International Journal of Fuzzy Logic and Intelligent Systems, vol. 1, no. 1, June 2001 pp. 1-5

A Fuzzy Traffic Controller Considering Spillback on Crossroads

Wan-Kyoo Choi and Sung-Joo Lee*

Division of Computer, Electronic & Communication Engineering, KwangJu University
592-1, Jinwol-Dong, Nam-Ku, KwangJu 503-703, Korea
*Department of Computer Science, Chosun University

Abstract

In this paper, we propose a fuzzy traffic controller that is able to cope with traffic congestion appropriately. In order to consider such situation as loss of green time caused by spillback of upper crossroad, it imports a degree of traffic congestion of upper roads which vehicles on a crossroad are to proceed to. We constructed the equal-partitioned fuzzy traffic controller that uses the membership functions of the same size and shape, and modified the size and shape of its membership functions by the membership function modification algorithm. In experiment, we compared and analyzed the fixed signal controller, the fuzzy traffic controller with the membership functions of the same size and shape, and the modified fuzzy traffic controller by using the delay time, the proportion of entered vehicles to occurred vehicles and the proportion of passed vehicles to entered vehicles. As a result of experiment, the modified fuzzy traffic controller showed more enhanced performance than others.

Key words: Fuzzy traffic controller, Membership function modification algorithm, Traffic congestion, Spillback

I. Introduction

FLC(Fuzzy Logical Controller) is able to use knowledge of experts and operators as the control rules and able 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 the fuzzy traffic control 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 signal, the number of waiting vehicles during the red signal, the mean density of vehicles, the duration time of the red signal and etc. as input variables, and used the duration time of the green time as output variable[2]

However, they could not be applied to the traffic congestion situation because they have been developed and applied for a non-congestion traffic flow. Under the traffic congestion situation, spillback on crossroads happens. Spillback on crossroads leads to over-saturation of roads. If spillback on upper crossroad happens, loss of green signal on lower crossroad is unavoidable[3]. Therefore, the traffic controllers not considering the traffic congestion situation can't cope successfully with the traffic congestion and the change of traffic situation.

In this paper, therefore, we propose a fuzzy traffic controller(FTC) that can cope with the traffic congestion appropriately. We use as a input variable a degree of traffic congestion of upper roads which vehicles on a crossroad are to proceed to.

At the first, we construct the equal-partitioned FTC that uses membership functions of the same size and shape for all linguistic variables. Then we modify the size and shape of its membership functions by the membership function modification algorithm (MFM-algorithm). MFM-algorithm can design more accurate fuzzy logical controller by clustering input/output data from fuzzy inference system.

We compare and analyze the fixed signal controller, the fuzzy traffic controller of the same size and shape, and the modified fuzzy traffic controller by using the delay time, the proportion of entered vehicles to occurred vehicles and the proportion of passed vehicles to entered vehicles.

Chapter 2 proposes the fuzzy traffic controller considering spillback on crossroads and introduces the input/output variables and the inference rules. Chapter 3 presents the membership function modification algorithm. Chapter 4 compares and analyzes the fixed signal controller, the fuzzy traffic controller of the same size and shape, and the modified fuzzy traffic controller. Chapter 6 is a summary of the research work.

II. Fuzzy traffic controller

The purpose of the intelligent traffic control using the fuzzy controller is to lighten the traffic congestion and to

Maniscript received March 15, 2001; revised May 1, 2001

decrease the delay time on crossroads by catching the traffic situation of current crossroad and related roads and by changing the traffic signal appropriately.

The pre-assumptions of design for this research are following.

1. The congestion of all roads can be detected by sensors.
2. Duration time of yellow signal can be decided by the width of crossroad and the length of vehicles.

Input variables of our FTC are the number of waiting vehicles during the red signal(that is, Volume), the duration time of the red signal(that is, RedTime) and a degree of traffic congestion of upper lanes(that is, DeCong) which vehicles on a crossroad are to proceed to. Its output variable is the duration time of the green signal(that is, GreenTime).

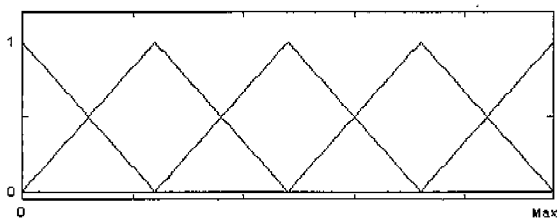

Fig. 1. The membership functions of the same size and shape

It uses five linguistic variables for input/output variables. The first designed FTC uses the membership functions of the same size and shape as shown in figure 1.

Our FTC infers a degree of complexity of current road(that is, DeComp) by employing the inference rules of table 1. It also infers the duration time of green signal by using table 2. The decided values are defuzified by the center of area method for applying to traffic control.

Table 1. Rule for inferring a degree of complexity of a road

Volume / RedTime	VS	LS	ME	LL	VL
VS	ME	LH	VH	VH	VH
LS	LL	ME	LH	VH	VH
ME	VL	LL	ME	LH	VH
LL	VL	VL	LL	ME	LH
VL	VL	VL	VL	LL	ME

Table 2. Rules for deciding the duration time of green signal

DeComp / DeCong	VL	LL	ME	LH	VH
VL	VS	LS	ME	LL	VL
LL	VS	LS	ME	LL	LL
ME	VS	LS	ME	ME	ME
LH	VS	LS	LS	LS	LS
VH	VS	VS	VS	VS	VS

In table 1 and 2, the linguistic variables are VS(Very Short), LS(Little Short), ME(MEdium), LL(Little Long) and VL(Very Long) for RedTime and GreenTime, and are VS(Very Small), LS(Little Small), ME(MEdium), LL(Little Large) and VL(Very Large) for Volume, and are VL(Very Low), LL(Little Low), ME(MEdium), LH(Little High) and VH(Very High) for DeCong and DeComp.

III. Membership function modification algorithm

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 because it employs the membership functions of the same size and shape for all linguistic variables. In this case, we can design more accurate controller by clustering the input and output data from controlling process[1, 4].

Therefore, we modify FTC, which employs the membership functions of the same size and shape, based on the membership function modification algorithm (MFM-algorithm) as shown in figure 2. For the purpose of enhancing performance of fuzzy traffic controller, MFM-algorithm modifies the size and shape of the membership functions of FTC by clustering the input/output data from its fuzzy inference system.

```
function MFM(FLC,eval_rules, α)
/*eval_rules: The control knowledge
   α: Threshold value
   FLC: FLC with the membership functions of the same
        size and shape*/
{
inoutdata = get_input_data(count);
while TRUE
  {
  get_output_data(FLC, inoutdata);
  if(eval(inoutdata, eval_rules) <= α)
       break;
  else
       {
       inoutdata = delete_inconsistent(inoutdata,
                                        eval_rules);
       centers = clustering(inoutdata);
       FLC=make_new_FLC(FLC, centers);
       get_output_data(FLC, inoutdata);
       }
  }
return FLC;
}
```

Fig. 2. A membership function modification algorithm

In figure 2, "get_input_data()" generates the input data set by the random number generator. "get_output_data()" generates the output values by using the input values as input of FLC. "eval()" computes fitness of the input/output data set by using the fitness measure of Eq.1.

$$fitness = \frac{|X_{incons}|}{|X_{all}|} \qquad \text{(Eq.1)}$$

where, |Xincons| is the number of input/output data which does not satisfy the control knowledge, and |Xall| is the cardinality of input/output data set.

"delete_inconsistent()" deletes a input/output data which does not satisfy the control knowledge from a input/output data set. "clustering()" clusters the reduced input/output data set by using the K-Mean algorithm and returns the central values of clusters. "make_new_FLC()" modifies the existing FLC based on the central values of clusters returned by "clustering()".

Table 3. Example of input/output data set

data	input 1	input 2	output
1	36	4	4
2	52	12	6
3	45	1	0
4	23	10	17
5	7	16	23
6	2	8	17
7	***4***	***9***	***16***
8	27	8	4
9	62	6	0
10	***6***	***7***	***17***
11	13	17	24
12	55	8	0
13	***55***	***19***	***12***
14	7	8	16
15	18	9	10
16	63	18	4
17	17	11	18
18	19	10	17
19	***49***	***20***	***11***
20	58	10	4

For example, let table 3 be a input/output data set of the fuzzy controller of 2-input and 1-output. Let the control knowledge be as follows.

Let d1 and d2 be elements of a input/output data set. If input 1 of d1 is greater than input 1 of d2 and input 2 of d1 is less than input 2 of d2, then output of d1 must be less than output of d2.

Then, in table 3, because data 7 and 10, and data 13 and 19 do not satisfy the above control knowledge, they are deleted from a input/output data set. Therefore, fitness of table 3 is 4/20=0.2.

Ⅳ. Experiment and Results

We developed the traffic-flow simulator by using Matlab as like figure 3 and estimated the performance of the proposed FTCs.

We constructed the equal-partitioned FTC with the membership functions of the same size and shape, and modified the size and shape of its membership functions by using MFM-algorithm.

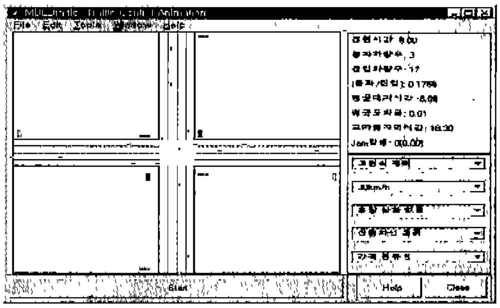

Fig. 3. Simulator

For applying MFM-algorithm to the equal-partitioned FTC, the threshold value α was 0.01 and the control knowledge inferred from table 1 and table 2 was as following.

Let d_1 and d_2 be elements of a input/output data set of FTC.
If RedTime of d_1 is longer than RedTime of d_2 and Volume of d_1 is smaller than Volume of d_2, then DeComp of d_1 is lower than Decomp of d_2.
If RedTime of d_1 and d_2 is same and Volume of d_1 is larger than Volume of d_2, then DeComp of d_1 is higher than Decomp of d_2.
If Volume of d_1 and d_2 is same and RedTime of d_1 is longer than RedTime of d_2, then DeComp of d_1 is lower than Decomp of d_2.
If DeCong of d_1 is higher than DeCong of d_2 and DeComp of d_1 is lower than DeComp of d_2, then GreenTime of d_1 is shorter than GreenTime of d_2.
If DeCong of d_1 and d_2 is same and DeComp of d_1 is higher than DeComp of d_2, then GreenTime of d_1 is longer than GreenTime of d_2.
If DeComp of d_1 and d_2 is same and DeCong of d_1 is higher than DeCong of d_2, then GreenTime of d_1 is shorter than GreenTime of d_2.

In our simulation, situation of a crossroad was assumed as shown in figure 4.

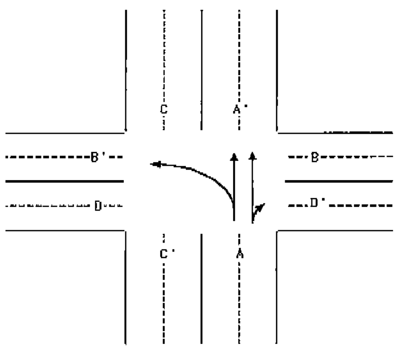

Fig. 4. Situation of crossroad

Velocity and occurrence of vehicles was assumed as five levels. The number of the occurred vehicles was 350

±50, 600±50, 1100±50, 1450±50 and 1800±50 respectively. Velocity of vehicles was 10km/h, 20km/h, 30km/h, 40km/h and 50km/h respectively. The green signal was circulated based on signal for straight and left-turn(that is, A→B→C→D→...). We assigned 18 seconds for straight and left-turn and 2 seconds for yellow signal. We used 4×(18+2)=80 seconds as basic cycle of signal. 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. Signal-cycle of the upper roads(shown as, A', B', C' and D' in figure 4) was decided randomly in range of [50 80] and the duration time of their green signal was decided by a degree of congestion. During green signal, if vehicles on current roads(shown as, A, B, C and D in figure 4) could entered upper roads, they entered a crossroad and proceeded to upper roads. Only if the occurred vehicles could enter the current roads, they entered the current roads.

In situation of the same velocity of vehicles, the same controller and the same number of the occurred vehicles, we simulated 20 times respectively.

Service levels of a crossroad with traffic signal are decided by the delay time. Delay time is loss of fuel and measure of discomfort. Because delay time is not always decided according to a degree of saturation, it is difficult to decide service level based on a degree of saturation[5]. Therefore, we estimated performance of controllers by using not a degree of saturation but the delay time.

The number of passed vehicles, which is commonly used for estimating performance of fuzzy traffic controller, did not assumed spillback of a crossroad. Therefore, it was not used for estimating performance of the proposed controllers. Instead of it, we used a degree of entrance(DE) and a degree of passage(DP). DE means the proportion of entered vehicles to occurred vehicles and DP means the proportion of passed vehicles to entered vehicles.

$$DE = \frac{Nmber\ of\ entered\ vehicles}{Nmber\ of\ passed\ vehicles}$$

$$DP = \frac{Nmber\ of\ passed\ vehicles}{Nmber\ of\ entered\ vehicles}$$

A spillback of a crossroad results to loss of green signal, decreases the number of passed vehicles, increases a degree of complexity of roads, and obstructs vehicles from entering roads.

Figure 5 to figure 10 show results of experiment. In figures, - -◆- - is the fixed signal controller(that is, C1), —●— is the fuzzy traffic controller of the same size and shape(that is, C3), and ·····■····· is the fuzzy traffic controller modified by MFM-algorithm(that is, C2).

In figure 5 and figure 6, delay-time of C2 and C3 is smaller than C1. When velocity of vehicles is over 25km/h and the number of occurred vehicles is over 700, delay-time of C2 is smaller than C3. In figure 7 to figure 10, DE and DP of C2 is higher than C1 and C3, but DE of C3 is not always higher than C1.

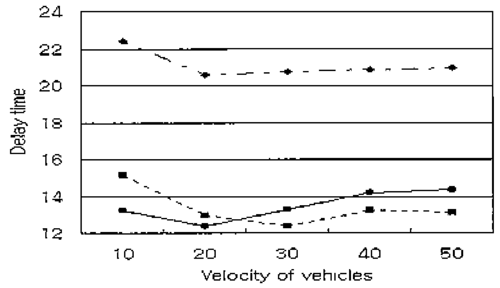

Fig. 5. Delay time according to velocity of vehicles

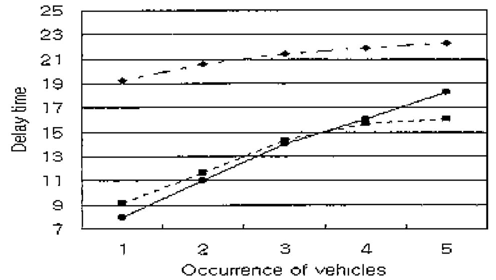

Fig. 6. Delay time according to occurrence of vehicles

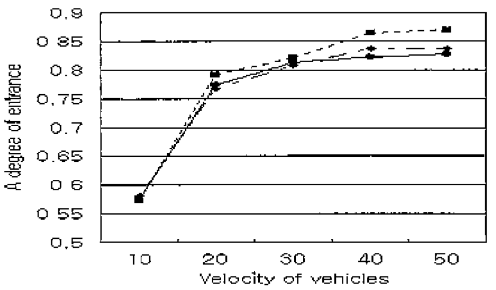

Fig. 7. DE according to velocity of vehicles

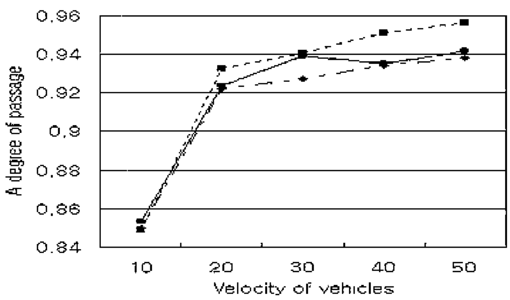

Fig. 8. DP according to velocity of vehicles

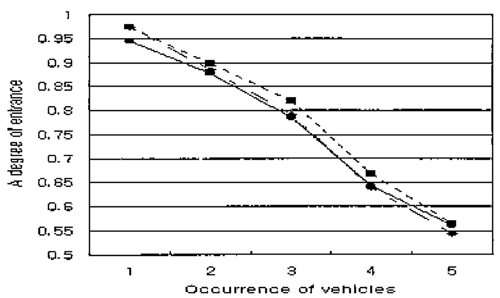

Fig. 9. DE according to occurrence of vehicles

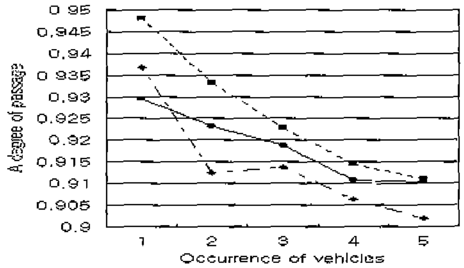

Fig. 10. DP according to occurrence of vehicles

Table 4 shows means of delay-time, DE, and DP. In table 4, C2 shows more enhanced performance than C1 and C3. However, from a DE's point of view, the performance of C3 is inferior to C1.

Table 4. Means of performance

Controller	C_1	C_2	C_3
Delay time	21.10	13.37	13.48
DE	0.766	0.782	0.762
DP	0.914	0.926	0.918

V. Conclusion

In this paper, we proposed a fuzzy traffic controller that can cope with the traffic congestion. In order to consider such situation as loss of green signal caused by the spillback of upper crossroad, we introduced a degree of traffic congestion of upper roads, which vehicles on a crossroad are to proceed to.

We constructed a fuzzy traffic controller that uses the membership functions of the same size and shape for all linguistic variables, and modified the size and shape of them by employing the membership function modification algorithm.

In experiment, the fuzzy traffic controller with membership functions of the same size and shape did not always show better performance than the fixed signal controller. In situation of increase of the number of vehicles and the velocity of vehicles, the fuzzy traffic controller designed by the membership function modification algorithm always showed better performance than others.

Reference

[1] Y. T. Kim, Y, J. Lee, S. H. Lee, T.S. Chung, Z. N. Bien, "A Survey on the Fuzzy Control Systems with Learning/Adaptation Capability", *Journal of KFIS*, vol. 5, no. 3, pp. 11-35, 1995.

[2] J. W. Kim, "A Traffic Light Controlling FLC Adaptable to Various Traffic Volumes", *Journal of KISS(B)*, vol. 24, no. 9, pp. 976-985, 1997.

[3] K. H. Lee, "Green-Split Coordination Strategy In Over-saturated Signal System", *Journal of KTRS*, vol. 11, no. 1, pp. 87-103, 1993.

[4] H. K. Park, S. G. Kong, "Performance Improvement of Distributed FLC by Nonuniform Membership Functions", *Proceedings of KFIS Fall Conference '97*, vol. 7, no. 2, pp. 37-40, 1997.

[5] J. M. Won, J. S. Choi, Traffic Engineering, Parkyoungsa:Seoul, pp. 146-175, 1993.

[6] Pappis, C.P. and Mamdani, E.H., "A Fuzzy Logic Controller for a traffic junction", *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-7, no.10, pp. 707-717, 1977.

[7] Favilla, J, Machion, A., and Gomide, F., "Fuzzy Traffic Control: Adaptive Strategies", *Proc. Of 2nd IEEE int'l Conf. On Fuzzy Systems*, pp. 506-511, 1993.

[8] Jamshidi, M., Kelsey, R., and Bissel, K., "Traffic Fuzzy Control: Software and Hardware Implementations", *Proc. Of the Fifth IFSA Word Congress*, pp. 907-910, 1993.

[9] Jongwan Kim, "A Fuzzy logic Control Simulator for Adaptive Traffic Management", *Proc. Of IEEE Int'l conf. On Fuzzy Systems*, pp. 1519-1524, 1997.

Wan-Kyoo Choi

Wan-Kyoo Choi was born October 16. 1964. He received the B.A. degree in Department of Religious Studies from Seoul National University, Seoul, Korea, in 1983, and the M.S. and Ph. D. degrees in Department of Computer Science form Chosun University, KwangJu, Korea, in 1997 and 200 respectively. He was in the employ of KongSung Comminication Ltd. from 1992 to1993 and HanYang System Ltd. form 1993 to 1995 respectively. Since 2000, he has been a faculty member of the Department of Computer Science at Kwangju University, where he is currently a Full Time Lecturer. His research interests are Software Engineering, Object-oriented System, Fuzzy Sets and Rough Sets.

Phone : +82-62-670-2501
Fax : +82-62-670-2187
E-main : wkchoi@kwangju.ac.kr

Sung-Joo Lee

Sung-Joo Lee was born October 31. 1943. He received the B.S. degree in Department of Physics from HanNam University, Seoul, Korea, in 1970, and the M.S. degree in Department of Computer Science form KwangUn University, Seoul, Korea, in 1992, and Ph. D. degree in Department of Computer Science from DaeGu Catholic University, DaeGu, Korea, in 1998. Since 1981, he has been a faculty member of the Department of Computer Science at Chosun University, where he is currently a Professor. His research interests are Software Engineering, Programming Language, Object-oriented System, Rough Set.

E-main : sjlee@mail.chosun.ac.kr