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DEVELOPMENT OF METHODS FOR IDENTIFYING THE STATE OF VARIOUS DYNAMIC OBJECTS

Artificial intelligence technologies are actively used to solve both general and highly specialized tasks. In the process of assessing (identifying) the condition of complex and heterogeneous objects, there is a high degree of a priori uncertainty regarding their condition and a small amount of initial data describing them. The trends of armed conflicts of the last decades and the regularities of the development of information systems, convincingly indicate the need to change approaches to the collection of information from various sources and their analysis. There is a constant transformation of the forms of information presentation and the order of storage and access to various types of data. The problem of integrating disparate sources of information collection into a single information space is also not fully resolved.

That is why the issue of improving the efficiency of assessing the state of complex and heterogeneous dynamic objects is an important and urgent issue. The objects of research are heterogeneous dynamic objects. The subject of the research is the identification of the state of heterogeneous dynamic objects. In the research, the method of identifying the state of heterogeneous dynamic objects was developed. The novelty of the proposed method consists in:

– taking into account the degree of uncertainty about the state of a heterogeneous dynamic object;

– taking into account the degree of data noise as a result of distortion of data characterizing the state of a heterogeneous dynamic object;

– reducing computing costs while assessing the state of heterogeneous dynamic objects;

– the possibility of performing calculations with source data that are different in nature and units of measurement.

It is advisable to implement the mentioned method in specialized software, which is used to analyze the state of complex technical systems and make decisions.

Keywords: *heterogeneous dynamic objects, complex technical systems, complex analysis, processing of various types of data.*

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1. Introduction

Artificial intelligence (AI) has become widely used in solving various tasks [1–3]. AI is used to increase the efficiency of data processing, processing of large data sets and to support decision making [3–5].

Analysis of changes in the forms and methods of armed conflicts in recent decades [1–5], and also the trends in the development of information systems of various functional purposes [6–10] convincingly indicate the need to change approaches to:

– the collection of information from various sources;
– an analysis of various data types;
– information presentation forms;
– procedures for storage and access to various types of data;
– integration of disparate sources of information into a single information space.

However, like any process (phenomenon), certain advantages (disadvantages) are inherent. The disadvantages of AI include:

– the availability of a sufficient amount of initial data for training hardware and software systems (complexes);
– the need to use adequate AI work and control algorithms;
– low legal regulation of the activity of systems and complexes using AI.

The advantages of AI include:

– the possibility of working with various data types;
– efficiency of processing large data sets;
– an opportunity for self-study;
– a reduction of subjectivity in the course of assessment and decision making, etc.

Taking into account the above, *the aim of the research* is to develop a method for identifying the state of heterogeneous dynamic objects.

The objects of the research are heterogeneous dynamic objects.

The subject of the research is the identification of the state of heterogeneous dynamic objects.

2. Materials and Methods

The problem of the research is to increase the efficiency of decision making regarding the state of a heterogeneous and dynamic object. Modeling was carried out using MathSad 14 (USA). Aser Aspire based on the AMD Ryzen 5 processor was used as hardware. The genetic algorithm was chosen as the basic mathematical apparatus in the proposed research.

3. Results and Discussion

3.1. The development of methods for identifying the state of heterogeneous dynamic objects. Let the output of the dynamic object be represented by measurements forming a sample of the volume s, i. e. [11, 12]:

$$\{y_i, t_i\}, i = \overline{1, s},$$

where $y_i \in R$ is measuring the output of a dynamic system at a moment in time $t_i \in [0, +\infty)$, $u = u(t)$ are the known input control data of the dynamic system.

The system is linear and is described by a linear differential equation of the form:

$$a_k \cdot x^{(k)} + a_{k-1} \cdot x^{(k-1)} + \ldots + a_0 \cdot x = b \cdot u(t),\ x(0) = x_0. \quad (1)$$

It is necessary to determine the parameters of the system and the order n of the differential equation based on the sample data, which let's consider limited, i. e. $n-1 \le M$, $M \in N$. It is assumed that there is a symmetrically distributed additive interference in the system output measurement channel $\xi: M(\xi) = 0,\ D(\xi) < \infty$, thus $y_i = x(t_i) + \xi_i$.

It turns out that when the order of the system is unknown, let's solve the problem of structural-parametric identification, and the task will be partially parameterized, since let's determine the maximum degree of the derivative included in the equation in advance, limiting the dimension of the search space. For the first time, such a statement was considered in work [13] and was further developed in work [14].

Let's assume that for a system of any order its coefficient at the highest degree is equal to 1, thus:

$$x^{(k)} + \frac{a_{k-1}}{a_k} \cdot x^{(k-1)} + \ldots + \frac{a_0}{a_k} \cdot x = \frac{b}{a_k} \cdot u(t), \quad (2)$$

or

$$x^{(k)} + \tilde{a}_k \cdot x^{(k-1)} + \ldots + \tilde{a}_1 \cdot x = \tilde{b} \cdot u(t). \quad (3)$$

Then, let's look for the solution of the identification problem as a differential equation of order $m \le M$, $M \in N$, such that the solution of the Cauchy problem in the given initial conditions:

$$x^{(k)} + \hat{a}_k \cdot x^{(k-1)} + \ldots + \hat{a}_1 \cdot x = \hat{b} \cdot u(t),\ \hat{x}(0) = x_0, \quad (4)$$

with parameters $\hat{a} = (0 \ldots 0 \quad \hat{a}_m \ldots \hat{a}_1 \quad \hat{a}_0)^T \in R^n$, thus $n = M + 1$, deliver the extremum of the selected function:

$$I_1(a) = \sum_{i=1}^{N} \left| y_i - \hat{x}(t_i) \right| \Big|_{\hat{a}=a} \to \min_{a \in R^n},$$
$$I_2(a) = \max_i \left| y_i - \hat{x}(t_i) \right| \Big|_{\hat{a}=a} \to \min_{a \in R^n}. \quad (5)$$

To evaluate the process model in the form (2) as a solution to one of the extremum search problems: (4) or (5), it is necessary to have information about the initial position of the system so that the Cauchy problem can be solved.

In the general case, the vector of the initial position of the system, if it is not known at first, can be numerically estimated, which, of course, is not always possible and depends on the properties of the sample. Another option for determining the initial position of the system is to include the vector of the optimization task. As a rule, for many tasks, the observation process starts with the mode, so all coordinates of the initial position for the dynamic system are equal to 0, except for the output position of the system.

Let's suppose that it is necessary to build a mathematical model of a dynamic process, which for convenience will be presented in matrix form:

$$\tilde{x}' = \hat{A} \cdot \tilde{x}(t) + \hat{B} \cdot u(t),\ x(0) = x_0, \quad (6)$$

where $\hat{A} = (\hat{a}_{ij})_{i=1,j=1}^{n,n}$ is the matrix of the system of linear differential equations; $\hat{B} = (\hat{b}_{ij})_{i=1,j=1}^{n,m}$ is the matrix of right parts, control coefficients; $\tilde{x}(t) \in R^n$ is the system state model; $u(t) \in R^m$ are the control actions, presented in the form of a vector function.

Given the fact that several different system outputs are observed, which may differ in response amplitude, it is necessary to normalize each criterion separately. To do this, let's determine the diameter of the set of measurements for each observed output while including this set of the initial position of the output. Then, the criterion takes the following form:

$$I(a) = \sum_{j=1}^{N_0} \frac{\sum_{i=1}^{s_j} \left| y_i^j - \hat{x}^j(t_i^j) \right|}{\sup\left(|a-b| : a, b \in Y^j \bigcup x_0^j\right)} \Bigg|_{\hat{A}=A, \hat{B}=B} \to \min_{A,B}, \quad (7)$$

where N_0 is the number of outputs of the dynamic system; s_j, $j = \overline{1, N_0}$ is the sampling volume of each output of the dynamic system; y_i^j, $i = \overline{1, s_j}$, $j = \overline{1, N_0}$ is the measurement of outputs forming samples; t_i^j, $i = \overline{1, s_j}$, $j = \overline{1, N_0}$ is the measurement time for each j-th output; $\sup\left(|a-b| : a, b \in Y^j \bigcup x_0^j\right)$ is the diameter of the set of measurement data for each output; $\hat{x}^j(t) \Big| \hat{A} = A, \hat{B} = B$ is the j-th output of the model for matrices A, B.

Criterion (7) is similar to the one-input-one-output problem criterion as (5). Thus, the task of identifying a dynamic object was reduced to finding an extremum in the space of vectors with valid coordinates. At the same time, the peculiarity of the representation of the object structure leads to the complex behavior of the objective function in the vicinity of some points of space, for which the first coordinates of the vector turn to 0.

The method of identifying the state of heterogeneous dynamic objects includes the following interrelated procedures:

1. Input of initial data about the state of a heterogeneous dynamic object.

2. Initialization of the initial model based on expressions (1)–(7).

3. Introduction of correction coefficients for noise and a priori uncertainty about the state of the object using expressions [2].

Given the lack of a priori information about the coefficients and the order of the differential equation, the use of the binary representation of the optimization variables becomes difficult and ineffective in the sense of finding a solution.

According to the accepted transition from a vector (an individual) to a differential equation, the vector, taking into account the peculiarities of the chosen presentation of the solution, contains information about the order, structure and coefficients of the differential equation, which must be taken into account to improve the operation of the algorithm.

4. Determination of the order of the differential equation.

Let $\hat{a}$ is a vector containing the solution to the problem, then, $i_{order} \in N$, $i_{order} \le M$, $i_{order} : \hat{a}_{i_{order}} \ne 0, \hat{a}_i = 0, \ i > i_{order}$. If $\hat{a}_M \ne 0 \to i_{order} = M$. Then the order of the equation will be determined by the index i_{order}. Considering the proposed approach to determine the order of the differential equation, let's note that it is important that the algorithm for solving the problem has the ability to store some coordinates, that is equal to 0.

5. Rounding of vector coordinates.

One of the special modifications of the algorithm was the introduction of the vector coordinate rounding operation:

$$op_j^i = round\left(op_j^i\right),\ j = \overline{1,n},\ i = \overline{1,N_1}, \tag{8}$$

where $round(\cdot): R \to Z$ is a function that rounds a number to its nearest integer. Such an operator, which affects the objective parameters of the algorithm, solves the task of reducing the coordinates of the vector to integers. Since it is important to represent the structure of the system that in some cases a certain number of solution coordinates vanish in a row and the stochastic search algorithm disturbs the variables due to the nature of the mutation operation, an operator is needed that would preserve the found order. The rounding operator is applied directly after the mutation operator and after rounding there is a local improvement of the resulting population.

6. Mutation of individuals in the population.

To increase the effectiveness of the search for solutions, the mutation operator was modified in relation to the state of the heterogeneous dynamic object, thus, the probability of mutation for each pair of the type objective – strategic parameter, $p_m = 1/q$. Then, random perturbations do not lead to a strong scattering of individuals of the next population around some found solution, which is not eliminated by further local improvement of the alternative after rounding.

7. Generation of the initial population.

Since, randomly drawing the coefficients for the starting population will not lead to the appearance in the population of different solutions that corresponded to equations of different order. Given such a presentation of solutions, let's generate the population as follows:

1) to each individual with probability $1/M$ the order of the differential equation is chosen;

2) for the selected order i_{order} each nonzero coordinate is solved uniformly on the interval [–5, 5];

3) all strategic parameters of an individual are played evenly on the interval [0, 1].

The proposed scheme was chosen as the best one by sorting through various options for the initial generation of solutions.

It is necessary to take into account some features of the local improvement of alternatives by the proposed random coordinate descent algorithm. The rounding operator (8) of each coordinate leads to the fact that the accuracy of the solution is lost due to the truncation of the mantissa. In order to compensate for the loss of accuracy and increase the efficiency of the algorithm as a whole, it is necessary that the coordinate descent takes such a number of steps that with the selected step length, the rounded coefficient could be refined so that the value that preceded the whole was returned.

The end.

3.2. The results of the analysis and discussion of the results. In the course of the research, the authors developed a method for identifying the state of heterogeneous dynamic objects.

To evaluate the effectiveness of the proposed method, 100 systems were randomly generated: 10 systems for each order of the differential equation, from the first to 10. The parameters of each system were chosen as follows: $\hat{a}_k^i: U(-5,5)$, $\hat{b}_k: U(-5,5)$, $i = \overline{1,10}$, $k = \overline{1,i}$. The operating time of the system was chosen equal to 5.

The management function of the analyzed tasks was chosen as a single function, thus $u(t) = 1$. The sample data are taken from the numerical solution of the differential equation. Let $\{x_i, t_i\}$, $i = \overline{1, T/h_{ode}}$ be the numerical solution of the system. Then for a given sample size $s < T/h_{ode}$, $s = 100$ let's choose s different points at random from the numerical solution of the differential equation.

In order to evaluate the effectiveness of the parameters of the optimization algorithm, identification without disturbances in the measurement channels was considered, so that this factor did not add additional complexity to the task and it was possible to evaluate the solutions found.

For each individual system, 20 runs of the algorithm were carried out with certain settings. All initial conditions of these tasks were taken equal to zero. The volume of the population was chosen equal to 50, the number of populations is 50, the parameters of local descent $N_1 = 50$, $N_2 = 50$ and $N_3 = 1$ at $h_l = 0.05$.

The research of the effectiveness of the proposed method showed that the average suitability increases as the order of the real object approaches the set parameter-limitation of the maximum order of the model. It turns out that the algorithms should work in such a way as to preserve the ability to reduce the order of the system, keeping the equality of the first coordinates 0. Therefore, modifying the mutation or adding a rounding operator leads to a significant improvement. At the same time, it is important to note that the increase in suitability is also related to the fact that during the time of observations, the higher-order system behaves in such a way that it is easier to build its model than, under similar conditions, a lower-order model.

Transient processes of different systems can coincide at a certain interval, so only an increase in the monitoring interval of the system output and an increase in the frequency of taking measurements can increase the efficiency of finding a solution. On the other hand, the reason for this may be the presence of a large number of local optima and a rather strong attraction zone.

The proposed method differs from the existing ones:
– it takes into account the degree of uncertainty of information about the state of a heterogeneous dynamic object and the noise level of the initial data about its state;
– it increases the efficiency of decision making while assessing the state of heterogeneous objects due to the search for a solution using population individuals;
– it solves the problem of falling into a global extreme.

The advantages of the research include:
– calculations that take into account the degree of uncertainty about the state of a heterogeneous dynamic object;
– taking into account the degree of data noise as a result of distortion of information about the state of a heterogeneous dynamic object;
– reduction of computing costs while assessing the state of heterogeneous dynamic objects;
– the possibility of performing calculations with source data that are different in nature and units of measurement.

The shortcomings of the mentioned research should include the availability of appropriate computing power and time for calculations.

It is advisable to implement the mentioned method in specialized software, which is used to analyze the state of complex technical systems and make management decisions.

The direction of further research should be considered the further improvement of the specified method to take into account a greater number of factors during the analysis of the state.

4. Conclusions

1. Development of methods of identifying the state of heterogeneous dynamic objects was carried out in the research.

2. The novelties of the proposed method consist in:
– taking into account while calculating the correction factor for the degree of uncertainty about the state of a heterogeneous dynamic object;
– adding a correction factor for data noise as a result of distortion of information about the state of a heterogeneous dynamic object;
– reducing computing costs while assessing the state of heterogeneous dynamic objects;
– the possibility of performing calculations with source data that are different in nature and units of measurement.

3. It is advisable to implement the specified method in specialized software, which is used to analyze the state of complex technical systems and make management decisions.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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