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Control of the reliability of the forecast of random time series based on a neuro-fuzzy network

Djumanov Olimjon Israilovich, Kholmonov Sunatillo Makhmudovich, Yuldoshev Farrukh Uktomovich

Candidate of Technical Sciences, Associate Professor, Department of Information Technologies, Samarkand State University, Samarkand, Uzbekistan
PhD in Technical Sciences, Department of Information Technologies, SamarkandStateUniversity, Samarkand, Uzbekistan
Graduate student, Department of Information Technologies, SamarkandStateUniversity, Samarkand, Uzbekistan

ABSTRACT: The methodological foundations for the design of methods, algorithms, and systems of intellectual analysis in automated control systems for technological processes for monitoring the reliability of forecasting random time series based on the components of the soft computing apparatus have been developed. Methods for the identification of linear, nonlinear dependencies through models fuzzy logic and neural network (NN), data preprocessing, as well as the implementation of the knowledge base of fuzzy rules and a database, are proposed. The effectiveness of forecasting methods for statistical calculations of time series on examples of results.

KEYWORDS: time-series, non-stationary object, forecast credibility, fuzzy model, neural network, database, knowledge base.

I. INTRODUCTION

Traditional analytical models for the analysis and forecast of nonstationary objects are applicable only if there is extensive a priori information and in conditions when the process being identified is characterized by strong variations in statistical parameters, as a result of which an adequate model of an object becomes difficult to describe, and its design is associated with complex calculations with a large parametric and structural uncertainties [1].

In this regard, the development of effective models, methods and algorithms that provide high accuracy of analysis and data processing with insufficient a priori information and large uncertainty of object parameters, uncomplicated algorithms at much lower costs is an urgent task of scientific and technical research. [2]. In this paper, methods have been developed to ensure the reliability of the forecast based on the application of neuro-fuzzy networks (NFN) with mechanisms for identification and approximation of non-stationary processes with an uncertain structure, limited information about the parameters of nonlinear high-order processes [3].

II. MECHANISMS FOR INCREASING THE CREDIBILITY OF FORECASTING RANDOM TIME SERIES BASED ON THE APPLICATION OF NEURO-FUZZY NETWORKS

Methods for increasing the reliability of forecasting random time series (RTS) based on NFN require the implementation of modified computational schemes for structural and parametric identification, fuzzy logic models and the use of a knowledge base (KB), including a wide set of fuzzy application instead of complex analytical functions and equations describing a nonstationary process [4]. The formal model the identification of the RTS based on the NFN is presented as

$$J = F(u(t-\Delta t), w, a), \tag{1}$$

where $u(t-\Delta t)$ – parameter obtained to configure the process of identifying the RTS according by values set in the previous step of the system execution;

w – vector of unknown parameters and random disturbances;

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a – vector of known parameters.

Based on analytical models, the identification carried out of the RTS using retrospective data [5]. When a priori information about the structure and properties of the $F(u,w,a)$ parameters is sufficient, then the construction of a mathematical expression of the reduced function (1) to ensure the reliability of the RTS forecast is not very difficulties.

In the general case, the task of ensuring the reliability of the RTS forecast is reduced to maintaining the value of some output (calculated) parameter u of the technological process at the required level, which depends on the patterns of the arrival of the input parameter x [6].

Non-stationary RTSs for the discretized input parameter x are set by a sequence of measurements from 0 to k, and for continuous parameters in the time interval from 0 to T.

The model for describing the RTS in the statistical approach is represented by differential equations, and the quality functional of continuous input parameters is represented in the form

$$u = \int_0^T (x(t)-g)^2\,dt \to \min . \qquad (2)$$

Note that there is an infinite lots of options for achieving x level g, however delivered in the optimization problem (2), to simplify the processes of searching for local and global minimum, the following options for control the reliability of the RTS forecast are proposed [7].

Option 1. The set of conditions is written as:

1. If $x < g$, then $u = 1$.
2. If $x = g$, then $u = v/k$.
3. If $x > g$, then $u = 0$.

However, under these conditions, time sampling and x changes are not taken into account when their value exceeds the required g level [8]. As a consequence of this, a mode of spasmodic change in the x parameter may occur, and consequently a distortion of the forecast. In this case, condition 2 is unreliable and requires its adjustment.

To eliminate the shortcomings of the conditions of option 1, the following conditions are proposed in terms of fuzzy sets [9].

Option 2. The conditions are of the form:

1. If $x = "less\ g"$ then $u = "\text{near } 1"$.
2. If $x = "g"$ then $u = "near\ v/k"$.
3. then $x = "less\ g"$ then $u = "near\ 0"$.

III. MECHANISM FOR CONTROLLING THE RELIABILITY OF THE RTS FORECAST BASED ON FUZZY MODELING

The introduction of fuzzy modeling is also due to the fact that modeling methods based on statistical approaches do not take into account complex nonlinearities, errors in measuring parameters, information distortions, time delays in the real dynamics of nonstationary objects [10].

The above version (2) of the conditions for monitoring the reliability of the forecast by the Sugeno models is set by a set of fuzzy rules of the form:

$$R_r : if \quad a \quad \bigcap_{i=1}^{m} (x_i = a_{ir}) \ then \ u = b_{0r} + \sum_{i=1}^{n} b_{ir} x_i \qquad (3)$$

where m – the number of fuzzy rules $r = 1,2,...,m$;

a_{ir} – is a fuzzy term with a membership function (MF) μ_{ir} for linguistic assessment of the x_i variable in the r $(r = 1,2,...,m;\ \ i = 0,1,...,n)$ rule;

b_{0r} – real numbers in the conclusion in the rule r.

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The Mamdani model is given by a set of fuzzy rules of the following form:

$$R_r : if \ \ a \bigcap_{i=1}^{m} (x_i = a_{ir}) \ then \ u = b_j \qquad (4)$$

where b_j – is a fuzzy term with MF η_j, applied for the linguistic estimation of the u variable in the j $(j = 1,2,...,k; k <= n)$ rule.

The solution to a specific problem of identifying the RTS requires the design of the NFN structure, which will consist of an input (zero) layer with external n-signs and subsequent k-layers, where each layer has m-nodes. Outputs of layer nodes form internal features for the next layer. A specified number of d inputs acts as a node [11].

The system under study implements the Sugeno fuzzy inference model of zero-order and NN with five layers, which perform the following functions: the first layer - forms the terms of the input variables; the second layer - antecedents (premises) of fuzzy rules; the third layer - normalizes the degree of rule execution; the fourth layer is the conclusion of the rules; the fifth layer - aggregation of the result obtained according to different rules [12].

Training samples are formed according to the following rules.

The rule 1. Signs (external or internal) are unite grouped according to the minimum entropy:

$$I(x) = \log(N_{x_1} \cdot N_{x_2} \cdot ... \cdot N_{x_d} / N_{x_1, x_2, ..., x_d}) \qquad (5)$$

where $N_{x_1} \cdot N_{x_2} \cdot ... \cdot N_{x_d}$ – the number of gaps with the RTS quasi-stationarity property;

$N_{x_1, x_2, ..., x_d}$ - the number of measurements in the separated RTS segments, which contained points with $x_1, x_2, ..., x_d$ coordinates.

The rule 2. Every sign (external or internal) is used only in one group and only once.

The rule 3. Signs (external or internal) that are not included in the group in the upper layer participate in the competition for an education of a group in the lower layers.

Note that when making decisions in the developed algorithms, heuristic methods of confirming or refuting hypotheses about the reliability of a forecast based on statistical research, expert knowledge, statistical criteria for evaluating the calculation of predictive indicators, as well as a procedure for comparing calculations performed in the computational schemes of NFN components with specified parameters are used.

IV. CONCLUSION

Thus, the implemented methods of teaching NFN create an opportunity for automatic correction of the parameters of the RTS model, and more accurate results of analysis and processing of information are obtained with strong variations in statistical parameters and non-stationary properties of the RTS..

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