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COMPARISON OF CONTROL SYSTEMS WITH DIFFERENT TYPES OF CONTROLLERS

The paper studies operation of control systems with different types of controllers by the example of acetylene generator. Their transient characteristics are obtained and quality indices are calculated. Recommendations as to expediency of the use of PID controller, fuzzy, adaptive and neural network controllers are presented.

Key words: *manufacturing process, control system, controller, simulation.*

Introduction

Control systems of manufacturing processes are extremely important as they determine, to a great extent, the end product quality and its cost. The importance of control system and quality of its operation grows essentially for industrial objects of continuous operation with large production volumes. The factor of dangerous productions should also be taken into account. Production of acetylene, an important and widely-used component of industry, is one of such processes.

Analysis of the problem

Although there are various methods of acetylene production, the so called carbide method, where an input raw material is carbide calcium supplied into water, remains one the most common methods [1]. Technologically, this method is realized in acetylene generator, where acetylene is released during the process of carbide decomposition. Acetylene production is accompanied by the emission of a large amount of heat, which creates the danger of extreme overheating of the reactive mass and, if cooling is insufficient, can cause an explosion. This confirms vital importance of the development of acetylene generator control system, particularly, for its temperature mode control.

Analysis of the research works shows that an overwhelming majority of industrial control systems are based on classical control theory approaches, which are realized quite simply by means of PID controllers. However, such systems cannot always provide the required quality of control, especially in the conditions of complexity, inertia, random perturbations, unavailability of qualitative and comprehensive information [2, 3].

Hence, the work aims at increasing the process control efficiency by comparison of different control systems and development of recommendations on the feasibility of their application.

Mathematical model of the PID controller object and setting

On the basis of the conducted analysis a conclusion can be made that temperature in the apparatus is the most important parameter of the process. This is explained by the fact that calcium carbide interaction with water occurs quite actively with the release of large amounts of heat, and for normal flow of the process it is necessary to maintain the set temperature.

There are several ways to control the generator temperature mode: to vary consumption of carbide or the water flow rate. Carbide consumption could be varied by means of varying rotation speed of the drum while water flow rate could be modified easily by means of a valve. This is the method used in practice. Therefore, “water flow rate for cooling – temperature in the apparatus” is taken as a control channel. On the basis of the material balance equations, using linearization and Laplace transformation, the following transfer function of the control channel is obtained [4]:

$$W(p) = \frac{1.54}{10.61\mathrm{p}+1} \cdot e^{-9.2p}.$$

Since accuracy is the most important system quality index, the mean squared deviation is chosen as the control system efficiency parameter. Synthesis of PID controller parameters is adjusted in the interactive mode in Control System Toolbox environment.

Control system with a fuzzy controller

At present, along with classical controllers fuzzy control algorithms are widely used. Advantages of fuzzy systems and the methods of their creation are described in detail in [2, 3, 5]. To create a controller, a classical scheme is used (Fig.1).

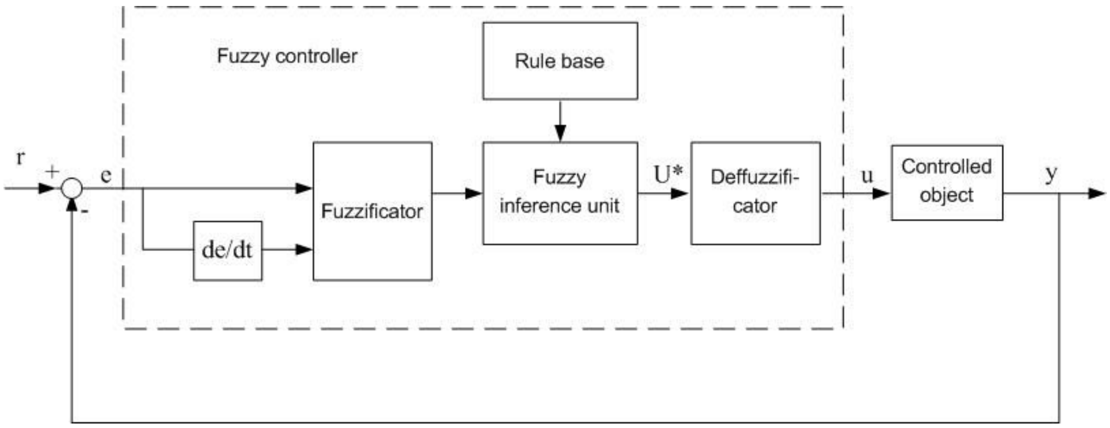


Fig. 1. Control system with a fuzzy controller

Fuzzy control system is created in Fuzzy Logic Toolbox environment of Matlab software package and is described in [4].

Control system with adaptive controller

As it is shown in [2], adaptive systems make it possible to solve a number of important control problems:

1. to optimize object operation;
2. to provide operability of the system with the required quality indices in the conditions of varying properties of the object;
3. to increase reliability and survivability of complex systems, to unify control algorithms for classes of objects;
4. to relax requirements to the system design process due to further acquisition of information in the process of operation.

Such functions are implemented using two approaches: regulator structure modifications and the change of regulator parameters. The paper proposes the second option presented in Fig. 2. The system operates as follows:

1. Control error is analyzed (its value, change rate, the sum)
2. On the basis of this information the controller parameters are computed in the adaptation unit.
3. Control signal is computed on the basis of PID law.

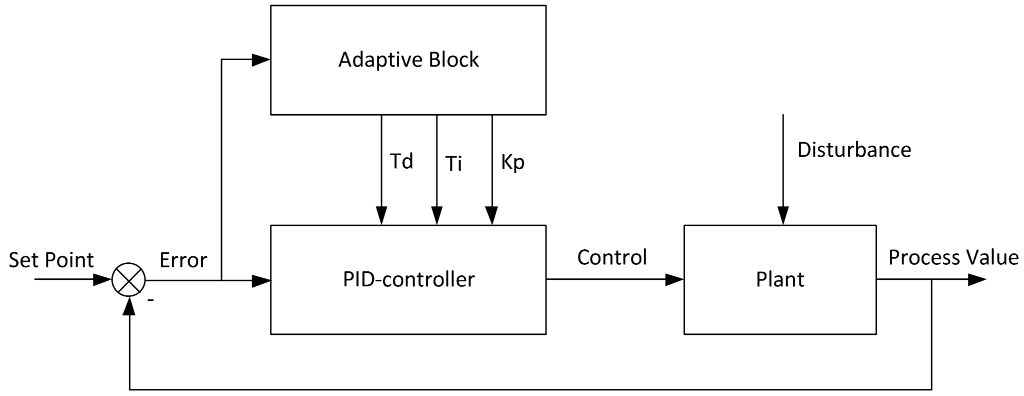


Fig. 2. Structure of the adaptive system

For realization of the above fuzzy algorithm Simulink environment and Fuzzy Logic Toolbox are used [6]. In Fuzzy Inference System Editor the system of Mamdani type is used and the following inputs are set: ε (k) – error value, deltaε (k) – the error change rate (a derivative), integralε (k) – error integral. The model outputs are the controller coefficients.

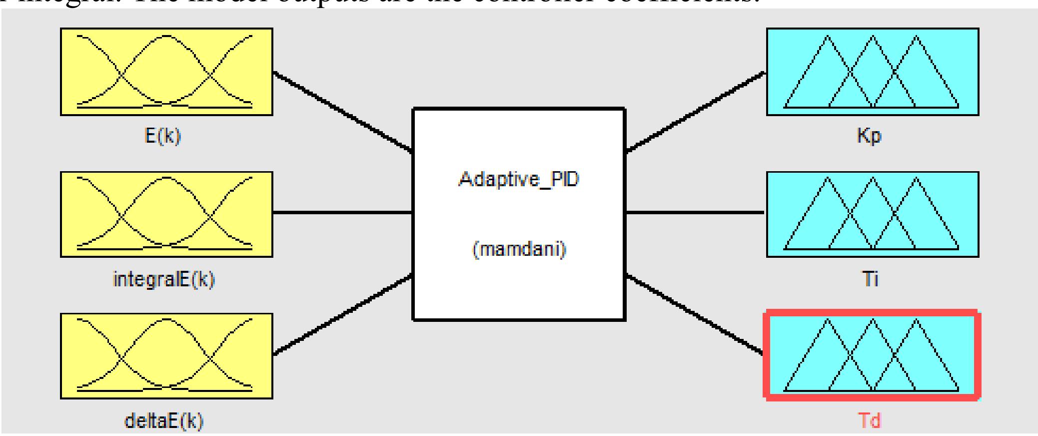
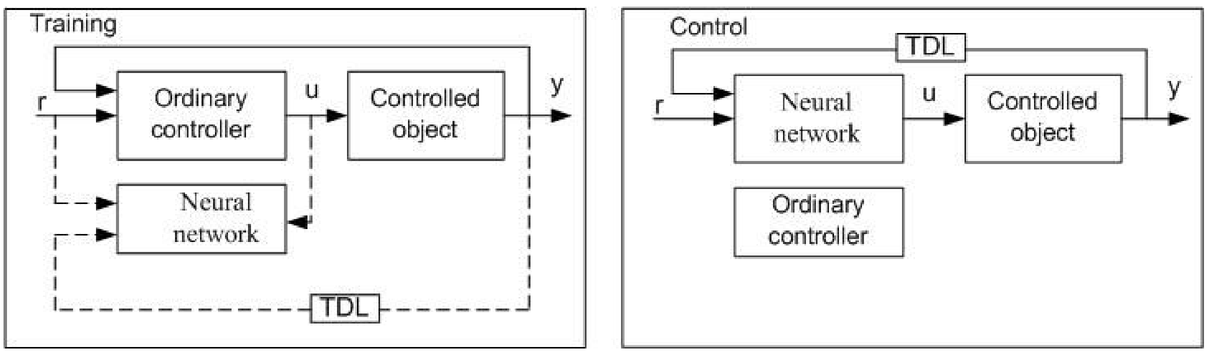


Fig. 3. Structure of the fuzzy adaptation unit

Simulation of the control system with a neural network controller

At present, there are more than seven ways of using neural networks in control systems [7]. One of the simplest among them is application of a neural control system where the controller learns by the examples of the conventional controller dynamics via feedback based on PID control scheme. The scheme of imitating neural control is shown in Fig. 4.



a) b)

Fig. 4. Scheme of the imitating neural network:
a) – neural network training mode; b) – control mode

After training the neural network exactly reproduces functions of the given controller and is connected instead of the initial controller. The obtained neural controller could be more economically advantageous than the initial controller. The main disadvantage of this method is the necessity of having a pre-set initial controller, which is not always possible. Besides, the neural controller, obtained by means of training, cannot, in principle, provide better control quality than the existing controller.

That is why, imitating neural control is used, mainly, for initial training of the neural network with the application of other methods for further training of the neural controller.

Neural network architecture comprises two layers and 20 neurons in the hidden layer. Construction of the neural network is performed in Matlab using nftool command, which allows to build a neural network of the required type. The program interface is presented in Fig. 5.

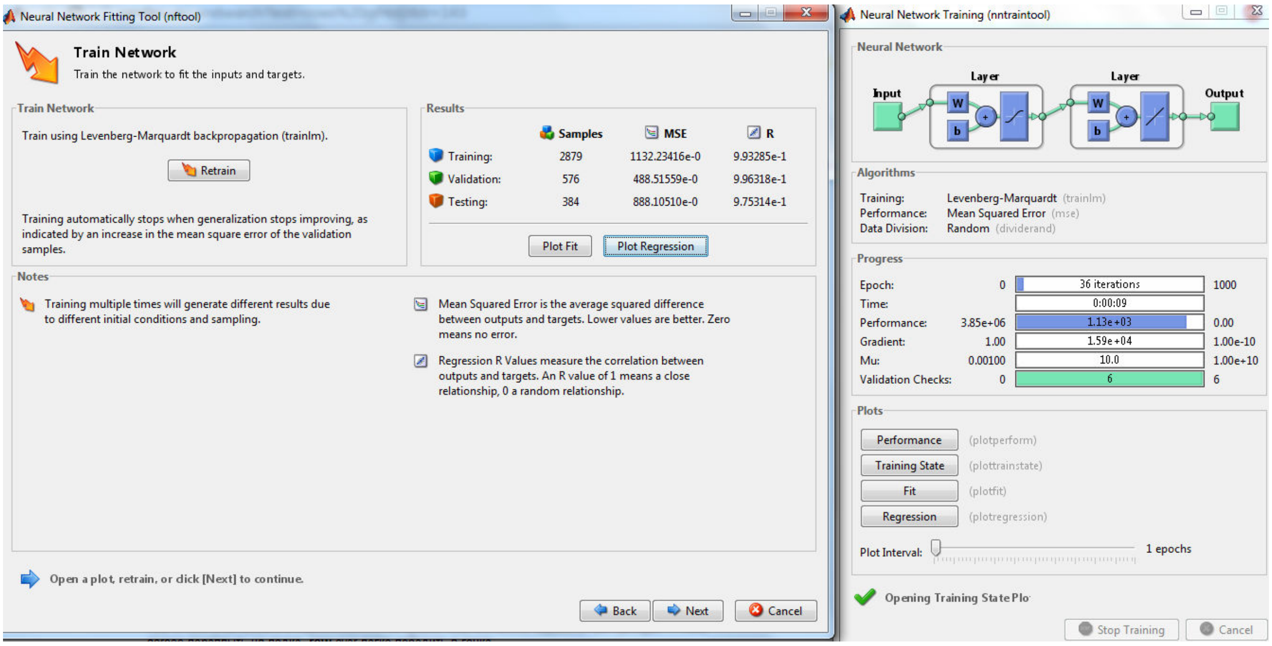


Рис. 5. Interface of nftool Matlab. The result of the neural network training

Neural network training was carried out using sampling obtained by means of studying the impact of random actions on the control object. The sampling size is 3893 points. The error values correspond to the input value and sampling of the control actions from the controller (PID controller in the classical loop) corresponds to the target value.

Comparison of control systems

All the networks were simulated in Simulink environment. Simulation scheme is shown in Fig. 6. For the analysis to be more convenient, data are loaded from Scope unit into Workspace and entered into a table. Then accuracy indices of control systems are computed.

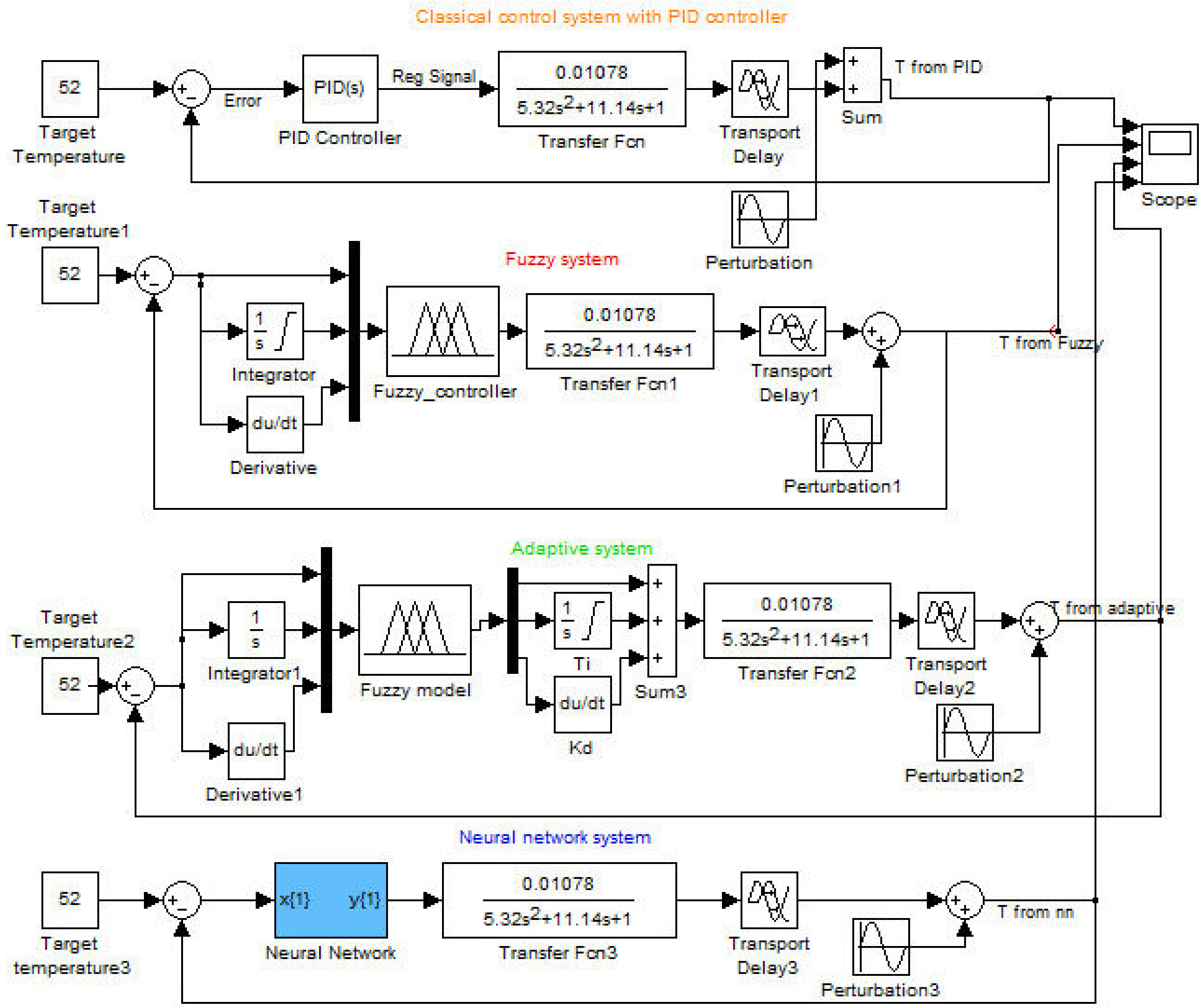


Fig. 6. Schemes of simulation of control systems in Simulink

Overshoot is calculated by the formula:

$$\sigma = \frac{h_{\max} - h(\infty)}{h(\infty)} \cdot 100\,\% \; .$$

The integral index is calculated by the formula:

$$I = \frac{1}{N}\sum_{1}^{N}(52 - y_i)^2 \; .$$

Experimental results

Transient processes in each system are shown in Fig. 7. Quantitative indices are presented in Table 1.

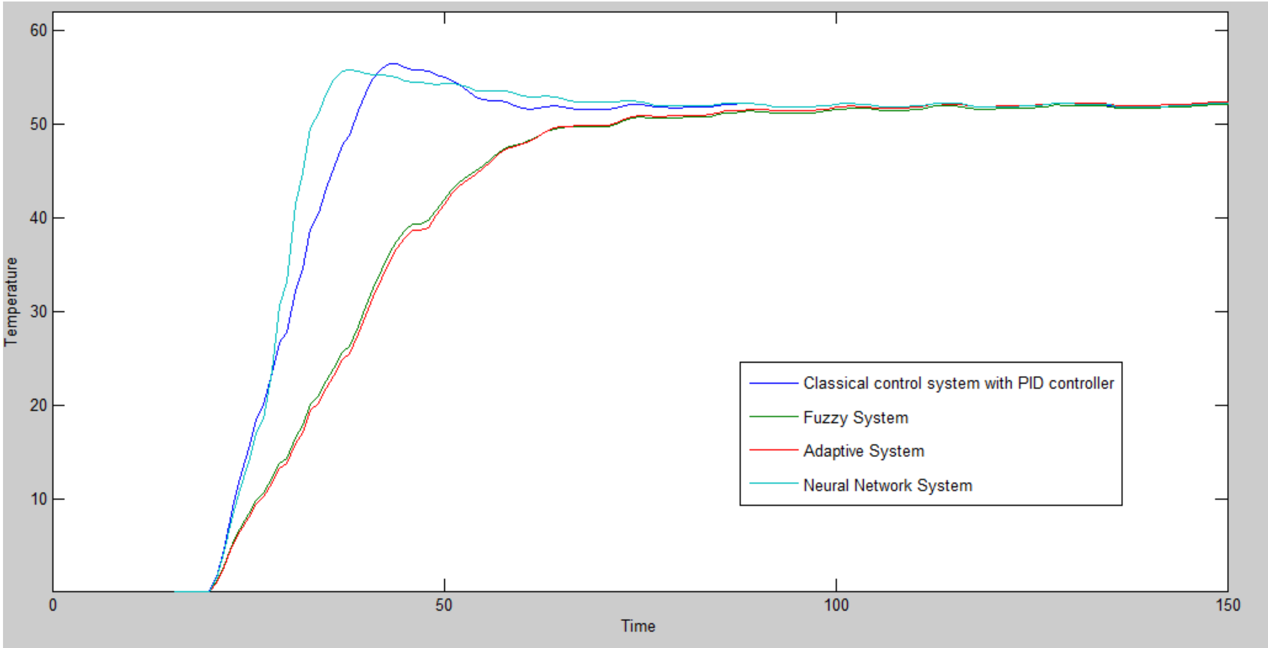


Fig. 7. Plots of the transient processes

Table 1

Simulation results

	Automatic control system with PID controller	Automatic control system with fuzzy controller	Adaptive automatic control system with fuzzy adaptation unit	Automatic control system with a specialized neural control
Overshoot, %	8,5%	0,3%	0,82%	7,2%
Transient process duration, c	64	97	97	67
Integral quality index	173,99	211,72	214,27	171,68

Conclusions

From the tables and plots the following conclusions can be made:

1. Automatic control system with PID controller is faster to achieve the set mode, automatic control system with fuzzy controller is slower, which could be due to the necessity of optimization of membership functions or due to the increased number of terms.
2. The biggest overshoot is observed in the automatic control system with PID controller. It should be noted that adjustments were performed automatically, i. e. it does not seem to be possible to improve this result. The least overshoot is demonstrated by the automatic control system with fuzzy controller, which is explained by slow and gradual process (without jumps) of achieving a steady-state mode. The same results are demonstrated by the adaptive system due to application of the fuzzy model as adaptation unit.
3. Automatic control system with a specialized neural control has the lowest integral quality index, which points to the smallest control error; automatic control system with fuzzy controller has the worst index.
4. In addition to the analysis of time criteria, comparison of control systems according to other criteria was performed. The results are presented in Table 2.

Table 2

Comparison of control systems

System / Criterion	Automatic control system with PID controller	Automatic control system with fuzzy controller	Adaptive automatic control system with fuzzy adaptation unit	Automatic control system with a specialized neural control
Mathematical model	Compulsory	Optional	Optional	Optional
Computation complexity	Average	Low	Low	High
Availability of D-analogs for chemical reactors	Available	Available	Partially available	Unavailable
Consumption of human resources for system construction	Low: operator	Operator-expert who creates the rules; developer	Operator-expert who create the rules; developer	Operator-expert who is responsible for test sampling; expert on neural networks
Model response time during system simulation process	Fast simulation process (Matlab)	Fast simulation process (Matlab)	Slow simulation process unless restriction unit is set correctly for integral component Matlab).	Time for training is required; several training cycles of NN or even NN architecture replacement could be necessary (Matlab)

Thus, each of the control systems has advantages and disadvantages according to different quality indices. None of the systems prevails over the others according to all indices. The choice of an appropriate control system architecture should be made on the basis of technological regulations as well as economic support of the system and is determined by the developer.

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