Neuro-Fuzzy Control of Traffic Lights

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***Abstract-* Traffic problems are becoming a major issue in most cities and there are various ways to overcome these problems. While some of these solutions may be costly or may take time to implement, a possible solution is to optimise actual systems, such as traffic lights, using intelligent control such as fuzzy logic or neuro-fuzzy technology. This paper involves the design of a neuro-fuzzy controller to monitor traffic lights at a junction. The neuro-fuzzy controller was developed using the fuzzy logic toolbox of MATLAB. The designed neuro-fuzzy controller was then evaluated in terms of average delay. This was done for varying traffic situations. The delay for pre-timed traffic signals was also evaluated for various cycle times and the two systems were compared. The neuro-fuzzy system was found to be the better one since it resulted in less delay than the pre-timed, especially at high traffic density.**

I. INTRODUCTION

Traffic management is nowadays a major issue in many countries. With the growing number of vehicles on the road, especially in cities [1], the actual systems and infrastructures used are no longer as efficient. Therefore new ways and measures have to be devised to cope with this situation such as new roads, flyovers, ring roads, introduction of trains, limiting vehicles in the city etc. While the solutions mentioned above can be costly and may take time to implement, an alternative would be to use artificial intelligence whenever and wherever possible. For instance, traffic lights can be improved using neural networks, fuzzy logic [2] or neuro-fuzzy (combination of both neural networks and fuzzy logic) technologies so as to reduce traffic congestion and delays while at the same time decreasing air pollution, fuel consumption, travel time and driver stress. Details on applications of traffic light fuzzy and neuro-fuzzy control can be found in [3] and [4].

Fuzzy logic [5, 6] allows the implementation of real-life rules similar to the way humans would think using *if-then* rules. For example, a policeman controlling traffic at junction would think as follows: if the traffic density on the north or south lanes is higher and the traffic density on the east and west lane is lower, then the traffic lights should stay green longer for the north and south lanes. Ideally, the green time allocated should be such that it minimises the average delay and it should therefore be based on the number of cars present behind the stop lines.

For the system to be efficient, it should generate the optimum green time for a given traffic situation. Thus neural networks technology can be used to train the fuzzy logic controller so that it generates the required output.

This paper is organised as follows. First, an overview of actual traffic lights control systems is given followed by a presentation of the intelligent traffic lights control system. Afterwards, the performance of the neuro-fuzzy traffic lights controller and the conventional pre-timed controller is compared and discussed.

II NEURO-FUZZY TRAFFIC SIGNALS

The two most common types of traffic signals are the pre-timed (fixed) traffic signals and the vehicle-actuated traffic signals [7, 8]. For the former type, the sequence in which the signals RED-GREEN-YELLOW-RED appear on each approach of an intersection, is fixed and repeated after a fixed interval in seconds. The time period for each signal light is predetermined and fixed in the signal equipment by a timing device. For junctions having a main and a secondary road, vehicle-actuated traffic lights are used. For such systems, the main street is given priority and proximity sensors placed near the stop line are used to detect vehicles in the secondary street. Upon vehicle detection, the green signal switches from the main street to the secondary one and back to the main street again.

The main problem with conventional traffic lights is that they are not smart enough to adapt to the random nature of traffic flow. For instance, road users often complain that they have to wait long behind a red light while the other side is showing green light even though there are no cars on that lane. Therefore, it would be a highly beneficial if traffic signals could be improved so as to reduce delay borne by users.

A possible enhancement to actual systems would be to make them adaptive. In other words, the green time allocated to any street at a junction would depend on the number of cars present on both streets. Fuzzy logic technology is an appropriate alternative for the intelligent traffic lights system as discussed subsequently.

A. Design criteria and constraints

The following assumptions have been made in the development of the fuzzy controlled traffic lights:

(i) The junction is a four-way junction with vehicles 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) Right and left turns are not considered.

(iv) The fuzzy controller will observe the density of the north and south traffic as one input and the west and east traffic as input.

(v) There is no main or side road. Green time is based on number of cars.

(vi) Minimum and maximum green time is 5 seconds and 105 seconds respectively while minimum and maximum cycle time is 20 seconds and 120 seconds [9] respectively.

(vii) The cycle times do not include pedestrian green time. However, pedestrian green time can be allocated at the end of the cycle if any request has been made from a push button during that cycle.

B. Description of the fuzzy logic traffic lights system

Firstly eight sensors (S1–S8) are put in specific positions as shown in Figure 1.

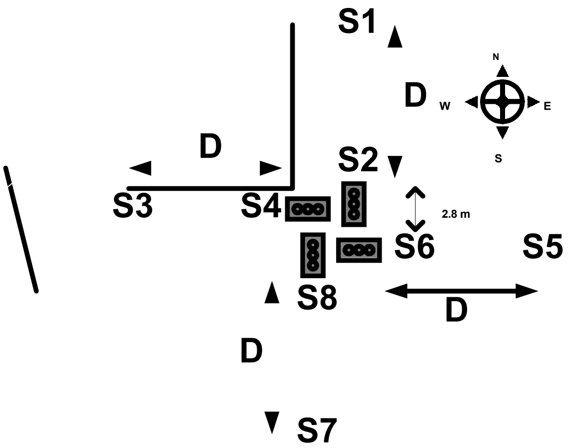


Figure 1: Diagram showing the position of sensors

The junction is divided into the four cardinal points namely North, South, East and West and a traffic light is present to control traffic for each of these directions.

The first sensor behind each traffic light counts the number of vehicles coming to the intersection while the second one counts the number of vehicles passing the traffic lights. The number of vehicles between the traffic lights is determined by the difference of the reading of the two sensors. For example, the number of vehicles behind traffic light North is S1 - S2 and the number of vehicles in the N-S lane is equal to [(S1 – S2) + (S7 – S8)].

Since the North and the South lanes receive the same green phase and the same applies to the East and the West lanes, the maximum of the North and South inputs (known as Input N-S) will be considered as one input to the fuzzy logic controller and the second input to the FLC will be the maximum of inputs East and West inputs (Input E-W). The maximum is taken to ensure that the maximum number of cars can cross the junction. Based on Input N-S and Input E-W at the start of a cycle, the cycle time and its components are determined and Green time NS will be outputted. At the end of this green time followed by Yellow time and Red time, Green time EW will be outputted according to the value the fuzzy controller has initially calculated. This cycle then repeats itself.

A phase diagram showing the sequence of signal operation can be drawn as shown in Figure 2. X and Y are variables that are the Green times for the N-S and E-W lanes respectively.

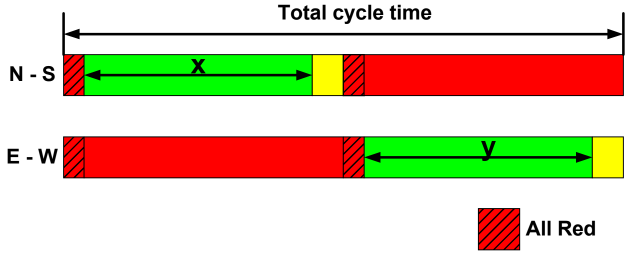


Figure 2: Phase diagram for the fuzzy logic controlled traffic lights

Next comes the process of inputting these inputs into the fuzzy logic controller so as to get the appropriate Green time as output as shown in Figure 3.

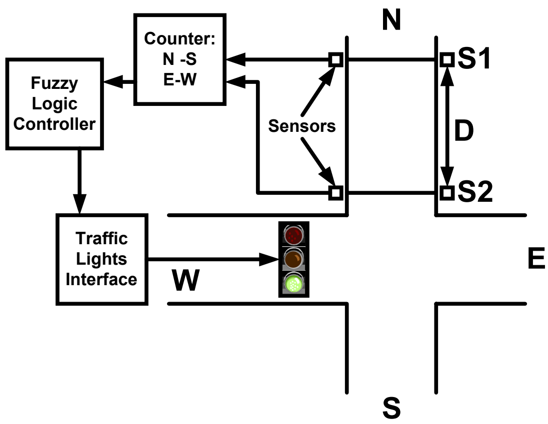


Figure 3: Diagram showing the general structure of the fuzzy logic controller

From the eight sensors used, the number of vehicles in both the N-S and E-W lane can be obtained. This data is then fed into the fuzzy logic controller, which then generates a corresponding output. This output is then used to control the length of green time via a traffic lights interface.

The proposed control has been summarized in the block diagram (Figure 4).

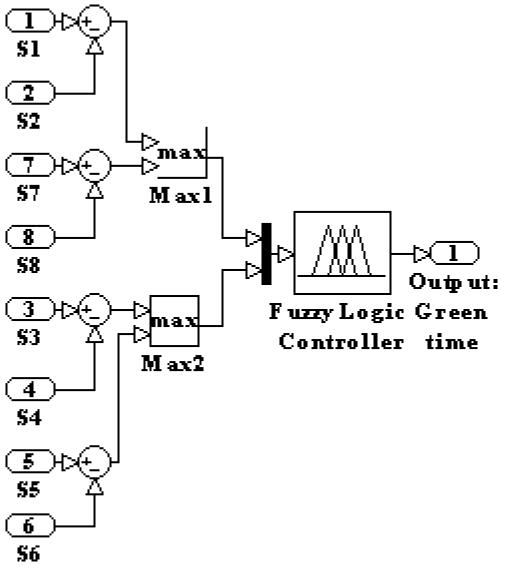


Figure 4: Block diagram of the proposed system

C. Fuzzy Logic Controller (FLC) design

The FLC is initially designed as follows with each input having five membership functions. The output is only described in terms of linguistic variables at this stage. Table 1 shows the linguistic variables for Input N-S, Input E-W, Green time N-S and Green time E-W.

Table 1: Linguistic variables for input and output.

Input (N-S & E-W)		**Green time (N-S & E-W)**	
Very Low	VLW	Very Short	VS
Low	LW	Short	S
Medium	M	Medium	M
High	H	Long	LG
Very High	VH	Very Long	VLG

Figure 5 shows the input membership functions corresponding to the different terms of the linguistic variables. The membership functions are initially the same for both the N-S and E-W inputs.

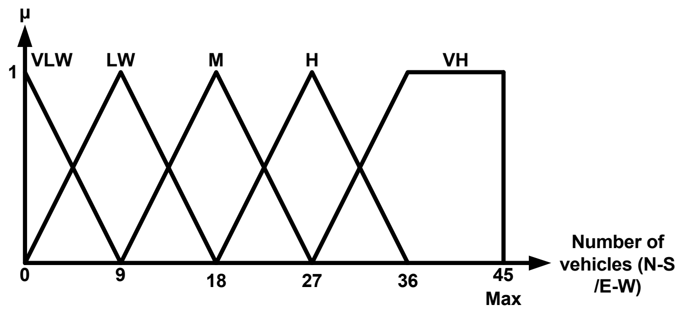


Figure 5: The initial input membership functions

The rule base for the FLC for output Green time N-S is shown in Table 2.

Table 2: Rule base for the FLC

INPUTS		**NUMBER OF CARS N-S**				
		VLW	***LW***	***M***	***H***	***VH***
NUMBER OF CARS E-W	***VLW***	VS	S	M	LG	VLG
	LW	VS	S	M	LG	VLG
	M	VS	S	M	LG	LG
	H	VS	S	M	LG	LG
	VH	VS	S	M	M	M

Table 2 is interpreted as follows: if input N-S is medium (M) and input E-W is high (H) the IF-Then rule would be *If input N-S is Medium And input E-W is High, Then Green time NS is Medium.*

Furthermore, the linguistic terms for the output corresponding to each set of possible inputs have been determined by performing calculations to satisfy traffic engineering principles that will minimise delay.

D. Training the ANFIS

The FLC has been designed for a maximum input of 45 vehicles and for any pair of input, the FLC should generate a required green time output. The set of desired outputs can be obtained by calculating the time taken for a given number of cars to cross the junction. The disadvantage of using a purely fuzzy logic system is that the system will have to be manually tuned to give the desired output. The tuning can be quite tedious and any inaccurate tuning will decrease the efficiency of the system. Since a set of the inputs and their corresponding outputs are available through calculation, this set of data can be used to train an ANFIS (Adaptive Neuro-Fuzzy Inference System) so that the generated output is equal to the desired output.

Random number generators substitute the real inputs (Input NS and Input EW) and they have a range of 0 to 45. For the generated inputs, the output of the ANFIS will be compared to the desired outputs that can be obtained from the set of training data and to the outputs according to the rule viewer. Figure 6 shows samples of training data sets for ANFIS and each data set contains 3 variables: Input NS, Input EW and its corresponding Green time NS in seconds. The Green time EW data are generated in a similar way.

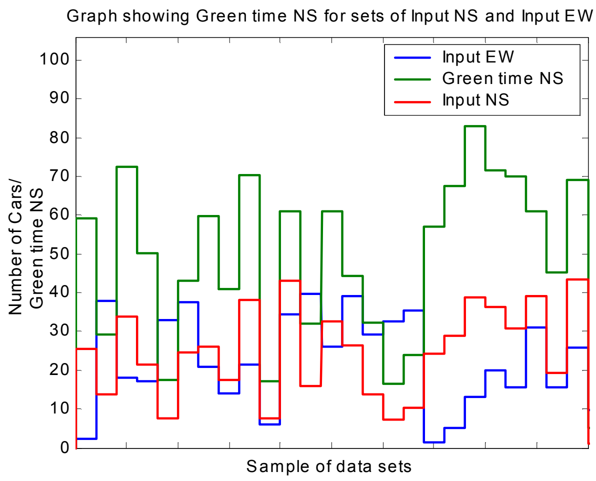


Figure 6: Green time NS for various sets of inputs

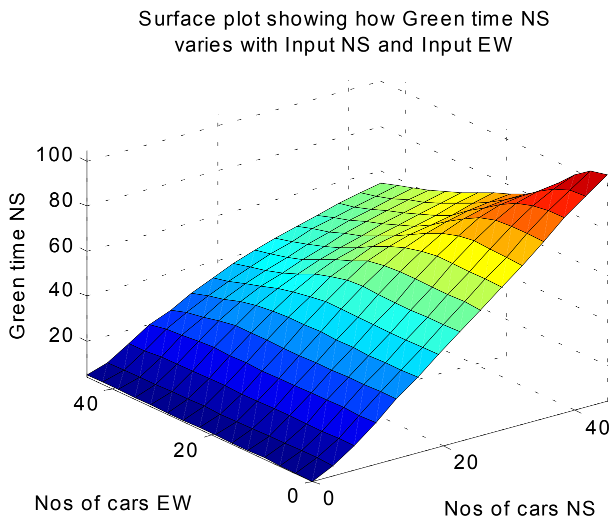


Figure 9: Surface viewer for the ANFIS

Considering Green time NS as the output, the following membership functions and surface viewer are obtained as shown in Figure 7, Figure 8 and Figure 9.

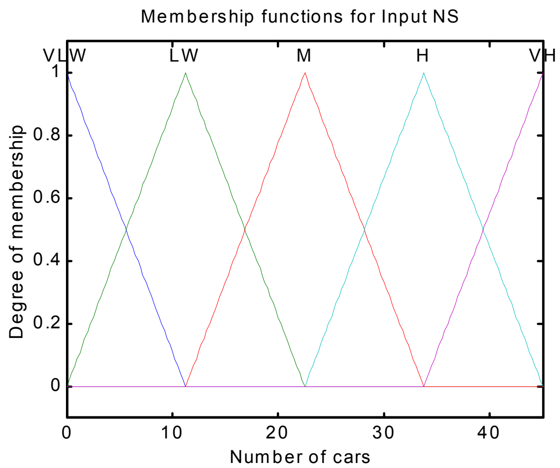


Figure 7: Membership functions for Input NS

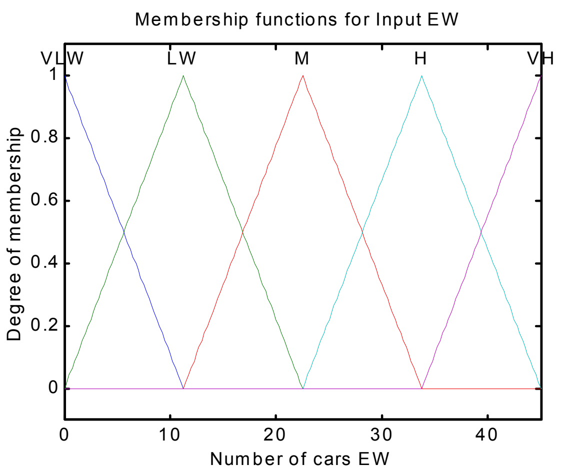


Figure 8: Membership functions for Input EW

III. EVALUATION OF THE NEURO-FUZZY TRAFFIC LIGHTS CONTROLLER

The performance of the neuro-fuzzy traffic signals is evaluated in terms of average delay [7]. Considering the scenario shown in Figure 10, graphs of average delay against number of cars waiting is plotted for neuro-fuzzy traffic signals and pre-timed traffic signals. The results are then compared.

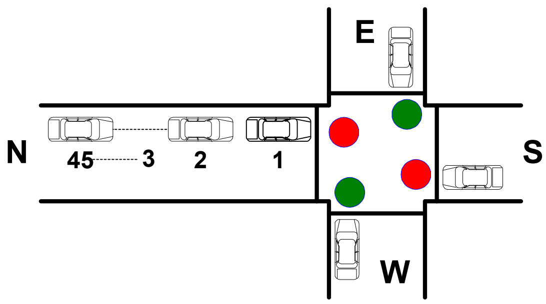


Figure 10: Diagram illustrating the scenario for which delay is being determined

By making some assumptions, a formula to calculate the average delay is as follows [7]:

$$T = NR - \frac{AN^2}{2} + \frac{N(N+1)D}{2} \quad (1)$$

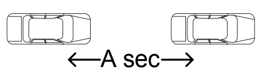
Average delay to each vehicle

$$= R - \frac{AN}{2} + \frac{(N+1)D}{2}, \quad (2)$$

where R: Red time interval

N: Number of vehicles stopped during red time

A: Average time headway of vehicle arrival at intersection in seconds



D: Departure headway (Delay in starting; assumed 2 s).

The major inconvenience with equations (1) and (2) is that it assumes, firstly, that while one lane (E-W) is having a green phase, all the cars on that lane will be able to cross the junction during that green phase. The second assumption is that when the lane (N-S) previously undergoing red phase will have green phase, again all the cars will be able to cross the junction during that green phase. These assumptions are not true in all situations namely in cases of congested traffic on both lanes. For instance, it may happen that a car undergoing red phase will not be able to cross the junction during the green time of that cycle but rather during the green time of the next cycle.

Thus, equations (1) and (2) will have to be modified to yield equation 6.4 which will take all these into considerations.

In addition, using equation (3), it can be shown how the efficiency of cycle times varies with traffic density. Consequently, equation (2) has been modified to the following equation (equation (3)) for cars that have to wait for subsequent cycles in order to be able to cross the junction.

Average delay to each vehicle

$$= (n \times C) + R - \frac{A}{2} + \frac{(N+1-k)}{2} \qquad (3)$$

where C = cycle time of pretimed system

n = number of full cycles which the car has to wait before being able to go through the junction

k = the number of cars (out of the initial number, say 45) that have already left the junction in previous cycles.

'k' represents the fact that cars at the back of the queue are no longer at the back but has come nearer to the stop-line as the cars in front of it has crossed the junction. Thus the departure delay of these cars decreases.

The scenario to demonstrate delay is that at the start of a cycle, one lane, say E-W is receiving green time while simultaneously the other lane is in red phase. Furthermore, a number of cars varying from 1 to 45 are initially waiting behind the North stop line as shown in Figure 9. The number of cars behind the South stop-line is not being considered in the determination of delay in this setting. The average delay for these cars is to be determined under various conditions as the initial number of cars waiting varies from 1 to 45 bearing in mind the fact that some of the initially waiting cars might pass the stop-line after subsequent cycles depending on the initial number of waiting cars.

For the fuzzy controlled traffic lights, the varying conditions will be the traffic situations on the lane (E-W) receiving green time. The possible traffic situations for the E-W lane are that the traffic density is Very Low (VLW), Low (LW), Medium (M), High (H), Very High (VH) and Max which is the maximum number of cars detected, i.e. 45 (Figure 11).

For the pre-timed traffic signals, the varying situations is the cycle time, C, which will take the following values namely 40 s, 60 s, 80 s, 100 s and 120 s (Figure 12).

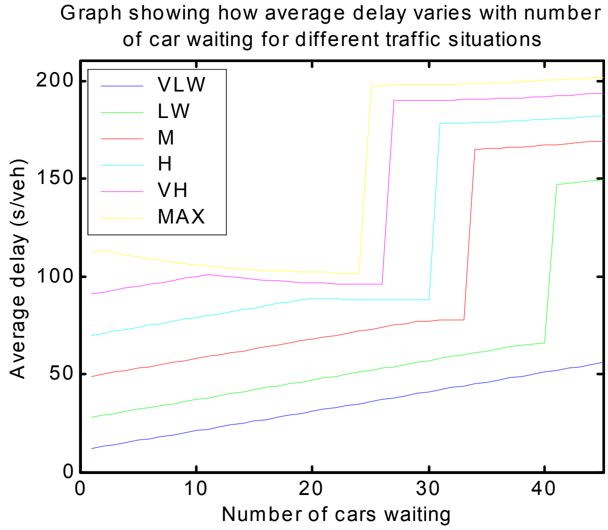


Figure 11: Graph to show how average delay varies with number of cars waiting on one lane and traffic density on the other lane for the FLC traffic signals.

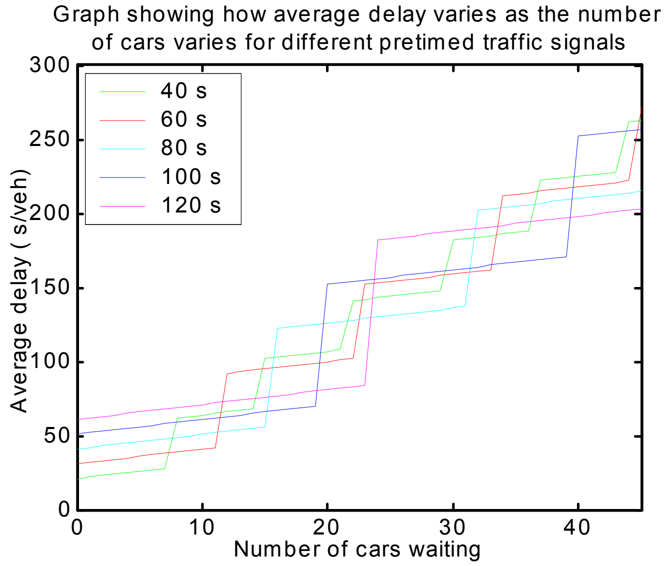


Figure 12: Graph to show how average delay varies with number of cars waiting on one lane for different cycle times, C.

IV. Conclusions

Comparing the two graphs, pre-timed signals have less delay than fuzzy controlled signals for low and very low number of waiting cars if the E-W side has High, Very high or Max number of cars. This is because for pre-timed traffic signals, the maximum green time is 55 s where as for the fuzzy system, the green time varies from 5 to 105 s. Thus for very low number of waiting cars and very high number of cars on the E-W lane, the cars on N-S lane might have to wait for at least 115 s(green time + lost time). However, it can be observed that as from the range of 15 to 25 cars waiting (the exact value depends on the cycle time of the pre-timed signals) it can be observed that the average delay for the fuzzy logic system is less than that of the pre-timed signal for all cycle times. For the maximum number of waiting cars (45), the fuzzy signal is as efficient as a pre-timed cycle of 120 s while the other pre-timed cycles are much less performing as seen from the graphs.

On the whole, the fuzzy system is more efficient than pre-timed signals especially when traffic is high. Pre-timed signals are better than fuzzy controlled signals only when the number of cars waiting on the N-S is low or very low while that of the E-W lane is high (from High to Max).

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