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Algorithms for correcting the dynamic errors of measuring instruments for monitoring systems and control of technological processes for drying and sorting agricultural products

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ABSTRACT: The article discusses algorithms that make it possible to obtain relatively complete information about the operation of automatic control systems for technological objects. These algorithms can be used to process the results of observations of the state of dynamic objects. These include the control and management systems for drying and sorting agricultural products.

KEYWORDS: problems of dynamic distortion, control actions, formation and construction of stable algorithms, regular methods, iterative algorithms.

I. INTRODUCTION

The problem of signal recovery is related to the general problem of distortion and correction in measuring and converting devices. Usually, the requirements for the minimum dynamic distortion of the measured value are imposed on monitoring, recording, measuring and converting devices. When this requirement is met, the correspondence of the values recovered and measured by the recording device is ensured. The general condition of minimum dynamic distortion is fulfilled when the input and output of the measuring system are interconnected by an algebraic relationship. It follows from this that if the equation describing the dynamics of the controlling, measuring or converting device is differential, then in the general case distortions are inevitable. This is due to the fact that the solution to an inhomogeneous differential equation is a function that differs from the right side of the original equation.

II. LITERATURE SURVEY

The construction of these systems allows one to obtain the most complete information about the operation of the automatic control system as a whole, as well as the necessary information about control actions, disturbances and coordinates belonging to the class of signals not measured and uncontrolled by measuring equipment [1, 8].
The problem of restoring the initial state and input action of a dynamic system from the results of measuring the output belongs to the class of inverse problems of the dynamics of controlled systems [2]. Since this problem is incorrectly posed, for its solution one should apply the methods developed in the corresponding theory [9].

III. SIGNIFICANCE OF THE SYSTEM

The paper deals with the formation and construction of stable algorithms for correcting the dynamic error of measuring instruments based on regular methods.

IV. METHODOLOGY

Consider a linear measuring system described by the equations

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$$x_{k+1} = A_k x_k + B_k w_k, \quad x(k_0) = x^0, \tag{1}$$

$$y_k = C_k x_k + D_k w_k, \tag{2}$$

where $x \in R^n, w \in R^p, y \in R^m$; $x = x_k$ - state of the system; x^0 - the initial state of the system; $w_k \in L_2^p$ - input not measurable impact on the system; $y_k \in L_2^m$ - system output; A_k, B_k, C_k, D_k - matrices of the corresponding dimensions.
Let be

$$\Theta = R^n \times L_2^p, \quad Y = L_2^m.$$

In space, we define a scalar product of the form

$$\langle \theta_1, \theta_2 \rangle_\Theta = \langle x_1^0, x_2^0 \rangle_{R^n} + \langle w_1, w_2 \rangle_{L_2^p},$$

which turns the space Θ into a Hilbert space.

Relations (1), (2) define a linear operator $F : \Theta \to Y$, which for each pair $\theta = (x_0, w) \in \Theta$, i.e. system input, assigns a function $y \in Y$ at the system output . Thus, we arrive at an operator equation of the form

$$F\theta = y, \quad \theta \in \Theta, \quad y \in Y. \tag{3}$$

Let us pose the problem of approximate recovery of the element $\theta = (x_*^0, w)$ from the results of measurements of the output of the measuring system. In practical tasks, the right side and the elements of the matrix F, i.e. the coefficients of system (3) are known only approximately. In these cases, instead of system (3), another system is used

$$F_h \theta = y_\delta, \tag{4}$$

such that. Thus $\|F_h - F\| \le h, \quad \|y_\delta - y\| \le \delta$, the approximate data are characterized by a set F_h, y_δ, η, where is $\eta = \{\delta, h\}$ the error vector.

When solving Eq. (4), as a rule, the conditions for the stability of the solution are violated, which are associated with the ill-conditioned matrix F_h. These circumstances lead to the need to apply regularization methods.
Let's write an expression for the smoothing functional [7]

$$M^\alpha[\theta_\eta^\alpha] = \|F_h \theta_\eta^\alpha - y_\delta\|_{Y^2} + \alpha \|\theta_\eta^\alpha\|_{\Theta^2}$$

where is $\alpha > 0$ the regularization parameter.
Let's introduce the following functions:

$$\gamma_\eta(\alpha) = \|\theta_\eta^\alpha\|_{\Theta^2},$$

$$\beta_\eta(\alpha) = \|F_h \theta_\eta^\alpha - y_\delta\|_{Y^2},$$

$$\rho_\eta(\alpha) = \beta_\eta(\alpha) - \left(\delta + h\sqrt{\gamma_\eta(\alpha)}\right)^2 - \mu_\eta^2$$

Here is θ_η^α the extremal of the functional $M^\alpha[\theta]$ at fixed $\alpha > 0$. Functions $\gamma_\eta(\alpha)$, $\beta_\eta(\alpha)$, $\rho_\eta(\alpha)$ are monotone and continuous as functions α in the domain $\alpha > 0$, $\mu_\eta = \inf_{\theta \in D} \|F_h \theta - y_\delta\|_Y$ is a measure of the incompatibility μ_η of equation (4) with approximate data on the set $D \in \Theta$.
The solution to equation (4) based on the regularization method is given by the formula [7]

$$\theta_\alpha = (\alpha I + F_h^T F_h)^{-1} F_h^T y_\delta = g_\alpha(F_h^T F_h) F_h^T y_\delta,$$

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where is $g_\alpha(\lambda)=(\alpha+\lambda)^{-1},\ \alpha>0,\ \ 0\le\lambda<\infty$ the generating system of functions for the method [7].

We will assume that the natural condition

$$\|y_\delta\|^2>\delta^2+\mu_\eta^2. \tag{5}$$

The generalized residual function $\rho_\eta(\alpha)$ has the following limit values at the ends of the segment

$$\lim_{\alpha\to+\infty}\rho_\eta(\alpha)=\|y_\delta\|_U^2-\delta^2-\mu_\eta^2,$$
$$\overline{\lim_{\alpha\to 0+0}}\,\rho_\eta(\alpha)=-\delta^2.$$

Thus, under condition (5) $\rho_\eta(\alpha)=0$ the $\alpha>0$ equation has a root in the domain $\alpha^*(\eta)$, and the element $\theta_\eta^{\alpha^*(\eta)}$ is uniquely defined.

If the numbers h and δ are unknown or their calculation is associated with significant difficulties, then the regularization parameter α should be determined on the basis of the quasioptimality method

$$\left\|\theta^{(\alpha_{i+1})}-\theta^{(\alpha_i)}\right\|=\min,\quad \alpha_{i+1}=\varsigma\alpha_i,\quad i=0,1,2,..,\quad 0<\varsigma<1.$$

In the absence of a priori information about the level of error in the initial data of Eq. (4), numerical schemes for choosing the regularization parameter with the use of rapidly converging iterative methods for solving equations such as the Newton tangent method [3] are also very effective.

When constructing an approximate solution to Eq. (4) in the case of an invertible operator F_h, a large role is also played by various iterative methods [4, 5]. These methods can be both linear, when the transition to the next iterative approximation requires applying a certain linear operator to one or more previous approximations, and nonlinear, when the transition operator is nonlinear. It is known [5] that usually used linear iterative methods can generate approximations in the case of an irreversible operator F_h. Equipped with a suitable stopping rule $r(\delta,h)$, these iterative processes, in turn, generate regularizing algorithms for problem (4).

From this point of view, the iterated version of the regularization method [7] is more convenient:

$$\alpha\theta_{r,\alpha}+F_h^T F_h\,\theta_{r,\alpha}=\alpha\theta_{r-1,\alpha}+F_h^T y_\delta\ (r=1,\dots,m). \tag{6}$$

The solution to equation (6) is given by the formula

$$\theta_{m,\alpha}=(I-F_h^T F_h\,g_{m,\alpha}(F_h^T F_h))\theta_0+g_{m,\alpha}(F_h^T F_h)F_h^T y_\delta, \tag{7}$$

where is θ_0 the initial approximation, and is $g_{m,\alpha}(\lambda)$ the generating system of functions for the iterated version (6), defined by the expression

$$g_{m,\alpha}(\lambda)=\frac{1}{\lambda}\left[1-\left(\frac{\alpha}{\alpha+\lambda}\right)^m\right],\qquad 0\le\lambda<\infty.$$

The parameter $r=r(\delta,h)$ in approximation (7) should be chosen in such a way [5] that

$$r(\delta,h)\to\infty,\quad (\delta+h)^2 r(\delta,h)\to 0,\ \text{при}\ \delta\to 0,\quad h\to 0.$$

Then $\theta_{r(\delta,h)}\to\theta_*$ for $\delta\to 0,\ \ h\to 0$ where is θ_* the solution to the equation.

$F_h^T F_h\theta_*=F_h^T y$.

Here it is advisable to use the following rule for stopping the iterative process:

The numbers $b_1>1$ and $b_2\ge b_1$ are set. If $\|F_h\theta_0-y_\delta\|\le b_2\left(\delta+\|\theta_0\|h\right)$, then we put $r=0$ and take as an approximate solution u_0 . Otherwise $r>0$, we choose at which

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$b_1\left(\delta+\|\theta_r\|h\right)\le\|F_h\theta_r-y_\delta\|\le b_2\left(\delta+\|\theta_r\|h\right)$. If the $r\in[0,\ d/(\delta+h)^2]$ residual has not reached the level at $\|F_h\theta_r-y_\delta\|\le b_2\left(\delta+\|\theta_r\|h\right)$, then the search r stops and is selected $r=d/(\delta+h)^2$.

To calculate the desired vector, one can also use, for example, other iterative schemes of the form [6]

$$\varepsilon\theta_r+F_h^TF_h\theta_r=\varepsilon\theta_{r-1}+F_h^Ty^\delta,\ \varepsilon>0,\ r=1,2,...,$$

$$(\alpha I+F_h^TF_h)\theta_r=\alpha\theta_{r-1}+F_h^Ty^\delta,\ r=1,2,...,$$

which are adjacent to regular iterative algorithms.

It can be shown [10] that a nonlinear iterative algorithm of the form is very effective for the problem under consideration:

$$\theta_{r+1}=\theta_r-(\varepsilon_rI+F_h^TF_h)^{-1}F_h^T(F_h\theta_r-f_\delta),\quad \theta_0=0,$$

$$\varepsilon_r=\begin{cases}\bar{\varepsilon}_r=\dfrac{\|F_h^T(F_h\theta_r-f_\delta)\|^2}{\|F_h\theta_r-f_\delta\|^2}, & \bar{\varepsilon}_r\ge\psi(\delta,h)>0,\\ \psi(\delta,h), & \bar{\varepsilon}_r<\psi(\delta,h),\end{cases}\tag{8}$$

where is $\Psi(\delta,h)$ a given threshold function such that

$$\lim_{\delta\to0,h\to0}\Psi(\delta,h)=0,\quad \Psi(0)=0.$$

Then, following the theory of iterative methods [5,6,10], it can be shown that if

$$\lim_{\substack{\delta\to0,h\to0\\ r\to\infty}}(\delta+h\|\hat{\theta}_\xi\|)\sum_{j=0}^{k}(\varepsilon_j)^{-1/2}=0,$$

then

$$\lim_{\substack{\delta\to0,\ h\to0\\ r\to\infty}}\left\|\theta_{r+1}-\hat{\theta}_r\right\|=0,\qquad \hat{\theta}\perp\ker F_h^TF_h.$$

The iterative process (8), while remaining nonlinear at the first iterations, converges faster than a number of known iterative algorithms.

V. CONCLUSION AND FUTURE WORK

The algorithms presented allow obtaining the most complete information about the operation of automatic control systems for various technological objects in general [11-14], as well as the necessary information about control actions, disturbances and coordinates belonging to the class of signals that are not measured and uncontrolled by measuring equipment and can be used for processing the results of observations of the state of dynamic objects, as well as in the control and management systems for technological processes of drying and sorting of agricultural products [15-17].

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