Temperature Control with Fuzzy Neural Network

Bin Dai, Ren Chen
School of Computer and Information Engineering
Xiamen University of Technology
Xiamen, China
bdai@xmut.edu.cn

*Rung-Ching Chen
Department of Information Management
Chaoyang University of Technology
Taichung, Taiwan
*crching@cyut.edu.tw

Abstract—Temperature control is a very common scene in industrial control. Combined with our previous research, the temperature control of drinking water is an important aspect of improving human health. Traditional temperature control methods include PID control, or considering multiple input factors, fuzzy control is used to adjust and control temperature. However, the deficiency is that the control accuracy is not ideal, and the feedback control is relative slow. It is a good idea and solution to optimize the condition of judging rules in temperature control by using the method of combining neural network and fuzzy control, and combining the optimization of algorithm to improve the precision and speed of temperature regulation. In this paper, the architecture of fuzzy neural network for drinking water temperature control and the algorithm design method are proposed, and the precision of temperature control and the improvement of regulation speed are provided.

Keywords — Fuzzy neural network*; *temperature control*; *fuzzy logic*; *BP

I. INTRODUCTION

Fuzzy control logic system has been widely used in system modeling and control since it was born. The fundamental reason is that the fuzzy system can make good use of the expert system [1], and it also can transfer non- accurate information into control strategy and reasoning system, you can use the rules to solve a lot of problems that cannot be precisely modeling. Its advantages are very obvious, Fuzzy control does not require controlled objects to have accurate numerical description, and the generated inference rules have good robustness and can handle complex logic systems [2]. Therefore, the fuzzy control model has good human-computer interaction ability, and can be widely used in the current intelligent system.

Intelligent control theory is based on the non-model or non-accurate models for features closer to the control theory of human thinking mode, which is based on knowledge and information as the basis for learning and reasoning, the heuristic method to guide the solving process, with complexity, uncertainty and ambiguity and unknown algorithms of non-traditional mathematical formula the process of divination. Among all kinds of intelligent control methods, fuzzy control, neural network control and expert control are regarded as three typical intelligent control methods. At present, rule-based traditional expert systems are also gradually giving way to fuzzy logic based fuzzy control systems and neural network control systems.

Thanks to the great progress of scientific computing power and computer technology, in the late 80s, artificial neural network also ushered in a high-speed development and universal application stage [3]. For example, the multi-layer back propagation learning algorithm (BP algorithm) [4] has been the most popular neural network in many fields. It has been widely used in pattern recognition, adaptive control and classification using its powerful computing power.

In the industrial control field, it is precisely because of neural network has the characteristic of good fault tolerance, it can adapt to the control requirements with offline or online way, it also can approximated to any nonlinear function [5], so combine with the advantage of neural networks and fuzzy control are very natural research ideas and methods.

From the common point of view, both fuzzy systems and neural networks have the ability of parallel data processing, and the intelligent processing and judgment of the proposed targets and the estimation of the cost. The difference is the way of samples processing, the storage methods, and reasoning methods. Neural networks generally use samples to learn, whereas fuzzy systems usually acquire knowledge from expert systems. Under normal circumstances, we can use the fuzzy system to determine the structure of the problem, and using neural networks to build the system learning and processing capabilities. Comprehensive combine fuzzy systems and neural network advantages to enhance the overall structure of learning ability and expression, is one of the focuses of our research.

In temperature control field, how to improve the accuracy of temperature control is a topic of concern. The traditional method of fuzzy system is usually using experience and valuation methods to build the rules, the outputs are often not accurate and lack of adaptability to the environment temperature changing. Using equivalent module in fuzzy systems with neural networks, to generate fuzzy inference rules with learning ability and mapping ability of neural network, it can enhance the learning ability and adaptive ability of structure of temperature controlling, it also can combine the knowledge representation of fuzzy system to optimize the conventional neural network [6]. The practical problem we face is that it is a nonlinear system that controls and identifies and optimizes the problem. The advantage of using both fuzzy neural networks is a worthwhile attempt.

978-1-5386-2965-9/17/$31.00 © 2017 IEEE

In the traditional fuzzy control design, the control strategy is constructed by means of non-deterministic numerical and expression methods. Most of the advantages of traditional fuzzy control systems are the single input output system (SISO), which uses the change rate of error and error as input to obtain the best effect of PD and PI. However, in our actual system requirements, such as drinking water temperature control. In the case of multivariable input, the results of accurate reasoning will encounter big problems, such as consuming a lot of computing time. In the research of this paper, using the neural network to resolve the fuzzy system rules complexity and optimization the process of learning, automatic adjustment rules, and optimization and accurate output is our focus.

II. Design of Fuzzy Logic and Infrastructure

The contradiction between the diversity of control objectives and the various goals makes it necessary to consider various factors in the design of the controller. The conventional control method is mainly aimed at linear dynamic systems with lumped parameters. The object must be quantized and all kinds of quantization parameters are required

The relation can be described by differential equations or difference equations, that is, the system has a precise mathematical model. With respect to linearity, nonlinearity is absolute and global. Linear systems in general sense are idealized or approximate descriptions of nonlinear systems. The remarkable characteristics of nonlinear systems are the existence of multiple equilibrium, limit cycles, bifurcation and chaos. The description methods of nonlinear systems are much more complex than linear systems. So far, there is no accepted model description.

In 1965, Lotfi Zadeh, published his famous paper "Fuzzy sets". Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms. This new logic for representing and manipulating fuzzy terms was called fuzzy logic. Fuzzy logic emphasized on describing the different level of the things in real life, it extended the range of truth values to all real numbers into the interval between 0 and 1. Unlike two-valued Boolean logic, fuzzy logic is multi-valued. It deals with degrees of membership and degree of truth. Fuzzy logic uses the continuous values between 0 and 1 to represent that things can be partly true and partly false.

The general fuzzy logic and infrastructure can be represented in figure 1. Fuzzy logic can accept linguistic variables as input data. The input variables in a fuzzy system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification". Inference engine is actually the processing stage invokes each appropriate rule coming from rule base and knowledge base and generates a result for each, then combines the results of the rules. The system structure is showed in Figure 1 and the detailed explanation is as follows.

We can use Fig. 1 to describe the general fuzzy logic and its infrastructure. Typically, fuzzy control logic can handle nondeterministic problems. For the specific problems that need to be dealt with, the fuzzy processing method can describe the input factors as fuzzy sets, and each fuzzy set can be expressed by the corresponding membership function. The process of converting a crisp input value to a fuzzy value is called "fuzzification" [6]. In fuzzy logic, rules are actually used to deal with similar problems or to make use of the data in expert systems. The process of defuzzification is actually the process of converting uncertain data into deterministic data. [7].

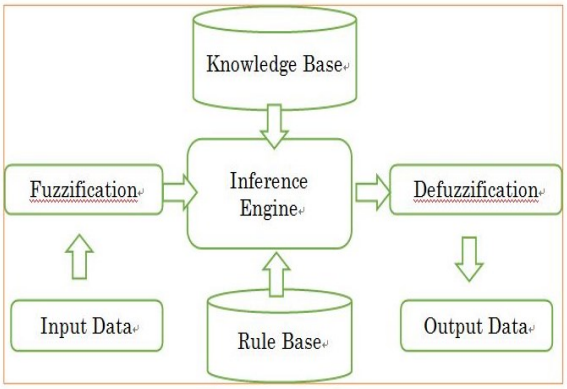

Fig. 1. The infrastructure of the fuzzy system

Taking water temperature control as an example, the input factors may include multiple factors, including environmental temperature, age, sex, and specific diseases. For each factor, the corresponding membership function can be designed. For example, environment temperature can be set to low-low, low, middle, high, high-high. In the fuzzy sets, the triangular membership functions are used because they have been proven to be successful in many places.

The fuzzy temperature control structure is shown in Fig. 2.

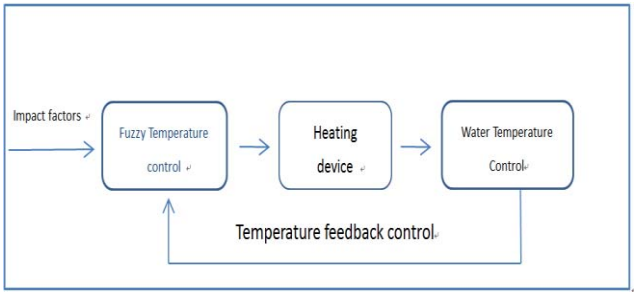

Fig. 2. The fuzzy temperature control structure

As shown in the fig above, the temperature control is ok and the temperature is around 22℃. But the result is not good because the difference of temperature is a little big. The reason is that the fuzzy sets are not good. In summary, the result proves that the fuzzy logic can control the temperature well.

III. Structural Design of Fuzzy Neural Network for Temperature Control

To construct temperature control fuzzy neural network, whose basic structure still takes advantage of the basic logic of fuzzy system, includes fuzzification, rule inference and defuzzification. At the same time, using neural network to solve the problem of initialization and training etc. Learning

978-1-5386-2965-9/17/$31.00 © 2017 IEEE

algorithm can have a variety of options according to the type of neural network; the neural network can generate an n-dimensional training data, through which to optimize the structure and output rules.

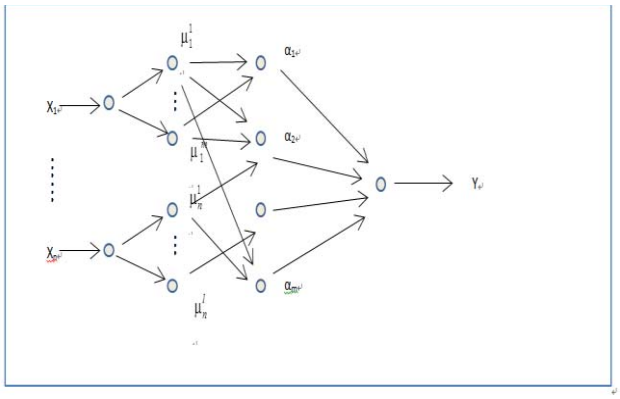

Fig.3. Temperature control fuzzy neural network infrastructure

As shown in Fig. 3, the first layer in the architecture is the input layer, and its nodes correspond to the input factors. The function is to transfer the input values X = {x1, x2, ..., xn} T to the next layer. The number of nodes is equal to the number of input factors. Here is the assumption that there are N input factors.

Each node in the second layer represents the fuzzy subset of each input factor, that is, the membership function. The function is to compute the membership function U of each input factor [8].

$$\mu_j^i = \mu_{A_j^i}(X_n^i) \qquad (1)$$

j=1, 2, 3…n, i=1, 2, 3,….l, N is the number of input factors, and j is the number of fuzzy subsets. If the membership function uses the Gauss function, then we can get the following formula [9]:

$$\mu_{A_j^i}(x_j) = \exp[-(\frac{x_j-\alpha_j^k}{\sigma_j^k})^2] \qquad (2)$$

Where α_j^k and σ_j^k represent the center and width of the membership function respectively. The total number of nodes in the second layer is

$$N_2=\sum_{j=1}^{m} m_j \qquad (3)$$

Each node of the third layer represents a rule that matches the fuzzy rule and calculates the suitability of each rule.

$$\alpha_j = \min\{\mu_1^{j_1}, \mu_2^{j_2}, \mu_3^{j_3}, \ldots . \mu_n^{j_n}\} \qquad (4)$$

For the input factor, the value of the variable near the center of the membership function value is larger, and the farther away from the center, the value is smaller. Therefore, in the rule layer, only a small number of nodes output is non 0, and most nodes output is 0, which is the principle and method of approaching network structure.

The last layer is the output layer, also known as the defuzzification layer, which can be expressed in vector form [8].

$$W=\begin{bmatrix} w_1^1 \\ w_2^1 \\ \vdots \\ \vdots \\ w_n^1 \end{bmatrix} \qquad \alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \vdots \\ \alpha_n \end{bmatrix}$$

W is the central value of the membership function, that is, the weight value.

IV. DISCUSSION

Neural networks and fuzzy logic systems are two effective methods in modeling and control of nonlinear systems. With the development of science and technology in related fields, the research of fuzzy theory and neural network technology has made remarkable achievements and breakthroughs in their respective disciplines. Especially the universal approximation theorem of theoretical results of three layer network in neural network can realize continuous nonlinear mapping and fuzzy logic system, which plays an important role in the modeling and control of nonlinear system identification. Since the turn of the century, the system of fuzzy theory has been developed

Fuzzy technology has been gradually improved, and achieved great success in the industrial control application, especially once again neural network research upsurge, many people naturally look to the combination of the fuzzy logic system and neural network is an important direction. From the end of the century to the beginning of the 20th century, the integration of fuzzy logic systems and neural networks began to attract academic attention. In recent years, the integration of these two methods has become a new hot spot in the research of intelligent control methods.

The adjustment of drinking water temperature under multi factor condition can be accomplished by using the traditional fuzzy control method. The rules of fuzzy control mainly depend on people's experience, but the experience is likely to be wrong, which will inevitably affect the accuracy and accuracy of control. At the same time, when the input factor increases, the sharp increase in the number of rules is also a big problem.

Using the method of fuzzy neural network to complete this kind of problem has many advantages, the neural network can have self-learning and self-adjustment function, and neural network can combine fuzzy control architecture and the use of weights in the processing parameters of fuzzy control. With the appropriate algorithm, the training times of fuzzy neural networks can enhance their learning ability. In the temperature control problem, the fuzzy neural network can enhance the control accuracy and shorten the feedback control time.

REFERENCE

[1] F.J. Lin, K.H. Tan, D.Y. Fang, and Y.D. Lee, "Intelligent controlled three-phase squirrel-cage induction generator system using wavelet fuzzy neural network for wind power," IET Renew. Power Gener., vol. 7, no. 5, pp. 552-564, 2013.

978-1-5386-2965-9/17/$31.00 © 2017 IEEE

[2] A. Mesemanolis, C. Mademlis, and I. Kioskeridis, "Optimal efficiency control strategy in wind energy conversion system with induction generator," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 4, pp. 238-246, Dec. 2013.

[3] H. Y. Chang, C.T. Tzeng, K.H. Yang, Y.K. Chuah, and M.C. Ho, "Energy saving and payback period for retrofitting air conditioning systems in Taiwan," Applied Mechanics and Materials, vol. 121-126, pp. 2850-2854, Oct. 2011.

[4] P.C. Chang, C.H. Liu, and C.Y. Fan, "Data clustering and fuzzy neural network for sales forecasting: A case study in printed circuit board industry," Knowledge-Based Systems, vol. 22, pp. 344-355, 7 2009.

[5] Q. Gao, X.J. Zeng, G. Feng, Y. Wang, and J.B. Qiu, "T-S-fuzzy-model-based approximation and controller design for general nonlinear systems," IEEE Trans. Syst. Man Cybern. B Cybern., vol. 42, no. 4, pp. 1143-1154, Aug. 2012.

[6] J.D.J Rubio and J. Rubio, "SOFMLS: Online self-organizing fuzzy modified least-squares network," IEEE Trans. Fuzzy Syst., vol. 17, pp. 1296-1309, Dec. 2009.

[7] E. Lughofer, "Evolving fuzzy systems-methodologies," in: Advanced Concepts and Applications, Berlin Heidelberg:Springer, 2011.

[8] P.C. Shill, K.K. Pal, M.F. Amin, and K. Murase, "Genetic algorithm based fully automated and adaptive fuzzy logic controller," in: Fuzzy Systems (FUZZ) IEEE International Conference, pp. 1572-1579, June 2011.

[9] O. Castillo and P. Melin, "Type-2 fuzzy logic: theory and applications," Studies in Fuzziness and Soft Computing, vol. 223, pp.45-52, 2008.

978-1-5386-2965-9/17/$31.00 © 2017 IEEE