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An algorithm for the diagnosis of reparable technical objects utilising artificial neural network

Keywords

Diagnostics of technical objects, neural networks, expert systems, knowledge base.

Słowa kluczowe

Diagnostyka techniczna, sieci neuronowe, systemy ekspertowe, bazy wiedzy.

Summary

This paper presents the diagnostic system utilising artificial neural network ANN for the purpose of the recognition of states in reparable technical objects. The initial diagnostic information is processed by the ANN together with the use of image recognition theory. A general scheme describing the inner structure of the object was developed. Diagnostic analysis was performed and the set of diagnostic signals was determined as an effect. The results presented in the table of states.

1. Introduction

The state of a technical object changes during the exploitation from the nominal, designed state. In effect, the usability features decrease in time, which usually decreases the functionality and/or the quality of the object.

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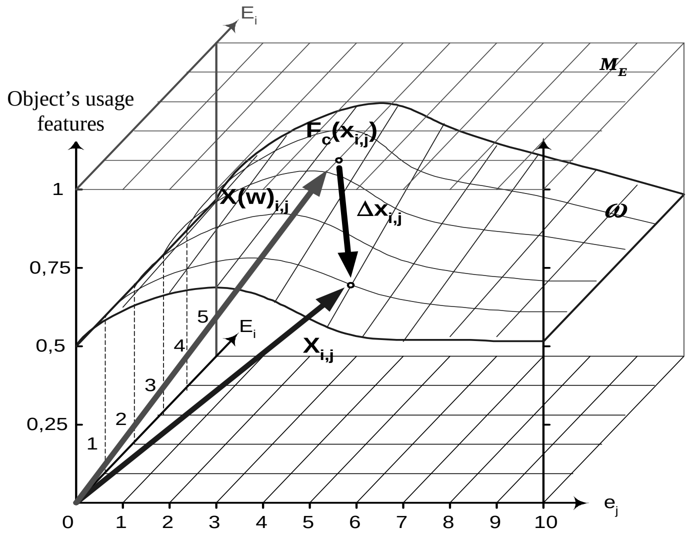
Among the set of indexes characterising the process of usage presented in literature [1, 4, 9], the two that reflect the object's usability features most are the usage quality function ($F_C(t)$) and usage quality ratio (F_C). The second one is derived from the boundary value of usage quality function ($F_C(t)$) for $t \rightarrow \infty$. The index of usage-quality-function attribute may be the assessment of the state of the object, thus it can be considered as the metric. The state of the object is determined by the subset of its physical properties that are significant in regard to the tasks of the object. During the use of object, the values of elementary functions presented in Fig.1 are conditioned by the difference between the present state of the object described by the vector of the actual property of the usage function ($\omega(e_{i,j})$) and the nominal vector ($F_c(e_{i,j})$). Therefore, the problem of the state recognition of the object occurs and becomes highly important. The recognition of object's state is identified with the deriving of the actual attribute of usage function vectors [$\omega(e_{i,j})$]. The set of vectors {$\omega(e_{i,j})$} achieved during diagnosing the object determines the surface of current object's usage features ($\omega(e_{i,j})$) (Fig. 1). For practical reasons, followed by [1, 2, 3, 4], the terms of the state of the object can be assigned to the metrics of these vectors [$\omega(e_{i,j})$].



where: ω – the surface of actual usability features of the object; M_E – the surface of the nominal usability features of the object; $F_c(X_{i,j})$ – the value of usage function; $X_{i,j}$ – vector of actual diagnostic signal; $X_{(w)i,j}$ – standard vector of diagnostic signal; $\Delta X_{i,j}$ – vector of differential metric of diagnostic signal

gdzie: ω – płaszczyzna rzeczywistych cech użytkowania obiektu; M_E – płaszczyzna nominalnych cech użytkowania obiektu; $F_c(X_{i,j})$ – wartość funkcji użytkowej; $X_{i,j}$ – wektor rzeczywistego sygnału diagnostycznego; $X_{(w)i,j}$ – wektor wzorcowego sygnału diagnostycznego; $\Delta X_{i,j}$ – wektor różnicowej metryki sygnału diagnostycznego

Fig. 1. The distribution of the changes of the object's states during operating time (example)
Rys. 1. Mapa przestrzenna zmiany stanów obiektu w czasie użytkowania (przykład)

The issues of the state recognition of the object are under constant consideration. One of the directions for the development of effective methods for diagnosing technical objects is the use of artificial neural networks. In this approach, the functional analysis of the object is a fundamental to further steps (Fig. 2). The functional analysis results in the determination of the set of diagnostic signals [4], which can be used directly for the preparation of the diagnostic information set.

For the purpose of the paper, the initial set of diagnostic information was prepared in the form of a diagnostic signal matrix (Tab. 1) and the matrix of their standards $\{X_{(w)i,j}\}$.

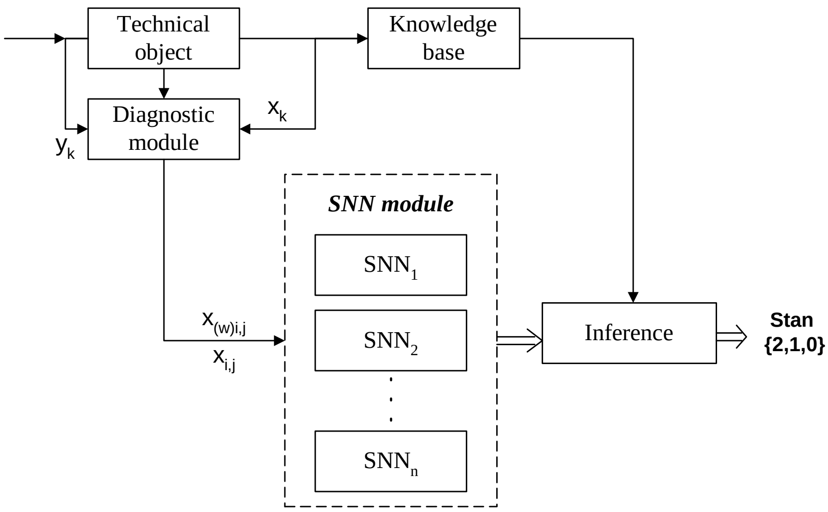


Fig. 2. The scheme of the diagnostic system utilising artificial neural network
Rys. 2. Schemat sygnału diagnostycznego

Table 1. Table of the initial diagnostic signals of the object
Tabela 1. Tablica wyjściowych sygnałów diagnostycznych

Object	Level of object E_i	Vector of initial diagnostic signals $\{X(e_{i,j})\}$				
		$X(e_{1,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
O	E_1	$X(e_{1,1})$	...	$X(e_{1,j})$	...	$X(e_{1,J})$
	⋮	⋮	...	⋮	...	⋮
	E_i	$X(e_{i,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
	⋮	⋮	...	⋮	...	⋮
	E_I	$X(e_{I,1})$	...	$X(e_{I,j})$	...	$X(e_{I,J})$

where: $X(e_{i,j})$ – diagnostic signal from the “j”- element in the “i”- module.

gdzie: $X(e_{i,j})$ – sygnał diagnostyczny j-tego elementu w i-tym zespole.

For the investigation presented in this paper, the artificial neural network (ANN) of self-organising type (Fig. 2) [8, 12,13] was used. In self-organising ANN, the learning process is not controlled so it is called “learning without a teacher.” Input signals to ANN are initially processed by a diagnostic modules (Fig. 2) on a basis of data transformation. The purpose is to maximise the extraction ability of the cell adaptive model, which should to lead to the maximum generalisation of the ANN. Other measures can not be replaced with data transformations of any kind before learning, but they can be adopted and changed afterward. The measures of information used in the process of data transformation can be both uniform and non-uniform.

It was assumed that the measures of the vector of length are uniform, and they are represented by the measures of similarity between the vector of the input signal and its standard. For the sake of the diagnosis process, it is extremely important to have the values of input diagnostic signals precise, accurate and reliable.

The values of the measures of the diagnostic signal’s properties do not always fit the normal distribution. Sometimes, a exponential distribution of data or even a logarithmic distribution may be observed along some dimension. For the problems of state classification, the most commonly used methods of diagnosis [1, 2, 5, 6] operate upon the assumption of similar or identical data distribution along particular dimensions of the input signal space.

2. The algorithm and structure of artificial neural network (ANN)

The developed ANN network is presented in Fig. 3. It consists of two layers: F_1 – input layer, F_2 – output layer. The input cells of layer F_1 process the initial diagnostic information accordingly to the algorithm depicted in Fig. 4.

All of the information processing neuron of ANN (Fig. 4) takes place in D-dimension diagnostic space (ω) (Fig. 1), determined by the elementary signal vectors (X_i). The input signal in the form of $X_i = [x_1, x_2, ..., x_n]^T$ is passed to all neurons of ANN’s input layer.

The input cells memorise the vectors of signal standards $\{X_i\}$. Then the neurons from the input layer determine the measures of similarity between the vector of the input signal and the vector of input signal standard and the length of input signal vector $\{X_i\}$ to all vectors of weights $w_{i,j} = [w_1, w_2, ..., w_n]^T$, with i =1,…,N.

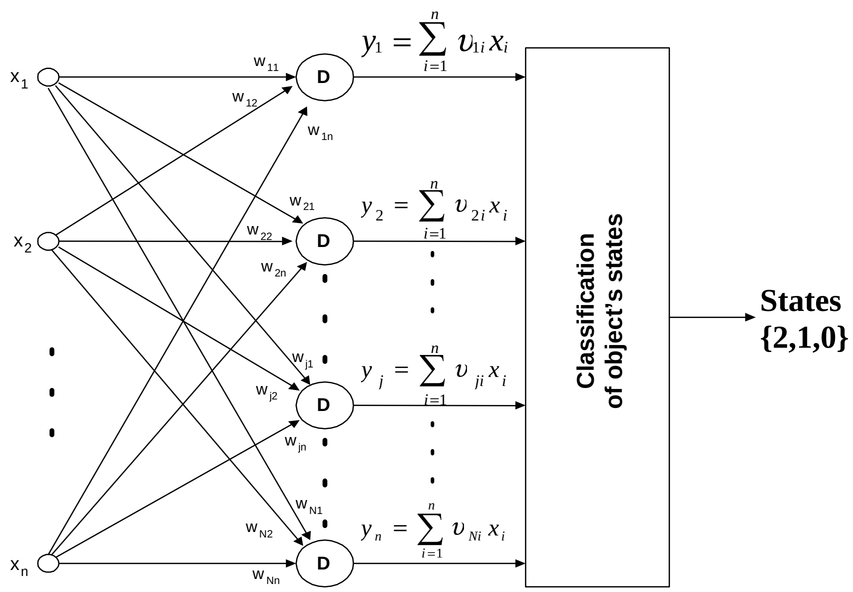


Fig. 3. Scheme of neural networks
Rys. 3. Struktura sztucznej sieci neuronowych

In the ANN network presented in Fig. 3, the neuron (i), placed in the layer $F_{1,}$ is connected to the neuron (j), placed in the layer F_2, where: j = 1,2,…N. Neuron (i) sends the signal of value (x_i) with the strength ($w_{i,j}$) of the activation function. Following the literature of the subject [5, 8, 10,11, 13], Minkowski's measure was used for the analysis of the measures of signal vectors. Minkowski's measure can be expressed by the following (1):

$$D_M\left(X_i, X_{(w)i}, \alpha\right) = \left(\sum_{i=1}^{N} \left|X_i - X_{(w)_i}\right|^{\alpha}\right)^{1/\alpha} \tag{1}$$

where: D_M – standard deviation of signal measure vector.

For the purpose of the comparative analysis of diagnostic signals, the special case of Minkowski's measure with the parameter α = 2 was used. Therefore, the relation (1) becomes the Euclidean measure and can be used with the ANN network [7, 8, 10, 12, 15]. Consequently, the transformation of input data is needed to reduce differences that are too high between the initial values in particular dimensions. For this reason, the normalisation of input data which transforms the values into the range of (0, 1) is performed according to relation (2).

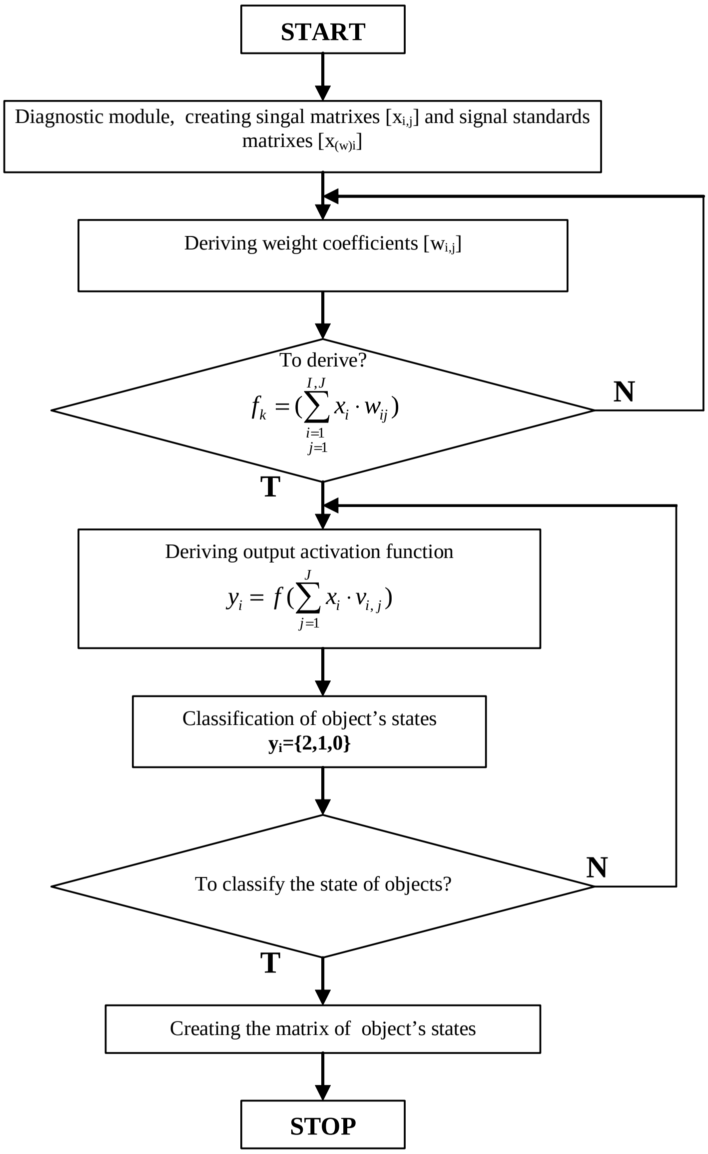


Fig. 4. The algorithm of diagnostic program DIAG
Rys. 4. Algorytm programu diagnozowania DIAG

$$\Delta X_{(n)_i} = \frac{X_i - X_{(w)i}}{D_i} \tag{2}$$

where: $\Delta X_{(n)i}$ – normalised vector of the measure of the length for signal "j".

The input cells of the ANN determine the values of weight coefficients ($w_{i,j}$) based upon relation (3).

$$w_{i,j} = \left| F(\Delta X_{(n)_i}) - F(\Delta X_i)_G \right| \tag{3}$$

where: $F(\Delta X_{(n)i})$ – determined value of the distribution function of the normalised vector of the measure of the signal properties length; $F(\Delta X_i)_G$ – border value of the distribution function of the normalised vector of the measure of the signal properties length.

For the ANN presented in Fig. 3, the neuron (i) is connected with the neuron (j) so it transmits a signal of value (X_i) with weight coefficient ($w_{i,j}$) and the activation function represented by the following relation:

$$f_l(x,w) = \sum_{i=1}^{K} w_{i,j} \cdot X_i \tag{4}$$

If neuron (j) is characterised by the minimal length between the vector of weight coefficients to the vector of the input signal, it adopts the value of “1” on its output and the other neurons adopts the value of “0”. This is why the model is being called “the winner takes all” and the activation of the neuron can be expressed by the following relation:

$$d(x, w_j) = \min_{1 \le i \le N} d(x, w_i) \tag{5}$$

where: d – measurement of signal similarity.

The program for searching for the winning neuron is realised using relation (5), so it compares the values of each neuron output. Alternatively, during the normalisation of the vectors of the signals and weights, the winner can be found by deriving, for each “j”-neuron, the length between its weight ($w_{i,j}$) and the vector of excitations (x_i). Then, the weight coefficients ($\nu_{i,j}$) are determined with the following relation:

$$d(x, w_{i,j}) = \upsilon_{i,j} = \left| 1 - w_{i,j} \right| = \sqrt{\sum_{i=1}^{N} \left(x_i - w_{i,j} \right)} \tag{6}$$

where: $d(x, w_{i,j})$ – the length of the j-vector of weight to the input signal.

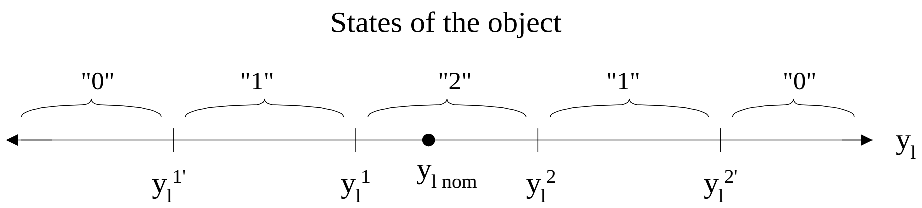
When the activity (value of potential) of j-neuron decreases below ($w_{i,j}$) = (w_{min}), the j-neuron does not take part in the “looking for a winner” competition, so the winner is searched for among the other neurons for which the weights fulfil the condition $(w_{i,j}) \geq (w_{min})$. It was assumed that the maximum value of potential can reach the value of "1". So for $(w_{min}) = 0$ all of the neurons take part in the competition, but for $(w_{i,j}) = 1$ there is only one. The value of output is derived from the relation (7).

$$y_l = f \sum_{i=1}^{K} \upsilon_{i,j} \cdot X_i \tag{7}$$

where: $\upsilon_{i,j}$ – weight coefficients.

Evaluation of network outputs $\{y_l\}$ make it possible to explicitly determine the set of elementary vectors of signals determining the diagnostic space of object (ω) (Fig. 1).

For the purpose of diagnosis of the object [1, 2, 4, 9], understood as its state recognition, the results of ANN operating are classify according to the scheme presented in Fig. 5.



where: (y_l^1, y_l^2) – the range of non-significant changes of the outputs; $(y_l^{1'}, y_l^1)$ and $(y_l^2, y_l^{2'})$) – the range of significant changes of the outputs, $((-\infty, y_l^{1'})$ and $(y_l^{2'}, +\infty))$ – the range of unacceptable changes of the outputs

Fig. 5. Range of the variability of diagnostic signal features

Rys. 5. Zakres zmienności cech sygnału diagnostycznego

The results of the diagnosis of the object are presented in Table 2.

Table 2. Object's states matrix

Tabela 2. Tablica stanów obiektu

State of object	State of module	Vector of states of elementary components $\{e_{i,j}\}$				
		$\varepsilon(e_{1,1})$	...	$\varepsilon(e_{i,j})$	...	$\varepsilon(e_{i,J})$
$W(\varepsilon(O))$	$W(\varepsilon(E_1))$	$W(\varepsilon(e_{1,1}))$	...	$W(\varepsilon(e_{1,j}))$	...	$W(\varepsilon(e_{1,J}))$
	⋮	⋮	...	⋮	...	⋮
	$W(\varepsilon(E_i))$	$W(\varepsilon(e_{i,1}))$	...	$W(\varepsilon(e_{i,j}))$	...	∅
	⋮	⋮	...	⋮	...	⋮
	$W(\varepsilon(E_I))$	$W(\varepsilon(e_{I,1}))$	...	$W(\varepsilon(e_{I,j}))$	...	$W(\varepsilon(e_{I,J}))$

where: $W(\varepsilon(e_{i,j}))$ – value of state assessment logic for element "j" within "i" module of the object, ∅ – symbol complementing the size of table.

The essential problem during learning ANN is the preparation of the algorithm of its training. The random patterns {ξ_1, ξ_2,…, ξ_n} achieved from a random number generator were used for the learning of state recognition. The average of the input signals' vector was assumed as standard values for the neurons of ANN. Following the rule stated by relation (8), only the weights of the winning neuron were modified in ANN training.

$$w_j(t+1) = w_j(t) + \eta(t)\left[x(t) - w_j(t)\right] \tag{8}$$

where: η – is the value of step of weights modification.

The idea of ANN learning is to change the weights corresponding to the input signal vector (x_i) of "s" class of states so that the "j"-neuron is a winner. Therefore, the "j"-neuron wins when the length of "j"-vector of weights is the smallest. Simultaneously, the weights should be modified in this way for all the M-learning patterns of signal vectors (x_j). Its length compared to the average of state classes were the smallest too.

The learning process [8, 12, 15] is called the minimisation of quantization terror represented by following relation:

$$\Theta = \frac{1}{M}\sum_{t=1}^{M}\left\| w^*(t) - x(t) \right\| \tag{9}$$

where: $w^*(t)$ – weight of the winning neuron after putting signal x(t) to the input of ANN.

The parameter (1/M) in relation (9) is interpreted as learning speed, the higher the value the stronger are the modifications of training vectors. Good results of learning can be achieved with the proper choice of ANN size – the numbers of neurons. The number of neurons determines the number of network hits. Using the random vectors of learning weights, it is possible that few of the neurons will never win during learning. The length of its weights to learning vectors becomes larger. This is why the weights will not modify and adopt. Such neurons are called dead neurons. In order to improve their activity, which increases their chance at the competition, we need to reconsider the strategy of the competition and to introduce the term of potential [8, 15].

4. Conclusions

The article presents the method for the recognition of the state of an object with the help of an artificial neural network. The method of diagnosis compares the images of diagnostic signals' vectors with the images of their standards. The basis for diagnostic decision of the states of the object is an analysis of elementary metrics of the vector of diagnostic signal lengths. The important step is the functional diagnostic analysis of the object, which results in the determination of the sets of input signals for further processing by ANN. The algorithm for diagnostic information processing by ANN was also developed and presented.

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References

[1] Rozwadowski T.: Diagnostyka techniczna obiektów złożonych. Wyd. WAT, Warszawa 1983.
[2] Będkowski L.. Dąbrowski T.: Podstawy diagnostyki technicznej cz. 2. Wyd. WAT, Warszawa 2006.
[3] Białko M.: Podstawowe właściwości sieci neuronowych i hybrydowych systemów ekspertowych. Wyd. Politechniki Koszalińskiej, Koszalin 2000.
[4] Duer S., Duer R.: Computer diagnostic system with expert knowledge for state's control of technical objects. "SYSTEM MODELLING CONTROL – SMC'2005". Proceedings of the 11th International Conference on " System Modelling Control", Zakopane, Poland 17-19 October 2005. Wyd. EXIT, Warszawa 2005.
[5] Hojjat A., Shih – Lin hung.: Machine learning, neural networks, genetic algorithms and fuzzy systems. John Walley End Sons, Inc 1995.
[6] Hertz J., Krogh A., Palmer R.G.: Wstęp do teorii obliczeń neuronowych. WNT Warszawa 1995.
[7] Jankowski N.: Ontogeniczne sieci neuronowe, O sieciach zmieniających swoją strukturę. Wyd. EXIT, Warszawa 2003.
[8] Krawiec K., Stefanowski J.: Uczenie maszynowe i sieci neuronowe. Wydawnictwo Politechniki Poznańskiej, Poznań 2004.
[9] Korbicz J.: Diagnostyka procesów. WNT Warszawa 2002.
[10] Kosiński R.: Sztuczne sieci neuronowe, dynamika i chaos. WNT Warszawa 2004.
[11] Knosala R.: Zastosowania metod sztucznej inteligencji w inżynierii produkcji. WNT, Warszawa, 2002.
[12] Madan M. Gupta, Liang Jin and Noriyasu Homma: Static and Dynamic Neural Networks, From Fundamentals to Advanced Theory. John Walley End Sons, Inc 2003.
[13] Mańdziuk J.: Sieci neuronowe typu Hpofielda, teoria i przykłady zastosowań. Wyd. EXIT Warszawa 2000.
[14] Nałęcz M.: Biocybernetyka I Inżynieria Biomedyczna, tom 6, Sieci neuronowe. Wyd. EXIT Warszawa 2000.
[15] Pedrycz W.: Fuzzy Control and fuzzy systems. John Walley End Sons, Inc 1993.
[16] Rutkowski L.: Metody i techniki sztucznej inteligencji. Wyd. PWN, Warszawa 2005.

Algorytm diagnozowania naprawialnych obiektów technicznych z wykorzystaniem sztucznej sieci neuronowej

S t r e s z c z e n i e

W pracy zaprezentowano system diagnostyczny wykorzystujący sztuczną sieć neuronową SSN w celu rozpoznania stanów naprawialnych obiektów technicznych. Artykuł przedstawia problematykę przetwarzania wstępnej informacji diagnostycznej przez SSN, wykorzystującą teorię rozpoznawania obrazów. Zaprezentowano ogólny schemat złożonego obiektu technicznego, opisano jego strukturę wewnętrzną. Wykonano analizę diagnostyczną, w efekcie której wyznaczono zbiór sygnałów diagnostycznych. Opisano algorytm diagnozowania obiektu technicznego przez SSN. Uzyskane wyniki zestawiono w postaci tablicy stanów obiektu.