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FEATURES OF DIAGNOSTIC ARTIFICIAL NEURAL NETWORKS FOR HYBRID EXPERT SYSTEMS

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ОСОБЛИВОСТІ ДІАГНОСТИЧНИХ ШТУЧНИХ НЕЙРОННИХ МЕРЕЖ ДЛЯ ГІБРИДНИХ ЕКСПЕРТНИХ СИСТЕМ

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Abstract. *In the proposed article, various methods of constructing an artificial neural network as one of the components of a hybrid expert system for diagnosis were investigated. A review of foreign literature in recent years was conducted, where hybrid expert systems were considered as an integral part of complex technical systems in the field of security. The advantages and disadvantages of artificial neural networks are listed, and the main problems in creating hybrid expert systems for diagnostics are indicated, proving the relevance of further development of artificial neural networks for hybrid expert systems. The approaches to the analysis of natural language sentences, which are used for the work of hybrid expert systems with artificial neural networks, are considered. A bulletin board is shown, its structure and principle of operation are described. The structure of the bulletin board is divided into levels and sublevels. At sublevels, a confidence factor is applied. The dependence of the values of the confidence factor on the fulfillment of a particular condition is shown. The links between the levels and sublevels of the bulletin board are also described. As an artificial neural network architecture, the «key-threshold» model is used, the rule of neuron operation is shown. In addition, an artificial neural network has the property of training, based on the application of the penalty property, which is able to calculate depending on the accident situation. The behavior of a complex technical system, as well as its faulty states, are modeled using a model that describes the structure and behavior of a given system. To optimize the data of a complex technical system, an evolutionary algorithm is used to minimize the objective function. Solutions to the optimization problem consist of Pareto solution vectors. Optimization and training tasks are solved by using the Hopfield network. In general, a hybrid expert system is described using semantic networks, which consist of vertices and edges. The reference model of a complex technical system is stored in the knowledge base and updated during the acquisition of new knowledge. In an emergency, or about its premise, with the help of neural networks, a search is made for the cause and the control action necessary to eliminate the accident. The considered approaches, interacting with each other, can improve the operation of diagnostic artificial neural networks in the case of emergency management, showing more accurate data in a short time. In addition, the use of such a network for analyzing the state of health, as well as forecasting based on diagnostic data using the example of a complex technical system, is presented.*

Keywords*: artificial neural network, hybrid expert system, diagnostics, emergency management, complex technical systems.*

Анотація. *У запропонованій статті були досліджено різні методи побудови штучної нейронної мережі в якості однієї зі складових частин гібридної експертної системи для діагностики. Був проведений огляд зарубіжної літератури останніх років, де розглядалися гібридні експертні системи, як складова частина складних технічних систем в області безпеки. Перераховано переваги і недоліки штучних нейронних мереж, а також вказані головні проблеми при створенні гібридних експертних систем для діагностики, доводячи цим актуальність подальшої розробки штучних нейронних мереж для гібридних експертних систем. Розглянуто підходи аналізу пропозиції природної мови, який застосовується для роботи гібридних експертних систем з штучними нейронними мережами. Показана дошка оголошень, описана її структура і принцип роботи.*

Структура дошки оголошень ділиться на рівні і підрівні. На підрівнях застосовується коефіцієнт достовірності. Показана залежність значень коефіцієнта достовірності на виконання тієї чи іншої умови. Також описані зв'язки між рівнями і підрівнями дошки оголошень. В якості архітектури штучної нейронної мережі застосована модель «ключ-поріг», показано правило роботи нейрона. Крім цього штучна нейронна мережа має властивість навчання, заснованого на застосуванні властивості штрафу, який здатний розраховуватися в залежності від аварійності ситуації. Поведінка складної технічної системи, а також її несправні стани моделюються за допомогою моделі, яка описує структуру і поведінку даної системи. Щоб оптимізувати дані складної технічної системи, використовується еволюційний алгоритм, за допомогою якого мінімізували цільову функцію. Рішення задачі оптимізації складаються з Парето-векторів рішень. Завдання оптимізації та навчання вирішуються шляхом використання мережі Хопфілда. В цілому гібридна експертна система описується за допомогою семантичних мереж, які складаються з вершин і ребер. Еталонну модель складної технічної системи зберігають в базі знань і уточнюють під час придбання нових знань. При аварійній ситуації, або при її передумові, за допомогою нейронних мереж відбувається пошук причини і самого керувального впливу, необхідних для ліквідації аварії. Розглянуті підходи, взаємодіючи між собою, здатні поліпшити роботу діагностичних штучних нейронних мереж в разі протиаварійного керування, показуючи більш точні дані за короткий термін. Крім цього, представлено застосування подібної мережі для аналізу стану працездатності, а також прогнозування на основі даних діагностики на прикладі наведеної складної технічної системи.

Ключові слова*: штучна нейронна мережа, гібридна експертна система, діагностика, протиаварійне керування, складна технічна система.*

INTRODUCTION

Hybrid expert systems (HES) are very important in ensuring safe operation for any complex technical systems (CTS) [1–5]. In [1] HES are used as decision support systems to reduce the risks associated with pumping stations. For this HES combines procedural and declarative rules, based on the judgment of experts, as well as encoded in the integrated production C (CLIPS) language system and is associated with the software MATLAB software to display the fuzzy functions. In [2] the prospects and trends of expert systems, which were presented at the World Congress of 3 expert systems. In [3] conducted a statistical analysis of HES and their applications. This analysis includes 91 articles from scientific journals, conference papers and literature reviews. The results show an increase in the number of recent publications, testifying to the popularity of the conquest of HES, as well as the development of many new industrial applications that use HES in recent years. In [4] examined trends in the development and applications of expert systems, including hybrid in medical diagnostics. The data are presented on the basis of links 173 articles from 124 journals over the past 25 years. In [5] proposed a new expert system for monitoring the performance of enterprise content management. It is based on an innovative hybrid technology, including the fuzzy cognitive maps and analytic hierarchy process. Because these indicators are interrelated, expert knowledge is extracted, modeled, are combined and processed in the proposed new HES. This makes it possible to accurately predict the impact of changes in the benchmark system performance by simulating different scenarios over time.

A common type of HES is a system, one of the constituent components of which are artificial neural networks (ANN) [6-9]. ANN is based on a mathematical model that reproduces the nervous system of a living organism. The properties of study and generalization of the ANN allow them to achieve the most reliable diagnostic results. In the context of the changing external environment, as well as emergency management, the ability of ANN to learn is a great advantage [10-12]. To train the ANN needs no a priori information about the structure of the required functional dependence [11]. Thanks to the training mode it is possible to quickly adjust to the changing reality of the network, at the moment, as the calculation of the weighting factors expert, additional costs time professionals. Another advantage of using the ANN relatively formalized expert by the dependent variable, is more accurate approximation of an expert opinion [13]. Also, another advantage of ANN is a generalization of the property allows the network after training and testing to give correct answers to the various inputs, which are not data of the training set [10].

However, despite the above advantages, the ANN have disadvantages that can in various cases, affect the accuracy of the results of the HES, in particular, the need to involve the training sample, the reliability and the dimensions of which have a great impact on the learning outcomes and, consequently, on the diagnostic quality technical state CTS [10]. Another disadvantage is the fact that the accumulated knowledge of the INS distributed between all of its elements, which makes them virtually inaccessible to the observer. [12].

When creating a HES following issues can occur for the diagnostics in some cases [14]:

– not taken into account the high level of uncertainty of diagnostic information that is obtained;

– there are no effective methods of integrating knowledge derived from diverse sources;

– existing knowledge acquisition methods usually have low adaptability and does not involve the use of feedback mechanisms to establish new dependencies and adjustment rules in the knowledge base (KB).

Thus, despite the widespread prevalence, as well as to eliminate deficiencies, the development of ANN for HES is an actual task.

PURPOSE OF ARTICLES AND STATEMENT OF THE PROBLEM RESEARCH

The purpose of this work is to ensure the emergency operation of the CTS, with the most effective diagnosis.

To achieve this purpose, it is necessary to develop and investigate the diagnostic ANN, which will be an integral part of the HES necessary for emergency management of the CTS.

MAIN PART

HES work with the ANN is based on the use of natural language. There are two approaches offers the analysis of natural language:

– syntactically oriented – on the basis of a detailed parsing of the proposal;

– semantically-oriented – the task of analyzing sentences of a natural language is presented as a problem of recognizing the meaning of the sentence on the basis of the use of the KB.

Syntactically oriented analysis of natural language has significant drawbacks that limit its application. more promising – semantically oriented analysis.

For the structuring of facts and hypotheses used ANN bulletin board. It is divided into levels, which correspond to the levels of the hierarchy of domain objects.

Levels is divided into sublevels (see Figure 1): object name, attribute name and name of value.

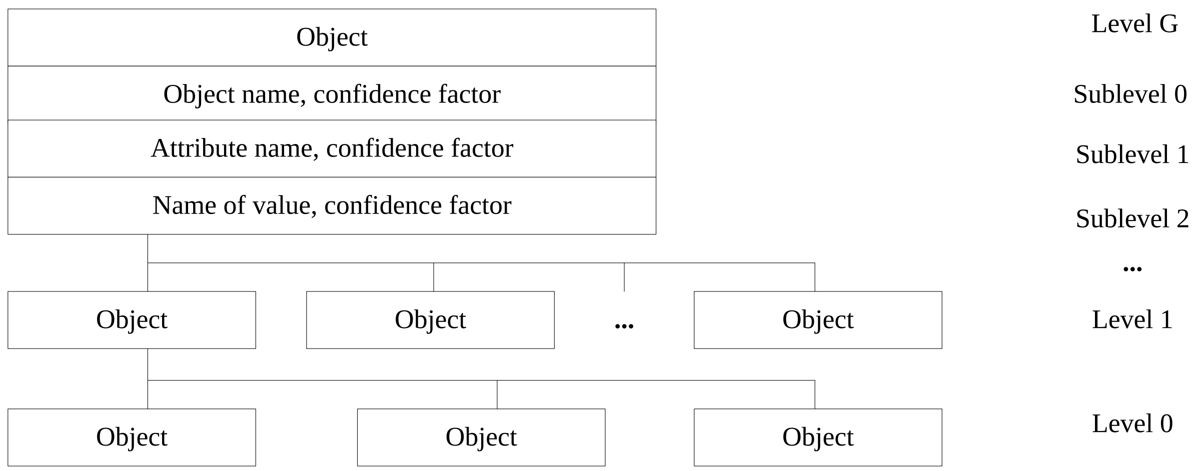

Figure 1 – The level scheme for the bulletin board

On sublevels term data is encoded and confidence factor K. K is a number from 0 to 100 which indicates the percentage of the probability of a particular event. Used in custody at the time of the formation of the frame slot value, as well as creating a rule. Below the threshold, the reliability of the facts ignored. In custody K has a default value of 100, and a condition – the value 0. They are translated into the range from 0 to 1.

K in a set of conditions defined as K conjunctions of fuzzy logic L. Zadeh, i.e. as the minimum value of a set of reliability values of the coefficients of all the conditions. K for instance frame-slot, which is formed on the basis of the findings, the product is K set conditions and K conclusion. In the case where a similar slot in a frame-copy is, the value of K will be located:

$$N = I + P \cdot (1 - I),$$

where N – the new value of the coefficient of reliability K; I – confidence factor K starting fact; P – confidence factor K, created with the rules.

If a K smaller than the threshold in the condition, the condition is not met.

The numbers of the level and sublevel are interconnected, and constitute a context showing the connection of an event with this level and its specific sublevels, where the processes of logical inference in a HES and subsequent associative processing in the ANN take place.

In the current separately taken sublevel name codes and describe the context – are inputs ANN. ANN output – the name of the code, which has such interpretations, depending on the ANN mode: code name of the current sublevel, at a lower sublevel and a higher sublevel.

2 sublevel has a lower sublevel and sublevel 0 to a higher sublevel considered 0 sublevel next level in the hierarchy. As the architecture of the ANN model will use «key-threshold». In this model, the ANN recognizes the binary vector using the Hamming distance. Neuron is working according to the rule:

$$n_i = \begin{cases} 1 \text{ if } & f(b,l) > z_i; \\ 0 & \text{otherwise,} \end{cases}$$

where $l = (l_{ij}),\ i = \overline{1,T},\ j = \overline{1,M}$ – vector key i-th neuron; $b = (b_{ij}),\ i = \overline{1,T},\ j = \overline{1,M}$ – input vector i-th neuron; $f(b,l)$ – function showing an equal level in the vectors b and l.

The network is trained. This occurs due to the fact that each neuron has an input ω, at which the signal has a fine property by changing the threshold of the neuron z or key l [15].

The concept of «fine» or «weight» of a rule, which is the technical equivalent of value, is introduced for each emergency combination of variables [16]. The fine of the CTS technical unit, at the same time, is equal to the penalty of own disconnection, as well as the fine of daughter outages.

$$E_{\Sigma} = E_{\text{own}} + E_{\text{daughter}},$$

where E_{Σ} – fine technical unit; E_{own} – a penalty of their own disconnection; E_{daughter} – fine child outages.

The behavior of the CTS and its faulty states are modeled using a model that describes the structure and behavior of the CTS. This model represents a three values $\langle P, R, O \rangle$, where P – a set of variables that describe the state of the system; R – modes of operation; O – relationships that bind a set of variables P, and describe the state of the system and operating modes R.

To optimize data CTS used an evolutionary algorithm for minimizing the objective function: power consumption and performance of CTS.

The set of solutions of the optimization problem consists of a Pareto-vector solutions. They cannot be improved at the same condition without degrading the other. Mathematical model of optimization for specific effective energy consumption is as follows:

$$\begin{cases} g_V(x) + \dfrac{1}{f_E(x)} - \text{max} - \text{objective function;} \\ E_1 \le f_E(x) \le E_2 - \text{the first boundary condition;} \\ g_V(x) \ge V_1 - \text{the second boundary condition;} \\ f_E(x) \cdot g_V(x) = E_1 \cdot V_1 - \text{limitation,} \end{cases}$$

where $f_E(x)$ – CTS function of energy consumption; $g_V(x)$ – CTS function of speed; E_1, E_2 – boundary values of energy consumption functions; V_1 – boundary values of speed functions.

In the model of 4 components: the objective function, the boundary conditions and limitation.

The boundary conditions indicate the limits of allowable values of target functions: energy consumption and CTC performance. The product of the limiting values for the target features shows limitation [17].

To solve the problem of optimizing the use and learning of the Hopfield network. In this case, an artificial ANN is trained by analyzing relational KB. As a result, the ANN becomes an epistemological model of learning knowledge base, and is used for the prediction and research, hidden in the KB, associative links.

The ANN Hopfield neurons in state –1 to 1, and also with the threshold 0, the similarity measure of the two truth vectors displayed:

$$\eta_{12} = \sum_i \operatorname{sgn}(b_{1i}, b_{2i}) \sum_j v_{ij} \Big/ \sum_j v_{ij} \ ,$$

where b_{1i} and b_{2i} – i-th bit vectors b_1 and b_2 respectively; function $\operatorname{sgn}(x)$ takes the value 1 if $x \ge 0$, and zero – otherwise; v_{ij} – weight between i -th and j -th neurons.

During the operation of the network Hopfield energy function is minimized:

$$E = -\frac{1}{2} \sum_{i=1}^{M} \sum_{j=2}^{M} v_{ij} s_i s_j \ ,$$

where s_i, s_j – the state of neurons i and j.

HES is described by semantic networks (see Figure 2), consisting of the vertices (concepts) and ribs (semantic relations). There are two types of concepts: the terminal T and the abstract A. Terminal concept – a word or phrase in natural language, and operators BAYAR language. Abstract concept – the concept of class. Two types of semantic relations: entry and equivalence.

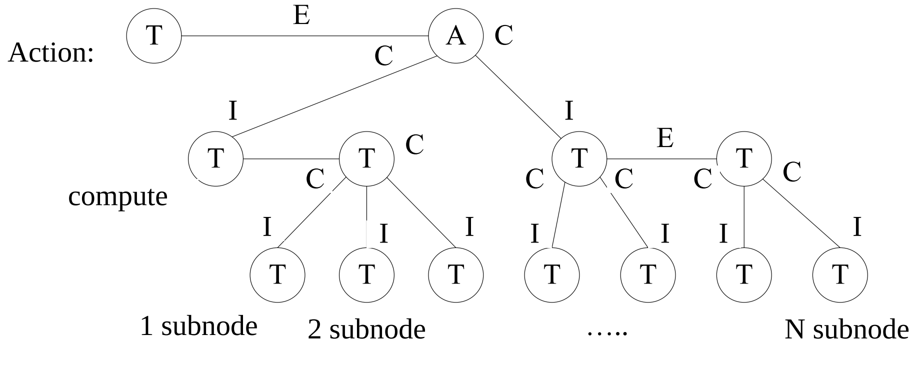

Figure 2 – An example of a semantic network

The semantic relations of occurrence in a concept reflect the composition of concepts of types, are not symmetrical and consist of such semantic relationships as occurrence in concept I and occurrence in C. The semantic relations of equivalence E reflect in the KB correspondences between concepts, they are symmetric [15].

The diagnostics of HES Reference Model CTS stored in the KB, and clarified the acquisition of new knowledge. The KB formed a real model, and a user requests communication takes place with the reference model. Building CTS state diagnosing system based on HES is carried out taking into account the characteristics of the external environment and adapt the specifics of HES models this environment (Table 1).

Table 1 – Knowledge Base HES

Emergency situation	The values of variables				Actions to address emergency	Spent time	Cost
	x_1	x_2	...	x_m			
a_1	H	A	...	L	D_1	T_1	C_1
a_2	L	H	...	A	D_2	T_2	C_2
...	...	...	...	...	...	...	...
a_n	H	L	...	A	D_n	T_n	C_n

In Table 1. H – the value of «high», A – the value of «average», L – the value «low», m – the number of variables, n – the number of emergency situations.

In the case where the diagnostics of CTS behavior speaks of an emergency, or about her background, using ANN is a search of the causes and control actions to eliminate the emergency. [18]. Figure 3 shows the structure of the HES decision support used the decision-maker.

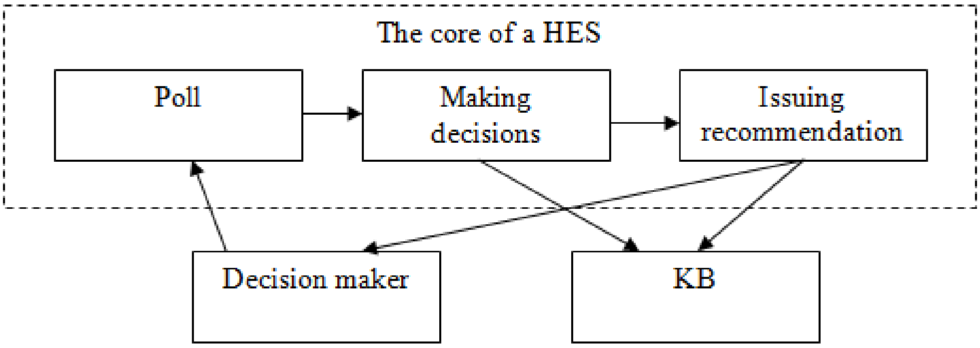

Figure 3 – HES Structure Decision Support

RESULTS

For example, use of ANNs in HES take CTS consisting of 4 technical units. Compose using Fuzzy Logic Toolbox ANN such CTS packet and simulate signals in an environment Matlab Simulink (see Figure 4) and (see Figure 5).

Signals $w_1, w_2, w_3, w_4,$ – this performance technical units. Operability CTS shown in block Display (W). For example, have been taken the data obtained as a result of expert assessments: $w_1 - 72, w_2 - 61, w_1 - 83, w_1 - 70.$ As a result, performance of CTS was 88.96.

Also check the possibility of using the work of HES forecasting technical condition CTS conditioning on the basis of its performance diagnostic data obtained via the editor Anfis [19].

In Table 2 and Table 3 presents data on operability CTS, which was taken for training and testing of the ANN.

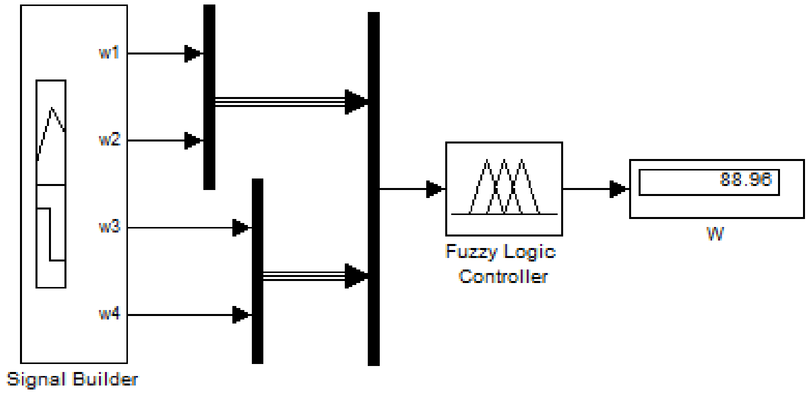

Figure 4 – Scheme in Matlab Simulink environment

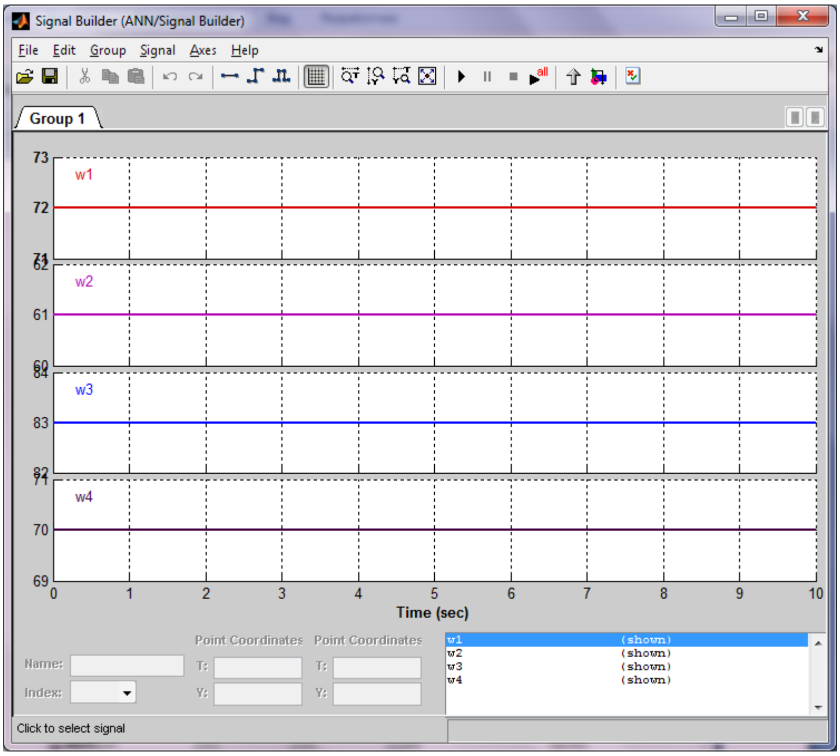

Figure 5 – Block Signal Builder

The results of the training and testing of ANN are shown in Figures 6 and 7, respectively. The result of the forecast makes it clear that for given values of working capacity, the technical condition of the CTS remains at a high level, even with a slight increase. Standard error of the data in this case is 2,1286, which is not sufficiently acceptable the result, but at the same time, gives the concept of efficient production of ANN sufficient HES in the diagnostics and subsequent prediction of technical condition of CTS.

CONCLUSION

As a result of the work, the ANN was investigated and compiled as an integral part of the HES, the main task of which is to ensure emergency management of the CTS. In the development of ANN have been taken into account the various features associated with the operation of such systems, to further obtain more reliable results of the CTS. They were simulated signals in the environment Matlab Simulink, for example ANN calculates performance CTS. Overall performance presented CTS eventually amounted to 88,96, indicating a high precision. In predicting the technical state the CTS based on the diagnostic data, ANN of the HES showed high values of efficiency. The value of mean square error performance technical condition is 2,1286, indicating a sufficiently high precision.

Table 2 – Data CTS operability for training ANN

90.5900	90.5567	90.2650	90.1550	90.1311
90.4546	90.6761	90.1934	90.3451	90.3935
90.5791	90.0975	90.0000	90.3557	90.4938
90.8941	90.0974	90.2234	90.2357	90.3019
90.5779	90.3411	90.8994	90.7894	90.1592
90.8100	90.7221	90.3411	90.0050	90.4923
90.3467	90.5742	90.7802	90.1255	90.1190
90.1234	90.5850	90.0001	90.3456	90.3209
90.0742	90.1111	90.0015	90.4567	90.3920
90.4568	90.4561	90.2346	90.4564	90.4920
90.6754	90.2233	90.6891	90.4567	90.3020
90.4662	90.5012	90.0993	90.5821	90.3920
90.3333	90.3851	90.1655	90.9363	90.4940
90.5671	90.2594	90.2356	90.2842	90.1111
90.6780	90.3302	90.1567	90.2940	90.4443
90.8899	90.0544	90.8765	90.5481	90.5553
90.1265	90.3821	90.7854	90.3018	90.6789

Table 3 – Data CTS operability for testing ANN

90.4211	90.0000	90.3431	90.3419	90.5912
90.3333	90.5545	90.3490	90.0970	90.5653
90.9899	90.5624	90.1000	90.8739	90.9000
90.5612	90.4567	90.0002	90.6342	90.1543
90.5690	90.5632	90.4221	90.4156	90.4333

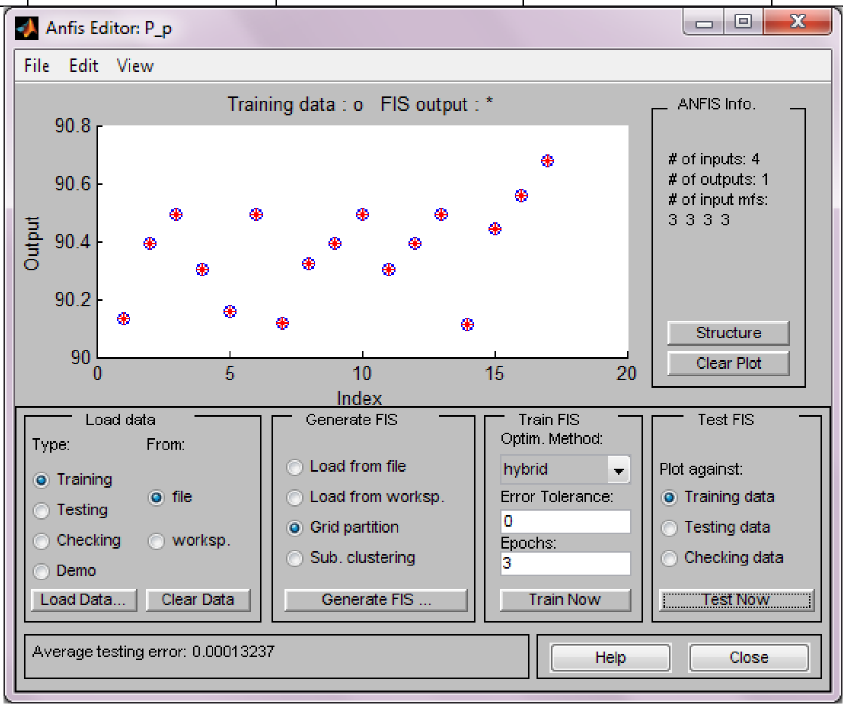

Figure 6 – The results of ANN training

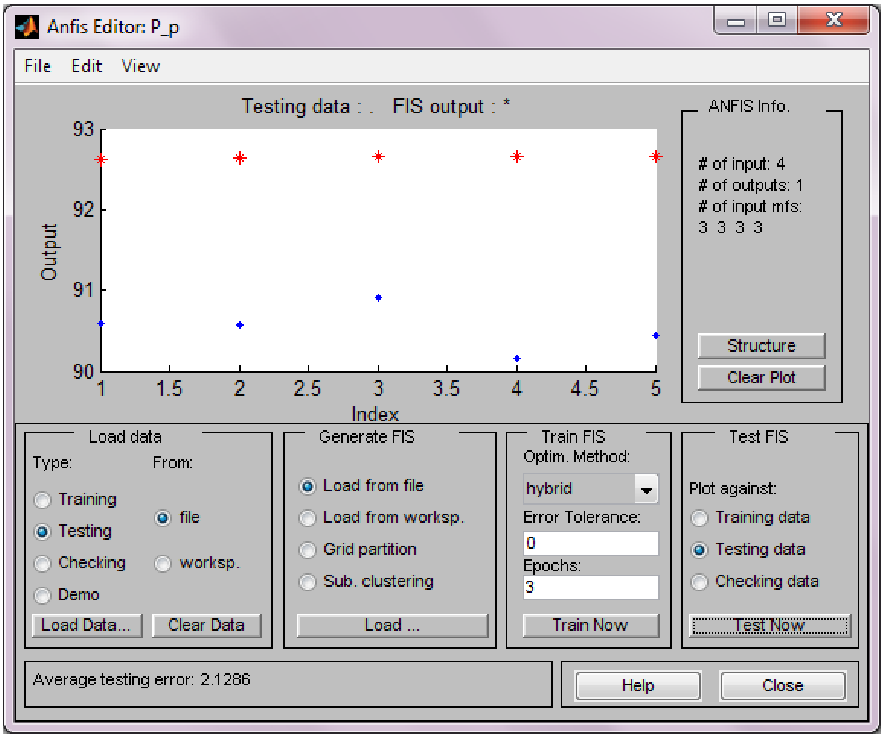

Figure 7 – ANN test results

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