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Procedia Computer Science 103 (2017) 253 – 259

Procedia Computer Science

XIIth International Symposium «Intelligent Systems», INTELS'16, 5-7 October 2016, Moscow, Russia

Information-hardware support of systems of the automated electromagnetic monitoring of geodynamic objects

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Abstract

In article the structure of an informational-hardware support of the automated system of data processing at electromagnetic monitoring of geodynamic objects is considered. The structure of interrelations of the object-oriented and serving subsystems realizing methodological, program and technical and information support of processes of filing and data processing of geodynamic monitoring is defined. It is noted that increase of geodynamic sensitivity due to selection of the abnormal components of signals and obligation of monitoring of variations of separate geodynamic objects in the studied environment results in need of expansion of informational saturation and a variety of geoelectric models. In this case the applied algorithms of informational processing can be focused only on the analysis of the abnormal signals, and the geodynamic assessment will be defined by structure of the models of geodynamic objects used at interpretation. It is defined that the problem of prediction of geodynamic processes can be solved on the basis of expected model operation.

Peer-review under responsibility of the scientific committee of the XIIth International Symposium "Intelligent Systems"

Keywords: Algorithms for data processing; monitoring system; geodynamic objects; forecasting

1. Introduction

Currently, due to the necessity to solve the problems of protection and prevention of accidents in the natural and man-made objects, the urgency of creation of geodynamic objects automated control systems greatly increased[1].

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Peer-review under responsibility of the scientific committee of the XIIth International Symposium "Intelligent Systems"

doi:10.1016/j.procs.2017.01.098

This is particularly important in cases of location of complex economic assets in seismically active areas, and also in areas of natural and artificial unstable geodynamic structures (landslides, slide rocks, devolutions and karst development zones).

The current systems of automated electromagnetic control and monitoring of geological objects are intended primarily for scientific research and are based on comparative time-series analysis with the filtration of natural and man-made rhythms and on the useful geodynamic component allocation[2]. In most cases, this approach is useful for research purposes, and in implementation of control function designed for rapid response to critical geodynamic changes in the object, it is extremely inefficient

Moreover, in their practical use a serious problem occurs, associated with the need to determine small geodynamic variations of certain volumes of geological environment. Increase in geodynamic sensitivity by determining abnormal component signals and necessity of control over variations of certain geodynamic objects in the environment under study results in the need to expand the information richness and diversity of geoelectric models. In this case, the information processing algorithms used may be focused only at the analysis of the abnormal signals, and geodynamic evaluation shall be determined by the structure of models of geodynamic objects used in the interpretation[3].

The objective of this paper is to review and analyze the organization methods of the automated electromagnetic control systems, which provide methodical, algorithmic, software and technical and information support of collection and processing of geodynamic information.

2. Organizational structure of the automated electromagnetic control of geodynamic objects

The complexity and diversity of manifestations of geodynamic environments leads to the need of increasing the number of monitored parameters of geodynamic objects with electromagnetic monitoring, which greatly increases the flow of the measurement information. These quality factor improvements, reducing the time of research and, accordingly, increasing of the geodynamic control efficiency are the main objective of development and application of automated systems of geodynamic studies exactly[4].

Figure 1 shows a generalized structure of the electromagnetic control system that reflects the characteristics of geodynamic impacts on the object under study and the basic processes of information processing.

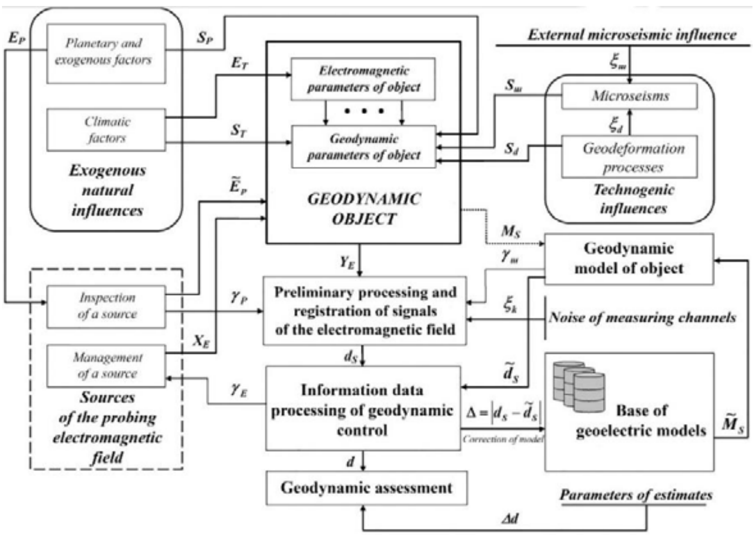

Fig. 1. The generalized structure of system of electromagnetic inspection of geodynamic objects.

The geodynamic object is under the influence of natural and anthropogenic factors determined by the combined geodeformational effects S_d and S_m (geodeformational processes and microseisms ξ_d, ξ_m), as well as under the influence of climatic and planetary factors S_T and S_p. In addition, under the influence of climatic factors E_T the electromagnetic parameters of the survey target are changed.

The processes of information processing are formed in accordance with the basic principles of solving the inverse problem of geodynamic control[5]:

$$(\mathbf{M_S},\mathbf{S})=\mathbf{A}^{-1}(\mathbf{d_S}),$$

where $\mathbf{M_S}$ is a vector describes the object model parameters; $\mathbf{d_S}$ is the observed data vector; $\mathbf{S}=\{\mathbf{X_E},\mathbf{E_P}\}$ are the parameters of the source of the probing field; $\mathbf{A}^{-1}$ is an operator of the inverse problem.

It should be noted that the geoelectric data are always recorded with noise defined both as interference in the measurement channels ξ_k, and specific climatic and anthropogenic factors. In this case, the inverse problem solution is to define such model $\mathbf{M_S}$ that generates predictive data $\mathbf{d_S}$, corresponding with the best accuracy the observed data:

$$\mathbf{d_S}=\mathbf{A}(\mathbf{M_S}),\ \left\|\mathbf{d_S}-\mathbf{d_S}\right\|^2_{\mathbf{L_2}}=\mathbf{min},$$

where **A** is an operator of the direct problem.

The geodynamic control processes optimization is achieved by controlling the registration of electromagnetic signals γ_m according to the model parameters of the object, control of γ_E parameters of the probing signals $\mathbf{X_E}$, and control γ_p according to data of selection of natural geomagnetic disturbances signals $\mathbf{E_P}$.

3. Object-oriented and servicing subsystems of geodynamic inspection data processing

In the organization of automated research and monitoring of geodynamic objects a number of object-oriented and servicing subsystems are defined, which implement methodical, software and technical and information support of processes of the information registration and processing. The structure of relationships that describe the characteristics of the research organization is shown in Figure 2.

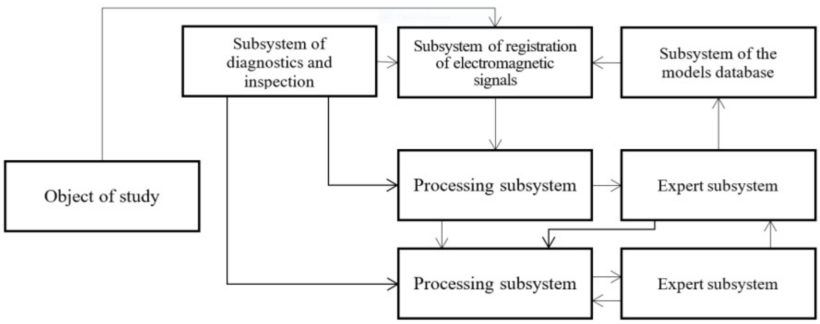

Fig. 2. Structure of interrelations of subsystems of the automated inspection geodynamic objects.

This structure reflects the main focus of the organization of automated geodynamic studies – it is the geodynamic control of individual determined objects based on the developed models of geodynamic objects and processes. The above structure closely matches the general scheme of electromagnetic geodynamic control organization (Figure 1)[6]. The registration subsystem provides distributed registration of electromagnetic signals in the environment and correspondingly metrological support of the measurements conducted with the required accuracy, and in this case, it enables to optimize the registration processes for a specific geodynamic object[7]. The processing subsystem includes both preliminary treatment and determining of useful electromagnetic signals based on filtering algorithms, and evaluation of geodynamic variations of the study objects and obtaining basic statistical and mathematical relationships[8]. The subsystem of diagnostics and control is designed to ensure the correctness of the obtained data of electromagnetic control of geodynamic objects and includes the modules of testing and correction of the registration subsystem measuring tracks parameters, and also the probing signal source control module[9]. The subsystem of the models database is the basis for creation of electromagnetic control of geodynamic objects; its distinctive feature is the use of dynamic models with the ability of current dynamic correction[10].

The presence in the developed structure of the expert system emphasizes the need to use geophysical and petrophysical data or involving geoinformation systems data.

It should be noted, that with such an approach at the output of the geodynamic control automated system we receive the processed data and accordingly received geodynamic evaluations on the developed models of geodynamic objects, processes and phenomena under study.

4. Approximation of equivalent transfer functions of geoelectric section and geodynamic variations evaluation

When the information processing and geodynamic evaluation the basic model is used as approximation of transfer functions of the geoelectric section with equivalent fractional rational functions of a complex variable $p = j\omega$, physically implemented with discrete electric circuits[11]. To solve the problems of geodynamic control the equivalence of geoelectric section functions should provide a match of performance not on the whole infinite range of frequencies and times, but only on a limited interval. For a fixed position of the field source and the registration point of the object geodynamics relative the daylight surface it can be written as follows:

$$H(p,x,y,z) = \frac{Y(p)}{X(p)} = \frac{W(p,x,y,z)}{V(p,x,y,z)} = \frac{b_0(x,y,z) + b_1(x,y,z)p + ... + b_n(x,y,z)p^n}{a_0(x,y,z) + a_1(x,y,z)p + ... + a_m(x,y,z)p^m} \quad (1)$$

where $n \le m$; V(p, x, y, z) - Hurwitz polynomial.

When changing the position of the electromagnetic field source and the registration point relative to the geoelectric section under study the real coefficients of the transfer function will change, without changing the order of the function used in approximation. The geodynamic variations of study objects will also be expressed in variations of real coefficients. Therefore, to solve the problem of approximation it is always possible to set such an order of function m, which will provide the required accuracy of geodynamic approach for any group of geoelectric section models.

The transfer function (1) sets a combination of discrete electrical circuits that determine the geodynamic model of the geoelectric section. When using electromagnetic methods of the environment control in the low-frequency wavelength range the geodynamics of individual selected objects is described well in presentation of the transfer function in the form:

$$H(j\omega,x,y,z) = \sum_{i=1}^{m} \varphi_i(x,y,z) A_i / (B_i + j\omega) \quad (2)$$

where the coefficients A_i, B_i and φ_i are functional dependencies and spatial parameters of electromagnetic environments composing geoelectric section. And the accuracy of approximation is estimated by middle-degree Chebyshev criterion[12]

$$\int_S \lambda(x,y,z) | H(p,x,y,z) - H^*(p,x,y,z) |^N \le \delta .$$

The weighting factor $\lambda(x,y,z)$ is determined by the used methods of determining of spatial geodynamic variations characteristics for the study object in the control zone Δ.

In assessment of geodynamics of the objects under study, it is convenient to use analytical spectral expressions for description of surface irregularities. The equation (1) in this case is presented in a spectral form, where the models of irregularities are used as spectral images:

$$S_y(k_x,k_y,z_0,p) = H(k_x,k_y,p) S_x(k_x,k_y,z_0,p) \quad (3)$$

where k_x, k_y - spatial frequencies.

$S_y(k_x,k_y,z_0,p)=\mathbf{L}Y(x,y,z_0,p)$, $S_x(k_x,k_y,z_0,p)=\mathbf{L}X(x,y,z_0,p)$ – spectral images of the recorded and the probe signal.

In this case, the spectral images of the near-surface irregularities can be obtained from a consideration of the spatial pulse response of the environment to a point source of the probing signal, which is obtained by moving the equivalent point source on the observation level z_0 along the profile of corresponding heterogeneity:

$$S_F(k_x,z_0)=\mathbf{L}F(\tau_x,z_0),\ F(\tau_x,z_0)=\int_{-\infty}^{+\infty} L(x-\tau_x,z_0)h(x,z,p)dxdz \tag{4}$$

Where L(x, z) is functional approximating the point source at the point of the environment x, z. The space impulse response of geoelectric section is determined in accordance with the inverse Laplace transformation over a piecewise-linear approximation of the transfer efficiency on formulas (1) and (2):

$$h(x,z,p)=\mathbf{L}^{-1}H(k_x,k_z,p).$$

In accordance with the above formulas (2-4) the geodynamic variations of near-surface irregularities can be estimated from the spectral images of the object within the geodynamic models used:

$$\Delta S_F(k_x,z_0)=\boldsymbol{L}\int_{-\infty}^{+\infty} L(x-\tau_x,z_0)\sum_{i=1}^{m}\frac{\partial h(x,z,p)}{\partial\alpha_i}\Delta\alpha_i dxdz \tag{5}$$

where the vector dimension of geodynamic variations α_i is determined by the number of the controlled parameters. The development model of the geodynamic process can be represented as a linear discrete system[13].

5. Results of practical application of the system

Figure 3 shows the preliminary interpretation of geological and geoelectric section in the area of geodynamic control, obtained with the experimental control system, developed in accordance with the above principles.

On the basis of regime observations the registered signals of geodynamic variations were interpreted. Figure 4 shows the dependence of the registered geodynamic variations of transfer efficiency of bipolar equipotential geoelectric machine during the annual observations from May 2013 to April 2014.

The data obtained closely match the data of hydrological observations of the water level in the river Oka and the mineralization coefficient calculated as the ratio of mineralization index after the v. Chud and before it.

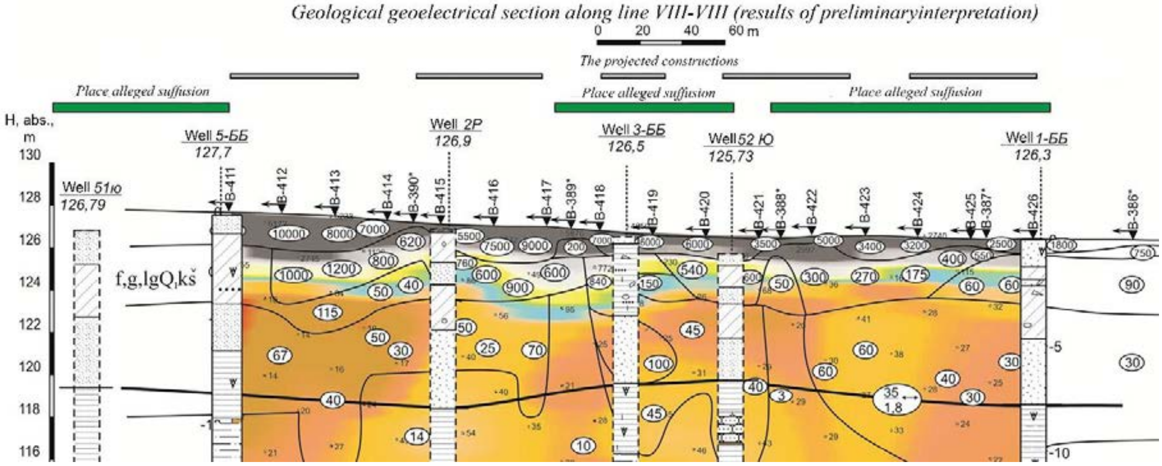

Fig. 3. The data preliminary interpretation of geological and geoelectric section in the area of geodynamic control.

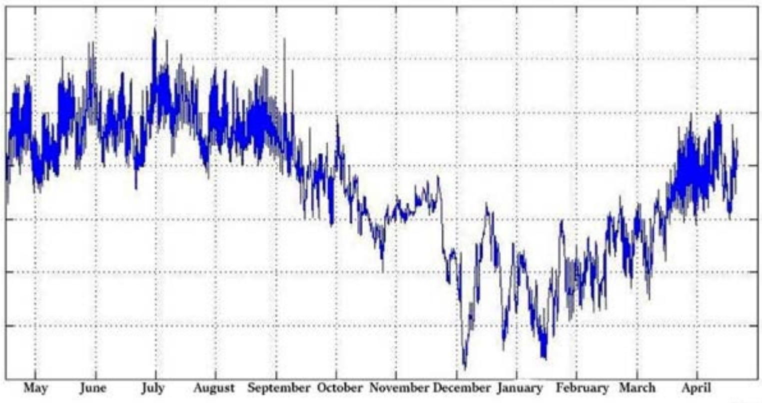

Fig. 4. Time series of geodynamic variations of the transmission coefficient of a two-pole equipotential geoelectric installation.

Acknowledgements

This article is realized with the support of Russian Federation President Grant MK-7406.2015.8

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