THE SYSTEM FOR AUTOMATED DECIPHERING OF COSMIC EARTH SURFACE PHOTOGRAPHS

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ABSTRACT

The report deals with the problems of object recognition at cosmic high-resolution photographs of the Earth surface for generation and revision of accurate digital terrain maps. The main attention is devoted to automatization of the mentioned processes. The algorithm of visually-analytic (interactive) recognition and the algorithm of automated recognition of topographic objects are presented. The visually-analytic recognition is performed with the help of expert deciphering system by method of sequential object exclusion from the number of possible one for analyzed geographical region. This method uses the image structure analysis, the direct and indirect deciphering features and a priori knowledges. The automated deciphering is realized by the comparison of quantitative characteristics of analyzed image and the set of computer analytic models of object classes. The result of recognition is the selection of the nearest class in terms of some criteria. The described algorithms are performed in the problem-oriented software «SADCO» (System of Automated Deciphering of COsmic photographs). Functional possibilities of SADCO allow to use it for solution of rather wide range of the applied problems: the generation of the new accurate digital terrain maps and the revision of existing ones, the monitoring of environment etc.

1 INTRODUCTION

Topographic object's physical features greatly vary. They have significant variability both during photo survey processing and during image processing. Also the traditionally applied visual deciphering method has insufficient effectiveness and difficulties. These reasons force to develop the additional algorithms and software for automated cosmic photography deciphering. The term «deciphering» for cosmic photo means the process of obtaining information about the object locality and object relation to the set of topographic classes. At present time the creation of high reliable deciphering systems, where all the processes are realized only with the help of technical instruments, is rather problematical. Because of that fact the automated deciphering systems are examined, where only some processing steps (the selection, the recognition, the counting of locality object features) are realized without human participant.

The general technological scheme of the automated deciphering process for Earth surface objects over cosmic photo is described. According to this scheme, the main deciphering steps are: the preliminary image processing, the detection and selection of objects at the image, the calculation of object quality and quantity characteristics and also object direct recognition. The report deals with two methods of object recognition for the Earth surface: the visually-analytic method and the automated method.

The described algorithms are performed in the problem-oriented software «SADCO» (System of Automated Deciphering of COsmic photographs). SADCO is used for solution of such applied problems as the generation of the new accurate digital terrain maps and the revision of existing ones, the monitoring of environment etc.

2 THE GENERAL TECHNOLOGICAL SCHEME OF THE AUTOMATED DECIPHERING PROCESS

2.1 Initial data

The deciphered photo images represent themselves as the material of small scale (from 1:60000 to 1:240000) detail photo survey of the Earth surface objects with the value of maximal resolution 140 mm^{-1} for the prime mire tone contrast ΔD=4.0b. All images are divided into three types: cadre, panoramic and aperture photo. In addition one can use spectra-zone, multi-zone and radio-locating images. The range of the optical density of the materials of black-white photo survey lies from 0.02 till 4.0b. All photo images are accompanied by the parameters of survey, apparatus, photo film and photo-chemical image processing. In addition to the images the cartographic and reference material (geographic and topographic maps of different scales, the descriptions of different objects and their features, geographic coordinates and so on) can be used. They allow obtaining necessary information about deciphering objects of locality and geographic landscape singularities.

The standard photo images of topographic objects are required for the creation of digital deciphering standards. The standard photo image is the image where the topographic object belonging to one or another class is truthfully known. These images must be surveyed with the same scale and almost the same season and climate conditions as the initial one. They also can be accompanied by the additional reference information, including such object features or survey singularities, according to which an image can be related to standard.

The topographic objects at photo image can be visually divided into classes according to geometric, optic (tone) and texture characteristics. The optic characteristics strongly depend on season and time factors, so the photo survey conditions of standards must be as various as possible.

2.2 The technological scheme

The Figure 1 shows the global technology scheme of the deciphering process for the cosmic photographs.

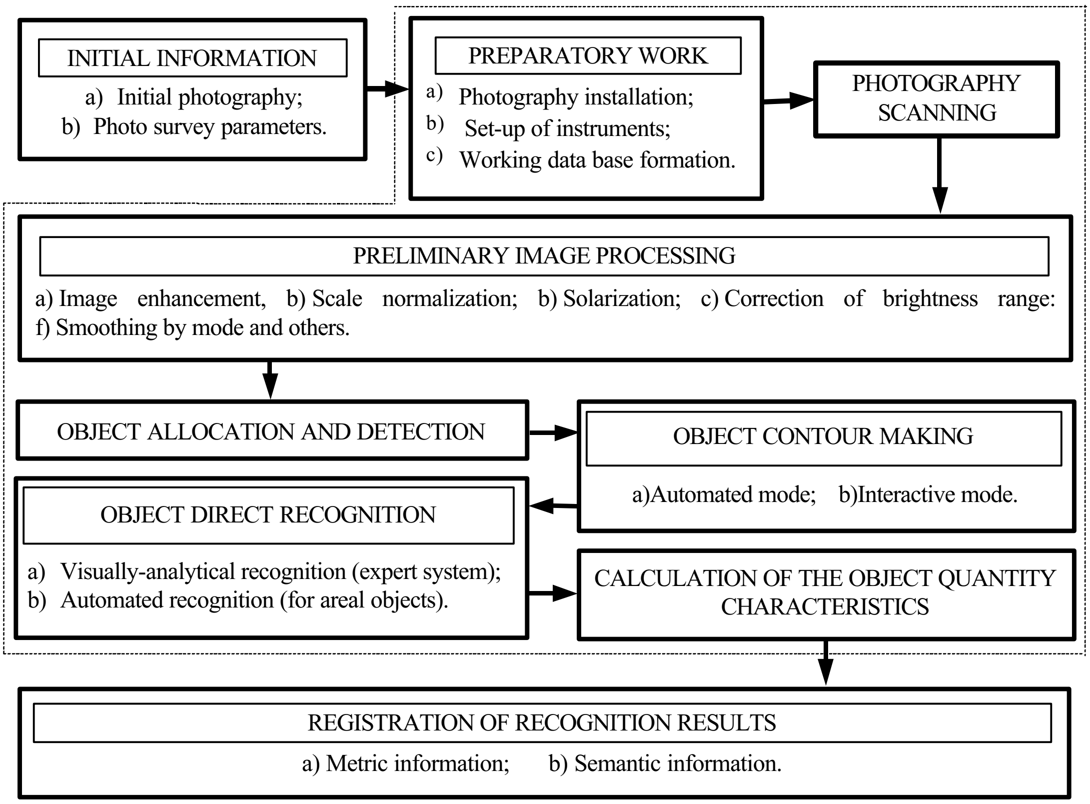

Figure 1. Technological scheme of the cosmic photo deciphering process.

The visually-computer object recognition includes eight main operations.

1. **The preliminary work.** The preliminary step includes the installation, orientation and studying the survey conditions of the initial photographs, the tuning of necessary technical instruments and the creation of working informational data base on analyzing region.
2. **The scanning of the cosmic photography.** The scanning step is about 1 m in locality coordinates. As a result of scanning, the optical density matrix elements represent themselves as byte value in the range from 0 to 255.

3. **The preliminary image processing.** The digital image is scaled to locality image. The scale normalization allows taking into account the influence of height oscillation, slope angle of relief and the type of photo survey system. The image transformation to the map projection and the elimination of geometrical distortion are performed with using the photogrammetric methods. The different mathematical combinations, connecting with optical brightness transformation and spatial image smoothing, are realized for the filtration of different noises and the compensation of looses, caused by nonoptimal scanning parameters. The following algorithms and their combinations are used for preliminary processing: solarization; correction of brightness range

Figure 2. Preliminary processing: the initial cosmic image (left) and the result (right) of image enhancement. The results of experimental test show that the looses of small details for improved image are insignificant in comparison to initial one, and the scale error for digital image is not grater then 2%

(brightness range transformation and histogram equalization); smoothing by average value (by mode, by median). Figure 2 illustrates the example of initial image and the results of preliminary processing.
4. **Object selection and detection.** The necessity in more effective methods of automated image processing reduces to researches in algorithm construction for segmentation (detection and selection), texture analysis and context classification of segmented images. The perspective segmentation algorithms are described in [Berdyshev, Gasilov, Kostousov and others, 1995]. They allow not only to select a separate class, but also to optimize the number of classes at the image.
5. **Object contour making.** The object contour selection is fulfilled both automatically and in interactive mode, for example, when object has complex contour. We have developed algorithms of automatic construction of objects of some types (roads, coastlines, borders of woods and other). The algorithms are based on geometric and textured models of objects.
6. **The direct object recognition.** Two methods of topographic object recognition are described: visually-analytic and automated.
7. **The calculation of quantity characteristics for objects.** The calculation of quantity characteristics of the object contour is realized. The linear sizes (length, width and height) are the most significant quantity characteristics. The photo features, the obtaining conditions and the measurements of object and its shadow length are used as the initial data for the calculation of characteristics. The conditions are placed in initial data file and the measurements are realized for the scanned image at the display screen. The accuracy of quantity characteristics calculation depends on scanning step of the initial image.
8. **The registration of recognition results**. The results of objects recognition are presented in the form of specialized output document. The output document consists of two parts: metrics (the coordinates of attached points and object contours) and semantics (Object type; Object code according CTI; Object features). The initial data for metrics are the files with digital information about contours. The metrics record for the object consists from the sequence of contour point coordinates in coordinate system of initial image. The initial data for semantics are the results of deciphering (object type and quantity characteristics). The object code is selected from the standard Catalog of Topographic Information (CTI).

3 THE METHODS OF OBJECT RECOGNITION

One of the perspective ways to automate the photo deciphering process is to apply an expert deciphering system (EDS) during the recognition of a priori detected and selected topographic object. The process of object recognition with the help of expert system we call the visually-analytic recognition.

3.1 Visually-analytic recognition.

In the foundation of EDS the knowledge base and the block of logical conclusion are taken place. The general EDS scheme is reflected on Figure 3. The knowledge in EDS is subdivided into three types: facts, procedures and control.

Fact knowledge. This knowledge type consists of the information about concrete deciphering situation (the photo survey conditions, the area coordinates, the types objects to decipher and so on). In EDS knowledge base the facts are represented in Data Base of Geographical Literature Reference Material (DB GLRM), Data Base of Topographic Objects (DB TO), Data Base of Standard Images for Topographic Objects (DB SITO).

The DB GLRM includes all information about the climate, topography, economy and so on, connected with different Earth geographical regions. Here are some topographic maps of different scales, tourist plans and schemes, the descriptions of climate and season singularities of the region.

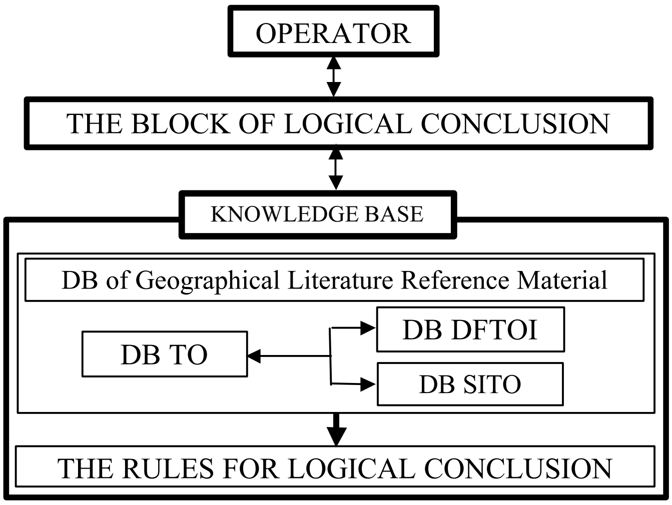

Figure 3. The structure of Expert Deciphering System.

The information about the topographic objects is organized in DB TO in the form of hierarchical data system. In that hierarchy every Earth surface object is corresponded to the object list at consequent lower level. Usually such method of data organization is called a tree [Kandoba, Kukushkin, Safronovitch, 1997]. At Figure 4 the tree fragment for the topographic class of grass vegetation and grounds is illustrated. All topographic objects are subdivided into three main groups: area objects, linear objects and compact objects. According to image scale some of the objects can belong to more than one main class. For example, the launching road depends on photo survey conditions and can be interpreted both as linear and as area topographic objects.

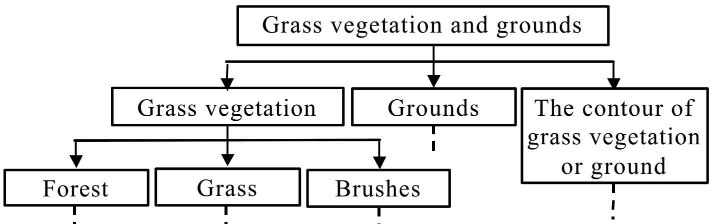

Figure 4. The example of the tree of topographic objects.

The images, where the topographic objects belonging to one or another class is truthfully known, form the information filling of DB SITO. These images can be accompanied by the additional reference information, including object features or survey singularities, according to which an image can be related to standard one.

Procedure knowledge. Procedures are gathered a priory by the specialists in deciphering according to special literature, experience or other sources. Here the region singularities are reflected, and the direct and indirect deciphering features for the main classes of topographic objects are described. The procedures form the kernel of EDS, used in reason block and allow making a conclusion. The main DB to include the procedure knowledge is the Data Base of Deciphering Features of Topographic Objects Images (DB DFTOI). The information in it is the text description of direct and indirect deciphering features of images of topographic objects. It is corresponded to the classes of topographic objects. Every feature is accompanied by special quantitative characteristic called weight, which corresponds to the occur frequency for the analyzed deciphering feature of an object. This weight is taken into account by the system during the process of making the deciphering conclusion. All features are classified according to landscape type, season and photo survey conditions.

Control knowledge. This knowledge type is a set of strategies, allowing to examine the alternative hypothesis and to pass from one strategy to another during the process. The knowledge base also includes the second component of EDS - the block of the rules for logical conclusion.

The block of logical conclusion. This block represents itself as interactive dialogue system, the functions of which are: the construction of deciphering hypothesis and the estimation of deciphering hypothesis.

The process of making the deciphering decision in EDS is realized by two correlative methods: group classification and detail classification. At the preliminary stage the main class of topographic objects is determined (area, linear or compact). After that the filtration of the information from knowledge base is realized, and the information only about the predefine class is remained. The procedures of the hypothesis construction use only filtered information.

The recognition in the case of group classification represents as the motion over object tree from upper levels to lower levels. The final decision can be assumed both at the lowest level of the object hierarchy and at any of the intermediate levels. It is the difference from the case of detail classification, where the hypothesis is formed among the objects, belonging to the lowest tree level. In the case of group classification at every tree level the list of the group object features is shown to the operator. The group feature is the relatively small number of the deciphering features. The group feature makes the global «robust» model of the object. During the process of image analysis, the operator selects the most suitable group feature among the list of group features. The new list of the deciphering hypothesis is formed from the set of topographic objects at the consequent lower tree level corresponding to the group, the feature of which was selected. During the process of construction of such an intermediate decision, the operator is able to look through the standard images of the selected group and to compare it to the analyzed one. He also is able to apply the information from DB GLRM. The situation is possible, when such a motion over the tree reduces to the dead end. In that case, an operator can return to the previous tree level and make a new analysis of the group features of that level objects or can recall the method of detail classification. The latest is recommended also in the cases, when the group features are not sufficiently informative for deciphered image and it is difficult to make intermediate or final decision according to them.

In the case of detail classification the number of possible deciphering features, shown to the operator for analyses is significantly greater. All suitable features for the object form more concrete («detail») model of the object. After the operator selects all the suitable features for analyzed object image, the hypotheses are formed. A priori-defined threshold on summarized weight of the deciphering features is taken into account. Only the hypothesis with summarized feature weight upper than the threshold, form a list of the possible deciphering decisions. This list can become more precise with the help of selection of additional features and by the variation of the threshold value. The hypothesis of the maximal weight is the final deciphering decision. The detail classification is less productive corresponded to group one, but it practically insures the operator from the error in the decision construction.

The described scheme of EDS is realized in the framework of specialized software called «SADCO».

3.2 Automated recognition.

The automated recognition is realized only for area objects and also for objects, which can be easily mathematically formalized. Among the topographic objects the automated recognition is used for the class of grass vegetation and grounds.

The automated recognition includes: the selection of the system of analytic deciphering features and the forming of general analytic models for classes; the calculation of analytic deciphering features at analyzed image; the construction of computer deciphering decision and the registration of the recognition results.

Assume that with the help of segmentation and contour making procedures the fragment was selected, corresponded to the image of object to recognize. The problem of automated deciphering is to determine the object belonging to one of the presented classes of topographic objects by means of comparison of the selected fragment to standard analytical models of classes. The algorithm of automated deciphering is based on local minimization of average distance from the object to the nearest analytical model of the class. The process is organized in two stages.

Stage 1. The forming of the standard analytical models of analyzed object classes. At the first stage the general models for object classes are constructed, corresponding to different photo survey conditions: landscape type, object type, image resolution, season, Sun height, age (for grass vegetation) and so on. For the model creation the standard photo images of topographic objects are required. The standard photo image is the image where the topographic objects belonging to one or another class is truthfully known. These images must be surveyed with the same scale and almost the same season and climate conditions as the analyzed one. They also can be accompanied by the additional reference information, including object features or survey singularities, according to which an image can be related to standard.

Over all standard images the calculation of some quantitative characteristics - the analytic deciphering features (ADF) are realized. These features characterize both tone and structure of the object class. All ADF are independent as such as possible from each other. The standard analytical model for every class is formed from ADF group over object images in the same photo survey conditions. The number of models for one class depends on both nature (age, season and day & night) variability of class objects and photograph resolution (scale).

During the experimental test for the algorithm for automated deciphering, which is realized at the framework of «SADCO» software, the six-dimensional vector of ADF was selected as the standard model for topographic classes. This vector was calculated in the neighborhood with fixed size and was consisted of following characteristics (the tree components from the beginning are the characteristics of tone and the other three - of texture):

- 1 - the mode of distribution histogram for optical brightness;
- 2-3 - the average value of brightness overfall in strings and columns respectively;
- 4-5 - the average series longitude in strings and columns respectively, calculated by formula $M(\mathtt{W})=(\Sigma_{s\,.\,\mathtt{W}}(\Sigma_{f\,.\,s}\, f(i,j)/n_s))/n$, where $\mathtt{W}$ - selected neighborhood, n - the number of observed series, s - series, n_s - the number of pixels in series s, $f(i,j)$ - optical brightness of pixel with (i,j) coordinates with respect to left top angle;
- 6 - the average length of the series with constant brightness.

It is necessary to note, that the neighborhood of selected center and the definition of «constant» brightness and brightness overfall are the algorithm parameters, with the help of which one can construct different standard analytical models of classes.

The advisability of such analytical model selection can be explained, firstly, by the fact that model consists of both tone and structure characteristics, secondly, by indirect information through the ADF features about geometrical form and object sizes and, thirdly, by rather simple mathematical formalizing of the features, what reduces the time of its calculations.

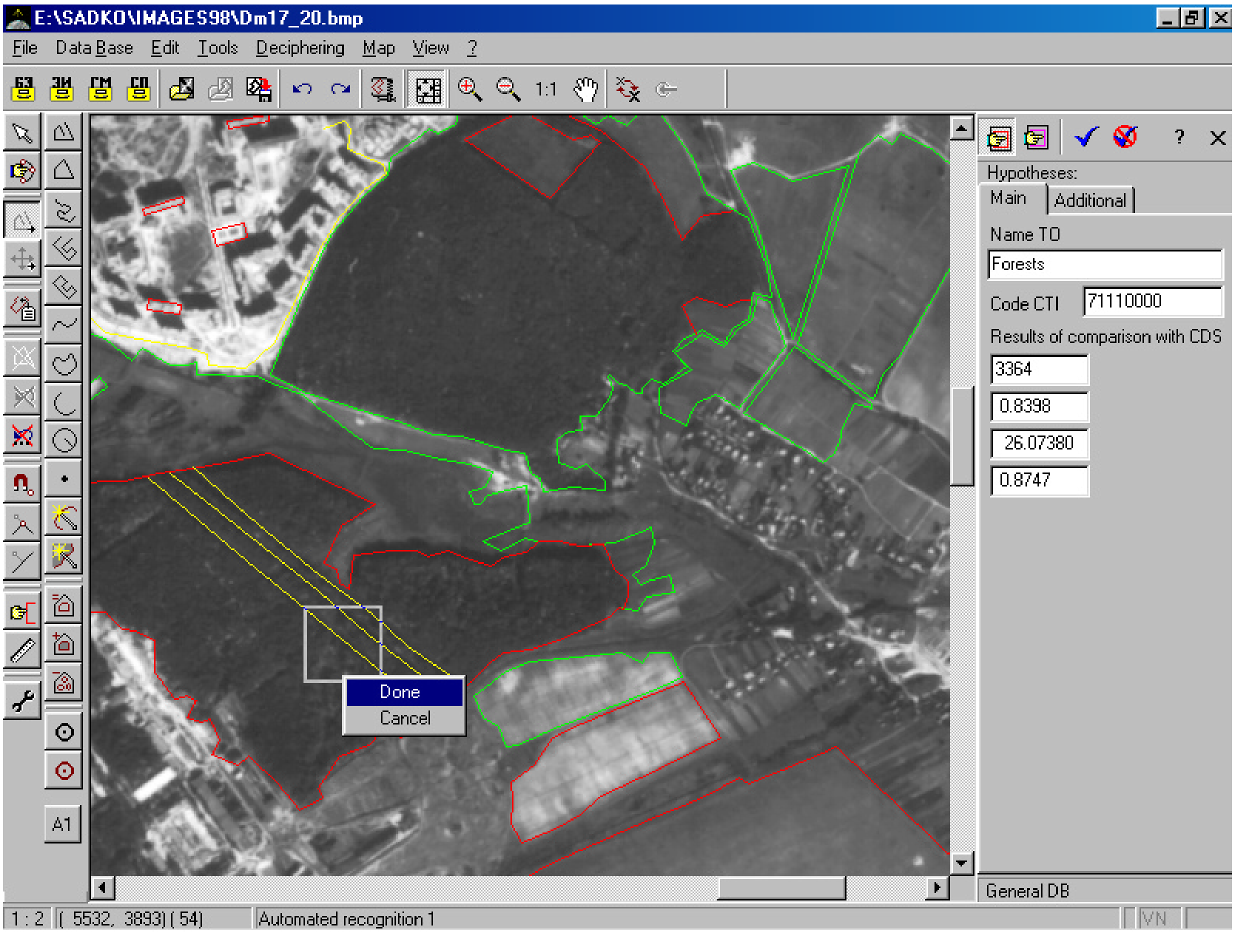

Figure 5. "SADCO". Automated deciphering of the object «forest» with the probability estimation of the recognition reliability in corresponding system of deciphering features.

Stage 2. The direct object recognition. The point inside the analyzed object is selected, and in its corresponding neighborhood the calculation of ADF from standard analytical models of the classes is realized. After that the comparison of calculated characteristics to standard one for every represented class is fulfilled. During the search among the conjectures about object belonging to any class the opportunity of «breakdown» is taken into account. In this case the breakdown means the difference between analyzed and standard ADF, which is grater then defined tolerance. Those conjectures, where the overfall conditions are fulfilled, can be estimated by means of special functional, determining the measure of closeness between analyzed and standard model.

Figure 5 illustrates the fragment of automated deciphering system work.

4 THE SPECIALIZED SOFTWARE "SADCO" (SYSTEM OF AUTOMATED DECIPHERING OF COSMIC HOTOGRAPHS)

The methods for visually-analytical and automated recognition of topographic objects at air and cosmic photographs are realized in the framework of specialized software "SADCO" (System of Automated Deciphering of COsmic photographs). "SADCO" represents a multilevel database management system and ensures interaction of functional modules of the system of images deciphering. The "SADCO" is realized in Borland Delphi and Visual C++ operational systems and works under the control of Windows 95 and its latter versions.

The functional possibilities of the system allow using it for solution of rather wide circle of the applied problems: generation of the new high accurate digital terrain maps and revision of existing ones, operating monitoring of environment etc.

"SADCO" has units structure and includes the followings systems: 1) the informational system; 2) the system of forming an Work Data Base (WDB); 3) the visual-analytical deciphering system based on Expert Deciphering System (EDS); 4) the automated recognition system; 5) the image processing system; 6) the contour making system; 7) the system of object semantic editing; 8) the system of output document forming; 9) the help system; 10) the service system.

The version 3.1 of "SADCO" allows:

1. To input and to operate by data of Informational System of "SADCO":
   - 1.1. To store and to process in special data base the information about the classes of topographic objects, the deciphering of which is accepted to realize;
   - 1.2. To have a quick access to direct and indirect deciphering features for all registrated types of topographic objects;
   - 1.3. To form and to use the catalog of standard images, classified according to such features as image resolution photo survey season, sun height, landscape type.
   - 1.4. To develop EDS knowledge base in the form of text description features for three main classes of topographic objects (compact, linear and area).
   - 1.5. To control the process of EDS logical conclusion by forming the values of weights of deciphering features corresponded to all topographic object subclasses.
   - 1.6. To form and to edit the Standard Analytical Models Data Base (DB SAM);
   - 1.7. To organize the photo input into image deciphering album;
2. To organize the halftone image processing to increase the visual quality of an image ant to realize photometric normalization.
3. To realize image segmentation and to make object contours in hand and automated modes;
4. To decipher compact, linear and area objects with the help of EDS, using an information from Data Base of Topographic Objects (DB TO) and Data Base of Standard Images for Topographic Objects (DB SITO);
5. To decipher area objects in automated mode, using DB SAM;
6. To realize the measurements of quantity characteristics over the images of topographic objects;
7. To registrate and to accumulate the results of deciphering for analyzed photography in specialized output document;
8. To output the copy of output document to printer or plotter;
9. To realize the synchronized digital deciphering photo image and topographic map image viewing with purpose to increase the reliability and productivity of deciphering process;
10. To convert the output document in formats used by other specialized systems (GIS Panorama);
11. To realize the administrative functions;
12. To have full and accessible reference information about any work in «SADCO» system.

5 EXPERIMENTS

Let M be the total number of images; m_i be the number of images of the i-th object class ($\sum m_i = M$); n_i be the number of recognized images of the i-th class, it devides into truly recognized k_i and falsely recognized l_i ($n_i = l_i + k_i$). Then the fraction k_i/m_i is called the completeness of the recognition and the fraction k_i/n_i is called the reliability of the recognition.

Image classes	The number of images (m_i)	The number of recognized images (n_i)	The number of truly recognized images (k_i)	The completeness of recognition (k_i/m_i)	The reliability of recognition (k_i/n_i)
The forest I (coniferous)	23	18	17	73,9%	0,94
The forest II (foliage)	17	16	14	82,4%	0,88
The water	28	18	17	60,7%	0,94
The agricultural area	27	30	24	88,9%	0,80
The marsh	17	12	10	58,8%	0,83
The grass vegetation	17	13	11	64,7%	0,85
TOTAL: The area objects	129	107	93	72,1%	0,87
The road	12	11	9	75,0%	0,82
The channel	4	2	2	50,0%	1,00
The railway	12	6	5	41,7%	0,83
TOTAL: The linear objects	28	19	16	57,1%	0,84

Table 1. The results of deciphering experiments

The approbation of Expert Deciphering System shows that the reliability of deciphering for compact topographic objects (the population localities, industrial buildings and constructions and so on) composes the value of 82%, for linear objects (railways and roads, river net and so on) - 87%.

As far as the system of automated recognition is concerned the executed wide experiments show that the average statistic estimation of reliability over main 15 classes of topographic objects, belonged to the class of grass vegetation and grounds, composes the value of 80%.

6 CONCLUSIONS

High reliability and validity of image recognition is reached due to preliminary preparing and tuning Work Data Base. The preliminary preparing and tuning Work Data Base is realized by the data selection from the General Data Base. The selected data correspond to characteristics of analyzed region (list of the landscapes and grass vegetation ages on this region), survey conditions (season and sun height) and parameters of the deciphering image (camera type and image resolution). The using of such Data Base leads to constraint of the space of decision search during work of the Expert Deciphering System and the automated recognition. Thereby, required reliability and validity of recognition are reached.

The service system for automated deciphering process in «SADCO» satisfies to the modern requirements and can be added, improved and modernized during further research work.

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