THE INTELLIGENT MONITORING TECHNOLOGY BASED ON INTEGRATED GROUND AND AEROSPACE DATA

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ABSTRACT

The new intelligent monitoring technology (IMT) developed is based on interdisciplinary methodology of creation and application of any information technology. Besides, it considers functioning dynamics and possible structure degradation of complex objects in critical situations, and operating structural dynamics of complex objects. Unlike existing systems, the IMT is universal, and it includes the combined methods and algorithms of decision making in various classes of monitoring problems, forecasting and safety control of complex objects regardless to their appointment.

Keywords: monitoring, intelligent information technology, integrated ground and aerospace data, complex natural-technical objects, data and information fusion.

1. INTRODUCTION

At the present day, the stable market for aerospace services customer foundation is being one of the major problems of the aerospace technology and system development. The problem core is concerned with the development of technologies and systems for the aerospace data collection, processing, treatment and application. The monitoring of complex natural, organizational and technical objects (CO) is one of the actual domains of ground and aerospace data applications.

Information sources for this kind of objects monitoring include technical state of constructions collected from the space-navigation data, technical parameters of units and systems, aerospace data about objects and adjoining territories.

Complication of CO is resulted in expansion of their parameters to be measured and controlled. Today the number of such parameters can achieve several hundreds or thousands for various classes of technical systems (Steinburg, Bowman, White, 1998; Stark 2004). Usually CO state monitoring is not automatized completely. Thus, operators receive semantic information about some elements of CO rather than information characterizing integral CO states. To estimate CO state the operators should be able to analyze various context conditions of interaction between CO elements and subsystems. There are no universal methods and technologies for solution of the above-mentioned problems (Okhtilev, Sokolov, Yusupov 2006). Existing program systems for gathering, processing, and analysis of CO telemetry usually depends on characteristics of particular control objects and is not adaptable to undesired alteration of objects' structure. The methods and tools for construction of monitoring algorithms and systems are very specific and can be used in narrow domains. The problems of CO monitoring were investigated first of all for aerospace and electric power systems (Okhtilev, Sokolov, Yusupov 2006). The most important results were received in this domain. However, semantic interpretation of integral CO states remains the prerogative of operators.

Other feature of modern monitoring system for CO (MS CO) is the changeability of their parameters and structures as caused by objective and subjective reasons at different stages of the MS CO life cycle. In other words we always come across the MS CO structure dynamics in practice. Reconfiguration is a widely used variant of the CO structure control. Reconfiguration is a process of the CO structure alteration with a view to increase, to keep, or to restore the level of MS CO operability, or with a view to compensate the loss of CO efficiency as caused by the degradation of its functions. But, unfortunately, now CO reconfiguration is not tied in with monitoring and control processes (Ivanov, Sokolov, Kaeschel 2010; Ivanov, Sokolov 2010; Sokolov, Ivanov, Fridman 2010).

So the aim of our investigation is to develop technologies oriented to concurrent on-line user software assurance for all sorts of measuring information (information fusion) specifying states of complex process (situation assessment) at all phases of CO life cycle and control function in real time.

This aim should be achieved by here suggested artificial intelligent information technology and modern control theory (Okhtilev, Sokolov, Yusupov 2006; Ivanov, Sokolov, Kaeschel 2010; Ivanov, Sokolov 2010; Sokolov, Ivanov, Fridman 2010). The suggested newly designed information technology is based on decision of basic research problem. This problem is monitoring and control of states of CO and complex process (situation assessment). The basis of this artificial intelligent information technology is flow computing models exploitable by state hipping (constraint programming) in real time. According to accepted classification the present technology covers the following levels of information fusion (Steinburg, Bowman, White 1998):

Level 1: Data fusion for object assessment;

Level 2: Information fusion for situation assessment;

Level 3: Information fusion for situation prediction.

In addition to solving research problems it is necessary to develop ways and organizational forms of the most effective implementation of the proposed IMT. This is the second objective of the research.

2. THE MAIN TASKS AND RESULTS OF INVESTIGATION

2.1. Investigation overview and related work

Analysis of a market dealing with modern software complexes oriented to monitoring automation for the states of complex technological processes shows that the existing software complexes have narrow application scopes strictly specified by controlled objects; they also have limited capacities for adaptation to environmental disturbances. This is why there exist many monitoring applicable software complexes having contiguous functionality and differing in organizational methods of computational processes, and in used operational environment. As an example three directions in practical implementation of analyzed software complexes could be mentioned (Steinburg, Bowman, White 1998; Okhtilev, Sokolov, Yusupov 2006; Norenkov 1998; Okhtilev 1999; Okhtilev 2000; Sethi and Thompson 2006):

1. Widely applied real time dynamic expert systems like G2 (software firm Gensym, USA), RT Works (software firm Talarian, USA), COMDALE/C (Comdale Techn., Canada), COGSYS (SC, USA), ILOG Rules (ILOG, France) are worth mentioning.
2. The results received through application of a so-called theory of unfinished computing based on constraint programming methods and the theory of multi-agent artificial intelligent systems. The following software packages demonstrate some advantages of this approach: integrated software product SPRUT (OCTORUS) and intelligent mathematical problems solver UniCalc.
3. The third direction incorporates so-called data fusion and control systems like SCADA-systems (Supervisor Control and Data Acquisition – data fusion and control system, operator’s interface, etc.). Well known products: Genesis, IsaGRAF, TraceMode could be good examples of this development line.A profound study of theoretical results showed that there exists a great number of publications in the area of measuring information processing and analysis methods, on the other hand, research in the areas of design automation for monitoring software complexes, development of techniques allowing to arrange for parallel processing and analysis of measuring information in computing environment with changing structure are poorly reflected in literature. The impact of types and structures of the processed information on the composition and structure of the considered software complexes is not well investigated either.

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Development of flow-oriented knowledge-representation models, methods, and algorithms for monitoring and control of objects and for reconfiguration of monitoring system plays the important role in decision of the main problems of synthesis and intellectualization of monitoring technology and system for complex technical objects under dynamic conditions in real time. This task includes the following subtasks:

- development of methodological basics for accumulation and use of ill-formalized knowledge about states of complex technical objects under "rigid" constraints (for example, real-time operation mode and recurrence of computational processes) applied to both process of knowledge accumulation and process of state estimation; development of methodological basics for structure reconfiguration of objects and of monitoring system (first line of investigation);

- development of model-and-algorithmic basics for analysis and synthesis of reconfigurable monitoring system (second line of investigation);
- development of new information technology for creation and maintenance of monitoring software and software prototype; approbation of the technology in typical application domains (third line of investigation).

Our investigation in the area of the structure dynamics control problems have shown that these problems belong under the class of the CO structure – functional synthesis problems and the problems of program construction, providing for the CO development (Sokolov, Yusupov, Okhtilev, Maydanovich, 2010; Okhtilev 2004; Okhtilev, Vasiliev 2004; http://litsam.ru).

The main feature and the difficulty of the problems, belonging under the above class is a follows: optimal programs, providing for the CO main elements and subsystems control can be implemented only when the lists of functions and of control and information-processing algorithms for these elements and subsystems are known.

In its turn, the distribution of the functions and algorithms among the CO elements and subsystems depends upon the structure and parameters of the control rules, actual for these elements and subsystems. The described contradictory situation is complicated by the changes of CO parameters and structures, occurring due to different causes during the CO life cycle. At present the class of problems under review is not examined quite thoroughly (Okhtilev, Sokolov, Yusupov 2006; Sokolov, Yusupov, Okhtilev, Maydanovich, 2010; Okhtilev 2004; Okhtilev, Vasiliev 2004; http://litsam.ru). The new theoretical and practical results were obtained on the following lines of the investigation: *the synthesis of the CO technical structure for the known laws of CO functioning (the first direction); the synthesis of the CO functional structure, in other words the synthesis of the control programs for the CO main elements and subsystems under the condition that the CO technical structure is known (the second direction); the synthesis of programs for CO construction and development without taking into account the periods of parallel functioning of the actual and the new CO (the third direction); the parallel synthesis of the CO technical structure and the functional one (the forth direction).*

Several iterative procedures for solving of the joint problems, concerning the first and the second directions are known at present. Some particular results were obtained within the third and the forth directions of investigations. All the existing models and methods for the CO structure – functional synthesis and for the construction of the CO development programs can be applied during the period of the internal and external design when the time factor is not very essential. Therefore, the development of new theoretical and technologies bases for CO structure-dynamics monitoring and control which are based on integrated ground and aerospace data is very important now.

2.2. The results of investigations

Within the first line of investigations the following scientific and practical results have been obtained by now.

It was established that the change from an automated processing of measuring information to a computer-aided analysis of received materials involves semantic aspects of data representation in place of syntactic ones. Thus, the information about control objects should rather be regarded as a set of interrelated parameters jointly characterizing objects' technical state than a simple collection of measurements. This provided for a conclusion that the metric-space concepts, typically used in simple monitoring problems, are weak and not suitable for our purposes, hence more general constructions should be used.

It was proved that the parameters of objects' technical states can be described via a system of open sets forming a base of topology. It was assumed that the set of parameters has a topological structure. Thus a system of neighborhoods (meeting the axioms of topological spaces) was established for each element. The notion of a technical state was worked out. By the technical state we meant an abstract collection of data including whole information both about object's current attributes and the state of computations within the monitoring process. This view lets optimize computations in order to receive monitoring results in real time. The following basic statements were proved: the whole set of technical-state parameters constructed trough the proposed model of knowledge representation is a lattice or a lattice ordered set; if the set of technical states have the greatest element and the least element (defining the initial data and the results correspondingly), then a complete lattice (an algebra over the set) can be formed via a construction of additive and multiplicative lattices; necessary and sufficient conditions for topology base existence were obtained for the set of technical parameters. The last result is very important, as the constructed topology is used for whole description of possible technical states and for planning of states analysis (for construction of computational scheme).

Moreover w*ithin the first line of investigations* we have been obtained the following the results (Okhtilev, Sokolov, Yusupov 2006):

- Formal description of all possible kinds of controlled states (assessed situation) accounting for their adequacy to actual actions and processes on controlled object caused by application of different mathematical apparatus for various functional objects. Multi-model formalization intends for describe actions and processes on the controlled object;

- New integrated methods of program synthesis for automatic analysis (AA) of measuring information (MI) about CO states were worked out. These methods, as distinct from known ones, give an opportunity of, firstly, interactive intellectual processing of data and knowledge about CO states for different physical properties (for example, functional parameters, range parameters, signal and code parameters, and integrated parameters) and for different forms of states description without reference to their physical features and, secondly, automatic generation of alternative program schemes for MI analysis according to the objectives of CTO control under the presence of changing environment;
- New algorithms of automatic synthesis of AA MI programs were proposed for poly-model description of monitoring processes via attribute grammars, discrete dynamic systems, and modified Petri nets. Applying of polytypic models resulted in adequate adaptation of the algorithms to different classes of CO. Another distinguishing feature of the algorithms lied in application of underdetermined calculation and constraint-driven programming and provided that CTO states could be estimated rather adequately even if some parameters were omitted and the measuring information was incorrect and inaccurate;
- A general procedure of automatic (computer-aided) synthesis of CO monitoring programs was developed. This procedure includes the following steps (Okhtilev, Sokolov, Yusupov 2006; Okhtilev 1999; Okhtilev 2000; Sokolov, Yusupov, Okhtilev, Maydanovich, 2010; Okhtilev 2004; Okhtilev, Vasiliev 2004).

The 1st step. Description of conditions and constraints for the problem of AA MI programs synthesis via a special network model connecting input data with goals. An operator (he need not be a programmer) uses a special problem-oriented language to execute this step.

The 2nd step. Automatic existence analysis for a solution of AA MI problem that is defined via a formal attribute grammar.

The 3rd step. If the solution exists then the alternative schemes for AA MI programs are generated and implemented in a special operational environment (problem solver of the CTO monitoring system).

The main advantage and substance of the proposed procedure is simple modeling of MI sources (models generation) that can be performed by a non-programming operator in the shortest time and the real-time implementation of the intellectual methods and algorithms of MI processing and analysis for arbitrary structure of the measuring information.

The proposed methods of monitoring automation and modeling let switch from heuristic description of the telemetry analysis to a sequence of well-grounded stages of monitoring program construction and adaptation, from unique skills to unified technologies of software design. These methods are based on a conclusion that a functional description of monitoring process is much less complicated than detailed examination of software realizations. Consecutive specification of software functions is the ground of technologies to be used for creation of monitoring systems. The suggested technology of continuous design process includes such well-known phases as new proposal phase based on special operational environment (Sokolov, Yusupov, Okhtilev, Maydanovich, 2010; Okhtilev 2004; Okhtilev, Vasiliev 2004).

Within the second line of investigations the following scientific and practical results have been obtained by now (Okhtilev, Sokolov, Yusupov, 2006; Ivanov, Sokolov, Kaeschel 2010; Ivanov, Sokolov, 2010; Sokolov, Ivanov, Fridman 2010).

System analysis of the ways and means to formalize and solve the problem of the control over structure dynamics of monitoring system (MS) servicing CO under changing environment was fulfilled. It was shown that the problems of structure-functional synthesis of monitoring systems and intellectual information technologies as applied to complex technical objects and the problems of CO structure reconfiguration are a special case of structure-dynamics control problem. Other variants of structure-dynamics control processes in MS are: changing of MS objectives and means of operation; reallocation of functions, tasks, and control algorithms between MS levels; control of MS reserves; transposition of MS elements and subsystems.

The basic concepts and definitions for MS structure-dynamics control were introduced. It was proposed to base formulating and solving of the structure-dynamic control problems on the methodologies of the generalized system analysis, the modern optimal control theory for the complex systems with reconfigurable structures and artificial intelligence. The stated methodologies find their concrete reflection in the appropriate principles. The main principles were marked out: the principle of goal programmed control, the principle of external complement, the principle of necessary variety, the principles of poly-model and multi-criteria approaches, the principle of new problems.

During our investigations the main phases and steps of a program-construction procedure for optimal structure-dynamics control in MS were proposed. At the first phase forming (generation) of allowable multi-structural macro-states is being performed. In other words a structure-functional synthesis of a new MS make-up should be fulfilled in accordance with an actual or forecasted situation. Here *the first-phase* problems come to MS structure-functional synthesis.

At *the second phase* a single multi-structural macro-state is being selected, and adaptive plans (programs) of MS transition to the selected macro-state are constructed. These plans should specify transition programs, as well as programs of stable MS operation in intermediate multi-structural macro-states. The *second phase* of program construction is aimed at a solution of multi-level multi-stage optimization problems.

One of the main opportunities of the proposed method of MS structure dynamics control (SDC) program construction is that besides the vector of program control we receive a preferable multi-structural macro-state of MS at final time. This is the state of MS reliable operation in the current (forecasted) situation. The combined methods and algorithms of optimal program construction for structure-dynamics control in centralized and non-centralized modes of MS operation were developed too.

The main combined method was based on joint use of the successive approximations method and the "branch and bounds" method. A theorem characterizing properties of the relaxed problem of MS SDC optimal program construction was proved for a theoretical approval of the proposed method. An example was used to illustrate the main aspects of realization of the proposed combined method.

Algorithms of parametric and structural adaptation for MS SDC models were proposed. The algorithms were based on the methods of fuzzy clusterization, on the methods of hierarchy analysis, and on the methods of a joint use of analytical and simulation models

The SDC application software for structure-dynamics control in complex technical systems was developed too.

Within the third line *of investigations the following scientific and practical results have been obtained* by now the pilot versions of computer-aided monitoring system (CMS) for CO states supervision (in space systems and atomics); it uses special operational environment (Sokolov, Yusupov, Okhtilev, Maydanovich 2010; Okhtilev 2004; Okhtilev, Vasiliev 2004), real-time database management system, multi-window interface, and programming language C/C++.

The prototypes of CMS belong under the class MMI/CACSD/SCADA/MAIS (man-machine interface/ computer-aided control system design/supervisory control and data acquisition/ multi-agent intellectual system).

Table shows technical and operating characteristics of the developed software prototype.

CONCLUSION

The new intelligent monitoring technology (IMT) considered provides integrated use of the available information of complex objects states and about a critical situation and its predictable consequences.

Table: Peak capacity and characteristics of monitoring software prototype for co state supervision

CHARACTERISTICS	VALUES OF CHARACTERISTICS
The number of parameters to be simultaneously analyzed	up to 1.6×10^{7}
Parameter range for integer parameters	from –2147483648 to +2147483647
Parameter range for real parameters	15 decimal digits with exponent part from –307 to +308
The number of parameters to be analyzed within one session	up to 6×10^{10}
Time accuracy for all events and phenomena	up to 10^{-3}
Complexity of unified structures	– situation matrix (up to 512 situations); – finite-automaton models; – linear-bounded automatons; – unique models of an arbitrary strength; – universal applications.
The number of forms	Is restricted according to ergonomic and hardware limitations.

The main possibilities of the IMT are shown below:

- The real-time processing of a considerable quantity of diverse parameters;
- The data and knowledge simultaneous processing;
- The intelligent analysis providing of the measuring information of any physical nature on the distributed computer complexes;
- The results visualization of the processing in a 2D and 3D format, the interface with geoinformation systems implementation;
- The ability for creation of concrete monitoring systems for non-professional users (non-programmers).

The IMT developed is based on interdisciplinary methodology of creation and application of any information technology. Besides, it lets consider functioning dynamics and possible structure degradation of complex objects in critical situations, and operate structural dynamics of complex objects. Unlike existing systems, the IMT is universal, it includes the combined methods and algorithms of decision making in various classes of monitoring problems, forecasting and safety control of complex objects regardless to their appointment.

Now IMT is successfully implemented in monitoring systems serving space branch, nuclear engineering, and the chemical industry.

IMT also can find applications in the situational centers, decision-support systems for management of emergency situations, monitoring of the difficult natural processes requiring processing and visualization of a considerable quantity of the diverse data.

The possibility of creation distributed, cross-border monitoring solutions for global ecosystems is supported by the IMT. The monitoring system mentioned is being used for the forecasting and the risk reducing of natural and anthropogenic accidents impacts. This is the reason for use the IMT as foundation of the actually nascent International Global Monitoring Aerospace System (IGMASS).

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