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AUTOMATION OF THE PRIMARY PROCESSING OF DATA OF A THERMAL EXPERIMENT

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The problems involved in automating the processing of experimental data are considered. Primary-processing algorithms based on methods of analyzing nonstationary random processes are described.

Considerable attention is being given at present to designing automated data-processing systems for thermal experiments. The need to construct such systems is obvious. Automated data-processing systems enable one to eliminate manual operation, which to a large extent affects the operational capability and accuracy with which the results can be processed. Until recently "stationary" experiments under steady-state heat-exchange conditions have largely been carried out when studying thermophysical processes. This approach has simplified the theoretical methods by which the experimental data is processed. The amount of computational work involved was, as a rule, small. Incidental computer calculations to a large extent met the requirements of the investigations. The need to solve more detailed and more complex experimental problems when studying different nonstationary thermal regimes [1] has necessitated the development of more complex methods, which considerably increase the complexity and the amount of processing work involved. Manual or incidental computer calculations now are not only not sensible but in many cases are generally impracticable. Hence, an automated data-processing system for thermal experiments should improve the quality, increase the accuracy and information content of the investigations as a result of a more complete and fundamental analysis of the measurement results, increase the operational capability of the experimental data processing, intensify the research, and reduce the cost of typical multiple experiments and tests. In addition, an automated data-processing system widens the possibility of rational planning of a thermal experiment, enables the processing and analysis of the data to be flexibly organized, and enables one to correct and simultaneously process and store large amounts of data. An important feature also is that an automated system eliminates any subjective approach when decoding experimental data and when estimating the characteristics obtained.

The presence in a thermal experiment of a large number of unconnected factors which affect the physical processes being investigated, and distortion of the useful data by the recording apparatus lead to the need for careful analysis of the results obtained. Consequently, it is necessary to organize the automated processing procedure in such a way as to reduce the loss of useful information to a minimum.

We propose the following principles for constructing the software of an automated data-processing system. Processing is divided into three stages: preparation of the experimental data, and primary and secondary processing. The preparation involves a specific apparatus part of the automated data-processing system, and at the end of the first stage matrices of the initial data are formulated in a form convenient for introduction into the computer of the automated data-processing system. Primary processing involves a statistical analysis of the experimental data [2, 3], while secondary processing involves solving the main applied problems.

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In the present paper we consider primary processing. In the context of automation it has a somewhat wider meaning, and it includes an algorithm for the automated control of the quality of the experimental data introduced into the computer (an automated editing algorithm).

The inclusion of statistical methods enables one, based on an attempt to study a wide range of random processes, to carry out a detailed analysis of the data of a thermal experiment, to separate out the useful information, and to estimate with a certain probability the accuracy of the experimental data. It is advisable to use the automated system (as already stated) when carrying out nonstationary thermal experiments. Consequently, the experimental data represent samples of a nonstationary random process. The statistical processing of nonstationary random processes is a fairly complex problem, since the conclusion that the processes are nonstationary is simply a negative statement, which states that the stationary property is not present and does not give an accurate determination of its nature. Hence, for each form of nonstationary random process it is necessary to develop special processing methods. When carrying out a thermal experiment it is necessary to record a time-varying parameter $A(\tau)$, for which a circuit is used which can be roughly represented as the state of a sensitive element, amplifier, or imaging (storage) system. Each section, which has a specific accuracy, makes its contribution to the distortion of the useful data. In this case the experimental data can be represented by the following model of a nonstationry random process:

$$\{x(\tau)\} = A(\tau) + \{y(\tau)\}. \tag{1}$$

This expression relates to a nonstationary random process with a time-varying mean value, where $A(\tau)$ is a deterministic function, and $\{y(\tau)\}$ is an unknown random process with mean $M[y(\tau)] = 0$ and variance $D[y(\tau)] = \sigma^2$.

In addition to the perturbations which give rise to the fact that any recording device has accuracy characteristics in a defined range, in the experimental data introduced into the computer one may encounter individual considerable overshoots of the values due to faults in the operation of the apparatus or due to errors in the manual preparation of the data. To ensure that large volumes of data can be processed in the automated mode, an automated-editing algorithm is proposed, a block diagram of which is shown in Fig. 1. The algorithm uses the method of predicting the current values of the time series $x_1, x_2, \ldots, x_n$ using the known previous values. For prediction purposes linear and quadratic extrapolation are employed (Fig. 1). The current value of the time series is regarded as recorded without a fault if the following condition is satisfied:

$$R_i \leqslant |x \cdot c|, \quad i = 1, 2, \ldots, n. \tag{2}$$

When compiling the algorithm automatic replacement of faulty values and a mode of operation in which a check of the processing is carried out for the introduction of controlling directives are provided for. In the automatic mode faulty values are replaced by values obtained using quadratic interpolation. At the end of the editing the experimental data is transmitted for an estimate of its mean value to be made. The estimate of the mean value, over the ensemble, does not give rise to any particular difficulties. The situation is somewhat different when estimating a time-varying mean value. For a random process of the form (1) several methods can be proposed: representation of the time trend $A(\tau)$ in the form of a polynomial, an estimate of $A(\tau)$ using a moving average, and an estimate of the cyclical trend using the sum of trigonometric functions. The use of polynomial trends is preferable, but it requires considerable apparatus for checking statistical hypotheses [2], which is a considerable obstacle to the automation of the processing process. A method based on the estimate of a cyclical trend gives good results when processing experiments with cyclical loading such as, for example, vibration tests. To process the data from a thermal experiment in many respects it is best to use the moving average or smoothing methods. By smoothing we mean here the representation of the time series $x_1, x_2, \ldots, x_T$ at a given point by means of a weighted average, observed in the neighborhood of this point. Such an estimate is only possible if the trend is smooth.

For a time series of observations $x_1, x_2, \ldots, x_T$ the estimate at the point is made as follows:

$$\hat{\mu}_\tau = \sum_{s=-m}^{m} C_s x_{\tau+s}, \quad \tau = m+1, \ldots, T-m. \tag{3}$$

The weights C_s are assumed to be normalized so that

$$\sum_{s=-m}^{m} C_s = 1. \tag{4}$$

Then, for (1)

$$\hat{\mu}_\tau = \sum_{s=-m}^{m} C_s A(\tau+S) + \bar{y}_\tau, \qquad \bar{y}_\tau = \sum_{s=-m}^{m} C_s y_{\tau+s}. \tag{5}$$

If we represent the weights C_s as $C_s = 1/(2m+1)$, a particular case, the arithmetic mean, is obtained

$$\hat{\mu}_\tau = \frac{1}{2m+1} \sum_{s=-m}^{m} x_{\tau+s} = \frac{1}{2m+1} \sum_{s=-m}^{m} A(\tau+S) + \frac{1}{2m+1} \sum_{s=-m}^{m} y_{\tau+s}. \tag{6}$$

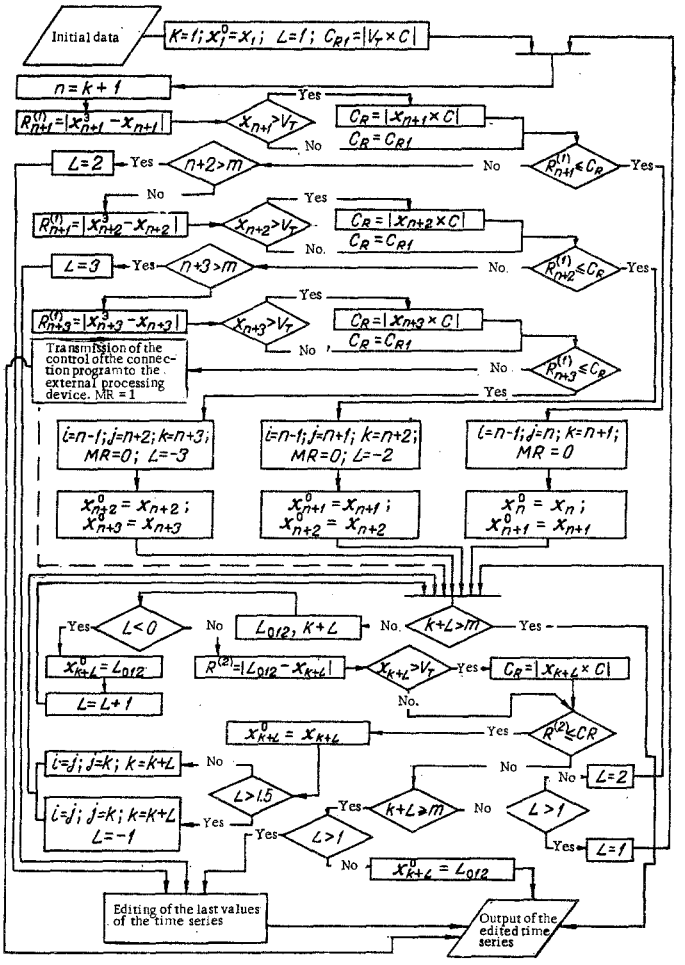

Fig. 1. Block diagram of an automated editing algorithm: i, j, k, n) number of extrapolation units; m) dimension of the time series of experimental data; (k + L), number of extrapolated values; x, initial sample; x^0, edited sample; x^e, extrapolated values (linear extrapolation); L_{012}, extrapolated values (quadratic extrapolation); V_T, limit of the constant relative comparison accuracy; MR, editing characteristic.

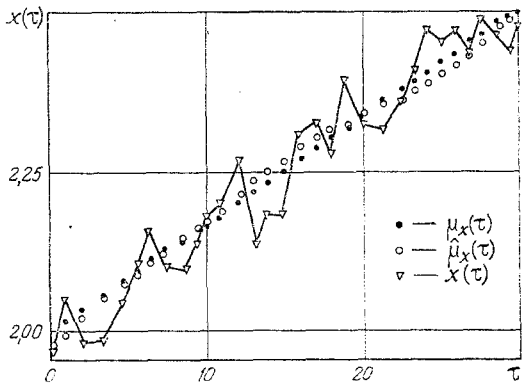

Fig. 2. A perturbation with a normal distribution is superimposed on the deterministic function $\mu_x(\tau)$. An estimate is made of the mean value $\hat{\mu}_x(\tau)$ of the sample of the nonstationary process $\{x(\tau)\}$ obtained in this way; $\mu_x(\tau)$, $\hat{\mu}_x(\tau)$, $x(\tau)$, τ are dimensionless quantities.

An advantage of this method is its flexibility in the sense that the assumptions for which it can be used are not very burdensome. Nevertheless, it should be noted that since the method is not based on an explicit probability model, its properties are not completely defined. Assuming also the fact that in practice all the subsequent processing of nonstationary random processes of the form (1) is based on the results of an estimate of a time-varying mean, we carried out a numerical experiment with the algorithm described by (6). The results showed that the region in which this algorithm can be used with a reasonable degree of accuracy corresponds to the region in which it can be used in the automated data-processing system. In Fig. 2 we present an estimate of the varying mean value of a nonstationary process obtained using this method.

All the algorithms considered form the basis of the software of an actual automated system for processing the data of a thermal experiment.

Notation

$\{x(\tau)\}$, a nonstationary random process; $\{y(\tau)\}$, an unknown random process (in a special case, a stationary random process); $A(\tau)$, a deterministic process; τ, time; $M[y(\tau)]$, mean value of the random process $\{y(\tau)\}$; $D[y(\tau)] = \sigma^2$, variance of the random process $\{y(\tau)\}$; R_i, difference between the recorded and predicted values; c, relative accuracy; $\hat{\mu}$, estimate of the mean value of the random process; C_s, a weighting coefficient; and T, observation period.

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THE PROBLEM OF PLANNING THERMAL MEASUREMENTS

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The solution of the problem of planning thermal measurements is considered. Cubic splines are used for a mathematical description of the relations investigated.

Optimum planning of measurements is being increasingly introduced into experimental research at the present time. A fairly full review of papers devoted to this question is contained in [1, 2]. A large number of papers are devoted to the theory and general methods of solution, but a much smaller number consider the practical application of these methods for planning physical, and in particular, thermal (laboratory and natural) experiments [3-5]. This is largely due to the complexity of the mathematical description of nonstationary heat and mass transfer processes which are encountered in practice, and also due to the rigid limitations imposed on the number of repeated experiments, due to the considerable material costs in preparing and carrying them out.

Methods of planning, which are becoming more and more widely used, are based on the assumption that the process is linear with respect to the parameters of the mathematical model of the process being investigated or on the possibility of linearizing it [3, 6, 7]. In addition, a number of fairly rigid constraints are imposed on the chosen model and on the required optimum plan, such as the requirement that the points of the plan should be orthogonal, that these points should be symmetrical, etc. [6]. In the case of several monitored variables, when the model is nonlinear, or when the conditions under which the experiment is carried out change with time, these methods are inapplicable and it is necessary to employ sequential planning.

Below we consider the problem of planning measurements when carrying out a thermal experiment. The purpose of the experiment is to determine the distribution of the parameter of nonstationary heat exchange $P(x, \tau)$ on the surface of a solid as a function of the coordinate x and the time τ. These parameters may be the pressure, convective and radiation thermal flows, the surface temperature, removal of mass, etc.

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