Information software of multi-level systems of monitoring and diagnostics of complex technical objects

Hanna Martyniuk[a], Nadiia Marchenko[b], Olena Monchenko[b], Larysa Chubko[b] and Tetiana Scherbak[b]

[a] *Mariupol State University, Povitroflotsky ave. 31, Kyiv, 03037, Ukraine*
[b] *National Aviation University, Liubomura Huzara ave.1, Kyiv, 03058, Ukraine*

Abstract

The article is considered intellectual information systems for monitoring and diagnosing complex technical objects, considering modern information technologies. Computer intellectualization ways of the functioning modes of such complex technical objects are shown. The analysis of efficiency parameters is carried out and made it possible to determine the main task decomposition of developing methods and means of building adaptive systems of multi-level monitoring and diagnosis of complex technical objects. The peculiarity of the work is to solve the building systems complex task of multi-level monitoring and diagnosing complex technical objects as integrated systems based on the self-organization principles of complex systems. The proposed two-level system for monitoring and diagnosing the condition of complex industrial facilities, which differs from analogues in the ability to automatically select the optimal operating modes of subsystems when the characteristics of the incoming flow of applications change, is a single approach that allows synthesizing the optimal structure of multi-level monitoring and diagnosis systems at the design stage and choosing the optimal operating mode of subsystems during operation. The research method of multi-level monitoring and diagnosis systems based on the multi-level model of mass service using the block of adaptation to changes in the intensity of the incoming flow is presented. The work presents the development of a generalized criterion for assessing the effectiveness of research into systems of multi-level monitoring and diagnosis of complex technical objects and partial criteria for each subsystem, as well as research and analysis of methods and means of organizing adaptive systems of multi-level monitoring and diagnosis of complex technical objects and the selection of effective modes work.

Keywords 1 Automated control systems, multi-level monitoring and diagnostics systems, adaptive multi-level monitoring and diagnostics systems, assessment of effectiveness, multi-level mass service models.

1. Introduction

Modern atomic, thermal and hydroelectric power plants, chemical and metallurgical productions, and large production enterprises are complex technical objects (CTO) operating under conditions of significant wear and tear of the main and auxiliary equipment. In the conditions of slow modernization, the only possibility of maintaining the operational efficiency of equipment is the development and application of object monitoring systems for the purpose of the timely and comprehensive analysis of

ITTAP'2022: 2nd International Workshop on Information Technologies: Theoretical and Applied Problems, November 22–24, 2022, Ternopil, Ukraine
EMAIL: ganna.martyniuk@gmail.com (A. 1), nadiiamar@gmail.com (A. 2); monchenko_olena@ukr.net (A. 3), chubkolarysssa@gmail.com (A. 4); tais2004@i.ua (A. 5).
ORCID: 0000-0003-4234-025X (A. 1); 0000-0001-5008-4116 (A. 2); 0000-0002-8248-5704 (A. 3); 0000-0003-4647-3156 (A. 4); 0000-0003-1170-8154 (A. 5).

technological processes taking place, diagnosis of the condition, determination of the residual resource and forecasts of future behavior [1, 2].

Monitoring systems used in industry, built on the basis of classical information and measurement systems, have some drawbacks [3]. They are designed for enterprises of a certain profile, are highly specialized, and can work only with a specific object, they are subject to the influence of external destabilizing factors that lead to failures and malfunction; poorly adapted to changes in the processes in the object, do not take into account the influence of the human factor; they are poorly protected against unauthorized, intentional or accidental interference with their work.

Systems of multi-level monitoring and diagnostics (SMMD) are partially devoid of the mentioned shortcomings. Compared to classical information and measurement systems, SMMD have increased resistance to external factors, increased security, and ensure the security of data transmission [1, 2]. The application of this concept (including in multi-level information and measurement systems (IMS) of monitoring and diagnostics) assumes that maintenance and repair of CTO should be carried out according to the actual condition [4]. That's why a much larger part of the equipment must be covered by reliability assurance systems, which must carry out constant or periodic control of its actual technical condition.

According to well-known sources, the tasks listed above sometimes are combined under the general name "Asset Management" [5]. Currently, both engineering and scientific work in this field is actively being conducted, leading manufacturers of powerful electrical equipment and it has already offered a number of software products designed to collect and summarize statistical information about operating conditions and the actual condition of CTO equipment.

Numerous publications aimed at solving the above-mentioned problems, we could point out works [5, 6, 7, 8], each of which considers certain issues related to the use of monitoring and diagnostic systems.

Thus, the work [6] is devoted to the issues of preliminary preparation of experimental data before their further processing by computing means, in particular, with the help of IMS monitoring and diagnostics. Moreover, data preparation has performed according to certain algorithms presented in this work and has provided an opportunity to reduce their volume for further processing. The work [7] is devoted to the issues of ensuring two-way exchange of information between different levels of electric power facilities. The paper presents the results of a complex experimental study with the statistical characteristics determination of information exchange wireless channel between objects at a power substation with a voltage of 500 kV. The paper [8] is considered the application of monitoring the state methods of individual power transformer units based on the use of informational diagnostic signals.

In recent years, the main directions of scientific research of the SMMD are methods of obtaining, transmitting, storing, monitoring and diagnosing information, improving the methods of processing the received data. The starting points for building models of objects are the results of measurements of their parameters, as well as data about the environment [9, 10]. Objects have a multi-level structure that are changing over time. Their state and behavior are typically described in discrete time and discrete state space.

The methods of constructing models of monitoring and diagnostic objects (MDO) that are currently used, in many respects, do not meet the requirements of practice. Due to the complexity of the tasks to be solved, their construction requires significant time costs, as well as costs of human and other resources. In addition, the emerging MDO models are not always accurate and reliable. Thus, the problem of building MDO models and their application to solving applied problems is relevant [1, 2, 11].

The integration of multi-level monitoring and diagnostics necessitated the creation of methods and means of building the SMMD. At the present stage, the problem of developing methodological principles for the construction of automated SMMD for the class of complex industrial facilities (HPP, TPS, NPP) is becoming particularly relevant [12, 13].

Certain difficulties arise in the event of the need to rebuild the structure of the monitoring system, change the algorithm of its work, solve scaling tasks, and process large data flows. Therefore, the development and research of SMMD, combining the ability to work reliably in harsh operating conditions with flexibility of application and competitive cost, is a serious scientific problem, and the solution of which is of great importance for domestic science and technology [1,7]. The use of work results increases the safety of operation of CTO, which is a significant contribution to the development of the economy of our country. Based on the above, the research topic is relevant.

The purpose of the work is the development and research of SMMD, which provide effective and high-quality monitoring of the parameters of complex technical objects with the simultaneous saving of material resources for the design, implementation, and operation of CTO.

To achieve the goal, the following scientific tasks were solved:

- to analyze the subject area of building models of observed objects based on the data of multi-level monitoring and diagnostics of their conditions. To formulate a scientific problem, to determine the requirements for multilevel models and methods of their synthesis.
- formulate construction principles, develop a structural diagram and a mathematical model of the SMMD;
- to develop and research mathematical models of the main functional components of SMMD, based on the proposed models to develop methods for determining system parameters and algorithms for synthesizing their optimal characteristics;
- justify the expediency of using intelligent information processing methods in SMMD, develop decision-making models and knowledge presentation, offer hardware and software tools for the implementation of intellectual systems; analyze the method of choosing the channels number, and develop algorithms for optimizing the multilevel signal conversion function, which, due to their versatility, can be used in related fields of science and technology.

2. Development of theoretical and practical principles and mathematical models for the study of multi-level monitoring and diagnostics systems

In the process of analysis, it was found that complex technical objects have a number of features: multifacetedness and uncertainty of behavior, hierarchical structure, excess and variety of constituent objects of elements and subsystems, the ambiguity of connections between them, multivariate implementation of management functions, territorial distribution. Therefore, in modern conditions, the development of methods, algorithms, and technical means of state constant monitoring of a complex object, analysis of the processes taking place in it, diagnosis, and prediction of the object's behavior in the future is becoming very relevant. The most effective multi-level monitoring tool is information and measurement systems, mathematical models, the theory of choice, and decision-making [2, 8].

The main problems in the intellectualization of SMMD are the formation and selection of the researched object model; selection of measurement and control methods; parameters selection of the measured object; system efficiency assessment.

The selection of existing methods, the method of logical inference based on the application of the theory of fuzzy sets, and the solution of the optimization problem were considered as a decision-making strategy.

2.1. Development of a mathematical model of multi-level monitoring and diagnostics systems

To assess the possibility of restoring multidimensional signals, a generalized mathematical model of SMMD was developed, which is determined by the equations [4, 10]:

$$\begin{cases} y_1(x_1,t) = F_1(x_1,x_2,\dots,x_n,a_1,a_2,\dots,a_m,t,z) \\ y_2(x_2,t) = F_2(x_1,x_2,\dots,x_n,a_1,a_2,\dots,a_m,t,z) \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ y_n(x_n,t) = F_n(x_1,x_2,\dots,x_n,a_1,a_2,\dots,a_m,t,z) \end{cases}, \quad (1)$$

y – output signals of SMMD; F is a set of operators; x – input processes; a - internal parameters; t - time; z is the influence of the environment.

If the internal parameters $a_1, a_2, \ldots, a_m$ are constant, the model can be considered dynamic deterministic and represented using Liapunov-Likhtenshtein operator [10]:

$$\begin{cases} y_1(x_1,t) = F_{LL}[x_1(t)] = \sum_{i=0}^{\infty} \int_0^t \ldots \int_0^t k_i(t,\tau_1,\tau_2,\ldots,\tau_i) x_1(\tau_1), x_1(\tau_2),\ldots, x_1(\tau_i) d\tau_1 d\tau_2 \ldots d\tau_i \\ y_2(x_2,t) = F_{LL}[x_2(t)] = \sum_{i=0}^{\infty} \int_0^t \ldots \int_0^t k_i(t,\tau_1,\tau_2,\ldots,\tau_i) x_2(\tau_1), x_2(\tau_2),\ldots, x_2(\tau_i) d\tau_1 d\tau_2 \ldots d\tau_i \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ y_n(x_n,t) = F_{LL}[x_n(t)] = \sum_{i=0}^{\infty} \int_0^t \ldots \int_0^t k_i(t,\tau_1,\tau_2,\ldots,\tau_i) x_n(\tau_1), x_n(\tau_2),\ldots, x_n(\tau_i) d\tau_1 d\tau_2 \ldots d\tau_i \end{cases} \quad (2)$$

k_i is the feature of the message $x_i$in the multidimensional channel.

Replacing the Liapunov-Likhtenshtein operator with the Volterr series makes it possible to assess the degree of model adequacy of the problems nature to be solved, to analyze the informational, energetic, and metrological characteristics of SMMD. External influences are compensated by system internal parameters:

$$\begin{cases} y_1(x_1,t) = F_\omega\big(x_1(t,z) - y_1(t,a_1,a_2,\ldots,a_m)\big) \\ y_2(x_2,t) = F_\omega\big(x_2(t,z) - y_2(t,a_1,a_2,\ldots,a_m)\big) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ y_n(x_n,t) = F_\omega\big(x_n(t,z) - y_n(t,a_1,a_2,\ldots,a_m)\big) \end{cases} \quad (3)$$

2.2. Characteristics of the SMMD model

As a result of the system structure analysis, information flows and time modes of operation, the SMMD under investigation can be presented in the form of a single-channel multiphase mass service system (MSS) with Puason’s input and output flows, exponential service time of requests in each phase and thinning of the input flow by the first and second phases [1, 11, 12]. The structural diagram of the MSS is presented in fig. 1.

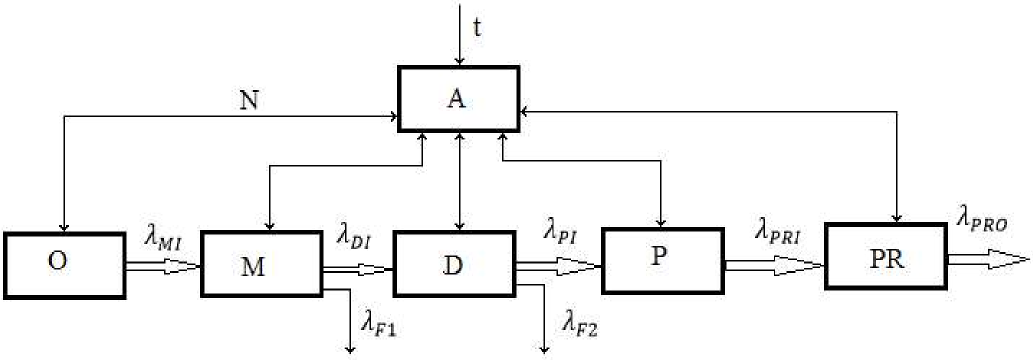

Figure 1: Structural diagram of the mass service system model

The MSS contains N objects of technogenic systems (O), a subsystem of control (M), diagnostics (D), forecasting of the residual resource (P), decision-making (PR) and adaptation (A). The input flow of applications λ_{MI} is first received at the input of subsystem M and is further processed in subsystems D, P and PR. Flows λ_{F1} and λ_{F2} characterize flows of screened applications corresponding to regulated states of complex technical objects.

The work uses the method of researching multiphase systems as a set of serially connected autonomous MSSs, united by joint control with the help of an adaptation subsystem [4, 10]. When creating typical MSSs, the choice of performance is made for the most stressful mode of the system at $\lambda_{MI} = \lambda_{max}$, taking into account the fact that in other cases the system will be guaranteed to work stably. At the same time, the redundancy that occurs during the operation of the system is usually not used [4].

A positive feature of the considered SMMD is that, when$\lambda_{MI} < \lambda_{max}$, the adaptation subsystem A initiates an increase in the service time T_0 for each subsystem and ensures the stability of the load factor of the processing nodes ρ_w according to the following expressions:

$$\rho = f\{\lambda \in V_I\}; \tag{4}$$
$$\rho_w = \rho \leq 1: \left\{T_{sys} \leq T_{sys\,max}, T_0 = \frac{\rho_w}{\lambda_{max}}: D(T_0) \geq D_s\right\};$$
$$T_{OI} = \frac{\rho_w}{\lambda_i}: \lambda_{i-1} \leq \lambda \leq \lambda_i, i = 1, \dots, n;$$

T_{sys} is the time of finding the application in the subsystem, D_s is the minimum permissible reliability of decision-making; λ_i is the current intensity of requests at the input of the subsystem, which is determined on the basis of forecast data and flow thinning coefficients; n is the number of application intensity levels.

Value T_{OI} is a setting parameter for each subsystem as a reaction to a change in λ, and in accordance with which each subsystem automatically rebuilds its functional model taking into account the maximum reliability of decision-making, according to the expression:

$$x_{ij} \in X_i: D_i = maxD_i\{V_2, T_{OI}\}, i = 1,2,3,4; j = 1,2, \dots \tag{5}$$

The selection of SMMD parameters according to (4), (5) allows to implement the algorithm of two-level adaptation of the system. At the first level, the system characteristics ρ i T_{OI} corresponding to the V_1 parameters are selected, at the second level, the subsystem characteristics corresponding to the T_{OI} and V_2 parameters are selected.

So, the work defines a class of complex technical objects, the main feature of which is the difficulty for monitoring and diagnosis, due to the stochasticity of the processes, the complexity of the design, and the lack of information available for control. The need to measure and control the parameters of complex technical objects and analyze the received data in real time is substantiated. The main and most effective tool for monitoring CTO is the information and measurement system, the characteristics of which largely determine the quality of multi-level monitoring and diagnostics. It has been proven that the most promising type of information and measurement systems for solving the existing problems of multi-level monitoring and diagnostics are SMMD, which provide effective, flexible and constant control of CTO parameters under conditions of destabilizing influence of external factors.

3. References

[1] N.B. Marchenko, O.V. Monchenko, G.V. Martyniuk, Multy-level monitoring and diagnostic systems as a constructive development of intellectual information systems, Scientific notes of Taurida National V.I. Vernadsky University, Series: Technical Sciences 32 (2021) 123-127. doi:10.32838/2663-5941/2021.1-1/20. (in Ukrainian)

[2] N.B. Marchenko, T.L. Scherbak, Multy-level monitoring and diagnostic systems of complex technical objects, Modeliuvannia ta Informatsiini Tekhnolohii, Kyiv G.E. Pukhov Institute for Modelling in Energy Engineering NASU, 86 (2019) 82-90. (in Ukrainian)

[3] B.S. Stogniy, O.V. Kyrylenko, O.V. Butkevych, M.F. Sopel, Information support of power systems management tasks, Energetyka: ekonomika, teknologii, ekologiya (2012) 13 – 22.

[4] M. Myslovych, R. Sysak, Design peculiarities of multi-level systems for technical diagnostics of electrical machines, Computational Problems of Electrical Engineering 4 (2014) 47 – 50.

[5] V.C. Gungor, Bin Lu, G.P. Hancke Opportunities and Challenges of Wireless Sensor Networks in Smart Grid, IEEE Transactions on industrial electronics 57 (2010) 3557 – 3564. doi:10.1109/TIE.2009.2039455.

[6] S. García, J. Luengo, F. Herrera, Data Preprocessing in Data Mining. Part of the Intelligent Systems Reference Library book series (ISRL, volume 72), Springer International Publishing, Switzerland, 2015. doi:10.1007/978-3-319-10247-4.
[7] A. Secic, M. Krpan, I. Kuzle, Vibro-Acoustic Methods in the Condition Assessment of Power Transformers, IEEE Access 7 (2019) 83915 – 83931. doi:10.1109/ACCESS.2019.2923809.
[8] G.-P. Zhou, H.-H. Luo, W.-Ch. Ge, Yi-L. Ma, Sh. Qiu, Li-Na Fu, Design and application of condition monitoring for power transmission and transformation equipment based on smart grid dispatching control system, The Journal of Engineering J. Eng. 2019 (2019) 2817-2821. doi:10.1049/joe.2018.8456.
[9] V.V. Il'yin, Introduction to Smart Grid, AVOK 7 (2012) 76 – 86.
[10] S.V. Babak, M.V. Myslovych, R.M. Sysak, Statistical diagnostics of electrical equipment, Institute of electrodynamics of the NAS of Ukraine, Kiev, 2015.
[11] S.M. Gertsyk, Formation of training sets for systems of diagnostics of the electric power equipment taking into account modes of its work, Pratsi Instytutu elektrodynamiky Natsionalnoi Akademii Nauk Ukrainy 52 (2019) 54-61. doi:10.15407/publishing2019.52.054.
[12] N.B. Marchenko Intelligent information systems of complex technical objects. In proceedings of Modern trends in the development of system programming, NAU, Kyiv Ukraine, 2021, pp. 40-41. (in Ukrainian)
[13] O. Nechyporuk, V. Nechyporuk, I.-F. Kashkevich et al, Identification of combinations of faults in multilevel information systems, in: Proceedings of IEEE XVI International conference "The perspective technologies and methods in MEMS Design (MEMSTECH)", Lviv Ukraine, 2020, pp. 76-81.