# Analysis of Forecasting Methods and Models

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**ABSTRACT**

Technological processes (TP) of formalin production are characterized by continuity, toxicity of raw materials, product and exhaust gases, fire and explosion hazard, a large number of interrelated input and output parameters, drift of parameters of the formaldehyde synthesis stage, and a long residence time of absorbed components in absorption apparatuses. The main mode of operation of formalin production units is static.

In problems of control of technological processes, algorithms for identifying the parameters of a control object (CO) based on the least squares method (OLS), as well as various variants of the stochastic approximation algorithm [ 1 ], are most often used .

The algorithm of the recursive least squares method [2 , 3] makes it possible to refine the estimates at each step of the arrival of new CO measurements and is written in the form:

$$C(n+1)^{-1} = C(n) + P(n+1)^{-1}X(n+1)[Y(n+1) - X^T(n+1)C(n)] \quad (1)$$

$$P(n+1)^{-1} = P(n)^{-1} - [P(n)^{-1}X^T(n+1)][1 + X(n+1)P(n)^{-1} * X^T(n+1)]^{-1}[P(n)^{-1}X(n+1)]^T; \quad (2)$$

where $C(n+1)$ is a vector parameter; - discrete time; $P(n+1)$ - matrix of size $(n+1)(n+1)$; $X(n+1)$ - vector of measurements of the object input at the $(n+1)$-th clock; $Y(n-+1)$ measurement of the scalar output of the object at the $(n+1)$-th clock.

The least squares method for a sequence of observations is also recurrent, i.e. solves the problem of improving the old estimate C (   ) [ 4 ]. In this algorithm, the next value of the vector of estimates of the parameters of the object is selected as the previous one, corrected by the value of the vector of the difference

between the true parameters of the object and their estimates C(n):

$C(n) = C(n-1) - \Gamma(n)\Delta C(n) = C(n-1) + \Gamma(n)[Y(n) - C(n-1)X(n)][X(n)^T X(n)]^{-1} X(n)^T$; ( 3 )

where $\Gamma$ (   ) is the gain matrix.

In [36], it was proposed to use a simplified one-step algorithm (   = 1), named after the author by the Kachmazh algorithm. The algorithm uses equation ( 23 ), which is transformed to the form:

$C(n) = C(n-1) + \dfrac{Y(n) - C(n-1)X(n)}{X^T(n)X(n)} * X^T(n)$;

(4)

where Y (n) is the scalar output of the object; X (n) - vector of CO observations at the n-th step; C (n), C (n - 1) - vectors of the object parameters at the n-th and (n - 1) -th steps.

The popularity of this algorithm is explained by the small amount of calculations required to recalculate the estimate when new measurements are obtained, and the small amount of memory required when implementing this algorithm on a computer. In addition, algorithm ( 4 ) can be applied in the presence of small measurement noise and slow drift of the parameter vector, while obtaining an acceptable accuracy of estimates.

The characteristics of the algorithm ( 4 ) essentially depend on the properties of the vector X (n). So, if the vectors X (1), X (2), ..., X (N) are mutually orthogonal, then "in exactly N measurements, the exact value of the sought vector C will be obtained. If X (n) is vector white noise with independent components and equal variances, it can be shown that the convergence time is

(4 ÷ 5) N [ 7]. An increase in the temporal correlation in X (n) leads to a significant increase in the convergence time of the algorithm and, therefore, deteriorates the accuracy of the parameter estimation during drift.

The paper [ 23 ] proposes a method for accelerating the convergence of the Kachmazh algorithm, which consists in introducing, along with the main algorithm, a correcting algorithm. The resulting set of algorithms forms a generalized algorithm that looks like:

$C(n-1) = C(n-1) + a(n)\big(C(n-2) - C(n-1)\big)$; $C(n) = C(n-1) + \dfrac{Y(n) - C(n-1)X(n)}{X^T(n)X(n)} * X^T(n)$;          (5)

Where

$a(n) = \begin{cases} 1, & if\ a\ P^2(C(n-2), C(n)) > P^2(C(n-2), C(n-1), \\ 0 & otherwise, \end{cases}$

(6)

$P^2(C(m), \big(C(k)\big) = \dfrac{(Y(k) - C(m)X(k))^2}{X^T(k)X(k)}$.          (7)

In [31], a high-speed robust (insensitive to variations in the noise distribution density) identification algorithm was proposed, which makes it possible to obtain effective estimates of the CO parameters under the influence of unsteady contaminated Gaussian noise on the CO. The essence of the algorithm is to replace the quadratic loss function F (e) = $e^2$ , where

e = Y - $\hat{Y}$ is the residual of the output signals of the real OA and the model, a square-linear loss function

$F(e) = \begin{cases} e^2, & |e| \le \Delta \\ |e|, & |e| > \Delta \end{cases}$          ( 8 )

which leads to the following change in algorithm (24 ): the residual value

e (n) = Y (n) - C (n - 1) X (n) is replaced by the value of the bounded residual e ogr (n)

$e_{limited}(n) = \begin{cases} e(n) & at\ |e(n)| \le \Delta(n-1) \\ \Delta(n-1)\ sign\ e(n) & at\ |e(n)| > \Delta(n-1) \end{cases}$
( 9 )

where $\Delta$ (n - 1) = C p [e (n - 1)]; C p - the parameter of robustness, depending on b - the degree of pollution of the Gaussian distribution;

[e (n - 1)] - the estimate of the final realization of the standard deviation of the random variable e at the (n - 1) th cycle.

Due to the nonstationarity of the Gaussian component of the noise, the considered algorithm adapts the variance of the residual using the recurrent procedure:

$\hat{M}[e(n)] = (1-a)\hat{M}[e(n-1)] + ae(n)$;

$\hat{M}[e^2(n)] = (1-a)\hat{M}[e^2(n-1)] + ae^2(n)$;          (10)

$$\hat{\sigma}\,[e(\text{n})] = \sqrt{\{\hat{M}[e^2(\text{n})] - \hat{M}^2[e(\text{n})]\}\frac{1-a/2}{1-a}},$$

where , and - estimates for the final implementation, respectively, of the mathematical expectation, the mathematical expectation of the square and the standard deviation of the random variable e at the th cycle; a is the smoothing coefficient, 0 <a <1. To eliminate the bias of the estimate $^2$, multiplication by (1 - a / 2) / (1 - a) is performed.

In the general case, when the vector C is nonlinear, it is impossible to find an analytical expression for the optimal vector C $^*$. Therefore, various approximate methods are used for solving equation [ 8], which is an optimality condition:
$$\nabla J(C) = M\{\nabla_C F\,[e(\text{n})]\} = 0\,,\qquad(11)$$
where M is the symbol of the mathematical expectation;   J (C), - gradients of average losses and loss functions, respectively.

Most of these methods are successive approximation methods. Their physical meaning is to replace the "static" equation, which is the optimality condition, by the "physical" one - a difference equation, the solution of which C ( ) with time $\rightarrow$ $\infty$ c tends to the optimal vector C $^*$ (see, for example, ( 4 ), ( 5 ) Such a difference equation underlies the stochastic approximation algorithm:
$$C(n) = C(n-1) - \Gamma(n)\nabla_C F[e(\text{n})].\qquad(12)$$
The specific form of the gain matrix Γ ( n ) is determined by a particular method of stochastic approximation. Scalar matrix T ( n ) = $\gamma$ (n) * e, $\gamma$ (n)> 0 corresponds to the gradient method, bias T ( n ) = $\gamma_i(n)$ * e , $\gamma_i(n)$ > 0, i = 1, K and G ( n ) = $\gamma$ (n) * B, B> 0 corresponds to the pseudo-gradient method. Here $\gamma$ is the coefficient ensuring the monotonic nature of the identification process; K is the dimension of the vector C; B is a positive definite matrix [25-33]. The

coefficients $\gamma$ (n) and $\gamma$ (n) must satisfy the Robbins - Monroe conditions:
a ) $\gamma_i(n) > 0$,          b) $\sum_{n=1}^{\infty}\gamma_i(n) = \infty$, c) $\sum_{n=1}^{\infty}\gamma_i^2(n) < \infty$,          ( 1 3)
which ensure the convergence of recurrent algorithms (1.23) for a wide class of loss functions F (e) and distribution densities of noise P (ξ).

Slow convergence characteristic of procedures (3 2 ), the existence of a transient process determined by the choice of the initial value C $_0$ , and a strong dependence of the rate of convergence on $\gamma$ (n) led to the use of the recurrent OLS algorithm in problems of technological process control and, in particular, the Kachmazh algorithm ...

Thus, when developing control algorithms and optimizing formalin production for high-quality and fast adaptation of the parameters of control models, one should focus on the use of identification algorithms based on recurrent OLS, including a simplified version of Kachmazh.

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