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Framing regional innovation and technology policies for transformative change

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Framing regional innovation and technology policies for transformative change

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Abstract. The current state of social and economic development of regions requires new approaches to increasing the efficiency of their activities, and above all scientific approaches to forecasting, as one of the main components of the strategy of transformative changes. It is proposed to use an architecture based on neuro-fuzzy networks for forecasting regional development, which is characterized by a high learning rate due to the linear dependence of outputs on adjustable weights. Scientific and methodological approaches are developed to determine the global minimum of the learning criterion, taking into account the decision rules "if-then".

1. Introduction

The task of processing multidimensional time series often arises in many socio-economic studies of regional development [1, 2]. The modern development of a market economy in Russia requires an increase in the efficiency of strategic planning, which will improve competitiveness in the face of rapid changes in the external environment. At the same time, forecasting should be considered as a necessary element of the regional management system, the main task of which is determined by the orientation towards possible cardinal changes in the state and development of management objects and their external environment. The modern economy of Russia requires systemic unity and consistency of technological, educational and forecasting strategies to help accelerate the quality of economic development of the regions.

Currently, the ability to generate, use and disseminate new knowledge for forecasting development is becoming the basis of national competitiveness and a basic prerequisite for accelerated economic growth. This ability is the main factor necessary to ensure the choice of the economic, social and cultural direction of the development of society based on the use of the achievements of science. A strategy of advanced intellectual and innovative development can provide opportunities for generating new technologies and predictive knowledge. At present, the scope and scale of forecasting activities, the quantitative and qualitative diversity of forecasting objects have expanded significantly. The social, economic, ecological, informational value of forecasts has increased [3, 4].

It should be noted that in many problems of forecasting regional innovative development, time series are characterized by a high level of nonlinearity (possibly even chaotic character) and nonstationarity of their parameters, the presence of irregular trends and abnormal outliers. It is clear that traditional methods for analyzing time sequences are ineffective, since they are based on regression, correlation, spectral and other similar approaches, and provide a priori availability of a sufficient sample of observations.

An alternative to traditional statistical methods can be the mathematical apparatus of computational intelligence and, above all, artificial neural networks and neuro-fuzzy systems due to their universal approximating properties. At the same time, extrapolation does not follow from the approximating properties, since taking into account previous data to build a predictive model can worsen the forecast quality. In this regard, when processing essentially non-stationary processes, it is necessary to abandon learning procedures based on error backpropagation or the least squares method in order to use procedures based on local conditions and short memory [5, 6].

At the same time, training methods should provide not only high performance, but also resolving properties to suppress the stochastic noise component in the processed signal. In this regard, the synthesis of specialized hybrid computational intelligence systems designed to solve the problems of processing essentially non-stationary multidimensional time series under conditions of uncertainty provides a high learning rate and noise filtering. This approach is quite an interesting and promising tool to support management decision-making.

Despite a large number of scientific works on this topic [7, 8], there is a problem of processing multidimensional time series, due to the need to improve the quality of the results obtained and increase the speed of data processing. In this regard, the task of developing methods for analyzing multidimensional time series based on neuro-fuzzy networks for sequential processing of nonlinear multidimensional time series is urgent. Such methods will make it possible to function under conditions of a priori information deficit and will provide the ability to process time series with a small training sample with an increased learning rate.

2. Methods for processing non-stationary multivariate time series

The methods widely used now for processing essentially non-stationary multidimensional time series have a number of disadvantages, namely: the radial-basis neural network is subject to the curse of dimension [9], and the adaptive fuzzy inference system [10] has a cumbersome architecture and learns rather slowly due to the use of backpropagation algorithm. This leads to an increase in the number of neurons and the number of fuzzy rules in the knowledge base, which implies the need to increase the volume of the training sample for setting up such a system. Neuro-fuzzy systems that use the backpropagation algorithm for training are characterized by a low speed, which makes their application in sequential data processing ineffective [11]. These disadvantages can be avoided by using hybrid systems that combine both the theory of artificial neural networks, which allows obtaining universal approximating properties and the ability to learn, and the theory of fuzzy logic, which makes it possible to provide the system with linguistic interpretability [12]. There are studies of the architecture of neuro-fuzzy predictor [13] and architecture based on multidimensional neuro-fuzzy networks [14], but it should be noted that they are very cumbersome and not high speed of data processing.

The development of the principles of verification of forecasts is one of the problems, the solution of which would make it possible to increase the reliability and validity of forecasts, and, consequently, the scientific level of management of innovative processes. Verification of the forecast is practically possible only before the end of the forecast period. But already at the final stages of forecast development, relative (preliminary) verification is possible and desirable. Such verification consists in determining the degree of compliance of the forecast with the requirements of modern science, trends in the development of social life, as well as the degree of reliability of the forecast. In relatively simple cases, the role of verification is played by expert assessments. In more complex cases, special procedures are required:

- forecasting by an alternative method;
- analysis of the forecast adequacy in the retrospective period;

- analytical and logical research of forecasts;
- expert survey.

The methods of expert assessments and statistical forecasting are most widely used in forecasting practice. These methods are based on the use of accumulated statistical information on changes in the main indicators. However, the variety of forecasting and strategic planning methods used at different stages requires ensuring the compatibility of the results obtained with their help and the development of a single procedure. In unstable conditions, accurate forecasts of economic dynamics rarely come true, and at the same time, the need for long-term estimates of the future is growing.

3. Neuro-fuzzy architecture for forecasting regional development

There is a multidimensional non-linear non-stationary stochastic time series, which can be represented as a vector $a_i = (a_{i1}, \dots, a_{iN})$ of input data of an intelligent system for forecasting regional development. The task is to quickly predict multidimensional nonlinear nonstationary stochastic or chaotic time series under conditions of uncertainty and a short training sample based on a neuro-fuzzy network, which is based on a multidimensional neuron and an adaptive method for its training. This approach provides a high quality of approximation and extrapolation, as well as a high convergence rate due to membership functions of a special type and the use of a high-speed learning algorithm.

The result of the proposed neuro-fuzzy network is the forecast vector $a_{i+1} = (a_{i+1,1}, \dots, a_{i+1,N})$. As an objective function, it is proposed to use the mean square forecast error, which should be minimized.

A multidimensional signal a_i is applied to the input of the system. Delay elements are used for the membership function layer. Then the signal from them goes to the synaptic scales again through the layer of delay elements. The output of a nonlinear synapse of a neuron is formed by summing the output signals of synapses, which are represented by nonlinear functions. They approximate a non-linear input-output mapping with a single neuron.

It is proposed to use a triangular function as a membership function.

$$MF_{ij}(a_i) = \begin{cases} \dfrac{a_i - b_{i,j-1}}{b_{ij} - b_{i,j-1}}, \ a_i \in \left[b_{i,j-1}, b_{ij}\right] \\ \dfrac{b_{i,j+1} - a_i}{b_{i,j+1} - b_{ij}}, \ a_i \in \left[b_{ij}, b_{i,j+1}\right] \end{cases} \quad (1),$$

where b_{ij} - the parameters of the centers of the membership functions in the interval [0,1], where $0 \le a_i \le 1$. This choice of membership functions ensures that the input signal a_i activates only two adjacent functions, and their sum will always be equal to one.

Triangular membership functions provide a piecewise linear approximation that degrades the accuracy of the results. In order to minimize this effect, it is possible to increase the number of synaptic weights and, thus, significantly complicate the architecture and learning algorithm. It is proposed to use cubic splines for the membership function (1). The use of cubic splines provides a smooth polynomial approximation and provides high-precision simulation of non-stationary signals.

The architecture of a fuzzy neuron as a component of a multidimensional neuron of a computing system is redundant, since a vector of input signals a_i enters the same type of nonlinear synapses of fuzzy neurons, each neuron of which generates a signal at the output a_{i+1}.

As a result, the components of the output vector $a_{i+1,1}, \dots, a_{i+1,N}$ are calculated independently. This redundancy of the system can be avoided by using a multidimensional fuzzy neuron [15]. The structural elements of such a computing system are composed nonlinear synapses, and each synapse contains l membership functions in a nonlinear multidimensional synapse MF_{ij} and k tunable synaptic weights. w_{js} . Although a multidimensional fuzzy neuron has kN synaptic weights, but only lN membership functions. There are p times fewer membership functions (p is the number of system outputs), than if the system were formed from traditional fuzzy neurons.

The proposed neuro-fuzzy system consists of multidimensional neuro-fuzzy synapses. The output signal at the next moment in time can be written as:

$$a_{i+1} = W_{i+1} MF_{i+1}, \quad (2)$$

Training of a multidimensional fuzzy neuron is implemented using a matrix modification of Kalman filter under a special state-space model [16].

In order to assess the effectiveness of the proposed neuro-fuzzy network and its training procedure, a multidimensional series of socio-economic indicators of the innovative development of Russian regions were selected as a test sample. The initial synaptic weights were set at random.

The proposed neuro-fuzzy network and the procedure for its training have shown their effectiveness in solving the problems of forecasting regional innovative development, taking into account the constructed “if-then” decision rules. Fewer configurable parameters should be noted. The number of adjustable parameters is one and a half times less compared to the architecture based on multidimensional fuzzy neurons [17] and more than two times less when compared with the adaptive neuro-fuzzy predictor [18]. It should also be noted the smallest time among all systems, but the time does not differ significantly from the time shown by the architecture based on multivariate fuzzy neurons. The proposed network showed the best results among neuro-fuzzy networks (the advantage over existing models was 14%).

4. Conclusion

A predictive neuro-fuzzy network based on multidimensional fuzzy neurons is proposed and a training procedure for processing multidimensional data is introduced. Cubic splines are used as membership functions, which provide high accuracy of approximation and extrapolation in comparison with known neuro-fuzzy prediction systems. The introduced system can be used to predict substantially non-stationary time series in the context of a short training sample of regional development data. The practical value of the results obtained lies in the fact that this network can be used to solve a wide range of problems of making managerial decisions and, above all, forecasting. Prospects for further research are to apply some other membership functions and test other types of nodes for neural fuzzy networks.

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