Intelligent Traffic Lights Control By Fuzzy Logic

Article *in* Malaysian Journal of Computer Science · January 1997

Source: CiteSeer

3 authors, including:

Rubiyah Yusof
Universiti Teknologi Malaysia

INTELLIGENT TRAFFIC LIGHTS CONTROL BY FUZZY LOGIC

Tan Kok Khiang, *Marzuki Khalid, and Rubiyah Yusof
Center for Artificial Intelligence and Robotics
Universiti Teknologi Malaysia
Jalan Semarak
54100 Kuala Lumpur.
(All correspondence should be sent to *)
marzuki@klred.utm.my
Tel: 03-2904892 Fax: 03-2904892

ABSTRACT

One of the ways to overcome traffic problems in large cities is through the development of an intelligent monitoring and control of traffic lights system. This paper addresses the design and implementation of an intelligent traffic lights controller based on fuzzy logic technology. A software has been developed to simulate the situation of an isolated traffic junction based on this technology. The software is highly graphical in nature and uses the Windows system. The software allows simulation of different traffic conditions at the junction and comparison can be made between the fuzzy logic controller and a conventional fixed-time controller. Simulation results show that the fuzzy logic controller has better performance and is more cost benefit.

Keywords: Fuzzy Logic, Traffic Lights Controller, Fuzzy Variables, Membership Functions.

1.0 INTRODUCTION

Monitoring and control of city traffic is becoming a major problem in many countries. With the ever increasing number of vehicles on the road, the Traffic Monitoring Authority or the Transport Ministry as the authority is known here in Malaysia, has to find new ways or measures of overcoming such problem. Among them are developing new roads and flyovers in the middle of the city, building several ring roads around the city such as the inner ring road, middle ring road and outer ring road, introducing city trains such as the light rapid transit (LRT), and monorails, restricting large vehicles in the city during peak hours, and also developing sophisticated traffic monitoring and control systems.

In the city of Kuala Lumpur, the registration of new vehicles each year increased by about twenty per cent. This increment is rather alarming and even with the development of the LRT and new roads other measures have to be stepped up and introduced as quickly as possible. In Kuala Lumpur the problem of traffic flow during peak hours has somewhat been under control by city traffic policemen. Last February the movement of traffic in the city was chaotic when traffic policemen were taken off their duties of manning the junctions. It was learnt that the Kuala Lumpur City Hall wanted to test their automatic traffic control system that had recently been installed which was still in its initial stage. 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 traffic policemen 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. A software based on Visual Basic has been developed to simulate an isolated traffic junction. The control of the traffic lights using both conventional fixed-time and fuzzy logic controllers can be simulated in the software. Analysis on the traffic lights simulation such as waiting time, density, cost, etc. can also be made using the software. The software can also be used as an exercise for undergraduate and graduate students to understand the concept of fuzzy logic and its application to a real environment. The rules and membership functions of the fuzzy logic controller can be selected and changed and their outputs can be compared in terms of several different representations. The software is highly graphical in nature and runs under the Windows environment.

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. The beauty of fuzzy logic is that it allows fuzzy terms and conditions such as “heavy”, “less”, and “longer” to be quantized and understood by the computer.

This paper has been organized as follows. First, a brief overview on traffic lights control system is presented. Then, the development of the software and its usage is next discussed. A comparison between the performance of the fuzzy traffic lights controller and the conventional fixed-time controller is analyzed and discussed in the section that follows.

2.0 TRAFFIC LIGHTS CONTROL SYSTEM

Basically, there are two types of conventional traffic lights control system that are in used. One 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. In the case of a less traveled street which may not need a regular cycle of green lights, proximity sensors will activate a change in the light when cars are present. This type of control depends on having some prior knowledge of traffic flow patterns at the intersection so that signal cycle times and placement of proximity sensors may be customized for the intersection.

Fuzzy logic traffic lights control is an alternative to conventional traffic lights control which can be used for a wider array of traffic patterns at an intersection. A fuzzy logic controlled traffic light uses sensors that count cars instead of proximity sensors which only indicate the presence of cars. This provides the controller with traffic densities in the lanes and allows a better assessment of changing traffic patterns. As the traffic distributions fluctuate, the fuzzy controller can change the signal light accordingly.

The general structure of a fuzzy traffic lights control system is illustrated as in Fig.1. There are two electromagnetic sensors placed on the road for each lane. The first sensor behind each traffic lights 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 amount of cars between the traffic lights is determined by the difference of the reading between the two sensors. This is in contrast to conventional control systems which place a proximity sensor at the front of each traffic lights and can only sense the presence of a car waiting at the junction, not the amount of cars waiting at the traffic. 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 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.

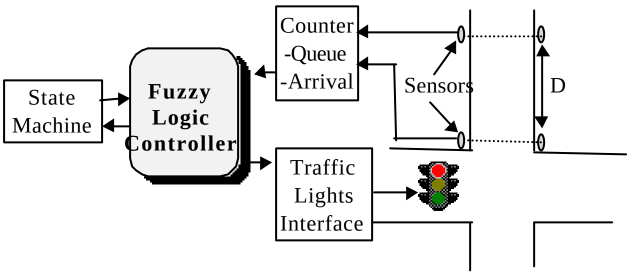

Fig.1 A general structure of the fuzzy traffic lights control system.

3.0 DESIGN CRITERIA AND CONSTRAINTS

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

- i) the junction is an isolated four-way junction with traffic coming from the north, west, south and east directions.
- ii) when traffic from the north and south moves, traffic from the west and east stops, and vice-versa.
- iii) no right and left turns are considered.
- iv) 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.
- v) the East-West lane is assumed as the main approach.
- vi) minimum and maximum time of green light is 2 seconds and 20 seconds respectively.

4.0 FUZZY LOGIC TRAFFIC LIGHTS CONTROLLER DESIGN

A fuzzy logic controller was designed for an isolated 4-lane traffic intersection: north, south, east and west as shown in Fig. 2. In the traffic lights controller two fuzzy input variables are chosen: the quantity of the traffic on the arrival side (Arrival) and the quantity of traffic on the queueing side (Queue). If the north and south side is green then this would be the arrival side while the west and east side would be considered as the queuing side, and vice-versa. The output fuzzy variable would be the extension time needed for the green light on the arrival side (Extension). Thus based on the current traffic conditions the fuzzy rules can be formulated so that the output of the fuzzy controller will extend or not the current green light time. If there is no extension of the current green time, the state of the traffic lights will immediately change to another state, allowing the traffic from the alternate phase to flow.

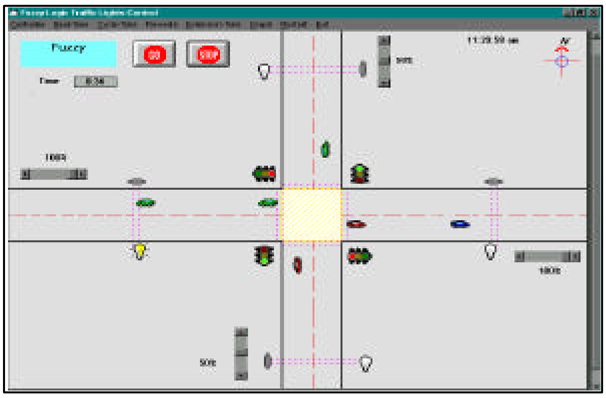

Fig. 2 Simulated output of the traffic junction using the developed software.

4.1 Input and Output Membership Functions

For the traffic lights control, there are four membership functions for each of the input and output fuzzy variable of the system. Table 1 shows the fuzzy variables of *Arrival*, *Queue* and *Extension* of the system. The right hand notations are used to shorten these variables.

Table 1 Fuzzy variables of *arrival*, *queue* and *extension* of the traffic light control.

Arrival		Oueu		Extensio	
Almost	AN	Verv Small	VS	Zero	Z
Few	F	Small	S	Short	S
Manv	MY	Medium	M	Medium	M
Too Manv	TMY	Large	L	Longer	L

The graphical representation of the membership functions of the linguistic variables is presented in Fig. 3. 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. For the output fuzzy variable the universe of discourse is the length of time to be extended in seconds. From Fig. 3, it can be observed that six cars have been assigned as a strong "Too Many" or "Large" fuzzy subsets in this simulation which have a full membership. For "Many" or "Medium" fuzzy subsets, a full membership is 4 cars and so on. For the output fuzzy variable, a strong "Long" fuzzy subset with a membership of "1" would be in the region of 6 seconds, whereas a strong "Medium" fuzzy subset would be in the region of 4 seconds, and so on. The configuration of these membership functions is done according to expert observation of the system and environment.

However, the width and center of the membership functions of these fuzzy subsets can be easily changed and configured according to different traffic situations and conditions. For example if the junction is too congested, the number of cars in the fuzzy subset "Too Many" or "Large" is needed to be increased. On the other hand, for a less congested junction the width of the membership functions can be reduced. It can be observed that in fuzzy logic control the transition from one fuzzy subset to another provides a smooth transition from one control action to another, thus, the need to overlap these fuzzy subsets. If there is no overlapping in the fuzzy subsets then the control action would resemble bivalent control (step-like action). On the other hand if there is too much overlap in the fuzzy subsets, there would be a lot of fuzziness and this blurs the distinction in the control action. A heuristic approach is to overlap the fuzzy subsets by about 25%.

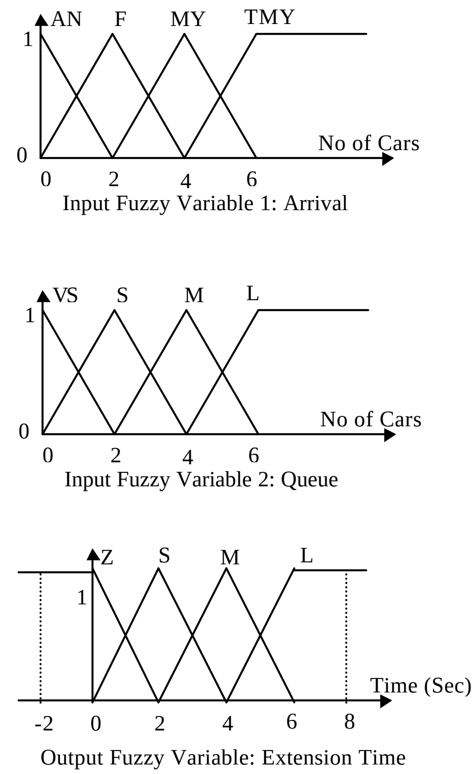

Fig. 3 Graphical representation of membership functions of the fuzzy logic controller.

4.2 Fuzzy Rule Base

The inference mechanism in the fuzzy logic controller resembles that of the human reasoning process. This is where fuzzy logic technology is associated with artificial intelligence. Humans unconsciously use rules in implementing their actions. For example, a traffic policeman manning a junction say, one from the north and one from the west; he would use his expert opinion in controlling the traffic more or less in the following way:

IF traffic from the north of the city is HEAVY
AND traffic from the west is LESS
THEN allow movement of traffic from the north LONGER.

Another opinion would be:

IF traffic from the north of the city is AVERAGE
AND traffic from the west is AVERAGE
THEN allow NORMAL movement of traffic for both sides.

The beauty of fuzzy logic is the possible utilization of approximate reasoning in the rules such as HEAVY, LESS, AVERAGE, NORMAL, LONGER, etc. Due to the membership assignment techniques as discussed, such linguistic variables, though fuzzy in nature, can be taken care of in the computer through fuzzy logic technology.

In the development of the fuzzy logic controller, we use almost similar rules and below are some examples:

If there are too many cars (TMY) at the arrival side
and very small number of cars (VS) queueing
then extend the green light longer (L).

If there are almost no cars (AN) at the arrival side
and very small number of cars (VS) queuing
then do not extend the green light at all (Z).

These rules can be shorten as follows:

IF Arrival is TMY AND Queue is VS THEN Extension is L
IF Arrival is F AND Queue is VS THEN Extension is S
IF Arrival is AN AND Queue is VS THEN Extension is Z

where "Arrival" and "Queue" are the antecedents and "Extension" of the green light is the consequent. Such rules can be easily developed according to the conditions of the traffic at the junction and a compact way to show these rules would be to use a matrix as shown in Fig. 4. The size of the matrix or the number of rules is equal to the number of input combinations derived from the number of membership functions per input. For example, in the traffic control system there are two inputs each having four membership functions, then the number of rules would equal sixteen. In many applications it is not necessary to fill up all the rules in the matrix bank, however, for this application it is necessary.

Arrival

Queue	**AN**	**F**	**MY**	**TMY**
VS	Z	S	M	L
S	Z	S	M	M
M	Z	Z	S	M
L	Z	Z	Z	S

Fig. 4 Configuration of the fuzzy rules in matrix form for the traffic lights control.

4.3 Inference Engine and Defuzzification

In the fuzzy logic controller once the appropriate rules are fired, the degree of membership of the output fuzzy variable i.e., Extension time, is determined by encoding the antecedent fuzzy subsets, in this case Arrival and Queue. In the traffic lights fuzzy control system, the max-min implication technique [1] is used. Using this technique, the final output membership function for each rule is the fuzzy set assigned to that output by clipping the degree of truth values of the membership functions of the associated antecedents. Once the membership degree of each output fuzzy variable is determined, all of the rules that are being fired are then combined and the actual crisp output is obtained through defuzzification. There are several of defuzzification methods and in this development, the center of gravity defuzzification technique is used.

5.0 DESCRIPTION OF THE SOFTWARE

A software was written to simulate the effectiveness of the fuzzy logic controller in controlling traffic conditions at an isolated junction. The software was written in Visual Basic using event-driven programming techniques and it is designed to work under the Windows environment. A mock junction is simulated in the software to show incoming and outgoing traffic as shown in Fig. 2. The software is highly graphical in nature and 'pop-up' and 'pull-down' menus are accommodated for easier user manipulation. The density of traffic in any one lane can be set as required from 0% to 100% by sliding the 'scroll bar' at the side of the lanes. The bulb and lines across each of the lanes show the sensors location. In real application, such sensors would be of the electromagnetic type embedded in the roads. Such sensor can easily detect vehicles such as cars, lorries, buses, etc. which are made of metals, through electromagnetic induction. Several analyses such as density of traffic, movement time, waiting time, cost, etc. can be made in the software using one of the available menus. A brief description of the software facilities are given in the following section.

5.1 Brief Description on Usage and Software Facilities

The software has a number of facilities for easy user manipulation and also analysis on the performances of the fuzzy and fixed-time controllers. This section briefly explains the facilities available and information on how to use the software.

i) Controller

Upon starting the software, the user can choose the type of controller in the simulation. By using this menu the user may choose to simulate the performance of either (1) a fixed-time controller, or (2) a fuzzy logic controller or (3) both. The fixed-time controller is a conventional type of controller that is open-loop in nature. It uses a preset cycle time to change the lights. The default cycle time for the green, amber and red signal lights, respectively, are 11, 4, and 15 seconds, respectively. There is also an option for the user to change the cycle time to any desired value.

In choosing the fuzzy logic controller to control the traffic lights, the cycle time for the green lights is determined according to the density of the traffic. The user may set up his/her own fuzzy control rules or may use the default rules as given. There is also an option to configure the membership functions as desired. Using the third option, the software will simulate both of these controllers sequentially. First the fixed-time controller is simulated then followed by the fuzzy controller according to the set time as requested. This third option is mainly used for comparing the performance of the fixed-time and fuzzy logic controllers. To start the simulation the user has to define the type of controllers intended and configure the relevant parameters which are discussed below. Then by clicking the GO menu, simulation will actually start. The simulation can be stopped at any time by clicking the STOP facility.

ii) Real Time

The simulation software also provides real time control using a dedicated fuzzy micro-controller AL220 by Adaptive Logic Inc., USA.

iii) Cycle-Time

The cycle time is the time that the fuzzy controller need to decide on the extension of the current green time period. It is not necessary to evaluate the system every second. This cycle time is dependent on the fuzzy rules and membership functions.

iv) Flowrate

Flowrate facility can be used to calculate the number of cars passing through a lane in one minute. The percentage of the flowrate is given by the following formula:

time (minutes)/car = 4*(100% / flow %)

The traffic flowrate can be set in two different modes. The user can set the flowrate by changing the scroll bar setting at the side of each lane. There is a facility where the user can set different flowrates at every minute. This facility is useful for determining how the controller will perform at a given intersection over the course of an entire day or some other time period.

v) Extension-Time

The actual green time extension in seconds for the output of the fuzzy logic controller is presented in the Extension-Time facility. These timings are generated automatically by the fuzzy logic controller and they are dependent on the settings of the membership functions and rules. Negative values in the table indicate immediate change. From the table, the user can determine whether the rules and membership functions have been well configured or not.

vi) Graph

The Graph facility allows the user to visualize and analyze the performance of the controllers graphically. There are seven types of plots that are available in this facility which are as follows:

- Car Sensed - shows the number of cars within the sensed area at each instant.
- Flowdensity - shows the traffic flowrate in each lane for every minute.
- Wait Time - shows the total waiting time of the cars at the junction for each lane for every minute of the simulation.
- Move Time - shows the total moving time of the cars at the junction for each lane for every minute of the simulation.
- Car In - calculates the number of cars moving into the sensed area in each lane for every minute of the simulation.
- Car Out - calculates the number of cars moving out of the sensed area in each lane for every minute of the simulation.
- Cost Function - provides numerical calculation of the cost using either of the controllers. A lower value indicates better performance of the controllers minimizing the waiting time and also fuel costs. This is calculated as follows:

  Cost = (Car In / Car Out)*(Wait Time / Drive Time)

vii) Restart

The Restart facility resets the simulation back to the initial state.

viii) Exit

This facility quits the simulation and brings the user back to the previous Windows environment.

6.0 COMPARISON BETWEEN FUZZY LOGIC CONTROL AND CONVENTIONAL FIXED-TIME TRAFFIC CONTROL

The performance of the fuzzy logic controller can be evaluated by comparing it to the fixed-time controller. This can be done by using the Controller facility where both the controllers are to be simulated. There are two types of simulation tests that can be carried out. One is the fixed flowrate and the other is the varied flowrate. The varied flowrate allows slightly complex traffic situation which reflects real-life conditions. The flowrate can be varied according to the description given in Section 5.1 (iv).

In order to make comparisons between the fuzzy logic and fixed-time controllers, identical conditions have to be set during the simulation. In order to see the effectiveness of the controllers, we set higher traffic density for one of the lanes. Figure 5 shows the traffic flow density for both system that has been set for twenty four minutes of simulation time. One minute in the simulation is equivalent to one hour in real-life conditions. The flow densities for the lanes are varied differently every minute using the Flowrate facility to reflect real-life traffic conditions.

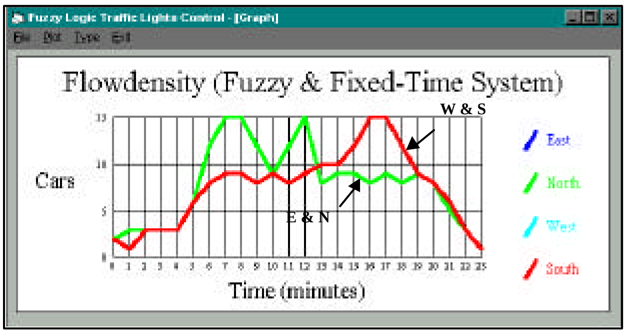

Fig. 5 Graph showing traffic flow density per minute in each lane of the simulation.

The membership functions and rules of the fuzzy logic controller are configured as already discussed in Section 4.0. From the simulation, the performances of the two controllers can be compared graphically using the facilities provided in the software. Figures 6 and 7 give a graphical representation of the waiting time of the cars and also the moving time, respectively. It can be observed that the fuzzy logic controller provides almost equal movement of cars in each lane whereas the fixed-time controller is rather lopsided. The total waiting time of the cars in each lane is much less using the fuzzy logic controller. In terms of cost, which reflects the fuel cost, efficiency, etc., the fuzzy logic controller performs much better than the fixed-time controller as shown in Fig. 8.

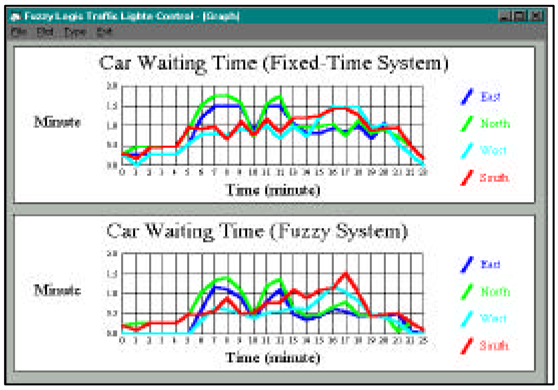

Fig. 6 Waiting time of the cars in the simulation.

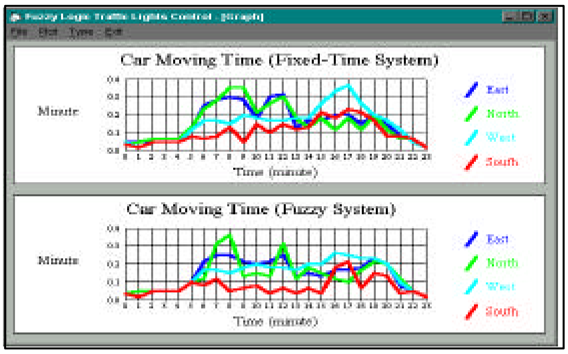

Fig. 7 Movement time of the cars in the simulation.

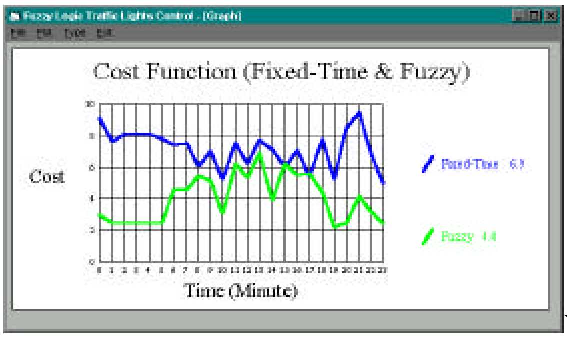

Fig. 8 Cost function reflecting the efficiency of the controllers.

6.0 CONCLUSION

The fuzzy logic traffic lights controller performed better than the fixed-time controller or even vehicle actuated controllers due to its flexibility. The flexibility here involves the number of vehicles sensed at the incoming junction and the extension of the green time. In the fixed-time controller, being an open-loop system, the green time is not extended whatever the density of cars at the junction. For vehicle-actuated traffic light controllers, which is an enhanced version of fixed-time controller, the green time is extended whenever there is a presence of a vehicle. However, these times are fixed in prior until a maximum time limit. For example when a car is detected, the green time is extended for another 5 or 10 seconds until the maximum time limit. In the fuzzy logic controller, the extension time are not fixed values. They are all fuzzy variables such as long, medium and small. The number of cars sensed at the input of the fuzzy controllers are also converted into fuzzy values, such as very small, small, medium, too many, etc. In addition to the fuzzy variables as mentioned, the fuzzy controller also has an advantage of performing according to linguistic rules in the manner of how a human would use. The reasoning method in the fuzzy controller is also the similar to the way how a traffic policeman handles the traffic flow at a typical junction.

A simulation experiment was carried out to compare the performance of the fuzzy logic controller and a fixed-time conventional controller. The flow density of the simulation is varied according to real life traffic conditions. It can be observed that from the results the fuzzy logic control system provides better performance in terms of total waiting time as well as total moving time. Less waiting time will not only reducing the fuel consumption but also reduce air pollution and noise pollution.

REFERENCES

[1] C.C. Lee, "Fuzzy Logic in Control System: Fuzzy Logic Controller - Part I & II", *IEEE Trans. on Systems, Man and Cybernetics*, Vol. 20, No. 2, Mar/Apr 1990, pp. 404-435.

[2] C.P. Pappis and E.H. Mamdani, "A Fuzzy Logic Controller For a Traffic Junction", *IEEE Trans. on Systems, Man and Cybernetics*, Vol. SMC-7, No. 10, Oct 1977, pp. 707-717.

[3] J. Favilla, A. Machion and F. Gomide, "Fuzzy Traffic Control: Adaptive Strategy", *Proc. 2nd IEEE Int. Conf. on Fuzzy Systems*, San Francisco, CA, March 1993, pp. 1371-1376.

[4] M. Nakatsuyama, H. Nagahashi and N. Nishizara, "Fuzzy Logic Controller For a Traffic Junction in The One-Way Arterial Road", *9th IFAC- World Congress*, Budapest, Hungary, 1984, Preprints pp. 13-18.

[5] R. L. Kelsey and K. R. Bisset, "A Simulation Environment For Fuzzy Control of Traffic Systems", *12th IFAC- World Congress*, Sydney, Austria, 18-23 July 1993, Preprints pp. Vol. 5, pp. 553-556.

BIOGRAPHY

Mr. Tan Kok Khiang is completing his Master Degree in Electrical Engineering at Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His interest is in intelligent system development.

Professor Marzuki Khalid is the Director of the Artificial Intelligence Center of the Faculty of Electrical Engineering of Universiti Teknologi Malaysia. His current research interests is in the area of artificial intelligence with applications to control, image processing and intelligent buildings. He is the recipient of the National Young Scientist Award for 1996, the IEM Young Engineer Award for 1994 and International Exchange Award from University of Tokushima, Japan.

Dr. Rubiyah Yusof is an Associate Professor of the Faculty of Electrical Engineering of Universiti Teknologi Malaysia. Her research interests is in the area of adaptive control and fuzzy expert systems.