Algorithms for monitoring the functioning of nonequilibrium information processing systems

S S Antsyferov, K N Fazilova and K E Rusanov
MIREA - Russian Technological University, 78, Vernadsky Avenue, Moscow, 119454, Russia

1 E-mail: fazilova@mirea.ru

Abstract. The authors have developed an algorithm for monitoring the functioning of nonequilibrium systems, which is based on such operations as establishing the range for permissible values of efficiency probabilities of structural elements functioning, establishing permissible values of structural elements amount, plotting the system entropy dependence on structural elements amount and their effectiveness probability, constructing phase space of the system functioning and determination of the boundaries of regions with nonequilibrium stability. Practical testing of the developed algorithm for monitoring the functioning of nonequilibrium systems has shown that this algorithm can be used to solve several practical problems related to functioning monitoring and predicting the state of a wide variety of nonequilibrium systems.

1. Introduction
There is a wide variety of systems that are distinguished by a complex structure and are associated with perception and processing of intensive changing information flows. This includes complex technical systems, research and production and educational processes, working groups that carry out important research and development work. Such systems belong, as a rule, to the category of nonequilibrium systems. To ensure high efficiency of the functioning of these systems, continuous monitoring of their state should be carried out in order, if necessary, to take appropriate measures, which may be associated, for example, with transformation of the structural construction of a particular system. One of the effective control methods can be representation of a nonequilibrium system in the form of a cognitive one, the functioning of which is described using a nonlinear differential equation. Several works [1-8] were devoted to the issues of studying such systems, in particular, those related to methodology development for assessing the nonequilibrium stability of cognitive systems.

The purpose of the work is to develop algorithms for monitoring the functioning of non-equilibrium processing systems.

2. Algorithm for formation of the functioning space of nonequilibrium systems
The formation of the systems functioning space in the mode of nonequilibrium stability is carried out by (figure 1) constructing a phase diagram of the system functioning in the mode of nonequilibrium stability and determining the boundaries of the nonequilibrium stability region. Assessment of the system state involves determination of the upper and the lower boundaries of the nonequilibrium stability region, i.e. boundary values $H$, $\dot{H}$ and $L$ for given (optimal) conditions of functioning ($P_{\text{min}}$ is
the minimum permissible value of the efficiency of structural elements functioning (SE), \( P_{\text{max}} \) is the maximum permissible value of the efficiency of SE functioning, \( N \) is the optimal number of SE).

\[ H = H_1 + H_2 \]
\[ H_1 = -\sum P \log P \]
\[ H_2 = -\sum P_j \log P_j \]
\[ H = (\Delta H / N)^{1/2} \]
\[ \Delta H = \Delta P \]

\( \Delta P = P_{\text{max}} - P_{\text{min}} \)

\( \Delta H \) is the change in the efficiency probability of SE.

3. Algorithm for monitoring the current state of the system
The real state of the system is determined by the real values of the SE efficiency probability, corresponding to the values of \( H \), \( \dot{H} \) and \( L \), which, in turn, determine the point position, which is adequate to the system state in the three-dimensional space of coordinates \( H \), \( \dot{H} \) and \( L \). In the case of a point “exit” outside the established area, a signal is sent to the coordinating unit and, if necessary, the system structure is transformed (figure 2).

Figure 1. Block diagram of the algorithm for the system functioning space formation.
4. Practical testing of the developed algorithms

We will consider the current master’s program as a kind of cognitive system, the SE of which are the disciplines studied within the framework of this program. It is natural to assume that each of the disciplines has its own probabilistic measure of effectiveness. We will assume that probabilistic connections between disciplines are indirectly subjective, i.e. for each individual student they are different. Therefore, when monitoring the effectiveness of the program, we will consider only the probabilities of the effectiveness of individual SE (disciplines). The investigated master’s program in the Russian Technological University MIREA “Metrological support of measuring processes” in the direction of training 04.27.01 Standardization and metrology consists of 17 SE.

According to the algorithm (figure 1), we will assume that \( P_{\text{min}} = 0.7; P_{\text{max}} = 0.9; N = 17; \Delta I > 0; \Delta J > 0 \). Following the algorithm, we will build the dependencies \( H(N, P) \) and find the boundary values of \( \Delta H \) along the coordinate \( H \). Using the phase diagram for \( \Delta I > 0 \) and \( \Delta J > 0 \) we find the boundary values of \( \Delta \hat{H} \) along the coordinate \( \hat{H} \). After that, we find the boundary values of \( \Delta L \) along the coordinate \( L \). As a result, we obtain the following boundary values \( H = 14.1 - 16.8; \hat{H} = -185.7 - 264.5; L = 0.08 - 0.23 \).

The next stage of the study is associated with determination of the values of the SE efficiency probabilities by the method of pairwise comparison [8], determination of the corresponding values of \( H, \hat{H}, L \) with the subsequent decision-making on the system state according to the algorithm for monitoring the current state of the system (figure 2).

Coordinate values of the system state point (figure 3): \( H = 16.3; \hat{H} = -248.7; H^* = 18.4 \) and \( L = 1 - \frac{H}{H^*} = 0.11 \).
According to the calculations, the master’s program is in the established area of nonequilibrium stability, however, close to the border of this area. This means that with insignificant fluctuations of the probabilistic parameters of this program, it may turn out to be outside the region of nonequilibrium stability, which confirms the position of point 2, obtained when the probabilistic indicators of the SE are reduced by the amount of error. To prevent such a situation, it is desirable to increase the initial values, which confirms the position of point 3, obtained as a result of increasing the probabilities by the amount of error.

The research and production unit has a structure that includes several interconnected departments (figure 4).

![Figure 3. Position of points in phase space.](image1)

![Figure 4. Structure of the research and production unit.](image2)

Evaluation of the effectiveness of each department was carried out according to four indicators and was of an expert nature. The results of the assessment are presented in table 1.
Table 1. Expert indicators.

| Department                          | Employee qualification level | Equipment level (MTB) | Completeness of normative and technical documentation | Mathematical software | P_s |
|-------------------------------------|-----------------------------|-----------------------|------------------------------------------------------|------------------------|-----|
| Design and Development Department   | 0.81                        | 0.8                   | 0.8                                                  | 0.7                    | 0.64|
| Design Department                   | 0.83                        | 0.8                   | 0.9                                                  | 0.7                    | 0.58|
| Technology Department               | 0.79                        | 0.9                   | 0.8                                                  | 0.6                    | 0.66|
| Production Department               | 0.79                        | 0.9                   | 0.8                                                  | 0.7                    | 0.60|
| Testing Department                  | 0.85                        | 0.8                   | 0.9                                                  | 0.6                    | 0.63|

According to the given calculations, the research and production unit is in the established area of nonequilibrium stability, however, as in the previous case, it is close to the border of this area (figure 5).

Figure 5. Position of points in phase space.

5. Conclusions
Practical testing of the developed algorithms has shown that they can be used to solve several practical problems related to monitoring the functioning and predicting the states of a wide variety of nonequilibrium complex technical systems approximated by a cognitive model.

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