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Structure Optimization of Fuzzy Neural Network by Genetic Algorithm

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ABSTRACT: This paper presents an auto tuning method of fuzzy inference using Genetic Algorithm. The determination of membership functions by human experts is a difficult problem. Therefore, some auto-tuning methods have been proposed to reduce the time-consuming operations. However, the convergence of the tuning by the previous methods depends on the initial conditions of the fuzzy model. So, we proposes an auto tuning method for the fuzzy neural network by Genetic Algorithm (*ATF* system). This paper shows effectiveness of the *ATF* system by simulations.

1. INTRODUCTION

Recently, fuzzy inference has been applied to the various problems: machine control, manufacturing system, and so on [8-12]. The fuzzy inference has the characteristic, which the fuzzy rules can describe the way in which human experts formulate their knowledge. However, the determination of the fuzzy rules, which depends on human experts, is a difficult problem. Therefore, auto-tuning methods are desirable to improve the wasted operations, and many works have been performed about the auto fuzzy tuning algorithm [10-12].

The Fuzzy-Neural Network, which is one of the auto-tuning methods [11,12], is actually an excellent in the manner of the adjustment of the fuzzy rules. However, the tuning method has a weak point, because the convergence of tuning depends on the initial conditions.

On the other hand, another method using the Genetic Algorithm (GA) is proposed for the purpose of auto-tuning and optimization of the structure of the fuzzy model [10]. The Genetic Algorithm is one of the optimization methods based on the biological evolution process [1-5]. However, the restriction of the position of membership functions prevents the construction of more compact structure of the fuzzy model.

Considering the background as mentioned above, we propose an auto tuning method for the fuzzy neural networks based on Genetic Algorithm (*ATF* system). The *ATF* system has two tuning processes. One is the coarse tuning process, which is based on the multiple point's search. The characteristic of the multiple point's search with GA discriminates this algorithm from the other random search methods [6]. The candidates of the optimal result exist in the search space, and the exchange or development among them enable to search the optimal result without stuck in the local minimum. The coarse process determines the appropriate structure and coefficient weights of a fuzzy model using the GA.

The other one is the fine tuning process. This process tunes the structure of the changeable membership functions and coefficient weights of the fuzzy model, which is given by the coarse tuning process, using the delta rule [7] respectively.

In the following chapters, we explain the composition of the *ATF* system for the auto fuzzy tuning. Furthermore, simulation results show effectiveness of our proposed system.

2. ATF system

In this chapter, we illustrate the construction of the *ATF* system to obtain the optimal simplified fuzzy model, which consists of the triangular-shaped membership functions on the antecedent part and the real values on the consequent part. This procedure is shown in Fig. 1.

(1) The initial generation which has some strings, in which each string includes a structure of fuzzy model, are generated randomly. (2)

Cross-over and Mutation operations are performed to create new strings. This operations correspond to the coarse tuning process, as mentioned before. (3) The membership functions and the real values are tuned by using the delta rule [7], which corresponds to the fine tuning process. (4) Each string is evaluated based on a fitness function to obtain the quantitative measure. (5) Based on the fitness value, each string is undergone the Selection operation, which changes the population of string and performs the "evolution." (6) If we can obtain the target string or the searching reaches the limited generations, the searching is over. Unless we can obtain, the flow goes back to operation-(2). We define that the target string whose fitness value converges within the target error.

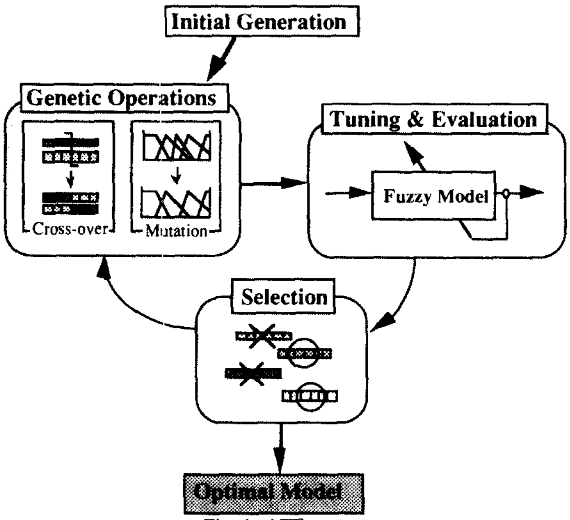

Fig. 1 ATF system

3. GENETIC ALGORITHM

In this chapter, we describe the coding method, the fitness function, and the genetic operations (cross-over, mutation, and selection) in the GA.

3.1 Coding

The type of fuzzy model is a simplified fuzzy inference, such that the antecedent part consists of membership functions and the consequent part consists of real values. The membership function, which constructs the input space, is a triangular-shaped without loss of generality.

A string has finite loci and each value represents the following genetic information: (1) the ratio which constructs the position for the summit of a membership function, (2) the width between the cortex and the base of a membership function, and (3) the real value on the consequent part. Figure 2 shows the relationship between a part of the string and the structure of an input space of the membership function. The ratio of the coordinate position divided by the sum of values represents the position of the summit of each triangular-shaped membership function. Several strings form a generation.

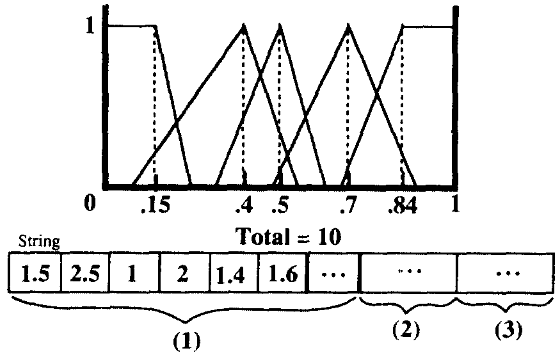

Fig. 2 Illustration of the membership function

3.2 Fitness Function

We set the fitness function, which is the criterion to evaluate each string. We define the function F in eqs. (1).

$$F(s_i) = E + A \times N, \qquad (1)$$

where

s_i: the i-th string, E: summation of squared error between output value of the fuzzy model and desirable one, A: coefficient, N: the number of the membership function.

We define that the smaller the fitness value is, the more the string has high fitness.

3.3 Cross-over

Cross-over operation in this paper is described as follows: two strings in a population are arbitrary selected. The locus, whose value constructs the position for the summit of a membership function in the string, is also arbitrary selected and the structure is exchanged between each string. The offsprings, which are undergone the cross-over operation, generate four species, which illustrates in fig. 3.

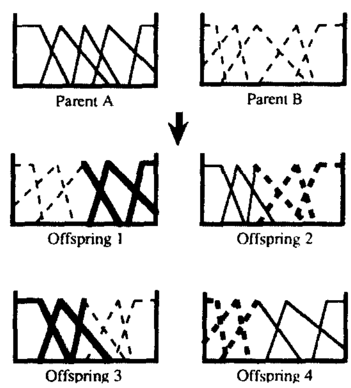

Fig. 3 Cross-over operation

(1) The structure of the right side on an offspring is inherited from one string (parent A) and the other side is inherited from the other string (parent B), which the structure is reduced. (2) The structure of the right side is inherited from the other string (B) and the other side is inherited from one string (A), which the structure is reduced. In the same way, (3) the structure of the left side is inherited from one string (A). (4) The structure of the left side is inherited from the other string (B). Offspring can inherit superior genes from two parents by Cross-over operation.

3.4 Mutation

Mutation operation occurs on locus in the strings, which undergo cross-over operation, with a probability Pm. Mutation operation in this paper means that the selected membership function is pruned.

We can expect to obtain the minimal structure of the fuzzy model by the Mutation operation.

3.5 Selection

In this paper, we adopt elite preservation strategy, which the strings having high fitness remain to the next generation, and sampling strategy, which the strings are selected randomly remain to the next generation.

4. TUNING ALGORITHM

In this chapter, we illustrate the tuning algorithm of the fuzzy rules, which are membership functions on the antecedent part and real values on the consequent part, respectively.

4.1 Tuning for Antecedent part

In this section, we express the tuning algorithm for the variable membership function on the antecedent part.

First, we describe the calculating formulas between input value and output value. The output value yk, which k means the output value with respect to the k-th input pattern, is expressed by

$$\mu_i = \prod_{j=1}^{m} A_{ij}(x_j) \quad (2)$$

$$y_k = \frac{\sum_{i=1}^{n} \mu_i \cdot w_i}{\sum_{i=1}^{n} \mu_i} \quad (3)$$

where

x_j : input value in j-th, m : dimension of input space, n : the number of fuzzy rule, μ_i : fitness in i-th fuzzy rule, A_{ij} : membership function, w_i : action variable.

The tuning formula for the antecedent part is given by

$$E = \sum_{k=1}^{p} \frac{1}{2}(y_k - y_{tk})^2 \quad (4)$$

$$\begin{aligned} Aw(t+1) &= Aw(t) - \alpha \cdot \frac{\partial E}{\partial Aw(t)} \\ &= Aw(t) - \alpha \cdot \frac{\prod_{j \neq k}^{m} A_{ij}(x_j)}{\sum_{i=1}^{n} \mu_i} (y_k - y_{tk})(w_i - y_k) \end{aligned} \quad (5)$$

where

E : summation of squared error between output value of the fuzzy model and desirable one, Aw(t) : width between vertex and base of a membership function in t-th tuning, y_{tk} : teach signal with respect to k-th pattern, α : coefficient constant.

4.2 Tuning for Consequent part

In this section, we express the tuning algorithm for the real value on the consequent part. In the same way as expressed before section, the tuning formula of the consequent part is expressed by

$$\begin{aligned} w_i(t+1) &= w_i(t) - \beta \cdot \frac{\partial E}{\partial w_i} \\ &= w_i(t) - \beta \cdot \frac{\mu_i}{\sum_{i=1}^{n} \mu_i}(y_k - y_{tk}) \end{aligned} \quad (6)$$

where

β : coefficient constant.

5. SIMULATION RESULTS

Simulations are carried out to show effectiveness of the ***ATF*** system by simulation. The ***ATF*** system is applied to the EX-OR problem, which is famous for a simple non-linear problem, and a function approximation problem.

Each string is expressed as a fuzzy model. In both problems, the structure of the fuzzy model consists of two inputs and one output and each input consists of five membership functions in the greatest number and the both sides of membership function are constant function. The range of an input space is $0 \le x \le 1$. In the simulation, the population size in a generation consists of 50 strings.

5.1 EX-OR Problem

We carry out searching with four teach signals. A target string, which the summation of squared error between desirable value and output value converges below 0.1 %, is obtained without depending on the initial conditions and within 9.6 generations on the average. Moreover, we can also obtain the optimal structure, which is pruned of all the six redundant middle positioned membership functions.

5.2 Function Approximation Problem

In this section, we deal with another function approximation problem, which the function is expressed by

$$y = \frac{\sin \pi \sqrt{2(x_1^2 + x_2^2)} + 1}{2} \quad (7)$$

Search is carried out 50 generations to obtain the optimal string with nine teach signals. The target string is also obtained without depending on the initial conditions.

Here, we compare the proposed method with the conventional method [10]. We can obtain the optimal string by using the ***ATF*** system, which is pruned three redundant membership functions. On the other hand, we obtain the string by using the conventional method, which is pruned two redundant membership functions. We can obtain the more compact and optimal structure by using the ***ATF*** system. Figs. 4-a and 4-b show one of the obtained structure by each method.

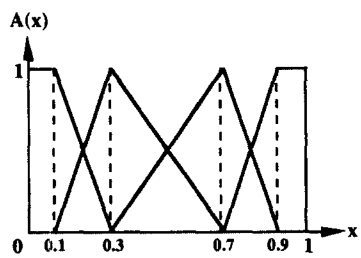

Fig. 4-a Optimized membership function by using the conventional method

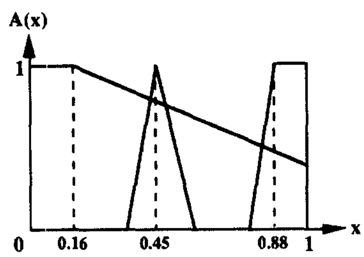

Fig. 4-b Optimized membership function by using the ***ATF*** system

6. CONCLUSIONS

In this paper, we have proposed a synthesis method of fuzzy neural network and Genetic Algorithm for auto fuzzy tuning, ***ATF*** system. The characteristic of the ***ATF*** system is to obtain the minimal and the optimal structure of a fuzzy model. The antecedent and the consequent part of the fuzzy model are tuned by the delta rule and the number of membership functions is optimized by the Genetic Algorithm.

Simulations show the effectiveness of the proposed method. We expect to substitute the ***ATF*** system for the human experts' operations to construct the fuzzy model. The ***ATF*** system can be applied to the various systems such as the robotic motion control, sensing and recognition problems.

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