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ADAPTIVE FUZZY ROAD TRAFFIC CONTROLLER SIMULATION.

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Abstract

Automated traffic control is important at road junctions to ease traffic control at all times, without need for traffic control officer. Some metropolis in Nigeria have traffic control lights installed at their junctions, however most of them are not intelligent and as a result cannot change timing for the intersections to cater for varying traffic demands. At times, especially at period of less traffic flow or when a particular event occurs at a part of the city, resulting in increased traffic flow in one direction than others, the fixed traffic timing performance is poor, as allotted time to an intersection will be wasted while the queue on another intersection would have grown very long. This calls for need for modern and intelligent approaches to traffic monitoring and control. This work uses fuzzy logic to control traffic at a [redacted] *four way road intersection. The performance is compared with that of a fixed time traffic control and result shows that the adaptive fuzzy based controller performed better especially when traffic is not too heavy.*

KEYWORDS: *Traffic Control, Fuzzy, Adaptive control, Pre-timed control*

Introduction

Good traffic flow is important to ensure efficient movement of goods and services, improved time management of people on transit and enhanced profitability in our daily activities and businesses. Traffic lights are defined as signaling devices positioned at road intersections, pedestrian crossings, and other locations to control

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competing flows of traffic. Several advancements have been made over the years to address the challenges of chaos that arise at intersections due to traffic flow. These traffic control technologies range from fixed time, non intelligent systems to adaptive, artificial intelligence based ones. To ensure free traffic flow at busy junctions, human vehicle traffic controllers may be deployed or automated vehicle traffic controllers may be installed. Where there are enough manpower, human vehicle traffic controller would usually perform better than the automated traffic controller (Mandar, 2002). This is why human vehicle traffic controllers are usually deployed when there are special events and the traffic light controllers are expected to fail. However, it is usually more cost effective to deploy automated traffic controllers. At the very beginning, traffic control had been performed by electro-mechanical devices, then, semiconductor-based controllers were introduced, and nowadays microprocessors as well as centralized computer based controllers are used in traffic control systems. These technologies are aimed at improving adaptability to different traffic situations, increasing reliability and efficiency of the system as well as reducing cost of installing the devices.

In fixed time traffic control system, the traffic flow pattern of the intersection concerned is studied at design time and times are allotted appropriately to each link. No intelligence is built into the control system and if at any time, there is a change in traffic pattern, the system performs poorly, and may lead to delays in one or more of the links. Owing to this possibility, there has been the move towards the use of more intelligent approaches to traffic control. Of the many possibilities, the fuzzy logic approach has been favoured because of the similarity of its workings to human reasoning. Traffic at intersections may experience many challenges as a result of a number of predictable and unpredictable occurrences, some of which are measurable while others are hardly measurable. Examples include road accidents, stalled vehicles, minor or major roadway maintenance, illegal parking, pedestrian crossings, rush hour and increase in traffic volume. Each of these poses different levels of challenges to the controller. While predictable variations like rush hour may be programmed into a fixed time controller, others such as

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increase in traffic volume may require a complete redesign of the system, while the unpredictable ones require more intelligent control.

The ubiquity of vehicles in many urban areas in Nigeria has resulted to an inevitable problem of traffic congestion, common among big cities world over. This traffic congestion has caused loss of lots of productive man hours. The many road intersections in cities have worsened matters and have made coordinated passage of vehicles at their locations very necessary if chaotic situations must be avoided. To solve the intersection associated problems, traffic light controllers have been installed at many intersections but the problem with Nigerian installations is that most of them are pre timed controllers which take no cognizance of the behavior and changing nature of the vehicle flow patterns in and out of the intersections. This work attempts to solve this problem by proposing a more intelligent traffic controller system that can easily adapt to changing traffic conditions.

This design focuses on developing a fuzzy logic based software that simulates traffic light controller that can be used under different traffic situations, to minimize congestion. The simulation is for an isolated four lane intersection.

Fuzzy Traffic Controller

The fuzzy logic based traffic light has the ability to mimic the intelligence of a human traffic controller and has been shown to perform better than a number of other intelligent traffic light control systems (Khalid et al, 1996), such as an actuated systems which do not work well during oversaturated or unusual load conditions. Since a human traffic controller would usually formulate rules for controlling traffic under varying traffic conditions either from experience or as a result of training; these rules can be easily formulated into a set of rules for the fuzzy traffic light controller using linguistic terms such as “less”, “heavy”, “longer” and so on. Fuzzy logic has found great application in various fields after it has undergone several developmental stages since its introduction. Mendel and Mouzouris(1997) identified the configuration in figure 1 for a typical Fuzzy Logic Controller (FLC).

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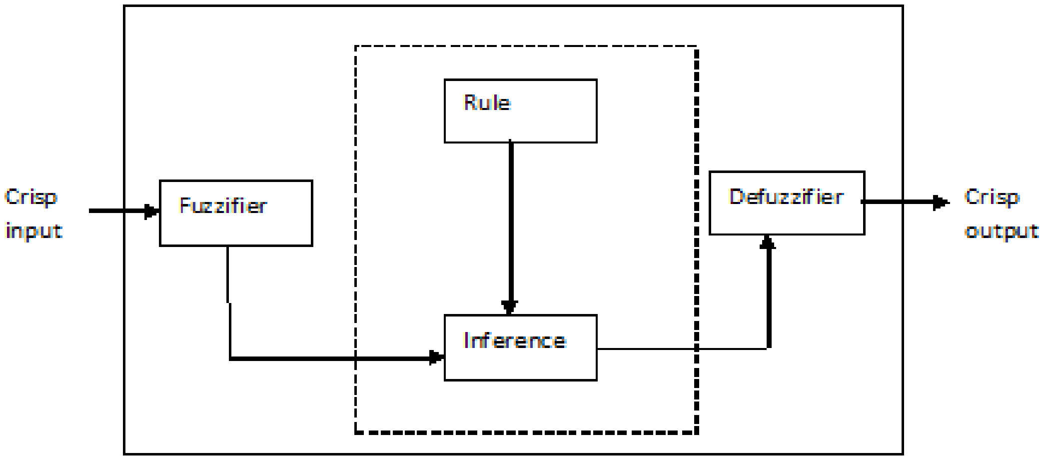

Fig. 1 Fuzzy Logic Controller (FLC)

The FLC maps crisp input into crisp outputs and has four main components: fuzzifier, rules inference engine and defuzzifier. The fuzzifier maps crisp inputs into fuzzy sets.

The fuzzy sets are needed to activate rules which are in terms of linguistic variables. The fuzzifier handles the first step in fuzzy logic processing, which is the domain transformation of crisp inputs into fuzzy inputs, e.g. a fuzzy crisp input of 50°C water temperature would be transformed to "warm" in fuzzy term, or a car moving at 130km/h would be transformed to "fast". To transform crisp inputs into fuzzy inputs, membership functions must first be determined for each input. With membership function in place, fuzzification takes real time input value such as temperature or number of vehicles in a queue and compares it with stored membership function information to produce fuzzy input values.

The Rules are expressed as IF.. THEN statements. The rules may be provided by an expert or may be extracted from numerical data (Mendel and Mouzouris, 1997). The general form for representing rule is:

IF x_1 is A_1 (1) and x_2 is A_2 (1) and … and x_n is A_n (1) THEN y is B (1) where x_1, x_2………… x_n and y are fuzzy variables, while $A_1(1)$, $A_2(1)$….$A_n(1)$ and B(1) are linguistic variables. The terms before the THEN are the antecedents and that after it is the consequent. We see that there can be several antecedent terms while the consequent is always single.

The core of a Fuzzy Control System is its knowledge base, which is expressed in terms of fuzzy rules and the rules evaluation. The inference

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engine handles all rule combinations to extract the most relevant and applicable rule. The inference engine handles such sensitive tasks as choice of relevant rules that apply, given some fuzzification result as well as handling of sentence connectives e.g. AND, OR, ALSO e.t.c. Once all input variable values are translated into respective linguistic variable values, the fuzzy inference step evaluates the set of if-then rules that define the system behavior

The defuzzifier produces a crisp output from the inference unit of the fuzzy logic system. Various methods of defuzzification listed by Mendel(1995) are; (i)**Maxiumum defuzzifier** which examines the fuzzy set B and chooses as its output the value of *y* for which $\mu_B(y)$ is a maximum. (2) **Mean of Maxima defuzzifier** which examines the fuzzy set B and then determines the values of y for which $\mu_B(y)$ is a maximum. It then computes the mean of these values as its output. If the maximum value of $\mu_B(y)$ occurs at only a point, this reduces to Maximum Defuzzifier. (iii). **The blending methods (also kwon as the Centre of Area)** which determines the centroid of the fuzzy set using the formula

$$\frac{\int_z \mu_A(x)x\,dx}{\int_z \mu_A(x)\,dx} = \frac{\sum_{k=1} \mu_A(x_k)x_k}{\sum_{k=1}^{n} \mu(x_k)}$$

These techniques when applied can generate different results, depending on the case being considered.

Related Work

Traffic signal control systems differing in sophistications and operation modes exist. A pre-timed controller repeats preset signal timings derived from historical traffic patterns while an adaptive controller considers traffic conditions for the whole approaches to an intersection and is able to adjust signal phasing and timing settings in response to real-time traffic demands at all or some of the approaches (Zhang et al, 2005). The pre-timed control is explained using the Webster method which determines the optimum cycle lengths (Webster, 1958). Webster has shown that minimum intersection delay is obtained when the cycle length is determined by the equation.

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$$C = \frac{1.5L+5}{1-\sum_{i=1}^{n} y_i} \quad . . . (1)$$

Where C is cycle length (second), L is total lost time per cycle, y_i is the critical lane group volume for ith phase, (measured in vehicles passing the lane per hour /saturation flow), and n is number of phases.
The total lost time is the time not used by any phase for discharging vehicles.
Total lost time is given as

$$L = \sum_{i=1}^{n} l_i + R \; . . . (2)$$

Where l_i is lost time for phase i, which is usually 4 seconds; and R is the total all-red time during the cycle.
The total effective green time, available per cycle, is given by

$$Gte = C - L \; . . . (3)$$

To obtain minimum overall delay, the total effective green time should be distributed among the different phases in proportion to their y values. The effective green time (G*ei*) for each phase is derived by.

$$Gei = \frac{y_i}{y_1 + y_2 + ... + y_n} Gte \quad . . .(4)$$

The actual green time for each phase (not including yellow time is obtained by

$$Gai = Gei + Li - \tau_i \; . . .(5)$$

Where τ_i is yellow time for phase i.

Design of the Simulation Environment

The Adaptive Fuzzy logic based traffic light simulation was designed for a four way traffic junction. The traffic flow rate determines how fast the queue grows. The set of control parameters used in the fuzzification are : Q_N = Queue length for the approach that will be getting the green phase, A_N = The average arrival rate for the approach that will be getting the green phase and G_N = The green phase pass duration. Q_N is categorized into three fuzzy sets of “SHORT”, “MODERATE” and “LONG” while A_N categories are “LOW”, “NORMAL” and “HIGH”. The output variables G_N has fuzzy sets “LESS”, “MEDIUM” and “MUCH”. The established membership functions are then assigned numeric meaning using diagrams that show the degree of membership for the linguistic labels .

The y-axis value refers to the degree to which the crisp input value applies to each of the membership labels. These diagrams are shown as follows:

Fig. 2 Membership functions for the vehicle QUEUE length

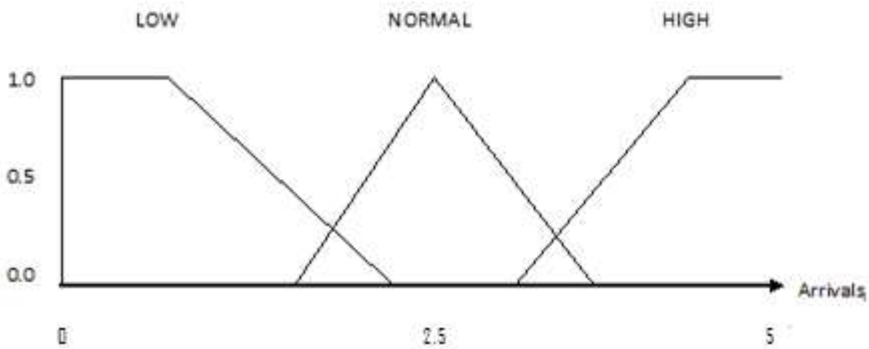

Fig. 3 Membership functions for the vehicle ARRIVAL rate

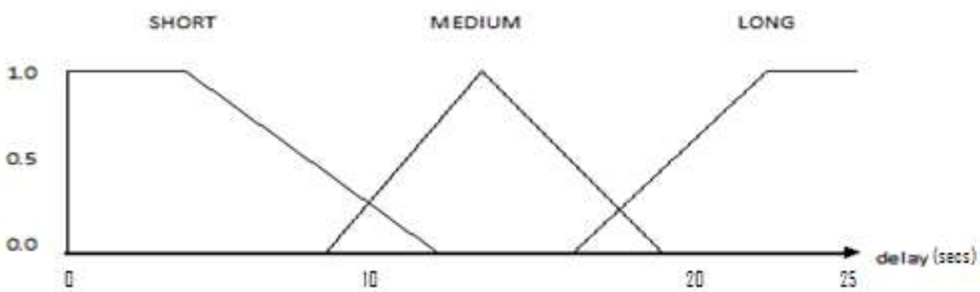

Fig. 3 Membership functions for the traffic light GREEN phase

The decision making process is based on a set of fuzzy rules implemented in an inference engine that has the general format:
IF (Q_N is S_1) AND (A_N is S_2) THEN (G_N is X_1), where S_1 and S_2 are natural language expressions of the intersection traffic nature and X_1 is the

natural language expression of the green phase allocation for each approach. The fuzzy rules are developed using fuzzy sets s1 and s2. In this system, Q_N and A_N have 3 categories for s1and s2, giving a total of 3 × 3 (i.e 9) rules. These rules are:

1. *If* QUEUE length is SHORT and vehicle ARRIVAL rate is LOW then the green light DELAY should be LESS
2. *If* QUEUE length is SHORT and vehicle ARRIVAL rate is NORMAL then the green light DELAY should be LESS
3. *If* QUEUE length is SHORT and vehicle ARRIVAL rate is HIGH then the green light DELAY should be MEDIUM
4. *If* QUEUE length is MODERATE and vehicle ARRIVAL rate is LOW then the green light DELAY should be MEDIUM
5. *If* QUEUE length is MODERATE and vehicle ARRIVAL rate is NORMAL then the green light DELAY should be MEDIUM
6. *If* QUEUE length is MODERATE and vehicle ARRIVAL rate is HIGH then the green light DELAY should be MUCH
7. *If* QUEUE length is LONG and vehicle ARRIVAL rate is LOW then the green light DELAY should be MUCH
8. *IF* QUEUE length is LONG and vehicle ARRIVAL rate is NORMAL then the green light DELAY should be MUCH
9. *IF* QUEUE length is LONG and vehicle ARRIVAL rate is HIGH then the green light DELAY should be MUCH.

These rules cover various traffic conditions that may be encountered in the system and represent the behaviour of the system being considered. The min-max composition method is applied for making inference. The steps for min-max implementation are as follows:

Step 1:For particular crisp input values, determine the degree of truth of each antecedent by using fuzzification transform.

Step 2: Find the strength of the entire rule, which is equal to the minimum of the antecedent's degree of truth.

Step 3: Derive the fuzzy output which is equal to the maximum rule strength for each consequent label.

Step 1 notation is as follows:

$$\mu A \cap B = \min(\mu_A[x], \mu_B[x]).$$

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In order to implement the steps outlined above, using the crisp input, a vertical line drawn at this point identifies the affected fuzzy input variables and the logical AND informs the taking of the minimum of the two membership functions for rule strength determination. Membership for the fuzzy sets is determined using the range 0 to 1. The generated fuzification values triggers some of the rules which are combined and rules with the highest strength are selected. The fuzzy output of the selected rule is then used for defuzzification. The defizzification method used is Centre of Area (COA) method also known as the Centroid Method.

$$\text{COA} = \frac{\sum_{i=1}^{n} \mu(xi)xi}{\sum_{i=1}^{n} \mu(xi)}$$

In this method, the output membership function above the value indicated by the respective fuzzy output is truncated. The 'clipped" membership functions are then combined and the overall centre of gravity is calculated. A typical COA diagram for GREEN phase computation is shown below.

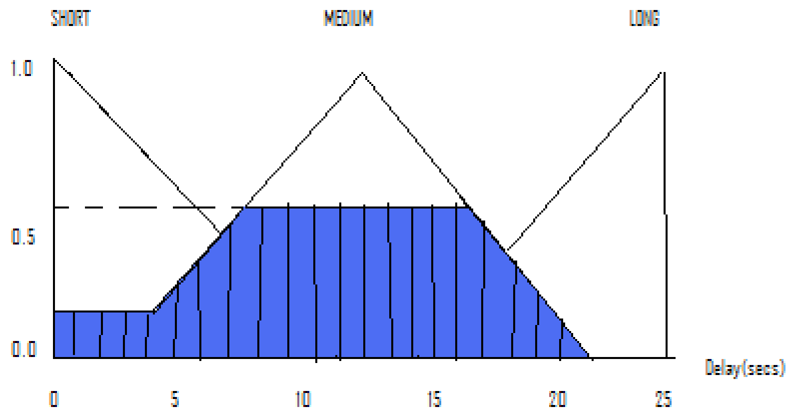

Fig. 4 Output membership functions for the GREEN phase

The traffic simulator is a graphical user interface (GUI) system developed with Visual C+. The system can simulate both pre-timed and adaptive controls. The fuzzy control uses the prevailing traffic condition to

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dynamically assigns time to each link. The fuzzy controller was found to assign split phase of 2 to 20 seconds, In the fuzzy implementation, all the fuzzy logic control principles such as fuzzification, rule evaluation / inference and defuzzification are implemented, to arrive at appropriate split (green) phase timing for the links.
The simulation software at development stage was broken down into various operational segments, such as road intersection environment drawing, vehicle generation and animation, traffic light sequence animation development and fuzzy split phase generation. These segments were tested independently and certified to produce valid result before they were merged to produce a full functional system. Depending on the arrival rate that will be used for simulation, varying random number generation seeding is done. The randomized output subsequently forms the number of vehicles that are generated on the lane. A variation on the randomization seed can be achieved by selecting from the range 2 to 5 using a slider available in a dialog box. This dialog box is shown in the figure 5.

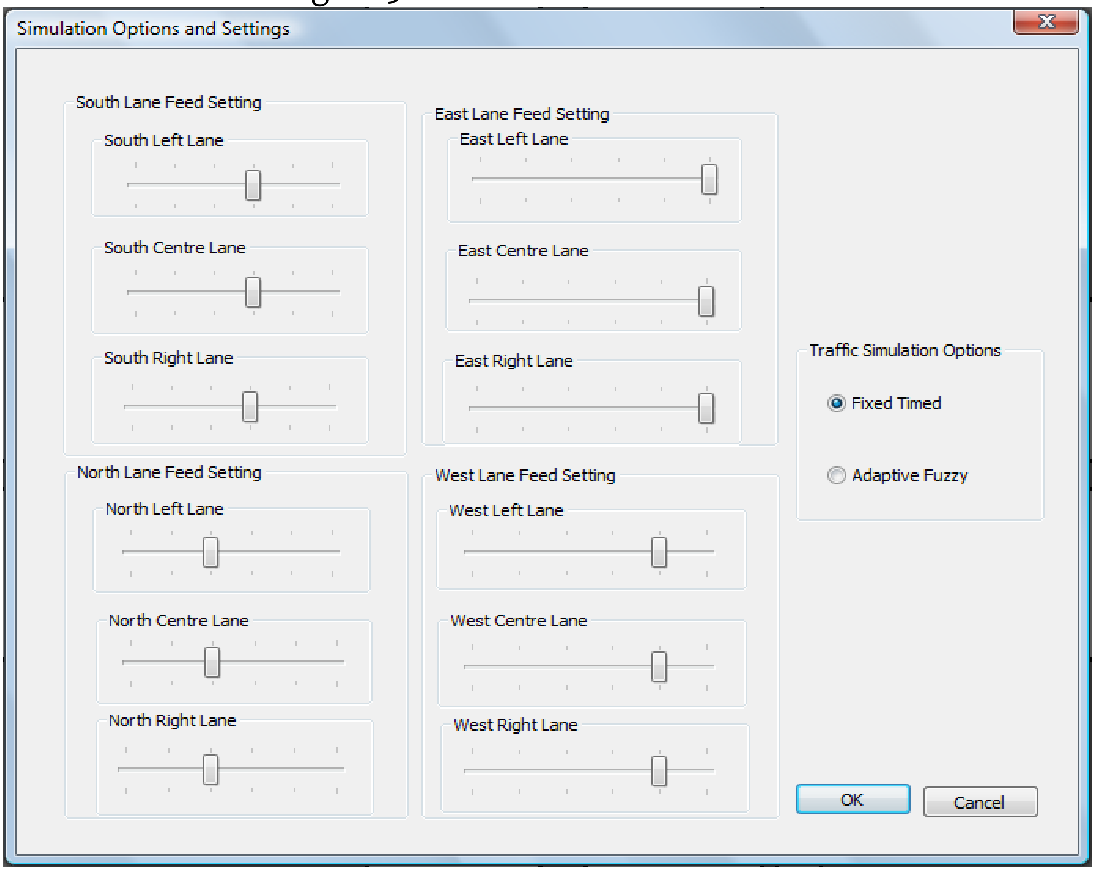

Fig 5 Simulation Options Settings Dialog box

To test the coupled system, a user would, through the dialog box select either fixed timed or Fuzzy Adaptive simulation option. The desired

Arrival rate is selected from the sliders and the value is used as a seed for generating a random number of vehicles for the simulation. The figure 6 shows the simulator environment.
Vehicle throughput and average waiting time of vehicles are used to compare the performance of the adaptive system with the pre-timed.

Discussion of Results

At the completion of development of the simulation software, five simulation tests were performed for both Pre-timed and Adaptive Fuzzy controllers for different cases of:

(1) Low vehicle arrival for all the approaches of the intersection
(2) Uneven vehicle arrival for the approaches(in which some approaches have low traffic while others have high) and
(3) High vehicle influx for all approaches. The average values for the intersection throughput and average delays experienced by the vehicles were calculated.

A table of the result obtained for the throughput and delays experienced by the vehicles before crossing the intersection at their turn of green phase is in the appendix.

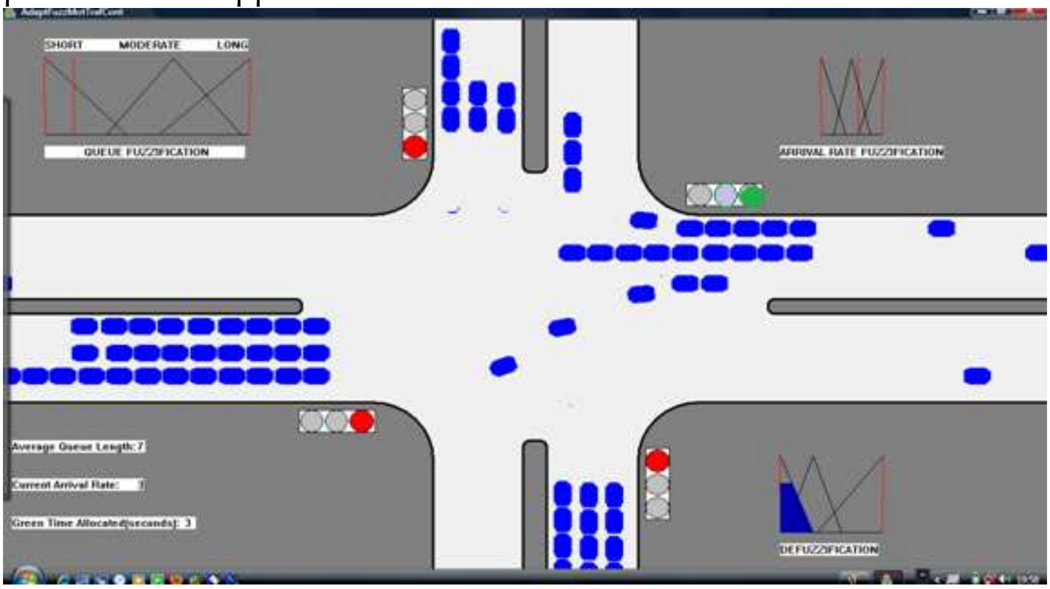

Fig 6 The traffic simulator

From the graphs of figures 4.1, 4.2 and 4.3, the Adaptive Fuzzy Controller outperforms the Pre-timed controller in all cases of vehicles arrival rates. This performance difference may not be very conspicuous because of the high scale of the axes used in the plotting. However this performance differences can be easily seen in the throughputs tables.

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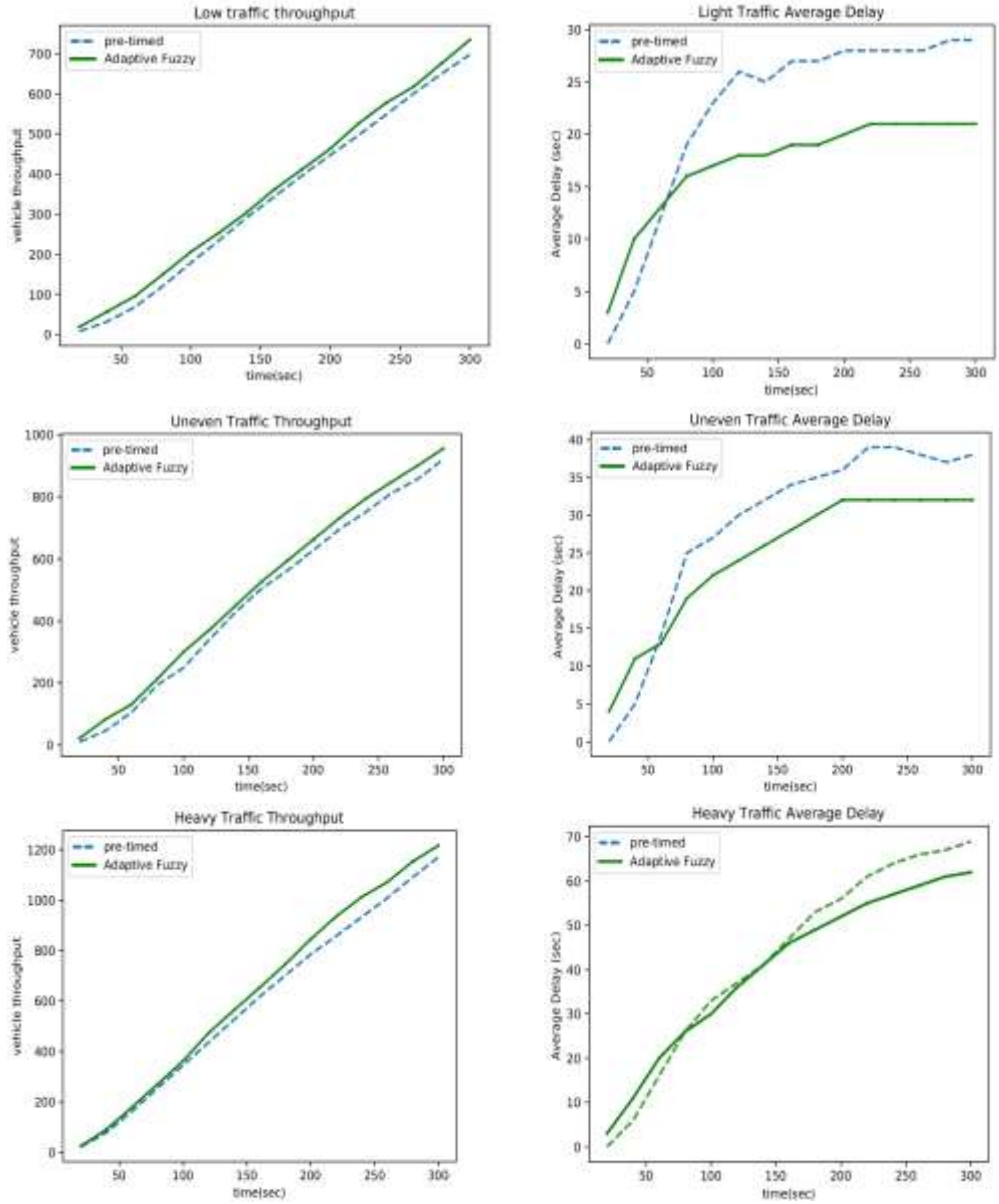

The plots in the figures above confirm better performance of the Adaptive system by the evidence of the vehicle controlled by Pre-timed system suffering higher delays. Also noticeable is the overall increase in vehicles delays for both systems as the traffic arrival rates rise. However in spite of the increase the Adaptive system performance is still better.

Conclusion

In this study, an adaptive simulation of a four way isolated junction traffic controller was developed for both Pre-timed and Adaptive systems. The fuzzy control strategy rules used is similar to linguistic approach a Traffic control police officer would naturally adopt. The fuzzy system decides the best time interval, enough to pass vehicles on a queue at a time, while also considering the arrival rate for the lane. The effectiveness of the two strategies was compared using performance measures such as vehicles throughputs and delays on queues. The fuzzy system showed substantial improvement over the Pre-timed for both evaluated methods used and for different cases of vehicle arrival rates considered. This suggests that fuzzy system has the potential to improve operation when used for road traffic control.

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Appendix Simulation Result

	Vehicle Throughput						Average Delay					
Time (sec)	Low traffic		Uneven traffic		High Influx		Low traffic		Uneven traffic		High Influx	
	Fixed	Adapp	Fixed	Adap	Fixed	Adap	Fixed	Adap	Fixed	Adap	Fixed	Adap
20	8	19 57	*10*	*22*	22	25	0	3	0 5	4 11	0	3
40	32	96	*46*	*83*	78	91	5	10	14	13 19	6	11
60	69	150	*105*	*131*	163	179	12	13	25	22	16	20
80	121	206	*194*	*214*	254	270	19	16	27	24	26	26
100	179	253	*249*	*300*	345	362	23	17	30	26	33	30
120	234	304	*340*	*371*	436	473	26	18	32	28	37	36

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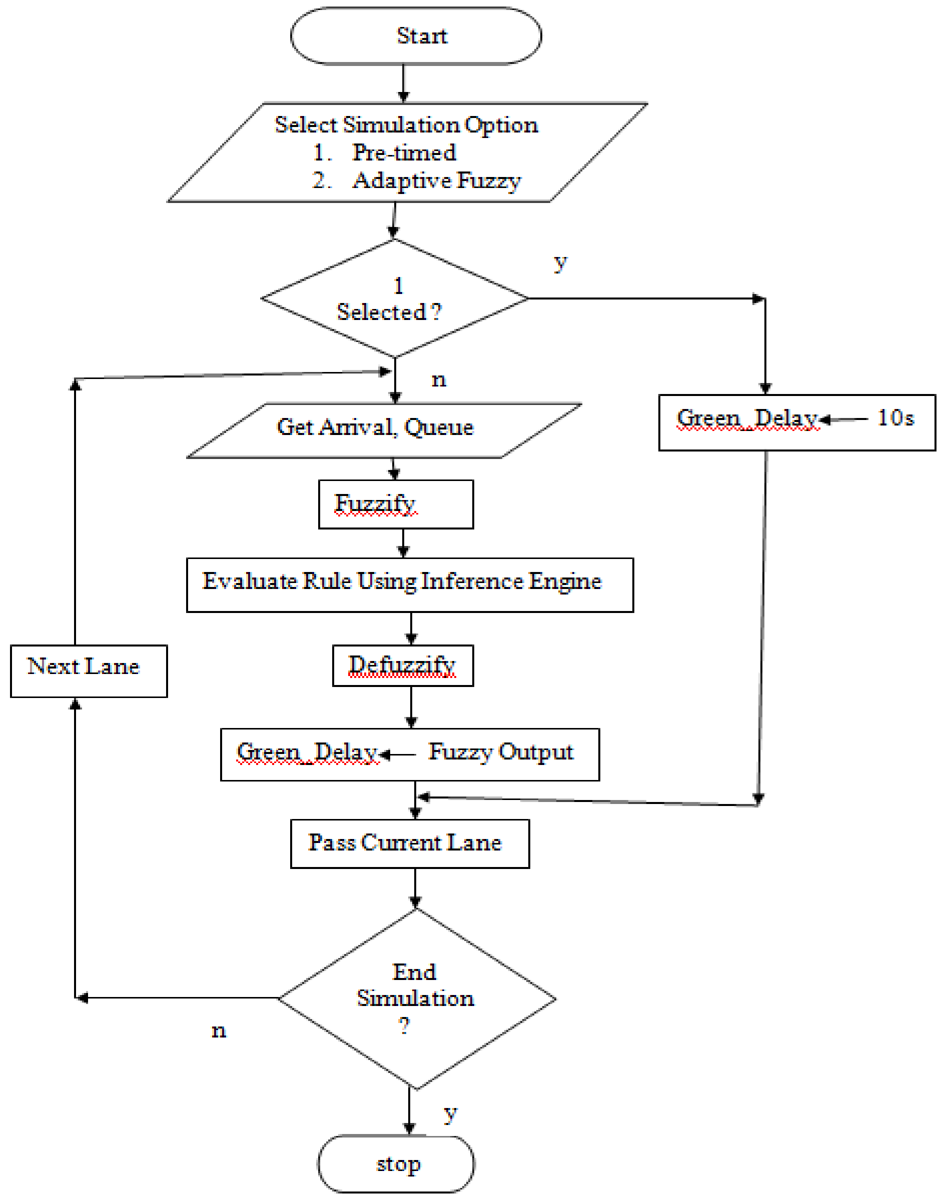
140	291	362	428	449	526	564	25	18	34	30	41	41
160	344	412	504	526	617	653	27	19	35	32	47	46
180	397	463	562	594	701	745	27	19	36	32	53	49
200	447	525	628	662	785	845	28	20	39	32	56	52
220	496	577	695	731	857	935	28	21	39	32	61	55
240	548	618	750	793	933	1012	28	21	38	32	64	57
260	601	676	811	847	1008	1071	28	21	37	32	66	59
280	650	734	856	900	1091	1153	29	21	38		67	61
300	697		921	955	1170	1216	29	21			69	62



The flowchart for the traffic control simulator.

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