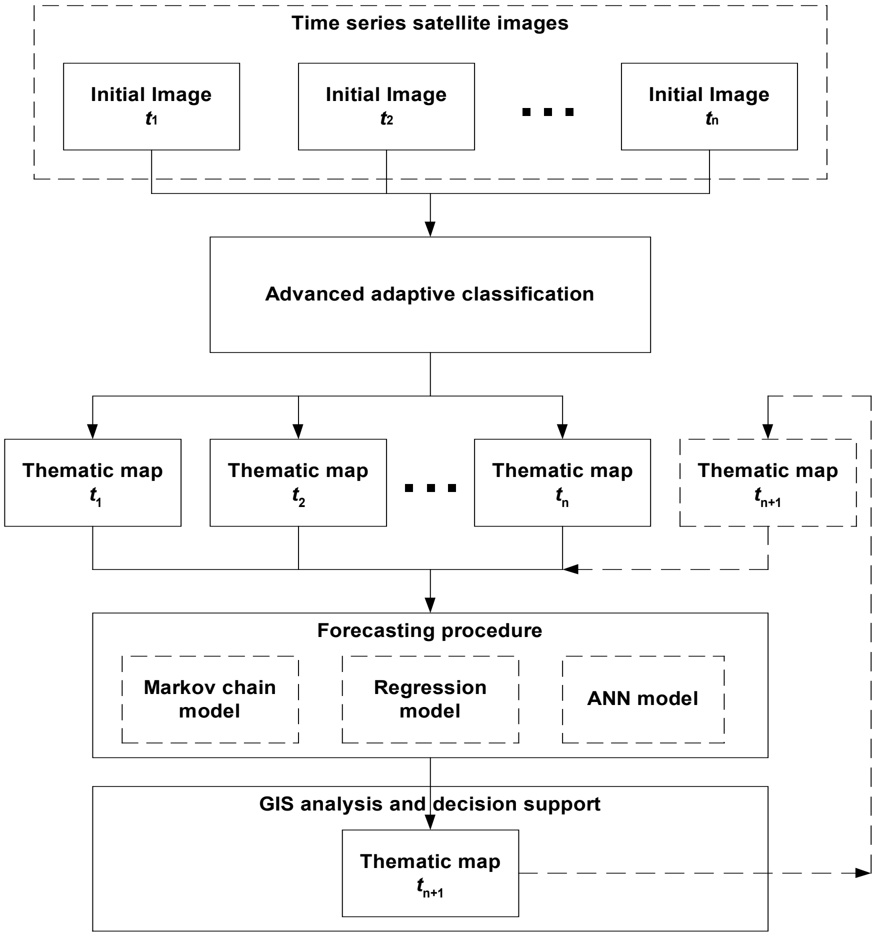


Fig. 1 Functional scheme of forecast map production.

Further let us consider the basic functions performed by the SOVR GIS for aerospace imagery interpretation and landscape thematic map design.

Designing Advanced Thematic Maps

As it has been mentioned above, in the FS for time series image analysis and forecasting a set of landscape thematic maps designed by means of ACP is used. The ACP employs an iterative imagery classification scheme with extended feature space and adaptive decision rule, what allows to overcome the limitations of traditional pixel-wise spectral classification techniques. Employing traditional pixel-wise techniques in spectral feature space (SFS) while classifying landscape features with unstable spectral "signature" is usually inefficient and may produce noisy classification results. The presence of the noise in the classification results is due to high degree of pixels confusion between pairs of different classes caused by their insufficient separability in SFS. As a rule the insufficient pairwise separability of the classes can arise due to insufficient number of informative features used for the classification. The problem can be solved through extending SFS with the complementary informative features. In the ACP improvement of the multispectral image feature space is performed by means of using complementary features describing texture of the processed image and making use of the image pixels context properties alongside with the initial spectral features. For quantitative estimation of texture content the ACP employs various descriptors which are calculated in a running window (3x3, 5x5,…, 15x15 etc.) for every pixel of the initial image. These descriptors are relative frequency index, variety index, statistical moments etc.

Statistical moments of different orders can be derived using either one-dimensional frequency histogram or two-dimensional one defined by joint distribution of image element brightness values GLCM (Grey Level Co-occurrence Matrices). The texture descriptors are computed in the running window of 3x3, 5x5,…, 15x15 size for each pixel of initial image forming new information (textural) channels to be used for comprising the extended feature space (EFS).The size of the running window chosen determines which landscape features properties in the image and in which scale the computed texture descriptors to be defined. Thus a bigger window size allows the texture homogeneity properties of the bigger landscape features to be defined clearer, whereas the influence of many pixels in a big window on the texture descriptor value decreases considerably and this may lead to degrading of spatial resolution and quality of the classification results. On the other hand a small window may contain insufficient statistical information to define the landscape features properties adequately.

In order to improve the ACP decision rules computational efficiency after the EFS has been generated the feature selection stage follows. The stage is based upon selecting more significant (informative) features and excluding the rest. In the ACP the feature selection is performed with use of criterion of pairwise separability of all the image classes defined by the corresponding training samples. The pairwise separability is computed as so-called Jeffries-Matusita distance.

The classification stage in ACP is performed with use of several supervised classification algorithms, combined with adaptive decision rule. Traditionally, the most accurate results can be achieved with use of classifiers based on parametric Bayesian decision rule and Gaussian probability density function (PDF) estimations. These classifiers are based on assumption of normal distribution of features in training regions. But if a distribution does not fit the form of Gaussian bell or represents a multimodal case, then the classification results will be inaccurate. In order to overcome the limitation a nonparametric Rosenblatt – Parzen (RP) PDF estimation in Bayesian decision rule can be used. Thus ACP enables alternative usage of two algorithms, corresponding to Bayesian rule with Gaussian PDF estimation and nonparametric Rosenblatt – Parzen PDF estimation. Adaptive rule allows the advantages of these two algorithms to be combined through their alternative using during the classification. For selecting the most efficient classification algorithm (based on parametric or nonparametric PDF estimations) the empirical criteria of classification accuracy and computing complexity are used. The criteria can be estimated by the test data as well as by the training data adopting cross-validation technique.

The time series landscape thematic maps produced with the ACP on the base of initial aerospace images are of better accuracy in comparison with those designed by the traditional classification techniques. This fact is of great value for increasing the accuracy of the forecast to be performed at the further stages.

Designing Forecast Maps

After producing time series thematic maps resulted from time series aerospace images, these thematic maps are used to design a forecast map. The FS implements the following forecast models: the model based on Markov chains, the regression model and the model based on artificial neural networks (ANNs).

While using the model based on Markov chains it is necessary to compute so-called transitions matrix the elements of which represents the probabilities of system's transition from one state to another. In this case the number of columns and rows of the matrix correspond to the number of classes found in the time series images by the ACP, and the matrix elements show the probability of transition from one landscape class to another. The example of a transition matrix element is a probability of change from the vegetation class to the urban class that takes place in a developing city. Thus, having the probabilities of change from each class to all others the forecast map of landscape features change can be obtained.

Another model being applied in the FS is the regression model. This model is based on revealing functional dependencies of the values being explored. Then the revealed functional dependency represented as a rule by a polynomial of second or third degree is used for the extrapolation procedure. In a matrix form the combined equations can be written as follows:

$$N A = Y, \qquad (1)$$

where N — the matrix consisting of coefficients of the parametric equations system; A — the column vector of undefined polynomial coefficients (a0, a1, a2,.., am); Y — the column vector of absolute terms. This equations system can be solved by the use of simple transformation and the technique of least squares.

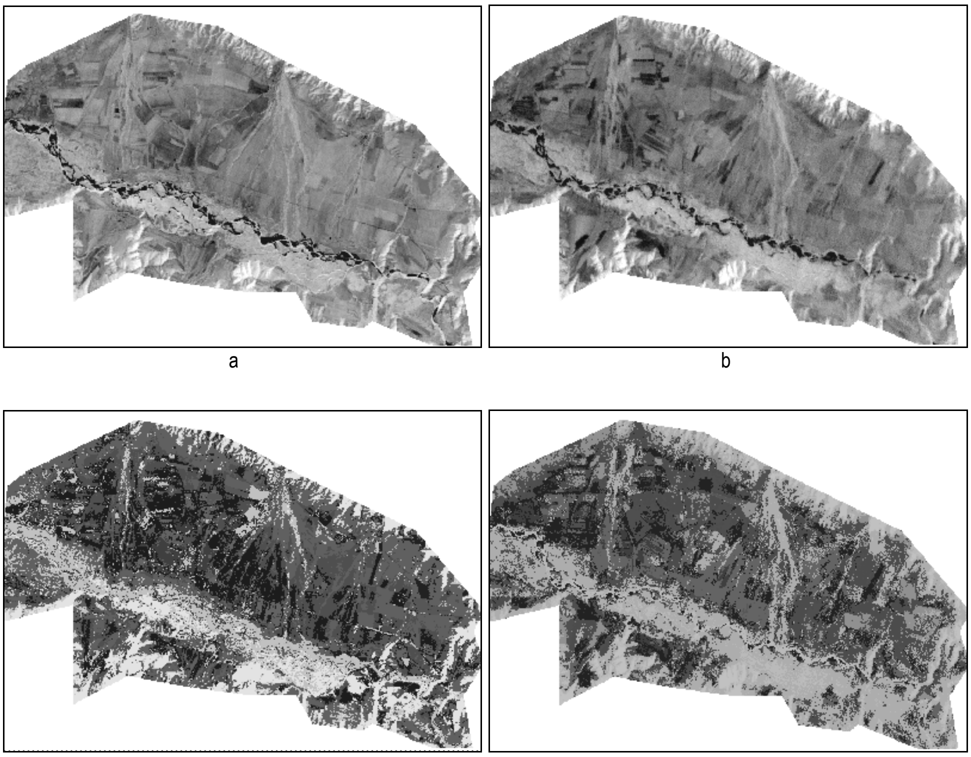
One more model applied in the FS uses ANNs [3], [4]. The base ANN topology used in this case is a multilayer perceptron (MLP). In order to perform the training process of the MLP a modification of back propagation error algorithm performs the updating of synapses weights. The training of MLP is performed as follows. m values of elements (pixels) corresponding to m thematic maps are given to the MLP input. The value corresponding to the element of (m + 1)-th map is given to the MLP output. After that, some kind of "shifting" is performed where the element of (m + 1)-th map is used as the input vector component, and the element of (m + 2)-th map is given to the output etc. Thus the output data will be used as input training data on the next iteration. The use of features of ANN is successfully used for various phenomena prediction that is why while forecasting landscape change the better result in comparison with existing forecast methods can be obtained.

All the forecast models mentioned above have advantages and disadvantages and in various cases provide various accuracy of forecasting. In order to have more accurate results the comparison of all forecast models employed in FS are provided. As a criterion of comparison of the models the criterion of forecast accuracy is used. The forecast accuracy is estimated by truncation of the recent aerospace image from the time series images, which is used for comparison of forecast accuracy by the integral accuracy criterion — Kappa index [5].

3. RESULTS AND DISCUSSION

In order to investigate the efficiency of the developed FS the forecasting of landscape features change situated in Uymon steppe has been performed. The preliminary analysis of time series aerospace images with use of the ground truth data allows to define the different landscape features such as the crops, the undeveloped land, the arable lands, the trees, the vegetation and others. This landscape information has been used for the supervised classification and obtaining the time series thematic maps. In this particular case the forecast on 2001 and 2002 with use of aerospace images of 1998, 1999 and 2000 has been performed. It was mentioned above about the FS feature allows to select the best forecast model. In the investigation for designing a forecast model the aerospace images of 1998, 1999 have been used and for estimating the forecast accuracy the aerospace image of 2000 has been applied. The best forecasting results in the FS in this particularly case were achieved with the model based on Markov chains.

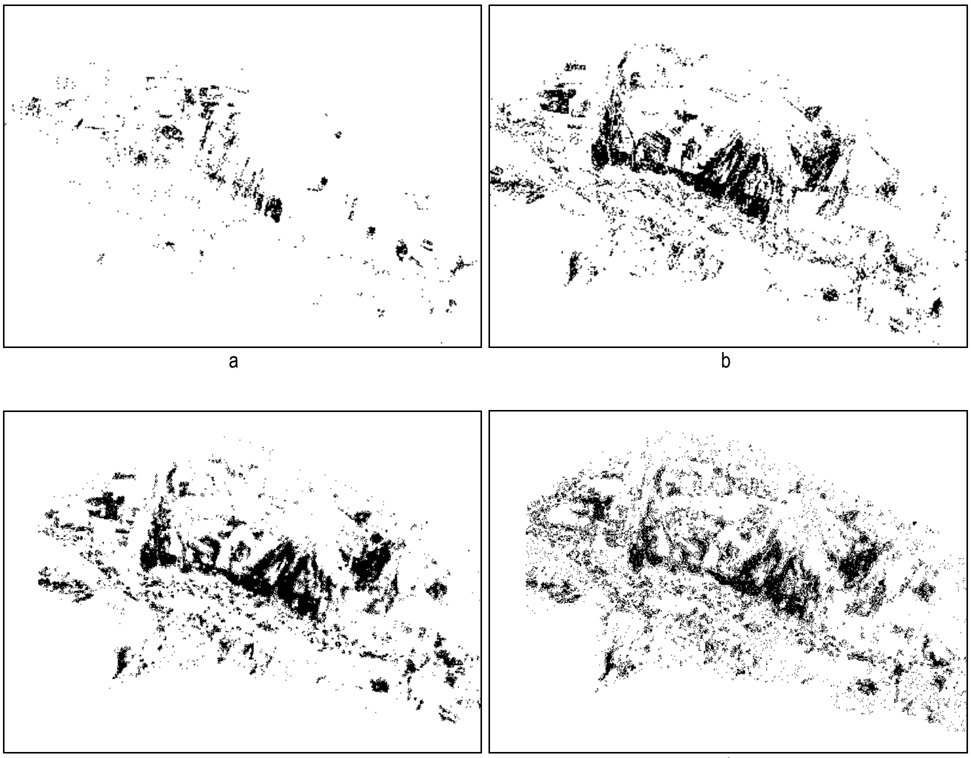
Fig.3 partially shows the forecasting results, which exhibit the dynamic change of the landscape boundaries. With use of the developed means of SOVR GIS for GIS analysis the square values of actual and forecast classes have been computed. In this particularly case the crops square is changing according the following: 11.750 km^2 — 1998, 55.997 km^2 — 1999, forecast on 2001 — 45.185 km^2 and forecast on 2002 — 50.278 km^2. The square of undeveloped earth is decreasing day by day: from 65.478 km^2 — 1998, 50.030 km^2 in 1999, and forecast square on 2001 — 33.538 km^2, 2002 — 31.370 km^2. Forecast results have been verified with ground truth data of Uymon steppe on 2000 and revealed the forecast error about 7%.



a b

c d

Fig. 2 Time series space images a) 1998 b) 1999 and thematic maps based on them c) and d) respectively.



a b c d

Fig. 3 Visual demonstration of dynamic change of crop. Actual information on a) 1998 b) 1999 c) forecasting of crops boundaries and squares on c) 2001 d) 2002.

4. CONCLUSION

Efficient solving of problems of natural resources management is possible with joint application of landscape thematic mapping technologies making use of aerospace imagery modern GIS as well as automated forecasting and decision making support facilities. In order to solve these tasks it is necessary to have the developed means of automate forecast based upon using various forecast models. In the paper the description of the forecasting software system is given which provides the functions of forecasting landscape change using time series aerospace images as well as the results of using the FS as a unit of the SOVR GIS are discussed.
The first forecast results which have been obtained with use of the FS SOVR GIS allow discuss the availability of the proposed approach. However in order to obtain more authentic results it is necessary to make experiments with use of a large amount of time series images.

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