ISBN 978-93-84468-11-8
Proceedings of 2014 International Conference on Artificial Intelligence & Manufacturing Engineering (ICAIME 2014)
Dubai, December 25-26, 2014, pp. 156-161

Traffic Light Control Using Adaptive Network Based Fuzzy Inference System

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***Abstract*: *This paper presents an Adaptive Network Based Fuzzy Inference System (ANFIS) for correcting the inefficiency performance of the fixed delay controller (FDC) in the Traffic Light Control System (TLCS). Fixed delay controller controls the traffic lights based on the fixed delay period program embedded in the microcontroller which does not depend on the traffic density on the roads. Therefore, causes unwarranted waiting time, high fuel consumption and environmental pollutions. The cross roads junction with two lanes per road was considered. One Traffic Light (TL) was used to control vehicle on each road. ANFIS-TLCS was simulated using graphic user interface tool of the MATLAB. The GUI was simulated for the FDC and ANFIS controller for specific simulation periods and the preset number of vehicles for each lane using slide button. Performance of the ANFIS controller was compared to the FDC using Driving Time (DT), Waiting Time (WT) and Cost Efficiency (CE). The results obtained showed that ANFIS controller performed better than the FDC.*

Keywords: *Cross road, Traffic Light, Driving Time, Waiting Time and Cost Efficiency,*

1. Introduction

Traffic controlling is one of the main roles of government in every country. It is agreeable, that traffic congestion do leads to environmental pollution as a result of high rate of release of the carbon mono-oxide from the exhaust of the vehicles, thereby resulting in green house effect, while carbon-monoxide too has a great impact on the quality of life [1]. One common approach to handle traffic congestion is to build infrastructure, such as roads and bridges by pass lane, fly over etc. In the past years, it was becoming increasingly more difficult to build more infrastructures to at least diminish traffic jams. The challenge was not only because of the high cost, but also the lack of space and the environmental damage of building new roads have to be considered. With respect to this, a manual method of controlling vehicle at junctions was put in place.

In Nigeria, the Government formulates a Traffic control (TC) unit in the police force that controls the flow of both vehicles and pedestrian across a junction. The manual control is cumbersome to the TC officers that stand for many hours and regardless of the unfavourable weather conditions. With the advent of technology, Traffic Light Control System (TLCS) based on analogue circuit with the use of 555 timer Integrated Circuit (IC) was invoked, so as to ease human being the stress of controlling vehicle manually. It was later discovered that this Traffic Light Control System (TLCS) with analogue circuit was inefficient, the use of digital circuit then came on board, with the use of flip flops and later embedded systems called micro-controller [2].

Different approaches were given by [3], based on the applying Artificial Intelligent (AI) in order to manage traffic flow in a more effective and efficient manner. This lead to a relatively new research area called Intelligent Transportation System (ITS) which is basically concerned with the application of Information and Communication Technologies (ICT) to the planning and operation of transportation system. Traffic observation, control and real time management is one of the major components within future ITS. This involves, for instance, the development of an Artificial Intelligent-based Traffic Control System (AI-TCS). It is widely accepted by the transportation community that ITS makes existing transportation facilities efficient, minimizing the need to build more infrastructure.

This intelligent traffic system also saves the motorists' time and reduces fuel consumption while waiting for the lights to change since it helps reducing congestion in the traffic intersections. [4], [5] and [6] proposed the implementation of traffic light control system using microcontroller based with fixed delay program. However, fixed delay program is inefficient during certain road condition such as un-prioritized access been granted to flow of traffic with respect to traffic density. In this paper, an Adaptive Network-based Fuzzy Inference System (ANFIS) of TLC technique is presented to mitigate the inefficient performance of fixed delay program.

2. Materials and Method

It is very important to model the field template, which will be simulated into the Graphical User Interface (GUI) of the MATLAB. The ANFIS controller system with a road network model was presented in figure 1. Figure 1 is a typical cross road junction of the four (double lanes) main roads. At the center was a circle, representing the roundabout. Four traffic lights were used, with one controlling each of the four roads as shown in figure 1. The traffic lights were named as TFA, TFB, TFC and TFD for controlling lanes R1, R3, R6 and R8 respectively. The arrow lines indicate the direction of vehicles flow. The sensors were placed in the middle of each road, which is fixed to a length of 100 meters apart to sense the numbers of vehicles waiting. The traffic lights control only the vehicles that want to cross the junction.

At the top right corner of the model in figure 1 is the ANFIS controller. The ANFIS controller senses the number of vehicle through the vehicle counter, from the sensors and compares this to the state monitor, then the state monitor feeds back to the ANFIS controller how to govern the controlling of the 4 traffic lights. The process is repeated every time there is changes in the state monitor and the vehicle counter responses.

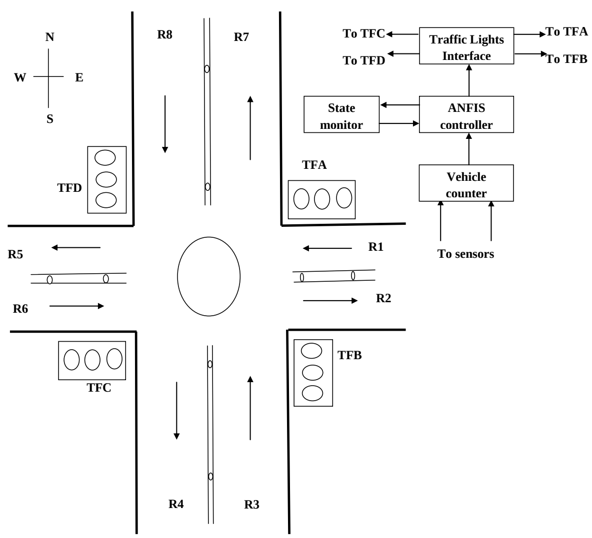

Fig. 1: A road network with ANFIS Traffic Light Control System

2.1. Roads and traffic flow assumptions

The ANFIS traffic lights control system was designed for a double lane or dual carriage road network, though the system can also be used for a single-lane road network. For the double-lane network, 8 roads are connected at a junction (round-about) as in Figure 1. 4 roads (R1, R3, R6, and R8) allow vehicles into the junction while the other 4 roads (R2, R4, R5, and R7) allow vehicles out of the junction. If the North-South lanes (R3 and R8) entering the junction, the West-East lanes (R1 and R6) are not allowed entry into the junction and vice versa. The vehicle going out of the junction on R2, R4, R5 and R7 are not affected by the traffic lights.

2.2. Traffic Lights Configuration

The junction consists of four Traffic Lights (TL) and each light indicates "GO" (green), "STAND-BY" (amber), and "STOP" (red). If the North-South lanes are the Arrival, then the West-East lanes are the Queue and vice versa. The traffic lights TFB and TFD will indicate the same thing while TFA and TFC will indicate the same thing at every instance of time. That is, if TFB is “GO”, TFD will also be “GO” while, if TFA is “STOP”, TFC will also be “STOP” because they are on the same West-East direction. This means that North and South lanes have the same state while West and East have the same state. The four TL are connected to the Traffic Light Interface.

2.3. Traffic Light Interface

This is where the traffic lights TFA, TFB, TFC, and TFD get their signals to “GO”, “STAND-BY” or “STOP”. The type of signal transmitted to the traffic lights from the interface is actually determined by the ANFIS controller.

2.4. Sensors

Electromagnetic sensors are placed to track the cars on the roads R1, R3, R6 and R8. Two pairs of sensors are located by the road sides of each road. The first pair of sensors are positioned by the traffic lights to count the number of vehicles passing the traffic light (v_f) while the second pair of sensors are positioned about 100 meters from the traffic light to count the number of vehicles entering the lane (v_b). The total number of vehicles (v_{total}) on a lane is calculated by finding the differences between the numbers of vehicle passing the traffic light and the number of vehicle entering the lane as

$$v_{total} = v_b - v_f \tag{1}$$

2.5. Vehicle Counter

This is the device that receives the signal from the sensors and computes the number of vehicles on each lane using equation 1 and uses the result to communicate the ANFIS traffic controller for decision making.

2.6. ANFIS Controller

ANFIS Controller is the device that processes the decision of the traffic lights interface using the combination of two techniques (Artificial Neural Network and Fuzzy Logic). It consists of a trained ANFIS object that determines how many seconds the “GO” (Green) should be extended for the Arriving lanes based on the Number of Arrival and Number of Queue. The Extension Time provided by the ANFIS Traffic Controller is based on logic (Artificial Intelligence) in a manner a human being will decide. For instance, if the arriving vehicles are many and the queuing vehicles are very small, then the green light of the arrival lanes should be extended by few seconds. This is different from the conventional traffic light system which changes the light based on preset times irrespective of the traffic densities in the lanes.

2.7. State Monitor

This is the device that signals the ANFIS traffic controller to make a decision after checking that the time of STOP has elapsed. If there is no vehicle queue, the device will not signal the ANFIS traffic controller to change state.

2.8. Design Assumptions and Constraints

The following assumptions and constraints were made for the successful simulation of the ANFIS controller

1. Vehicles going out of the junction cannot go through roads R1, R3, R6 and R8
2. Roads R2, R4, R5 and R7 are meant for vehicles leaving the junction so no vehicle can come into the junction through these roads.
3. When traffic from the North and South moves, traffic from the West and East stops and vice versa.
4. The minimum time for “GO” (green light) is 5 seconds while the maximum time is 20 seconds.

2.9. Development of the ANFIS Objects

An ANFIS traffic controller object was developed for the system. The ANFIS object consists of two inputs variables namely “Arrival” and “Queue”. The Arrival denotes the number of vehicles on the arrival side while the Queue denotes the number of vehicles on the queuing side. If the North-South lane is the Arrival, then the West-East lane will be the Queue and vice versa. The ANFIS object has 1 output variable namely “Extension”.

The “Arrival” has 3 membership functions namely “Very Few”, “Few” and “Many”. The “Queue” has 3 membership functions namely “Very Small”, “Small” and “Large”. The extension time also has 3 membership functions namely “None”, “Short” and “Long”. These membership functions are determined numerically as presented in table I.

TABLE I: Membership Function

Extension (in seconds)	Arrival (No of vehicles)	Queue (No of vehicles)
None: 0	Very Few: 0 to 3	Very Small: 0 to 2
Short: 1 to 3	Few: 4 to 7	Small: 3 to 4
Long: 4 to 6	Many: 8 and above	Large: 5 and above

2.9.1 Membership Functions

A membership function (MF) is a table that defines the degree to which an input value falls within a boundary or degree of membership.

2.10. Fuzzy Logic Rule List

The fuzzification of the input was done by a function evaluation, which represents an input variable with a MF value. An example of the rule of the ANFIS traffic controller is as follows:

IF Arrival is “Very Few” VF and Queue is “Very Small” VS, THEN Extension is “Short” S

IF Arrival is “Many” M and Queue is “Small” S, THEN Extension is “Long” L

IF Arrival is “Few” F and Queue is “Long” L, THEN Extension is “None” N

“Arrival” and “Queue” are the antecedents and “Extension” is the consequent.

The antecedents are the training data inputs while the consequents are the target output to an Artificial Neural Network (ANN). The “Arrival” and “Queue” data (in number of vehicles) together with the corresponding “Extension” data in seconds are first transformed into a fuzzy logic Rule Lists. The fuzzy logic rules are the then used to train an ANN object to form the ANFIS object. The trained ANFIS object is used to provide an appropriate “Extension” time based on the values of “Arrival” and “Queue”.

2.11. Simulation of the ANFIS Traffic Controller System

The ANFIS traffic light controller system was implemented in the MATLAB environment followed the graphical user interface (GUI) developed and associated MATLAB code were written to simulate the system. The GUI provided an option for simulating either the conventional Fixed Controller (FC) or the proposed ANFIS controller. In FC, the “GO” (green light) configured to: stay for 15 seconds; “STOP” (red light) stay for 13 seconds while “STAND BY” (amber light) stay for 2 seconds.

The GUI is an event-driven platform and it consists of the road lanes, sensors, sliders and vehicles. The slider for each lane can be used to set the traffic density. The maximum number of vehicles passing a lane was set to 6. At the start of the simulation, the North-South lanes were the main approach. The time of simulation, in seconds, can be set before the start of the simulation. At the end of a simulation, the values of performance parameters were displayed for evaluation. These parameters were described as follows:

1) Vehicles In: this is the number of vehicles entering the sensors area (back sensors)
2) Vehicles Out: number of vehicles passing the junction (front sensor)
3) Drive Time (secs.): this is the total time allowed for vehicles to drive pass a particular lane; that is “GO” time.
4) Wait Time (secs.): this is the total time vehicles on particular lanes are disallowed from driving; that is “STOP” time.
5) Arrival: the lanes that are given green light (“GO”)
6) Queue: the lanes that are given red light (“STOP”)
7) Extension Time: extension time of green light (in seconds)
8) CE: It should be low for a better performance and can be determined as proposed in [7]

$$cost\ efficiency = \left(\frac{number\ of\ vehicles\ in}{number\ of\ vehicles\ out}\right) \times \left(\frac{wait\ time}{drive\ time}\right) \quad (2)$$

Figure 2 is the simulated GUI of the ANFIS controller

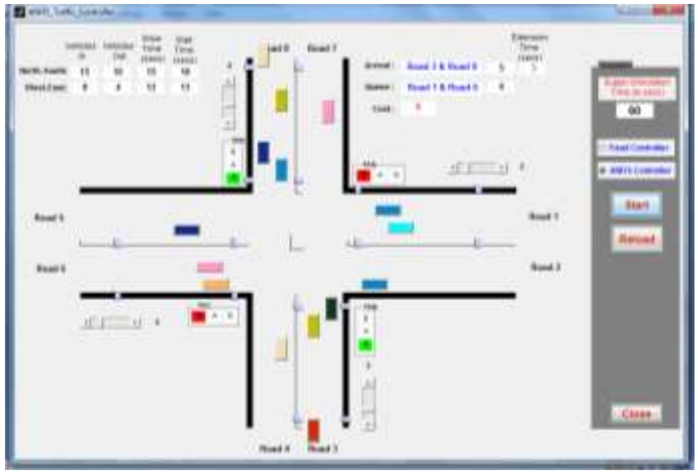

Fig. 2: Simulated GUI of the ANFIS controller

3. Results

Following a set of rules in which the number of vehicles at the arrival (Road 3 and Road 8) is high, and the number of vehicle at the queue (Road 1 and Road 6) is less as presented in Table II

TABLE II: Number of vehicle setting at the arrival and queue lanes using slide

Road Names	Nunmber of Vehicles
8	4
6	2
3	3
1	2

Therefore the total number of vehicles at the arrival (R3 and R8) is 7 and the numbers of vehicles at the queue (R6 and R1) is 4. With these set of rules in place, the drive time table is therefore presented in Table III.

Table III revealed that the number of drive time and the wait time of both the arrival (R3 and R8) lanes and the queue (R1 and R6) lanes using the FC system gave the same values while the drive time on (R3 and R8) with higher number of vehicle on the ANFIS controller system gave higher drive time compare to the queue (R1 and R6) lanes, this can be justified because the lanes with higher number of vehicle, approaching the junction was programmed to have more extension time, therefore they gain much drive time, while the lanes with less number of vehicle approaching the junction was programmed to have no extension time when priority granted them to drive.

Using the same setting in Table II, the result obtained for the waiting time of fixed delay controller and ANFIS controller is presented in Table IV. Table IV revealed that the wait time, irrespective of the number of vehicles on both the arrival and the queue lanes using the FC, the system gave the same wait time while the ANFIS controller system gave smaller wait time to the vehicles in the arrival (R3 and R8) lanes that contains higher number of vehicles compared to the queue (R1 and R6) lanes that contains lower number of vehicles. This is justified because the ANFIS controller has been trained to give lanes with higher number of vehicle to wait for smaller period of time as against the lanes with a fewer numbers of vehicles which have to wait a bit longer for the lanes with high number of vehicle to drive.

Table V is the Cost Efficiency (CE) table using the FC and ANFIS controller when the simulation period was considered in minutes. It can be observed from Table V that the ANFIS controller system is highly efficient, because the efficiency value generated from the simulation is lower compared to that of the FC system when subjected to the same condition.

TABLE III: Drive Time

Simulation Time (seconds)	Fixed Controller System (seconds)		ANFIS Controller System (Second)	
	N-S	W-E	N-S	W-E

60	30	30	38	26
120	60	60	77	51
180	90	90	117	74
240	120	120	161	94

TABLE IV: Wait Time

Simulation Time (seconds)	Fixed Controller System (seconds)		ANFIS Controller System (Second)	
	N-S	W-E	N-S	W-E
60	28	28	21	33
120	56	56	42	67
180	84	84	60	103
240	112	112	76	143

TABLE V: Cost Efficiency

Extension (Minutes)	Fixed Delay Controller System	ANFIS Controller System
30	0.7321	0.0619
60	0.4894	0.0401
90	0.3657	0.0192
120	0.0985	0.0067

4. Conclusion

The TLC system has been developed using the GUI tool of the MATLAB. All the necessary parameters such as the sensors, the TL and the cross-roads template were also incorporated into the system. The sliders were used in order to pre-set the traffic density on each arriving lanes, approaching the junction. Performance of the system was tested with the ANFIS controller and the FC using the performance metrics such as the drive time, the wait time and the CE. The system with ANFIS controller eliminated the problem of not considering the traffic density but a fixed delay period characterized by the FC based TLC system.

It was observed that the ANFIS control system provided better performance in terms of total waiting time as well as total driving time. Therefore it is imperative to say that the ANFIS system is not only highly efficient but also has successfully curbed the menace of traffic deadlock which has become a phenomenon on our roads as less waiting time for the vehicles on the most densely road lane will not only reduce the fuel consumption but also reduce the air and noise pollutions. The ANFIS controller is therefore recommended to the control engineers as an efficient and better controller for the TLCS at the roads junctions.

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