Optimizing modeling of complex-structured objects in the problem of improving the efficiency of their functioning

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Abstract. The paper discusses the characteristics of objects with complex structure. The properties of the objects of the considered type are determined. The analysis of features of their management is carried out, the results of which are used to find the problems arising at their functioning. The methods of improving their efficiency are investigated basing of the results of optimization modeling. The paper gives the procedure for forming an optimization model of a complex structured object for the task, as well as a generalized scheme for finding its solution. On the basis of the proposed generalized scheme and properties of the studied type of objects, the development of adaptive algorithms for numerical optimization is carried out to increase the efficiency of the considered class of objects.

1. Introduction
New types of objects appear annually in the world around us. For innovative objects, it is typical to use new management methods based on adapting and evolving the existing methods and algorithms. At the same time, adaptive and evolutionary procedures should be based on the properties of a new type object [1, 2].

The paper considers the features of the properties of a complex-structured object that affect the principles of increasing the efficiency of its functioning. It gives the results of developing an optimization model of an object of the type under consideration. It also presents the results of the development of adaptive optimization algorithms based on the behavior algorithm of monkeys, the main purpose of which is to increase the functioning efficiency of objects with a complex structure.

2. Characteristics of objects with the structurally-variable form of control
An example of an innovative object is an object with a complex structure. Let us formulate a definition for a given type of object, and then consider its properties. To do this, let us give the concept of structural and variable forms of control [3, 4].

The structural form of control is such a form of control, a feature of which is that the structure of the object of research is created before the beginning of the control process, while its architecture and element base do not change in its course [5, 6].

The structural control (structural optimization) is the search for such a structure of the object under study that will be the most rational and effective under the existing conditions.
The variable form of control is such a form in which a solution that allows one to increase the efficiency of the control process of a selected object is determined by choosing the most suitable option for a particular condition from a number of acceptable options.

Based on the above, let us formulate a definition for the structurally-variable form of a complex object control.

The structurally-variable form of control is the form in which the effectiveness of the control process is achieved by searching for the structure of the object under study that will be the most rational and effective under existing conditions by choosing the most suitable option for a particular condition from a number of acceptable options. As an object with a structurally-variable form of control, we will consider a certain organizational whole system, the achievement of the set goals of which is carried out by varying the components of the structure, which represent a set of elements united by various kinds of connections.

Based on the analysis of optimization objects of various types, let us formulate the properties that objects with a structurally-variable form of control have [7, 8]:

1. Variable structural components \( s = 1, S \) in a formalized form are represented by a vector \( X \), which includes three subsets of variables \( X^1, X^2, X^3 \):
   \[
   X^1 = (x^1_1, \ldots, x^1_j, \ldots, x^1_J) \quad \text{- the subset of alternative variables,}
   \]
   whereas \( x^1_j = \begin{cases} 1, & \text{if some } j^{th} \text{ element or connection is included in the object's structure,} \\ 0, & \text{otherwise, } j = \overline{1,J}; \end{cases} \)
   \[
   X^2 = (x^2_1, \ldots, x^2_i, \ldots, x^2_L) \quad \text{- the subset of variables that take discrete values;}
   \]
   \[
   x^2_i = (x^i_1, \ldots, x^i_n, \ldots, x^i_m), \quad x^2_i \geq 0, \quad m = \overline{1,M};
   \]
   \[
   X^3 = (x^3_1, \ldots, x^3_n, \ldots, x^3_M) \quad \text{- the subset of continuous variables, the change of which is limited to a certain interval } x^{3\text{min}}_n \leq x^3_n \leq x^{3\text{max}}_n, \quad x^{3\text{min}}_n \geq 0, \quad n = \overline{1,N}, \quad \text{and characterizes the parameters of the structural components.}
   \]
2. Wes should consider dynamic, depending on the time \( \tau \in [\tau_0, \tau_f] \) and static modes of operation of the object with structurally-variable control.
3. Adequate reflection of the dependence of the indicators of the natural object \( y = (y_1, \ldots, y_n, \ldots, y_l) \) characterizing the given goals on the varied structural components is identified by some computational environment that allows one to determine the values of the component of the vector \( y \) with a fixed version of the structure \( s^0 \) and the corresponding value of the vector \( X^0 \):
   \[
   y = f_{sd}(X^0) \sim f_{sd}(s^0),
   \]
   where the sign \( \sim \) denotes similarity.

Further, we will consider the simulation model as the base computing environment \( f_{sc} \).

4. The achievement of the given goals is determined by a set of experimental \( y_{i1} = f_{i1}(x) \rightarrow \text{max (min), } i_1 = \overline{1, I_1} \) and boundary \( y_{i2} = f_{i2}(x) \rightarrow b_{i2}, i_2 = \overline{1, I_2} \) requirements, where \( b_{i2} \) is the permissible level of the indicator \( y_{i2} \).

5. We will consider network information and communication, technological, and transport systems as the main groups of natural objects with structurally-variable control.

After we have carried out the formalized description of a class of objects with a complex structure in the form of \( f_{sd}(X) \), let us pass to problems of optimization of such objects.

### 3. Developing an optimization model of an object with a complex structure

We will determine the optimality of the structure of an object by any of the criteria that most affect it. This criterion will be the criterion of the optimality of the structure of the object and will be expressed in the objective function in the mathematical model of the problem [9, 10].

Schematically, the cycle of work with an optimization problem for an object with a structurally-variable form of control can be represented as the diagram in figure 1.

![Diagram](image)

**Figure 1.** The scheme of the model formation cycle for the optimization problem and searching its solution.

Based on the considered properties 1 and 4, the object with a structured control suggests representing the problem of choosing an optimization solution in the general case in the form of the following invariant model \( (\mu_1) \):

\[
f_{i_1} = (x^1, x^2, x^3) \rightarrow \max, i_1 = 1, I_1,
\]

\[
f_{i_2} = (x^1, x^2, x^3) \leq b_{i_2}, i_2 = 1, I_2,
\]

\[
x^1_j = \begin{cases} 1, & j = 1, 7, \\ 0, & j = 1, 7, \end{cases}
\]

\[
x^2_j = (x^2_{i_1}, x^2_{i_2}, \ldots, x^2_{i_m}), 1 = 1, L, x^2_{i_m} \geq 0, m = 1, M,
\]

\[
x^3_{i_n} \leq x^3 \leq x^3_{i_n}, n = 1, N, x^3_{i_n} \geq 0, n = 1, N.
\]

- the single-criterion optimization model \( (\mu_2) \):

\[
f_{i_1} = (x^1, x^2, x^3) \rightarrow \max, i_1 = 1, I_1,
\]

\[
x^1_j = \begin{cases} 1, & j = 1, 7, \\ 0, & j = 1, 7, \end{cases}
\]

\[
x^2_j = (x^2_{i_1}, x^2_{i_2}, \ldots, x^2_{i_m}), 1 = 1, L, x^2_{i_m} \geq 0, m = 1, M,
\]

\[
x^3_{i_n} \leq x^3 \leq x^3_{i_n}, n = 1, N, x^3_{i_n} \geq 0, n = 1, N.
\]

- the multi-criteria model without restrictions \( (\mu_3) \):
\[ \psi_{12} = (x^1, x^2, x^3) \rightarrow \max \]
\[ f_{12} = (x^1, x^2, x^3) \leq b_{12}, i_2 = 1, I, \]
\[ x_j^2 = \begin{cases} 1, & j = 1, 7, \\ 0, & \end{cases} \]
\[ x_1^2 = (x_{11}^2, ..., x_{m1}^2, ..., x_{in}^2), 1 = 1, I, x_{in}^2 \geq 0, m = 1, M, \]
\[ x_{n}^{3_{\text{min}}} \leq x_{n}^{3_{\text{max}}}, n = 1, N, x_{n}^{3_{\text{min}}} \geq 0, n = 1, N. \]

- the model including alternative and discrete variables (\( \mu_4 \)):

\[ f_{ij} (x^1, x^2) \rightarrow \min, \quad i_1 = 1, I, \]
\[ f_{12} (x^1, x^2) \leq b_{12}, \quad i_2 = 1, I, \]
\[ x_j^1 = \begin{cases} 1, & j = 1, 7 \\ 0, \end{cases} \]
\[ x_1^1 = (x_{11}^1, ..., x_{m1}^1, ..., x_{in}^1), 1 = 1, I, x_{in}^1 \geq 0, m = 1, M. \]

**Figure 2.** Structural scheme of the numerical procedure for the task of the static type on the basis of the adaptive behaviour of monkeys.
the single-criterion model without restrictions, including only discrete variables ($\mu_i$):

$$f(x_k, x_l, ..., x_m) \rightarrow \max,$$

$$x_k = \{x_k^1, x_k^2, ..., x_k^K\}, x_k \in K',$n

$$x_l = \{x_l^1, x_l^2, ..., x_l^L\}, x_l \in L',$n

...$$

$$x_m = \{x_m^1, x_m^2, ..., x_m^M\}, x_m \in M',$n

$$x_k > 0, x_l > 0, ..., x_m > 0.$$

where $K', L, ..., M'$ - the set of acceptable options for the parameters of the object (a set of solutions).

From this, we have that the objective function, expressed as $f(x_k, x_l, ..., x_m)$, will display the dependence of the optimality criterion on the main parameters of the object.

Restrictions on variables in the developed optimization model will be set in discrete form, and their values will be selected from finite sets $K', L, ..., M'$, respectively, and can take values strictly more than 0.

Let us find the solution to the problem in the form of a vector $X$: $X = \{X_k^{n_1}, X_l^{n_2}, ..., X_m^{n_M}\}$

After that, it is necessary to carry out preliminary transformations of the original problems $\mu_i, \mu_n$ and their variables [11, 12].

The process of solving this problem by classical optimization methods is laborious and, in some cases, impossible. This is due to a number of factors: nonlinearity, multiextremality, high computational complexity of the function being optimized, high dimensionality of the region of the search for solutions, etc.

4. Algorithmization of the solution to the problem of improving the efficiency of object operation with structurally-variable control

In order to improve the efficiency of functioning of objects with structurally-variable control, it is necessary to consider the solution of this problem in the combination of two control modes (static and dynamic). For each of these modes, the model will have the form discussed above. The algorithm for solving the problem for each of the modes:

$$f(x_{\kappa}(\tau), x_{\nu}(\tau), x_{\nu_1}(\tau), ..., x_{\nu_n}(\tau), \tau) \rightarrow \max,$$

$$x_{\kappa}(\tau) = \{x_{\kappa}^1(\tau), x_{\kappa}^2(\tau), ..., x_{\kappa}^K(\tau)\}, x_{\kappa}(\tau) \in K',$$

$$x_{\nu}(\tau) = \{x_{\nu}^1(\tau), x_{\nu}^2(\tau), ..., x_{\nu}^L(\tau)\}, x_{\nu}(\tau) \in L',$$

...$$

$$x_{\nu_n}(\tau) = \{x_{\nu_n}^1(\tau), x_{\nu_n}^2(\tau), ..., x_{\nu_n}^V(\tau)\}, x_{\nu_n}(\tau) \in V',$n

$$x_{\nu_1} = x_{\nu_1}^{n_1}, x_{\nu_2} = x_{\nu_2}^{n_2}, ..., x_{\nu_n} = x_{\nu_n}^{n_n};$$

$$x_{\kappa}(\tau) > 0, x_{\nu}(\tau) > 0, ..., x_{\nu_n}(\tau) > 0.$$

For the static mode, the block diagram of the algorithm will have the form shown in figure 2, for
the dynamic mode - in figure 3.

**Figure 3.** Structural scheme of the numerical procedure for the problem of the dynamic type, based on the adaptive behavior of monkeys.
5. Conclusion
Thus, in order to improve the functioning of objects with a complex structure, it is advisable to take
into account the static and dynamic modes of operation. Based on the results obtained in the
framework of the presented research, it can be concluded that the proposed adaptive forms of
algorithms based on the monkey search algorithm are effective.

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