Synthesis of channels of information-measurement systems based on accuracy and incomplete accuracy criteria

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ABSTRACT

The problems of synthesis of information channels of multi-parameter information-measurement systems based on accuracy and incomplete accuracy criteria are considered. The problem of assessing the incomplete accuracy criterion of information channels of the functional model, which characterizes the quality parameters of control and monitoring objects, is solved, a structural model of the system that meets these criteria is built, and the functional scheme of the corresponding information channels is determined.

1. Introduction

All controlled technical, technological objects, being multi-parameter, have certain characteristics and properties [1]. These properties are differently manifested in the application of the data class in the control of the corresponding objects. From this point of view the accuracy criteria used in the evaluation of information-measurement and control systems, characterized by a large number of parameters, i.e. a large number of input and output parameters, open up great opportunities for improving the applied information society for managing the existing problems of society in all spheres [2]. The difference between the aforementioned systems is related to the purpose of the objects in which they are applied, the former are technical, technological, artificially created systems, while the latter are socio-natural.

Not all characteristics of objects are used in evaluation, but only those variables and parameters that reflect properties and quality that strongly influence evaluation. By characterizing these properties with a generalized parameter, we denote it as a quality parameter Q, which can be used as the final result of solving the control problem and which shows the compliance potential of the object.

The difference between two properties of objects with certain boundaries is determined by the absolute value of the difference of quality parameters $|Q_2 - Q_1|$. External factors (y) influencing the object change its state. At the same time the quality parameter Q also undergoes a corresponding change. A change in possible values when setting or measuring x, which is a set of certain informative parameters, cannot directly affect the change in the output of the control object. Therefore the functional model (f) reflects a quality parameter Q showing the impact of all characteristics of the control object, the relationship between the values of impact factors y and informative parameters x,

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and allows us to investigate and analyze these relationships.

2. Problem statement

A functional model of an object includes the features of the concepts developed in the special field for these types in the process of application [1]. The actual characteristics of objects are very important for control purposes, and they have points that should get special attention in the implementation of control.

Structural complexity of any model when evaluating its actual characteristics on the basis of the functional model of the object does not guarantee the absence of systematic errors. This is also due to the fact that this functional dependence does not fully reflect the existing properties of the object under study. Therefore, it is necessary to determine the thresholds of methodological errors, based on the concept of measuring the set of given parameters.

It is possible to reduce the estimates of errors of measurement results of characteristic indicators of the object to the required limit, at which the appropriate organization of measurements is considered acceptable. The set of parameters X $(x_1,\ x_2, \dots, x_n)$ influencing the quality parameter Q of the object, its current state, at conducting measurements in different shared channels, and the set of excitatory factors Y $(y_1,\ y_2, \dots, y_m)$ is heterogeneous and can be repeated in various combinations in measurement processes. Thus the measurements carried out with a view of estimation of level of quality or a state of object on the basis of the functional model f constructed for the object are multi-parameter.

The general block diagram of the multi-parameter system, which implements the functions of management and control based on the collection, measurement, processing of data through information channels and allows us to determine the overall quality indicator and other characteristics of the above parameters based on the set of parameters affecting the object and the set of excitatory factors, is shown in Fig. 1 [3].

The block diagram in Fig. 1 shows certain important points related to the system based on multi-parameter measurements, the general principles of structural synthesis based on the accuracy criteria of the ideal automated system with the functions of collecting and processing multi-parameter data, where the main principle is to reduce the output error of the system by minimizing the errors in various information channels.

It should be noted that in the concept of multi-parameter measurements first of all simple functions are implemented in multi-parameter data acquisition and processing systems. Regardless of the purpose, the following tasks must be accomplished:

1) in the process of determining the set $(x_1,\ x_2, \dots, x_n)$ of parameters x_i measurement of specific informative parameters and evaluation of the current level of the quality parameter (state) Q of the control object by rank;

2) the processing of a certain set $(y_1,\ y_2, \dots, y_m)$ of control factors y_i $(i = \overline{1, m})$ that change the object's output, and transfer it to the multi-parameter control system;

3) measurement of certain parameters $y_k, k\epsilon\{1, 2, \dots, s\}$ of the set of independent external factors $(y_1,\ y_2, \dots, y_k)$ that cause changes in the state of the object;

4) synchronicity of the moments of measurement of the corresponding values of the sets $(x_1,\ x_2, \dots, x_n)$, $(y_1,\ y_2, \dots, y_k)$ and the system generating parameters $(y_1,\ y_2, \dots, y_j)$ $(\cup\, x_i,$ $\cup\, y_k,\ \cup\, y_j -$ uknown quantities);

5) in the process of measuring the current values of the parameter Q through the functional model f, the presence of a variety reflecting the difference $|Q_2 - Q_1|$ properties of the object, avoiding the recognition of objects beyond the boundary values of the parameters.

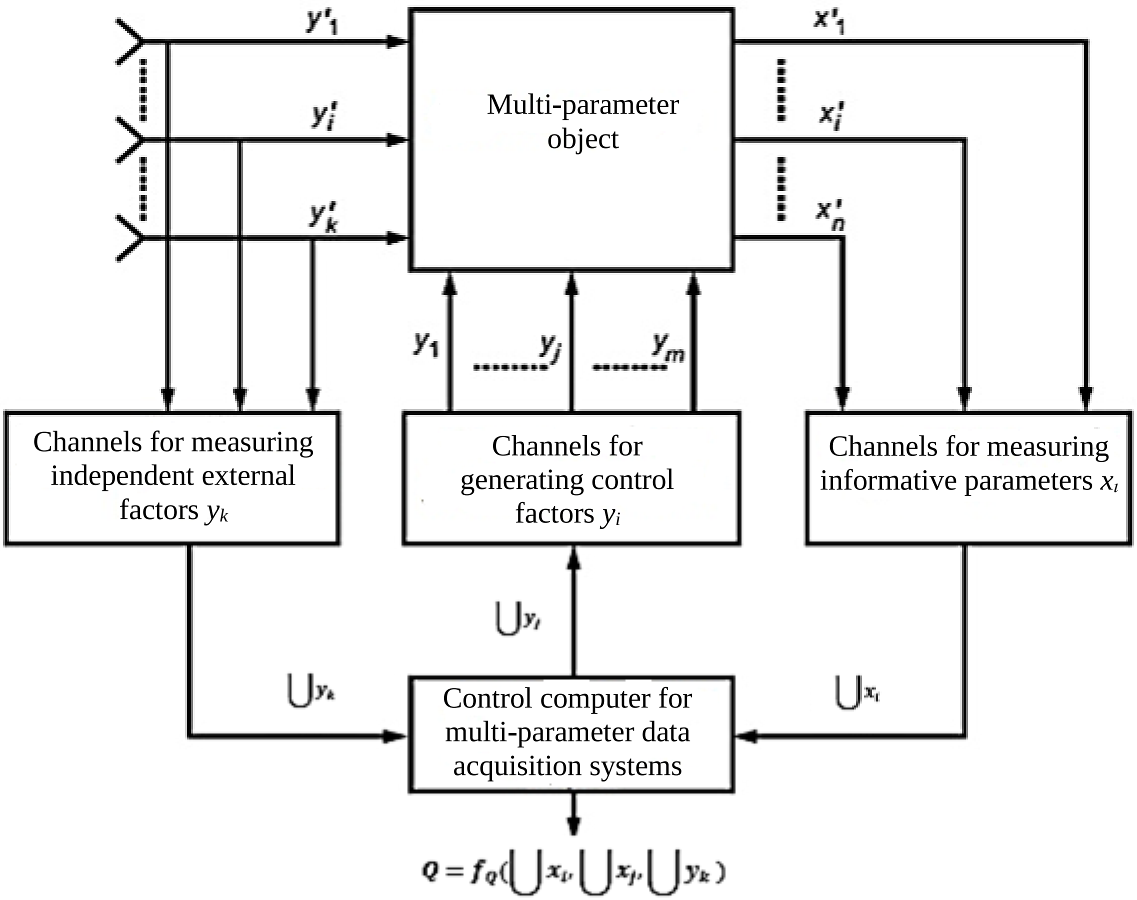

Fig. 1. A structural model of a multi-parameter system

The requirements defining the structure and functions of such an information-measurement system can be interpreted as follows:

1) a set of n measuring channels to determine the current values of parameters x_i representing the current level of quality indicator Q of the object

2) availability of m channels to generate a control set of external impacts y_i that have a strong influence on transition of the object from one state Q_{ij} in the process of measurements;

3) a set of s channels to measure independent external factors y_k that affect the object and change its current state;

4) multi-parameter measurement and control computer, which ensures the integration of all information channels as well as measurement algorithms into a single system;

5) software that performs measurement algorithms based on a multi-parameter functional f for a given object type.

3. Solution

The main parameter that determines the accuracy of the impact on the system and the set of a large number of parameters that characterize it, is the quality indicator Q_{ijk}. When assessing the current level of the indicator Q_{ijk} for the object, the uncertainty should not be higher than the allowable maximum error, should not exceed the allowable limit of maximum error. To ensure a given level of reliability when assessing the quality indicator the appropriate metrological characteristics and structure of channels for access to information of the system are selected, and on their basis the accuracy criterion corresponding to the structure of the system under study is determined [4].

The accuracy criterion is fulfilled, as in the measurement process, by providing normative (selective threshold) estimates of metrological (accuracy and uncertainty) characteristics of the system.

According to the accuracy criterion of the system structure, in the general method of synthesis there is no specific impact of a specifically defined form of the above-mentioned characteristics. For example, it may be considered appropriate to take the maximum permissible value of the accuracy criterion as the final result when evaluating the accuracy criterion in the system for obtaining information about objects with numerous parameters $\sigma_m Q$ for standard deviation of error [5]. This criterion allows to take into account the influence of different parameters on the output, characterizing the total accuracy at the system output.

The normalized value for $\sigma_m Q$ depends on the data corresponding to the absolute values of the difference of useful object properties (for dynamic boundaries in their measurement) $|Q_2 - Q_1|$, the required quantization interval dQ, as well as the specified accuracy coefficient k_p (where p is the concealment probability) [2]:

$$\sigma_m Q \leq \frac{|Q_2 - Q_1|}{k_P N} = \frac{dQ}{k_p}, \quad (1)$$

where $\sigma_m Q$ is accuracy criterion for the synthesis of the structure of the data acquisition system, the maximum permissible value for the standard deviation of the system error; $|Q_2 - Q_1|$ is the dynamic measurement boundary Q; k_p is the system accuracy coefficient; N is the number of connections in the system; $dQ = |Q_2 - Q_1|N$ is the quantization interval.

To synthesize the structure of the system at the channel level, it is first necessary to determine the relationships between the metrological characteristics of the system channels in accordance with expression (1), providing the required accuracy according to the criterion of accuracy in multi-parameter measurements.

Finding the connection between the system accuracy criteria and a part of the channel accuracy criteria is the essence of the considered structural synthesis. Such parametric arrangement is clearly shown in the expansion of the mathematical model f (according to the scope of its application). Taking this into account, the connection between the standard deviations of random errors arising by different parameters in different channels in the information system and the standard deviations of relative errors of the system can be shown as follows:

$$(\sigma_m Q)^2 \geq \left[\sum_{i=1}^{m} (\frac{\partial f_Q}{\partial x_i})^2 (\sigma_m x_i)^2\right] + \left[\sum_{j=1}^{n} (\frac{\partial f_Q}{\partial y_j})^2 (\sigma_m y_j)^2\right] + \left[\sum_{k=1}^{s} (\frac{\partial f_Q}{\partial y_k})^2 (\sigma_m y_k)^2\right], \quad (2)$$

here $\sigma_m x_i$, $\sigma_m y_j$ and $\sigma_m y_k$ are accuracy criteria (incomplete) of the corresponding channels of the system (in this case, the standard deviation of the maximum permissible values of errors of the channels of the system under consideration); $\frac{\partial f_Q}{\partial x_i}$, $\frac{\partial f_Q}{\partial y_j}$ and $\frac{\partial f_Q}{\partial y_k}$ are load coefficients (also called weighting coefficients), taking into account the relationship between the parameters x_i , y_i and the changes y_k by Q in the corresponding channels.

If f is a differentiable function, then the load coefficients are special derivatives of the function in the change of y_k in a multi-parameter data acquisition system x_i , y_i .

The synthesis of the system based on expressions (1) and (2) is considerably faster. Suppose that the contribution of all channels to the total error of the data acquisition system is the same. Then, taking the effects of load factors and incomplete accuracy criteria in systems of this type as equal, we can write the following:

$$(\frac{\partial f_Q}{\partial x_i})\sigma_m x_i = (\frac{\partial f_Q}{\partial y_j})\sigma_m y_j = (\frac{\partial f_Q}{\partial y_k})\sigma_m y_k \quad (3)$$

Here *i, j, k* are arbitrary numbers.

Thus, mathematical estimation can be applied to information-measuring channels (linear, measuring tracts) of any system of this type. Accordingly, it is possible to build the following functional diagram for the variant of a measuring channel (Fig. 2):

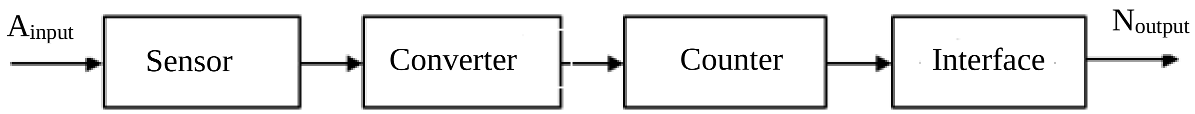

Fig. 2. A functional block diagram of a measuring channel

Expressions (1) and (2) are used to determine the number of channels. For each of the channels in the system, we obtain the basic expressions that allow us to estimate the incomplete accuracy criteria:

$$\left.\begin{aligned} \sigma_m x_i &\le \sigma_m Q / \left(\frac{\partial f}{\partial x_i}\right)\sqrt{a}; \\ \sigma_m y_i &\le \sigma_m Q / \left(\frac{\partial f}{\partial y_i}\right)\sqrt{a}; \\ \sigma_m y_k &\le \sigma_m Q / \left(\frac{\partial f}{\partial y_k}\right)\sqrt{a}, \end{aligned}\right\} \quad (4)$$

where a is the total number of channels; $a = (m + n + s)$.

In the full accuracy criterion, the system is considered at the first level of structural synthesis. In the incomplete accuracy criterion, the values given in (4) when synthesizing different channels of the system allow quantitatively moving from one level to another.

The number of information channels included in this type of multi-parameter systems is determined by the number of objects as well as the number of applications. In this case, the system is synthesized structurally by the accuracy criterion. There are two types of structures of functional scheme sequences, in which the set of channels is complete. According to the structure of the functional scheme with a measurement channel, shown in Fig. 2, the overall measurement process can include the following blocks:

1) entering of the measured parameter in the system input (A_{input} - sensitive element - sensor);

2) device (converter) that converts the parameters of the electrical signal at the sensor output into a value equivalent to the measured value;

3) counter that measures the code equivalent of the generated code and parameter according to the set value;

4) interface for entering digital codes of measured values into the system.

Fig. 3 shows the corresponding structure of the channel path, which has a controlling effect. This influence allows the object to move from one state to another.

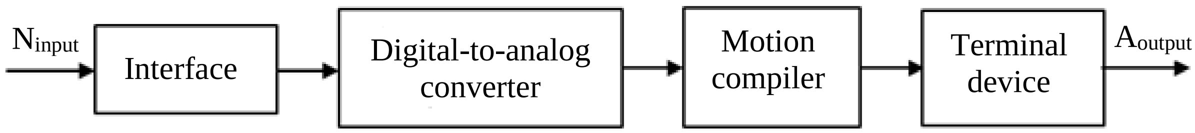

Fig. 3. Functional block diagram of the control action channel

The scheme includes the following blocks:

1) channel interface of the data acquisition system (DAS) entering data into the computer, which accepts parameters N_{input} control factors $y_i, (i = \overline{1, m})$ in the form of a code;

2) digital-to-analog converter (DAC) that converts information in code form into parameters proportional to an intermediate or control signal;

3) generator that converts the intermediate signal into the set values of the output parameter to obtain the control action;

4) terminal device that transmits the output signal to the actuator in the object.

According to this block diagram, control signal output channels are created at the control outputs of a multi-parameter DAS. The direction of information flow between the computer and the object is determined by the general properties of the control signals transmitted through the channels.

The channel coordinator, which implements the connection between circuits, can consist of different parts. Therefore, from the point of view of structural synthesis of the channel by the criterion of incomplete accuracy, it is necessary to isolate at least one of them, differentiating the components of this scheme in order to estimate the incomplete errors corresponding to each of the components, as well as to analyze them. The second point to be investigated in the channel synthesis is determining the form of the functional model. This model essentially describes the characteristic of information transfer from input to output. The most suitable form of the model from the point of view of accuracy criterion for channel synthesis are expressions in terms corresponding to analytical formulas in the form of a differentiable function.

4. Results of synthesis according to the accuracy criterion

Analysis of multi-parameter measurements in various fields shows that generalization of existing analytical expressions on these models can be carried out in two different forms:

1) an algebraic sum of incomplete homogeneous parameters characterizing the transfer of measured parameters between links;

2) a product of incomplete transfer functions reflecting the dynamics corresponding to the relevant parameters transferred between the functional schemes shown in Fig. 2 and 3.

For measuring and transmitting such parameters as spatial coordinates, time intervals, dependencies between parameters, phase dependencies, etc., it is more appropriate to use the first of the mentioned model forms.

The following formula is usually used as an analytical expression to describe the channel transmission characteristics in a multi-parameter DAS:

$$R_x = R_\Sigma - R_1 - \cdots - R_i - \cdots - R_n \,, \tag{5}$$

where R_x is the measured (generated) parameter; R_Σ is the results of parameter estimation over the whole measurement chain, R_1, R_i, R_n are incomplete values of the parameters, reflecting the impact of the chain links.

The following analytical expression is used to describe the transmission characteristics of the working channels:

$$V_{çıxış} = V_{giriş} k_1 k_2 \ldots k_i \ldots k_N \tag{6}$$

where V_{output} and V_{input} are parameters of input and output channels, respectively; $k_1 k_2 \ldots k_i \ldots k_N$ are transformation (transmission) connections in the channels.

Expansion of the transfer function in the form of a parametric series allows establishing the relation between the incomplete errors and the error values. Here, discarding the intermediate values for structural synthesis on the basis of the priority channels accuracy criteria, converting them to the standard deviation error, we obtain the following expression from (5):

$$(\sigma_m R_x)^2 \geq \left(\sigma\, R_\Sigma\right)^2 + (\sigma\, R_1)^2 + \cdots + (\sigma\, R_i)^2 + \cdots + (\sigma\, R_n)^2, \qquad (7)$$

where, $\sigma_m R_x$ is incomplete accuracy criterion (IAC), formed in the channel and determined by formulas (3)-(5); $\sigma\, R_i, (i = \overline{1,m})$ is the incomplete accuracy criterion, which should be accepted for structural links in the chain of priority type channels. All limits in (7) are standard deviations of absolute values of the corresponding incomplete errors.

For the purposes of synthesis of the generated channel according to the accuracy criterion, the following expression is obtained similarly to (6):

$$\left(\sigma_m^{rel} V_{çıxış}\right)^2 \geq \left(\sigma^{rel} V_{giriş}\right)^2 + (\sigma^{rel} k_1)^2 + \cdots + (\sigma^{rel} k_i)^2 + \cdots + (\sigma^{rel} k_n)^2, \qquad (8)$$

where $\sigma_m^{rel} V_{output}$ is IAC obtained from (3)-(5) for the generated channel type; $\sigma^{rel} V_{input}, \ldots, \sigma^{rel} k_i$ is the IAC applied to the blocks in the synthesized type of the functional channel.

Formula (8) for the generation channel is similar to formula (7) for the priority channel. The difference is that the standard deviation for matching incomplete errors in (7) has relative values, which are determined as follows:

$$\begin{cases} \sigma_m^{rel} V_{çıxış} = \sigma_m V_{çıxış} / V_{çıxış} \\ \sigma^{rel} V_{giriş} = \sigma\, V_{giriş} / V_{giriş} \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ \quad \sigma^{rel} k_n = \sigma\, k_n / k_n. \end{cases} \qquad (9)$$

To obtain channels by means of the basic synthesis of the DAS structure according to the accuracy criteria based on (3)-(5), the measuring channels in the multi-parameter DAS can be synthesized by one of expressions (7) and (8) by IAC.

As a result of channel synthesis, the filled limits corresponding to the metrological characteristics in the form (7) for priority channels and (8) for generation channels must be satisfied.

The next step is to determine the base IAC value for the priority channel, taking into account the number of connections N in the sequence of channel circuits:

$$\sigma_m R_i \leq \frac{\sigma_m R_x}{\sqrt{N}}, \qquad (10)$$

for the generation channel we get

$$\sigma_m^{rel} V_i \leq \sigma_m^{rel} V_{Çıxış} / \sqrt{N}, \qquad (11)$$

where *N* is the number of connections in the sequence of channel circuits.

Synthesis of a limited number of solutions in problems of this type accelerates convergence, allowing to realize the application of the correct solution to channel synthesis. Two main cases should be considered here:

1. The possibility of analyzing the impact of the intrinsic functionality of channel links, which is difficult to study with the measurement of the specific value of the parameters of the next level in a DAS divided into subsystems.

2. The presence of equal contributions associated with the channel error value, which is useful for preparing this base probability to accelerate convergence, that is, solution accumulation, during synthesis in multi-link channels.

5. Conclusion

Thus, it is reasonable to apply the chosen options of architecture based on the criteria of accuracy of structural links of the studied data channels in the development of multi-parameter information and measurement systems. Here, the general (integrated) quality indicator of multi-parameter information-measurement control and management system will be determined by the value of random errors arising on all channels, minimized in the process of synthesis of information channels on the basis of the accuracy criterion.

References

[1] M.M. Isayev, G.Q. Yusufova-Ağabalayeva, P.M. Isayeva. Seçicilərin inteqral göstəricilərinin qiymətləndirilməsi üçün çoxparametrli nəzarət-ölçmə sistemi, AMEA-nın Xəbərləri, Bakı. XXXIV No.6 (2014) pp.156-162. [in Azerbaijani: M.M. Isayev, G.G. Yusufova-Agabalayeva, P.M. Isayeva. Multi-parameter control-measurement system for the evaluation of ıntegral ındicators of voters, Transcations of ANAS, Baku].

[2] А.Ф. Страхов, Многопараметровые объекты и многопараметровые измерения, Измерительная техника. No.11 (2004) pp.11-14. [In Russian: A.F. Strakhov, Multi-parameter objects and multi-parameter measurements, Izmeritelnaya tekhnika]

[3] Y.H. Hasanli, M.M. Isayev, P.M. Isayeva, G.G. Yusufova-Agabalayeva, Multi-Parameter Control-Measurement System for the Evaluation of Integral Indicators of Voters, Pridneprovskiy Nauchniy Vestnik. No.3(150) (2014) pp.96-103.

[4] E. Thomsen, OLAP solutions: building multidimensional information systems, 2nd ed., N.Y.: John Wiley & Sons Inc., (2002) 661 p.

[5] D. Larose, Data mining methods and models, D. Larose, John Wiley & Sons Inc., (2006) 322 p.