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ANFIS-based Intelligent Traffic Signal Control of Two Interconnected Junctions

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***Abstract*—In this paper, a hybrid system that combines fuzzy logic and artificial neural network called adaptive neuro-fuzzy inference system (ANFIS) to automatically and effectively manage traffic flow in two interconnected junctions adaptively according to the prevailing traffic situation is developed. The ANFIS model was trained with datasets that reflect expert warden's judgments at different traffic situations at the intersections of the case study. The ANFIS-based traffic signal control scheme was implemented in Simulink environment in MATLAB. The performance of scheme was analysed and evaluated for the two intersections in terms of average delay, throughputs and queue length. From the improvement index analysis, it was observed that for low, medium and peak traffic volume scenarios considered, ANFIS-based control performs significantly better than the fixed-time control scheme. For instance, for a peak traffic volume scenario ANFIS-based control reduced delay by 43.4%, increased throughputs by 8.2% and reduced queue length by 69.2% for intersection 1; and reduced delay by 39.1%, increased throughputs by 6.5% and reduced queue length by 61.3% intersection 2. Also, paired t-tests analysis conducted on peak traffic data indicated statistical significance of the improvements of ANFIS-based control method over the fixed-time control method in terms of average delay, throughputs and queue length.**

Keywords—ANFIS, Traffic signal control, Fixed-time, Interconnected Intersections, Queuelength, Waiting time, t-test

I. INTRODUCTION

Traffic congestion in major roads in big cities across the globe has become a recurring decimal. This can be mainly attributed to the geometrical increase in population which has in turn resulted in high demand of cars [1, 2]. Many of the roads operate at full capacity for hours each day during the peak periods. The socio-economic sector is suffering as productivity is seriously affected owing to the loss of man hour because of unnecessary delays. Several efforts have been made to mitigate the cause of traffic congestion through more effective means of signal [3 – 5].

Construction of new roads and highways, and expansion of existing ones can potentially increase the capacity and alleviate the congestion problem, and helps in the reduction of delay. However, new construction projects are not always feasible for reasons of high cost or not being able to accommodate the new expansions. Even when construction projects are feasible, they require closing of roads and detouring traffic away from the construction site for the duration of the project, thus traffic in the affected area is disrupted. Even when roads are constructed, there is a need to have an effective and efficient traffic control scheme in place to avoid congestion. There is a need for better management of existing resources and it can be achieved through efficient traffic control.

The traffic signal control scheme deployed in most cities is fixed-time control type. It works by directing traffic alternately to stop and to move. It operates using a pre-specified signal plan based on historical information, and regardless of the traffic conditions that are currently occurring on the road [6 – 8]. The plan used may not be the best suited to deal with the current traffic conditions, which leads to inefficient traffic control. As a result long queues at road intersections are common scenarios, which led to significant economic loss and environmental pollution. Also, the uncertain and random nature of traffic processes makes it rather too difficult to have an all-time best signal plan for the fixed-time control scheme [9].

Adaptive traffic signal systems have been operating successfully in many countries since early 1980's, with Sydney Coordinated Adaptive Traffic System (SCATS) and Split Cycle and Offset Optimization Technique (SCOOT) being the two most widely deployed systems [10 – 12]. SCATS selects the best phase timings and offsets from a set of predefined plans based on the prevailing traffic flow conditions. SCOOT uses gradient search to incrementally adjust green durations, cycle length and offset of each intersection in the traffic network. Having recognized the rewards of adaptive control over the traditional selection of fixed cycle length timing patterns, U.S. Federal Highway Administration (FHWA) sponsored several programs since 1990, aimed at developing adaptive signal systems, such as Optimization Policies for Adaptive Control (OPAC) with rolling horizon optimization and Real-Time Hierarchical Optimized Distributed and Effective System (RHODES) with hierarchical optimization [13].

The afore-mentioned adaptive control strategies, though out-perform the traditional fixed-cycle controls, have several limitations including uncertain traffic flow prediction and difficulty in estimating the arrival time [14–18]. The rapid developments in artificial intelligence (such as fuzzy logic) in recent years have revealed cutting-edge approaches in adaptive traffic signal control [19, 20]. Fuzzy logic is adopted in adaptive traffic signal control to model human expert's knowledge in the situation where development of an exact mathematical model of the phenomenon is very difficult or even impossible [21]. The inherent ability to mimic biological intelligent enables fuzzy logic-based traffic signal control to outperform the existing fixed-time control methods under congested conditions [22].

This paper presents a hybrid system that combines fuzzy logic and artificial neural network called adaptive neuro-fuzzy inference system (ANFIS) to automatically manage traffic flow in two interconnected junctions adaptively according to the prevailing traffic situation. The ANFIS-based traffic signal control scheme was implemented in Simulink environment in MATLAB software.

II. ANFIS ARCHITECTURE

ANFIS is an algorithm that combines the gains of fuzzy logic and artificial neural network (ANN). The rules of ANN learning are to identify and tune the structure and parameters of a Fuzzy Inference System (FIS). A typical ANFIS architecture is shown in Fig. 1. The circle designates a fixed node, while the square designates an adaptive node. There are also input and output nodes, as well as hidden layers. The system has a total of five layers [23].

Layer 1 *nodes* contain the input membership functions. Their parameters are called premise parameters. Every node *i* in this layerissquare and adaptive with a function:

$$O_i^1 = \mu_{A_i}(x) \;\; for\ i = 1{,}2 \qquad (1)$$

Layer 2 is the rules node.The node generates the output (firing strength) by cross multiplying all the incoming signals:

$$O_i^2 = \mu_{A_i}(x) \text{x}\, \mu_{B_i}(x) \;\; for\ i = 1{,}2 \qquad (2)$$

Layer 3 contains the average nodes.The i^{th} node computes the ratio of the i^{th} rule's firing strength to the sum of all rules' firing strengths. The outputs are then as given:

$$\bar{w}_i = \frac{w_i}{w_1+w_2},\ for\ i = 1{,}2 \qquad (3)$$

Layer 4 contains theconsequent nodes.It includes a linear function which gives the contribution of i^{th} rule towards the total output and/or the function defined is calculated.

$$O_i^4 = \bar{w}_i f_i = \bar{w}_i(p_i x + q_i y + r_i) \qquad (4)$$

where $w_i$is the output of layer 3, and $\{p_i,\ q_i,\ r_i\}$ are the parameter. These parameters are referred to as the consequent parameters.

Layer 5 contains the output node.The node computes the overall output by summing all the incoming signals:

$$O_i^5 = overalloutput = \textstyle\sum_i \bar{w}_i f_i \qquad (5)$$

III. METHODOLOGY

The ANFIS-Based traffic control model bock diagram is presented in Fig. 2. The traffic data processing module acquires real-time data from the traffic sensors mounted at the different phases in an intersection. The acquired data is then used to compute phases' queue lengths as well as the time spent by the vehicles in queue before the next green light.

The ANFIS Module used the queuelength and waiting time of each phase as well as the downstream queuelength (a reflection of the queued vehicles expected to come into the phase from the adjoining intersection) to determine the each phase priority level. The ANFIS model was trained with datasets that reflect expert warden's judgments at different traffic situations at the intersections considered.The trained model block diagramis shown in Fig. 3.

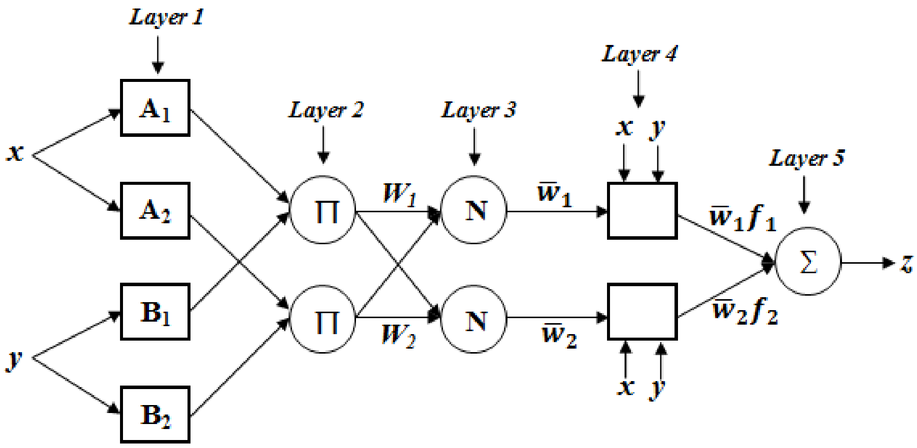

Fig. 1: ANFIS architecture

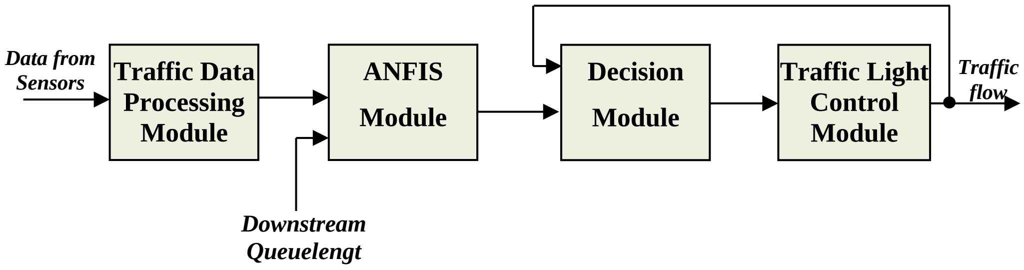

Fig. 2: Block diagram of the ANFIS-based traffic signal controller

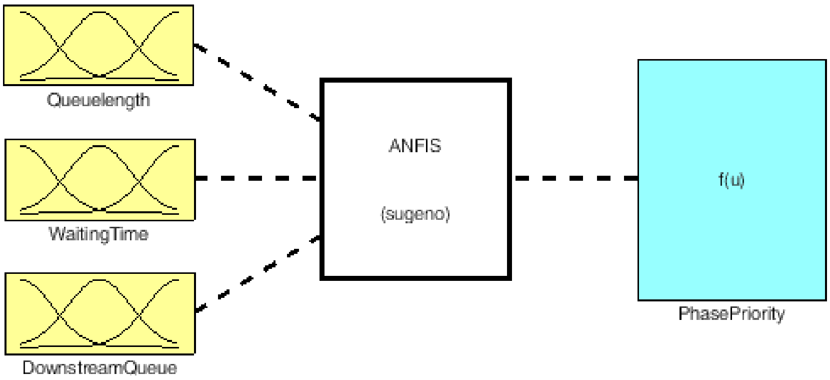

Fig. 3: Block diagram of ANFIS model

The Decision Module makes the decision whether to switch to the next phase or not by comparing the priority levels of all the different phases in each intersection. If the priority level of another phase other than the current phase is highest, there will be a change of phase; otherwise there will be an extension of the current phase.

The traffic light control module interfaces the controller and the traffic lights. Appropriate signal to change the states of the traffic lights is initiated whenever there is decision to change to another phase.A particular mode will last as long as the green time does not elapse.

IV. CASE STUDY

In order to test the effectiveness of the developed adaptive traffic control model, real-time traffic data obtained from two traffic congestion prone intersections in Uyo metropolis in Nigeria (shown in Fig. 4) were taken. A schematic diagram of the studied environment and the route is shown in Fig. 5. At the time of this investigation, fixed time traffic controllers where used to control traffic at the intersections.

The Simulink model for the implementation of the developed ANFIS-based traffic control scheme is as shown in Fig. 6.

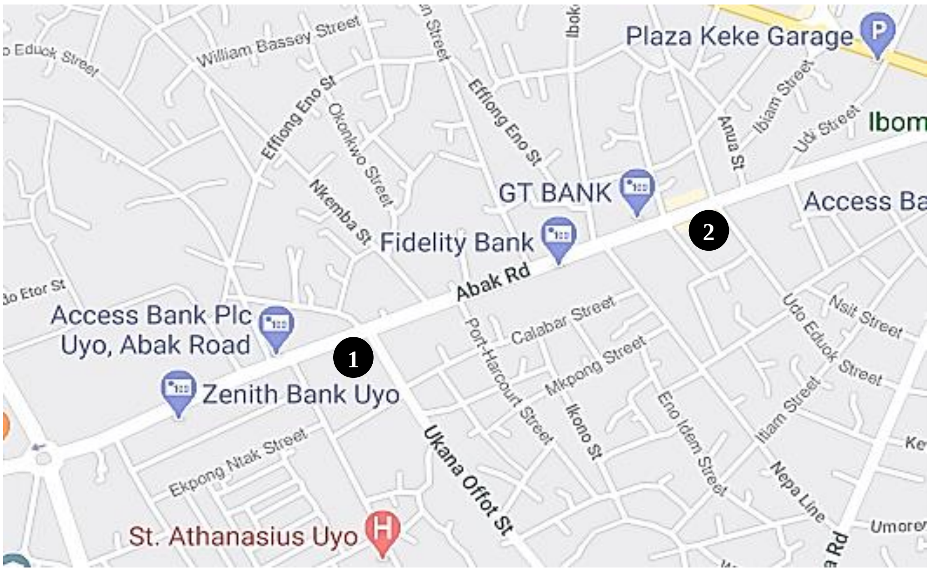

Fig. 4: Google map of Uyo Metropolis showing interconnected intersections considered

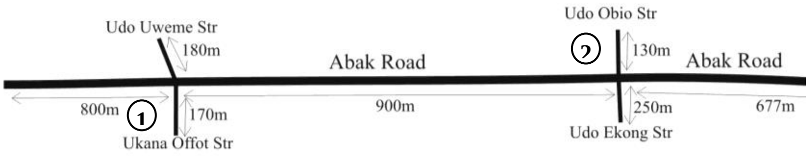

Fig. 5: Schematic diagram of the area considered for the study

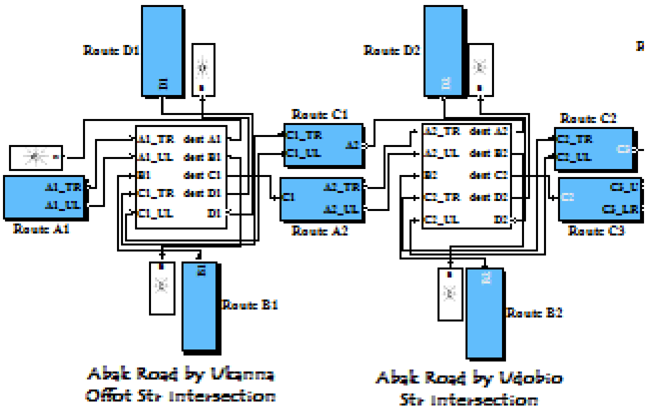

Fig. 6: Simulink model of the ANFIS-based traffic control of interconnected intersections

V. PERFORMANCE INDICES

The following performance indices were used to evaluate the performance of the developed traffic control scheme.

A. *Improvement*

This is the percentage difference between the ANFIS-based and the fixed-time traffic control schemes.

$$Improvement = \frac{ANFIS\ based - fixed\ time}{fixed\ time} \quad (6)$$

B. *Test of Significance*

In a t-test on paired observations the mean difference $\mu_D = \mu_B - \mu_A$ is tested, where μ_A and μ_B are the mean values of the observations in sample A and B. In this thesis, sample A is data from the fixed-time control scheme and sample B is data from the ANFIS-based control scheme. The structure of the paired observations will be as follows:

Table 1: Structure of the paired observations in t-test analysis

Pair	Sample A	Sample B	D = B – A
1	x_1	y_1	$D_1 = y_1 - x_1$
2	x_2	y_2	$D_2 = y_2 - x_2$
3	x_3	y_3	$D_3 = y_3 - x_3$
.	.	.	.
.	.	.	.
.	.	.	.
N	x_n	y_n	$D_n = y_n - x_n$

The *t* statistic is given in (7).

$$t = \frac{\bar{D}}{\sigma/\sqrt{n}} \quad (7)$$

where $\bar{D}$ is the mean difference of the paired observations, n is the number of pairs (simulations), and σ is the standard deviation of the paired observations given by (8).

$$\sigma = \sqrt{\frac{\sum D^2 - \frac{(\sum D)^2}{n}}{n-1}} \quad (8)$$

where D is the difference between the two sample data.

The null hypothesis H_0 states that mean difference,$\mu_D = 0$, there is no difference between the two samples. The research hypothesis H_1 states that$\mu_D \neq 0$ (i.e. $\mu_D > 0$ or $\mu_D < 0$), there is a difference between the two samples. In this work, $\mu_D > 0$ means that ANFIS-based control scheme is better in terms of throughput and worst in terms of average delay and queue length compared to fixed-time control schemes, while $\mu_D < 0$ means that ANFIS-based control scheme is better in terms of average delay and queue length and worst in terms of throughput.

The *t* test statistics follows a t-distribution with *n – 1* degrees of freedom. If the critical value obtained from the *t*–distribution table is smaller than the calculated |*t*| value, null hypothesis, H_0 is rejected and alternative hypothesis, H_1 accepted, otherwise H_0 is accepted and alternative hypothesis, H_1 rejected.

VI. RESULTS

The simulated traffic results for the traffic control schemes based on the different traffic scenarios (low, medium and peak) are presented in Table 2. It can be seen that in all cases, there is an improvement in traffic control with ANFIS-based scheme compared to the fixed time scheme.

In simulation tests, the traffic situation in one particular simulation run may, by coincidence, be extremely suitable for the control scheme, and the control performance may seem to be better than what it actually is. To avoid such coincidences 30 one-hour simulations were run for each control scheme under consideration.

To compare the ANFIS-based control scheme with the existing and optimized fixed-time schemes, identical simulations were run on ANFIS-based and fixed time control schemes. The vehicles were generated at the same time instants in all the simulation runs, and any change in their behaviour resulted only from a change in the control scheme. Thus, the observations in each performance index (average delay, throughputs and queue length) were paired (i.e. ANFIS-based/ fixed time), and *t*-tests on paired observations were used to compare the means of each performance index in the simulation runs. The statistical analysis is presented in Table 3. The results show that ANFIS-based traffic control scheme performed significantly better than fixed-time control schemes for the two intersections considered.

Table 2: Performance comparison of ANFIS-based and fixed time schemes for different traffic density period

Intersection	Traffic Density	Control Scheme	Ave. Delay (sec/veh)	Throughputs (veh/hr)	Queue length (veh)
Abak Road by Ukana Offot Street	Low	Fixed-Time	50.8	1160	8
		ANFIS-Based	21.8	1177	6
		Improvement	57.1%	1.5%	25.0%
	Medium	Fixed-Time	56.2	2574	55
		ANFIS-Based	33.1	2661	15
		Improvement	41.1%	3.4%	72.7%
	Peak	Fixed-Time	144.1	3412	235
		ANFIS-Based	57	3835	26
		Improvement	60.4%	12.40%	88.94%
Abak Road By Udobio Street	Low	Fixed-Time	56.9	1230	23
		ANFIS-Based	22.5	1273	4
		Improvement	60.5%	3.5%	82.6%
	Medium	Fixed-Time	59.7	2771	57
		ANFIS-Based	36.1	2866	19
		Improvement	39.5%	3.4%	66.7%
	Peak	Fixed-Time	131.1	3545	227
		ANFIS-Based	76	3916	86
		Improvement	42.0%	10.47%	62.11%

Table 3: t-test statistical analysis of the developed ANFIS-based control

Intersection	Traffic Scheme	Statistics	Ave. Delay (sec/veh)	Throughputs (veh/hr)	Queue length (veh)
Abak Road by Ukana Offot Street	Fixed Time	$\bar{x}_e$	134.16	3453	257
	ANFIS-Based	$\bar{x}_a$	61.15	3824	37
	ANFIS-Based Vs Fixed Time	$\bar{D} = \bar{x}_a - \bar{x}_e$	-73.00	371	-220
		$Stdev, \sigma$	14.01	50	39
		|t|	28.55	40.38	30.83
		Critical Value	2.045	2.045	2.045
		Accept	$\mathbf{H_1}$	$\mathbf{H_1}$	$\mathbf{H_1}$
		Comparison	Better	Better	Better
Abak Road By Udobio Street	Fixed Time	$\bar{x}_e$	156.66	3528	259
	ANFIS-Based	$\bar{x}_a$	83.71	3953	69
	ANFIS-Based Vs Fixed Time	$\bar{D} = \bar{x}_a - \bar{x}_e$	-72.95	425	-190
		$Stdev, \sigma$	9.39	52	23
		|t|	42.55	44.43	44.76
		Critical Value	2.045	2.045	2.045
		Accept	$\mathbf{H_1}$	$\mathbf{H_1}$	$\mathbf{H_1}$
		Comparison	Better	Better	Better

VII. Conclusion

In this paper, an ANFIS-based traffic control scheme for two interconnected junctions was developed. Input-output datasets for the training of ANFIS model was constructed using the obtained field data. Both fixed-time and ANFIS-based traffic control schemes for the two intersections considered were implemented in Simulink environment in MATLAB software. The performance of the developed scheme was analysed and evaluated based on results obtained from simulations in terms of average delay, throughputs and queue length. The evaluations were conducted using low, medium and peak traffic volume data considered at different traffic conditions. The results show that in general the ANFIS-based control performed better than the fixed time control. Statistical significance was also conducted for ANFIS-based control scheme over the fixed time schemes. The *t*-test analysis also confirmed that ANFIS-based control is significantly better than the fixed-time controls.

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