Method of Control and Diagnosis Integrated Systems and Communication Systems Based on Thermal Processes*

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Abstract. The significant number of failures in modern software and hardware communication systems of large integrated systems are associated with thermal conditions changes. The effective method of control and diagnosis software and hardware communication systems is thermal control of electronic modules elements. The system of control should allow detect hidden defects in software and hardware communication systems, substitute nature modeling defects to program simulation for decrease time of creating state base. The subject of investigation is control of technical condition software and hardware communication systems in working state real time. The purpose of investigation is increasing efficiency of technical control in working state. For development of thermal control instruments are used methods: to modelling thermal processes in electronic modules of software and hardware communication system is used finite difference method, to processing thermogram is used wavelet-analysis. For experimental verification obtained results is choosed electronic module of modern hardware and software systems, for which created state base by developed model and compared results of recognition technical condition with developed methodic and without. As a result of investigation were developed thermal model of hardware and soft-ware communication systems, the methodic of recognition abnormal states electronic modules based on wavelet-transforms and the algorithm creating state base soft-ware and hardware communication systems. Based on the obtained results is develop technical proposals that will improve efficiency of determining the technical condition and realize the possibility of preventing failures.

Keywords. Aerospace systems Large integrated systems Software hardware communication complex Wavelet analysis.

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1 Introduction

During the operation of aerospace organizational and technical complexes [1], including autonomous objects, such as robotic systems, autonomous space and underwater vehicles, automated communication centers and radio centers, the urgency of creating a method for their diagnosis and non-destructive testing of technical status is increasing [1-5]. Knowledge of the actual technical condition is necessary when making managerial decisions at the organizational and technical level to ensure the functioning of critical infrastructure facilities. The decision of control and diagnosis task is based on measuring thermal values electronic modules elements surfaces.

In result of control technical condition electronic modules (EM) of software and hardware communication systems (SHCS) should recognized type of state (perfect state, up state, down state, fault state) [1].

The nondestructive control on registration electromagnetic infrared radiation is effective and perspective method of control SHCS EM. Therefore, control task decision is based on monitoring changing elements temperatures. The using of infrared radiation is based on next factors:

- from 70% to 80% energy in radio elements transforms in heat radiation;
- a series of experiments shown the thermal control one of the most informative type of control;
- main reasons defects progress is deviation of radio elements heat conditions.

When thermal control of the technical condition of EM of SHCS of large integrated systems, the current state will be characterized by a matrix of temperature which obtained by teplovision sensors. In investigation are used termograph testo 875-2 is providing thermogram by size 120×160, it is allowing for measuring temperature of controlled elements (Fig. 1).

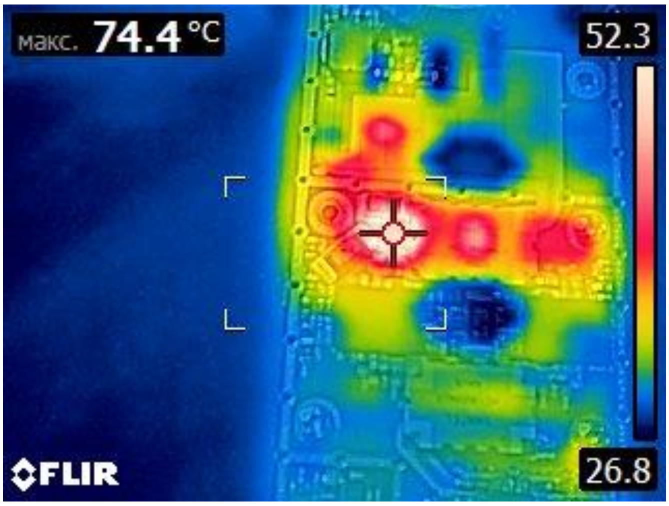

Fig. 1. Thermogram image of EM SHCS in grayscale

Since the boards are in different positions, it is necessary to segment the EM SHCS in thermal images by geometric transformation and standardize the images of the actual aspect ratio by affine transformation.

The resulting rectangular images are called EM SHCS thermograms [6]. The wavelet transform method is an effective way of reducing the feature space and information compression [7].

The analysis of different approaches to solving the problem of recognition of the type of anomalous state of the thermal regime of SHCS is based on the wavelet transform and shows that the problem is solved in the following formulation.

The initial data for solving the problem are:

- the standard thermal behavior of SHCS information (internal parameters values for different external conditions);
- information characterizing the main types of SHCS states in the analysis of thermal SHCS modes (tolerance intervals in different modes);
- the studied measurement information obtained in the analysis of thermal conditions of SHCS (different types of defects and failures);
- frequency of obtaining temperature values of EM SHCS elements;
- a set of orthogonal basis wavelet functions: daubechies, symlets, coiflets [7].

It is necessary to determine the type of anomalous state from the library of anomalous states based on the results of evaluation of SHCS thermal behavior. The anomalous state is understood as a deviation from the nominal mode of operation associated with changes in external and internal factors.1

2 Using wavelet transforms to form a state base

Application of the wavelet transform in this paper is considered from the standpoint of its use as a tool with which it is possible to obtain a feature space for subsequent recognition. The choice of the discrete wavelet transform (DWT) for solving recognition and classification problems is due to the universality of the mathematical apparatus of wavelet analysis, its ability to adapt to the signal form, the similarity of the studied signals with basic functions (wavelets) [7].

The choice of the analyzing wavelet is largely determined by the information to be extracted from the signal. Taking into account the characteristic features of different wavelets in time and in frequency space, it is possible to identify in the analyzed signals certain properties and features that are invisible in the presence of strong noises.

When analyzing any signal, it is necessary, first of all, to choose the appropriate basis, i.e. a system of functions that will play the role of “functional coordinates”. However, the choice of the analyzing wavelet is not defined in advance. It should be chosen according to the task to be solved. Simplicity of operation with wavelet and presentation of the results (minimization of the used parameters) plays an important role.

An unsuccessful choice of a specific form of wavelet can lead to the impossibility of solving the problem or a high error, and, consequently, to an incorrect definition of the type of technical condition of the SHCS. Select the type of basis function from the number used bases in the General case depends on the degree of adequacy of the functions and selections. Quantitatively, the degree of optimal choice can be determined by the entropy criterion [7].

As a criterion for choosing the optimal decomposition basis, we take the Shannon entropy criterion, which quantitatively characterizes the reliability of the transmitted signal and is used to calculate the amount of information. The entropy determined by Shannon's formula gives a criterion of how many effective components are needed to represent a signal in a certain basis [3].

3 Modeling thermal processes in different technical states

Modern SHCS are multimode and multifunctional equipment, and the deviant of tolerance level temperature in their can realized by changing functional mode (inner and outer factors) and do not depend of technical condition.

To implement the pattern recognition capabilities of the technical condition of the SHCS at the exit of the temperature values outside the tolerance intervals creates a base state of many of the alleged effects of external factors and possible defects. While conventionally, there are abnormal state (“pre-failure” and “failure”) [3, 6]. The base of anomalous states is a set of wavelet coefficients of SHCS thermograms obtained by modeling, each of which corresponds to an anomalous state or defect.

The modeling of heat condition is realized stage-by-stage transition from up level hierarchy with racks group and construction to down level with simplest elements which inseparable elements [3].

First created heat processes models or macro model of studied construction.

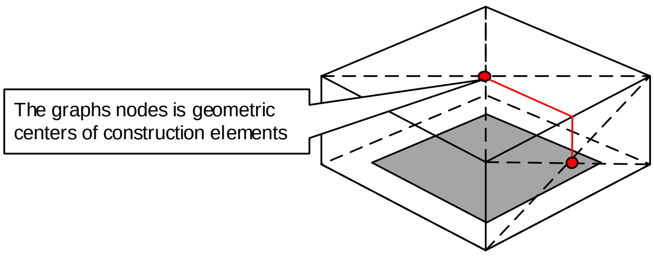

Fig. 2. Length of thermal flow length between pair sides definition

The model construction is beginning at the finding graphs nodes. The next, nodes associates between themselves to definition heat relation (Fig.2).

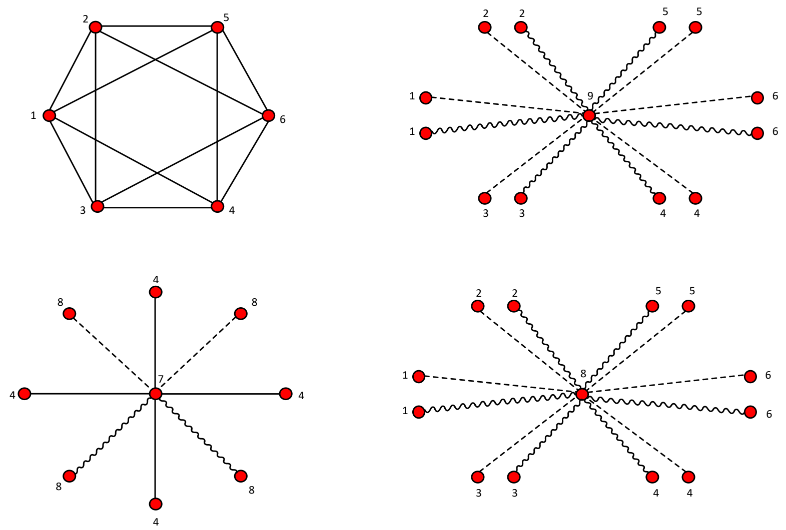

Fig. 3. Topologic model of SHCS in case

The Fig. 3 are indicated by numbers: 1 – left side case, 2 – up side case, 3 – forward side case, 4 – down side case, 5 – backward side case, 6 – right side case, 7 – electronic module, 8 – air inside, 9 – air outside.

Between sides are defined conditions of heat exchange size characterized heat flow cross-sectional area, length way of heat flow, thermal conductivity of material.

Heat exchange with the environment is characterized by natural convection from a flat surface into the environment and radiation from an undeveloped surface. The heat exchange of the board with the air inside the case is determined by the conditions of radiation and convection from a flat undeveloped surface. The parameters are setting surface length, surface width (height), surface orientation, environmental pressure.

The heat exchange of the board with the air inside the case is determined by the conditions of radiation and convection from a flat undeveloped surface. Since the EM is solve this problem, the equation of similarity and heat transfer equation, the method of nodal potentials for the formation of a mathematical model of heat processes in the form of a system of ordinary differential equations or a system of nonlinear algebraic equations are used [4]. Located on the lower wall of the housing, the conductive heat exchange of the EM with the lower wall of the housing is specified.

Based on the topological model (Fig. 3), a system of equations is formed and calculated:

$$\begin{cases}\frac{T_1-T_2}{R_{12}}+\frac{T_1-T_3}{R_{13}}+\frac{T_1-T_5}{R_{15}}+\frac{T_1-T_4}{R_{14}}=P_1(T_1);\\ \frac{T_2-T_1}{R_{21}}+\frac{T_2-T_5}{R_{25}}+\frac{T_2-T_3}{R_{23}}+\frac{T_2-T_6}{R_{26}}=P_2(T_2);\\ \frac{T_3-T_1}{R_{T_{31}}}+\frac{T_3-T_4}{R_{34}}+\frac{T_3-T_2}{R_{32}}+\frac{T_3-T_6}{R_{36}}=P_3(T_3);\\ \frac{T_4-T_3}{R_{43}}+\frac{T_4-T_6}{R_{46}}+\frac{T_4-T_1}{R_{41}}+\frac{T_4-T_5}{R_{45}}=P_4(T_4);\\ \frac{T_5-T_2}{R_{52}}+\frac{T_5-T_6}{R_{56}}+\frac{T_5-T_1}{R_{51}}+\frac{T_5-T_4}{R_{54}}=P_5(T_5);\\ \frac{T_6-T_5}{R_{65}}+\frac{T_6-T_4}{R_{64}}+\frac{T_6-T_2}{R_{62}}+\frac{T_6-T_3}{R_{63}}=P_6(T_6);\\ 4\frac{T_7-T_4}{R_{74}}+2\frac{T_7-T_8}{R_{78}}+2\frac{T_7-T_8}{R_{78}^{rad}}=P_7(T_7);\\ \sum_{i=1}^{7}\frac{T_8-T_i}{R_{8i}^{rad}}+\sum_{i=1}^{7}\frac{T_8-T_i}{R_{8i}^{conv}}=P_8(T_8);\\ \sum_{i=1}^{7}\frac{T_9-T_i}{R_{9i}^{rad}}+\sum_{i=1}^{7}\frac{T_9-T_i}{R_{9i}^{conv}}=P_9(T_9).\end{cases} \quad (1)$$

where $P_i(T_i)$ – heat power of element *i*, R_{ij} – heat resistance between *i* and *j* elements.

To solve this problem, the critical equations of similarity theory and heat transfer equation, the method of nodal potentials for the formation of a mathematical model of thermal processes in the form of a system of ordinary differential equations or a system of nonlinear algebraic equations are used [12].

Unlike other types of models, topological models of thermal processes allow us to set boundary conditions of various kinds [13] and their combinations in terms of volumes and surfaces of the SHCS structure using the appropriate graph components (branches, sources of a given temperature and (or) sources with preset thermal power).

Any thermogram of the state base is formed as follows: a change is made in the mathematical model of the SHCS, which corresponds to a defect or abnormal state, then a thermogram is obtained that reflects this state. Therefore, the resulting thermogram of such a modified model will correspond to the state of the SHCS, in which there is coincident defect, in this element. After that, the wavelet transform is performed and the resulting wavelet coefficients are preserved. In this way, the wavelet coefficients for all defects inherent in this SHCS are obtained. Modeling of thermal processes SHCS performed using computer-aided design, feeding the input model SHCS, and the output, receiving a thermogram or temperature values of the elements [4]. Then the wavelet transform of the obtained thermogram is performed to preserve the wavelet coefficients. To creation state base disigned next sequence of steps:

Step 1. Taking into account the operating conditions and the impact of external factors make a list of parameters for different states.

Step 2. Parameters for states with different types of defects are determined on the basis of failure statistics.

Step 3. Based on the generated parameters simulation of thermal conditions of SHCS is performed.

Step 4. Wavelet transform of the simulated thermogram of the technical state, reduction of the characteristic space.

Step 5. The obtained wavelet coefficients for the simulated anomalous state are stored in the state base.

Step 6. If all data according to the list of abnormal States and defects is stored, then proceed to the step 8.

Step 7. Conclusion of information that the modeling of anomalous states is completed.

Thus, looking through the list of anomalous states (step 3-7) peculiar to this SHCS, we obtain a set of wavelet coefficients for each state [5-10]. The element of the list of states (2) q_j^F consists of: a) the serial number of the element in the SHCS, b) what parameters reflect the defect and how to change them.

$$Q^F = (q^F{}_1 \ldots q^F{}_j \ldots q^F{}_n), \tag{2}$$

where Q^F – many defects of the controlled SHCS (list of defects), $q^F{}_j$ – a specific defect of a given SHCS element.

The set of wavelet coefficients of thermograms $C(R_M)$ SHCS is resulted (3), each of which corresponds to one of the anomalous states

$$C(R_M) = (C(R_M^1), \ldots C(R_M^n), C(R_M^{\text{norm}})), \tag{3}$$

where $C(R_M^n)$ – wavelet coefficients of the thermogram obtained in the simulation of thermal processes SHCS, which corresponds to the anomalous state with the parameters q_j^F .

When using the state base to recognize the state of SHCS, the wavelet coefficients from the state base are compared with the wavelet coefficients of the currently obtained SHCS thermogram.

In the general case, the database state SHCS produced by the experimental studies (by conducting a production test of the control object (prototype products) experimentally) at the factory. Select one sample with the closest indicators to the ideal or several samples. Next, a defect from the list of defects Q^F (3) is introduced into the sample and temperatures are measured in a stationary mode.

Eliminate the defect, bringing the sample to its original state, then carry out the same with other defects of Q^F (2) etc.

The result is an expression (4), not simulated but experimental temperature. Such acquisition of the state base is very difficult. Therefore, the proposed method using modeling and wavelet transform is beneficial, given the fact that modern computers can easily cope with the problem of modeling and calculation of wavelet coefficients.

$$T_M = (T_M^1, \ldots T_M^n, T_M^{\text{norm}}), \tag{4}$$

where T_{M}^{n} – consists of n sets. Each *j*-th set $T_{\text{M}}^{\partial j}$ corresponds to a manufacturing defect q_{j}^{F}, where $j = 1, n+1$.

$$T_{\text{M}}^{j} = (T_{\text{M1}}^{j}, T_{\text{M2}}^{j}, \ldots, T_{\text{M}k}^{j}), \tag{5}$$

where T_{M2}^{j} – the temperature in the element 2 obtained from the simulated images R_{M}^{j}, which corresponds defect with number *j* in list (1).

Generally, the thermal control of electronic modules of software and hardware communication systems of large integrated systems. Recognizing of state carried out by comparison of ccurrent state wavelet coefficients and states signatures wavelet coefficients of state base (Fig. 4). The graph is built for state base are including thermograms of electronic modules be size 160×120 mm and their wavelet-coefficients.

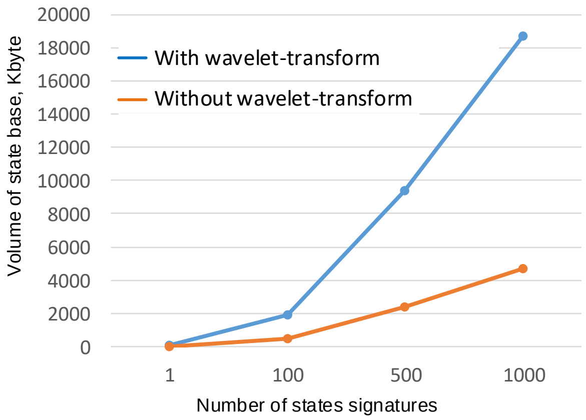

Fig. 4. Volume of state base with wavelet-transform and without wavelet transform.

4 Conclusion

Thus, the results of investigation are shown that using designed method provides at first increase the reliability of the identification results because in existing system of control is add thermal control, at second increase sensitivity to the detection of emergency situations, because appear facility of detecting gradual failure, thirdly increase sensitivity to the detection of emergency situations, also increase state recognition speed and decrease volume of state base.

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