Compressing the Geospatial Data of Testing Grounds

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Abstract: - The paper discusses an algorithm for obtaining the compressed spatial images of testing grounds, which are described by attribute data. The attributive representations of data make it possible to use the hardware and software resources of geographical information systems (GIS) more economically. The objects, that can be presented by a boundary, are considered as the observable ones. The efficiency of the testing ground description is achieved by representing all its areas by boundaries, encoding the boundaries using the Freeman code, and applying the entropy encoding at the last stage of image processing. At the same time, the compressed set of attributive data can be unpacked into the original image with almost no recovery errors or with acceptable accuracy, but not below the limit set by the specification. The theoretical principles of the method are illustrated by the example of processing the segmented image of the contour. The comparative assessment of the efficiency of compression of the combined method under consideration and that of the entropy encoding method is presented.

Key-Words: - Testing ground, Protection of Nature, Image, Attribute, Freeman-Code, Compression, Boundary.

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1 Introduction

The efficient method for encoding the remote observation data has been considered. The areas of application of monitoring of man-made and natural objects are sufficiently fully reflected in the scientific and technical literature, [1], [2]. The task of monitoring nature and landscape is to provide targeted and relevant information for the efficient protection of the natural and landscape. Environmental monitoring of agricultural territories makes it possible to quantify the changes in nature's biodiversity and state of the landscape as well as to make practical conclusions from the results obtained with appropriate correction of production activities or protective measures, [3].

The spatial data may have high dimensionality. In many applications, it is desirable to replace the set of pixels depicting the object with a description of the latter`s boundary to reduce the volume of the data array. The representation in the boundary forms is suitable for cases where the following geometrical characteristics of the object are in the focus of attention: length, area, bends, contours, and concavities, [4].

The methods and technical means to be used for reliable measurement, fast and reliable registration, and automated analysis of video information of remote observation require continuous modernization of monitoring systems and complexes. The task of technical improvement of the GIS is associated to a large extent with the introduction of new observation and storage tools as well as modern methods for transmitting signals and images based on the application of an information theoretic approach and fast (efficient) computational algorithms for digital processing of 1D and 2D data.

2 Problem Formulation

The efficient description of the object boundaries becomes a challenge when solving problems related to the detection or search of certain objects on images as well as recognition or identification of them. One of the important characteristics of engineering and geodetic monitoring is the efficiency of automated measurements, obtaining the spatial information about the observation of changes in the behavior of infrastructure facilities (utilities, transport systems, etc.) and natural objects, for example, forests and wetlands of Polesia in Belarus. Some monitoring images, for example, agricultural areas and landscape territories usually do not require measurements with centimetre-level accuracy. For such objects under monitoring, their attributive representation is convenient and efficient.

3 Problem Solution

It is assumed that the data are generated after the process of segmentation of images of the geographic objects of interest. The description of monitoring data proposed for consideration is implemented through the following computational stages.

1. Stage of initial description of the object of interest. The stage includes processing and coding in the spatial domain of the initial date of the testing ground on a discrete grid, [5]. It is assumed that the data of various monitoring objects (swamp, forest, agricultural land, etc.) are stored in separate files. The categories of land plots do not overlap. In this case, the testing ground attributes can be stored in a single spatial data layer, while the encoding matrices differ in numerical attribute values or non-spatial data. To reduce the computational costs of spatial processing, it is proposed to perform the encoding for each testing ground category. In addition, the encoding should be only performed for boundaries that define the territory of the category (reservoir, roads, field, etc.).
2. Encoding the boundaries of the testing ground objects using the Freeman-Code, [6].
3. Entropy encoding of the Freeman-Code sequence with the specified component connectivity, [7].
4. Formation, storage, and transmission of the integrated compressed file of the observed image data.

3.1 Theoretical Principles

Let $g_i, i = 1,...,K$ denote the t^{th} spatial object present on the image of interest under observation and K is the number of objects of a single-layer testing ground ***G***. The highlighted objects of the testing ground were obtained after the segmentation process. Note that the mathematical principles under consideration underlie also the processing of multilayer testing grounds. In this case, either a sequential algorithm for processing each layer or a parallel simultaneous computational algorithm for processing images of objects using a multi-core processor is implemented. In the digital representation, the image of the testing ground G is described by the matrix $\mathbf{G} = (g_{m\,n})$ with the dimensions $M \times N$. The matrix $\mathbf{G}$ is characterized by the values of variances $\sigma_i{}^2$ and those of the covariance function $\mathrm{cov}(\mathbf{g}_i)$. A priori knowledge of these statistical characteristics makes it possible to pre-evaluate the efficiency of the data presentation and description. The expression corresponds to a single-layer testing ground.

$$\mathbf{G} = \bigcup_{i=1}^{K} {}_i,\ \mathbf{g}_i \cap \mathbf{g}_j = \varnothing, i \neq j,\ \mathbf{g}_i, i = 1,...,K. \quad (1)$$

The improvement of the efficiency of processing the testing ground image is achieved by reducing the number of arithmetic operations. To do this, the object is represented as attributes by performing a dot encoding operation. As a result, the statistical characteristics of the testing ground image change, which is important for obtaining its compact record and efficient transmission. The uniform point encoding, [5], of the following kind

$$\mathbf{C} = f_i(g_{m\,n})[\mathbf{G}], \quad (2)$$

is performed, where $\mathbf{C} = (c_{m\,n})$ is the matrix, the elements of which correspond to homogeneous images of the testing ground objects;
$f_i(g_{m\,n}),\ i = 1,\ ...,\ K$ is the point operation function over the matrix (1).
The point operation (2) changes the levels of brightness of all pixels of objects g_i of the testing ground G. The encoding (2) highlights the main highlights the main attribute of the object of interest under observation. The encoding (2) of the process $g_{m\,n}$ is implemented by assigning the attributes

$$c_i, i = 1,\ ...,\ K,\ c_i \in \mathbb{Z}^+,\ c_i \neq c_j.$$

For example, the 2D code word with the attribute $c_1 \in \mathbb{Z}^+$, corresponds to all pixels with the "forest" category; the code word with the attribute $c_2 \in \mathbb{Z}^+$ corresponds to the pixels with the "swamp", etc. The new data image $\mathbf{C}$ with the variance $\sigma_c{}^2$ and covariance $\mathrm{cov}(c_{m\,n})$. After operating (2), the distribution of spatial two-dimensional variances of the matrix $\mathbf{C} = (c_{m\,n})$ becomes highly uneven which makes it possible to reduce the computational complexity of processing the source data, [8].

To reduce the dimension of the testing ground represented by the matrix $\mathbf{C} = (c_{mn})$ the additional encoding is only performed for the boundaries of the entire data array. The result will consist of a sequential set of adjacent pixels located on the boundaries of the testing ground objects. The distinctive statistical property of a typical image of contour is a property of high linear dependence – high correlation of the values of discrete samples.

The existence of this property makes it possible to perform efficient data compression with a z ero value of the image restoration error.

$$\varepsilon = \frac{1}{N}\sqrt{\sum_{n=0}^{N-1}\left(x(n)-\tilde{x}(n)\right)^2} \approx 0,\ N = \mathbb{Z}^+,$$

where $x(n)=\left(x_0,\ ...,\ x_{N-1}\right)$ and $\tilde{x}(n)=\left(\tilde{x}_0,\ ...,\ \tilde{x}_{N-1}\right)$ are sequences of values of the boundary pixels before compression and after the inverse transform (restoration);
N is the number of pixels of the boundary;
n is the current reading number.

It is assumed that the elements of boundaries of the objects form a co nnected set with the connectivity component S. In this case it is possible to achieve the high efficiency of describing the boundaries using the Freeman-Code, Figure 1.

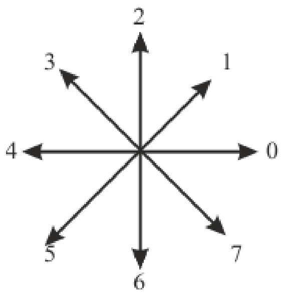

Fig. 1: Direction coding in a an 8-neighborhood

In general, the accuracy of the border description is determined by the size of the grid step and the number S, [4]. Several modifications of the code with different connectivity are used, when the direction code from the initial phase of 0 degrees changes clockwise in increments of 90, 45, or 22,5 degrees, respectively. Then the boundary image is represented by the closed sequence of vectors − of binary code words. The sequence elements are determined by the current changes of the motion direction over the boundary. The length of each vector (code word) is determined by the connectivity value S. For example, encoding the boundary with the use of four-component connectivity is implemented by words with the length of 2 bits. In this case, each pixel is described by two bits instead of eight. As a result of the encoding, the 1-D sequence is formed:

$$x(n)=\left(x_0,\ ...,\ x_{N-1}\right) \qquad (3)$$

with the base depending on t he connectivity component value S.

Following the concept of the information theory, sequence (3) describes a discrete memoryless source $\{q_0,\ ...,\ q_{s-1}\}$ with a known law of probability $P=\{P(q_1),\ ...,\ P(q_s)\}$ of the boundary pixels and. The set of symbols $\{q_1,\ ...,\ q_s\}$ of the source X corresponds to the vectors of directions, Figure 1. For example, a binary vector of code word corresponds to the symbol $q_3 \rightarrow 3$. $x_3 = (0\ 1\ 1)$.

The main characteristic of the random origin from the standpoint of its efficient representation is entropy $H(X)$, [9]. Then an algorithm for optimal non-uniform entropy encoding of the sequence (3) can be applied for a compact description of such an origin. To ensure the reliable and trustworthy transmission of geospatial information via a channel with noise, the encoding of the received entropy code words with an interference-resistant code is further performed.

3.2 Example of the Efficient Description of Geodata

Figure 1 shows a relatively complex single-layer testing ground.

Fig. 1: Testing ground image

The spatial objects of the testing ground belong to the class of fuzzy ones, [10]. There are images of four categories of objects: forest area, utility territory used for processing and storage of wood, deforested area, and lake mirror. Monitoring of this testing ground may include information about changes in the areas of objects, extent, features of the structure of the soil, forest and other characteristics.

At the stage of the initial compact description of the testing ground, a grid sampling rate shall be selected to meet the specified specification (level of detail of the objects or spatial resolution of the image, time spent for the data processing, etc.), [11].

The pixel size should be sufficient to cover the required details, but not too large so that it would be possible to perform efficiently the data analysis and store (transmit) the data in a GIS database. The categories of visible objects are encoded by the attributes (identifiers) presented in Table 1.

Table 1. Testing ground attributes

Testing ground				
Object	Forest	Utility territory	Lake	Deforested territory
Attribute	1	2	3	4

The evaluation of the efficiency of the geomonitoring data description method is considered for one of the testing ground objects, the “Lake”. Based on the selected grid sampling rate, the cost of the digital representation of the original image of this object in pixels is $L_8 = 271$.

In general, the amount of memory for storing an image with 8-bit quantization will be $V_8 = 2168$ bits.

In the case of applying the approach with the transition to attribute data, the required amount of memory for storing the “Lake” category is $V_{\text{Attribut}} = 813$ bits.

At the same time, the shape of the object remains unchanged. Note that the amount of memory does not depend on the number of object categories because it is necessary to ensure the storage (transmission) of all pixels of the testing ground image. In addition, testing grounds with a larger number of categories require a larger number of bits per pixel due to the peculiarities of the Freeman-Code build.

The object boundary description is implemented using the Freeman-Code with the connectivity component $S = 8$. Since the entropy value does not depend on the order of sequence of the source symbol, the 1-D sequence (3) of the boundary is represented by the matrix $\mathbf{X}_s$ in the alphabet $\{q_0, ..., q_{s-1}\} = \{0, 1, ..., 7\}$. To do this, a lexicographical record of the sequence (3) by columns was applied.

$$\mathbf{X}_s = \begin{pmatrix} 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 4 & 4 & 4 & 4 & 4 & 4 & 4 \\ 4 & 4 & 4 & 4 & 4 & 4 & 5 & 4 & 4 & 4 & 4 & 5 & 5 & 5 & 5 \\ 5 & 7 & 7 & 6 & 6 & 6 & 7 & 7 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 7 & 7 & 0 & 1 & 0 & 7 & 1 & 0 & 0 & 7 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}.$$

The amount of memory for storing the image of the boundary of the “Lake” category is $V_{\text{Freeman}} = 180$ bits.

The matrix $\mathbf{X}_s$ describes a discrete memoryless source with a known law of probability of the pixels

$$P = \{P(q_0), ..., P(q_{s-1})\} = \{P(0), ..., P(7)\} = \{0.2, 0.08, 0.133, 0, 0.28, 0.08, 0.1, 0.133\}.$$

The characteristic of the source $\mathbf{X}_s$ is the entropy

$$H(X_s) = \sum_{i=0}^{7} P(q_i)\log_2 P(q_i) = 2{,}6.$$

The value $H(X_s)$ determines the upper value of the average length E of the prefix code, with the use of which you can compress the source X_s. As a result of the entropy encoding of the source X_s by the optimum Huffman code the obtained value of the average length of the code approaches the value $E \Rightarrow H(X_s) = 2{,}6$. The amount of memory for storing the image of the boundary of the “Lake” category is $V_{\text{Huffman}} \approx 156$ bits.

Table 2 presents the data on the efficiency of compression of the “lake” category at the intermediate and final stages of the image processing. The efficiency was evaluated by the compression ratio

$$\eta = V / V_{\text{cod}},$$

where V are the costs of the object description without encoding;

V_{cod} are the costs of storing (transmitting) the data after efficient encoding according to the algorithm: attributive encoding $\Rightarrow$ Freeman-Cod encoding $\Rightarrow$ Huffman encoding.

Table 2. Compression Efficiency for Different Source Data View

Data type	Data size, bit	Compression ratio	Bit/pixel
8-bit	2168	0	8
Attributive	813	2.66	3
Freeman-Code	180	12	0.67
Huffman-Code	156	13.8	0.58

As seen from Table 2, the costs for describing the attributes of the "Lake" object of the testing ground, Figure 1 have been reduced from 8 bits per pixel to 0,58 bits per pixel. The gain will increase even more if the original testing ground image is presented with a high resolution, for example, 10 or 12 bits per character.

As follows from example 3.2, the considered computational algorithm for the representation and description of the boundary can be used for analyzing the shape and technical objects. The efficient solving of the problem of recognizing technical (artificial) objects in shape is relevant for many applications, in the particular communication, space, and military ones. The recognition of objects by shape in these applications is implemented based on algorithms using computationally expensive linear operations of convolution or correlation. The transition from an operation on the set of all pixels of the object to an operation on the set of pixels of the boundary simplifies the execution of convolution or correlation operations, which is important if it is necessary to solve quickly the recognition problem.

4 Results and Their Discussion

Experimental studies have shown that the method makes it possible to reduce the initial testing ground size represented by the attributes down to 15 ÷ 20%. The efficiency of the description depends on the geometric characteristics of the testing ground, and the value of the correlation between adjacent pixels of the Freeman sequence. On average, the implementation of three encoding stages made it possible to reduce the storage volume of geospatial data on the testing ground by about 80%.

The main investigations have been performed for boundaries with smooth characteristics of the shape. The presence of abrupt changes in the boundary shape reduces the processing efficiency for a condition, where the value of the image restoration error tends to zero.

Improvement of the boundary description accuracy requires the reduction of the image sampling grid interval and preliminary filtration of the image to eliminate distortion due to the effect of noise in the data channel. In turn, it reduces the data processing efficiency due to the elongation of the Freeman-Code. Therefore, the application of the method in practice should be based on a compromise between the efficiency of describing the geodata as well as the accuracy and complexity of the processing.

The proposed method provides a computational effect in solving problems of recognizing technical objects by shape.

4.1 Conclusion

The effective application of aerospace sensing systems and geographic information systems to solve various monitoring tasks requires the introduction of more productive methods of digital image processing. In this direction, an approach making it possible to solve problems related to the analysis of testing ground structures with less time and computational costs was described. Based on the research performed, the following conclusions can be drawn:

1. The features of the algorithm for the point numerical encoding of images of testing ground areas make it possible to use relatively simple encoding algorithms based on the Freeman code and entropy approach for compression of testing grounds.
2. The considered method based on the union of the three encoding algorithms ensures the acceleration of the process of information transmission and processing and allows energy saving.
3. The method can be used not only to describe the shape of objects but also to solve the problems of segmentation and classification of objects.
4. The application of the considered method for compressing the information on the infrastructure of transport networks and utility lines makes it possible to reduce the excessiveness of the original spatial data concerning such objects.
5. The shortening of the time required for the information transmission improves the reliability of the system from the information security standpoint and reduces the probability of the information capturing by a hacker.
6. The considered computational algorithm can be used to quantify such geometric parameters as the length of the boundary, contour, and area of the object of observation.
7. The approach can be used in medicine to increase the trustworthiness of clinical and morphological diagnosis of diseases using a medical image analysis system.
8. The considered data processing method is relatively simple to implement with the use of modern programming languages.
9. Further theoretical and experimental research in the field of representation and description of geospatial data can be aimed at constructing effective computational algorithms with the use of coordinate transformations on the Euclidean plane, [12]. For example, coefficients of discrete cosine transformation can be used in this case as descriptors of the data source. In contrast to the considered method of data processing in the spatial domain, the results providing a computational and temporal gain in the geodata processing in the field of spatial frequencies can be also expected.

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