ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 8 , August 2019

Estimation of Parameters of Settings of Regulators Based on Active Adaptation Algorithm

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ABSTRACT: The issues of synthesis of regulator settings parameters in adaptive process control systems are considered. Estimation algorithms based on active adaptation algorithms are presented. To minimize the auxiliary functional of some observable process, algorithms based on stochastic approximation methods and sensitivity theory are used. The above algorithms make it possible to efficiently evaluate the settings of adaptive controllers under conditions when the covariance matrices of the object noise and measurement noise are a priori unknown.

KEY WORDS: controller settings, parameter estimation, active adaptation algorithms.

I. INTRODUCTION

In theory and practice of automation of technological processes, adaptive control systems are widely used. The goal of adaptive control systems, as is known, is to eliminate the uncertainty associated with ignorance of the object's parameters and the statistical characteristics of external disturbances. This is achieved using algorithms that, as a result of processing available observations, ultimately properly change the parameters of the control device so that the control system as a whole provides a minimum of one or another performance criterion.

To date, various synthesis algorithms for control devices in adaptive control systems are known under conditions of full or partial information about the controlled process and the statistical characteristics of object noise and measurement interference [1-8]. In these works, effective methods are proposed and constructive conditions are investigated that guarantee the required asymptotic properties of tuning algorithms in the presence of information on the internal structure of disturbing processes.

However, many control systems for dynamic objects are characterized by a large uncertainty in the conditions of their work. Information about the actual values of the parameters of control objects is very inaccurate, and the laws of their possible changes are known very approximately, insufficient information about the initial state of the automatic control system, uncertain information about possible input signals and disturbing influences. Despite the fact that disturbing influences under construction conditions can be small, they affect the self-tuning process and require additional studies, in which special attention should be paid to two issues: the justification of the working conditions of typical direct adaptive control schemes in the presence of disturbing influences and the development of modification methods for standard algorithms that ensure the convergence of adaptation processes. In this regard, the development of effective algorithms for assessing the settings of regulators in adaptive control systems of technological objects is becoming very important.

Various approaches are used to adapt Kalman filters: Bayesian, maximum likelihood method, correlation methods, covariance matching methods [4,5]. There is also an approach called active [9, 10], which, unlike the indicated ones, does not require the accumulation of any statistics or estimates of unknown parameters. An important advantage of the approach is the comparative simplicity of computational procedures based on the stochastic approximation method.

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II. FORMULATION OF THE PROBLEM

We assume that the equations of the controller parameters and the measurement process are described by equations of the form

$$\theta_k = \theta_{k-1} + w_k , \quad (1)$$

$$z_k = H_k \theta_k + \upsilon_k , \quad (2)$$

where θ_k is the n -dimensional vector of controller parameters; z_k is the vector of measurements of size m; H_k is the size measurement matrix $m \times n$; w_k and υ_k are normally distributed disturbances with zero averages.

The covariance matrices Q and R are assumed to be unknown, but constant in time. Under these conditions, the tasks of adaptive filtering and prediction consist, respectively, in obtaining a simultaneous estimate $\hat{\theta}_{k|k}$ of the vector θ_k and a predicted estimate $\hat{\theta}_{k+1|k}$ of the vector θ_{k+1} based on observations of

$$Z^k = \{z_k, z_{k-1}, ...\}.$$

The solution to these problems, when the matrices Q and R are exactly known, is given by the Kalman filter in the form [1,5]:

$$\hat{\theta}_{k+1|k} = \hat{\theta}_{k|k} ,$$

$$\hat{\theta}_{k|k} = \hat{\theta}_{k|k-1} + K(z_k - H\hat{\theta}_{k|k-1}) ,$$

$$K = MH^T(HMH^T + R)^{-1} = PH^T R^{-1} , \quad (3)$$

$$P = (I - KH)M = (M^{-1} + H^T R^{-1} H)^{-1} = M - MH^T (HMH^T + R)^{-1} HM ,$$

$$M = P + Q ,$$

где $P = E\left[(\theta_k - \hat{\theta}_{k|k})(\theta_k - \hat{\theta}_{k|k})^T\right]$, $M = E\left[(\theta_{k+1} - \hat{\theta}_{k+1|k})(\theta_{k+1} - \hat{\theta}_{k+1|k})^T\right]$.

Considering the above matrices Q and R unknown, we consider the filter

$$y_k = D\xi_k , \quad (4)$$

$$\xi_k = y_{k-1} + B(z_k - Hy_{k-1}) , \quad (5)$$

coinciding in structure with the optimal filter (3), where D and B are some matrices. At the same time, we require that in the process of filter adaptation convergence with probability one

$$D \to I , \; B \to K ; \quad (6)$$

then with the same probability $y_k \to \hat{\theta}_{k+1|k}$, $\xi_k \to \hat{\theta}_{k|k}$.

Estimating the quality of filtering and prediction by unobservable errors

$$e_k = \theta_k - \xi_k , \; p_k = \theta_{k+1} - y_k , \quad (7)$$

form the observed process

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$$\varepsilon_k = H^{-1} z_k - \xi_{k-1}. \tag{8}$$

N view of (1), (2), (7), we represent (8) in the form

$$\varepsilon_k = e_{k-1} + (w_{k-1} + H^{-1} \upsilon_k), \tag{9}$$

and using the decomposition

$$\theta_k = \sum_{j=0}^{\infty} w_{k-1-j}\ ,\ \xi_k = \sum_{j=1}^{\infty} (D - BHD)^j B z_{k-j}\ , \tag{10}$$

which are stationary solutions of equations (1) and (4), (5), we obtai

$$E\left[\varepsilon_k \varepsilon_k^T\right] = E\left[e_{k-1} e_{k-1}^T\right] + \left[Q + H^{-1} R (H^{-1})^T\right].$$

Given the stationarity of the processes, this leads to a relation of the form [9]:

$$J_{\varepsilon} = S_p E\left[\varepsilon_k \varepsilon_k^T\right] = J_e + const\ ,$$

where $S_p\left[Q + H^{-1} R (H^{-1})^T\right] = const$ is a value independent of the filter parameters. The last relation allows us to take J_{ε} as an auxiliary quality functional and adapt the filter

III. SOLUTION OF THE TASK

Consider the possibility of reducing the volume of a priori information when constructing an adaptive filter that minimizes the auxiliary functional of some observable process. Let in the filter (4), (5) $D = I$, $B = K$. Then the prediction error determined from (7) and equal to (1) with the value

$$P_k = \theta_{k+1} - y_k = (\theta_k - y_k) + w_k = e_k^* + w_k, \tag{11}$$

$$e_k^* = \theta_k - y_k\ ,$$

such that the functional

$$J_p = E\left[p_k^T p_k\right] = E\left[e_k^{*T} e_k^*\right] - SpQ$$

minimal.

This is due to the fact that the vectors e_k^* and w_k are not correlated with each other. Since the second term in the last expression does not depend on the filter parameters, the functional is also minimal

$$J_{e^*} = E\left[e_k^{*T} e_k^*\right] = E\left[e_{k-1}^{*T} e_{k-1}^*\right]. \tag{12}$$

From (1), (2), (11) and taking into account the fact that $v_k = z_k - H y_{k-1}$ we obtain

$$v_k = H e_{k-1}^* + H w_{k-1} + \upsilon_k\ . \tag{13}$$

We form the observed process $\delta_k = H^+ v_k$. Then from (13) for $J_\delta = E\left[\delta_k^T \delta_k\right]$ we can obtain [9,10]

$$\delta_k = H^+ v_k = (H^+ H) e_{k-1}^* + H^+ H w_{k-1} + H^+ \upsilon_k\ , \tag{14}$$

$$J_{\delta} = E\left[e_{k-1}^{*T} H^{+} H e_{k-1}^{*}\right] + Sp\left[H^{+} HQH^{+} H + H^{+} R(H^{+})^{T}\right], \tag{15}$$

where $H^{+}H$ is the symmetric idempotent matrix, most deviating in the quadratic norm from the identity matrix I [11]. Under condition $rank(H^{+}H) = n$, it coincides with the indicated identity matrix [11,12]. In this case, instead of (15), taking into account (12), we can obtain

$$J_{\delta} = J_{e^{*}} + Sp\left[Q + H^{+} R(H^{+})^{T}\right]. \tag{16}$$

To minimize functional (16), it is advisable to use algorithms based on stochastic approximation methods and the apparatus of the theory of sensitivity [13,14]. Calculating the matrix of partial derivatives of functional (15), we obtain

$$\partial J_{\delta} / \partial B = -2E\left[\delta_k^T (\partial y_{k-1} / \partial B\right],$$

$$\partial J_{\delta} / \partial D = -2E\left[\delta_k^T (\partial y_{k-1} / \partial D\right],$$

where $\partial y_{k-1} / \partial B = \{b_k (B, D)\}$, $\partial y_{k-1} / \partial D = \{d_k (B, D)\}$ is the set of sensitivity functions of the vector y_{k-1} for each of the elements of the matrices B and D. By entering into the filter (4), (5) instead of D, B the matrices D_k, B_k that change during the adaptation process and emphasizing this fact by a stroke over the variables can be get adaptive filter equations in the form [9]

$$y_k' = D_k \xi_k', \ \xi_k' = y_{k-1}' + B_k (z_k - H y_{k-1}'),$$

$$B_k = B_{k-1} + \gamma_k \left\{\delta_k'^T b_k'\right\}, \tag{17}$$

$$D_k = D_{k-1} + \gamma_k \left\{\delta_k'^T d_k'\right\}, \tag{18}$$

$$\delta_k' = H^{+} (z_k - H y_{k-1}'),$$

$$b_k' = b_k (B, D)\big|_{B=B_k, D=D_k}, \ d_k' = d_k (B, D)\big|_{B=B_k, D=D_k}.$$

In the expressions for B_k and D_k, the factor γ_k is selected from conditions ensuring convergence (6) of procedures (17), (18) [15].

IV. CONCLUSION

Thus, adaptation algorithms (17), (18) are based on the direct minimization of some auxiliary quality functional, which depends only on the processes available for observation, and allow one to efficiently evaluate the adaptive controller settings in conditions when the covariance matrices of the object noise and measurement interference are a priori unknown.

The above algorithms were used to automate the control of a specific technological object under conditions when the covariance matrices of the object noise and measurement interference are a priori unknown and have shown their effectiveness.

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