Distributed control network for complex radio engineering systems on continuum computers

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Abstract. The article proposes a method for evaluating the radio engineering system functional characteristics based on the use of continuum processors that combine the logical and computational capabilities of state continuous parametric assessment of a functional system. The hardware implementation of the knowledge processing system is created on the basis of continuum processors. It is integrated into the means of functional control and maintenance a state of preparedness of complex electronic equipment.

1. Introduction

Modern radio engineering systems (RES) contain a large number of hardware equipped with numerous monitoring sensors [1]. Information from the sensors is recorded by the integrated control system (ICS) of the product, which allows to determine the failure of the RES components in real time.

In the existing integrated control system [2], the flow of information about the RES functional-algorithmic systems (FAS) elements state creates a significant load on the data processing facilities. Therefore, functional control systems monitoring is one of the most difficult problems in the development of radio electronic equipment complexes.

A specialized system for monitoring and diagnosing functional characteristics of the FAS should combine complex analytical calculations with logical calculations that determine the cause-effect
relationships of parameters and characteristics. Artificial intelligence methods based on knowledge processing are effective for their logical analysis [3]. Such systems require cyclic processing of rules and facts that determine knowledge about the object of functional control [4, 5]. Delegating the task of monitoring the technical condition of the RES elements to the central computer significantly complicates its software, which leads to a decrease in the speed of solving tactical problems, a decrease in reliability, and an increase in the complexity of developing control algorithms. An alternative to a centralized control system is a distributed network of computers [6], which allows to improve the monitoring capabilities of RES and increase the efficiency and reliability of control.

Based on the above conditions, the computational complexity of the solving functional control problem is determined not only by the complexity of calculating the functional characteristics \( F=\{f_1, f_2, \ldots, f_N\} \), but also by their logical relations, as well as the need to perform functional-logical analysis. The controlled parameters \( Z=\{z_1, z_2, \ldots, z_N\} \) change in time and functionally depend on other parameters \( z_i = f(x_1, x_2, \ldots, x_m, t) \). The domain of characteristics \( F=\{f_1, f_2, \ldots, f_N\} \) is limited by the set \( \Theta \) of permissible parameter values \( X=\{y_1, y_2, \ldots, y_N\} \) are the values of the external environment parameters, \( Z=\{z_1, z_2, \ldots, z_N\} \) are the values of the FAS parameters. A generalized mathematical model of a functional RES is the N-dimensional domain \( Q \), inside which all the functional characteristics of the RES FAS should be located. The model can be represented in mathematical form:

\[
\exists f_i \in F : \{ f_i(x_1, x_2, \ldots, x_m, t) \subseteq Q, i = 1 \div N, \forall x \in X, \bar{x} \in \Theta \}
\] (1)

The second aspect of the functional control problem is the influence of the RES functioning modes on the interdependence of FAS parameters. Changing the operating mode leads to a change in the functional relationships of the entire system. Thus, the logical component of the functional control system appears, establishing the dependence of its characteristics on the state of the control object.

Both of the presented aspects of the concept must be taken into account in the process of developing computing devices of a distributed RES functional control system based on knowledge processing.

The aim of this work is to create a distributed computing network that performs continuous functional-logical monitoring of the RES FAS characteristics.

2. **Continuum processors of a computer network of a system for evaluating functional characteristics**

The basic element of a system distributed computing network of a system for assessing functional characteristics is a continuum processor (CP) [7], which is understood as a device that performs continuous processing of telemetric information flows using logical and functional transformations of analog signals characterizing FAS parameters and characteristics. Analog logic is used in the CP. It gives the processor fundamentally new opportunities compared to the well-known analog processors FPAA (Field-programmable Analog Array) [8].

The main feature of the CP, in comparison with digital computers, is the ability by interpolation methods to perform calculations of nonlinear functions in the continuous domain of their determination. If we consider a generalized model of the FAS characteristics and blocks (1), then at each moment of time \( t \) the system should be in a deterministic state. It is determined by the values of interconnected functional \( F=\{f_1, f_2, \ldots, f_N\} \). When they change, the signal levels of the CP change too (see expressions (2) and (3)), i.e. the states of the computer network of the system for assessing functional characteristics change. The continuous calculation of the functions \( f_1, f_2, \ldots, f_N \) values is the most important property of the CP.

An important aspect of the RES functional control system construction is the formation of a knowledge base. In contrast to widespread expert systems [9,10,11,12,13,14] in a distributed control system, a knowledge system is understood as a set of functional-logical dependencies linking the characteristics of RES blocks with signs of FAS failure occurrence. A cyclic decision search in the parameter estimation loop can significantly reduce the speed of decision making. Any delay in the process of choosing \( F_i \) functions in strict restrictions on the minimum speed can lead to a loss of time to restore the performance of the RES.
3. Control systems integrating in the structure of the RES

The ability to combine analytical calculations with a logical analysis of the processes state and the unification of the CP allows structurally dispersing calculators over individual FAS and RES units. In each FAS and unit, all actions are localized, which are necessary both for determining the state of processes that affect failures and for transmitting values of functional characteristics to the system. FAS or a block with attached CPs form a functional-logical cluster of signal synthesis for parameter estimation (figure 1).

![Figure 1. FAS functional control circuit.](image)

The functional-logical cluster of the FAS parameter estimation contains \( k \) CP, defining a certain information processing mode. The control mode in the \( i \)th cluster cluster can be represented as a predicate:

\[
\text{if } \theta_i(x_1,x_2,...,x_n,t) \wedge \varphi_i(x_1,x_2,...,x_n,t) \wedge \psi_i(f_i,x_1,x_2,...,x_n,t) \text{ then } q_i(t) = 1
\] (2)

\[
\text{if } q(t) = 1 \text{ then } r_i(t) = f_i(x_1,x_2,...,x_n,t)
\] (3)

At the input of the CP, the value of the parameter \( f_i \), continuously obtained at given stimulating signals \( x_1(t), x_2(t),...,x_n(t) \). The calculation conditions \( \theta(t) \) and \( \varphi(t) \) determine the possibility of applying the \( i \)th control method. CP checks that \( f_i \) is in the tolerance field:

\[
e_i^{\text{min}} < f_i(x_1(t),x_2(t),...,x_n(t)) < e_i^{\text{max}}
\]

If FAS is operable by the checked parameter, then the binary function \( \psi_i=1 \) and the value of the \( r(t) = f(x_1,x_2,...,x_n,t) \) and a logical signal \( q(t)=1 \) are transmitted to the output of CP. Otherwise, the function output is blocked and a signal is output to the logic output \( q(t)=0 \). The value of the parameter \( r(t) \) can be used to further process the state of the control object and the logical signal \( q_i \) to notify the network about the operability of the control object.

CP operating modes in the cluster are incompatible. The output of the cluster can be fed only one signal CP. When the control mode of the \( i \)th CP is performed by opening the keys in the control signal circuit, commands from other CPs of the same cluster are automatically blocked. Therefore, it is possible to combine the functional outputs of the CP connected to the monitoring object.

Figure 2 shows the structure of the functional control of the RES. Several CPs are connected to the control object, each of which sets a certain mode for evaluating the parameters depending on the parameters coming from the sensors. Connection CP sets the logic of their interaction when executing commands.

The network simultaneously activates all the calculations for which the conditions of the control mode are fulfilled. The choice of active CP in the \( j \)th cluster is determined by the logic of cluster interaction, the internal logic of the cluster, and the values of the parameters coming from the sensors. Calculations are performed at the rate of change of cluster states, which depends on the speed of
transistor switches in the output circuits of the CP. The average rate of control of parameters is about one megahertz throughout the network.

The most important property of the functional control structure is the ability to quickly adapt to the conditions of use. The calculated functions are either synthesized in the process of learning the CP, or are set according to the known dependences of the output signal on the parameters $x_1, x_2, \ldots, x_n$. In the course of training, CPs receive exemplary values of functions for given parameters of FAS $Z^*$ at the studied discrete points of the control area. In the process of preparing the network for operation, the obtained reference values are used for flashing a constant analogue memory device CP.

![Network structure of the functional control of the FAS.](image)

Figure 2. Network structure of the functional control of the FAS.

4. Conclusion

Distributed continuum systems have significant advantages in the speed of information processing compared to digital systems, which is achieved through parallel computing and continuous interaction of CP clusters in real time. The speed of processing by a continuous signal processor is determined by:

- key circuits in analog logic circuits (speed of about a hundred nanoseconds),
- analog methods for calculating function values,
- rejection of digital traffic for transmitting information about functional characteristics.

The performance of continuum networks makes it possible to integrate into the complex of an operational assessment of the functional characteristics of the RES a knowledge processing system for assessing the state of FAS.

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