DEAL WITH UNCERTAINTY SYSTEMS USING INTELLIGENT CONTROL METHODS

ĐỐI PHÓ VỚI HỆ THỐNG KHÔNG CHẮC CHẮN SỬ DỤNG PHƯƠNG PHÁP ĐIỀU KHIỂN THÔNG MINH

Ta Van Phuong, Nguyen Quoc Tan, Nguyen Thanh Luan,
Ta Minh Giang, Ly Thanh Hung
Ho Chi Minh City University of Technology and Education, Viet Nam

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ABSTRACT

This paper represents superior properties of advanced control methods such as Fuzzy Logic, Neural network to PID controller for uncertainties systems to achieve good tracking response in real time. All three control methods are based on the feedback error signal that is then calculated on the processor through algorithms and outputting the optimal control signals. In particular, the uncertainties system such as an AC motor control model, temperature control model. These are two characteristic models, which differ in response latency and inertia control. Firstly, These models are controlled by the PID controller. Afterward, the Fuzzy controller and Neural controller are utilized for these models to explore the adaptive capability to changes in parameters of the advanced control methods. The experimental results for the AC motor speed control model and temperature control model are showed to verify the effectiveness and applicability of the advanced control methods for the uncertainty systems.

Keywords: *Nonlinear system control; Fuzzy rule-based; PID algorithm; Neural network controller; Adaptive control.*

TÓM TẮT

Bài báo này trình bày các đặc tính vượt trội của các phương pháp điều khiển hiện đại như điều khiển mờ, mạng nơ-ron đến bộ điều khiển PID cho các hệ thống không chắc chắn để đạt được phản hồi đáp ứng theo thời gian thực. Cả ba phương pháp điều khiển đều dựa trên tín hiệu lỗi hồi tiếp sau đó được tính toán trên bộ xử lý thông qua các thuật toán và xuất ra các tín hiệu điều khiển tối ưu. Đặc biệt, hệ thống không chắc chắn như mô hình điều khiển động cơ AC, mô hình điều khiển nhiệt độ. Đây là hai mô hình đặc trưng, khác nhau về độ trễ đáp ứng và quán tính điều khiển. Đầu tiên, các mô hình này được điều khiển bởi bộ điều khiển PID. Sau đó, bộ điều khiển Fuzzy và bộ điều khiển mạng nơ-ron được thực hiện để khám phá khả năng thích ứng với những thay đổi trong các thông số của các phương pháp điều khiển hiện đại. Các kết quả thử nghiệm trên mô hình điều khiển tốc độ động cơ AC và mô hình điều khiển nhiệt độ đã chứng minh được tính hiệu quả và khả năng ứng dụng của các phương pháp điều khiển hiện đại cho các hệ thống không chắc chắn.

Từ khóa: *Điều khiển hệ thống không tuyến tính; giải thuật mờ; giải thuật PID; mạng nơ-ron trong điều khiển; điều khiển thích nghi.*

1. INTRODUCTION

Dynamic equation of process systems can't be exactly achieved due to undefining parameters or change in parameters during operation. Therefore, the classic controller can't obtain good performance [1]. In recent years, many advanced controllers have been developed to deal with the uncertainty of the system such as the Fuzzy controller, Neural network [2]. In this study, the superior properties of the Fuzzy and Neural network controllers are also used to minimize error function to achieve high convergence speed and precision. The strong point of the Fuzzy controller is not needed to mention on describing the mathematical model. On the contrary, the characteristics of the system are described in the form of the language variable [3]. Neural network controllers (NNs) have a capability of learning from the training data sets to achieve desired objects. Through learning, NNs can also generalize to new situations or estimate nonlinear functions accurately. As a result, they are well used for uncertainty models with high complexity [4].

2. FUZZY AND NEURAL NETWORKS

2.1 Fuzzy logic

From the control point of view, there are usually two types of Fuzzy control [4]: *Direct control, Indirect control.*

Control method: In this study, we already used the direct control method to control the motor speed and temperature. The feedback signal is compared with a reference. If there is an error then the controller will adjust the control signal to reduce the error to zero [5].

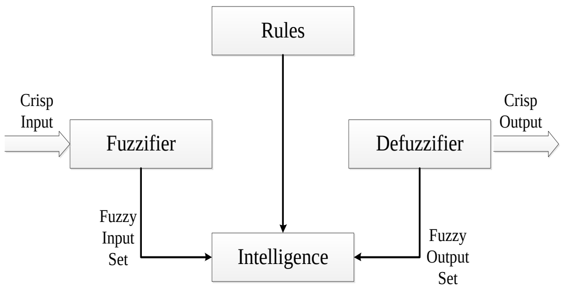


Figure 1. *Block Diagram of Fuzzy Logic Controller*

The overall structure of the Fuzzy logic controller is represented in FIG. 1. The controller consists of four blocks : Fuzzifier, intelligence, Rules Base and Defuzzifier. Fuzzifier defines input variables of membership functions and converts crisp input values into corresponding Fuzzy values. Intelligence and Rules Base are considered the brain of the Fuzzy controller that define a relationship between inputs and outputs based on the Fuzzy rules relating to the designer's experience. Defuzzifier is an interface which converts the combined results in the Fuzzy intelligence stage back into a specific control output value [6]-[7].

Fuzzy sets: A Fuzzy set on an X space is defined as follows:

$$\tilde{A} = \{(x, \mu A(x)) | x \in X\} \quad (1)$$

Membership function μA(x) defines the degree to which the x elements belong to the base set X. The value 0 means that x is not a member of the Fuzzy set; the value 1 means that x is fully a member of the Fuzzy set. The values between 0 and 1 characterize Fuzzy elements, which belong to the Fuzzy set only partially.

Fuzzy rules: The general name of a model represents one or more membership function.

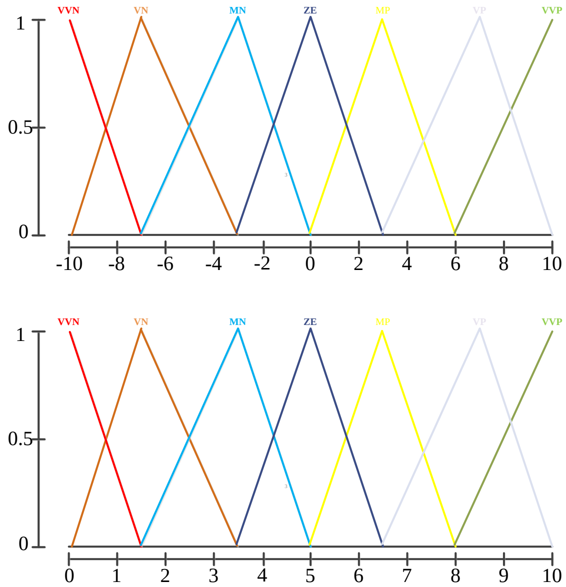


Figure 2. *Membership functions of inputs e(t), de(t)/dt and output r*

Table 1. *Rule base of Fuzzy controllers*

de/dt \ e	VVN	VN	MN	ZE	MP	VP	VVP
VVN	VVP	VVP	VVP	VVP	VP	MP	ZE
VN	VVP	VVP	VVP	VP	MP	ZE	MN
MN	VVP	VVP	VP	MP	ZE	MN	MN
ZE	VP	VP	MP	ZE	MN	VN	VN
MP	MP	MP	ZE	MN	VN	VVN	VVN

VP	MP	ZE	MN	VN	VVN	VVN	VVN
VVP	ZE	MN	VN	VVN	VVN	VVN	VVN

2.2 Neural Controller

Neural Networks imitate biological neural networks and have a basic structure as FIG. 3. [8]

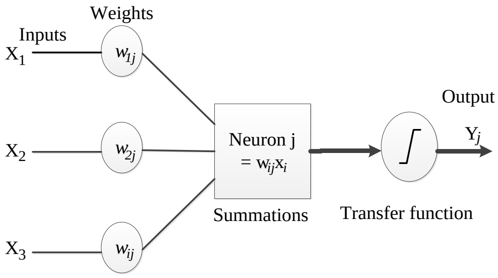


Figure 3. *Multiple-Input Neural.*

The individual inputs x_1, x_2, x_3, ..., x_n are each weighted by corresponding elements w_{1j}, w_{2j}, …,w_{ij}. The nonlinear functions are used as output activation functions. The output value of these functions are given as bellow

$$z = \sum_{i=1}^{p} w_i x_i + b = \left[w^T b \right] \begin{bmatrix} x \\ 1 \end{bmatrix} \quad (2)$$

Where b is bias constant of the inputs. [5][8]

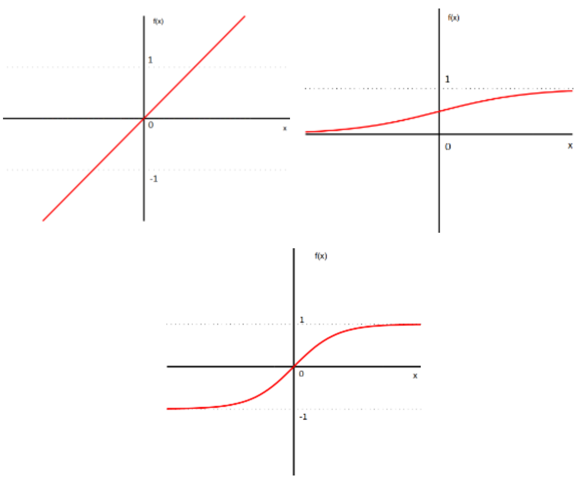


Figure 4. *Activation functions:*

(a) Purelin; (b) Logsig; (c) Tansig;

➢ Neural Network Architectures

Feed-forward Neural network: Neural networks are built in layers. The information moves in only one direction from the input layer through the hidden layers to the output layer. There are no cycles or loops in these networks.

Back-propagation Neural network: Neural networks are built in layers. The regression are performed inside the same layer or from the end to the first layer.

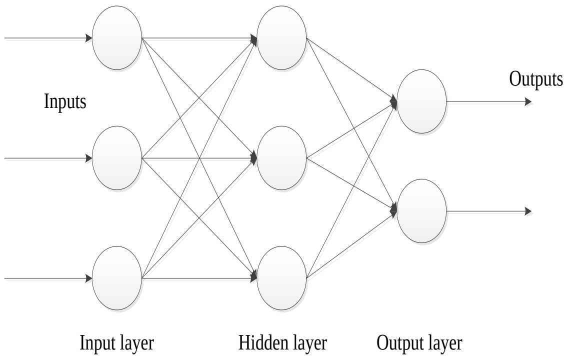


Figure 5. *Feed-forward Neural network.*

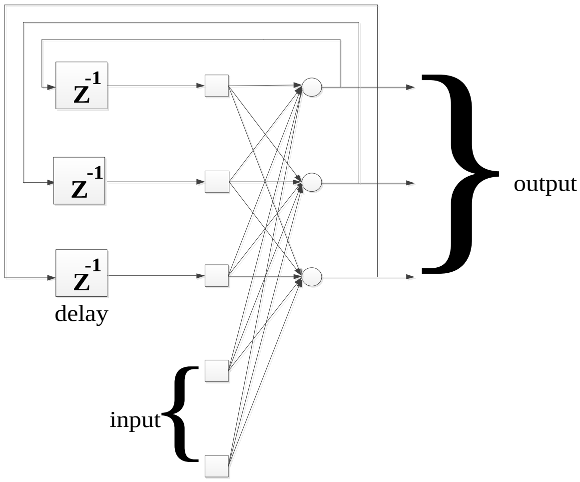


Figure 6. *Back-propagation Neural network.*

➢ Neural Network Training

Multilayer Neural network training algorithm includes two processes: Linear process and backpropagation [9].

Linear process: Data from the input layer through the hidden layers to the output layer. As each layer, the weights are changed to reduce an error between real output values and desired values to a presribed value.

Back-propagation: The errors propagate backward from the output layer to inner layers. The training process will find the weights to obtain the smallest error.

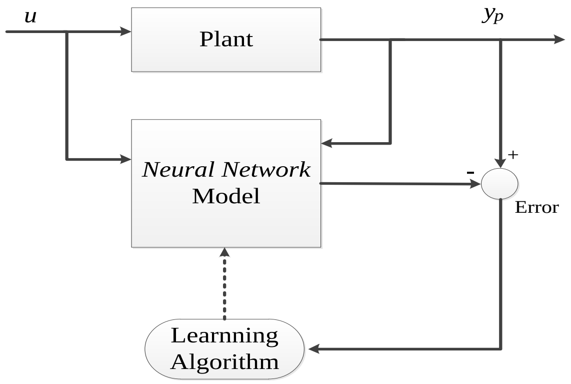


Figure 7. *The model uses Neural system identification.*

➢ **Backpropagation algorithm**

Asuming that X and D are the input and desired ouput vectors of the Neural network as follows.

$$X = \begin{bmatrix} x_1^T \\ x_2^T \\ . \\ . \\ . \\ x_n^T \end{bmatrix} \qquad D = \begin{bmatrix} d_1^T \\ d_2^T \\ . \\ . \\ . \\ d_n^T \end{bmatrix} \tag{3}$$

Where $x_i, i = 1,...,n$ and $d_i, i = 1,...,n$ are the number of inputs and desired ouputs, respectively.

The net input, neural output, network output and error can be described as follows

$$Z = X_b W^h, \ X_b = [X \ \ 1] \tag{4}$$

$$V = \sigma(Z) \tag{5}$$

$$Y = V_b W^o, V_b = [V \ \ 1] \tag{6}$$

$$e = D - Y \tag{7}$$

Where W^h, W^0, σ, Y and e are hidden weights, output weights, activation function, network output and error, respectively.

The mean square error is used as objective function to adjust network weights by backpropagation algorithm.

$$J(\mathrm{k}) = \frac{1}{2} e_k^2 \tag{8}$$

Weights are adjusted according to the following formula

$$w_i(k+1) = w_i(k) + \Delta w_i(k) = w_i(k) - \eta_i \frac{\partial J(k)}{\partial w_i(k)} \tag{9}$$

Where η_i is the learning rate value of [0 1]. The smaller learning rate, the more accurate can be obtained but learning time is longer.

3. EXPERIMENTAL SYSTEMS

3.1 Heating control system

The heating control system is described in FIG. 8. The image practical system is showed in FIG. 9. The system includes temperature sensor Pt100 (0 – 100℃), a transmitter (4 – 20mA), a converter from (4-20mA) to 0.66 – 3.3V, the heater powered by Solid State Relay. The microcontroller STM32F4 is utilized to control the system in real time. Besides that, the parameters of the controller and temperature are set and monitored with Matlab Simulink.

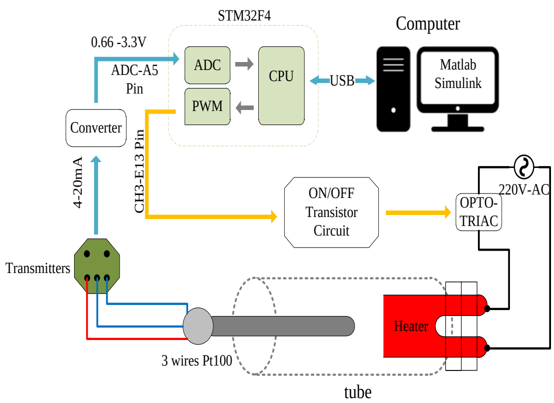


Figure 8. *Heating system block diagram*

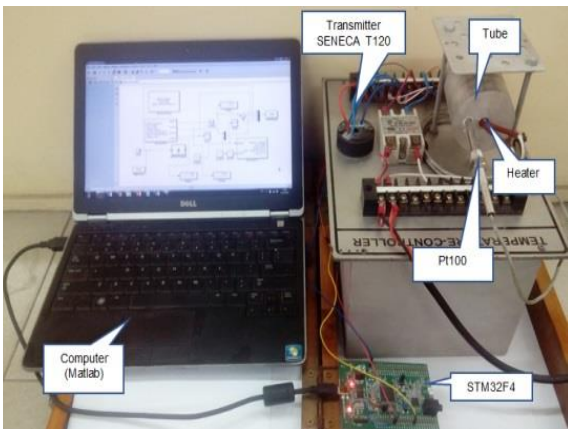


Figure 9. *Image of practical heating control system*

3.2 Motor speed control system

The motor speed control system is described in FIG. 10 and the image of the practical system are shown in FIG. 11. The system includes induction motor, generator, Encoder, Danfoss Inverter VLT 2800 and microcontroller STM32F4. All parameters of the controller and motor speed are set and monitored on PC by Matlab Simulink.

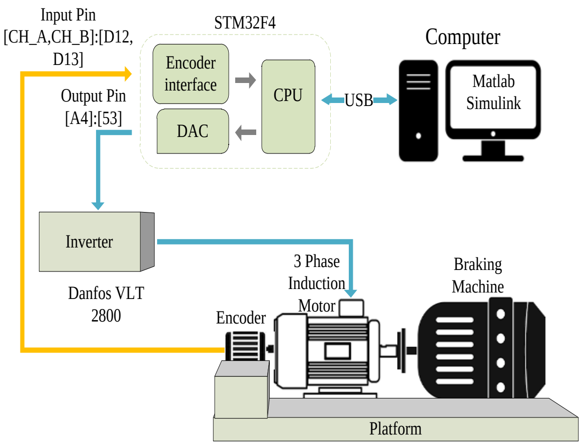


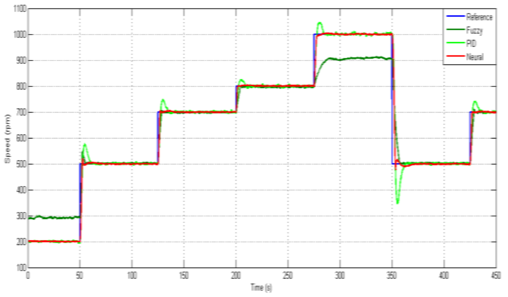
Figure 10. *Motor speed control system block diagram*

Figure 11. *Image of practical motor speed control system*

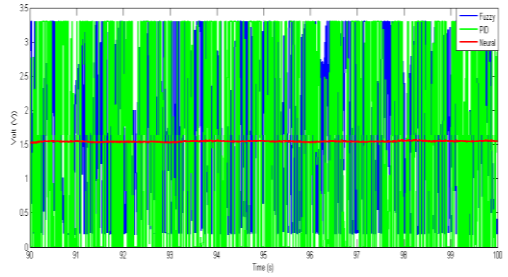
4. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results of control methods for two systems are given as follows:

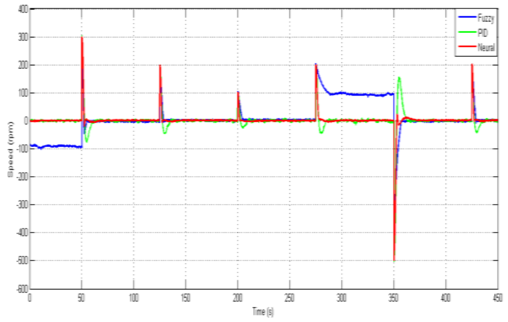
➢ **Motor speed control system**



(a)



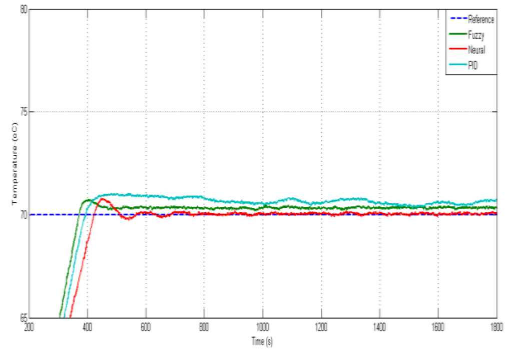
(b)



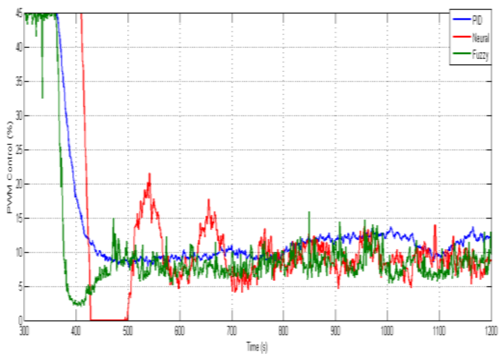
(c)

Figure 12*. Experimental results of motor speed control system: (a) Tracking to step references (b) control signal; (c) errors*

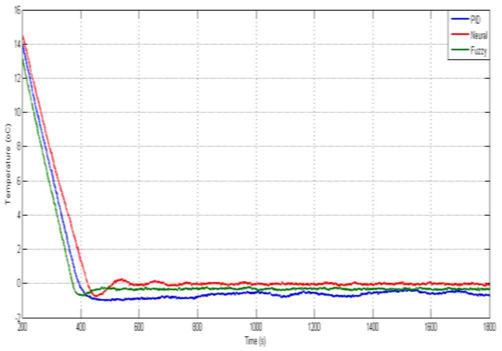
➢ **Heating control system**



(a)



(b)



(c)

Figure 13*. Experimental results of heating control system : (a) Tracking to step reference; (b) control signal; (c) errors*

➢ **Discussion**: The experimental results obtained from the above two systems match with the theory. Three control methods can convergence to the desired value as their limit range. However, the PID controller showed overshoot (FIG. *12(a)*) and much chattering existed in control signal (FIG. *12(c)); the* Fuzzy Logic controller showed good tracking respond without overshoot and less chattering but the working range is small. The Fuzzy controller works well from 300 to 900(rpm), (*FIG. 12(b)).* For the Neural network, the controller obtained good tracking response, reduced significantly overshoot and chattering at control signal (FIG. *12(a)-12(b), 13(a)).* Besides that, the features of heating systems are high acceleration and slow temperature reduction, we had to limit the control signal of all controllers at 45% PWM cycle (*FIG. 13(b)*). The experimental results showed that the NNs had the smallest state error (error ≈ 0^0C) comparing to Fuzzy (error ≈ 0.3^0C and PID (error ≈ $0{,}5^0$C) (FIG 13(c). However, the control signal of NNs of the heating system was not qualified (FIG. *13(b)*). This limitation can come from different reasons such as unsuitable learning rate setting, selecting unsuitability number of hidden layers, degree of the dynamic system in identification phase…etc.

5. CONCLUSION AND FUTURE WORK

➢ **Conclusion:** In this study, the PID algorithms, Fuzzy algorithms, and Neural network algorithms were already applied to control motor speed and temperature successfully in real time. Each control methods has its advantages and disadvantages. For the PID, the controller can obtain good tracking response if the parameters Kd, Ki, Kd are selected accurately. The Fuzzy algorithm has good performance if the Fuzzy sets and Fuzzy rules are suitability selected, these completely depend on programmer experience [10]. The Neural network needs to accurately identify the dynamic system, select a suitable number of hidden layers, weight, and bias to achieve good performance. However, the above experimental results showed that the NNs had better performance than Fuzzy and PID on convergence error, overshoot, a control signal and the range of operations.

➢ **Future work:** In the next study, we will improve the Neural network controller to achieve good performance on tracking response, convergence error, setting time and control signal. Furthermore, the controller should be applied to different complex nonlinear systems.

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Corresponding Author:
Ly Thanh Hung
Ho Chi Minh City University of Technology and Education
Email: 14151046@student.hcmute.edu.vn