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Fuzzy Traffic Controller of Sugeno's Model

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***Abstract* - We propose a fuzzy traffic controller of Sugeno's fuzzy model so as to model the nonlinear characteristics of controlling the traffic light. It uses a degree of the traffic congestion of the preceding roads as an input so that it can cope with traffic congestion appropriately, which causes the loss of fuel and our discomfort. In order to construct fuzzy traffic controller of Sugeno's fuzzy model, we first model the control process of the traffic light by using Mamdani's fuzzy model, which has the uniform membership functions of the same size and shape. Next we make Mamdani's fuzzy model with the non-uniform membership functions so that it can exactly reflect the knowledge of experts and operators. Lastly, we construct the fuzzy traffic controller of Sugeno's fuzzy model by learning from the input/output data, which is retrieved from Mamdani's fuzzy model with the non-uniform membership functions. We compared and analyzed the service level of the traffic light controllers by using the delay time. As a result of comparison, the fuzzy traffic controller of Sugeno's fuzzy model shows the best service level of them.**

I. Introduction

FLC(Fuzzy Logical Controller) is able to use knowledge of experts and operators as the control rules and to process the ambiguous information. For that reason, it has been applied to control of the complex nonlinear systems or to control of systems that have no a mathematical model [1].

There have been many researches [2, 6, 7, 8, 9] on FTC(Fuzzy Traffic Controller), which is FLC for controlling a traffic light, that used such advantages as the linguistic description and the qualitative modeling of fuzzy logical controller. They used the number of entering vehicles at the green light, the number of waiting vehicles during the red light, the mean density of vehicles, the duration time of the red light and etc. as input variables, and used the duration time of the green light as output variable [2].

Though the existing researches were simulated and evaluated in various situations, they have the several problems. First, they could not be applied to crossroads with the congestive traffic flow because they have been developed and applied for a non-congestive traffic flow. Under the congestive traffic flow, spillback on crossroads unavoidably happens. Spillback on crossroads leads to over-saturation of roads. If spillback on upper crossroad happens, loss of green light on lower crossroad is unavoidable [3]. Second, an object of simulating the traffic flow and analyzing performance is mostly a single crossroad. In a single crossroad, the number of the passed vehicles is able to become a meaningful measure. It however can't be used as a meaningful measure under such multiple crossroads that spillback on crossroads happens. Third, it is at issue that the inference of FTC can generate the exact result that experts and operators expect. The most of the inference models represent approximately the control knowledge of experts and operators.

In the consequences of the above issues, FTC must consider the traffic congestion of the preceding roads, which vehicles on a crossroad are to proceed to, in order to cope successfully with the traffic congestion and the change of traffic situation. The inference model of FTC must be modified and tuned up in order to make it generate the exacting result that experts and operators expect.

In this paper, therefore, we propose a FTC that can cope with the traffic congestion appropriately by using as an input variable a degree of the traffic congestion of the preceding roads. The proposed FTC employs the first-order Sugeno's fuzzy model, which is constructed from Mamdani's fuzzy model with the uniform membership functions of the same size and shape. The membership functions of Mamdani's fuzzy model are tuned up and modified by the membership function modification algorithm [4] so that the inference of FTC can generate the exacting result that experts and operators expect. From Mamdani's fuzzy model tuned up by the membership function modification algorithm, we construct FTC of the first-order Sugeno's fuzzy model of 3-inputs and 1-output.

We compared and analyzed the service level of the traffic light controllers by using the delay time. As a result of comparison, the proposed FTC of them shows the best service level.

II. MFM algorithm and ANFIS

In Mamdani's fuzzy model well-suited to human intuitive input, the triangular membership is well suited to simple computation, and its position and width can be used easily as parameters. But it cannot exceed the definite performance if it employs the uniform membership functions for all linguistic variables. In this case, we can design more accurate controller by clustering an input/output data set from controlling process[1, 10].

The membership modification function algorithm, which is referred to *MFM-algorithm*, modifies the size and

shape of the membership functions of FLC with the uniform membership functions by clustering the input/output data from it, and makes it generate the more exact result that experts and operators expect[4].
If an input/output data set, which represents exactly the knowledge of experts and operators, is given, we can construct a more compact and computationally efficient FLC by using the adaptive techniques that learn from the data. ANFIS(Adaptive Network-based Fuzzy Inference System) is the learning algorithm suitable to this purpose. ANFIS allows fuzzy systems to learn from the data that they are modeling, by using the adaptive techniques [11, 12]. Using a given input/output data set, ANFIS constructs a fuzzy inference system whose membership function parameters are tuned and adjusted using either a backpropagation algorithm alone, or in combination with a least squares type of method.
Mamdani's fuzzy model is the most commonly seen fuzzy methodology. It is intuitive, and has widespread acceptance and is well-suited to human input.
Compared with Mamdani's fuzzy model, Sugeno's fuzzy model is computationally efficient, and works well with linear techniques and with optimization and adaptive techniques, and has guaranteed continuity of the output surface, and is well-suited to mathematical analysis. It is suited for modeling nonlinear systems by interpolating multiple linear models [11].
Sugeno's fuzzy inference method lends itself to the use of adaptive techniques for constructing fuzzy models, because it is a more compact and computationally efficient representation than a Mamdani's fuzzy inference method. Therefore, if an input/output data set is given, we can employ ANFIS in order to compute the membership function parameters that best allow Sugeno's fuzzy model to track the given input/output data.
In general, ANFIS works well if the training data presented to it for training membership function parameters is fully representative of the features of the data that the trained FLC is intended to model. We collect the training data from FLC with the non-uniform membership functions tuned by MFM-algorithm, which generates the numerical data that experts and operators expect.
We, in this paper, use Sugeno's fuzzy model trained by ANFIS in order to model the nonlinear characteristics of controlling the traffic light.

III. Fuzzy traffic controller of Sugeno's fuzzy model

The purpose of controlling the traffic flow by FLC is to lighten the traffic congestion and to decrease the delay time on crossroads by finding out the traffic flow of the current crossroads and by changing the traffic light appropriately.
In order to achieve this purpose, we design FTC based on the following assumptions: First, sensors can detect the congestion of corresponding roads. Second, the width of crossroad and the length of vehicles decide the duration time of yellow light.

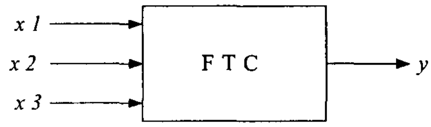

Fig.1. The model structure of the proposed FTC.

In order to identify FTC of Sugeno's fuzzy model that models the nonlinear characteristics of controlling the traffic light, we use the similar modeling approach to many system identification techniques. First, we hypothesize a parameterized model structure, which is modeled by FTC of Mamdani's fuzzy model with the uniform triangular membership functions, which is called to the *uniform FTC*. Second, we tune up and adjust the uniform FTC by the MFM-algorithm so as to generate FTC of Mamdani's fuzzy model with the non-uniform membership functions, which is the *non-uniform FTC*. Lastly, in order to identify FTC of Sugeno's fuzzy model, we collect input/output data from the non-uniform FTC and modify the membership function parameters by ANFIS.
Figure 1 shows the model structure of FTC of Sugeno's fuzzy model with 3-inputs and 1-output that is proposed in this paper. Its rule base is consisted of 8 rules for the purpose of simplifying inference and design. Its input variables are $x1$, $x2$ and $x3$.
$x1$ is a degree of the duration time of the red light, which indicates the proportion of the duration time of the red light to the predefined cycle time of traffic lights.

$$DDRL = DRL/PCT \qquad \text{(Eq.1)}$$

where, DDRL is a degree of the duration time of the red light, and DRL is the duration time of the red light, PCT is the predefined cycle time of traffic lights.
$x2$ is a degree of the traffic congestion of the current road.

$$DTC_c = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} LV_{ij}}{\sum_{i=i}^{m} LL_i} \qquad \text{(Eq.2)}$$

where, DTC_c is a degree of the traffic congestion of the current road, LV_{ij} is the length of *j-th* vehicle on *i-th* lane of a road and LL_i is the length of *i-th* lane of a road.
$x3$ is the mean degree of the traffic congestion of the preceding roads.

$$MDTC_p = \frac{\sum_{i=1}^{n} DTC_i}{n} \qquad \text{(Eq.3)}$$

where, $MDTC_p$ is the mean degree of the traffic congestion of the preceding roads, DTC_i is a degree of the traffic congestion of *i-th* preceding road.
Figure 2 shows the membership functions of input variables $x1$, $x2$ and $x3$. They all are consisted of 2 membership functions.

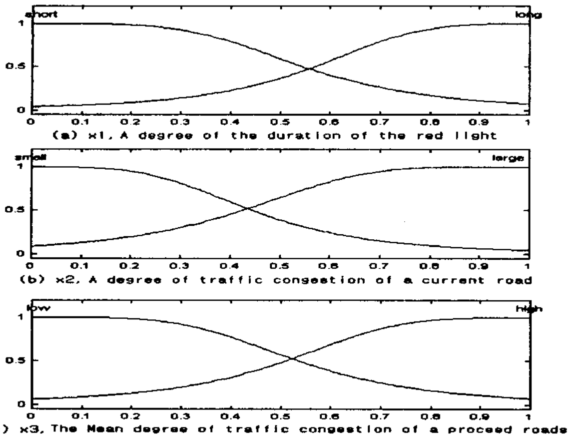

Fig. 2. The membership functions for the input variables of the proposed FLC

Output variable is y, which indicates a degree of increase and decrease of the duration of the green light on a crossroad. The first-order linear equation for deciding y is as follows.

$$y = p_0+p_1x_1+p_2x_2+p_3x_3 \qquad \text{(Eq.4)}$$

The duration of the green light is obtained by the follows.

$$DGR = \text{PDGR} + (\text{PDRG} * \text{y}) \qquad \text{(Eq.5)}$$

where, DGR is The duration of the green light , and PRGR is the predefined duration of the green light.

In order to identify coefficient of eq.4, we first model the traffic light control by the uniform FTC. We generate the non-uniform FTC by tuning up and adjusting the uniform FTC by MFM-algorithm. Table 1 shows the coefficients for deciding y of the proposed FTC of Sugeno's fuzzy model, which are retrieved by training a data set from the non-uniform FTC by ANFIS.

Table 1. Coefficients for deciding y of the proposed FTC

Rules	p_0	p_1	p_2	p_3
1	-1.0746	1.0342	0.2479	-0.04
2	0.19508	-0.089	-0.278	-0.163
3	0.19616	0.0824	-0.981	0.2649
4	-0.0177	0.004	-0.429	0.0618
5	-0.1386	-0.423	-0.104	-0.145
6	0.00108	0.0803	0.008	-0.396
7	-0.2498	0.3629	0.4118	-0.152
8	0.00794	-0.151	-0.295	-0.033

IV. Experiment and results

We developed the traffic-flow simulator and estimated the performance of the proposed FTC. The number of the used crossroads is 16. Crossroads for simulating the traffic flow was assumed as show in figure 3.

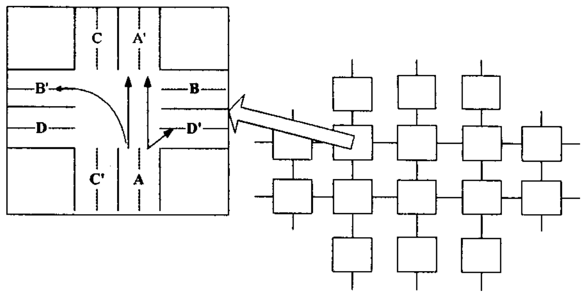

Fig. 3. Crossroads for simulating the traffic flow

In figure 3, the length of vehicles was assumed as $4m$ and length of all roads was $50m$. We did not consider crosswalks and vehicles of right-turn. The green light was circulated based on the straight and left-turn (that is, A->B->C->D...). We assigned 18 seconds for the straight and left-turn and 2 seconds for yellow light. We used 4×(18+2)=80 seconds as the basic signal-cycle.

For simulation, the occurrence of vehicles and the velocity of vehicles were assumed as six levels. The number of the occurred vehicles were 1710, 3156, 4076, 5427, 8052 and 10860 respectively. Velocity of vehicles was 10km/h, 20km/h, 30km/h, 40km/h, 50km/h and 60km/h respectively. We simulate the traffic flow during 900 seconds.

During the green light, only if the preceding roads (that is, A', B', C' and D' in figure 3) have enough space to accommodate a vehicle, vehicles on the current roads (that is, A, B, C and D in figure 3) could enter the preceding roads.

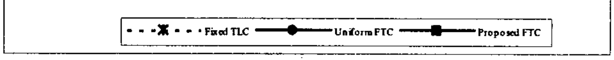

Fig.4. The mean delay time of 36 cases on 16 crossroads

Service level of a crossroad with the traffic lights is decided by the delay time. Delay time indicates the loss of fuel and time, and is the measure of discomfort. It generally happens on the red time. A degree of saturation indicates whether assignment of signal-cycle is pertinent or not. It, however, is difficult to decide service level based on a degree of saturation because delay time is not always decided according to it [5]. Therefore, we compared the service level of the fixed traffic light controller that is called to the *fixed TLC*, the uniform FTC and the proposed FTC by using not a degree of saturation but the delay time.

Table 2. The mean delay time of 16 crossroads

	Fixed TLC	Uniform FTC	Propose d FTC
Delay time	33.94387	23.97323	22.02472

Table 2 shows the means of the delay time about 36 cases on each traffic controller. Figure 4 shows the mean delay time of crossroads.

In tables 2, the proposed FLC decreases the delay time about 35% in comparison with controller and 8% in comparison with the uniform FTC. As result of simulation, the delay time has no correlation with the traffic volume.

V. Conclusion

In this paper, we proposed FTC(Fuzzy Traffic Controller), which is FLC for controlling a traffic light, that can cope with the traffic congestion well. In order to consider such situation as loss of the green light caused by the spillback of the preceding roads, we used as an input variable a degree of traffic congestion of the preceding roads, which vehicles on a crossroad are to proceed to. We employed Sugeno's fuzzy model in order to model the nonlinear characteristics of controlling the traffic light.

As a result of experiment, the proposed FTC showed more enhanced service level than the fixed traffic light controller and the uniform FTC on the most cases. The mean delay time of the proposed FTC is smaller than the others. In specially, the higher the congestion of roads is, the lower the service level of crossroads is.

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