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Fuzzy Traffic Light Controller Using Sugeno Method for Isolated Intersection

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Abstract— **This paper presents a Sugeno-type fuzzy traffic controller for controlling isolated traffic intersection. The model framework used in this study developed using M/M/1 queuing theory. The principles and rules for the fuzzy control system are modeled based on the arrivals of vehicles, vehicles queue length at current green phase, and vehicles queue lengths at the other phases. The phase sequence and phase length extension are used in the decision making to switch the current phase to the appropriate next phase. Using the information from its traffic detectors at each of the four lanes of isolated intersection, the fuzzy rule-based system gives optimal signals to adapt the phase lengths to the traffic conditions. The phase sequence is managed by a simple program using *if-else* statement. In this paper, an isolated traffic intersection is simulated for both fixed-cycle traffic control system and fuzzy logic based traffic control system. The comparison of performance between the two models of traffic light system clearly indicates that the fuzzy logic based traffic lights control system is more efficient, flexible and adaptable in controlling the traffic flow.**

Keywords-fuzzy traffic controller; Sugeno-type; phase sequence; phase length extension.

I. INTRODUCTION

Research on improving traffic light controllers at traffic intersections has been done by many researchers. Tan *et al.* [1] discussed the design and implementation of an intelligent traffic lights controller based on fuzzy logic. The control of the traffic lights using both conventional fixed-time and fuzzy logic controllers was simulated in an isolated traffic junction model developed in Visual Basic. Simulation results indicated that fuzzy logic traffic lights controller performed better than the fixed-time controller or even vehicle actuated controllers.

Abbas *et al*. [2] designed a Fuzzy Rule Based System for oversaturated intersections with left and right turns. The fuzzy logic controller makes the decision to what extent the current green phase has to be extended based on a set of fuzzy rules and real-time traffic information.

Khalid *et al*.[3] proposed fuzzy traffic lights controller which is capable of communication with neighbor junctions and manages phase sequences and phase lengths adaptively. The simulations had shown that the proposed fuzzy controller performed better than that of preset cycle time and vehicle-actuated controllers.

Che Soh *et al.*[4] presented the development of intelligent traffic light system based on the fuzzy logic approach applied to multiple-multilane intersection. The controller is developed based on the cooperation mechanism and synchronizing mechanism with the neighboring intersections. The controller is able to manage the phase sequences and phase lengths adaptively for its neighbors as well as its own traffic conditions. Comparison between fixed-cycle and fuzzy logic based traffic control systems for multilane-multiple traffic intersection clearly indicated that fuzzy logic based traffic light control system is more efficient, flexible and adaptable in controlling the traffic flow.

Based on the reviews of research above, generally, fuzzy logic traffic controllers perform better than conventional controllers. However, most of the proposed fuzzy controllers were developed using Mamdani method. There is not much fuzzy logic traffic controller based on Sugeno method.

This paper presents the development of adaptive traffic light system based on Sugeno-type fuzzy logic approach applied to isolated intersection. The controller is developed based on the arrivals of vehicles, vehicles queue length at current green phase, and vehicles queue lengths at the other phases. The phase sequence and phase length extension are used in the decision making in fuzzy controller for phase switching. The simulation of isolated traffic intersection is implemented based on the fixed cycle traffic controller which is the traditional approach and also the fuzzy logic controller.

The paper is organized as follows. In the next section, an overview of isolated intersection traffic model is described. Section 3 briefly discusses the details of the proposed Sugeno-type fuzzy traffic controller. Section 4 discusses the simulation results of the fuzzy traffic controller with comparison to the traditional controller on isolated intersection. The conclusion of this paper is summarized in the last section.

II. ISOLATED INTERSECTION MODEL

A dynamic model for isolated intersection using queuing theory from [5] is used for the simulation of Sugeno type fuzzy traffic signal controller. The typical four-legged isolated intersection is as shown in Figure 1. There are 8 movements in this intersection which consist of one through movement and one right turn movement at each of the four-legged.

Based on model from [5], an isolated traffic intersection framework is modeled based on an M/M/1 queue theory. Here “M” stands for a “memoryless” (that is, exponential) distribution of inter-arrival times. The “M” in the second position stands for a “memoryless” distribution of “i.i.d.”

service times. The "1" in the third position stands for "one server". The single intersection has a single server, traffic signal, which provides service to a single signal phase at a time. The vehicles queue has the FIFO discipline.

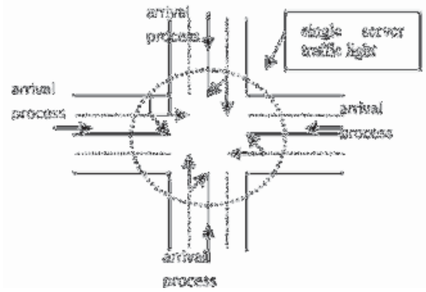

Figure 1. Isolated traffic intersection [5].

The service mechanisms which comprise of customers, queues, and servers are the three main concepts in queuing theory. Customers joining the queuing system are generated by an input source according to a statistical distribution in which the distribution describes their inter-arrival times. The inter-arrival times are the times between arrivals of customers. The basis on which customers are selected to be serviced by the server, which consists of service mechanism, at various times is called queue discipline.

As discussed in [5], traffic arrival and service times at a given intersection are considered as independent random variables, with known distributions. Due to the random nature of traffic arrival, the Poisson distribution usually makes a good fit for the memoryless nature of the exponential distribution which has been widely accepted by researchers in fitting randomly distributed service times, such as those at signalised intersections.

Vehicles arrive at a single-server facility according to a Poisson process with mean arrival rate λ (vehicles per unit time). Equivalently, the inter-arrival times between vehicles are independent and identically distributed with mean $1/\lambda$. Vehicles, therefore, enter the system according to a Poisson process with arrival rate λ.

Service time is defined as the time used to discharge the individual vehicles from the intersection during the time where traffic light stays green. This should not be confused with the total service time of a given signal phase, which is the effective green time or green phase length. The departure process is the time to cross the intersection (service times) and is arbitrarily and independently distributed.

III. SUGENO TYPE FUZZY TRAFFIC CONTROLLER

In this chapter, a detail description of Sugeno type fuzzy traffic controller has been presented. There are three modules in the fuzzy traffic controller which are Next Phase Module, Green Phase Module, and Switch Module. Figure 2 shows the schematic diagram of the controller.

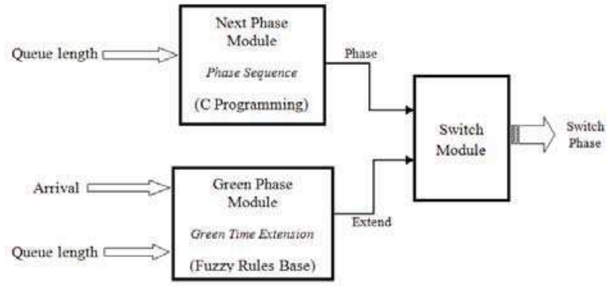

Figure 2: A schematic diagram of the proposed Sugeno type fuzzy traffic signal controller.

A. *Next Phase Module*

In this module, C programming language is written in embedded MATLAB function block to control the phase sequence based on the current queue length at each of the four routes in East, South, West, and North, respectively. The module selects one candidate for the green phase based on traffic conditions of all phases. The phase that has the longest queue length among the four phases is selected. There are four phases in this module which are phase 1, phase 2, phase 3, and phase 4. Green light in East direction is phase 1, green light in South direction is phase 2, green light in West direction is phase 3, and, lastly, green light in North direction is phase 4.

The queue lengths at each of the four directions are compared using *if-else* statement. The value of queue lengths from the sensors at East, South, West, and North directions are fetched into this module. Then, the queue length in the East direction is compared with the other three queue lengths in South, West, and North directions. If the queue length in the East direction is the longest then phase 1, which is corresponding to green light in the East direction, is selected. Else, the comparisons of length between queues proceed until the longest queue length is detected.

B. *Green Phase Module*

The traffic conditions of the green phase are observed by the Green Phase Module. Green light extension time of the green phase is produced by this module according to the condition of observed traffic flow. The output fuzzy variable, extension which means the extension time of green light, consists of four membership functions. The four membership functions are zero (Z), short (S), medium (M), and long (L) where the values of these four membership functions are actually constant.

Basically, in this module, there are two set of fuzzy rules in two separate Sugeno-type fuzzy inference systems. The first set of fuzzy rules consists of a total of sixteen rules and the fuzzy inference system (FIS) which contains these rules takes the arrival rate and the current queue length as its antecedents and generates 'extension' as output. In order to evaluate the possibility that the green phase should extend, the second fuzzy inference system in this module, which consists of second set of fuzzy rules of a total of thirteen rules, takes the generated 'extension' output from the first fuzzy inference system and the queue lengths in the other three phase as its antecedents and generates the 'extension2'.

Generally, Sugeno output membership functions are either linear or constant. A typical rule in a Sugeno fuzzy model has the form as shown below:

If Input 1 = x and Input 2 = y, then Output is z = ax + by +c

For a zero-order Sugeno model i.e. constant output membership functions, the output level z is a constant (a = b = 0).

In this paper, constant output membership functions are used for both of the Sugeno fuzzy inference systems developed in Green Phase Module. This means that the output level z for both Sugeno FIS in this module is constant i.e. z = c. There are four output levels for the first Sugeno FIS where each of the four output levels is represented by different constant values. Similarly, the second Sugeno FIS also has four output levels with different values.

The output levels ‘extension’ and ‘extension2’ for both of the Sugeno FIS in this module are weighted by their respective firing strength w_i of the rule where w_i = AndMethod ($F_1(x)$, $F_2(y)$). For the first Sugeno FIS in this module, F_1 and F_2 are the membership functions of inputs ‘arrival’ and ‘queue’, respectively. For the second Sugeno FIS, F1 and F2 are the membership functions of inputs ‘extension’ and ‘queues’, respectively. The final output of the system is the weighted average of all rule outputs, computed as shown below:

$$Final\ Output = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i}$$

For the first Sugeno fuzzy inference system, Figure 3 and Figure 4 show its corresponding membership functions of input variables: arrival and queue, respectively, of current green phase. Figure 5 shows the membership functions of output variable ‘extension’ for the first fuzzy inference system. Table 1 shows some examples of rules of the first Sugeno fuzzy inference system.

Figure 3: The membership functions of the input variable ‘arrival’ for the first Sugeno fuzzy inference system.

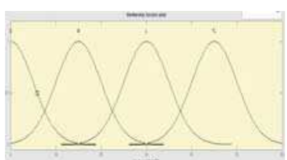

Figure 4: The membership functions of input variable ‘Q’ for the first Sugeno fuzzy inference system.

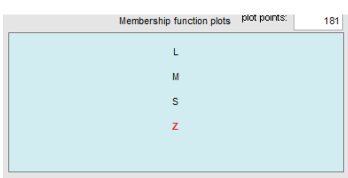

Figure 5: The membership functions of the output variable ‘extension’ for the first Sugeno fuzzy inference system.

TABLE I. SOME EXAMPLES OF RULES THE FIRST SUGENO FUZZY INFERENCE SYSTEM

Rules	Arrival	Queue	Extension
1	Zero	Small	**Zero**
2	Zero	Long	**Short**
3	Few	Long	**Short**
4	Medium	Short	**Short**
…	…	**…**	**…**

For the second Sugeno fuzzy inference system, Figure 6 and Figure 7 show its corresponding membership functions of input variables: extension and queues from the other three lanes, respectively. Figure 8 shows the membership functions of output variable ‘extension2’ for the second fuzzy inference system. Table 2 shows some examples of rules of the second Sugeno fuzzy inference system.

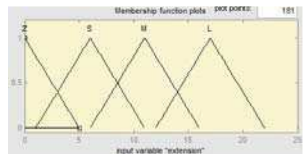

Figure 6: The membership functions of the input variable ‘extension’ for the second Sugeno fuzzy inference system.

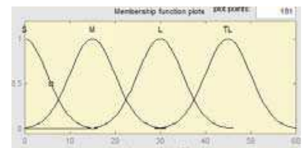

Figure 7: The membership functions of input variable ‘Q’ for the second Sugeno fuzzy inference system.

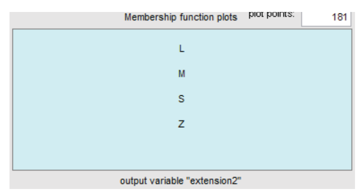

Figure 8: The membership functions of the output variable ‘extension2’ for the second Sugeno fuzzy inference system.

TABLE II. SOME EXAMPLES OF RULES THE SECOND SUGENO FUZZY INFERENCE SYSTEM

Rules	Extension	Queue	Extension2
1	Zero	Short	**Zero**
2	Short	Short	**Short**
3	Short	Medium	**Short**
4	Medium	Short	**Medium**
…	…	**…**	**…**

C. Switch Module

The Switch Module switches current phase to the appropriate next phase based on the inputs from the outputs of Green Phase Module and Next Phase Module. Basically, this module switches the current phase to the next phase based on the outputs of Next Phase Module. If the other phases have longer queue than the queue of current phase, then, the Next Phase Module will give signal to Switch Module to switch to the phase that has the longest queue. The output from the Green Phase Module to the input of Switch Module will determine the length of the extension time of the next phase based on the conditions observed from other phases.

IV. Simulation Results And Discussions

The performance of the developed Sugeno fuzzy controller is evaluated by simulation. The simulation is done in isolated intersection model developed in MATLAB. The proposed method and fixed-cycle method are simulated under the same condition.

The average delay and average departure of vehicles at the intersection are used as indices of performance. The simulation results are summarized as in Table III. The table shows the indices that are measured in seconds, and the improvement of the proposed method over fixed-cycle method. The proposed method shows improvements from 0.75% to 17.61% over the fixed-cycle in each phase as shown in Figure 9. From the graph, the performance of each phase are plotted to show clearly the differences in delay time for each phases between fixed-cycle controller and fuzzy controller. The average delays of each of the four phases for fuzzy controller are lower than fixed-cycle controller.

TABLE III. Performance Of Phase

Index	Phase	Fixed-Cycle (second)	Fuzzy (second)	Comparison Fixed versus Fuzzy
Average delay	1	1.060000	1.018000	3.96%
	2	1.219000	1.199000	1.64%
	3	1.200000	1.183000	1.42%
	4	1.189000	1.074000	9.67%
Average departure	1	338	320	5.33%
	2	400	397	0.75%
	3	176	145	17.61%
	4	162	175	-8.02%

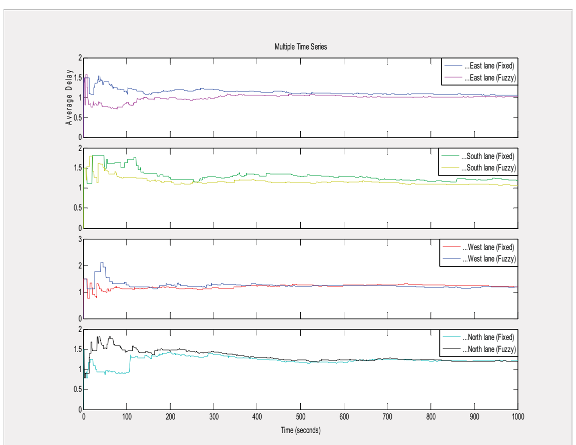

Figure 9: Comparison of average delay in all four phases four based on fixed-cycle controller and fuzzy controller.

Figure 10 shows the comparison of average departure between fixed-cycle controller and fuzzy controller. As shown by histogram in Figure 10, generally, the number of departure vehicle for fuzzy controller is less than that of fixed cycle controller. Hence, the overall performance of the proposed method is better than that of fixed cycle method.

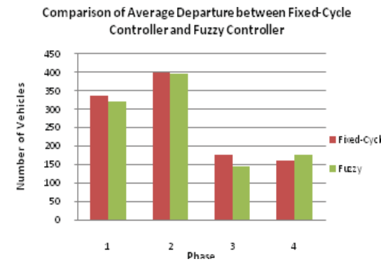

Figure 10: The comparison of average departure between fixed-cycle controller and fuzzy controller.

V. Conclusions

The proposed method shows good performance during simulation in the isolated intersection model. The effectiveness of the proposed Sugeno type fuzzy traffic controller is superior to the traditional fixed-cycle controller due to the former's ability to adapt to different traffic conditions. The time extendibility is not fixed and it can freely determine the length of the green phase according to traffic conditions at the intersection, which does improve the efficiency of the controller. The proposed Sugeno fuzzy traffic signal controller can be improved further for better performance and it also can be used as a reference in designing a more complex traffic signal controller for multiple-multilane intersection in urban area.

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