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Methodological and Technological Foundations of Remote Sensing Monitoring and Modelling of Natural and Technological Objects

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Abstract **– In this paper, the remote sensing monitoring of natural and technological objects is represented as a concept of integrated modelling and simulation of the processes of the complex technical–organizational system (CTOS). The main goal of the study is to use in practice predetermined modelling. The paper considers the technology of remote sensing monitoring of the natural and technological objects, methodological foundations of the integrated modelling and simulation, and the process of CTOS operation. Special attention is devoted to the continuity of the model and object solving practical issues. Moreover, the results of CTOS remote sensing monitoring make it possible to adapt models of this system to a changing environment.**

Keywords **– Airborne and ground measurements, complex technical–organizational system, control process, integrated modelling, processing of the space, remote sensing monitoring**

I. INTRODUCTION

The monitoring of the natural and technological objects is one of the primary ranges of the space imagery application. It is provided on the local, regional and global levels. The quality of the adaptations of the management decisions is increased as a result of the remote sensing monitoring. These adaptations are used to maintain the ecological safety of the research site and optimize the events concerning the elimination of the disturbance consequences. The executor of the project aims to obtain the required information of high quality and at a minimum cost. The effectiveness of the project depends of the source data quality (remote sensing data), methodological approach, software and the project result presentation. The integrated modelling of the basic technological processes of remote sensing monitoring is implemented to carry out the synthesis of technical requirements for hardware and software.

Nowadays, the scientific and practical issue of the synthesis of space monitoring component requirements is solved on the basis of modelling and simulation, determination of system parameters and expert analysis of the perspective of application solutions.

In this paper, we propose to use in practice predetermined modelling; where remote sensing monitoring is the complex technical–organizational system (CTOS). We can present the modified multiple-model multi-criteria description of CTOS problems:

$$J_{\theta}(\vec{x}(t),\vec{u}(t),\vec{\beta},\vec{\xi}(t),t) \to \underset{\vec{u}(t)\in\Delta_{\theta}}{extr}, \tag{1}$$

$$\Delta_{\Theta} = \left\{\vec{u}(t) \mid \vec{x}(t) = \vec{\phi}_{\Theta}(T_0, \vec{x}(T_0), \vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_{\Theta}, t)\right\}, \tag{2}$$

$$\vec{y}(t) = \vec{\psi}_{\Theta}(\vec{x}(t), \vec{u}(t), \overleftarrow{\xi}(t), \vec{\beta}_{\Theta}, t), \tag{3}$$

$$\begin{aligned}
&\vec{x}(T_0) \in X_0(\vec{\beta}_{\theta}), \vec{x}(T_f) \in X_f(\vec{\beta}_{\theta}),\\
&\vec{u}(t) = \| \vec{u}_{pl}^{T}(t), \vec{v}^{T}(\vec{x}(t),t) \|;\\
&\vec{u}_{pl}(t) \in Q_{\theta}(\vec{x}(t),t);\\
&\vec{v}(\vec{x}(t),t) \in V_{\Theta}(\vec{x}(t),t);\\
&\vec{\xi}(t) \in \Xi_{\Theta}(x(t),t); \vec{\beta}_{\Theta} \in B; \vec{x}(t) \in X(\vec{\xi}(t),t);
\end{aligned} \tag{4}$$

$$\vec{\beta}_{\Theta} = \| \vec{\beta}_0^{T} \vec{w}^{T} \|^{T}; \vec{w} = \| \vec{w}^{(1)T}, \vec{w}^{(2)T}, \vec{w}^{(3),T} \|^{T} \tag{5}$$

The formulas define a dynamic system describing CTOS structure-dynamics control processes. Here $\vec{x}(t)$ is a general state vector of the system, $\vec{y}(t)$ is a general vector of output characteristics. Then, $\vec{u}(t)$ and $\vec{v}(\vec{x}(t),t)$ are control vectors. Here $\vec{u}(t)$ represents CTOS control programs (plans of CTOS functioning), $\vec{v}(\vec{x}(t),t)$ is a vector of control inputs compensating perturbation impacts $\vec{\xi}(t)$). The vector $\vec{\beta}_{\Theta}$ is a general vector of CTOS parameters. According to [3], these parameters can be divided into the following groups [7]:

$\vec{w}^{(1)}$ is a vector of parameters adjusted through the internal adapter. This vector consists of two subvectors. The first one $\vec{w}^{(1,n)}$ belongs to the scheduling model, and the second one $\vec{w}^{(1,p)}$ belongs to the model of control at the phase of plan execution;

$\vec{w}^{(2)}$ is a vector of parameters adjusted through the external adapter. This vector consists of the subvector $\vec{w}^{(2,n)}$ belonging to the scheduling model and the subvector $\vec{w}^{(u)}$ includes parameters of simulation model for CTOS functioning under perturbation impacts. In its turn, $\vec{w}^{(u)} = \| \vec{w}^{(2,o)\mathrm{T}}, \vec{w}^{(2,b)\mathrm{T}}, \vec{w}^{(2,p)\mathrm{T}} \|^{\mathrm{T}}$, where $\vec{w}^{(2,o)}$ is a vector of parameters characterizing objects in service; $\vec{w}^{(2,b)}$ is a vector of parameters characterizing the environment; $\vec{w}^{(2,p)}$ belongs to the model of control at the phase of plan execution;

$\vec{w}^{(3)}$ is a vector of parameters adjusted within a structural adaptation of CTOS models.

The vector of CTOS effectiveness measures is described as (6).

$$\vec{J}_{\Theta}(\vec{x}(t),\vec{u}(t),\vec{\beta},\vec{\xi}(t),t)= \| \vec{J}^{(g)T},\vec{J}^{(0)T},\vec{J}^{(k)T},\vec{J}^{(p)T},\vec{J}^{(n)T},\vec{J}^{(e)T},\vec{J}^{(c)T},\vec{J}^{(v)T} \| \quad (6)$$

Its components state control effectiveness for motion, interaction operations, channels, resources, flows, operation parameters, structures, and auxiliary operations [2]-[5]. The indices «g», «o», «k», «p», «n», «e», «c», «n» correspond to the following models: models of order progress control (M<g,Q>); models of operation control (M<o,Q>); models of technological chain control (M<k,Q>); models of resource control (M<p,Q>); models of flow control (M<n,Q>); models of operation parameter control (M<e,Q>); models of structure control (M<c,Q>); models of auxiliary operation control (M<n,Q>). In (5) the transition function $\vec{\phi}_{\Theta}(T_0,\vec{x}(T_0),\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_{\Theta},t)$ and the output function $\vec{\psi}_{\Theta}(\vec{x}(t),\vec{u}(t),\vec{\xi}(t),\vec{\beta}_{\Theta},t)$ can be defined in the analytical or algorithmic form within the proposed simulation system; $Q_{\Theta}(\vec{x}(t),t),V_{\Theta}(\vec{x}(t),t),\Xi_{\Theta}(\vec{x}(t),t)$ are allowable areas for program control, real-time regulation control inputs, perturbation inputs, respectively; B is an area of allowable parameters; $X(\vec{\xi}(t),t)$ is an area of allowable states of CTOS structure-dynamics. Expression (4) determines end conditions for the CTOS state vector $\vec{x}(t)$ at time t = T0 and t = Tf (T0 is the initial time of a time interval, at which the CTOS is investigated, and Tf is the final time of the interval).

In our paper, the proposed multiple-model multi-criteria description of CTOS will be used.

II. PROBLEM STATEMENT

The framework of the main technological processes of the remote sensing monitoring is presented (Fig. 1). With regard to technical characteristics of space monitoring and facts influencing these characteristics, it is necessary to choose in the capacity of the source data one or some space vehicles and/or the airborne equipment complex, to choose optimal conditions for the survey conducting base on the seasonal and daily variability of the reflectance and radiative characteristics of the landscapes and mode of operation of equipment, to organize the thematic treatment of the remote sensing data and the ground measurements using hardware and software, to present the results of the project in the user-friendly form enabling one to make management decisions promptly and reasonably.

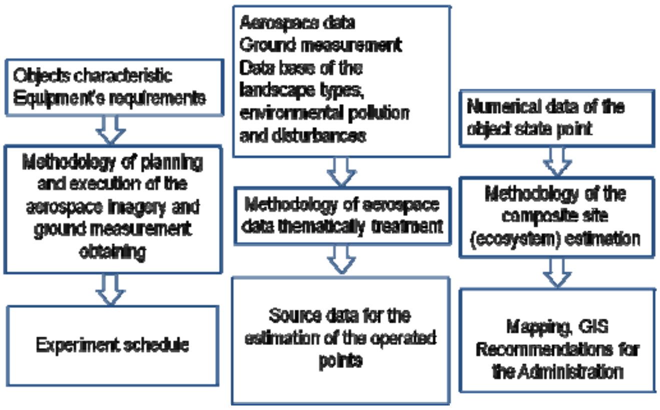

Fig. 2. Framework of the methodology of the space monitoring data application

The modelling and simulation of the technological processes have some uncertainty and limitations that influence the quality of the optimization task (the vector $\vec{\beta}_{\theta}$, $\vec{u}_{pl}(t)$).

The CTOS has the following sources of information as space imagery in the visible, infrared and super high frequency spectral bands, airborne imagery, pilotless vehicle imagery and test ground measurements for the verification of the results of the imagery thematic treatment.

The execution of the space ecological monitoring consists of some stages. Firstly, it is the planning and preparation of the tasks (the vector $\vec{w}^{(1,n)}$ and $\vec{u}_{pl}(t)$). This stage includes the choice of the objects, the list of controllable parameters determining and scheduling the survey.

Secondly, it is the data acquisition. The stage includes the process of survey and ground-based measurement (the vector $\vec{w}^{(1,p)}$).

The name of the third stage is the processing of data and the presentation of results. The treatment of the remote sensing data and ground measurement, creation of the thematic layer of the digital map, forming the forecast models, calculation of assessments and recommendations are executed (the vector $\vec{w}^{(u)}$).

The most convenient form of the project result presentation is the thematic layers of the digital map with the attributive information and database and photo scheme as a raster image.

Moreover, it is possible to estimate the system functioning quality and the choice of the optimal monitoring conditions to obtain the required imagery quality. The prediction is accomplished on the basis of the optical system taking into account the monitoring conditions and provides for a qualitative result. The spatial resolution of the image forms the main predictive parameter and determines a background contrast value as an object.

The movement of equipment, the Sun height, irradiance of the object, albedo of the site, physical specifications of the atmosphere are taken into account.

Thus, the modelling and simulation of the private elements of the space monitoring system and expert evaluations of the system functioning determine the values of the parameters of the space monitoring system.

In the future research it is planned to develop the generalizing model of the space ecological monitoring for practical issues.

III. THEMATIC PROCESSING OF THE SPACE IMAGERY

Thematic treatment of the remote sensing data is the key link in the system of space ecological monitoring. Generally, the primary and secondary treatments are applied. The operations are done based on the modelling and simulation in an automatic mode supported by the expert's knowledge.

The experience of the thematic treatment of the multi- and hyperspectral data with the high spatial resolution defined some important factors. One of them is the data presentation with the automatic identification of the test sites for algorithm training and adaptation. The next one is the complex treatment of the source multi(hyper)spectral and temporal remote sensing data and ground measurements. The third factor is the data result calibration and validation and optimal application of the spectral feature database of the landscape elements with reference to seasonal and daily variability. Lastly, the organization of the distributed access to the data is exchanged on the basis of the special portals, geographic informational system capability and crowd sourcing.

The informational flow rises and the necessity of the integrated modelling is determined. Furthermore, the qualitative and quantitative requirements are increased.

The main steps of the thematic treatment of the remote sensing data are presented as the generalized technique for estimating and controlling the quality of models of objects [1]. It is possible to conduct experiments and to obtain the values of some measured characteristics by using the modelled system (Fig. 2).

In Fig. 2, we take the following notation: 1 – for forming the goals of functioning; 2 – for determination of input actions; 3 – for setting goals of modelling; 4 – for the modelled system (objects) of the first class; 5 – for the model of the investigated system; 6 – for the estimation of the quality of a model (poly-model system); 7 – for controlling the quality of models; 8 – for controlling the parameters of models; 9 – for controlling the structures of models; and 10 – for changing the concept of model description.

Usually the main steps of the thematic treatment of the remote sensing data are designated for the qualitative solution of the integrated modelling task:

Phase 1. Input data array (block 3, Fig. 2)

Step 1. Optimal survey parameters;

Step 2. Change reflective and radiative settings of the landscape elements in seasonal and daily variability;

Phase 2. Data acquisition and treatment

Step 1. Imagery radiometric correction and calibration;

Step 2. Imagery geometric correction;

Step 3. Maintaining the system initial data relative to the reflective and radiative characteristics of the landscape elements;

Step 4. Combination of methods and algorithms of the thematic treatment (cluster analysis, Fourier analysis, method of principal components, classification algorithms and others) (blocks 8 and 9, Fig. 2);

Step 5. CTOS modelling and simulation based on the expert's knowledge (blocks 1 and 3, Fig. 2);

Step 6. Analysis of the situation dynamics based on the multi-temporal remote sensing data treatment (block 6, Fig. 2);

Step 7. Predictive modelling of the influence of Step 5 results on the ecological situation (block 5, Fig. 2);

Step 8. Crowdsourcing through the geo-informational portal application (blocks 1, 3 and 4, Fig. 2);

Step 9. Automatic environmental assessment in the space ecological monitoring network (blocks 6 and 7, Fig. 2);

Phase 3. Creation of the thematic layers and attributive information of monitoring

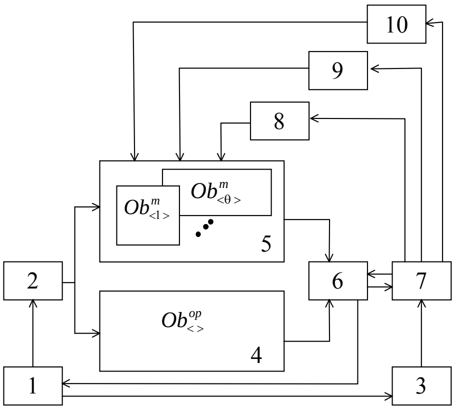

Fig. 2. The generalized technique of estimation and control of the quality of models of the first class

Analysis of the main trends for modern systems of the remote sensing monitoring of natural and technological objects indicates their peculiarities, for example, multiple aspects and uncertainty of their behaviour, hierarchy, structure similarity in the detection and recognition of the landscape elements, redundancy from the source data and variety of implementations for control functions. One of the main features of modern systems of remote sensing monitoring is the variability of their parameters and structures due to objective and subjective causes at different phases of the system life cycle. In other words, we always come across the system structure dynamics in practice.

IV. EXAMPLE

The example demonstrates the system of space monitoring of the road management objects described as the integrated modelling and simulation of CTOS.

The integrated modelling and simulation application to the data collection, processing and result presentation of space monitoring determines the source data requirements, the monitoring frequency and efficiency.

Road management objects such as highways and railways are the major source of the adverse environmental impact.

On the basis of the thematic processing of remote sensing data, the following tasks for the highway and railway management are tested. CTOS is presented as original software for the admissible noise level along the road, types of the roadbed injury, the dumps and garbage, the dead trees and damaged shrub vegetation identification. CTOS consists of the input RS data (block 3, Fig. 2), automatic RS data processing (blocks 1, 3, 4, 5-9, Fig. 2) and results. The perturbation influences are presented by the control model parameters that can be evaluated on the real data available in CTOS and parameters that can be evaluated via simulation models for different scenarios of future events.

The evaluated model parameters from block 3 include:

- type of the satellite system, above all, spectral and spatial resolutions;
- length of the analysable part of the road;
- square of the processing area of the space image.

The evaluated model parameters from blocks 1, 3, 4, 5-9 include:

- the threshold of some vegetation indices;
- the method of classification, number of classes, distance function;
- the method of reclassification;
- the threshold of entropy;
- the minimum dump or roadbed injury dimension;
- spectral radiance values from the database.

Results include the noise level, dumps and roadbed injury, dead trees and damaged shrub vegetation outlines in the geographic informational system.

Consequently, the method of the estimation and control of the model organization is determined.

Examples of the remote sensing monitoring of highway and railways are illustrated at the website of the ESTLATRUS projects 1.2./ELRI-121/2011/13.

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Vjačeslavs Zelencovs, Boriss Sokolovs, Olga Brovkina, Viktors Močalovs. Dabas un tehnogēnu objektu stāvokļa aerokosmiskā monitoringa un modelēšanas metodoloģija un metodiskie pamati

Rakstā ir piedāvāti dabas un tehnogēno objektu stāvokļa aerokosmiskā monitoringa un modelēšanas metodoloģija un metodiskie pamati. Šajā gadījumā pētījuma objekts ir aprakstīts ar dažādu klašu modeļu kompleksu vai kombinētajiem modeļiem. Uzmanība ir pievērsta adaptācijas modelēšanas vadošajai lomai aerokosmiskās uzņemšanas materiālu tematiskās apstrādes tehnoloģijā pie pamatotas parametru, algoritmu struktūras un lietišķo uzdevumu risināšanas metodiku izvēles. Adaptācija ir īstenota, izmantojot speciālus modeļus, kuros tiek novērtēta sistēmas kompleksa modelēšanas kvalitāte un atbilstošu parametru izvēle. Pirmajā etapā kosmiskā monitoringa tehnoloģija paredz uzdevuma risināšanu par uzņemšanas materiāla prasībām, uzņemšanas darbu izpildes apstākļiem un uzņemšanas procesu kā tādu. Tālāk, balstoties uz tematiskās apstrādes algoritmiem un uzņemšanas materiālu interaktīvajām metodēm, notiek dabas un tehnogēno objektu ekoloģiskā stāvokļa raksturojumu skaitliskās vērtības noteikšana. Nepieciešamības gadījumā, izmantojot virszemes devējus, veic testa mērījumus. Nobeigumā ir veikta iespējamās nelabvēlīgās iedarbības novērtēšana, ir izstrādāti priekšlikumi vadības lēmumu pieņemšanas atbalstam. Rakstā ir demonstrēti aerokosmiskās uzņemšanas materiālu izmantošanas piemēri, kas parāda aktuālo uzdevumu operatīvās risināšanas priekšrocības, balstoties uz telpiskiem datiem un piedāvāto metodoloģiju.

Вячеслав Зеленцов, Борис Соколов, Ольга Бровкина, Виктор Мочалов. Методология и методические основы аэрокосмического мониторинга и моделирования состояния природных и техногенных объектов

В данной статье приводятся методологические основы экологического мониторинга природных и техногенных объектов. В рассматриваемом случае объект исследования описывается комплексом моделей разного класса или комбинированными моделями. Обращается внимание на ключевую роль адаптационного моделирования в технологии тематической обработки материалов аэрокосмической съемки при обоснованном выборе параметров, структуры алгоритмов и методик решения целевых задач. Адаптация осуществляется с помощью специально выделенных модулей, где оценивается качество моделирования и выбор соответствующих параметров программного комплекса системы. Технология космического мониторинга предусматривает на первом этапе решение задачи обоснования требований к материалам съемки, условиям выполнения съемочных работ и непосредственное осуществление съемки. В дальнейшем на основе алгоритмов тематической обработки и методик интерактивной обработки материалов съемки осуществляется определение числовых значений показателей, характеризующих экологическое состояние природных и техногенных объектов. При необходимости выполняются тестовые наземные измерения. В заключение осуществляется оценка возможного неблагоприятного воздействия, разрабатываются предложения по принятию управленческих решений. Примеры использования материалов аэрокосмической съемки демонстрируют преимущества оперативного решения актуальных задач на основе пространственных данных на базе предлагаемой методологии.