ENVIRONMENTAL SAFETY OF CONSTRUCTION AND MUNICIPAL SERVICES

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SYSTEM OF ECOLOGICAL TOXICANT IDENTIFICATION IN CLOSED PREMISES

Statement of the problem. Increase in ecological safety of building materials, products and structures as well as in real-time monitoring of hazardous substances content in closed premises is an urgent problem. The aim of the paper is to develop a modern pattern of a multisensor system based on chemical sensors to recognize the presence of typical ecological toxicants in closed premises at a level exceeding maximum permissible concentrations. The system is aimed at the control of environmental safety in building construction and municipal services.
Results. A mathematical model of toxicant detection system of using the intelligent processing of information based on the neural computer technology was suggested. An algorithm for analytical monitoring of organic pollutants as well as a scheme for gas analysis of toxic substances. The system is designed to detect hazardous substances in closed spaces.
Conclusions. The methodology of artificial neural networks for signal processing multisensory recognition system toxicants indoors is proposed.

Keywords: modeling, detection system, neural control network, organic toxicants, environmental safety.

Introduction

Housing construction in Russia is now at the stage of taking its requirements to the next level and committing to high standards and excellence of abroad by promoting the quality of works and services and endeavoring to meet growing demand for environmental safety and living comfort. This calls for increasing environmental safety level of construction materials, products and structures as well as close control of the content of harmful and toxic substances in closed rooms [1, 2].

The reason why toxic substances travel from polymer materials is that failure takes place caused by a range of chemical and physical factors (oxidation, temperature oscillations, insulation, etc.). It is also initial raw materials being ecologically not clean enough, their manufacturing technology inconsistent and inappropriately applied. A release of gas toxic substances is increasingly on the rise as the temperature on the surface of polymer materials increases and so does the relative air humidity in a facility. A release of gas toxic substances is considerable as a result of combustion of polymer construction materials [3—5].

A variety of research suggests toxic volatile matter travels from almost all polymer and finishing materials based on low molecular monomers. The former are likely to have an adverse effect on living organisms as well as a human health [1—5].

1. Analytical control algorithm by means of the multisensor system

A component wise control of volatile matter in the environment is normally conducted following a routine sampling by means of expensive methods of gas or liquid chromatography. Multisensor systems ("electric nose" type) are increasingly used in operation monitoring. One of the advantages of these systems is their compactness and capacity to operate under "hands on" conditions. They are easy to use and are potentially helpful in detecting gas harmful and toxic substances in closed facilities (e. g. in composite and polymer construction materials).

The performed analysis of the existing models of detection systems [6, 7] allowed us to choose what will become a basic model for the device configured to perform a non-destructive analysis of substances and construction materials and a multi-level neuron model that accounts for the mechanism of the olfactory system. This choice is caused by a strive for a maximum similarity to the model and its biological analogue (nose) and simple variation of the parameters of the software realization. Following this model, the olfactory system is looked upon as three interacting subsystems. The first one is the collection of primary information (piezosensor). The second one is the transmission by a programmed logical integral scheme into a personal computer (PC). Finally, the third one is a software module of collection, processing and further analysis of the piezosensor signals.

Piezosensors collect primary information about the nature and content of the gaseous state, i. e. correspond to the olfactory receptor neurons of the first subsystem of the suggested model:

$$Y_i = f_i\left[\overline{X}, \sum_{i=1}^{n} x_i \omega_i\right],$$

$$\vec{Y}(X) = \frac{1}{1+\exp^{-\alpha x}}\left[\overline{X}, \sum_{i=1}^{n} x_i \omega_i\right],\ i = 0,\ n-1,$$

where f_i is the activation function, $\overline{X}$ is the matrix of the characteristics of the values of frequency signals, weighted sum of incoming signals. The initial condition $\vec{f_i}(0) = \overrightarrow{f_i^0}$ is an initial value of the function of neuron activation.

The signals of piezosensors depending on their sensitivity and concentration of the analyzed substance are grouped by the system of the collection, transmission of information in the second subsystem of the model. For a multi-channel registration of piezosensor signals in the system of the "electric nose" type and further transmission of the obtained data into the personal computer Altera ПЛИС was used.

This enables us to come up with a small dimension highly integrated system of data collection with a flexible structure that supports the function of on-board programming.

An incoming signal of the "electric nose" is processed in the third subsystem of the model which is located in the PC. The third subsystem of the model in the "electric nose" system is presented by a multilayer neuron network which is capable of back propagation learning. [7]. The elements of this network are neurons which depending on the total effect of incoming signals can get excited or slow down. Each signal coming through a dentrite of a nerve cell. i. e. has some negative or positive weight. As a neuron reaches a certain threshold value of the perturbation level, its activation starts taking place and an axon transmits a signal to the other elements which make up a mutually connected consecutive row of layers.

The total signal of the "electric nose" system includes a set of the following three parameters: the maximum frequency signal of a piezosensor in the course of the analysis Δf_{max} (a piezosensor signal to the analyzed sample), the time τ_{max} the value Δf_{max} of a piezosensor is reached, the area $S_{\Delta y}$ of the figure constrained by the function $\Delta f = \xi(\tau)$ and axes Δf and τ.

After the total signal of the analyzer is in place, a database is created with the information on the chemical nature of the substance and the concentration. Based on the obtained information, an incoming signal for a layer of major neurons is formed.

A vector of the values of frequency signals obtained from the piezosensors is used as the primary data as well as a moment of time this vector was obtained. Therefore for the analysis of the gaseous medium at the input of artificial neuron networks (ANN) a matrix of the values of the system signals is transmitted

$$\overline{X} = \begin{bmatrix} t_1 & x_{11} & x_{1j} & x_{1m} \\ t_i & x_{i1} & x_{ij} & x_{im} \\ t_n & x_{n1} & x_{nj} & x_{nm} \end{bmatrix}, \ i = \overline{1,\ n},\ \ j = \overline{1,\ m},$$

where $\overline{X}$ is a matrix of the characteristics of the frequency signals obtained as a result of the experiment; t_i is a moment of time another vector of the frequency signals is obtained, sec; X_{ij} is the value of the frequency signal of the j^{th} sensor at the i^{th} time moment, $i = \overline{1, n}, j = \overline{1, m}$, n is a number of sensors, m is the duration of the experiment.

The results of processing the sensor data ($\overline{X}_i$) are transmitted into the input layer of the multilayer neuron system of the layer of reducing dimensionality of the input vector. The layer of reducing dimensionality of the signal coming at the input of the neuron system synthesizes a unit vector based on the values of three transmitted parameters. This enables the use of a simplified model of the neuron network and thus a reduction in the time needed to process and obtain the final information. The above is followed by the transformation and transmission of the information between the interior layers of the network. The values of the required output and modeled signal of the system are compared and the formula

$$e = \sum_{i=1}^{n} \left| y_i - D_i \right|^2$$

error is calculated. The research of the analyzed medium is closed by registering the signal (y_i) of the output layer of the system.

The research allowed us to set forth the following algorithm for the analytical control of toxic substances using a gas analyzer (Fig. 1) [8].

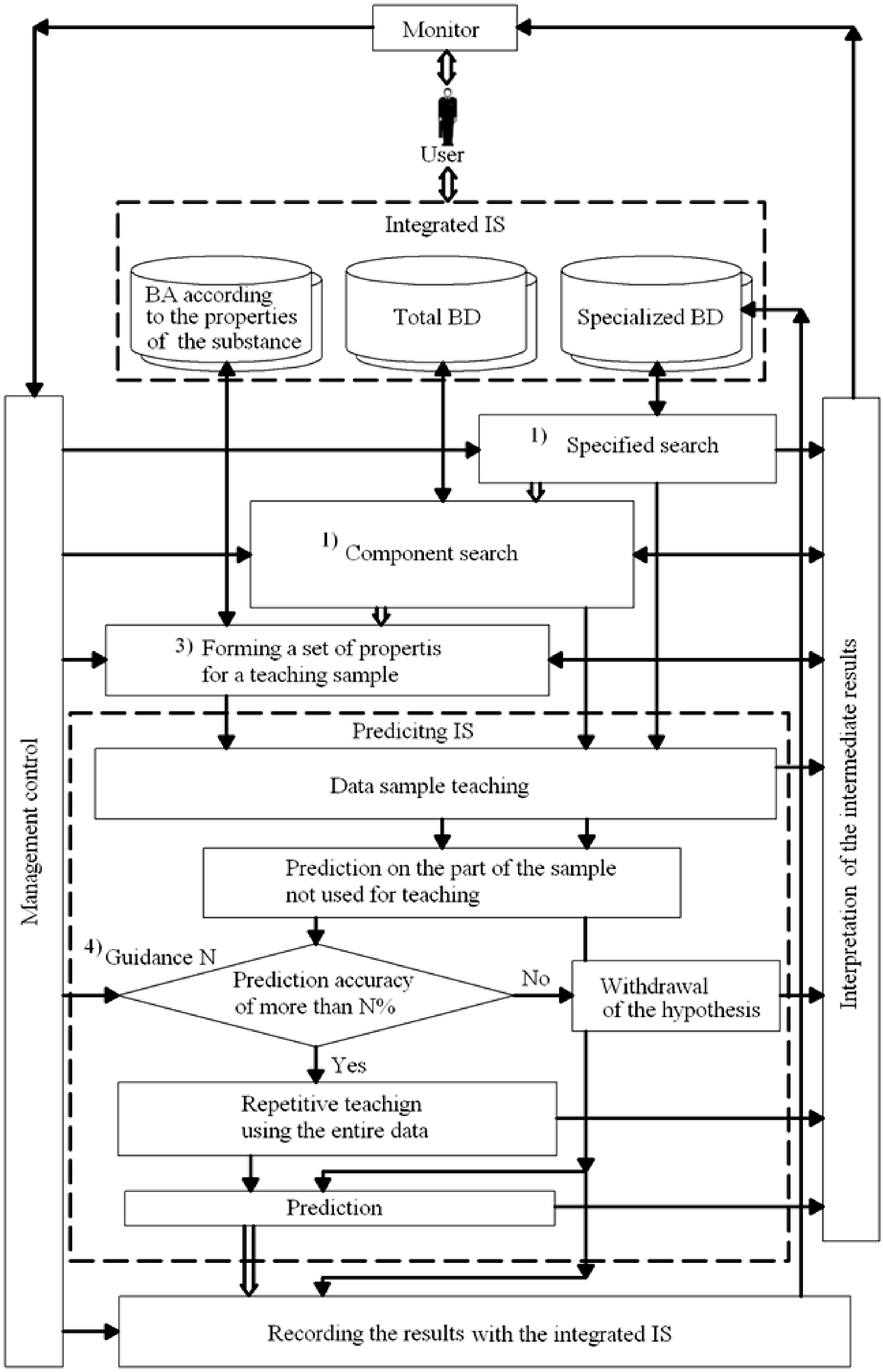

Fig.1. Algorithm for the analytical control of organic toxicants

2. Defining the output data of the network

For the sake of simplicity of presenting the final analysis data, a decision was made to give each ecotoxicant an individual code according to which the text presentation of the output data could be resumed in the process of putting together the final report. The code of each substance is an individual numerical identificator of the ecotoxicant using which the database is searched for corresponding characteristics of the substance to put together the final report that contains the results of the gas mixture analysis. The code of the ecotoxicant is specified in accordance with the algorithm for indexing at the moment of adding the substance in question into the "Ecotoxicant" database [8-9]. This parameter is a constant value and stays the same as the rest of the characteristics of the ecotoxicant (of the teaching sample and basic data) change.

A multilayer perception is used as a neuron network as shown in Fig. 2. The input layer contains n neurons, which corresponds to a number of piezosensors considering the moment the signal was registered (n+1), there is one neuron in the output layer whose output relates to the code of the ecotoxicant.

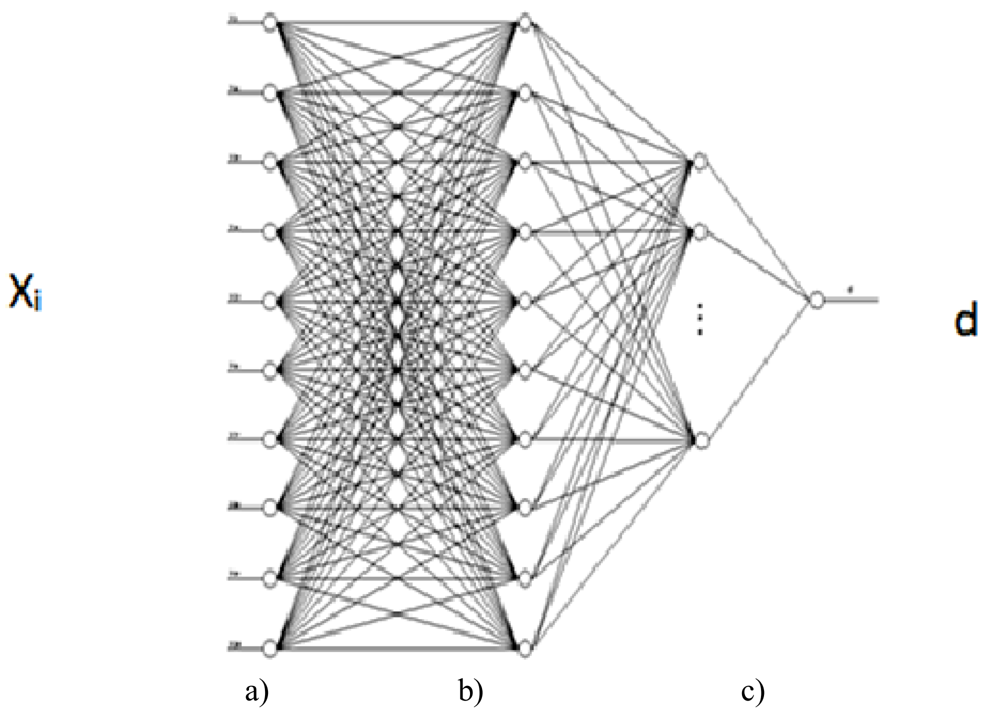

Fig. 2. Architecture of the neuron network:

a) input layer; b) intermediate (hidden layers); c) output layer;

X_i are values of the frequency signals of the j^{th} sensor at i^{th} moment of time;

d is an output signal of the system

The problem of finding a functional dependency at a limited set of initial data generally can be solved in a variety of ways.

In order to restrict the search scope the problem tackled in learning is the minimization of the target error function $E(\omega)$ of the multilayer neuron system which is found using the method of least square. The summation is conducted in all the neurons of the output layer and all the images processed by the network. Neural network learning was performed by means of the method of gradient descent (Fig. 3).

At stage 2 the network is randomly given the teaching sample vectors.

The system test results revealed that the simplest method of gradient descent does not really work for when the derivatives in different weights are distinctly different. This case is similar to when the value of the function S for some neurons is close to 1 in its module or to when the module of some weights is much greater than 1.

In this case in order to gradually decrease the likelihood of errors we need to choose a very small learning rate which invariably ends in a significantly longer learning period. The simplest method of eliminating this is by introducing the moment μ when the effect the gradient has on changes in the weights changes over time.

Another advantage of introducing the moment is the capacity of the algorithm to ignore small local minima.

A profile analysis (leaf diagram) is used for a complex comparison of the sensor operation under different conditions. This method is based on that certain sensor signals when combined lend the object in question a completely new characteristic. Finding out the most common features of a particular substance allows one to define the profile of the material in general as well as to study the effect of different factors (parameters) on the resulting image (pattern).

The above methodology is universal and is not dependent on the nature of ecotoxicants. Presently the detection system is experimentally developed on mixtures of low molecular hydrocarbon and their oxygen and nitrogen derivatives. In order to implement the system, it is necessary we have a multisensor detector with several (5—10) piezosensors with at least partial selectiveness to this or that analyte (ecotoxicant) connected to the laptop through the interface fitted with the software adjusted to operate with digital neural networks.

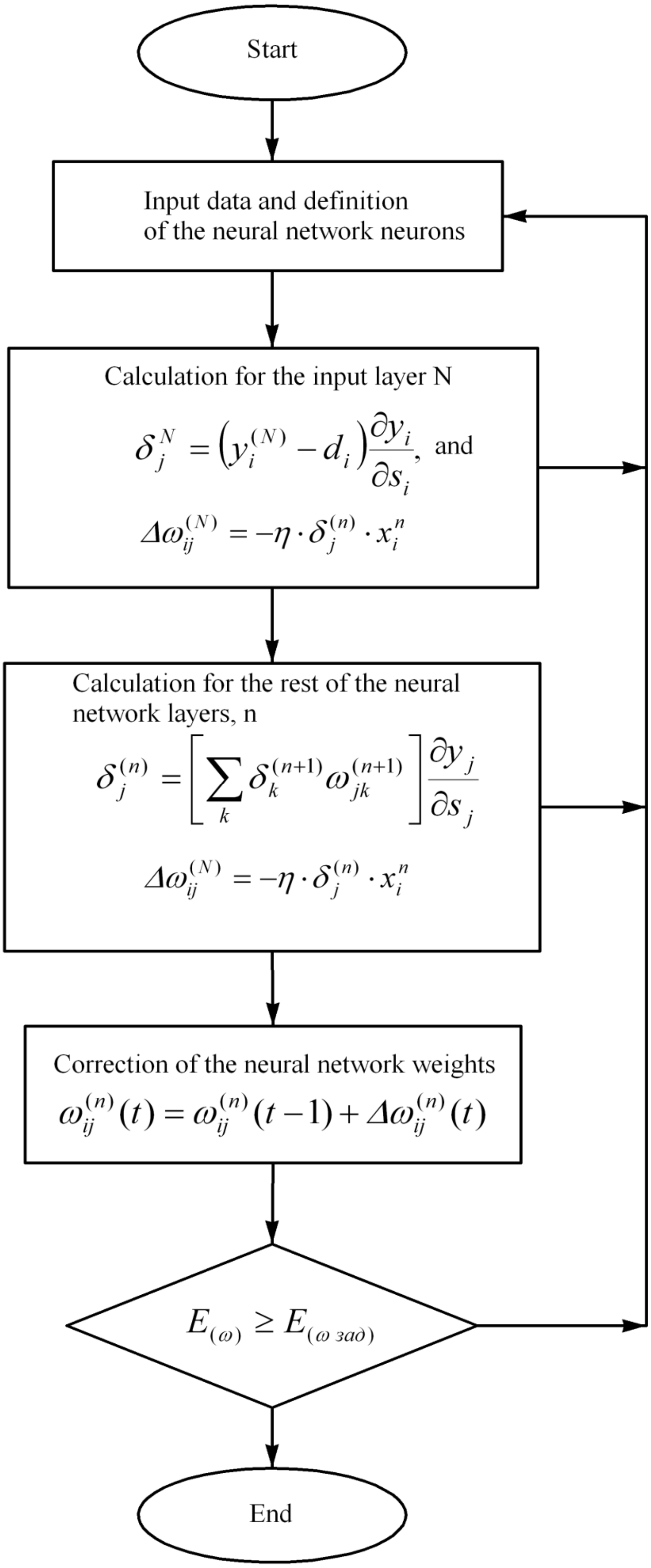

Fig. 3. Learning algorithm for the developed artificial neural network

Conclusions

1. The method of using artificial neural networks for processing signals of multisensor system of ecotoxicant detection was proposed.
2. In our view, the pilot measurement system we have presented in this paper is good for use in monitoring, environmental toxicity control as well as in closed facilities since this analyzer can self — adjust to the specified analyte making up for the inaccuracy of the incoming information and yield an appropriate outcome. This system can also be applied in handling signal starting devices.
3. It is worth mentioning that the analysis takes not long to perform and the measurement system is small which is significant to detection systems of fire hazardous, harmful and toxic substances in closed facilities.

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