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METHODS FOR IMPROVING THE DATA RELIABILITY IN INFORMATION AND CONTROL SYSTEMS

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***Abstract*—*The paper deals with the questions of analysis and estimation the information reservation validity increase in information-control systems. A device for parallel-serial information reservation has been developed to increase the reliability and validity of data and minimize the limiting factors: reducing the number of parallel reserved information source, information aging time, correlation of random noise, failures and self-restoring failures in information and control systems. The results of mathematical modeling of the device operation are presented, by which it can be concluded that if the parallel and sequential information redundancy is correctly combined, then the number of reserved information source and the number of consecutive checks can be optimally reduced to increase the reliability of the data. The development and use of a device based on a combined reservation to ensure high reliability of information in the information and control systems, as well as a significant reduction in the probability of nondetected and false alarms in alarm dangerous situations systems.*

Index Terms—Efficiency; information reservation; information-control systems; mathematical modeling; increasing the data reliability; device.

I. INTRODUCTION

It is known that the efficiency and quality of information and control system (ICS) functioning significantly depends on the reliability of information received at the input of controlled computing systems, from various types of information sources, that control the state and parameters of ICS functioning. Real sources of information (IS) have the ultimate accuracy of the representation of the information controlled by them. At the same time, accuracy and reliability of information is determined both by design features and technical reliability of IS and, as a rule, does not meet or not fully satisfy the requirements for accuracy and reliability of information supplied to the inputs of automated ICSs.

To determine the parameters of controled object various technical sensor and means are used, which are characterized by certain accuracy and probabilistic characteristics of its work. In addition, for control are used different monitoring and control systems, which formed control signals based on information from measurement systems. The operation quality of any measurement, monitoring or control system depends on the data reliability, which came on its inputs. Thus, the principal requirement for the effective operation of automatic control and monitoring system is the high confidence of the input data, the source of which are measurement and control sensors.

II. PROBLEM STATEMENT

The operation statistics of the technical systems indicates a significant specific volume among the total number of functional failures of such systems, the so-called "false" alarms. According to statistics from 8 registered alarm, the 6 of them turned out to was false. The causes of false positives, as before, were the insufficient reliability of the executive units and sensors [1]. In this regard, along with the reliability of correct detection, the probability of a “false” alarm is taken as a criterion for the quality of the system.

Therefore, there is a need to increasing data reliability in information-control systems. In this case, the most expedient is the use of information reservation. The method of parallel reservation of information significantly reduces the probability of not detecting the situation and has little effect on reducing the probability of a false alarm. The method of sequential reservation can significantly reduce the probability of false alarm and has little effect on reducing the probability of not detecting of controlled phenomenon. The combined use of parallel and sequential redundancy can effectively reduce both the probability of a false alarm and the probability of non-detection with minimal economic costs. That why one the most informative is the combined information reservation. Thus, there is a need to develop a device for parallel-serial information reservation in order to increase the data reliability in information-control systems.

III. REVIEW

Typically, data sensors provide information with insufficient reliability. A number of technical measures utilize for increasing the data reliability, which complicated the system, increasing cost and decrease technical reliability. At the same time, the reliability of the received data remains low due to low sensors technical reliability. To increase the input data reliability it is most expedient to use the information reservation, in which instead of one technically complex, reliable and expensive sensor are used several simple ones with high technical reliability and low cost.

As a rule, each separate such sensor is characterized by insufficiently high accuracy and probabilistic characteristics: the probability of correct detection a, the probability of false alarm b, the probability of nondetection d. It is known from the theory of static solutions [2] and [3] that in order to increase the accuracy of estimating these probabilities, it is necessary to increase the number of statistics data.

There are two main ways of information reservation: parallel information reservation, in which several sensors controls the same parameter and used in parallel; serial information reservation, in which the same sensor is requested successively several times.

Using of serial information reservation in information-control system of the aircraft alarm system is considered in [4]. In the case of serial information reservation, the decision about the reliability of data is taken according to the criterion "k of m", when the number of positive assurance exceeds or equal to "k for m" consecutive measurements. The application of parallel information reservation in aviation navigation systems is considered in paper [5]. In the case of parallel information reservation, the decision about the reliability of data is taken on the majority principle, when most of the sensors confirm the presence of a controlled phenomenon. The article [6] conducts the evaluation of the effectiveness of various methods of information reservation. In the paper is offered the information criterion for quality estimation of various methods of information reservation and shown that the most informative is modular and combined reservation.

IV. PROBLEM SOLUTION

Each of the main methods of information reservation has its advantages and disadvantages. Thus, the method of parallel information reservation is much less dependent on the technical reliability of the sensors, but with this method, there are economic problems of increasing the cost of the system with an increase in the number of parallel sensors. The method of serial reservation, in which only one sensor is used, significantly reduces the cost of the system, but at the same time, there are the problem of technical reliability as well as the information aging, determined by the delay in obtaining reliable data. Therefore, it is advisable to combine both methods of reservation, using a combined information reservation. Figure 1 shows, as an example, a functional diagram of a parallel-serial information reservation device (PSIRD) that implements a method of parallel-serial information reservation. Proposed PSIRD can be used in any information and control system to improve the system quality.

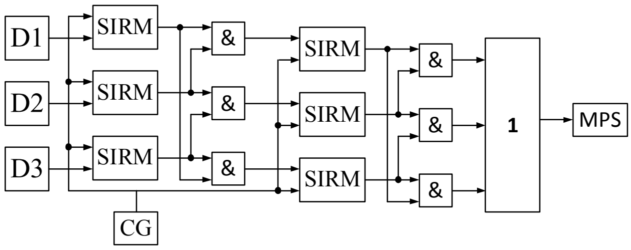

Fig. 1. Functional diagram of parallel-serial information reservation device

The device receives information from three sensors D1, D2, D3, which in parallel monitor the same parameter. Measurement data from three sensors D1, D2, D3 are sent in parallel to three serial information reservation machines (SIRM), in each of which the decision criterion "3 of 4" is autonomously realized, according to which the information is considered reliable if 3 times out of 4 possible is confirmed presence of a controlled signal. Output signals with increased reliability from 3 SIRM schemes are fed to three logical circuits AND that are connected so that the majority principle of parallel information reservation is fulfilled according to the criterion "2 of 3", according to which the information is considered reliable if it is confirmed by any 2 of 3 channels.

The input signals with increased reliability from the 3 logic circuits AND the first phase are fed in parallel to the 3 SIRM circuits of the second phase, where the principle of serial information reservation by the criterion "3 of 4" is implemented again. The output signals from the 3 circuits SIRM of the second phase are again fed to 3 logical circuits AND, on which the majority principle of parallel information reservation is implemented according to the criterion "2 of 3". Output signals that determine the presence of a controlled phenomenon with a high degree of reliability, which appeared at the output of at least one of the 3 logical circuits "AND" of the second phase, are fed through the logic circuit OR to the input of the microprocessor system MPS.

In Figure 2 is shown a functional diagram of the SIRM. SIRM consisting of an RS-flip-flop, 2 binary counters, 2 logic circuits AND, 2 logical OR circuits and a time delay element. The SIRM device operates as follows. The monitored signal is fed to the switching input S of the TT flip-flop, and at the same time, the output signal Q from the TT flip-flop opens a logic AND circuit through which pulses are sent from the clock generator CG to the counting input of the binary counter BC2 A. The same pulses are fed to the counting input of the binary counter BC2 B, and through the time delay element (TDE) and the OR logic circuit, the TT trigger is reset. At the same time, the readings of the BC2A and BC2B counters are increased by 1. This process will be repeated if the monitored signal is fed back to the input S of the TT trigger. As a result, the number of repeated receipts of the monitored signal is fixed on the counter A, and the total number of clock pulses on the counter B is fixed. If such a number reaches the value 4, a signal will appear at the output of the 3rd digit of the binary counter BC2B, which will reset both BC2A and BC2B counters, and through the OR circuit B will reset the TT trigger. In this case, the account will be repeated, and each time at the output of the OR circuit A there will be a monitored signal with a high degree of reliability if the counter A counts at least 3 consecutive receipts of the monitored signals. Thus, the SIRM device implements the "3 of 4" criteria for checking the serial receipt of monitored signals. The CG frequency of the timing pulses is selected from condition:

$$\frac{1}{f} \le \frac{t.d.start}{8}, \tag{1}$$

where $t.d.start$ is the permissible aging time of information.

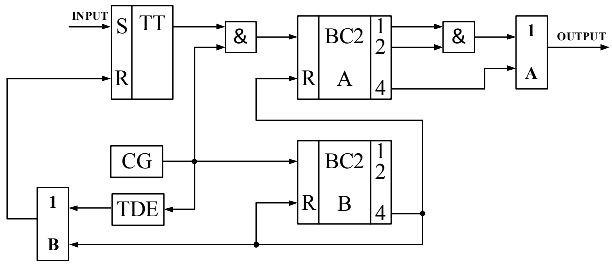

Fig. 2. Serial information reservation machines

The delay time t_{del} realized by the delay circuit (Fig. 2) is chosen such that condition

$$t_{\text{pul}} < t_{\text{del}} < \frac{1}{f}, \tag{2}$$

where t_{pul} is the duration of the timing pulses.

The number of statistical checks in the PSIRD (Figs 1 and 2) increases with increasing the number of sensors, the number of serial requests of each sensor, and the number of phases parallel-serial reservation. At the same time, the PSIRD scheme allows to significantly increase the number of statistical examination with a small number of sensors, which control the same parameter. So, in accordance with the above diagram (Figs 1 and 2), three sensors are used, each of which is sequentially requested 4 times in the first phase, and the controlled phenomenon is considered established if a signal about its presence appears in at least 3 of 4 requests for each sensor. Then in the 1st phase all 3 sensors are checked in parallel, and makes a decision about the presence of a controlled phenomenon on the base of majority principle, when 2 of 3 sensors confirm the presence of controlled phenomena with account for previous analysis. Thus, in essence, a static check is performed 12 times in the first phase, under which the controlled phenomenon is considered established, if its presence is confirmed no less than 6 times. In the second phase, the same process of statistical refinement is repeated, again for each sensor the serial check is repeated 4 times, and therefore the total number of checks will now be equal to 48 times. Since in the second phase the controlled phenomenon is considered as established, if it is confirmed at least 3 times after serial 4 requests and from 2 sensors for the majority principle, the total number of checks at which the controlled phenomenon is deemed to be established will be no less than 36 times.

According to the above PSIRD scheme, the total number of statistical checks is 48, and a controlled phenomenon is considered established if at least 36 times it is confirmed. This significantly increases the probability of reliable determination of the presence the controlled phenomenon for 3 sensors. For the total number n of parallel checks and the number m of serial checks in each of the k phases, the total number N of checks can be determined by the formula $N = n\,m^k$. For the rules of determining the reliability of serial requests "W from m" for each sensor and the majority principle "V of n" for all sensors, then the controlled phenomenon can be define if it is confirmed M from N times. In this case, the number M can be determined by the formula $M = V^k\,W^k$.

Thus, an increase in the number k of phases and the number m of serial checks of each sensor in each k phase substantially increases the number of statistical checks and the reliable determination of the controlled phenomenon. But increasing in the numbers k and m is associated with an increase in the time delay. The information aging time limits the possibilities for increasing the numbers k and m. In each specific situation it is possible to determine the optimal value of these numbers k_{opt} and m_{opt} .

In the case, when the same source of information is requested periodically with a certain time interval, then according to the theorem of Bayes [2], [3] with a given α priori probability and given probability characteristics of information sources (probabilities of a reliable detection a, nondetection d and false alarm b), the posterior probabilities of a reliable detection P_{cd}, nondetection P_{nd} and false alarm P_{fa} can be determined using the following formulas:

$$P_{cd} = \frac{\alpha a}{\alpha a + (1-\alpha)b} + \frac{(1-\alpha)a}{(1-\alpha)a + \alpha d},$$
$$P_{nd} = \frac{\alpha d}{(1-\alpha)a + \alpha d}, \quad P_{fa} = \frac{(1-\alpha)b}{\alpha a + (1-\alpha)b}. \tag{3}$$

Let us introduce the following notation: apriority coefficient of controlled phenomenon β_1, quality factor for the source by false alarm γ_1, quality factor for the source by nondetection χ_1. The coefficients β_1 , γ_1 , χ_1 are determined by the relations:

$$\beta_1 = \frac{1-\alpha}{\alpha}, \quad \gamma_1 = \frac{b}{a}, \quad \chi_1 = \frac{d}{a}, \tag{4}$$

where α is the a priori probability of waiting the controlled phenomenon, a, b and d denotes the probability of reliable determination the controlled phenomenon, the probability of false alarm and probability of nondetection.

Given the above formulas, the probabilities of reliable detection, nondetection and false alarm, determined during serial analysis in the 1st phase, are expressed in accordance with formulas:

$$p^{(1)}_{1seq}(W) = \alpha\frac{1}{1+\beta_1\gamma_1^w} + (1-\alpha)\frac{\beta_1}{\beta_1 + \chi_1{}^{\omega}},$$
$$p^{(1)}_{2seq}(W) = (1-\alpha)\frac{\chi_1^w}{\beta_1 + \chi_1^w}, \tag{5}$$
$$p^{(1)}_{3seq}(W) = (1-\alpha)\frac{\beta_1\gamma_1^w}{1+\beta_1\gamma_1^w}.$$

The probabilities a, b and d are the initial indicators the quality of the sensor. According to the PSIRD scheme (see Fig. 1), after a serial analysis, a parallel refinement of the data on the majority principle is made. In this case, the probabilities $p^{(1)}_{1\,par}$, $p^{(1)}_{2\,par}$, $p^{(1)}_{3\,par}$ are determined in accordance with the polynomial distribution [2]:

$$p^{(1)}_{1\,par} = 1 - \sum_{i=n-v+1}^{n} C_n^{n-1} P_{1seq}^{(1)\cdot(n-1)} (1 - p_{1seq})^i,$$
$$p^{(1)}_{2\,par} = \sum_{n=i=0}^{\nu-1} C_n^{n-i} p_{1seq}^{n-i} \sum_{i-j}^{\nu-n+i+1} C_i^{i-j} p_{2seq}^{(1)(i-j)} p_{3seq}^{(1)\,j}, \tag{6}$$
$$p^{(1)}_{3\,par} = \sum_{i-j}^{n} C_n^{i-j} p_{3seq}^{(1)(i-j)} p_{2seq}^{(1)\,j}.$$

The obtained data recursively determine the new values of the coefficients quality factor for the source by nondetection and false alarm

$$\beta_2 = \frac{1 - P_1^{(1)}par}{P_1^{(1)}par}, \quad \gamma_2 = \frac{P_3^{(1)}par}{P_1^{(1)}par}. \tag{7}$$

On the base of obtained values of the coefficients β_2 and γ_2, the probabilities of reliable detection $P^{(2)}_{1seq}(W)$, nondetection $P^{(2)}_{2seq}(W)$ and false alarm $P^{(2)}_{3seq}(W)$ are recurrently determined according to formulas (5), in which the coefficients β_1 and γ_1 are replaced by the values of β_2 and γ_2. The values $P^{(2)}_{1seq}(W)$, $P^{(2)}_{2seq}(W)$ and $P^{(2)}_{3seq}(W)$ are substituted into formulas (6), and the probabilities of reliable detection $p^{(2)}_{1(2)par}$, nondetection $p^{(2)}_{2(2)par}$ and false alarm $p^{(2)}_{3(2)par}$ are determined with parallel reservation in the 2nd phase. The economic efficiency $E_{\text{eff}}(n,m,k)$ as a function of the number of sensors n, the number of consecutive checks m and the number of phases k can be determined according to the expression:

$$E_{\text{eff}}(n,m,k) = \frac{P_1^{(k)}par}{n \cdot c_1 + k.c_2}, \tag{8}$$

where c_1 is the cost of a system with one sensor; c_2 is the cost of one-phase SIRM.

Formula (8) implicitly takes into account the permissible delay time t_{del} for obtaining reliable information, which should not exceed the permissible aging time $t_{\text{p. agin}}$ [3].

Formulas (3) – (8) express the algorithm for determining the optimal values the number of sensors n_{opt}, the number of consecutive checks m_{opt} and the number of phases k_{opt}. If as the criterion of optimality choose the maximum value of the economic efficiency of the circuit $E_{\text{eff}}(n,m,k)_{\max}$ for a given value of the permissible data aging time $t_{\text{p. agin}}$ and use method of searching the extremum, the Gauss–Seidel method for example [3], then is possible to find the optimal parameters of the system, using recursive calculations by the formulas (3) – (8).

Analysis the above algorithm shows that the data aging time and the economic costs on the implementing the method are in a dialectically contradictory relationship. To reduce the delay time for obtaining reliable data is need to increase the number of sensors, which will be associated with an increase in additional costs.

V. RESULTS OF RESEARCH

The paper deal with the parallel-serial information reservation device, which allows to increase the data reliability about controlled parameter before the signal enters in the monitoring and control systems. In the process of mathematical modeling the work of a parallel-serial data reservation device constructed graphs of the dependence the reliability of information on the number of consecutive requests (Fig. 3), the dependence on probability of reliable determination of primary information sensors (Fig. 4) and the dependence on the probabilities of reliable operation of primary information sensors (Fig. 5).

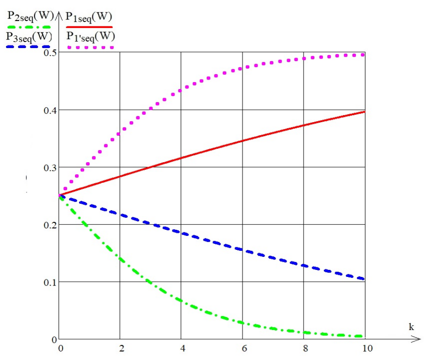

Fig. 3. The dependence of the information reliability of on the number of consecutive requests

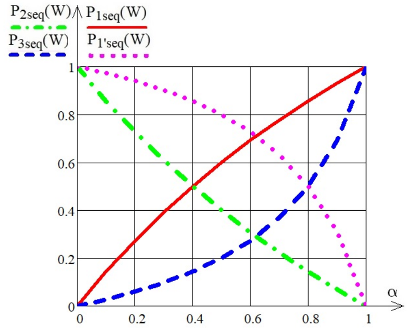

Fig. 4. The dependence of information reliability on probability of reliable determination of primary information sensors

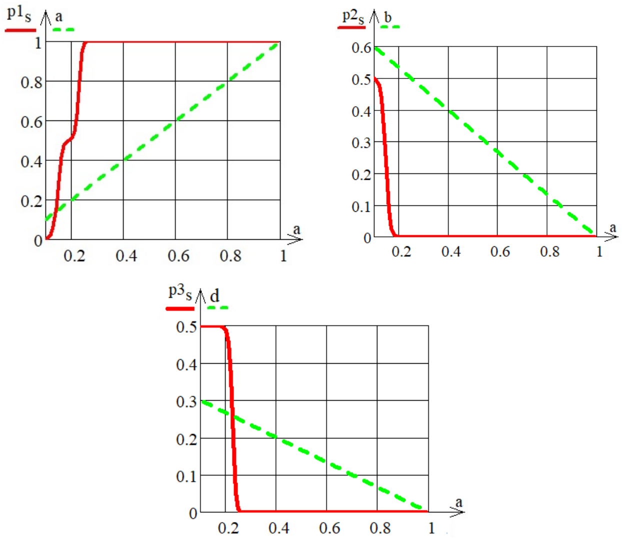

Fig. 5. The dependence graph the reliability of information on the reliability of the primary sensors operation

After analyzing the graphs, the following conclusions can be done: with increasing the number of consecutive requests and increasing reliability of the primary sensors operation lead to significant increasing the reliability of information.

VI. CONCLUSIONS

The paper deal with development of a device for increasing the data reliability in information-control systems. In this work, the functional diagram of a parallel-serial information redundancy device is proposed. In this device the measurement data from three sensors are sent in parallel to three serial information reservation machines, in each of which the decision criterion "3 of 4" is realized. Simultaneously provide parallel information reservation of data from SIRM with decision criterion "2 of 3". In this work, the mathematical models of sequential, parallel, and combined information redundancy, implemented directly by the proposed system, are built. The results of mathematical modeling of the device operation are presented in the work. As a result of mathematical modeling It has been established that using the combined backup method, the economic efficiency increases by 48 times, the effectiveness of correct detection 2 times, the probability of false alarm decreases by 2.5 times and non-detection by 25 times.

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Алі Аль-Амморі, Х. А. Аль-Амморі, А. Є. Клочан, О. П. Тимченко, Ахмад Аль-Ахмад. Методи підвищеня надійності даних в інформаційно-управляючих системах

У статті розглянуті питання аналізу і оцінки підвищення достовірності резервування інформації в інформаційно-керуючих системах. Розроблено пристрій паралельно-послідовного інформаційного резервування для підвищення надійності та достовірності даних та мінімізації обмежуючих факторів: зменшення числа паралельно зарезервованих джерел інформації, часу старіння інформації, кореляція випадкових перешкод, збоїв і самовідновлюються відмов в інформаційно-керуючих системах. Представлені результати математичного моделювання роботи пристрою, за якими можна зробити висновок що, якщо правильно поєднувати паралельне і послідовне інформаційне резервування, то можна оптимально скоротити як число зарезервованих джерел інформації, так і кількість послідовних перевірок для підвищення достовірності даних. Розробка і використання пристрою на основі комбінованого резервування забезпечить високу достовірність інформації в інформаційно-управляючих системах, а також істотне знижує ймовірності невиявлення і помилкової тривоги в системах сигналізації небезпечних ситуацій.

Ключові слова: ефективність; інформаційне резервування; інформаційно-управляюча система; математичне моделювання; підвищення надійності даних; пристрій.

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Али Аль-Аммори, Х. А. Аль-Аммори, А. Е. Клочан, А. П. Тимченко, Ахмад Аль-Ахмад. Методы повышенной надежности данных в информационно-управляющих системах
В статье рассмотрены вопросы анализа и оценки повышения достоверности резервирования информации в информационно-управляющих системах. Разработано устройство параллельно-последовательного информационного резервирования для повышения надежности и достоверности данных и минимизации ограничивающих факторов: уменьшения числа параллельно зарезервированных источников информации, времени старения информации, корреляция случайных помех, сбоев и самовосстанавливающихся отказов в информационно-управляющих системах. Представлены результаты математического моделирования работы устройства, по которым можно заключить что, если правильно сочетать параллельное и последовательное информационное резервирование, то можно оптимально сократить как число зарезервированных источников информации, так и число последовательных проверок для повышения достоверности данных. Разработка и использование устройства на основе комбинированного резервирования обеспечить высокую достоверность информации в информационно-управляющих систем, а также существенное снижение вероятности необнаружения и ложной тревоги в системах сигнализации опасных ситуаций.
Ключевые слова: эффективность; информационное резервирования; информационно-управляющая система; математическое моделирование; повышение надежности данных; устройство.

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