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Optimization of identification of micro-objects with error control and statistical image filtering mechanisms

Isroil I Jumanov and Sunatillo M Kholmonov

Samarkand state university, University boulevard 15, Samarkand, 140104, Uzbekistan

E-mail: sunatilloxolmonov@gmail.com

Abstract. Scientific and methodological foundations have been developed for the optimal identification of non-stationary objects transmitted by random time series in control systems of industrial and technological complexes, monitoring of environmental protection and ecology, palynology, medicine based on the use of statistical, dynamic, neural network models and mechanisms for extracting statistical, dynamic specific characteristics of information. The mechanisms for controlling the error in the identification of RTS, based on the use of statistical criteria - the rules of the sequential analysis, Bayesian estimation, $\pm 3\sigma$, confidence interval, have been investigated. The problem of control of the error in the identification of RTS by the confidence interval, the mechanisms of threshold control of the values of the random time series elements, their increments, the error of prediction by statistical, trend, dynamic models, algebraic polynomials, parabolic, cubic interpolation, extrapolation spline functions. Mechanisms for regulating the variables of the random time series identification models based on autoregressive, adaptive smoothing by R. Brown, Newton, Lagrange polynomials, orthogonal algebraic polynomials of 3, 5, 7 orders have been developed. The methodology for assessing the quality of the identification of RTS by mathematical expectation and variance and the criterion of correspondence between the relations of mathematical expectation and variance of two consecutive elements have been implemented. The experimental study was carried out according to the real data of the power grid enterprise. The effectiveness of the implemented mechanisms was studied according to the criteria of the minimum root-mean-square error, labor intensity, cost of information processing.

1. Introduction

In control systems for production and technological objects, monitoring of environmental protection and ecology, as well as in medical and biological research, methods and technologies for intelligent analysis of various functional purposes are widely used designed called to optimize the identification of random time series (RTS) of non-stationary objects with control mechanisms for data processing errors [1-3].

The development of mechanisms for extracting statistical, dynamic, specific characteristics and features of RTS information, as well as the use of the unique properties of neural networks (NN) is an urgent and highly demanded research, the results of which contribute to the optimization of identification, data processing, and network training [4-6]. Moreover, the technologies for optimizing the identification of RTS based on the NN guarantee the credibility, high accuracy of information processing under the condition of a priori limitation, the uncertainty of parameters, nonstationarity of processes [7-9].

This study is aimed at developing methods for optimal data processing based on mechanisms for regulating the statistical parameters of RTS, the use of statistical, dynamic, specific characteristics of information, a wide range of identification models for RTS and NN of various architectures. It is assumed to build algorithms and software modules that perform the functions of identification, error control, regulation, optimization, analysis and forecasting of non-stationary objects [10-12].

2. Main part

2.1. Control mechanisms for the identification error of RTS based on statistical criteria

The mechanisms for controlling the error in the identification of RTS are based on the use of the following statistical criteria - rules: sequential analysis; Bayesian estimation; $\pm 3\sigma$; confidence interval, etc [13-15].

The problem of control of the error in the identification of RTS based on the confidence interval with a mechanism for determining the functional dependencies of the x_l* и y_l* variables has been solved $x_l* = f_i(\overline{X},\overline{b}_i) - f_j(\overline{X},\overline{b}_j)$; $y_l* = 2y - f_i(\overline{X},\overline{b}_i) - f_j(\overline{X},\overline{b}_j)$, where $f_i(\overline{X},\overline{b}_i)$, $f_j(\overline{X},\overline{b}_j)$ - i, j indices of functional dependencies.

The introduced $y_l* = \lambda_{ij} x_l*$ model makes it possible to obtain the coefficient of adequacy of two functional dependencies in the form $\hat{\lambda}_{ij} = \sum_{l=1}^{N} y_l^* x_l^* \Big/ \sum_{l=1}^{N} (x_l^*)^2$.

The lower and upper bounds of the confidence interval are determined as

$$T_H = \hat{\lambda}_{ij} - t_{kp}\left(\sum_{l=1}^{N}(y_l^* - \hat{\lambda}_{ij} x_l^*)^2 / \gamma \sum_{l=1}^{N}(x_l^*)^2\right)^{1/2}; \quad T_B = \hat{\lambda}_{ij} + t_{kp}\left(\sum_{l=1}^{N}(y_l^* - \hat{\lambda}_{ij} x_l^*)^2 / \gamma \sum_{l=1}^{N}(x_l^*)^2\right)^{1/2},$$

where $\gamma = N - k$ - the number of degrees of freedom; $k = \inf\{k_i, k_j\}$; t_{kp} – the significance of the Student's criterion.

Identification of non-stationary RTS is characterized by a large error value, which is determined by the probability of information errors, the impact of the external and internal environment at all stages of input, transmission, storage, identification and processing of data [16-19].

A wide range of mechanisms has been investigated and developed to control the error in the identification of RTS of non-stationary objects based on threshold control, control of the increment values, control of the error of predictions by statistical, trend, dynamic models, algebraic polynomials, parabolic, cubic interpolation and extrapolation spline functions and NN.

Mechanisms for regulating variable identification models of RTS based on autoregressive, adaptive smoothing by R. Brown, Newton, Lagrange polynomials, orthogonal algebraic polynomials of 3, 5, 7 orders have been developed and implemented [20-24].

The important statistical parameters used in the mechanisms for controlling the error in the identification of RTS are the mathematical expectations and variances.

The mathematical expectation $M[\Delta(x_i)]$ of the error of the quantized value of the RTS $\Delta(x_i)$ contour before the application of information control is set as $M[\Delta(x_i)] = \sum_{i=1}^{n} \Delta(x_i) P_i = P_i \sum_{i=1}^{n} \Delta(x_i)$, where n – the number of RTS elements taken into account when assessing $M[\Delta(x_i)]$; i – the number of the element in the sequence; P_i – is the prior probability of the element. The mathematical expectation $M[\Delta(b_i)]$ of a quantized value after receiving information in the form of a $\Delta(b_i)$ variable is determined in the form $M[\Delta(b_i)] = \sum_{i=1}^{n} \Delta(b_i) P_i = P_i \sum_{i=1}^{n} \Delta(b_i)$. The quality of identification of the RTS with the error control mechanism is assessed according to the criterion of compliance of two compared quantities $M[\Delta(x_i)] / M[\Delta(b_i)]$ values in the form

$$M[\Delta(x_i)]/M[\Delta(b_{1i})]=P_i\sum_{i=1}^{n}\Delta(x_i)/P_i\sum_{i=1}^{n}\Delta(b_{1i})=\sum_{i=1}^{n}\Delta(x_i)/\sum_{i=1}^{n}\Delta(b_{1i}).$$

The results are presented as the ratio of the sum of the values of the $\Delta(x_i)$ errors to the sum of the values of the $\Delta(b_i)$ errors for all RTS elements. Another characteristic of error control - $D[\Delta(x_i)]$ variance before information control is defined as

$$D[\Delta(x_i)]=\sum_{i=1}^{n}(\Delta(x_i)-M[\Delta(x_i)])^2P_i=P_i\sum_{i=1}^{n}(\Delta(x_i)-M[\Delta(x_i)])^2.$$

The dispersion of $D[\Delta(b_{1i})]$ information after the reception is determined as

$$D[\Delta(b_{1i})]=\sum_{i=1}^{n}(\Delta(b_{1i})-M[\Delta(b_{1i})])^2P_i=P_i\sum_{i=1}^{n}(\Delta(b_{1i})-M[\Delta(b_{1i})])^2.$$

The compliance of the criteria is given by the form

$$\frac{D[\Delta(x_i)]}{D[\Delta(b_{1i})]}=\frac{P_i\sum_{i=1}^{n}(\Delta(x_i)-M[\Delta(x_i)])^2}{P_i\sum_{i=1}^{n}(\Delta(b_{1i})-M[\Delta(b_{1i})])^2}=\frac{\sum_{i=1}^{n}(\Delta(x_i)-M[\Delta(x_i)])^2}{\sum_{i=1}^{n}(\Delta(b_{1i})-M[\Delta(b_{1i})])^2}.$$

The error control mechanism of the RTS sequence considers that it consists of distorted and undistorted elements. The mechanism reduces distorted RTS elements and singles out a sequence of undistorted elements. When $N\to\infty$, then the probability of occurrence of an erroneous element in the RTS sequence is measured by the expression $P_i=1/n$. The mathematical expectation of the error in the identification of RTS with distorted elements is represented in the form:

$$M[\Delta(x_i)]=P_i\sum_{i=1}^{n}\Delta(x_i)=\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i);\quad M[\Delta(b_{1i})]=P_i\sum_{i=1}^{n}\Delta(b_{1i})=\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i}).$$

Dispersions and their ratios are represented as: $D[\Delta(b_{1i})]=\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})-\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})^2$; $D[\Delta(x_i)]=\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)-\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)^2$; $\frac{D[\Delta(x_i)]}{D[\Delta(b_{1i})]}=\frac{\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)-\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)^2}{\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})-\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})^2}$.

The error probability of the i - th element, represented by an eight discharge code, is determined as

$$P_i=P(1-P)^{n-1}=P(1-P)^7.$$

The mathematical expectation of $M[\Delta(x_i)]$ is defined as $M[\Delta(x_i)]=\frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)=\frac{1}{n}\sum_{i=1}^{n}2^{n-1}=31.85$.

The mathematical expectation $M[\Delta(b_i)]$ is defined as $M[\Delta(b_{1i})]=\frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})=31{,}75$.

The averaged errors of the RTS elements are obtained:

$$M[\Delta(b_1)]_{1p}=\{16\times8+8(7(16+0{,}06)+8(16\text{-}0{,}06))+7(7\times0{,}06\text{-}$$
$$\text{-}8\times0{,}06)\}/241=(128+8\times239{,}94\text{-}7\times0{,}06)/241=2047{,}1/241=8{,}49;$$

…… ….. ……..

$$M[\Delta(b_1)]_{8p}=\{128\times8+8(7(128+7{,}53)+8(128-7{,}53))+7(7\times7{,}53\text{-}$$
$$8\times7{,}53)\}/241=(1024+8\times15299{,}76\text{-}52{,}71)/241=16271{,}1/241=67{,}52.$$

Attitude mathematical expectations $M[\Delta(x_i)]/M[\Delta(b_i)] = 31{,}875/31{,}75 = 1{,}004$. Dispersion

$$D[\Delta(x_i)] = \frac{1}{n}\sum_{i=1}^{n}\Delta(x_i) - \frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)^2 = 1/8\cdot\{(8{,}49 - 1/8\cdot 253{,}95)^2 + (16{,}98 - 1/8\cdot 253{,}95)^2 +$$
$$+ (33{,}96 - 1/8\cdot 253{,}95)^2 + (67.92 - 1/8\cdot 253.95)^2 + (8.44 - 1/8\cdot 253.95)^2 + (16.88 - 1/8\cdot 253.95)^2 +$$
$$+ (33.76 - 1/8\cdot 253.95)^2 + (67.52 - 1/8\cdot 253.95)^2\} = 4120.05/8 = 515.$$

Variance ratio

$$D[\Delta(x_i)]\cdot D[\Delta(b_{1i})]^{-1} = \sum_{i=1}^{n}\Delta(x_i) - \frac{1}{n}\sum_{i=1}^{n}\Delta(x_i)^2 \cdot (\sum_{i=1}^{n}\Delta(b_{1i}) - \frac{1}{n}\sum_{i=1}^{n}\Delta(b_{1i})^2)^{-1} = 1715.36/515 = 3.33.$$

Winnings in identification accuracy depends on its process dynamics. In this regard, for optimization, the use of mechanisms for controlling the error and correction of the weights of the RTS elements is proposed.

2.2. Control mechanism for identification error of RTS with correction of element weights

Control mechanism for identification error of RTS with correction of element weights. Let K_i be the membership classes of all elements of the RTS, where $i = 1,...,m$; x_j - a priori dictionary - classification signs; $f_i(x_j)$ - conditional and $P(K_i)$ - unconditional (a priori) probability distribution functions of RTS elements. The range of variation of the quantized values of the RTS $\Delta_i^1(x_k), \Delta_i^2(x_k),..., \Delta_i^m(x_k)$ element differ from zero. The probability of finding an x_k element in the K_i class is determined as $P_m = \sum_{i=1}^{m} P(K_i)P[x_k \in \Delta_i^m(x_k) \mid i] = \sum_{i=1}^{m} P(K_i) \int_{\Delta_i^m(x_k)} f_i(x_k)dx_k$, where $\Delta_i^m(x_k)$ – intervals; $f_i(x_k)$ – separation functions, $i = 1,2,...,m$. Let us denote by $M(z) = \sum_{z=1}^{m} zP_z$ - the average value of the RTS elements for each class of belonging, which is estimated with the probability P_z, $z = 1,2,...,m$. The identification error control mechanism evaluates the degree of belonging of elements to the class of features, compares the mathematical expectations of $M_{x_k}(z)$ and $M_{x_s}(z)$ of the first and second RTS elements. A comparison of the mathematical expectations of x_k and x_s elements is carried out in order to determine which of these estimates has the best-separating properties. If $M_{x_k}(z) > M_{x_s}(z)$ or $M_{x_s}(z) > M_{x_k}(z)$, then it is considered that the estimates of the x_k and x_s elements have the best-separating properties. In the first case, the degree of belonging of the x_k element to the required class is higher than that of the x_s element, and in the second case, the degree of membership of the x_s element is higher than that of the x_k element. Optimization is carried out according to the average variance of j - th elements, taking into account the variance of the transformed elements formed during the transition from a class to class $\overline{D}_{ji} = M\{[m_{ji} - M(m_{ji})]^2\}$. Along the axis of the x_k variable elements belonging to different classes at distant distances are located than elements located along the axis of the x_s variable. The x_s element belonging to the required class is checked according to the $\overline{D}_{ki} > \overline{D}_{si}$ condition and assessed according to the $K_j = M[D_{ji}]/\overline{D}_{ji}$ criterion. Optimization is carried out according to the average attitude $\min_j K_j = \min_j\{M[D_{ji}]/\overline{D}_{ji}\}$. If the value of the criterion is $K_k < K_s$, then the x_k element is considered to belong to the required class of features. The RTS measurements were formed, of which 14 sets of real observations and 14 sets of reduced RTS elements were made. Calculated mean, variance, empirical distributions for each set. For this, simplified methods of accelerated calculation of statistical parameters are proposed, the results of which are also compared with calculations by the classical method of mathematical statistics. The closeness of the found mean values was checked by the t - Student criterion with a guaranteed probability $\mathrm{P}=0{,}95$. The experimental study was carried out according to the real data of the power grid enterprise. The estimates obtained are no less accurate in comparison with the estimates of classical methods. The calculation time of statistical parameters is reduced by almost 2 times.

2.3. Identification error control mechanisms based on conditional probabilistic characteristics of RTS

A mechanism for controlling the error in the identification of RTS is proposed, which is based on the use of the following conditional statistical characteristics: $\varpi_2(\xi,\eta,t_2,t_1)$ - two-dimensional probability distribution density function of ξ and η elements of two dependent sequences of RTS; σ_ξ^2, σ_η^2 - unconditional variances, α_ξ, α_η – mathematical expectations; $R(\tau)$ – autocorrelation coefficient, τ - discrete difference; $m(\eta/\xi)$ and $m(\xi/\eta)$ - conditional mathematical expectations of the elements of the ξ and η of the dependent elements of the RTS; $D(\eta/\xi)$ and $D(\xi/\eta)$ – conditional variances of the elements of the RTS; $B_\eta=\eta_{\max}-\eta_{\min}$ and $B_\xi=\xi_{\max}-\xi_{\min}$ – the ranges of the practical range of values of the elements of RTS, η and ξ – respectively; P_α and P_β - the average probability of information errors.

Errors in information, variations in the RTS dynamics, transform the true values of η and ξ elements into other values, i.e. $\eta\to\alpha$ and $\xi\to\beta$. The error control mechanism is based on the following rules: a) $m_H(\beta/\alpha)\le m(\beta/\alpha)\le m_B(\beta/\alpha)$; b) $m(\beta/\alpha)<m_H(\beta/\alpha)$; $m(\beta/\alpha)>m_B(\beta/\alpha)$.

If condition a) is met, then the value of the RTS element is considered reliable. Otherwise, the RTS element is considered invalid. The element AA is checked in the same way β a) $m_H(\alpha/\beta)\le m(\alpha/\beta)\le m_B(\alpha/\beta)$; b) $m(\alpha/\beta)<m_H(\alpha/\beta)$, $m(\alpha/\beta)<m_B(\alpha/\beta)$, where $m_H(\beta/\alpha)$, $m_H(\alpha/\beta)$ and $m_B(\beta/\alpha)$, $m_B(\alpha/\beta)$ – lower and upper boundaries, which are determined by conditional distributions of $w(\beta/\alpha)$, $w(\alpha/\beta)$. The solution to the problem is to find the optimal control boundaries for the identification error of the RTS, which the sequence of elements considers in the subsets of allowed and forbidden values. The effectiveness of the mechanism is investigated by the risk function, given by the probability of undetected errors [25-29]. In figure 1 depicted the principle of control of the identification error of RTS. Straight-line - OO' is the β regression line with respect to α. Straight lines $x(\beta)x'(\beta)$ and $y(\beta)y'(\beta)$, drawn parallel to the regression line OO', mean the boundaries of checking whether the values of the RTS elements belong to the subset of permitted values. The coordinates of any point lying inside are considered the shaded area allowed. The mechanism leaves two kinds of errors undetected. The error of the first kind occurs when the value of an α element is distorted but is believed to be reliable. The error of the second kind is tolerated when α is transmitted correctly but is considered invalid. Figure 2 illustrates the graphs of the relative root-mean-square error $F_i^2=\sigma^2/B$ of three mechanisms: the first - control of the error by the conditional average (solid line); the second - by the confidence interval $T_H\le m(\beta/\alpha)\le T_B$ (dash-dotted line); the third is the threshold control (line with two dash-dotted lines). Optimization of control requires minimizing the probabilities of undetected errors of the first and second kind. It has been determined that the regulation of the width of the permitted borders control reduces either decreases or increases the values of the probabilities of errors of the first and second kind. Solutions to the problem are obtained for various variations of statistical parameters - conditional averages, variance, correlation function, distribution function. The study was carried out for the average probability of $P=10^{-3}$ errors, the relative average value of the RTS $Q_\alpha=a_\alpha/B$, $Q_\alpha=0{,}3,\ 0{,}5,\ 0{,}9$. It was found that at

small values of the Q_α parameter and the $P > 10^{-3}$ probability, the mechanism of threshold control reduces the root-mean-square error of identification by more than one order of magnitude.

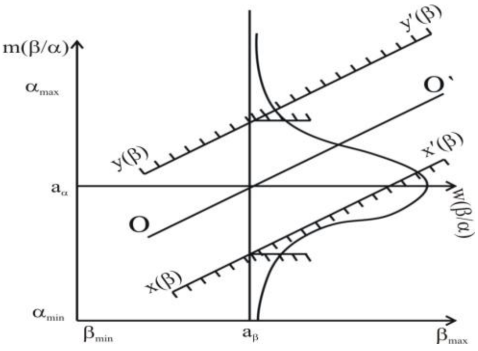


Figure 1. Verification principle.

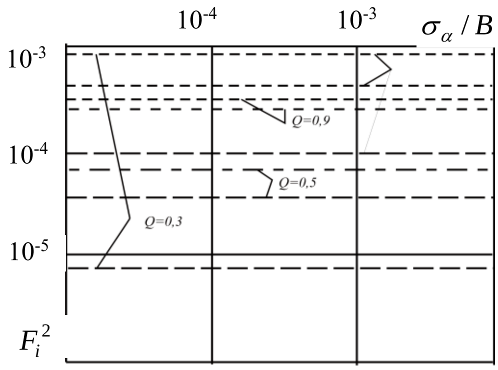


Figure 2. Effectiveness of mechanisms.

Analytical expressions are obtained for estimating the root-mean-square error and optimal control boundaries for various autocorrelation functions and conditions for variance variation, mathematical expectation, correlation functions, and distribution laws.

2.4. The mechanism for controlling the error of identification of RTS based on dynamic characteristics

The problem of control of the error in the identification of RTS on the basis of an autoregressive model (AM) with a mechanism of retranslation of the dynamic properties of the RTS on the AM is solved, in which the current value of the x_t element is represented by a finite linear set of the previous x_{t-i} elements $\hat{x}_t = \sum_{i=1}^{l} b_i x_{t-i}$, where l – AM order; b_i – AM coefficients, $i = \overline{1,l}$.

The weight coefficients of the RTS elements are determined as $b_H = b_C - k\ grad(\sigma_t^2)$, where b_H and b_C – new and old weights of RTS points; k – weighting factor $(k > 0)$; σ_t^2 – mean-square error of identification of RTS, estimated by the difference of $\sigma_t = \hat{x}_t - x_t$; $grad(\sigma_t^2)$ – vector-gradient.

The mechanism provides the following functions: correction of the weights of the RTS elements; the old weight of the element is corrected by multiplying by the coefficient k of the gradient taken in negative sign; the gradient components are found by differentiating the σ_t^2 parameter by the $\partial\sigma_t^2 / \partial b_t = -2\sigma_t x_t$ weights; the $grad(\sigma_t^2)$ rating is being performed; adjustments to the weights of the RTS element are made using the expression $b_H = b_C + 2k\sigma_t x_i$. If $k = h / 2\sum x_t^2$, then $(\sigma_н)_t = (\sigma_c)_t (1-h)$. The values of the minimum root-mean-square errors for the exponential, bell-shaped, triangular autocorrelation function are obtained. The efficiency of the error control mechanism based on nonlinear functions of identification of RTS, in particular, algebraic polynomials, is investigated. It has been determined that more acceptable qualities of RTS identification are provided by orthogonal algebraic polynomials. Table 1 shows algorithms with an adaptation mechanism.

Table 1. Algorithms with an adaptation mechanism.

Adaptable variables	Algorithms with an adaptation mechanism	
	WAB	WAV
$e(s)^*$	85	38
R_{n-k}	4.5	3

Below, the quality of the identification of the RTS is compared using the identification algorithm without an adaptation block (WAB) and an algorithm with an adaptation of variables (WAV).

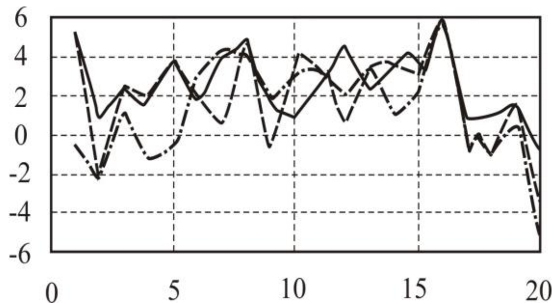
It is proved that algorithms with WAB in the case of identification of a dynamic RTS show better results. The solutions of the identification problems of the RTS of a dynamic process are obtained based on the use of the following mechanisms: parallel computations, cyclic multigrid functions, Gauss-Seidel approximation with upper relaxation of the RTS, optimization based on conjugate gradients. The design of grid functions from the q level to the $q-1$ level is determined by bilinear approximation and fourth-order approximation. The operator I of the bilinear interpolation $U_h^q \xrightarrow{I} U_{ijk}^{q-1}$, $U_h^q \in S_q$, $U_h^{q-1} \in S_{q-1}$ is written as:

$$U_{ijk}^{q-1} = U_{ijk}^q \,;\; U_{i\pm1/2,jk}^{q-1} = \frac{1}{2}(U_{ijk}^q + U_{i\pm1,jk}^q)\,;\; U_{i\pm1/2,j\pm1/2,k}^{q-1} = \frac{1}{4}(U_{ijk}^q + U_{i\pm1,jk}^q + U_{i,j\pm1,k}^q + U_{i\pm1,j\pm1,k}^q)\,;$$

$$U_{i\pm1/2,j\pm1/2,k\pm1/2}^{q-1} = \frac{1}{8}(U_{ijk}^q + U_{i\pm1,jk}^q + U_{i,j\pm1,k}^q + U_{i\pm1,j\pm1,k}^q + U_{ij,k\pm1}^q + U_{i\pm1,j,k\pm1}^q + U_{i,j\pm1,k\pm1}^q + U_{i\pm1,j\pm1,k\pm1}^q)$$

and with bilinear interpolation of the fourth order, it will be written as:

$$U_{ijk}^{q-1} = \frac{1}{24}(12U_{ijk}^q + U_{i+1,j+1k}^q + U_{i+1,j-1,k}^q + U_{i-1,j-1,k}^q + U_{i-1,j+1,k}^q + U_{i+1,j,k+1}^q +$$
$$+ U_{i+1,j,k-1}^q + U_{i-1,j,k-1}^q + U_{i-1,j,k+1}^q + U_{i,j+1,k+1}^q + U_{i,j+1,k-1}^q + U_{i,j-1,k-1}^q + U_{i,j-1,k+1}^q).$$



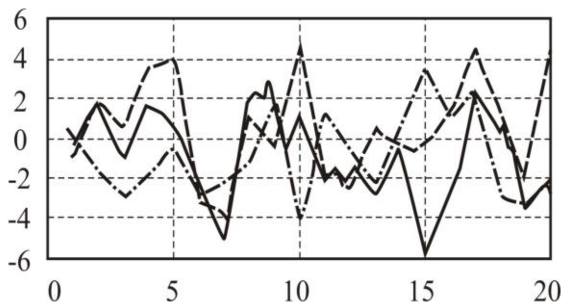


Figure 3. The efficiency of optimization of identification of RTS, a) working days, b) weekend.

In figure 3 a), b) plots of RTS identification models are compared, which are obtained on the basis of the synthesis of parallel computing mechanisms with autoregression (dashed line) for smoothing (solid line), multivariate regression model (dash-dotted line). The study was conducted based on the data provided for predicting the electrical load in working days (Figure 3 a)) and weekends (Figure 3 b)) of the electric grid company. It was revealed that the root-mean-square error of forecasting RTS for working days was 2.5 %, and for weekends – 1.5 %. Error control mechanisms are show high in regulating auto and pair correlation coefficients.

3. Conclusion

The scientific and methodological foundations for optimizing the identification of RTS of non-stationary objects with mechanisms for error control, variable control, the use of information and statistical connections, variance, correlation coefficients, statistical relationships, distribution laws, confidence interval, threshold control, as well as a wide range of statistical, dynamic models and neural networks. Methods and algorithms for controlling the RTS identification error are proposed, based on the use of moving average, autoregressive, adaptive smoothing, threshold control mechanisms, and stochastic cognitive analysis. It is proved that the implemented mechanisms for controlling the error in the identification of RTS effectively detect the non-stationary component, conducts filter random bursts, reduce and correct distorted elements, and form sets of a reliable sequence of RTS elements. The efficiency of the algorithms has been investigated according to the criteria of the minimum root-mean-square error, labor intensity, and the cost of information processing. It is established that algorithms in conditions close to practical accuracy of identification and information processing increase enhance by almost enhance two orders of magnitude.

References

[1] Vizilter Yu V 2010 *Image Processing and Analysis in Machine Vision Problems: Lecture and Practical Class Course* (M.: Fizmatkniga)
[2] Shashev D V 2016 *Information-measuring equipment and technologies* (Tomsk) pp 544-50
[3] Verma B *et al.* 1999 *Journal of Intelligent Systems* **9(1)** 39-54
[4] Durai A S, Saro A E and Phil M 2006 *GVIP Journal* **6**(2) 122-8
[5] Gonzalez R 2005 *Digital image processing* (M.: Tekhnosfera)
[6] Duda R O *et al.* 2001, *Pattern Classification* (New York: John Wiley & Sons)
[7] Jumanov I *et al.* 2021 *E3S Web Conf.* **304** https://doi.org/10.1051/e3sconf/202130401007.
[8] Golovko V A 2001 *Neural networks: training, organization and application* (M.: IPRZhR)
[9] Liu D, Wang S, *et al.* 2016 *Computers in Biology and Medicine* **72** 185-200
[10] Banarse D, France I and Duller A W G 2000 *Advances in engineering software* pp 944
[11] Boucher A *et al.* 2000 *In 2nd European Symposium on Aerobiology* (Vienna Austria) pp 3.
[12] Jumanov I I, Djumanov O I and Safarov R A 2021 *Journal of Physics: Conference Series* **1791** 012099, doi:10.1088/1742-6596/1791/1/012099.
[13] Bertalmio M, Caselles V and Provenzi E 2009 *International Journal of Computer Vision* **83** 101–19
[14] Kimmel R, Elad M, *et al.* 2003 *Int. Journal of Computer Vision* **52** 7–23
[15] Kuleshov S V, Aksenov Yu A and Zaitseva A A 2015 *Innovative Science* **5** 82-6
[16] Ibragimovich J I, *et al.* 2021 *Advanced in Intelligent System and Computing* **1323** 170–9 DOI:10.1007/978-3-030-68004-6_22
[17] Bezuglov D A, Rytikov S Yu, Yukhnov V I and Shvidchenko S A 2012 *Modern problems of radio electronics: IV int. scientific conf.* (Rostov-on-Don) pp 203-12
[18] Stringer S M *et al.* 2009 *Self-organizing continuous attractor networks and path integration: one-dimensional models of head direction cells* pp 217-42
[19] Liu D, Wang S, Huang D, Deng G, Zeng F and Chen H 2016 *Computers in Biology and Medicine* **72** 185-200.
[20] Jumanov I I, Djumanov O I and Safarov R A 2019 *Chemical Technology, Control and Management* **5** 71–8 https://doi.org/10.34920/2019.6.71-78.
[21] Provenzi E, Fierro M, Rizzi A, De Carli L, Gadia D and Marini D 2007 *IEEE Transactions on Image Processing* **16** 162–71
[22] Marini D and Rizzi A 2000 *Image and Vision Computing* **18** 1005–14
[23] Jumanov I I, Djumanov O I and Safarov R A 2020 *Int. Russian Automation Conf.* pp 626–31 DOI:10.1109/RusAutoCon49822.2020.9208164
[24] Ma W, Morel J M, Osher S and Chien A 2011 *In Proceedings of IEEE Conf. on Computer Vision and Pattern Recognition* (CVPR, IEEE, 2011) pp 153–60
[25] Zhang X *et al.* 2012 *Proc. 21st Int. Conf. Pattern Recognit*. (ICPR) pp 2034-7
[26] Ibragimovich J I, Isroilovich Dj O and Abdullayevich S R 2020, *Int. Conf. on Information Science and Com. Tech*, 9351483, DOI:10.1109/ICISCT50599.2020.9351483.
[27] Ibragimovich J I, Isroilovich D O and Maxmudovich X S 2020 *Int. Conf. on Information Science and Communications Technologies* 9351486 DOI:10.1109/ICISCT50599.2020.9351486
[28] Li L, Wang R, Wang W and Gao W 2015 *Proc. IEEE Int. Conf. Image Process* pp 3730-4

[29] Igamberdiyev H Z, Yusupbekov A N, Zaripov O O and Sevinov J U 2017 *Procedia Computer Science* **120** 854–61. https://doi.org/10.1016/j.procs.2017.11.318
[30] Jumanov I I and Xolmonov S M 2021 *IOP Conference Series: Materials Science and Engineering* **1047(1)** 012064. DOI:10.1088/1757-899X/1047/1/012064
[31] Mirzoyan K, Mirzaakbar H and Alisher K 2021 *Procedia Computer Science* **186** 360–5 https://doi.org/10.1016/j.procs.2021.04.157
[32] Djumanov O I and Kholmonov S M 2010 *4th Int. Conf. on Application of Information and Communication Technologies* **AICT2010** 5612037 DOI:10.1109/ICAICT.2010.5612037