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NEURAL NETWORK SUPPORT FOR AUTOMATION OF OBJECT CONTROL WITH MULTIFACTORIAL INPUT UNDER CONDITIONS OF UNCERTAINTY

Abstract. High dimension of the factors, their noisiness, subjectivity of the human factor breed high uncertainty in the implementation of effective monitoring and productive management in the areas of production and consumption, and hinder the optimal decisions making. In these conditions, it is appropriate to apply intelligent data analysis procedures based on artificial neural networks. Purpose of the study is to substantiate the technology for constructing of effective neural network models for automatic assessment of the object states and their control by finding the optimal values of input factors based on the analysis of the initial set of retrospective data. The desired product is set of neural network models for simultaneous assessment of the current object states and the calculation of the input factors values that ensure the achievement of the required objective function indicators. To automate the processes of recognizing the states of the study object and adapting the factors that bring the current state to the target one, a functional dependence of the states and factors is found based on forced learning of a synthesized models ensemble. The proposed technology and technical tools make it possible to automate the processes of classifying the states of the study objects, adapt the input factors to the target states, and evaluate the quality by model testing. The practical significance of the study results is in the creation of a universal toolkit for a whole class of objects in the tasks of automatic state classification and search for input factors space that is adequate to the target state space. Functionally, the ensemble of trained models can be implemented as a data analysis software unit in the format of two subsystems: for recognizing the states of the study object and adapting input factors to target states. Automation of the state classifying tasks and adapting the input set in the proposed technology that is performed on the basis of standard technical data analysis packages, makes it possible to increase the efficiency of decision-making and reduce financial costs in the implementation of industrial and commercial projects.

Keywords: automatic state classification, data analysis, input factor vector, neural network, objective function.

Introduction

Nowadays enterprises, organizations, and companies are objects that function, develop, and modernize, solving certain target tasks in a competitive environment, in conditions of lack of data or insufficiently reliable, distorted information.

In the decision making theory, these conditions are characterized by high entropy, the multidimensionality of the input factor vector, the impact of a noisy external environment that makes it difficult or, in some cases, prevents effective monitoring and management in the organization's life activity.

However, automation and digitalization of social spheres is a modern sustainable trend that requires search for the scientific and engineering solutions for the transition to a new technological level through the introduction of information technologies at all stages of the value chain of products and services. Main objective of this process is to increase the competitiveness and efficiency of the enterprise. Deep digitalization involves the introduction of new information technologies into production and management, promoting the development of promising direction in these technologies – neural network control under multifactorial input action in uncertainty [1, 2].

Task statement

High dimension of the factors, their noisiness, the subjectivity of the human factor breed high uncertainty in the implementation of effective monitoring and productive management in the areas of production and consumption, and hinder the optimal decisions making.

In these conditions, it is appropriate to apply intelligent data analysis procedures based on artificial neural networks [3–8]. This choice is due to the important pragmatic advantages of neural network technologies:

– neuromodels are learning systems that extract information about real states from retrospective data under conditions of hidden, incomplete and noisy parameters and implicit, fuzzy connections between them;

– their using is based on the neural network training to extract information from retrospective data, which ensures consistency and objectivity of the results.

However, a universal software base for automating of monitoring and management of the study object is not provided in open publications. For each subject area, it is necessary to synthesize its own models that take into account power of the sample of precedents, their information content, types of variable and their dimensions, cross-correlation, distribution and amplitude swing.

Therefore, in this situation the neuromodel synthesis is based on a creative approach in choosing the network type, its complexity, learning method, activation function, initial conditions, etc. The complex of these measures contributes to the creation of productive technological maintenance and software for the neuromodel syntheses that allow automating the monitoring of the state of the study object and control of this state to get the required parameters of the objective function [3,4].

Purpose of the study is to substantiate the technology for constructing of effective neural network models for automatic assessment of the object states and their control by finding the optimal values of input factors based on the analysis of the initial set of retrospective data. The desired product is neural network models for simultaneous assessment of the current object states and the calculation of the input factors values that ensure the achievement of the required objective function indicators.

Formulation of the problem

Let's consider a two-stage operation mode of the synthesized model: assessment of the current state of the study object and search for input factors values adequate to the desired target state of the object. Then the formal synthesis problem can be represented by the expression:

$$Sup\ K_E\ (S, P, X),\ \ \Re_u(\delta) \le B_0, \tag{1}$$

where P is set of predictions of possible states of an object; X is set of input factors; K_E is a decision efficiency criterion; $\Re_u(\delta)$ are expected losses from errors; B_0 are allowable losses (limitations).

Thus, based on expression (1), it is necessary to find an analytical form of the relationship between the states of the study object with the input factor vector and the efficiency criterion of the made decisions, and then apply the mathematical apparatus for analyzing this relationship in order to determine the set of adequate control factors from the input set.

Solving of the problem

First, let's solve the problem of the current state recognizing.

According to the condition of the problem, there is a set of input data, including a list of factors-features in this subject area W, where

$$W = \{\omega_g\},\ g \in \overline{I} = \{1, 2, ..., I_m\}$$

and fixed their belonging to the classes

$$\Omega_p, \Omega_g = \{1, 2, ..., J_i\}\ .$$

When an object for analysis arrives, the problem of assigning it to a particular class is solved with some errors. The grouping of objects, taking into account the analysis of the compactness of their features, can be formally represented by the expression

$$F = A(\omega, \{\omega_g\}), \tag{2}$$

where $A(\omega, \{\omega_g\})$ is a rule for assignment of the object state ω_g from state set ω to a class $\Omega_k:\ \omega_g \in \Omega_k$ on condition that

$$A(\omega, \{\omega_g\}) = max_i\ A(\omega, \{\omega_i\})$$

and $B \le B_0$.

In this case, objects should be grouped in the format

$$\Re_0\left(\omega_{pk}, \omega_{gi}\right) = \sum_{j=1}^{N}\left(x_{pk}^{(j)} - x_{gl}^{(j)}\right).$$

It is a metric of feature compactness in classes p, g at analysis of *k,l* objects of *j* type.

So, we have a generalized optimization problem of analyzing the current state of an object in the language of its features.

The second stage of synthesis is creation and application of the technology for adapting of input factors to the desired state of the study object. A similar problem has already been solved and the results are presented in the paper [4]. Let's use them by changing the input data, initial conditions and selected constraints, applying the well-known technology for a new purpose.

This procedure is reduced to searching for an approximating dependence "state - factors", and then to establishing the values of the factors corresponding to the function target value. Formally, it looks like this:

$$F: X(t) \to Y(t) \Leftrightarrow Y_0(t) \to F_0:\ Y_0(t) \to X_0(t), \tag{3}$$

where $Y_0(t)$ is target vector of the object state; $X_0(t)$ is vector of adapted input feature values; F_0 is productive functional of modifying of the current input factors array to the desired set, adequate to the target state.

The current state of the study object ($y(x)$) is analytically connected with the feature dictionary according to [2]:

$$y(x) = \alpha \sum_{i=1}^{H} v_i\ (w_{i1}x_1 + ... + w_{in}x_n + u_i), \tag{4}$$

where H is training sample power, α, v are neural network parameters, n is number of neurons, $w_{i1}, w_{i2}, ..., w_{in}$ are weight coefficients of neurons.

The functional diagram of the implementation of (3) and (4) illustrates all the necessary mathematical operations of the task (Fig. 1).

At the direct propagation of signals, the problem of estimating of the object states is solved, and at reverse propagation the required values of input factors are found that are adequate to the target state specified by the problem condition. The well-known technology [4] is implemented to calculate error (residual) functions:

$$E(X) = \frac{1}{2}\sum_{i=1}^{M}(y_i(x) - y_{iz})^2$$

and the desired values of the input factors based on the calculation of the partial derivatives of the error function gradient by the variables of the input set (X):

$$X^{t+1} = X^t - \eta_1 \cdot grad\ E(X^t).$$

As a modeling tool, Statistic Neural Network module of the data analysis technical package Statistika.

Mathematical operations implemented according to the functional diagram (fig. 1) are invariant to the subject area of the study object, which significantly expands the use of this technology in various fields. In support of this statement, we give two examples from economics and medicine.

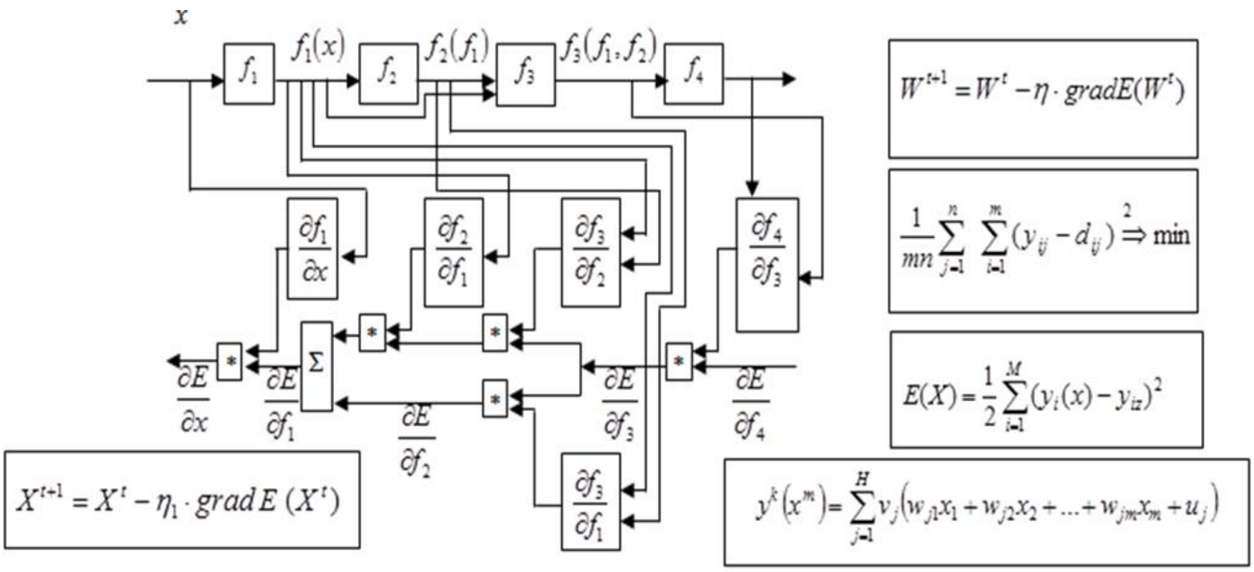


Fig. 1. Functional diagram of the implementation of synthesis of the recognition and adaptation model

In the first case, sixteen factors describe the enterprise state by classes: successful, bankrupt. In the second case ten factors describe the patient's condition by classes: healthy, unwell, sick. You can choose other subject areas.

It is only important to ensure multifactoriality, high uncertainty, noisiness, intersection of feature spaces, etc., that is, to fix a high degree of uncertainty.

The input data are presented in table 1 and table 2:

Table 1 – **Standardized input set data (example 1)**

	1 Пер1	2 Пер2	3 Пер3	4 Пер4	5 Пер5	6 Пер6	7 Пер7	8 Пер8	9 Пер9	10 Пер10	11 Пер11	12 Пер12	13 Пер13	14 Пер14	15 Пер15	16 Пер16	17 Пер17
1	0,8837	-0,5479	0,2919	0,6792	-0,4415	0,6136	1,9925	0,9094	4,0435	0,8837	-0,5479	0,2919	0,6792	-0,4415	0,6136	0,8837	1
2	0,5883	-1,0988	-0,6074	0,6520	-0,3159	1,4419	1,7502	0,0522	0,1502	0,5883	-1,0988	-0,6074	0,6520	-0,3159	1,4419	0,5883	2
3	-0,0352	2,3186	1,4300	0,5840	1,1915	-1,2156	0,4696	0,7104	1,5660	-0,0352	2,3186	1,4300	0,5840	1,1915	-1,2156	-0,0352	1
4	-0,2896	-0,5173	-0,2702	-0,8574	-0,0088	1,8561	1,0580	-0,4834	-0,4611	-0,2896	-0,5173	-0,2702	-0,8574	-0,0088	1,8561	-0,2896	2
5	0,7934	-0,4663	2,1606	-0,0415	0,6053	1,7871	2,6156	-0,3610	0,5203	0,7934	-0,4663	2,1606	-0,0415	0,6053	1,7871	0,7934	1
6	-1,0444	0,9925	0,8117	-0,2183	1,1915	2,7707	4,1039	1,2767	0,2307	-1,0444	0,9925	0,8117	-0,2183	1,1915	2,7707	-1,0444	2
7	0,4488	2,0024	0,0389	-0,3135	0,8844	0,6654	-0,7073	0,3124	2,3704	0,4488	2,0024	0,0389	-0,3135	0,8844	0,6654	0,4488	1
8	0,6621	-0,1399	-1,0149	0,5296	-0,1344	-0,1802	-0,4996	-0,5600	-0,6542	0,6621	-0,1399	-1,0149	0,5296	-0,1344	-0,1802	0,6621	2
9	-0,1911	-0,6499	-0,3685	1,6446	1,4427	-0,1630	-0,7592	0,2971	-0,5255	-0,1911	-0,6499	-0,3685	1,6446	1,4427	-0,1630	-0,1911	1
10	-0,0352	-1,0580	-0,7619	-0,0823	0,2145	-1,1811	-0,1188	-0,4988	0,4237	-0,0352	-1,0580	-0,7619	-0,0823	0,2145	-1,1811	-0,0352	2

Table 2 – **Standardized input set data (example 2)**

	1 Головний біль	2 Температура тіла	3 Біль у м'язах	4 Біль в животі	5 Сонливість	6 Локальні болі	7 Відсутність апетиту	8 Пульс	9 Чутливість рецепторів, %	10 Роздратованість	11 Здоров'я
1	0	36	0	0	1	1	0	65	100	1	1
2	1	37	1	0	1	1	1	70	95	0	3
3	0	36	0	0	0	0	0	69	60	1	1
4	0	37	1	1	0	1	1	85	78	1	3
5	0	38	1	1	1	1	1	89	69	1	3
6	1	39	1	0	0	1	1	95	75	0	3
7	1	35	0	1	1	0	0	66	98	0	3
8	1	36	0	0	0	1	0	68	100	1	2
9	0	36	0	0	1	1	1	76	87	1	2
10	1	40	1	0	1	1	1	105	72	0	3

The conducted experiments with the training of the synthesized models showed the results of modifying the weight coefficients acceptable for practice (Fig. 2, 3).

Fig. 4, 5 visualize the results of model training and confirm the stability of the error convergence process to the available minimum.

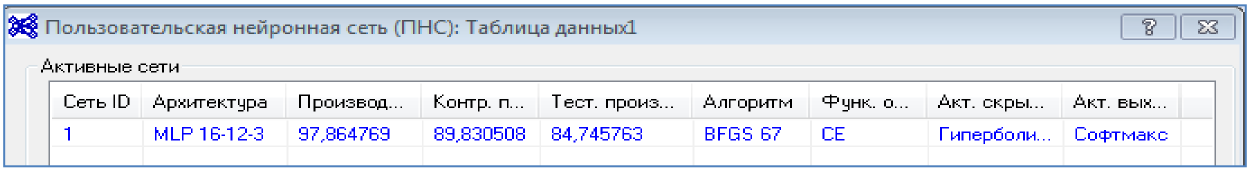
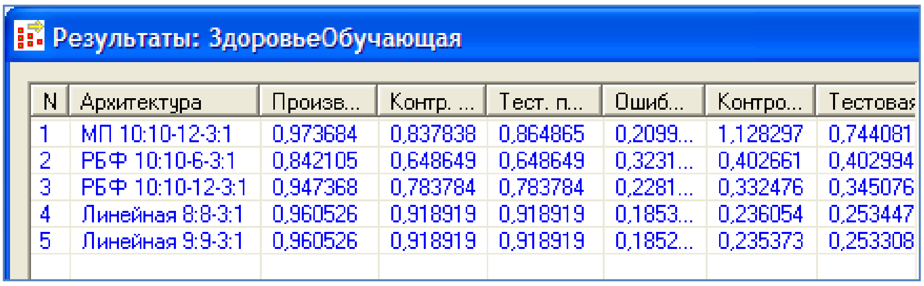


Fig. 2. Profile of the trained model (example 1)



Результаты: ЗдоровьеОбучающая

N	Архитектура	Произв...	Контр. ...	Тест. п...	Ошиб...	Контро...	Тестовая
1	МП 10:10-12-3:1	0,973684	0,837838	0,864865	0,2099...	1,128297	0,744081
2	РБФ 10:10-6-3:1	0,842105	0,648649	0,648649	0,3231...	0,402661	0,402994
3	РБФ 10:10-12-3:1	0,947368	0,783784	0,783784	0,2281...	0,332476	0,345076
4	Линейная 8:8-3:1	0,960526	0,918919	0,918919	0,1853...	0,236054	0,253447
5	Линейная 9:9-3:1	0,960526	0,918919	0,918919	0,1852...	0,235373	0,253308

Fig. 3. Profiles of the trained model ensemble (example 2)

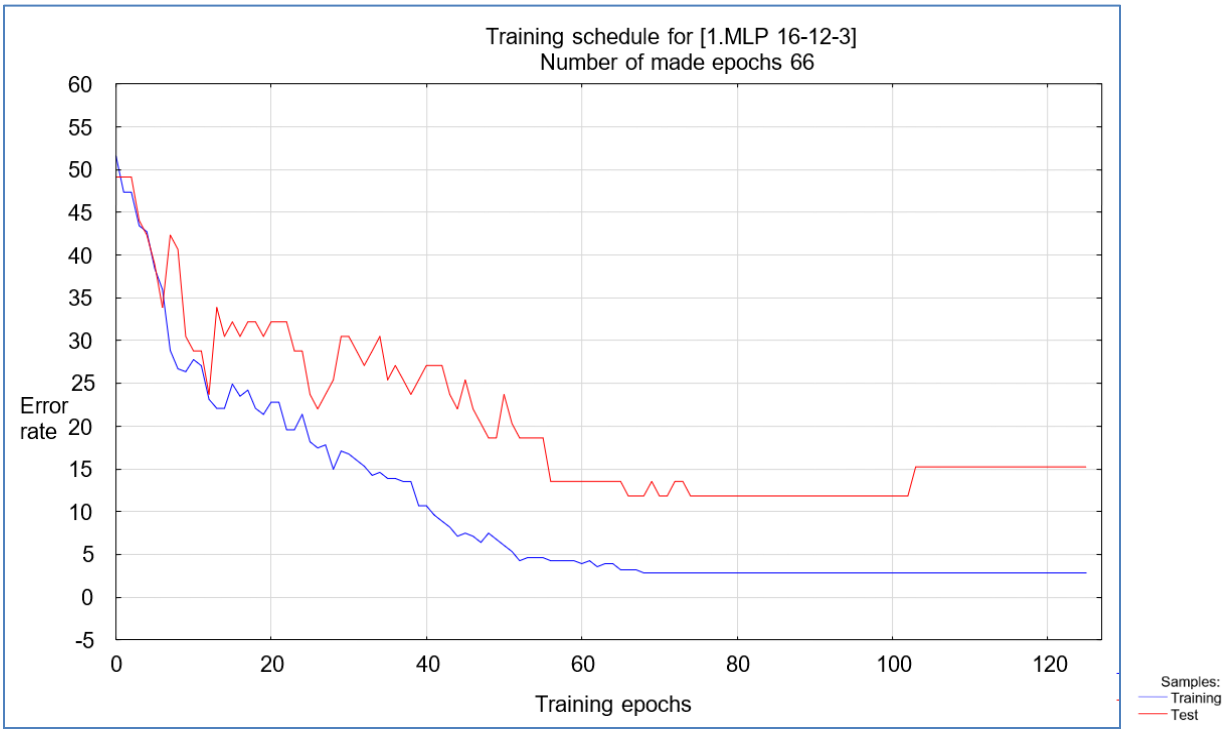


Fig. 4. Convergence of the learning process (for example 1)

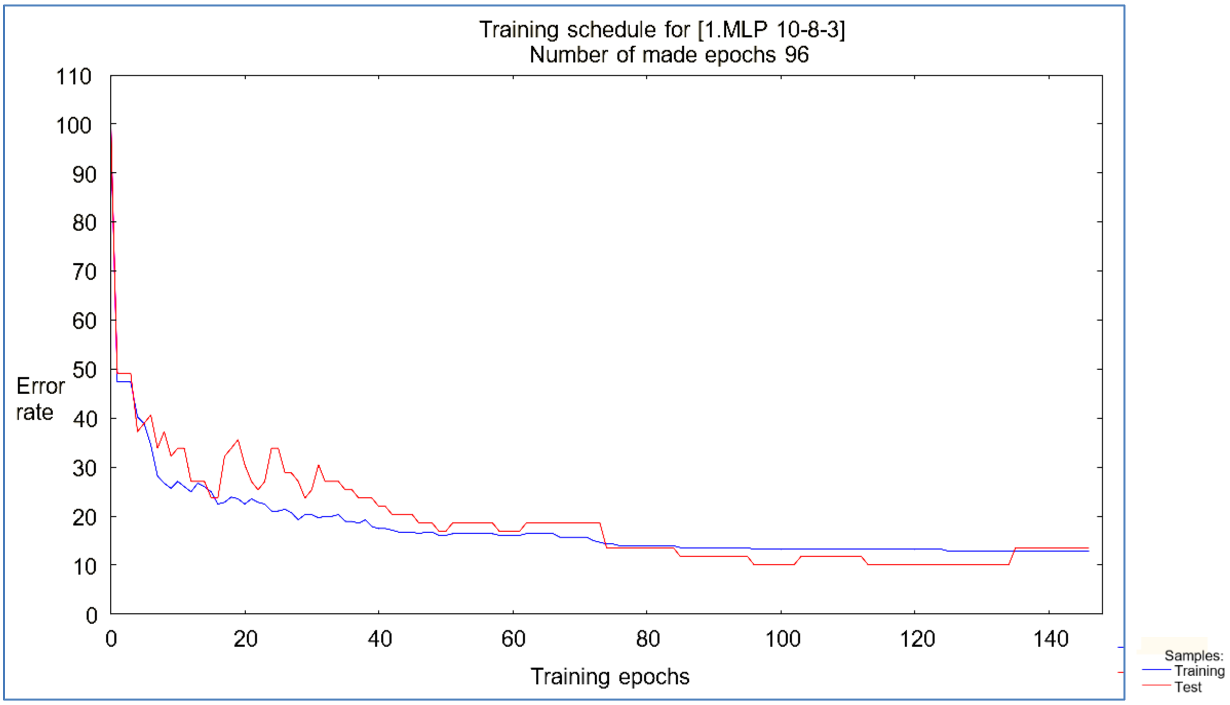


Fig. 5. Convergence of the learning process (for example 2)

The process of adaptation of input factors to the target object state is controlled by a standard neuroemulator procedure by implementing the options "User observations" - "User values".

In variety of the experiments, the adequacy of adaptation was confirmed.

Conclusions

1. To automate the processes of recognizing the states of the study object and adapt the factors that bring the current state to the target one, a functional dependence of the states and factors is found based on forced learning of a synthesized models ensemble.

2. The proposed technology and technical tools make it possible to automate the processes of classifying the study objects states, adapt the input factors to the target states, and evaluate the quality by model testing.

3. The practical significance of the study results is in the creation of a universal toolkit for a whole class of objects in the tasks of automatic state classification and search for input factors space that is adequate to the target state space.

4. Functionally, the ensemble of trained models can be implemented as a data analysis software unit in the format of two subsystems: for recognizing the study object states and adapting input factors to target states.

5. Automation of the state classifying tasks and adapting the input set in the proposed technology that is performed on the basis of standard technical data analysis packages, makes it possible to increase the efficiency of decision-making and reduce financial costs in the implementation of industrial and commercial projects.

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Нейромережне забезпечення автоматизації управління об’єктом при багатофакторному вхідному впливі в умовах невизначеності

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Анотація. Висока розмірність факторів, їх зашумленість, суб’єктивізм людського фактору породжують підвищений ступінь невизначеності у реалізації ефективного моніторингу та продуктивного менеджменту сфер виробництва та споживання, перешкоджають прийняттю оптимальних рішень. В цих умовах доцільно застосувати інтелектуальні процедури аналізу даних у базисі штучних нейронних мереж. Мета дослідження – обґрунтувати технологію побудови ефективних нейромережних моделей автоматичної оцінки станів об’єкта та керування ними шляхом знаходження оптимальних значень вхідних факторів на основі аналізу множини ретроспективних даних. Шуканим продуктом є нейромережні моделі одночасної оцінки поточних станів об’єкта та розрахунку значень вхідних факторів, що забезпечують досягнення необхідних показників елементів цільової функції. Для автоматизації процесів розпізнавання станів об’єкта аналізу та адаптації факторів, що приводять поточний стан до цільового, знайдено функціональну залежність станів та факторів на основі примусового навчання ансамблю синтезованих моделей. Запропонована технологія дозволяє автоматизувати процеси класифікації станів об’єкту дослідження, адаптацію вхідних факторів до цільових станів та оцінити якість тестування моделей. Практична значимість результатів дослідження полягає у створенні універсального інструментарію для цілого класу об’єктів у завданнях автоматичної класифікації їх станів та пошуку простору вхідних факторів, адекватних простору цільових станів. Функціонально ансамбль навчених моделей може бути реалізований як програмний блок аналізу даних у форматі двох підсистем: розпізнавання станів об’єкта дослідження та адаптації вхідних факторів до цільових станів. Автоматизація завдань класифікації станів та адаптації вхідної множини на основі запропонованої технології, що виконується на базі стандартних пакетів технічного аналізу даних, дозволяє підвищити ефективність прийняття рішень та знизити матеріальні витрати при реалізації виробничих та комерційних проектів.

Ключові слова: автоматична класифікація станів, аналіз даних, вектор вхідних факторів, нейронна мережа, цільова функція.