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A Fuzzy Approach to Elevator Group Control System

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Abstract—The elevator group control systems are the control systems that manage systematically, three or more elevators in order to efficiently transport the passengers. In the elevator group control system, the area-weight which determines the load biases of elevators is a control parameter closely related to the system performance. This correspondence proposes a fuzzy model based method to determine the area-weight. The proposed method uses a two-stage fuzzy inference model which is built by the study of area-weight properties and expert knowledge. The proposed method shows more desirable results than the conventional method in simulations that use real traffic data.

I. INTRODUCTION

The elevator group control system is a control system that manages systematically three or more elevators in a group to increase the service for passengers, and reduces the cost such as power consumption. Most of the elevator group control systems have used the *hall call assignment method* which assigns elevators in response to a passenger's call. In this case, the elevator group control system considers the current situation of a building to select the most appropriate elevator [19].

The hall call assignment method assigns a new *hall call* to the elevator having the smallest *evaluation function* value among all the elevators. The *area-weight* is a parameter which affects the evaluation-function value of the elevators in the area close to the hall call. The area-weight is one of the most important variables in the evaluation function which affects the system performance.

Some methods to obtain the area-weight have been proposed in [20], [21], [22]. [20] and [21] used the area-weight defined in advance according to passenger's traffic patterns. In [22], the area-weight is determined by simulation method. However these methods have some problems in determining the appropriate area-weight not only because of the system complexity, but also because of uncertain factors such as a passenger's arrival time on each floor, the destination floors of passengers and, the time for getting on and off elevators.

In general, when the system complexity is high and the correct prediction of system state is not easy, it is difficult to make a correct model to control the system. Therefore, the approximation methods based on the fuzzy theory have been used [1], [10]-[14]. Many applications of fuzzy reasoning to construct advanced controllers have been reported [3]-[5]. Most of these controllers use a fuzzy model. In this correspondence, the fuzzy model is used to describe the system state and expert knowledge, and the fuzzy inference method is used to determine the area-weight parameter. In an experiment, the inference methods using fuzzy theory have shown better results than the conventional method.

In Section II we describe the elevator group control system and the area-weight of the control system. In Section III we propose a fuzzy model to determine the area-weight; its performance is analyzed through the simulation in Section IV.

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II. ELEVATOR GROUP CONTROL SYSTEM

A. The Elevator Group Control System

In the elevator group control system, there are two types of calls. The *hall call* is given through buttons on the hall of the building, and the *car call* is given in the elevator by the passengers [15], [16]. An elevator group control system has a pair of hall call buttons on each floor, one for *up hall call* and the other for *down hall call*. If a passenger presses a hall call button, an elevator is selected by the group control system for the passenger. The elevator group control system has to consider many factors about both the current and future states of the elevator system [17]. In this step, we know the current data such as the position of each elevator and the hall call's and car call's allocation states, but do not know the information such as the number of passengers where a hall call happened. Furthermore the information about the future hall calls and car calls are uncertain. Therefore it is difficult to select an appropriate elevator when a call has happened. Elevator group control systems are so complex to describe in detail, and somewhat different from each other. So I will describe the main parts, which are most important to select a suitable elevator.

The most important task of an elevator group control system is selecting a suitable elevator for each passenger's hall call (up, down). The selection is made in order to minimize the average waiting time of passengers, the long wait probability (the probability which a passenger waits for a long time), and the power consumption [19]. The selection method is called the *hall call assignment method*. In this method, an *evaluation function* is used to achieve the above multiple objectives.

The function is evaluated for each elevator and the elevator with the smallest function value is selected. Let $\phi(k)$ be the evaluating function for the k -th elevator, then this function is represented with the following formula:

$$\phi(k) = T_{AVR}(k) - \alpha \cdot T_{\alpha}(k) + T_E(k).$$

When a new hall call is given on floor h , the function value is evaluated for the k -th elevator where $k = 1, \dots, n$. In the above formula, $T_{AVR}(k)$ is the estimated arrival time of the k -th elevator, which is the waiting time of the passenger when we assign the k -th elevator for the new hall call. $T_{AVR}(k)$ is calculated by the following formula

$$T_{AVR}(k) = \sum_{\text{stop}} T_{\text{stop}}(k) + \sum_{\text{drive}} T_{\text{drive}}(k)$$

$$T_{\text{stop}}(k) = T_{\text{speed_down}} + T_{\text{get_on/off}}(k) + T_{\text{speed_up}}.$$

In the above formula, we divide the path of the elevator into *stop* and *drive*. *stop* means floors where hall calls and car calls are assigned. *drive* means floors where there are no calls near the floor. We call $T_{\alpha}(k)$ the *area value* and α the *area-weight*, where $T_{\alpha}(k)$ is determined when a hall call is generated. If a new hall call is generated on the floor where the k -th elevator is going to stop, the value $\alpha \cdot T_{\alpha}(k)$ is subtracted from the evaluating function value of the k -th elevator. Therefore the probability of selecting of k -th elevator is increased. $T_E(k)$ is the elevator's status value. This value is added to prevent selecting the k -th elevator if there exists a special kind of call (wheelchair call, VIP call) or the elevator is not running.

B. The Area-Weight

If elevator k is going to floor n , the *area* of elevator k for floor n is defined. When a hall call happens in this area, our fundamental strategy is to select elevator k for the call. The area represents the range (floors) which can be served easily by that elevator. The

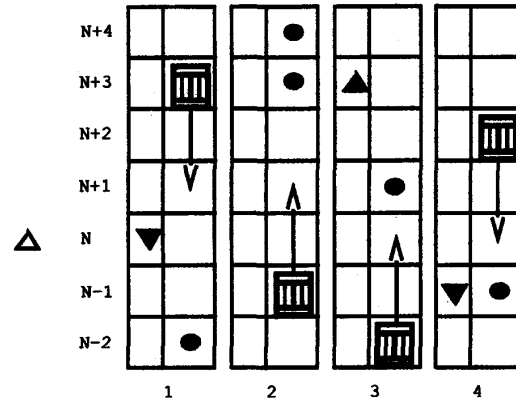


Fig. 1. Example of the area-control.

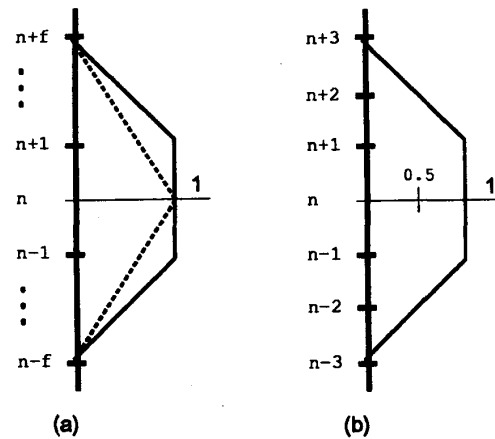


Fig. 2. Example of the area value.

area-weight is the value to increase the assignment probability for an elevator which is going toward the floor where a hall call was generated.

Fig. 1 shows a situation of a 4-elevators system. In this figure the arrow represents direction of each elevator. A black circle indicates the car call which was generated by passengers in the elevator. A black triangle represents the hall call which will be served by the elevator. Finally, any new hall calls generated on a floor are marked by a white triangle. In Fig. 1 the 1st elevator is going down, has a car call on floor $N - 2$, and is assigned a hall call on floor N for passengers who want to go down. A new hall call has occurred on floor N for up, but it is not yet assigned to any elevator. If an elevator is assigned to serve a call on a floor, the area of the elevator on the floor is defined. In general the area is defined in the form of a triangle or a trapezoid as shown in Fig. 2(a). In Fig. 2(b), the trapezoidal area of elevator k on the floor n is given. We can see that the area value $T_{\alpha}(k) = 1$ for the floor n ; $n + 1, n - 1, T_{\alpha}(k) = 0.5$ for floor $n + 2, n - 2$; and $T_{\alpha}(k) = 0$ for the others. The area value $T_{\alpha}(k)$ is defined for the floors where a call (hall and car) has happened.

In Fig. 1, 1st and 4th elevators are going down and $T_{AVR}(1)$ and $T_{AVR}(4)$ must be large, so I will show 2nd and 3rd elevators to assign a new hall call. The following formula shows evaluating function values of 2-th and 3-th elevators to select a service elevator. In this

case the area value $T_\alpha(k)$ for the 2-th elevator is zero, i.e., $T_\alpha(2) = 0$.

$$\begin{aligned} \phi(2) &= T_{AVR}(2) - \alpha \cdot T_\alpha(2) + T_E(2) \\ &= T_{AVR}(2) + T_E(2) \\ \phi(3) &= T_{AVR}(3) - \alpha \cdot T_\alpha(3) + T_E(3). \end{aligned}$$

Here, let's have assumptions on the state value $T_E(k)$ and the estimated service time $T_{AVR}(k)$ such that $T_E(2) = T_E(3)$ and $T_{AVR}(2) < T_{AVR}(3)$. If $\alpha \cdot T_\alpha(3) < T_{AVR}(3) - T_{AVR}(2)$ then the elevator 2 is assigned, otherwise the elevator 3 is assigned.

In the previous example, we can see that $T_\alpha(3)$ is a fixed value, and $T_{AVR}(2)$ and $T_{AVR}(3)$ are estimated values. However, the value α is calculated whenever a call is generated. Therefore the determination of the value α is important in the hall call assignment method.

If the value α is big, the possibility that the elevator close to the relevant floor can be selected is increased. Consequently, the transportation load may be assigned to a specific elevator which is in the area. Furthermore, the average waiting time increases and the total running frequency of elevators decreases. Therefore the power consumption is reduced. If α is small, the average waiting time decreases and the running frequency increases.

In [21], the predefined area-weight is used and it is defined according to the traffic modes classified by the passenger's traffic pattern. In this case, it is difficult to reflect traffic changes in the same traffic mode and this method can not consider some important characteristics of different buildings. In [22], the simulation method is used to determine the area-weight. In this method, they simulate the future situation of the system with some predefined area-weights and then select the area-weight giving the best performance. As this method simulates with a fixed number of area-weights, we cannot expect a precise control. Furthermore, because the hall call data used in the simulation is forecasted, the simulation may differ from the real situation and the uncertainty of the data limits the reliability of the model. In this study we use the fuzzy approach to model the uncertain situation of the system and to determine the area-weight.

III. A FUZZY MODEL TO DETERMINE THE AREA-WEIGHT

To handle the uncertainty of elevator group control system, we use the fuzzy approach [6]–[9]. In this approach we use the fuzzy model to represent the fuzzy knowledge and the fuzzy inference method to determine the area-weight. Fuzzy knowledge is generally formulated in the form of rules.

A. Fuzzy Rules

We classify the facts related with the determination of area-weight into two groups. The first group includes the up-going and down-going traffic amount, and the second group includes the average waiting time, long wait probability and power consumption. However we can see that the area-weight is determined mainly according to the first group factors.

The passenger's traffic varies from hour to hour, and we can see that it is classified into some basic patterns.

- up-peak pattern
This pattern is the case of which the up-going traffic is very large but the down-going traffic is very small.
- down-peak pattern
In this pattern, the down-going traffic is much more than the up-going traffic
- normal pattern
The case of which both up-going and down-going traffic are approximately equal.

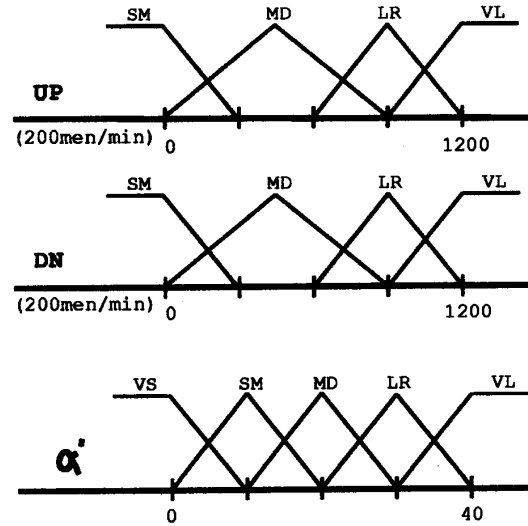


Fig. 3. The membership functions (UP, DN, α').

Let UP, DN and α' be the up-going traffic, down-going traffic and area-weight respectively. We can represent the traffic (UP, DN) knowledge related to the area-weight in the form of fuzzy rules as follows:

- If UP is VL and DN is SM Then α' is VS
- If UP is MD and DN is SM Then α' is MD
- If UP is MD and DN is SM Then α' is VL
- If UP is SM and DN is VL Then α' is SM
- If UP is SM and DN is SM Then α' is VS
- ⋮
- If UP is MD and DN is MD Then α' is SM.

In the fuzzy rules the words such as SM (Small), MD (Medium), LR (Large) and VL (Very Large) are fuzzy sets defined on the variable UP and DN. The terms VS (Very Small), SM (Small), MD (Medium), LR (Large) and VL (Very Large) are defined on α' as shown in Fig. 3.

When the traffic is fixed, the average waiting time and long wait probability decrease as the area-weight becomes smaller, while the power consumption decreases if the area-weight increases. After the first step of determination by the first group factors, the area-weight is adjusted according the second group factors.

Let AWT be the average waiting time, PC be the power consumption and LWP be the long wait probability. We introduce an adjustment value k which represents the influence of the second group factors. This adjustment value will be added to the area-weight α' and give new area-weight α (that is, $\alpha = \alpha' + k$). Then we can represent fuzzy rules as follows:

- average waiting time–area-weight rules (AWT- k)
 - If AWT is VL Then k is NL
 - If AWT is SM Then k is PL
 - ⋮
 - If AWT is MD Then k is ZE
- power consumption–area-weight rules (PC- k)
 - If PC is VL Then k is PL
 - If PC is SM Then k is NL
 - ⋮

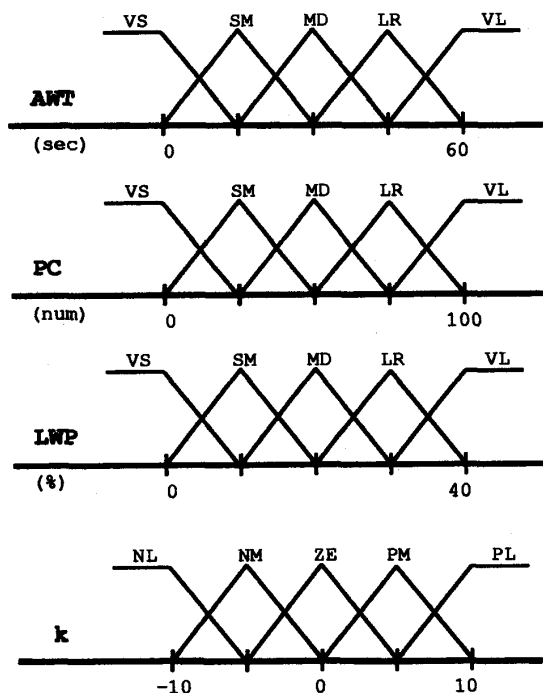


Fig. 4. The membership functions (AWT, PC, LWP, k).

If PC is MD Then k is ZE

- long wait probability-area-weight rules (LWP- k)

If LPW is VL Then k is NL

If LWP is SM Then k is PL

⋮

If LWP is SM Then k is ZE.

In the fuzzy rules words such as VS (Very Small), SM (Small), MD (Medium), LR (Large) and VL (Very Large) are fuzzy sets defined on the variable AWT, PC and LWP. The terms NL (Negative Large), NM (Negative Medium), ZE (ZEro), PM (Positive Medium) and PL (Positive Large) are defined on k as shown in Fig. 4.

B. Fuzzy Model

We propose a fuzzy model to determine the area-weight through a two step fuzzy inference. The inference system uses the fuzzy rules described in the previous section.

The adjustment value k is determined through the second step inference using the average waiting time, long wait probability, and power consumption values. Finally the addition of the predetermined area-weight α' and the adjustment value k will produce a definite area-weight α . Such two step inference mechanism improves the system's stability from external accidents and reduces the complexity of the system. Fig. 5 shows the two step fuzzy inference mechanism.

In Step 1 of the fuzzy inference engine, the predetermined area-weight α' is calculated by using the up-going (UP) and down-going (DN) traffic. In this step the Mamdani's max-min inference method [11] is used with the rules presented in Section 3.1. The result of the inference is obtained through the defuzzification using the center of gravity method [18].

In Step 2 the adjustment value k is determined through the fuzzy inference mechanism using the average waiting time, the

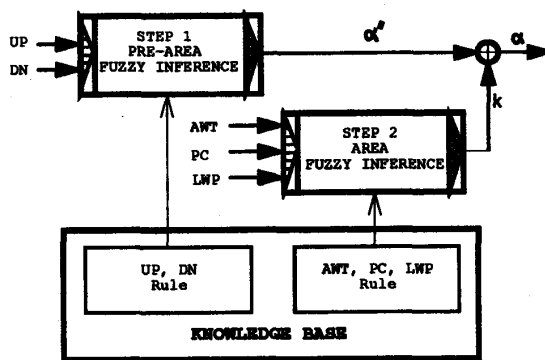


Fig. 5. The fuzzy model to determine the area-weight.

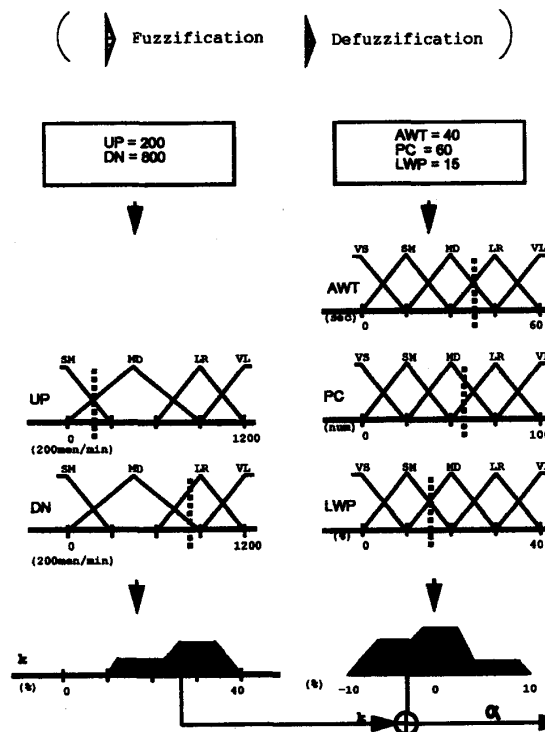


Fig. 6. An inference example of the proposed fuzzy mode.

long wait probability, and the power consumption values. After the defuzzification of the result of the second inference, this value is added to the predetermined area-weight.

The Fig. 6 shows an inference example of the proposed fuzzy model when the up-going traffic is 200, the down-going traffic is 800, the average waiting time is 40, the long wait probability is 15 and the power consumption is 60. In this example the computed values are $\alpha' = 26$, $k = -4$, $\alpha = 22$.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

We have implemented a simulation environment to evaluate the proposed elevator group control system's performance. The simulation environment consists of four parts. First part is a real elevator group controller. Second part is a CPU emulator which is used for

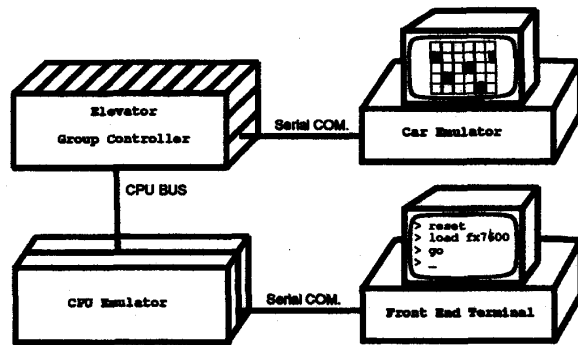


Fig. 7. Simulation environment.

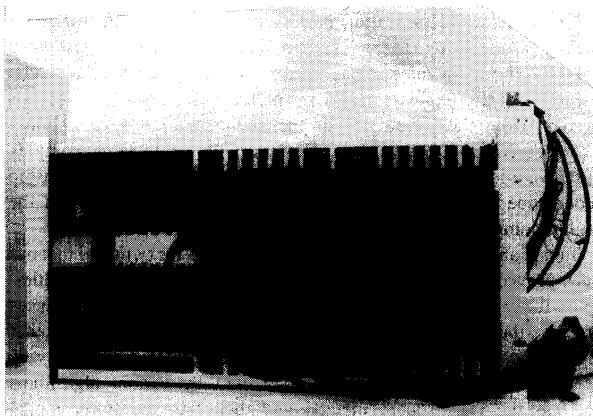


Fig. 8. The fuzzy elevator group controller.

convenience of programming and debugging. Third part is a car emulator which generate hall calls and car calls as like real elevators. Moreover, it can collect the simulation result and show statistical data. The car emulator is developed on the IBM PC. Final part is a front end terminal. We use another PC to program and debug our elevator group control system. In the simulation environment we used real hardware from an elevator group control system and developed a car emulator which simulates the elevator's moving and operations. (See Figs. 8 and 9).

We simulated our fuzzy model based elevator group control system and the conventional system in our simulation environment and compared the results. The conventional system is a product which uses the predefined area-weight method [21]. For the simulation, real traffic data of the Twin building in Seoul, Korea was used.

The conditions of simulation are shown in the Table I. According to the traffic pattern, the simulation situation is divided into several periods such as before lunch time (12:00 ~ 12:40), after lunch time (12:40 ~ 13:20) and common time (13:20 ~ 15:00). The evaluation criteria is the means of the average waiting times (AWT), power consumptions (PC) and average long wait probabilities (LWP). In the simulation, the number of elevator runs is interpreted as the power consumption for that elevator. The average waiting time is measured in seconds and the long wait probability is in percent (%). The simulation results represented by these evaluation criteria are shown in Table II. In Table II, "conv." is conventional system, "prop." is proposed system, and "imp." is improvement.

As shown in Table II, in the case of heavy traffic (for example, before and after lunch time) our model shows a decrease in the average

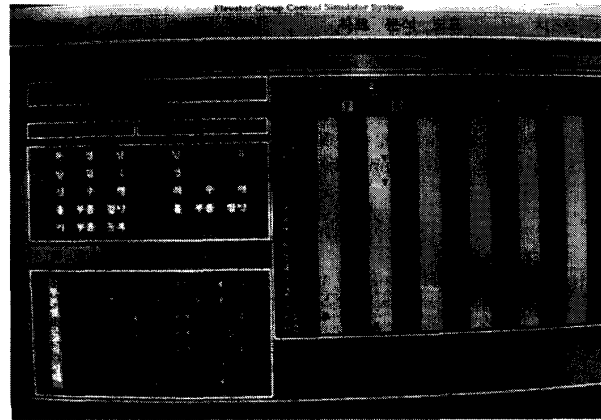


Fig. 9. Simulation of elevator group control system.

TABLE I
THE CONDITIONS OF SIMULATION

number of floors	18
number of elevators	6
elevator speed	180 m/min
elevator capacity	24 man
simulation time	12:00 ~ 15:00
simulation data	twin building, April, 1992

TABLE II
THE SIMULATION RESULTS

		conv.	prop.	imp.(%)
before lunch	AWT	23.8	20.2	17
	PC	44	48	-9
12:00 ~ 12:40	LWP	8.3	5.1	62
after lunch	AWT	24.8	24.6	1
	PC	47	46	2
12:40 ~ 13:20	LWP	9.4	8.6	9
common time	AWT	24.0	21.8	10
	PC	54	51	5
13:20 ~ 15:00	LWP	6.9	6.8	1
total	AWT	24.2	22.1	9
	PC	50	48	4
12:00 ~ 15:00	LWP	8.2	6.8	20

waiting time and long wait probability but the power consumption is increased a little. But in the light traffic (common time) we can see that all factors are improved. The comparison in the total period from 12:00 to 15:00 shows that the average waiting time is improved by 9%, the power consumption by 4%, and the long wait probability by 20%.

We have simulated several times using other traffic data. By the simulation the average waiting time is improved by 7 ~ 20%, the power consumption by 3 ~ 12%, and the long wait probability by 19 ~ 52%.

V. CONCLUSION

In this study the fuzzy approach was used to determine the area-weight which is one of the most important parameters of the hall call assignment method in the elevator group control system. We examined effects of the area-weight on the elevator group control system and represented the expert's knowledge about it. By using the knowledge the fuzzy inference model was built to determine the area-weight. To analyze the performance of the system, we simulated

the proposed system and a conventional system. We could see that our system improved the system performance by 4 ~ 20% compared with the conventional method.

The developed system was commercialized in 1992 by an industrial company, and this product has a good reputation in the market. In this study, the area-weight was determined by the fuzzy approach. In a further study we will apply the same approach to other variables.

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Neural Network Based Fuzzy Identification and Its Application to Modeling and Control of Complex Systems

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Abstract—This paper proposes a novel fuzzy identification approach based on an updated version of pi-sigma neural network. The proposed method has the following characteristics: 1) The consequence function of each fuzzy rule can be a nonlinear function, which makes it capable to deal with the nonlinear systems more efficiently. 2) Not only each parameter of the consequence functions but also the membership function of each fuzzy subset can be modified easily on-line. In this way, the fuzzy identification algorithm is greatly simplified and therefore is suitable for real-time applications. Simulation results show that the new method is effective in modeling and controlling of a large class of complex systems.

I. INTRODUCTION

Fuzzy model identification is developed based on the fuzzy set theory proposed by Zadeh [1] and has been widely investigated [2]-[5]. The main interest has been on building fuzzy relationship models that are expressed by a set of fuzzy linguistic propositions derived from the experience of the skilled operators or a group of observed input-output data. However, for some large complex systems, it is almost impossible to establish such a fuzzy relationship model due to the large amount of the fuzzy prepositions and the highly complicated multidimensional fuzzy relationship.

Takagi and Sugeno [5] proposed a new type of fuzzy model that has been proved to be effective in overcoming some of these difficulties. Their fuzzy model consists of fuzzy implications whose consequences are described by crisp linear input-output relation functions. Another significance of their fuzzy model we think is that, since every of its consequence parameter is identified by certain algorithms such as the least square method and therefore, the fuzzy model established is more systematic and objective. Unfortunately, the identification procedure is quite complicated and is carried out off-line (although Sugeno and Tanaka [6] suggested a successive identification algorithm, it still has difficulties for real-time implementation.), which makes it incompetent to deal with time-varying systems.

The theory of Artificial Neural Network (ANN) has been greatly developed in the recent years. Due to its strong nonlinear mapping and learning abilities, applications of ANN to control systems have been so successful that neurocontrol is no longer strange to those who work in the discipline of automatic control [7]. Mainly, there are two kinds of applications of neural networks to control systems, namely Neural-Network-Integrated Control (NNIC) and Neurocontrol or Neuromorphic Control (NC). By NNIC, we mean those control schemes that use neural networks to enhance the performances of some conventional control strategies, such as adaptive control, optimal control, internal model control and predictive control, as well as expert control and fuzzy control. NC, on the other hand, uses neural networks directly as the controller and no other conventional control means are involved. It is desirable to note that the marriage of neural networks with fuzzy set theory is showing special promise and is receiving more and more attentions. Use of neural networks to perform the adjustment of fuzzy membership functions and modification of fuzzy rules makes it practical to design adaptive fuzzy models and self-organizing fuzzy controllers.

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