Adaptive algorithm of selecting optimal variant of errors detection system for digital means of automation facility of oil and gas complex

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Abstract. To date, the problems associated with the detection of errors in digital equipment (DE) systems for the automation of explosive objects of the oil and gas complex are extremely actual. Especially this problem is actual for facilities where a violation of the accuracy of the DE will inevitably lead to man-made disasters and essential material damage, at such facilities, the diagnostics of the accuracy of the DE operation is one of the main elements of the industrial safety management system. In the work, the solution of the problem of selecting the optimal variant of the errors detection system of errors detection by a validation criterion. Known methods for solving these problems have an exponential valuation of labor intensity. Thus, with a view to reduce time for solving the problem, a validation criterion is compiled as an adaptive bionic algorithm.

Bionic algorithms (BA) have proven effective in solving optimization problems. The advantages of bionic search include adaptability, learning ability, parallelism, the ability to build hybrid systems based on combining. [1].

1. Introduction
The internal DE structure with control can be represented as n-subsystems, each of which is controlled by any method.

Let us denote the composition of the control system's vector by \( Y = \{y_i\}_{i=1}^n \), \( i \)-component corresponds to \( j \)-method of control for \( i \)-block. Each vector of control is in line with the vector of detecting ability \( D = \{p_j\}_{j=1}^l \), components of which are the error detection's probability to the \( l \)-multiplicity. It includes additional cost's sector \( C_j = \{c(\gamma_y)\} \), components of which mean the additional implementation costs of \( j \)-method of control. Besides, each method of control corresponds to the ratio of logical coverage \( K_i \), which means the probability of micro-operation's coverage in \( i \)-block. The following step, the vector of errors’ multiplicity is denoted as \( \hat{A} = \{h_j\}_{j=1}^l \), which components are \( z \)-multiplicity’s errors.
Using these vectors, the expression for effectiveness control can be obtained, it is calculated as follows:

\[ Z_i = K \sum_{j=1}^{n} b_j P_{ij} \]  

(1)

The characteristic system given above is based on the calculating methods of digital equipment reliability with monitoring; it allows one to detect an error system to be sufficiently described and designed.

The general dependability indicator is the function of the dependability of all blocks:

\[ P(t, Y) = P(T, y_1, y_2, ..., y_n) \]  

(2)

Similarly, an authenticity indicator is a function of the authenticity of all DE blocks:

\[ R(t, Y) = R(t, y_1, y_2, ..., y_n) \]  

(3)

As the subsystems are connected consistently and reliably, they can be shown like that:

\[ P(t, Y) = \prod_{i=1}^{n} P(t, y_i) ; \]  

(4)

\[ R(t, Y) = \prod_{i=1}^{n} R(t, y_i) \]  

(5)

The task of optimal control system choice appears in case of limitations imposed on the means aimed at improving its reliability.

2. Samples and experimental methods

In the considered tasks, expended resources are increasing with the increase of the controlled blocks number and with the improvement of the quality characteristics of the control method, i.e.:

\[ \tilde{N}(Y) = \sum_{i=1}^{n} C_i (y_i) \]  

(6)

The task of choosing the optimal control system for authenticity in the presence of one limit can be finally formulated as follows:

1) to find the vector of system composition \( Y_0 \), that is:

\[ C(Y_0) = \inf_{Y \in \mathcal{R}} C(Y) \]  

(7)

where \( Y \) is the multiplicity of all possible acceptable solutions, i.e:

\[ R(t, Y_0) > \tilde{R} \]  

(8)

2) to find vector \( Y_0 \), that is:

\[ R(t, Y_0) = \sup_{Y \in \mathcal{R}} R(t, Y) \]  

(9)

where \( Y \) is the multiplicity of acceptable solutions, i.e.:

\[ \tilde{N}(Y) \leq \tilde{C} \]  

(10)

In the case of several limits, the task is formulated in the following way: to ensure maximum authenticity with limits imposed on additional equipment costs, time etc. In other words, it means to find vector \( Y_0 \) that is:

\[ R(t, Y_0) = \sup_{Y \in \mathcal{R}} R(t, Y) \]  

(11)

where \( Y_0 \) - the multiplicity of acceptable solutions.

Besides the mentioned limits, which can be called methodical, there are also some limits to be specified. Control systems in DE can be arranged using a distributed principle of construction or a centralized one. Actually a variant of continuous control without any interruptions is possible with either all DE blocks under control or most of the part. Such conditions give a chance to check several blocks immediately using one controlling device. Naturally, for different construction variants, the difference in temporary failure detection for modern DE appeared with hand leverage control is small.
compared to even the localization time of the fault, which can be neglected. To solve the optimization
task in the given formulation, it is necessary for each of the monitoring methods to calculate the
detection ability vector and the vector of additional equipment costs (if necessary, additional time
expenditure).

The calculating technique of control characteristic methods and estimating the equipment
additional expenses and time for the realization of control methods is given in [1]. Let us consider
the task solution of the error detection system based on the authenticity criteria, limited with additional
equipment and time expenses.

Let us pass in (5) from a multiplicative to adaptive expression:

\[ \ln R(t,Y) = \sum_{i=1}^{n} \ln R_i(t,Y) \] \hspace{1cm} (12)

Then the task to choose the optimal error detection system with the criteria:

\[ \sum_{i=1}^{n} \ln R_i(t,y_i) \] \hspace{1cm} (13)

and limits

\[ D(Y) < D, \ \theta(Y) < Y \]

can be solved in the easiest way simply by variants searching. Attention should be paid to the fact that
the arguments of function \( R(t,y) \) are stated with table method and inequalities are the limits. In more
complicated cases (when there are many variants), this task can be solved using the dynamic
programming method, the method of branches, boundaries etc. It should be noted in such task
formulation of error detection choice of the optimal system, there is a certain analogy with the optimal
reservation task [2]. The dynamic programming algorithm to solve the optimal reservation task is
described in work [3]; for its solution in [4] modification is used. The task of optimal error detection
system choice by the authenticity criteria can also be formulated as the optimal task on graphs [5].

The procedure of optimal task solution choice for the error detection system (EDS) is the
following:

The first stage is to divide DE into controlled blocks according to the stage of different information
passing - managing and numerical. It is reasonable to make division up to the level of functional
blocks \( B_j \) with defined micro-operations of machine \( M_j \).

Then, the equipment taking part in \( j \)-microoperation is defined.

After that, having an obligatory set of instructions for the machine for each micro-operation,
frequency calculation \( \nu \) of information circuit is carried out. This frequency \( \nu \) can be specified by
taking into account the frequency of commands inclusion into any common program.

Calculation analysis of extreme errors is made for each DE block by analyzing the equipment
functioning that perform \( M_j \) micro-operations set.

Hereby it is necessary to point out the dependence that micro-operations impose on the control
methods used. For instance, \( j \)-micro-operation control by \( i \)-way may require the control of the previous
micro-operations, that can be in convenient due to the time and equipment expenses.

Further, for the given DE structure and its blocks parameters, the intensity of failure and breakage
cases for DE blocks is calculated, which provides the calculation authenticity characteristics, the
intensity of the missed errors \( \lambda'_{\text{control method of the } i \text{-block}} \).

The additional expenses of equipment \( D(y_{ij}) \) are calculated to be implemented in \( y_j \)- control
method of \( i \)-block and also intensity of failure and breakage of additional currents is considered,
caused by control devices \( \Delta \lambda(\text{y}_{ij}) \).

Additional time expenses \( \Theta \) for the implementation of control methods are calculated.

The calculation results are put in the tables. With usage of the tables data, a directed finite graph
\( G(\nu, U) \) is constructed upon the following rules. [6]
Each edge $i_k^m$ from the sub-multiplicity $I^{(i)}$, correspondent with the control methods $k$-block of DE, goes in correspondence $m$-control method $y_{lm}$, additional equipment expenses $D_{\Sigma}^{\infty}(y_{lm})$1 and function $D_{\Sigma}(Y_i)$, defined by the multiplicity of $i_k^m$ ways $Y_i = \{i_0, i_1, ..., i_k, i_{k+1}, ...\}$.

Graph curve $u(i_k^m, i_{k+1}^m)$ goes in intensity correspondence of missed errors $\lambda_{\Sigma} = \frac{-\ln R_i(t, y_t)}{t}$ and $D_{\Sigma}(Y_{i,j})$.

Graph edge $i_k^m$ and $i_{k+1}^m$ are connected with the curve and carried out under the following conditions:

a) $\min D_{\Sigma}(Y_i) + D_{\Sigma}(y_{lm}) < D,$

b) $H_i^m = H_{i+1}^m$ (control methods index symbolises expediency of combination $m$- and $f$-control methods of $k$- and $(k+1)$-blocks.

If the control method allows one to cover several blocks at once, combination of the indicated blocks into one conditional block, and, accordingly to it, a curve is drawn in the graph [7].

After constructing graph $G_{\nu}(I, U)$, the task of the optimal choice EDS is reduced to finding the shortest possible path in the graph [8]. Well-known methods to determine the shortest paths in a graph have an exponential complexity estimation. In such a way, in order to reduce the time of task solutions for error detection based on authenticity criteria, an adaptive bionic algorithm for choosing the optimal variant should be considered.

Bionic algorithms have proved their effectiveness to solve complicated tasks of optimization, approximation, and intelligent data processing. The advantages of bionic search are the following: adaptability, learning ability, parallelism, the ability to construct hybrid systems based on combination [9,10].

The effectiveness of DE in terms of increasing convergence speed of the algorithm and the percentage of finding a global or close to it solution is influenced by methods of potential solutions coding and selected population parameters, which include population size and the mechanism of initial population construction, types of genetic operators - mutations, crossing-over, selection, selection chromosomes, etc.

3. Results and discussion
In BA, the solution is represented with a chromosome, which is a linear sequence of genes. The chromosome corresponds to a certain order of graph’s edge describing the shortest (longest) path.

The given approach to chromosome coding is the simplest in implementation and effective enough for solving the problems of the shortest path.

This approach to chromosome coding for the extremal path task is the following. The chromosome is non-homologous, the gene values are not repeated.

Each gene of the chromosome corresponds to a definite status:
- a fixed element (the position of the element that is coded by the current gene is constant.) In the process of genetic operators performing, this gene does not change its meaning);
- a free element (an element is not repeated in the run, such elements are placed the last).

The gene status will allow to have the most efficient decoding process.

The interaction of the bionic algorithm (BA) with the heuristic algorithm allows to carry out the adaptation of parameter sets and focus on the best solutions.

The BA structure is based on the fact that all building blocks (GO, EA) are connected with both the adaptation block and with each other. The adaptation block defines the evolution not in a simple form of the connection between the hereditary variability of the population and the environment, but in a more complex form. The purpose of this unit is to configure and change the usage order and application of various genetic operators (GO) and search schemes. For the work of recombination
operator work, the following adaptive strategy is offered. To come into practice, recombination should be divided into two stages:

1. Research of population size change influence on the BS characteristic.
2. Working out the strategy of population size adaptation based on the results of the first stage.

As the result task solution of the first stage based on the experimental data appears formulation of the strategy of population size adaptation. «If the objective function value in the current population is worse or unchanged as in the previous one without any improvement, then the population size should be increased. When objective function is improving in population, its size should be decreased».

The following implementation of the general strategy of population size adaptation bases on Eratosthenes sequence that allows one to adapt to BA characteristics:

\[ N(t+1) = N(t) + (N(t)-KI) \frac{z(t)}{qN}, \]

\[ KI = (1-p(xkt))R_p, \]

\[ z(t) = \begin{cases} 1, & F(t) \geq F(t+1) \\ -1, & F(t) > F(t+1) \end{cases}, \]

\[ q_t = \begin{cases} u_k, & q(t) = q(t-1) \\ u_1, & q(t) \neq q(t-1) \end{cases}. \]

where \( KI \) – number of elite species, \( R_p \) - population size, where \( N(t) \) - population size in \( t \) generation; \( u_k \) – \( k \) sequence member of Eratosthenes screen; \( q(t) \) - change direction (increase or decrease) population size in the generation \( t \); \( F(t) \) - meaning of the objective function in the population, \( k \) - generation number, within them \( q \) - direction remains constant.

With the further algorithm implementation, the best and selected elements from parents and descendants will be chosen to form a new population.

Modified mutation operators, realized under the influence of natural selection [10], play the main role in evolution determination.

The necessity to compromise between the evolution modeling time in the subpopulation and the time of information exchange demands the selection of the optimal subpopulations number (correspondingly their size) to decrease the total time. Migration determines the search quality and the algorithm efficiency. Frequent migration results in potentially necessary genetic material exchange, but the downside is the increase of information exchange expenses. This is mostly essential topology ties, in which each population exchanges with all the others. The balance between the migration level and the task quality should be found to increase the speed [10].

Let’s input the procedure for a modified migration operator construction, formula for the necessary number of chromosomes selection should be used:

\[ n = \frac{t^2 \sigma^2}{\Delta^2} \]

where \( n \) is the number of selected chromosomes for migration;
\( \Delta \) - is acceptable sampling error, top limit of the absolute value
\( \sigma \) - root mean square deviation;
\( t \) is the coefficient determined from Laplace table, \( \Phi(t)=p \), where \( p \) is the required probability of the migration operator determined by the decision maker.

4. Conclusion
The tests carried out showed that the use of the modified operator, shortens the running time of the algorithm. The ongoing sorting of the current population of alternative solutions makes it possible to increase the effectiveness of BA due to the greater structuredness of the set of alternative solutions and enables dynamic regulation of the search direction. Thus, an additional tool is available for self-adaptation and adjustment of the BA parameters.

In conclusion, it can be said that using the analysis of unpromising solutions when detecting errors in digital equipment of automation systems of oil and gas complex facilities allows one to collect and analyze the resolves obtained during the implementation of the bioinic algorithm.
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