CONTROL OF HEATING PROCESSES IN TRANSPORT MECHATRONIC SYSTEM USING SIGMOIDAL FEED FORWARD NEURAL NETWORK

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Abstract: In this article interest is concentrated on the climate parameters optimization in passengers' interior of mechatronic systems (public electric transportation vehicles- train, tram or trolleybus). Idea is to use feed forward artificial neural network to create an algorithm and coordination mechanism for heating system parameters control to save electrical energy, and to increase the level of comfort for passengers. A special interest for investigations and further development is devoted to intelligent HVAC system allowing more flexible control of the system's compressor, fan and heater operation, and, therefore, improvement of efficiency and energy saving. This paper provides the mathematical model and algorithm for optimal control of the climate control system.

1. INTRODUCTION

Nowadays great attention is paid to increasing level of passengers' comfort in public electric transport. The aim of it is to provide passengers with a transportation service of a high quality. Elaboration of new HVAC (heating, ventilation and air conditioning) systems has to be performed in order to provide it. Effective work of them can be provided by elaborating control systems with usage of artificial intellect methods and progressive algorithms.

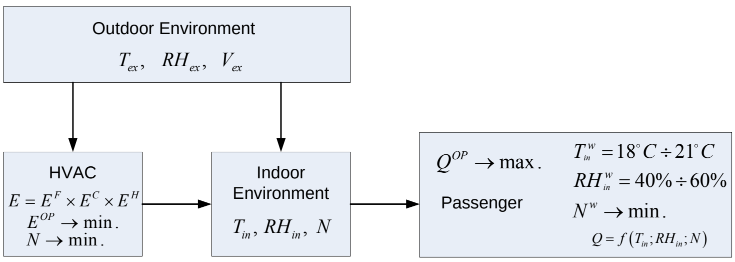


Fig. 1. Environment and HVAC system connection (Q – passengers comfort level, E – energy consumption, RH – air humidity, N – acoustic noise, V – air velocity, T – temperature, ^{OP} – optimal choice of parameters, $_{in}$ – indoor, $_{ex}$ – outdoor. Ability of HVAC system to provide optimal level of comfort Q^{OP} is directly dependent on energy consumption E of HVAC system)

Indoor environment parameters of vehicle passengers' interior to large extent depend on outdoor environment parameters (Fig. 1), frequency and intensity of both environments connecting (when opening doors and windows) as well as on effectiveness of HVAC system (Beinarts and Levchenkov, 2007).

2. PROBLEM FORMULATION

The main purpose of the paper is to develop structure scheme of HVAC intellectual control system and to describe its working algorithm, as well as to define the optimal HVAC system working regime, taking into account priorities of consumers, and trying to reduce consumption of electric energy as much as possible.

Deep and detailed investigation of the behaviour of such a system, its operation and running processes requires its generalized mathematic modelling, taking into account all possible regimes of the operation of compressor, fan motors, heater and setting an algorithm of their control under any condition. Possible problem solution is intelligent coordination mechanism – intelligent control system with the artificial neural network, which gives possibility to save the electrical energy min., at the same time providing high level of comfort to passengers max.

3. HVAC SYSTEM

The modelling and investigation are based on the typical architecture of HVAC system (Sauer et al., 1994) with a traditional application of AC induction motors for driving both compressor and fan of the conditioner. The well-known field-oriented method (Bimal and Bose, 2002) has been considered for the modelling.

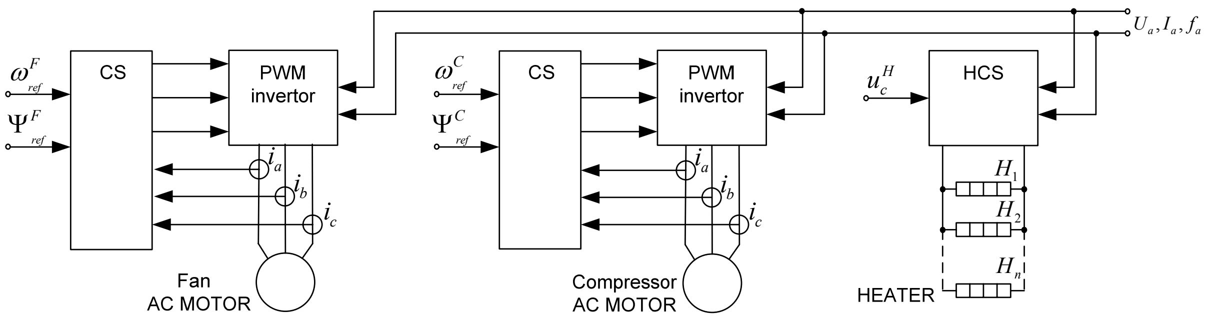


Fig. 2. Power part of HVAC system (CS – control system, ω – speed control, ψ – flux linkage, T_{sx}, u – voltage, u_c^H – heater control signal)

There are two control systems (CS) – one is for compressor motor control and the other – for fan motor control (Fig. 2). Heater control system (HCS) is used for control of electric heaters, control of which is realized according to signal.

4. CONTROL SYSTEM DESIGN

HVAC system control is performed using computer system. Processing of environmental parameters and passengers' wishes regarding climate parameters is realised using program agents.

Overall structure scheme of control system is given in Fig. 3. Passengers' wishes of necessary level of comfort are described as fuzzy variables and processed with fuzzy logic controller (FLC) which is described in (Beinarts and Levchenkov, 2008).

Signal Q_P^S, characterising wishes of passengers, is produced on FLC output. Environmental parameters of passengers' interior are controlled using suitable sensors, which are connected to ANN inputs $x_1 - x_6$. Inputs $x_8 - x_{10}$ are connected to separate power elements (cooler, fan, heater) of HVAC system for acquiring data about summary energy consumption E from electro energy power supply (EPS) that is characterized by signals E^C, E^F, E^H respectively. Information acquired from sensors and FLC are processed by ANN and according ANN rules respective output signals y^C, y^F, y^H are generated, which contain information on necessary work regimes of air conditioner, cooler and heater.

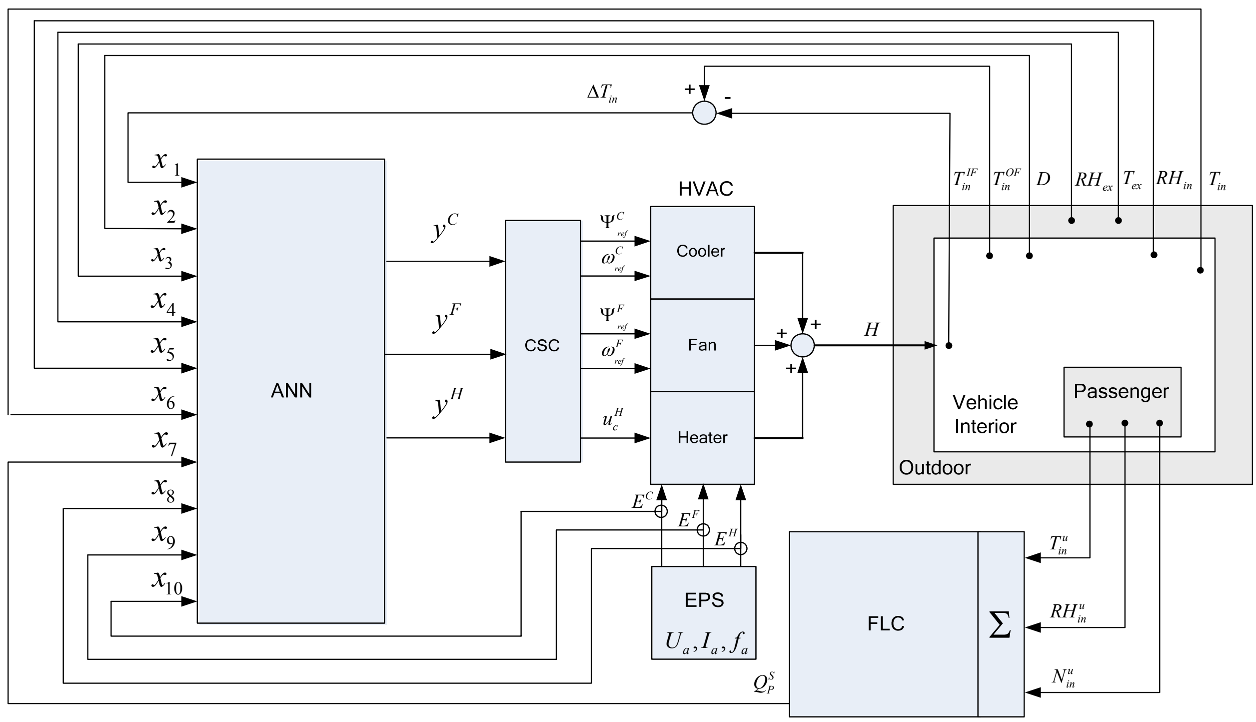


Fig. 3. Heating control system structure

ANN outputs are connected to the input of control signal controller (CSC). CSC performs HVAC power part control with signals ω_{ref}, ψ_{ref} and u_c^H.

EPS provides HVAC system with controlled flow of electric energy: $E = E^F \cdot E^C \cdot E^H$, size of which is controlled and data on its value E are passed to ANN, which provides an optimal control regime of energy consumption.

5. PROBLEM DECISION METHODOLOGY

5.1. Artificial neural network

In the paper there is used a sigmoidal type feed forward artificial neural network, which is also known as Multi-Layer Perceptron (MLP) (Haykin, 1998). Structure of three-layer MLP is given in (Fig. 4).

Sigmoidal (logistic) neuron activation function is used in the network:

$$f(s) = \frac{1}{1+e^{-as}}, \tag{1}$$

where s – output value of neuron inputs sum, a – steepness parameter.

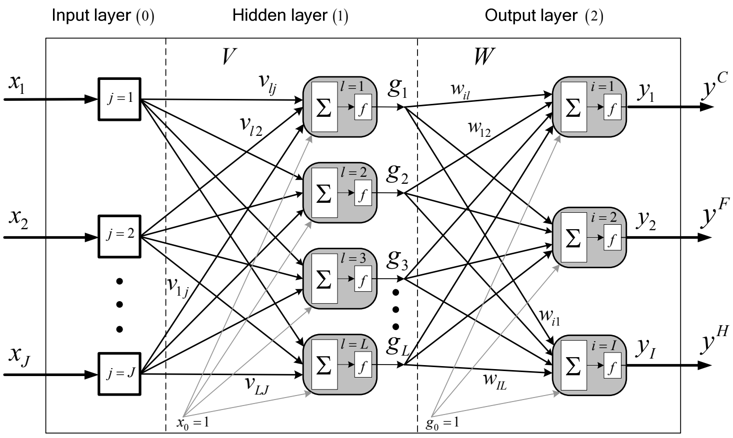


Fig. 4. Feed-forward MLP type artificial neural network (Input layer signals: $x_j \in \{x_1, x_2, \ldots, x_J\}$, hidden layer output signals: $g_l \in \{g_1, g_2, \ldots, g_L\}$, output layer signals: $y_i \in \{y_1, y_2, \ldots, y_I\}$, hidden layer weights: v_{lj} – output layer weights: w_{il} – neuron activation function: f – um of input signals: Σ, HVAC system control signals: $\{y^C, y^F, y^H\}$, C – cooling, F – fan, H – heat process)

Sigmoidal expression shows that values of neuron output can be in range [0, 1]. As one of the most important characteristics of the function is simplicity of its derivation:

$$f'(s) = a \cdot f(s) \cdot [1 - f(s)] \tag{2}$$

In order to simplify description an extended designation of the input vector of the network is used described as $x = [x_0, x_1, \ldots, x_J]^T$, where $x_0 = 1$ corresponds to a signal of polarization. Input vector x is interconnected with the real output signal vector $y = [y_0, y_1, \ldots, y_I]^T$ and the desired output vector $d = [d_0, d_1, \ldots, d_I]^T$.

Output signal of the hidden layer neuron is calculated according to formula:

$$g_l = f\left(\sum_{j=0}^{J} v_{lj} \cdot x_j\right) \tag{3}$$

where index $j = 0$ corresponds to the signal and weights of polarization, and $x_0 \equiv 1$, $g_0 \equiv 1$.

Output signal of the output layer neuron is calculated according to formula:

$$y_i = f\left(\sum_{i=0}^{I} w_{il} \cdot g_l\right) = f\left(\sum_{i=0}^{I} w_{il} \cdot f\left(\sum_{j=0}^{J} v_{lj} \cdot x_j\right)\right) \tag{4}$$

5.2. Neural network training

The aim of the training is to adjust such values of weights v_{lj} and w_{il} for all layers of the network so that when input vector x is set, then such output signal values y_i are obtained which would match with necessary precision with desired values d_i, when $i = 1, 2, \ldots, I$. If to look at the polarization signal as to the one of the components of the input vector then polarization weights can be added to the vectors weights of corresponding neurons of both layers.

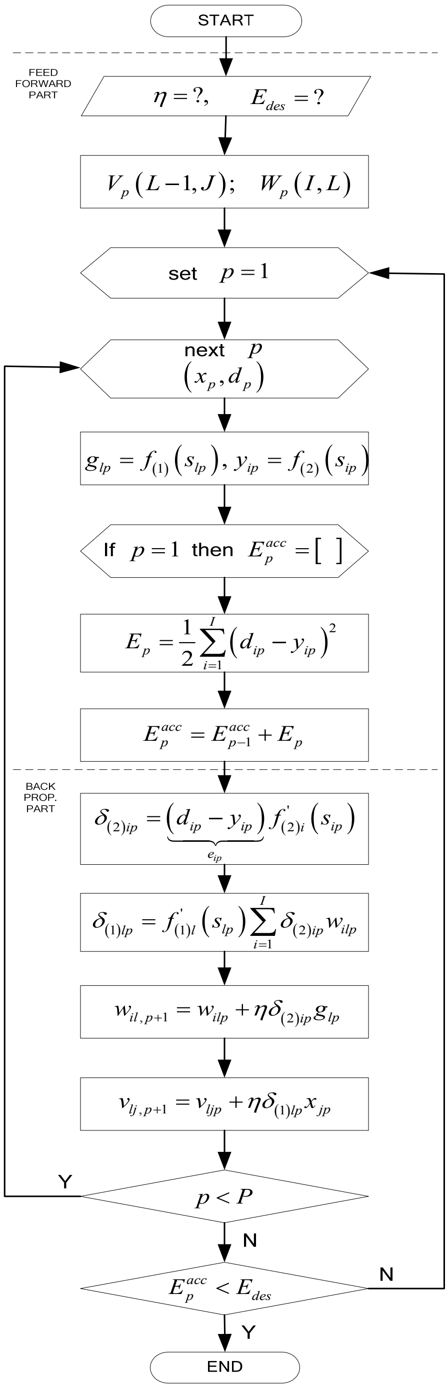
5.3. Error back propagation algorithm

The error back propagation algorithm (Kecman, 2001) for multilayer ANN defines weights adjusting strategy using gradient methods of optimization. It is considered as a one of the most effective training algorithms at the moment. Algorithm is based on the target function which is formulated as a square sum of difference between desired and real output signals values:

$$E(w) = \frac{1}{2}\sum_{i=1}^{I}(d_i - y_i)^2 \tag{5}$$

$$E(w) = \frac{1}{2}\sum_{p=1}^{P}\sum_{i=1}^{I}\left(d_j^{(p)} - y_i^{(p)}\right)^2 \tag{6}$$

Making more precise weights values can be done each time after presenting of each training pattern p according formula (5) (regime „On-Line“), or one time after presenting of all training patterns when many training patterns are presented $p = 1, 2, \ldots, P$ according formula (6) (regime „Off-Line“). There is „On-Line“ training regime used in the paper.



Step1. Choose the learning rate η and predefine the maximally allowed, or desired, error E_{des}.
Step 2. Initialize weights matrices.
Step 3. Start new learning epoch.
Step 4. Perform the on-line training, apply the new training pair (x_p, d_p) in sequence or randomly to the hidden layer neurons.
Step 5. Consecutively calculate the outputs from the hidden and output layer neurons.
Step 6. Initialize $E_p^{acc} = [\ ]$. Perform only in the first step of an epoch ($p = 1$).
Step 7. Find the value of the sum of errors square cost function E_p for the data pair applied and the given weights matrices V_p and W_p.
Step 8. Value of the cost function is accumulated over all the data pairs.
Step 9. Calculate the output layer neurons' error signals. $i = 1, \ldots, I$.
Step 10. Calculate the hidden layer neurons' error signal $l = 1, \ldots, L-1$.
Step 11. Calculate the updated output layer weights.
Step 12. Calculate the updated hidden layer weights.
Step 13. Compare actual p with P.
Step 11. The learning epoch is completed: $p = P$. For $E_p < E_{des}$, terminate learning.

Fig. 5. „On-Line" version of error back propagation algorithm

If assume that the target function is continuous then gradient methods of optimization are the most effective for the network training. Adjusting of weight vectors is done according to formula:

$$w(i+1) = w(i) + \Delta w \quad (7)$$

where $\Delta w = \eta p(w)$, and η – training coefficient, $p(w)$ – direction in space w. Structure of error back propagation algorithm is given in Fig.5.

A set of P measured data pairs that are used for training is given: $X = \{x_p, d_p, p = 1, \ldots, P\}$, consisting of the input pattern vector: $x = [x_1, x_2, \ldots, x_J + 1]^T$ and the output desired responses: $d = [d_1, d_2, \ldots, d_K]^T$.

6. PROBLEM DECISION ALGORITHM

Step 1. Initialization. In the object O (vehicle passengers' interior) HVAC system provides minimal necessary climate parameters Q_O^S set by an operator.
Step 2. ANN is trained using error back propagation algorithm on the base of training data pattern set P prepared by a supervisor.
Step 3. Passengers' climate parameter perception slopes T_{in}^u, RH_{in}^u, N_{in}^u are determined, and the comfort level set-point Q_S^P is defined by FLC.
Step 4. ANN is processing information obtained from environmental parameters' sensors placed in the interior of an object and comparing energy consumption values of HVAC system power plant, and in the result it activates ANN output signals y^C, y^F, y^H. Target is minimization of electrical energy consumption $E = E^C \cdot E^F \cdot E^H \rightarrow$ min. in compressor, fan motors and heater, considering consumer wishes Q_S^P with control regime C with ANN decision making D under control procedure $C_w^{DM}(t)$ during time t.
Step 5. ANN output signals y^C, y^F, y^H that contain information about the necessary changes of HVAC system power elements' parameters are processed by CSC. In the result, CSC forms control signals of HVAC system $\omega^C{}_{ref}$, $\psi^C{}_{ref}$, $u^C{}_{ref}$ and address of destination power unit.
Step 6. Work regime of HVAC system $C_w^{DM}(t)$ is set according computation results.
Step 7. HVAC system, according to CSC control signals, provides changes of climate parameters in the object, taking into account optimal consumption of electro energy: $E(t) \rightarrow$ min. with comfort level of passengers' $Q(t) \rightarrow$ min.

7. SUMMARY

The provided results prove that the use of feed forward ANN of sigmoidal type (MLP) with application of the proposed algorithms can be useful for solving HVAC technology control problems in the public electric transport. Usage of the created models and algorithms in the climate parameters control system in the passengers' interior will raise possibility to increase efficiency of electro energy usage, so exploitation costs of transport will reduce as well as passengers' comfort level will be increased. Appropriate for this purpose are systems working using control core, developed on the basis of artificial intelligence, which can control the current condition of all system, environment parameters independently on operator, and taking into account predictable changes of these conditions, it can take decision on the necessary system actions. The elaborated system model can be used for sustaining microclimate in different facilities, public electric transport vehicles and buildings.

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