Information and Telecommunication Intellectual Monitoring Technology and System for Complex Technical Objects under Dynamic Conditions in Real Time

Michael Yu. Okhtilev, Boris V. Sokolov, Alexey V. Vinel and Eugene M. Zaichik
St.-Petersburg Institute for Informatics and Automation
39, 14th Line, Spiiran, St. Petersburg, 199178, Russia

Abstract. The aim of the investigation is to develop methods, models and algorithms of synthesis and intellectualization of monitoring technology and system oriented to concurrent on-line user software assurance for all sorts of measuring information specifying states of complex technical objects under dynamic conditions in real time. This aim should be achieved by here suggested artificial intelligent information technology. The basis of this artificial intelligent information technology is flow computing models exploitable by state hipping (constraint programming) in real time and in territorially distributed computing network. At the same time each network node represents artificial intelligent agent. Furthermore, the problem of efficient information transmission between the complex technical objects and monitoring systems by means of contemporary wireless technologies is considered.*

1 Introduction

Many complex technical objects (CTO) are remotely controlled [1, 2, 3]. Operators (dispatchers) receive information about current CTO states in a form of telemetry. Complication of modern technical objects 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 [4, 5]. Usually CTO state monitoring is not automatized completely. Thus, operators receive semantic information about some elements of CTO rather than information characterizing integral CTO state. To estimate CTO state the operators should be able to analyze various context conditions of interaction between CTO elements and subsystems. There are no universal methods and technologies for solution of the above-mentioned problems [6, 7]. Existing program systems for gathering, processing, and analysis of CTO telemetry usually depend on characteristics of particular control objects and is

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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 CTO monitoring were investigated rather thoroughly in USA and in Russia (former USSR), first of all for aerospace and electric power systems [7]. The most important results were received in this domain. However, semantic interpretation of integral CTO state remains the prerogative of operators.

Other feature of modern monitoring system for CTO (MS CTO) is the changeability of their parameters and structures as caused by objective and subjective reasons at different stages of the MS CTO life cycle. In other words we always come across the MS CTO structure dynamics in practice. Reconfiguration is a widely used variant of the MS CTO structure control. Reconfiguration is a process of the MS CTO structure alteration with a view to increase, to keep, or to restore the level of MS CTO operability, or with a view to compensate the loss of MS CTO efficiency as caused by the degradation of its functions. But, unfortunately, now MS CTO reconfiguration is not tied in with monitoring and control processes [2, 8 9].

So the following main problems complicate formalization of state-monitoring process and systems under dynamic conditions now: firstly, the rules of CTO interaction cannot be discovered and described in a simple way, secondly, there are no universal methods of interaction representation for a broad class of objects and finally, there are no universal methods and models of MS CTO optimal reconfiguration under dynamic condition [8,10]. We consider that description of monitoring procedures and system should be based on system methodology and modern conception of intelligent information technology in order to fit various classes of CTO. This description must be clear to different specialists implementing general rules of monitoring to particular objects. Our investigation contributes to a solution of the fundamental problem lying in synthesis and intellectualization of monitoring and control processes for complex technical objects under dynamic conditions via multiple-model complexes and multicriteria approaches.

So the first aim of our investigation is to develop methods, models and algorithms oriented to concurrent on-line user software assurance for all sorts of measuring information (information fusion) specifying states of complex technological process (situation assessment) at all phases of complex technological process life cycle and control function in real time. The second aim of our investigation is a development of models, methods and algorithms for real-time monitoring system reconfiguration under the presence of structure degradation.

Additionally, we develop simulation and analytical models as well as conduct testbed experiments for the analysis of the efficient monitoring information transmission between the MS and CTO. We believe that contemporary wireless communication technologies should be used for this purpose, especially for the cases when CTO are located distantly and in the regions difficult of access from the MS CTO. Due to the requirement of monitoring in real-time, communication technology should be chosen and configured appropriately in order to provide desired time-probabilistic characteristics of the transmission. This problem becomes challenging in wireless environment, where characteristics of the communication channel may significantly vary in time. Therefore, the third aim of our investigations is to conduct performance analysis and optimization of contemporary wireless protocols and standards.

2 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 [4, 6, 11]:

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, Trace-Mode could be good examples of this development line.

A thorough 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 [12, 13, 14]. The impact of types and structures of the processed information on the composition and structure of the considered software complexes is also not well investigated. The above-mentioned circumstances become important if to account for the fact that a certain successful experience in practical realization of software complexes for monitoring of states of complex technological process is based upon the better solutions of structural and functional as well as organizational problems dealing with the synthesis of software complexes. However, experimentally received positive results in software complexes for monitoring creation and implementation are of the heuristic nature and are based on intuition and experience of developers; their elaboration also requires time-consuming, labor-intensive experiments at the synthesis stage. Moreover, the existing methodology and software do not meet certain requirements for embedded special software of geographically distributed real-time complex technological systems with variable structures [14].

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).

As a relatively separate subtask we emphasis the problem of performance evaluation of wireless communication protocols by means of analytical models, simulations and test-bed experiments. We consider the following contemporary wireless technologies IEEE 802.11 Wi-Fi, IEEE 802.16 WiMAX, IEEE 802.15.14 ZigBee etc. Our objective is to identify, design, test and evaluate wireless network technologies and architectures, which are able to interconnect CTO in an energy-efficient, secure, robust, and powerful way to MS CTO under dynamic conditions to guarantee real-time stable monitoring process. Mechanisms based on the conceptions of cognitive network for stable and energy-efficient operation of wireless mesh and sensor networks are required.

Cross-layer design conception is becoming increasingly important in wireless networks. They abuse the traditional layered approach by direct communication between nonadjacent layers or distribution of internal information among layers [21]. Cognitive radio is a paradigm in which either a network or a wireless node changes its transmission or reception parameters to communicate powerfully avoiding interference [22]. The cognitive radio concept is extended also to higher protocol layers, what results in the introduction cognitive networks [23]. A cognitive network can recognize current network conditions and adapt accordingly. The network can learn from these adaptations and use them to make decisions in the future.

Therefore, the forth line of investigations is the development of new protocols and architectures based on the above paradigms as well as performance evaluation of internationally standardized protocols.

3 The Results of Investigation

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 [18, 19, 20]:

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 CTO states were worked out. These methods, as distinct from known ones, give an opportunity of, firstly, interactive intellectual processing of data and knowledge about CTO 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 CTO. 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 CTO monitoring programs was developed. This procedure includes the following steps.

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 [18, 19, 20].

Within the second line of investigations the following scientific and practical results have been obtained by now [10].

System analysis of the ways and means to formalize and solve the problem of the control over structure dynamics of monitoring system (MS) servicing CTO 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 CTO 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 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 CTO states supervision (in space systems and atomics) work in network of IBM/PC-compatible computers; it uses special operational environment [18, 19, 20], 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).

Within the forth line of investigations the following scientific and practical results have been obtained by now: sufficient number of different analytical and simulation models for contemporary wireless networks, methods to compute time-probabilistic characteristics and to optimize the performance of these networks (e.g. [24], [25]).

4 Conclusions

Suggested intelligent information technology will allow reducing costs of complex technological process underlying the elaboration of a system for monitoring and control of states of complex technological process, and will facilitate significantly its further modification. At that systems for real time monitoring of states of complex technological process acquire principally new qualities. Particularly they allow monitoring in real time the states of complex technological process characterized by great number of measured parameters under structure reconfiguration of the controlled objects. The proposed information technology rises the automation level of complex technological processes control, increases possibilities of control of objects under degradation of their structures, improves reliability and efficiency of control processes, increases possibilities of early detection of various technical faults as well as timely prediction of catastrophes allowing to make right decision and to undertake appropriate prevention measures. The proposed approach to the problem of MS structure reconfiguration control in the terms of general context of MS structural dynamics control enables the following: common goals of MS functioning can be directly linked with those implemented (realized) in MS control process; a reasonable decision and selection (choice) of an adequate consequence of problems to be solved and operations to be fulfilled related to structural dynamics can be made (in other words, MS control method can be synthesized and developed); a compromise(trade-off) distribution of a restricted resources appropriated for a structural dynamics control can be found without additional expenses.

References

1. Klir, G.J. (1985). Architecture of Systems Problem Solving. Plenum Press, New York.
2. Sokolov B.V., Yusupov R.M. Complex Simulation of Automated Control System of Navigation Spacecraft Operation// Journal of Automation and Information Sciences (2002), Vol. 34, #10, 19 –30.
3. Arkhipov A.V., Ivanov D.A., Sokolov B.V. Intelligent Supply Chain Planning in 'Virtual Organization'// PRO-VE'04 5th IFIP Working Conference on Virtual Enterprises, France, Toulouse (2004), Proceedings, Vol.8, Part 8, 215-224.
4. Steinburg, Alan N., Bowman, Christopher L., White, Franklin E. Revisions to the JDL Data Fusion Model, presented at the Joint NATO/IRIS Conference, Quebec (1998).
5. Okhtilev M.Yu. Specifics of technology for development of special computer-aided systems analizing information measured in real-time //Automatic Control and Computer Science, Allerton Press Inc., New York, Vol. 39, # 6 (2001).
6. Okhtilev M.Yu. New Information Technology for Designing and Exploitation of Software for Monitoring of the Complex Technical Objects in Real Time (2001) //http://www.edi.lv/journal/raksti/ohtilev.htm.
7. Okhtilev M.Yu. Theoretical Basics for Real-Time Computer-Aided Analysis of Telemetry Information. Synthesis of the Analysis System. SPb: Mozhaisky University (1999).
8. Sokolov B.V. Optimal Structure Reconfiguration in a Complex-Technical Systems (MS): principles, models, methods and algorithms for the MS structure dynamics control // VI ISTC Scientific Advisory Committee Seminar "Science and Computing", Moscow, Russia, (2003) Proceedings, Vol. 1. 142 –149. //www.istc.ru/istc/db/sem.nsf/wu/S0310012.
9. Sokolov B.V. Yusupov R.M. Conceptual Foundations of Quality Estimation and Analysis for Models and Multiple-Model Systems // Journal of Computer and System Sciences International (2004) #6 (accepted for publication in USA).
10. http://www.spiiras-grom.ru.
11. Norenkov I.P. The approaches to designing of automation systems //Information Technology (1998) Vol. 2. 2-9.

12. Okhtilev M.Yu. Topology in a set of measurable and computable parameters in real-time estimation of the state of complex technical objects //Automatic Control and Computer Science, Allerton Press Inc. New York. Vol. 33 # 6 (1999) 1-8.
13. Okhtilev M.Yu. Topological approach to construction of computation algorithms in real-time estimation of complex technical objects //Automatic Control and Computer Science, Allerton Press Inc. New York. Vol. 34. #1 (2000) 8-16.
14. Okhtilev M.Yu. Construction of Programs for Real-Time Processing and Analysis of Measuring Information //Programming and Computer Software», Kluwer Academic/Plenum Publishers (2001).
15. Napolitano M.R., Swaim R.L. A New Technique for Aircraft Flight Control Reconfiguration // Proc. AIAA Guidance, Navigation and Control Conf. (1989) Pt 1, 1-9.
16. Napolitano M.R., Swaim R.L. An Aircraft Flight Control Reconfiguration Algorithm // Proc. AIAA Guidance, Navigation and Control Conf. (1989) 323-332.
17. Siliak, D.D. (1990) Decentralized Control of Complex Systems, Academic Press, New York.
18. Sokolov B.V., Okhtilev M.Yu. Data Flow and Distributed Calculations Technology for Decision of Information Fusion Tasks in Real Time // VI ISTC Scientific Advisory Committee Seminar "Science and Computing", Moscow, Russia (2003) 70-72, http://www.istc.ru/istc/db/sem.nsf/wu/S0310012
19. Okhtilev M.Yu. The Data Flow and Distributed Calculations Intelligence Information Technology for Decision Support System in Real Time // ICEIS 2004, Proceedings of the 6th International Conference on Enterprise Information Systems, Porto, Portugal (2004). Vol.2. 497-500.
20. Okhtilev M. Yu., Vasiliev I. Ye. The data flow and distributed calculations intelligence information technology for decision support embedded system in real time // 16th IFAC Symposium on Automatic Control in Aerospace (2004), Saint-Petersburg, Russia, Vol. 2 235-239.
21. Srivastava V., Motani M. Cross-layer design: a survey and the road ahead, IEEE Communications Magazine, December (2005).
22. Akyildiz I, Lee W., Vuran M., Mohanty S. A Survey on Spectrum Management in Cognitive Radio Networks, IEEE Communications Magazine, April (2008).
23. Thomas R., Friend D., Dasilva L., Mackenzie A. Cognitive networks: adaptation and learning to achieve end-to-end performance objectives, IEEE Communications Magazine, December (2006).
24. Ni Q., Vinel A., Xiao Y., Turlikov A. Jiang T. Investigation of Bandwidth Request Mechanisms under Point-to-Multipoint Mode of WiMAX Networks, IEEE Communications Magazine, Vol. 45, № 5 (2007).
25. Vinel A., Ni Q., Staehle D., Turlikov A. Capacity Analysis of Reservation-Based Random Access for Broadband Wireless Access Networks // IEEE Journal on Selected Areas in Communications, Special Issue: Broadband Access Networks: Architectures and Protocols, Feb., pp. 172–181 (2009).