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MODEL-FREE ADAPTIVE HEATING PROCESS CONTROL

VYUŽITIE MFA-REGULÁTORA V RIADENÍ PROCESU VYKUROVANIA

Abstract

The aim of this paper is to analyze the dynamic behaviour of a Model-Free Adaptive (MFA) heating process control. The MFA controller is designed as three layer neural network with proportional element. The method of backward propagation of errors was used for neural network training. Visualization and training of the artificial neural network was executed by Netlab in Matlab environment. Simulation of the MFA heating process control with outdoor temperature compensation has proved better results than classic PID control. MFA controller can ensure zero control deviation between desired and actual variable of indoor temperature more quickly than PID controller.

Abstrakt

Cieľom tohto príspevku je analýza dynamických vlastností MFA- regulátora na riadenie procesov vykurovania. MFA-regulátor je navrhnutý ako 3-vrstvová neurónová sieť s proporcionálnym členom. Na trénovanie neurónovej siete bola využitá metóda spätného šírenia chýb. K vytvoreniu a trénovaniu MFA -regulátora bol použitý NETLAB Toolbox v prostredí MATLAB. Výsledky simulácie modelu ekvitermickej regulácie s použitím MFA-regulátora, čo sa týka presnosti a rýchlosti regulácie, sú lepšie v porovnaní s modelom ekvitermickej regulácie s použitým PI regulátorom.

1 INTRODUCTION

The classical verified approach to the heating process control is using of outdoor temperature compensation which may be (especially in smaller buildings) supplemented with the temperature sensing in the reference room too. It is possible than to reach more accurate indoor temperature control of the building. Such heating process control may be than called outdoor temperature compensation with room influence. The classical outdoor temperature compensation ensures equilibrium between supplied power and heat loss of building while outdoor temperature compensation with room influence can extra ensure compensation on the other heat gains or losses into heated space.

There are several theoretical possibilities of the correction of desired supply water temperature (calculated by classic outdoor temperature compensation from the set up heating curve and actual outdoor temperature) according to the temperature in reference room. The principle of correction based on adding of the superior control loop with Model-Free Adaptive (MFA) controller was used.

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2 MODEL-FREE ADAPTIVE CONTROLLER

Multilayer neural networks with forward propagation and adequate number of the hidden neurons are universal approximation tool and so they are able to describe (with required accuracy) input-output behavior of any continuous function. They can be understood as universal instrument for regression analysis of the function defined by trained set where form of the simulated function will be designed by architecture of the artificial neural network (by neurons connection topology and set-up of the weight and threshold coefficients). This feature can be utilized for identification of the complex systems where classical methods fail.

The control objective for the controller is to produce an output $u(t)$ to force the process variable $y(t)$ to track the given trajectory of its setpoint $r(t)$ under variations of setpoint, disturbances and process dynamics. Then our problem is to create and train such artificial neural network (ANN) which will generate such output $u(t)$ so that process variable $y(t)$ would follow up the setpoint $r(t)$. In other words, the task of the Model Free Adaptive (MFA) controller is to minimize the error $e(t)$ in an online fashion, where $e(t)$ is the difference between the setpoint $r(t)$ and the process variable $y(t)$. Figure 1 illustrates the detailed architecture of a SISO MFA controller. The neural network has one input layer, one hidden layer with N neurons and one output layer with one neuron.

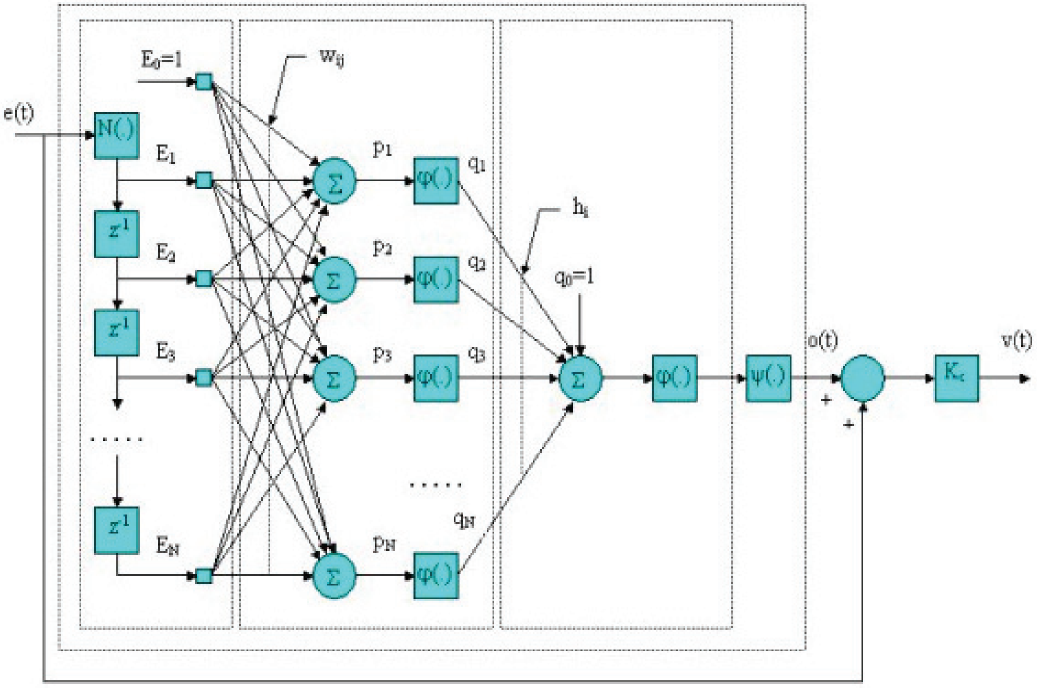

Fig. 1 Architecture of the Model-Free Adaptive controller

Model Free Adaptive (MFA) controller based on artificial neural network has several advantages in comparison to classical PID controller. For example MFA controller "remembers" a portion of the process data providing valuable information for the process dynamics. In comparison, a digital version of the PID controller remembers only the current and previous two samples. In this regard, PID has almost no memory and MFA possesses the memory that is essential to a "smart" controller.

2.1 Feedback law

The discrete MFA controller is designed as the sum of 3-layer perceptron neural network (Φ) and a proportional element. The feedback law calculates the current control output *u*(*t*) based on the last *N* samples of the control deviation *e*(*t*) with sample time *T*:

$$u(t) = \Phi\big(e(t), e(t-T), e(t-2T), \cdots, e(t-(N-1)T); w\big) + K_c e(t)\,. \tag{1}$$

Here *w* represents the vector of the weights of the neural net Φ. The control objective is to make the measured variable *y*(*t*) track the given trajectory of its setpoint *r*(*t*). This means, that we have to minimize the quadratic error

$$E_s(t) = \frac{1}{2}e^2(t) = \frac{1}{2}\big[r(t) - y(t)\big]^2 \tag{2}$$

through adjusting the weights of the neural network. This is made by using online learning with gradient descent.

The input signal *e*(*t*) to the input layer is scaled by a scaling function *L*(.):

$$L(.) = \frac{K_c}{T_c}\,, \tag{3}$$

where $K_c > 0$ is defined as controller gain and T_c is the user selected process time constant. They are important parameters for the MFA controller since K_c is used to compensate for the process steady-state gain and T_c provides information for the dynamic behavior of the process. The use of T_c as part of the scaling function permits a broad choice of sample intervals T_s, because the only restriction is that T_s must conform to the formula $T_s < T_c / 3$ based on the principles of information theory.

2.2 Adaptive algorithm

Within the neural network there is a group of weighting factors (w_{ij} and h_i) that can be updated as needed to vary the behavior of the controller. The algorithm for updating the weighting factors is based on the goal of minimizing the error between the setpoint and process variable. Since this effort is the same as the control objective, the adaptation of the weighting factors can assist the controller in minimizing the error while process dynamics are changing.

Let us consider that activation function is non-linear and differentiable. The partial derivative of the objective function considering weight coefficients can be (on the base of rule for derivative of complex function) written as:

$$w(t+T) = w(t) - \eta \cdot g(w(t))\,, \tag{4}$$

$$g(w(t)) \approx \frac{\partial E_S(t)}{\partial w(t)}\,, \tag{5}$$

$$\frac{\partial E_S(t)}{\partial w(t)} = e(t)\frac{\partial e(t)}{\partial w(t)}\,, \tag{6}$$

where $\eta > 0$ is the learning rate defined as:

$$\eta = 0{,}0029T - 2e^{-5}\,. \tag{7}$$

Dependence of learning rate η on sample time *T* defined by (7) was found out through the stability analysis of the Model-Free Adaptive control in Matlab Simulink.

3 BLOCK DIAGRAM OF MFA HEATING PROCESS CONTROL

The classical verified approach to the heating process control is using of outdoor temperature compensation. Outdoor temperature compensation is a specific case of the follow-up control. The temperature of supply water is desired variable for control and it is operated by temperature of outdoor air according to set up heating curve. Consequently heating curve describes dependency of supply water temperature on outdoor air temperature. This dependency is non-linear and is given by heat insulation facilities of building. For practical application there are several heating curves that are characterized by different steepness (number). The heating curve with higher temperature of supply water is set up for heating systems dimensioned for higher temperature drop. For good insulated buildings it is possible to set up the curve with lower temperature of supply water. The temperature change into heated spaces can be made by shifting of heating curve too.

The classical outdoor temperature compensation was supplemented with the temperature sensing in the reference room and correction of desired supply water temperature based on adding of the superior control loop with Model-Free Adaptive (MFA) controller was used (Figure 2).

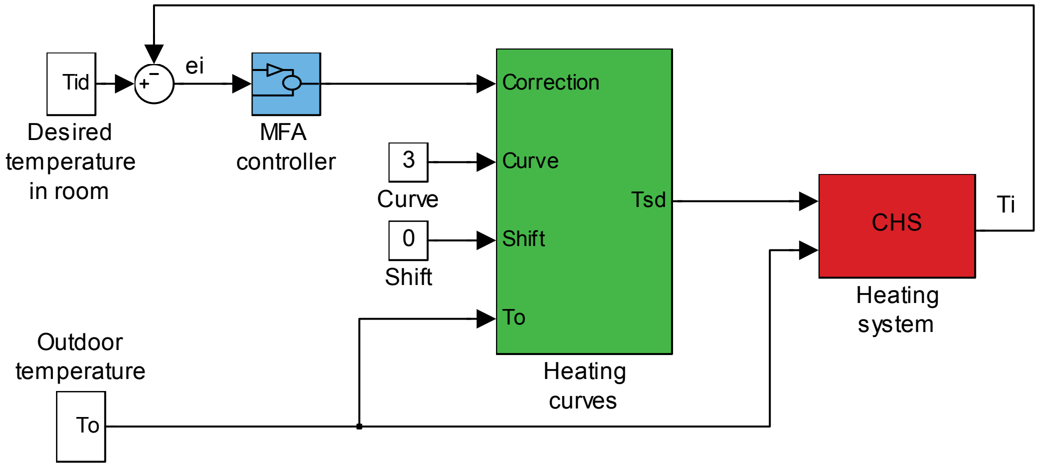

Fig. 2 Block diagram of MFA heating process control

MFA controller according to control deviation between desired and actual temperature value in reference room increases or decreases desired supply water temperature calculated from the set up heating curve and actual outdoor temperature. The variables in block diagram on Figure 2:

T_{id} – desired variable of indoor temperature,

T_i – indoor temperature,

e_i – control deviation of desired and actual value of indoor temperature,

T_o – outdoor temperature,

T_{sd} – desired variable of supply water temperature.

The major section of block diagram on Figure 2:

- superior control loop on the base of MFA controller,
- heating curve consisting of functional block of default heating curves and blocks for option of heating curve number and shift,
- heating system block comprehensive of the model of heating body and heated space.

4 SIMULATION OF MFA HEATING PROCESS CONTROL

On the base of designed block diagram of MFA heating process control the simulation model has been created and simulated by Matlab Simulink. The Netlab Toolbox in Matlab has been used to create and train the neural network. The NETLAB toolbox is designed to provide the central tools necessary for the simulation of theoretically well-founded neural network algorithms for use in teaching, research and applications development. The network was created as MLP (Multi-Layer Perceptron). The MLP is probably the most widely used architecture for practical applications of neural network. In most cases the network consists of two layers of adaptive weights with full connectivity between inputs and hidden unit, and hidden units and outputs. This two-layer architecture is the one implemented in Netlab.

Simulation results for change over of desired variable of indoor temperature between 19°C to 21°C are on Figure 3. It results from simulation that by using of MFA controller it is possible to reach zero control deviation of desired and actual temperature value in reference room also by relative incorrect set up heating curve.

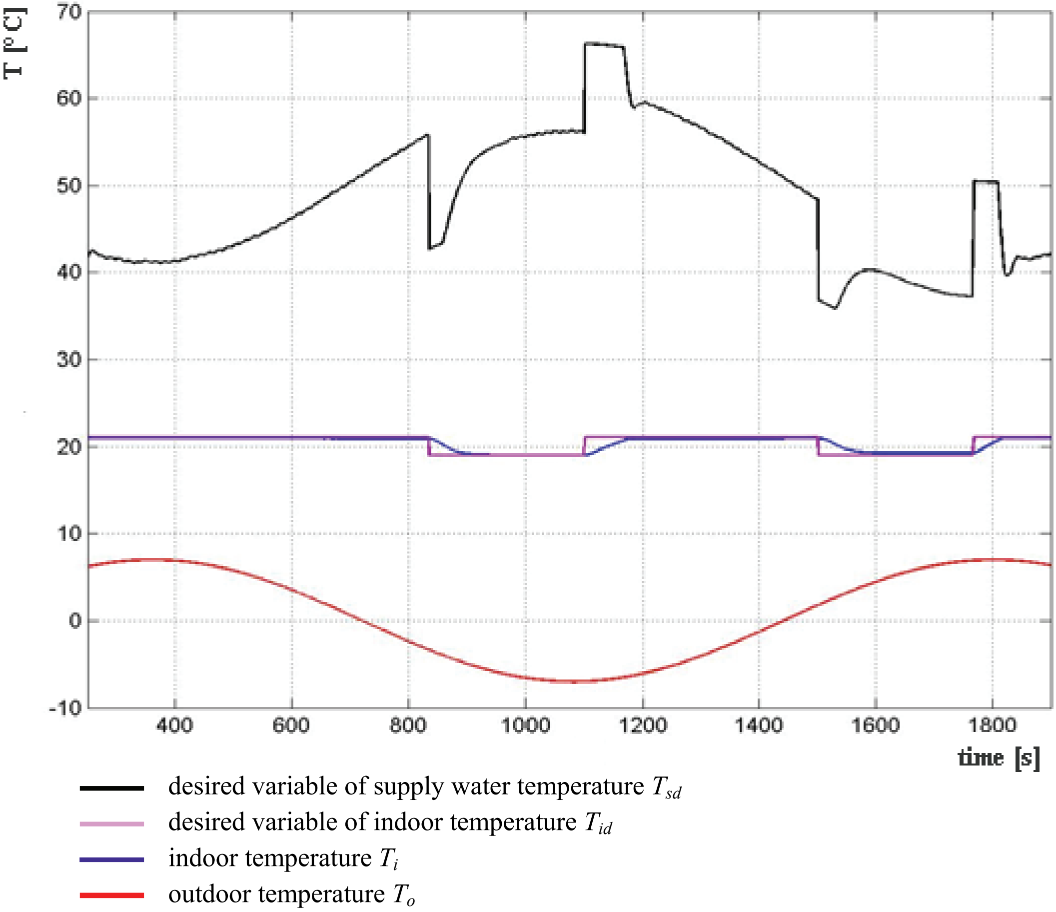

Fig. 3 Simulation results of MFA heating process control

5 CONCLUSIONS

Testing of the MFA controller adaptation and its comparison to a classic PID controller on heating process control model has proved that MFA controller can adapt to process structure changes in heating process very well. The better control behaviour of MFA controller can ensure zero control deviation more quickly than PID controller. MFA controller "remembers" a portion of the process data providing valuable information for the process dynamics. MFA controller possesses the memory that is essential to a "smart" controller.

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