The research of multiversion methods for improving the fault tolerance of software systems for monitoring the parameters of technological processes

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Abstract: The article reviews current multiversion methods for improving the fault tolerance of software systems. The technological object of control and the monitoring system of the technological process parameters are considered as the subject of the research. There are given model examples of the programming method implementation by N-copy programming and N-version programming method with tie breaker and acceptance test when constructing the monitoring system of the technological process.

1. N-copy programming

We will consider the method of N-copy programming (NCP) as one of their methods aimed at improving the fault tolerance of software. This method is proposed [1] and conceptually based on the principle of data diversity that implies an indirect change of the execution conditions. This principle is based on obtaining the connected set of points in the program data space and the implementation of the identical software (copies) for these points, and then using the decision-making algorithm to determine the resulting output [2].

We will consider the model design example of the environmental monitoring system using the N-copy programming method (Figure 1). The initial program uses the inputs \( t, c, v \), where \( t \) is the temperature of the flue gases in the places of sampling, \(^°\text{C}\); \( c \) is the quantity of substances and the content of suspended particles, kg/m\(^2\); \( v \) is the gas flow velocity, m/s. A smoke removal system consisting of chimneys from a firing installation and a chimneystack that as a whole is based on a volumetric operation principle acts as the technological control object. The measurement of technological process parameters in objects of a similar class is based on the principles of multi-point and spatial measurement, taking into account the requirements of design features and physical processes to generate an average value of each parameter. The multipoint measurement principle makes it possible to take into account the degree of deviation from the homogeneity of both gas velocity and particles emission velocity [3]. This is due to the design features of the smoke exhaust system, in particular the bending effect. It should be noted...
that the inertial effect is observed when measuring the temperature of the flue gases in the plane of the chimney, since in practice there is the effect of sensor fouling by precipitated suspended particles, with a subsequent violation of heat transfer. This requires periodic sensor calibration that is output value adjustment. Wherein in the case of the spatial arrangement of the sensors (before and after the filtration system), heat losses are necessary to be taken into account.

The N-copy programming method involves the use of DRA (data re-expression algorithms) [4]. In this example, we are using 6 DRAs:

- through DRAs that redirect the original input data without modification (DRA 1.1, 2.1);
- DRAs that take into account the reduced averaging coefficient for the technological process parameters before filtering (DRA 1.2, 1.3);
- DRAs that take into account the reduced averaging coefficient for the technological process parameters before filtering (DRA 2.2, 2.3).

These re-expressed input data is sent in copies of the algorithm. As the algorithm there is provided the calculation of the modal ratio of the difference of the parameter measured and given to the given. The resulting expression is a formula term (1) that expresses a generalized quality criterion characterizing the state of the technological process [5,6].

$$\frac{|r_1-x_1|}{x_1} + \frac{|c_1-x_2|}{x_2} + \frac{|r_2-x_3|}{x_3} + \frac{|r_2-x_4|}{x_4} + \frac{|c_2-x_5|}{x_5} + \frac{|v_3-x_6|}{x_6} = K$$

(1)

In its turn, the DM (decision maker) algorithm solves several problems. Firstly, it summarizes the outputs of algorithm copies (Copy 1, 2, ... 6) to form a generalized quality criterion. Secondly, it compares the outputs of algorithm copies (Copy 1, 2, ... n) with a view to exceeding the established tolerance by expressions, that is outputs of algorithm copies by a majority tolerance (MT). The measurement parameter is also controlled so that the single value of the term does not become critical.

**Table 1.** Model numerical parameters of the measurement plane of the monitoring system before filtering.

| Before filtering | Position coefficient of the smoke exhaust system element profile | Reduced averaging coefficient |
|------------------|---------------------------------------------------------------|-------------------------------|
| Average gas velocity, \( v = 14 \text{ m/s} \) | 0.8 | \( K_{v} = 1.25 \) |
|  | 1.2 | \( K_{v} = 0.83 \) |
| Average emissions value per area unit, \( c = 23 \text{ kg/m}^3 \) | 0.4 | \( K_{c} = 2.5 \) |
|  | 1.5 | \( K_{c} = 0.66 \) |
| Flue gas average temperature, \( t = 200^\circ\text{C} \) | 0.99 | \( K_{t} = 1.01 \) |
|  | 1.01 | \( K_{t} = 0.99 \) |

**Table 2.** Model numerical parameters of the measurement plane of the monitoring system after filtering.

| After filtering | Position coefficient of the smoke exhaust system element profile | Reduced averaging coefficient |
|------------------|---------------------------------------------------------------|-------------------------------|
| Average gas velocity, \( v = 13 \text{ m/s} \) | 0.5 | \( K_{v} = 2 \) |
|  | 1.3 | \( K_{v} = 0.77 \) |
Average emissions value per area unit, \( c = 15 \text{ kg/m}^3 \),

\( K_{2c} = 3.33 \)

Flue gas average temperature, \( t = 190^\circ\text{C} \),

\( K_{2t} = 1.02 \)

Since the procedure of technological process parameters measuring is multi-point, for data sources modeling in one plane it is necessary to obtain averaged values taking into account the positional coefficients of the smoke exhaust system element profile. We will express the reduced averaging coefficient for the technological process parameters of diverting flue gases and suspended particles to obtain an average model value taking into account the experimental parameters given in the table 1, 2 [3]. As a result, we are obtaining the following tables of the reduced averaging coefficients. When entering in NCP the scheduler sends data from sensors of technological process parameters of the flue gas and suspended particles diverting to three parameters before the filtration system and to three parameters after the filtration system of six DRAs for re-expression. Moreover, each parameter has three-point character of measurement, taking into account the peculiarities of the sampling location (figure 1). DRA launches its re-expression algorithms in the input receiving the following re-expressed inputs:

- DRA1.1 (200; 23; 14) = (200; 23; 14) through DRA;
- DRA2.1 (190; 15; 13) = (190; 15; 13) through DRA;
- DRA1.2 (198; 9.3; 11) = (198*1.01; 9.3*2.5; 11.1*1.25);
- DRA2.2 (186.3; 4.5; 6.4) = (186.3*1.02; 4.5*3.33; 6.4*2);
- DRA1.3 (201; 34.50; 16.8) = (201*0.99; 34.50*0.66; 16.8*0.83);
- DRA2.3 (193.8; 25.5; 16.9) = (193.8*0.98; 25.5*0.58; 16.9*0.77).

| Copy | \( f_i \) | DM Algorithm |
|------|----------|--------------|
| 1    | 0; 0; 0  | \( f_{1.1.1}(t) + f_{1.1.2}(t) + \ldots + f_{2.3.3}(t) = K \) |
| 2    | 0; 0; 0  | \( K = 0.070032 \) |
| 3    | 0.0001; 0.01087; 0.0093 | \( |0.01087 - 0| = 0.01087 \geq 0.01 \) |
| 4    | 0.000105; 0.000105; 0.01538 | \( |0.01538 - 0| = 0.01538 \geq 0.01 \) |
| 5    | 0.00505; 0.01; 0.0043 | \( |0.01 - 0| = 0.01 \geq 0.01 \) |
| 6    | 0.000052; 0.014; 0.00077 | \( |0.014 - 0| = 0.014 \geq 0.01 \) |

The scheduler collects the re-expressed input data, formats the calls in \( N = 6 \) copies and through these calls distributes the re-expressed input data for these copies. Each copy, \( C_i (i = 1, 2, 3, 4, 5, 6) \) is executed. The results of \( f_i \) copies are collected by the scheduler and transferred to the DM. DM studies the results (see table 3).

The obtained result is the following:

- The generalized quality criterion \( K = 0.070032 \);
- The value of the elements forming the generalized quality criterion (0.01087; 0.01538; 0.01; 0.014) exceeding the established tolerance of 0.01 that characterizes the monitoring quality of the particular technological process parameter (table 3).
Figure 1. The example of programming implementation by N-copy taking into account the measurements multi-point of monitoring parameters and the spatial distribution of sensors.
As a result, control returns to the scheduler. The scheduler transfers the correct results outside of NCP, and the NCP module terminates. In general, for this method both advantages and disadvantages can be noted.

Advantages:

- Costs are limited to the development and debugging of one version (source copy) of the software;
- The use of DRA for data pre-processing including in monitoring systems to increase the fault tolerance.
- The ability to use developed decision-making algorithms in general;

Disadvantages:

- Related errors in software development will appear in all copies;
- Developed scheduler work mechanisms are required to ensure work synchronization of DRA and individual copies.

2. N-version programming with a tie breaker and acceptance test

We will consider another method aimed at improving the software fault tolerance. It is the N-version programming method with a tie breaker and acceptance test (NVP-TB-AT). This method was developed [7] to illustrate modeling performance and make changes to the program architecture to increase performance.

We will consider the previous example of model design of monitoring environmental system using the N-version programming with a tie breaker and acceptance test. As components of the implementation method of the N-version programming with a tie breaker and acceptance test, a scheduler is used that controls and synchronizes actions, three versions (Version 1, 2, 3) of the algorithm / program, which, firstly, take into account the reduced averaging coefficient (table 1.2) for the technological process parameters before and after filtering, secondly, they provide a calculation of the modular ratio of the difference between the parameter measured and the given to the given. The resulting expression (version output) is the formula term (1) which expresses a generalized quality criterion characterizing the state of the technological process. The comparator provides a comparison of the resulting version outputs. The decision mechanism (DM) algorithm solves several problems. Firstly, it summarizes the outputs of algorithm copies (Version 1, 2, 3) to formulate the generalized quality criterion or its term, and secondly, it compares the outputs of versions to exceed the established tolerance by the expressions – the outputs of algorithm copies by the majority tolerance. The final stage is acceptance test, the execution algorithm of which determines the resulting value of the generalized quality criterion and comparing it with the tolerance.

Upon entering NVP-TB-AT, the scheduler sends data from the technological process parameters sensors of flue gas and suspended particles diverting, to three parameters to the filtration system (Version 1, 2, 3) and to three parameters after the filtration system.

Moreover, each parameter has a three-point character of measurement, taking into account the characteristics of the sampling location (Figure 2).

- Each version, \( V_i \) (\( i = 1, 2, 3 \)) is executed.
- The results of the two fastest execution versions \( R_{1,1} \) and \( R_{1,2} \) are collected by the scheduler and transmitted to the comparator. The comparator analyzes the comparable elements of string data arrays:

\[
R_{1,1} = 0 \quad 0 \quad 0 \\
R_{1,2} = 0.0001 \quad 0.01087 \quad 0.0093
\]

Results do not match.
Figure 2. The example of the implementation of N-version programming with a tie breaker and acceptance test taking into account the measurements multi-point of monitoring parameters and the spatial distribution of sensors.

A case of results coincidence is zero values characterizing the absence of deviations from the normal course of the technological process, other possible variants of coincidences are practically not feasible, since the probability of identical data in the string array with the number of decimal places 4-5 is minimal.

- The scheduler expects the slowest version to complete the execution.
- The slowest version, V3, completes the execution.
• The result from the slowest version, $R_{1.3}$, is collected by the scheduler and together with $R_{1.1}$ and $R_{1.2}$ is presented to the decision-making mechanism.
• The decision-making mechanism compares the results in accordance with the majority tolerance algorithm and forms the term of the generalized quality criterion. $R_i = (0.01087; 0.01) \ K_i = 0.03962$.
• Control is transferred to the scheduler.
• The scheduler, in its turn, passes the DM result for acceptance test.
• The resulting data of the decision-making mechanism of the measurement plane of the monitoring system (after filtering) are also received for acceptance test.
• AT summarizes the elements of the generalized quality criterion and evaluates for exceeding the value of the established tolerance. In case of exceeding the output data set is the value of the generalized quality criterion as a whole and the individual results of the versions that have passed DM.
• Management control is passed to the scheduler.
• The scheduler transfers the resulting data set ($0.01087; 0.01; 0.01538; 0.14; K = 0.070032$) outside NVP-TB-AT, and the NVP-TB-AT module terminates.

3. Conclusion

In general, for this method, both advantages and disadvantages can be noted:

Advantages:

• The possibility of multivariate analysis of error eliminations.
• The possibility to use developed decision-making algorithms on the whole;

Disadvantages:

• High costs for the development and debugging of each version of the software;
• Developed mechanisms are needed for the scheduler work to ensure the work synchronization of versions, the comparator, the decision-making mechanism, and the acceptance test algorithm.

As a result of the research, it can be concluded that the considered multiversion methods to increase the fault tolerance of software systems have a high potential for application in the technological processes monitoring systems that take into account the multipoint of parameter measurements and the spatial distribution of sensors at technological control objects [8-11]. An important factor is the presence of empirical characteristics (coefficients) of technological equipment for constructing adequate software models.

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