DESIGN AND IMPLEMENTATION OF GROUP TRAFFIC CONTROL SYSTEM USING FUZZY LOGIC

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ABSTRACT

Describes how to compute the optimal extension time that will add to the fixed time control system. The system has been developed to simulate isolated traffic junction with respect to the situation of its backward and forward neighbours based on fuzzy logic. By using MATLAB (Fuzzy Logic Toolbox) we also show the simulation and the results obtained from the system. A comparison can be made between this type of cooperative traffic junction and isolated traffic junction by using different fuzzy algorithms. Simulation results show that the fuzzy logic controller has better performance and is more cost effective.

Keywords: *Fuzzy logic, extension time, Traffic junction, Simulation*

1. INTRODUCTION

The traffic signal control is an important aspect in Modem City traffic system. As we all known, traffic systems are time-varying, random system. So a lot of conventional methods for traffic signal control based precise models fail to deal efficiently with the complex and varying traffic situations. One of the main features of modern cities is the permanent growth of population in a relatively small area. The consequence of this fact is the increase in the number of cars and also the necessity of movement and transport of people and goods in urban city networks.

Operating traffic signals is inherently a difficult task with many conflicting objectives. The traffic control should be effective by minimizing the waiting times of the vehicles while maximizing the capacity of the intersection. In addition to this, the emissions should be minimized and benefits should be given to e.g. public transportation. All these objectives should be realized without compromising the safety of the road users. The aims described above are hard to cope with by using traditional time-based or detector-based control methods since there is no intuitive way of seeing how individual parameter changes affect the overall performance. There are two kinds of research based on fuzzy logic. One is focused on simple traffic conditions and researches single intersection. Obviously, these researches can't apply to complex traffic systems with many intersections as a whole in a modern city. The other new methods Pappis et al [1] try to consider all these intersections as a whole and make the average delay time of vehicle lower. In all the cities in the world, the registration of new vehicles each year increased by about twenty percent. This increment is rather than alarming and even with the development of the new roads other measures have to be stepped up and introduced as quickly as possible Kim et al [2], Favilla et al [3], Bagheri et al [4],Tan et al . [5], Nakatsuyama et al [6]. It is understandable that automatic control systems should relieve humans from manual control; however, such automatic system does not work well in many circumstances especially during oversaturated or unusual load conditions which could be due to limitations of the algorithms or sensing devices. In this respect manual control seems to be better due to the intelligence of the humans in understanding the traffic conditions at the respective junctions.

In this paper we discuss the implementation of an intelligent traffic lights control system using fuzzy logic technology which has the capability of mimicking human intelligence for controlling traffic lights. Software based on MATLAB has been developed to simulate an isolated traffic junction with containing information form the neighbours being used through the simulation. Fuzzy logic technology allows the implementation of real-life rules similar to the way humans would think. For example, humans would think in the following way to control traffic situation at a certain junction: "if the traffic is heavier on the north or south lanes and the traffic on the west or east lanes is less, then the traffic lights should stay green longer for the north and south lanes". Such rules can now be easily accommodated in the fuzzy logic controller.

2. PROBLEM FORMULATION

Traffic control strategies have also improved since the installation of the first traffic controller. The strategies can be classified. The most important strategies are as follows:

1- *Fixed-time* (FT) strategies. The control (signal plan) is calculated in advance, using statistical data.

2- Real-time (RT) strategies. The real-time data about traffic processes are used to determine control or its modification.

The first type of control uses a preset cycle time to change the lights. The other type of control combines preset cycle time with proximity sensors which can activate a change in the cycle time or the lights. The main control measure in urban road networks is the traffic lights at intersections. Traffic lights, besides ensuring the safety of road crossings, may also help in the minimization of the total time spent by all the vehicles in the network, provided that an optimal control strategy is applied.

Fuzzy logic is an approach trying to mimic human thinking by using computer algorithms. In practice, the measured values (e.g. queue lenghts) are first transformed into *fuzzy sets*. These sets describe measured values by intuitive truth-values such as “long” queue or “medium” number of approaching vehicles. The logical operations, such as “IF length of queue is *long* AND number of approaching vehicles is *low* THEN extension of the green light is *short*”, are applied to these sets.

This provides the controller with traffic densities in the lanes and allows a better assessment of changing traffic patterns. The general structure of a fuzzy traffic lights control system is illustrated as in Fig. 1. The structure cosists of four levels which are the current traffic case, the information obtained from detectors, traffic controller and traffic model. Fig.2 is maximization of detector information part. There are two electromagnetic sensors placed on the road for each lane. The first sensor behind each traffic light counts the number of cars passing the traffic lights, and the second sensor which is located behind the first sensor counts the number of cars coming to the intersection at distance D from the lights.

The number of cars between the traffic lights is determined by the difference of the reading between the two sensors. The distance between the two sensors D, is determined accordingly following the traffic flow pattern at that particular intersection. The fuzzy logic controller is responsible for controlling the length of the green light time according to the traffic conditions. The state machine controls the sequence of states that the fuzzy traffic controller should cycle through. There is one state for each phase of the traffic light. There is one default state which takes place when no incoming traffic is detected. This default state corresponds to the green time for a specific approach, usually to the main approach. In the sequence of states, a state can be skipped if there is no vehicle queues for the corresponding approach.

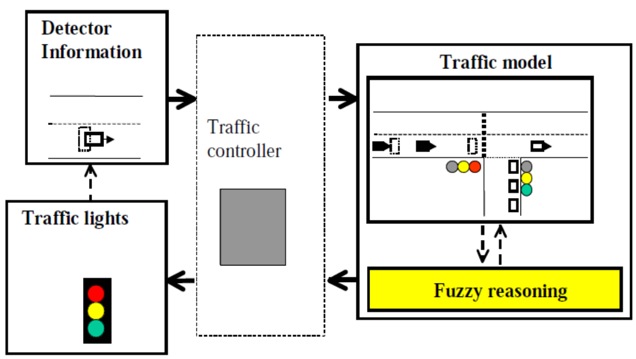

Fig. 1. General Structure of Fuzzy Traffic Controller

In the development of the fuzzy traffic lights control system the following assumptions are made:

1- When traffic from the north moves, traffic from the west,
south and east stops, when traffic from the south moves, traffic from the west, north and east stops and when traffic from the north and south moves traffic from east and west stops.

2- The fuzzy logic controller will observe the density of the north and south traffic as one side and the west and east traffic as another side.

3- There are only three conditions for each car: (a) entering the traffic network; (b) existing the traffic network; (c) waiting in a intersection.

4- The rate of car running in the lane is constant.

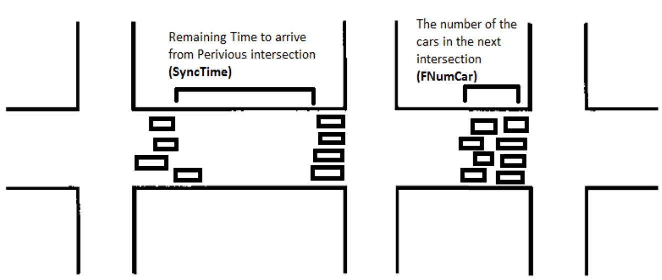

Fig.2. FnumCar and SyncTime inputs representations

3. FUZZY INPUT/OUTPUT VARIABLES AND THEIR MEMBERSHIP FUNCTIONS DESIGN

The fuzzy input and output variables should be a reflection of traffic congestion. Fuzzy controllers have five inputs variables as follows:

1- The quantity of the cars on the arrival side.
2- The quantity of the cars on the queue side.
3- The time remaining to arrive the cars from the previous intersection(for arrival link).
4- The number of cars in the next intersection(for arrival link)
5- The time duration that the queue side traffic stays on red signal(for queue side).

And one output variable which is the external time that given to the green signal.

The intersection have 5 inputs that help us to determine the long of external time giving to the green signal for arrival side. The current intersection work cooperatively with the pervious and the next intersection. These intersections plays important role in making desicion. ArrivalSide, QueueSide, FnumCar, SyncTime and Waiting time represents the abbreviation for the five inputs. FnumCar and SyncTime represents the parameters for the neigbours intersection, Fig.2 shows graphically the mean for these two inputs.

The membership functions of these variables is presented in Fig. 3.a, 3.b, 3.c, 3.d, 3.e; it can be observed that the y-axis is the degree of the membership of each of the fuzzy variable. For the input fuzzy variables the universe of discourse (the x-axis) is the quantized sensor signals which sensed the quantity of the cars. Each input and output have the same linguistic variables, which is {Zero, Small, Many, Large, Very Large}. The fuzzy Set Theory defines fuzzy operator on Fuzzy Sets in terms of simple *if-then* rules. The controller described by using 80 possible combination of AND rules , Table1 shows some of these rules.

ArrSide	QueSide	SyncTime	Fnumcar	WaitingTime	Ex.Time
S			L		Z
VL		VL			M
	L			Z	S
L	Z				L

Table1. Some of the control rules

Till now every thing looks like there is no any foundation for mathematical formulas and this is the difference of fuzzy which can be observe by conneting lingustic terms and rules based on human expert with the fuzzy sets and calculations. If we take a look to the one or two of the rules and try to represent mathematically N. Baykal et al [7]:

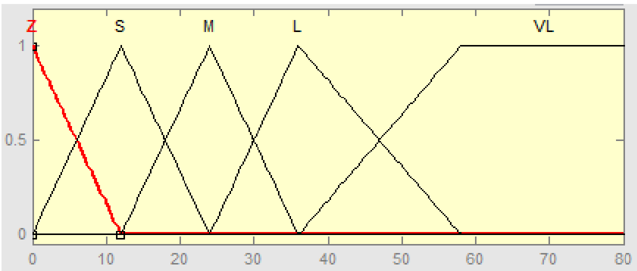

Fig. 3.a. Arrival & Queue sides membership

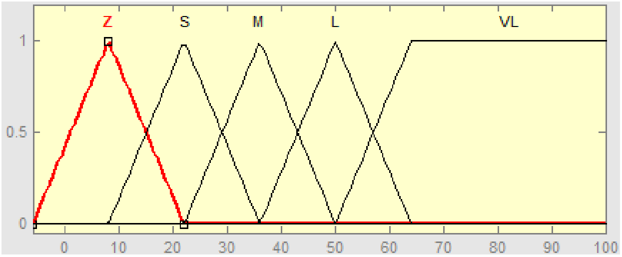

Fig. 3.b. Syncronization time membership

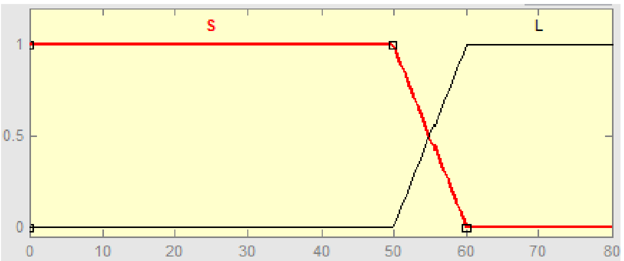

Fig. 3.c. Forward cars number membership

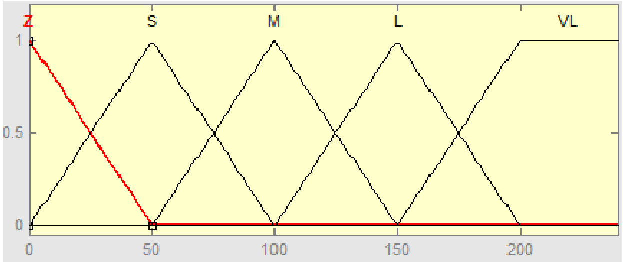

Fig. 3.d. Waiting time number membership

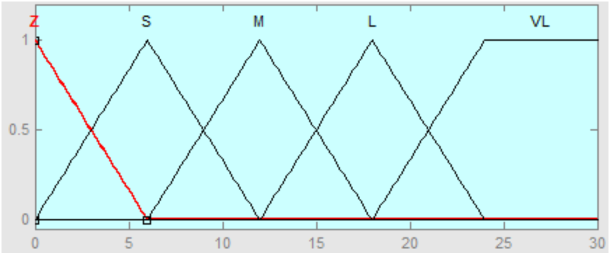

Fig. 4.e. Extension time membership

Arrival side is SMALL AND the number of the cars in the next intersection is LARGE then the extension time will be ZERO

First to determine the membership degree for arrival side SMALL we use the following formulas to obtain two different degree :

$$\mu_S(x) = \frac{x-12}{12} \qquad \text{If } 0 \le \text{ArrivalSide} \le 12$$

$$\mu_S(x) = \frac{24-x}{12} \qquad \text{If } 12 \le \text{ArrivalSide} \le 24$$

Then the membership degree for next intersection, which is in this example LARGE. We obtain this by using the followin formulas N. Baykal et al [7]: :

$$\mu_L(x) = 1 \qquad \text{If FnumCar} \ge 60$$

$$\mu_L(x) = \frac{60-x}{10} \qquad \text{If } 50 \le \text{FnumCar} \le 60$$

After determining the membership degree for both inputs in specified rule, the next step used to produce the ZERO variable as a extension time. The term AND which is used to connect the two input variables represent MIN operation in fuzzy set theory. Mamdani and Sugeno are the most using methods during this step.

Mamdani Controller :

Mamdani controller using Min, Max operator on fuzzy rules to make a decision. The fuzzy implication "*if- then*" is also a fuzzy phrase R defined on ArrSide x QueSide x FnumCar x SyncTime x WaitingTime x Ex.Time with grades of membership function N. Baykal et al [7]: .

μR**(**ArrSide,FnumCar) = min {μs(x),μL(y)}

Finally two or more fuzzy implications R, S, connected

By "else" form a fuzzy clause C defined on ArrSide x FnumCar x Ex with grades of membership function μR**(**ArrSide,FnumCar) = max {(μs(x),μL(y)), μs(x),μL(y)),...}

Takagi-Sugeno-Kang Controller:
Tagaki-Sugeno-Kang(TSK) fuzzy rule systems are receiving more and more attention in the recent years. Fuzzy rule base structure by TSK can be given as follows N. Baykal et al [7] :

$$R : \underset{i=1}{\overset{c}{ALSO}}\left[IF \quad \underset{j=1}{\overset{nv}{AND}}\left(x_j \in X_j \ \ \text{isr} \ A_{ji}\right) \ \text{THEN} \ y_i = a_i x^T + b_i \ \right]$$

- a_i and b_i are regression line coefficients associated with *i* th rule,
- y_i is the model output of *i*th rule, R_i,
- THEN is the connective, which weights y_i for each rule by using corresponding degree of firing of a given observation in order to find the model output from each rule,
- ALSO is the connective, which takes the weighted average of the model output of each rule in order aggregate the model outputs of fuzzy rules.

4. SIMULATION RESULT AND DISCUSSION

After the controller was carefully designed, we test the system and discuss the impact of the input variables on the output. The two methods Mamdani and Sugeno implemented by using matlab fuzzy logic toolbox Ranger Jang et al [8], Sivanandan et al [9]. The simulation made based on the copmarision of single intersection Askerzade et al [10] and group interseciton. In the first step from simulation Fig.4 shows the arrival side vs. queue side in both situation(single and group).

1 – Density of the *arrival side* with the density of the *queue side vs. external time* .

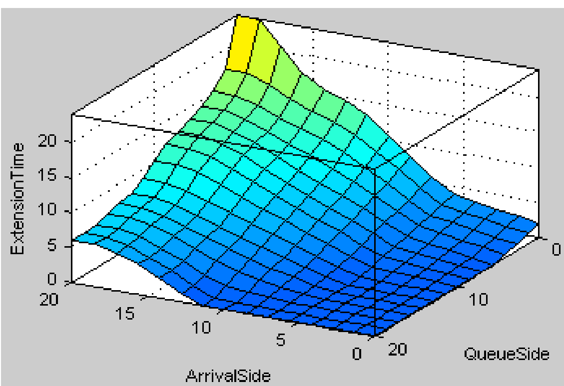

Fig. 4.a. “Arrival side” and “Queue side” vs. External time

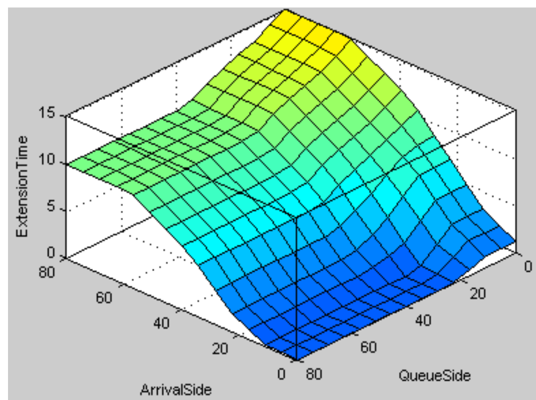

Fig. 4.b. “Arrival side” and “Queue side” vs. External time

Fig.4.a and Fig.4.b shows single and group intersection respectively, the external time (z-axis) is small when the density of arrival side (y-axis) is small and the density of the queue side (x-axis) also small. The main difference here is in the case of group intersections the number of cars will extend up to 80 cars and the extension time become bigger than single intersection for the same conditions(arrival is small and queue is bigger) .

2- Effect of *SyncTime* and *FnumCar* to the *External time*
To show the effect of the neighbours intersecitons to the current intersection external time we take SyncTime for perivous interseciton and FnumCar for the next interseciton and oberserving their results. Fig.5.a and Fig.5.b shows the Mamdani and Sugeno results respectively. In case of Mamdani Fig5.a when the number of cars in the next intersection FnumCar (x-axis) is small and the time remaining to reach from perivious interseciton SyncTime (y-axis) is very long then the extension time (z-axis) become zero and start in growing when SyncTime decreasing till reaching to the maximum value in case of very small.

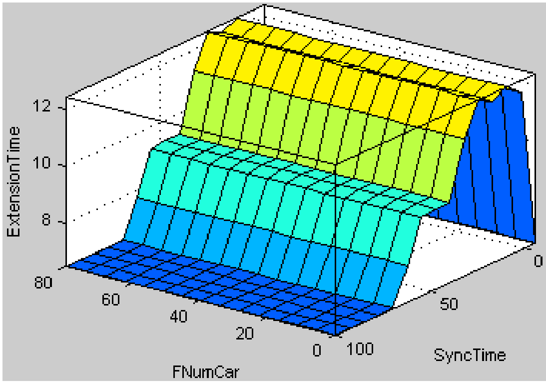

Fig. 5.a. "FnumCar" and "SyncTime" vs. External time (by Mamdani)

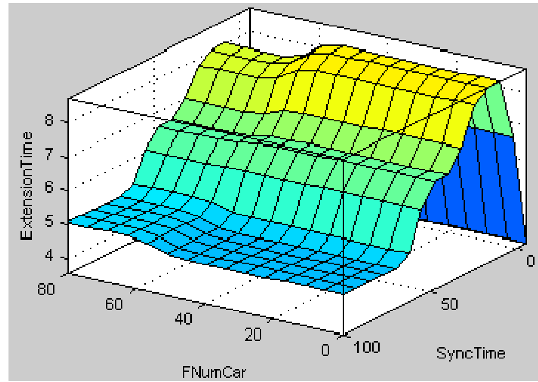

Fig. 5.b. "FnumCar" and "SyncTime" vs. External time (by Sugeno)

In the case of Sugeno Fig.5.b the same result can be observed with a little change which appear when SyncTime (y-axis) is very large and whatever is FnumCar (x-axis) the extension time (z-axis) become small rather than zero in Mamdani case.

Fig.6 and Fig.7 shows the graphical representation for the entered information in Table1 and their results in Table 2. In Table1 there are 15 different traffic conditions tested by using Matlab. The results compared with the single junction traffic results by using Mamdani and Sugeno methods.

ArrivalSide	QueueSide	SyncTime	FnumCar	WaitingTime
10	20	20	70	100
10	20	20	30	100
20	30	5	60	100
20	30	40	60	50
33	45	32	65	150
33	45	50	65	150
33	45	120	40	80
5	18	100	20	80
5	18	10	20	80
5	18	10	58	80
40	40	30	30	55
40	40	90	70	55
55	35	70	30	70
55	35	40	30	70
55	35	40	58	70

Table 1. Entered traffic data

Single Intersection		Group Intersection	
Mamdani	Sugeno	Mamdani	Sugeno
4.92	3.5	4.94	2.2
4.92	3.5	5.11	2.94
5.79	3.75	8.2	2.6
5.79	3.75	5.04	1.5
6.06	4.97	9.81	5.3
6.06	4.97	8.2	4.88
6.06	4.97	5.19	3.5
3.92	2.75	5.04	1.85
3.92	2.75	5.27	3.65
3.92	2.75	5.11	2.88
7.8	8.67	11.4	7.58
7.18	8.67	6.18	5.05
9.2	12.9	9.58	7.72
9.2	12.9	12.2	9.72
9.2	12.9	11.1	8.94

Table2. Results obtained during testing Tablo1 data

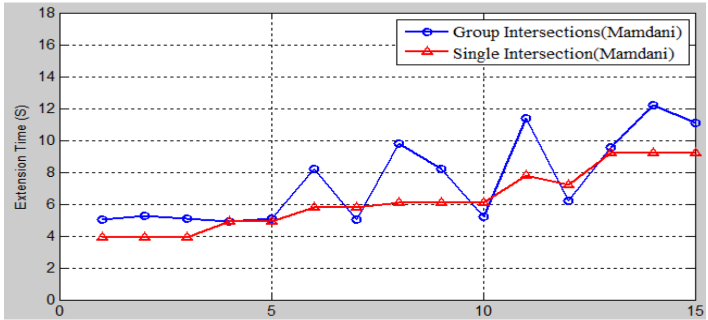

Fig.6 Graphical representation for single and group traffic junctions by using Mamdani method

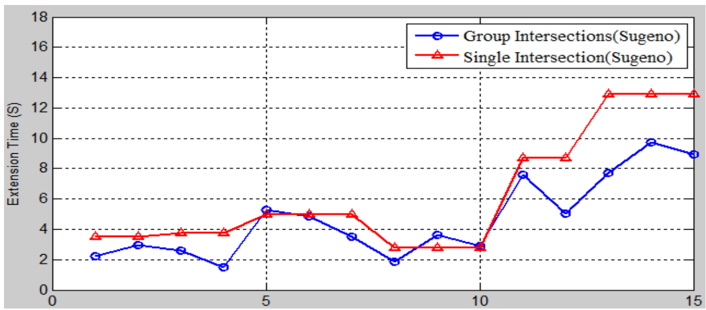

Fig.7 Graphical representation for single and group traffic junctions by using Sugeno method

When the traffic becomes more than one intersection this make it difficult to decide the correct extension time because we must take into account the state of all other intersection which can change our desicion in may be very big way. When we take a look to the Fig.6 carefully , we can observe that in the state of group intersection some times there are really big difference comparing with single intersection Askerzade et al [11]. The result almost going in a bad way in mean of average waiting time. The two inputs FnumCar and SyncTime can make radical change in the result for example when SyncTime equal to 32 the extension time become 9.81 seconds but for the same conditions with just changing SyncTime to 120 the extension time become 5.19 seconds. This mean that the system try to clear the cars for the arrival side when there are less time to reach cars from the perivous intersection to the current intersecion.

5. OVERALL CONCLUSIONS

As obtained from experimental results there are regression in the traffic control performance when we take group of intersections and treated them by using fuzzy logic. The reason for this is there are many disagreable states for the system which gives results become uncomfortable for other factors. In the mean of average waiting time for the traffic being processed by fuzzy controller, the neighbours of the traffic affect the results in badly way. For example if there are large number of cars in the arrival side for current traffic and there are also large number of cars in the next traffic, the controller can't give the necessary time to clear the arrival side completely because the next traffic does not cleared yet. If we ignored this point and giving large extension time for the arrival side this due to very heavy traffic conditions for the next interseciton. So that this method of taking group of traffic congerstions and treated them together have also the advantages of creating a stable traffic situation for the whole traffic of any city. Always it's better if this type of approach being applied to the center of cities or the places that almost have heavy traffic situations and applying the single interseciton approach Askerzade et al [11] in the case of total traffic is small (e.g. the places away from the center of the city).

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