Development of a new method of management of ergotechnical system on the basis of its dynamics monitoring

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Abstract. This paper explores the state assessment and management of complex human-machine systems that ensure that results are quickly obtained with the desired accuracy. The problem is solved by monitoring the real parameters of the process and comparing them with the results of the simulation, taking into account their fuzziness, incompleteness and lack of definition. The proposed method of solving control problems can be used in a number of subject areas (robotics, aero-space monitoring, etc.).

1. Introduction

In the modern world of digitalization of many technical and socio-economic processes ergatic systems are dominant in both public and private life. The effectiveness of such systems depends not only on their technical perfection and human professionalism, but also on the architecture of the system of their interaction, integrity, self-organization, level of synergy.

One of the necessary conditions of creation of effective system of information support of state management of ergatic systems (further - ES) is the unity of methodological approaches to the synthesis of such systems, giving the opportunity to form the theoretical basis of this synthesis and makes it possible to further standardize the mathematical, information and software processes assessment of the current state of ES from different application fields of engineering, technology, management, etc.

It should be noted that, depending on the specific situation, the features of digital transformation, it can be not only (and even not so much) about the synthesis of a new ES, but about the harmonization and adaptation of the functioning of individual components of the so-called (SoS) - System of Systems [1-3].

Currently, there is no unified methodology for creating systems for assessing the state and functioning of ES, but there is a theoretical basis for its development in the form of general systems theory, artificial intelligence theory, fuzzy logic systems, combinatorial topology, classical control theory [4-5].

2. Problem statement

The purpose of this research is to develop the foundations of adequate modeling within Soft Computing, the development of theory and creation of mathematical models for the assessment of the
state of ergatic systems, providing the construction of tools in the form of mathematical and software intelligent systems and formational support for the state of ES.

This goal can be achieved by solving the following main tasks:

- Analysis of the possibilities of a systematic analysis of the methods and tools used to evaluate ergatic systems, clarification and definition of their role, which will be aimed at solving specific developments;
- Determination of the system of components of the generalized system description of dynamic models of ergatic systems and its constituent parts, including the scientifically-based structural decomposition of ES;
- Carrying out theoretical evaluation of the state of ES and construction on the basis of their classification of new estimates of ergatic systems;
- Definition of structure, role and place of information support systems for ES state management and development of their classifications;
- Development of generalized system-dynamic models and algorithms of human activity within ES.

3. Method of researches

The theoretical and experimental studies carried out by the authors are based on the application of methods of complex systems theory, set theory, combinatorial topology, control and regulation theory, artificial intelligence, ergatic systems theory, as well as engineering psychology and ergonomics.

In real situations, researchers find it convenient to act on the assumption of the chaotic nature of the observed process [6]. As shown in [6-8] the attractor of the system is quite simple to recover, there are also numerical methods for estimating its dimension. Methods of approximate solution of the inverse dynamics problem [2,9], i.e. restoration of the given type of differential equations from experimental data, are developed.

Let the time series be available for measurement characterizing the dynamics of ES \( \{y_k\}, k=1…n \), it is assumed that this series is generated by a system whose discretized form looks like:

\[
\begin{align*}
    x_{k+1} &= f(x_k, \ldots, x_0), \\
    y_k &= g(x_k),
\end{align*}
\]

where \( x \) – this \( n \)-dimensional point in the state space; 
\( y \) - observed one-dimensional process; 
\( k \) - selectable time (number); 
\( f, g \) - function vectors.

The use of discrete models is conditioned to the features of a digital source of initial data about ES state and allows to operate with the data obtained as a result of the experiment.

Phase trajectory representing the state of \( x_k \) dynamic system in time \( t = kT \), where \( T \) is time between measurements. For stable systems under study, the attractor is a point, for vibrational ones is closed trajectories (cycles). For chaotic ones, there is an attractor called strange, in which case the trajectories are contracted into some subset of phase space.

There are several variants of classification of scenarios of transition to chaos:

- through cascade of bifurcation of the doubling period (Feigenbaum);
- through the destruction of a two-dimensional torus or through the destruction of a closed invariant curve (Ruel-Takens);
- alternation in time of almost regular oscillations with intervals of chaotic behavior (Pome-Manneville).

Let’s stay on one of them [8].

The research of scenarios of transition to chaos allows predicting the possibility of chaotic behavior of dynamic system in the control parameters change. To concretize our proposed approach we will use the Ruel-Takens scenario.

Note that the attractor is an invariant characteristic of the system, so it is preserved after admissible transformations. The task considered in the study is to build a model of type (1) \( \{y_k\} \).
4. Simulation of systems with chaotic dynamics based on the evaluation of weak symmetry breaking in the reconstructed attractor

Source data: time series \{y_k\}

Step 1. Lyapunov exponents are calculated by numerical methods [10]. The conditions for the existence of chaos are given in table 1.

Step 2. Recovering the attractor by the method of Packard (delay method) [2,8].

Step 3. If the assumption of chaotic dynamics is confirmed, the presence of symmetries (under conditions of weak symmetry breaking) is checked on the basis of the reconstructed attractor analysis [9-10].

Step 4. According to the accepted symmetries of the Hausdorff-Lee formula the type of equations is built in the minimal invariant diversity [1].

Step 5. The structure of the equations is parametrically identified [2].

Step 6. The qualitative difference between the dynamics of the model and the initial series is estimated.

Step 7. The output is a model in the form of finite difference equations.

The significant number of papers are devoted to the first two steps of the method, so their discussion is beyond the scope of this article. Let’s stop on the fourth step.

The algorithm for finding symmetric sections of reconstructed trajectories under conditions of weak symmetry breaking solves the problem, which is NP-complete, was described in detail in [10].

The algorithm consists of five stages. The initial data of the algorithm are n-dimensional points belonging to the reconstructed attractor in the phase space. The whole algorithm is implemented in the form of a program in MATLAB.

Note that, in fact, there is a check whether the system allows the specified transformations, in conditions of weak symmetry breaking. The latter is verified as the existence of some small quantity that deviates slightly from the symmetric representation.

The algorithm of quantitative assessment of the state of the system model assumes the following sequence of actions:

- formation of Cauchy model based on reconstructed attractor;
- obtaining Jacobi matrix composed of partial derivatives of the right parts of the corresponding differential equations;
- substitution of initial conditions;
- finding own value of the resulting numerical matrix [8] for \( n=3 \) there are three: \( \mu_1, \mu_2, \mu_3 \);
- finding Lyapunov exponents of the first order as the real part of own value \( \lambda_1 = \text{Re} \mu_1 \);
- finding the one-dimensional Lyapunov exponent \( \lambda_1 = \max_j \lambda_1^j \);
- finding \( \lambda_2^1 = \lambda_1^1 + \lambda_2^1; \lambda_2^2 = \lambda_1^2 + \lambda_1^3; \lambda_3^2 = \lambda_3^3 + \lambda_2^1; \)
- finding \( \lambda_2 = \max_j \lambda_2^j \);
- finding \( \lambda_3^1 = \lambda_1^1 + \lambda_2^1 + \lambda_3^1 \)

Cauchy initial model Jacobian matrix of the model Initial conditions of the simulation

\[
\begin{align*}
\dot{x} &= -10(x - y) \\
\dot{y} &= -xz - y + 28x \\
\dot{z} &= -26z + xy
\end{align*}
\]

\[
\begin{bmatrix}
-10 & 10 & 0 \\
28 & -1 & -x \\
y & z & -2.6
\end{bmatrix}
\]

\[
\begin{array}{ccc}
| a | b | c |
\hline
X(0) & 1 & 1 \\
Y(0) & 2 & 3 \\
Z(0) & 4 & 7 \\
\end{array}
\]
During the machine experiment, one parameter was fixed, initial conditions were introduced on other parameters and each point of the phase space was evaluated from the point of view of determining the attractor type. A variant of this study is shown in Fig. 1 for three initial conditions.

5. Conclusion
The obtained models can be used to construct "robust chaos" [2], as well as to generate chaos with specified qualitative properties.

The research showed the principal possibility of analytical assessment of the stability of trends emerging in the process of economic activity. It turned out that this can be done quickly, using high-quality visual and cognitive evaluations and computer programs with a point-by-point evaluation of the entire phase space.

The use of dynamic models of chaotic processes allows predictive proactive management for dynamic resource allocation in complex socio-economic infrastructures. An important task is to choose the shape of the model. Using the proposed in this paper forms will allow to obtain reliable computational models that, on the one hand, reflect the essential qualitative properties of nonlinear socio-economic systems, on the other - have the necessary robustness - not sensitive to small changes of the parameters.

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