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NEW FUZZY LOGIC SYSTEM FOR CONTROLLING MULTIPLE TRAFFIC INTERSECTIONS WITH DYNAMIC PHASE SELECTION AND PEDESTRIAN CROSSING SIGNAL

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Abstract

The purpose of this paper was to demonstrate a distributed fuzzy inference system for controlling traffic lights signal from multiple intersections by selecting dynamic phase and controlling signals for pedestrian crossings. The controller adaptively adjusted the phase sequences and phase lengths to optimize the vehicle's movement to go straight or turn right and to arranged opportunities for pedestrians to cross the street. At each intersection, there was a fuzzy system that can communicate with other fuzzy systems in the connecting intersection. Each fuzzy system consisted of three main modules: The Green phase, red phase, and decision modules. A traffic intersection simulator was developed to test the performance of the fuzzy controller. The proposed method was compared to two other traffic light controllers: Preset-Cycle-Times (PCT) and Vehicle-Actuated (VA) controllers. The measured performance index is the average delay time of vehicles and pedestrians. The simulation results revealed better performance of the proposed controller compared to the PCT and VA controllers. However, in heavy traffic conditions, only a few improvements have been made. This finding indicates that the fuzzy controller provides better traffic control performance than the VA and PCT controller that allows vehicles and pedestrians to have shorter waiting time at the intersection that applies this fuzzy controller.

Keywords: Distributed controller, Dynamic phase selection, Fuzzy inference system, Multiple traffic intersection, Pedestrian signal control.

1. Introduction

Traffic congestion is very influential on the quality of life, environmental quality, road safety, and travel time [1]. The use of effective traffic signal controllers can be one way to reduce traffic congestion. Common traffic signal controllers are Preset Cycle Time (PCT) controller and Vehicle Actuated (VA) controllers [2]. In the PCT, the duration of the signal and length phases is made to be constant, while in the VA system, the duration of the green phase will be determined by checking whether there is still a vehicle on a link or the maximum green phase time has been reached. The presence of many traffic cops during the heavy traffic hours indicates that the common traffic signal controllers are still inadequate. Since the traffic flow usually contains uncertainty, fuzzy controllers can be an alternative to handle it because the fuzzy system has an advantage in dealing with uncertainty issues [3].

Researches on fuzzy logic applications on traffic light control have been widely conducted. Niittymaki and Pursula [4] reported that, based on the simulation results, the use of fuzzy logic controller can shorten the vehicle delay and lower stopping percentage of the vehicle. Lee and Lee-Kwang [5] proposed a fuzzy controller for multiple intersections. Each controller can interact with other nearby controllers. Khalid et al. [6] were continuing research conducted by Lee and Lee-Kwang [5] by testing the system of real data collected from real intersections. Lai et al. [7] proposed the use of the Adaptive Neural-Fuzzy Inference System (ANFIS) on the multilane-isolated intersection. They reported that the efficiency and performance of ANFIS controllers are better than fuzzy. Aria [8] proposed the use of type-2 fuzzy controllers to control traffic lights at several adjacent intersections and proved that their proposed controller is better than fuzzy type-1. Aria [9] proposed the use of a fuzzy system to dynamically control the phase of a traffic signal to optimize the vehicle to move either straight or turn right. Oianrewaju et al. [10] have discussed the integration of fuzzy systems in controlling traffic lights and signal lights for pedestrians to cross the street. However, the system was only applied in the case of a straight road and has not yet been applied in the case of crossroads. No previous research has particularly discussed the traffic lights with dynamic phase setting to optimize the vehicles for straight or right-turning movements that can be implemented to control multiple adjacent intersections and to control the signal lights for pedestrians to cross the street.

Based on the previous works [8, 9], the contribution of this paper was to propose a new architecture of Fuzzy Inference System (FIS) for complex traffic intersection control with dynamic phase setting to optimize the vehicles to move straight or turn right. FIS is also able to control signal light for the pedestrian to cross the street. The fuzzy system consists of three modules: green phase, red phase, and decision modules. The fuzzy system is installed at each intersection and can communicate with other fuzzy systems present at the neighbouring intersection. The proposed controller is then tested using a simulator and its performance is then compared to PCT and VA controllers.

2. Method

2.1. Vehicles and pedestrian detectors

To get information about the number of vehicles on a lane, two detectors were used: The rear detector that was placed on the back of the link and the front detector that was located near the intersection. These two detectors were used to count how many vehicles are in a lane. Meanwhile, to get information about pedestrians' waiting times to cross the street, a button called Push-to-Walk Button was employed. Pedestrians who want to cross must press the button first. The pedestrian waiting times were gained by measuring how long it has passed since the button was pressed.

Figure 1 shows the example of the location of the detectors and Push-to-Walk Button. It was assumed that the inside lane was for the right-turning vehicle. The outside is for the straight-moving vehicle.

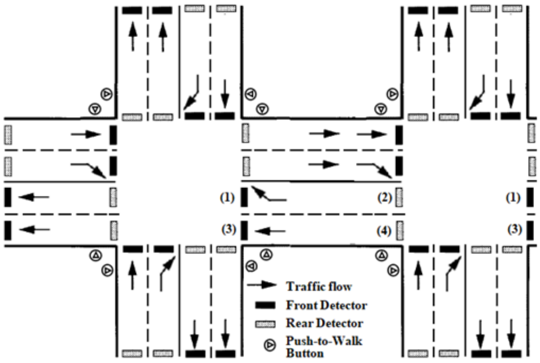

Fig. 1. Example location of the detector and push-to-walk button. (1) Front detector to detect a turning vehicle, (2) Rear detector to detect a turning vehicle, (3) Front detector to detect a straight vehicle and (4) Rear detector to detect a straight vehicle.

2.2. Controller overview

The controller features were to reduce the waiting time of the waiting vehicle (either going straight or turning), to avoid heavy traffic jams at the intersection, and to reduce the waiting time of the pedestrian to cross the street. The controller adjusted the phase length and phase sequence adaptively based on traffic conditions [11, 12]. As proposed by previous studies by Lee et al. [5], Khalid et al. [6], Aria [8, 9], the controller used three fuzzy modules namely green phase, red phase and decision module.

2.3. Green phase module

The green phase module calculates the urgency of the green phase to extend the time of this phase. The input is Pedestrian Waiting Time (PWT), Queue Num (QN), and Front Num (FN). The output is the Extend Degree of Phase (EDP). The definition of QN and FN is the same as that given by Lee and Lee-Kwang [5] and Aria [9]. PWT is time duration the pedestrians wait to cross. EDP is the level of urgency to extend the green phase.

If there is more than one traffic flow that has a green phase, this module evaluates the extend degree of each of these traffic flows. That Extend Degree is called Extend Degree of a Traffic Flow (EDT). The minimum value of all EDTs becomes EDP values of the phase.

Figure 2 shows the traffic phase from west to east and from east to west. EDT for each traffic flow was evaluated. For traffic from east to west QN (EW) is the number of vehicles waiting in the straight-going lanes of the east link, FN (W) is the number of vehicles waiting at the west link and PWT (E&W) is the length of time the pedestrians wait to cross both on east and west link.

Using green phase Module, we get EDT (EW) value. The same process is also applied to traffic from west to east, and we will get EDT (WE). The EDP of this phase is the minimum value of EDT (EW) and EDT (WE).

This module has 125 rules. Based on studies by Lai et al. [7] and Aria [8, 9], we developed a rule created by adding PWT input. Rules and examples from this module are shown in Table 1, and the fuzzy Membership Function (MF) of QN, FN, PWT, and EDT is shown in Fig. 3. The urgency of this phase will decrease if QN is small.

If there are many vehicles at the next intersection, it will make the urgency of this phase. It will decrease and reduce the number of vehicles that will enter the already crowded link. If pedestrians have waited long enough, it will make the urgency of this phase to stay green will decrease too.

Table 1. Rules examples of the green phase module.

Input variable			Output	Input variable			Output
QN	**FN**	**PWT**	**EDT**	**QN**	**FN**	**PWT**	**EDT**
Z	S	M	Z	Z	S	VL	Z
S	S	M	S	S	S	VL	S
M	S	M	M	M	S	VL	S
L	S	M	L	L	S	VL	S
VL	S	M	L	VL	S	VL	S
Z	L	M	Z	Z	VL	VL	Z
S	L	M	S	S	VL	VL	Z
M	L	M	S	M	VL	VL	Z
L	L	M	S	L	VL	VL	Z
VL	L	M	S	VL	VL	VL	Z

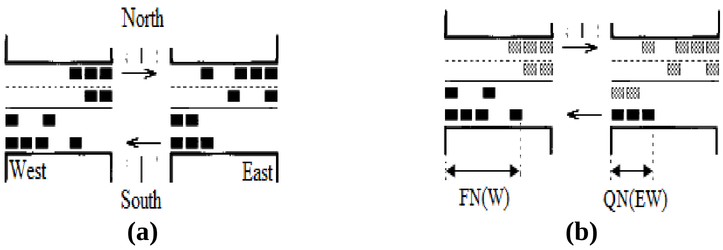

Fig. 2. QN and FN illustration for evaluation the traffic from east: (a) Traffic conditions and (b) QN and FN of the traffic from east to west.

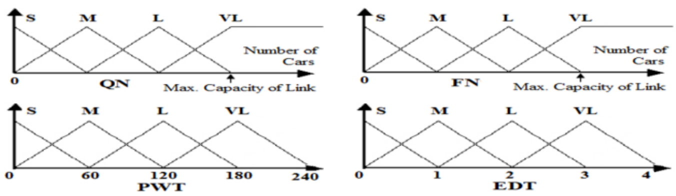

Fig. 3. Fuzzy MF of QN, FN, PWT and EDP.

2.4. Red phase module

This module calculated the Urgency Degree of a Phase (UDP) of all red phases to get green. UDP was obtained by evaluating the degree of urgency of all traffic flow associated with these phases. The Urgency Degree of a Traffic flow (UDT) represents the conditions of the traffic flows. The minimum value of all UDTs will be UDP value of these phases. The candidate for the next green phase is the phase with the highest UDP value. This module has four inputs: QN, FN, PWT and Red Time (RT). RT is the time duration of the vehicle waits because of a red signal.

The fuzzy rule of the red phase module is generated, in which, UDT will increase proportionately in accordance with the increase in QN and RT values. However, if the FN grows, UDT will decrease. Thus, it will reduce the number of vehicles entering the next intersection. PWT was also employed as input since the proposed fuzzy controller will select the next phase dynamically. It is possible that the selected phase will still prevent pedestrians from crossing. Thus, at such a phase, the red phase urgency will decrease as PWT values increase in that phase. Table 2 shows some examples of rules from this module.

The fuzzy MF of QN and FN in this module is the same as the fuzzy MF of QN and FN in the green phase module. The fuzzy MF of PWT and RT in the red phase module are the same as the fuzzy MF of PWT in the green phase module. And, the fuzzy MF of UDT in the red phase module is the same as the fuzzy MF of EDT in the green phase module.

Table 2. Rules examples of the red phase module.

Input variable				Output	Input variable				Output
QN	**FN**	**PWT**	**RT**	**UDT**	**QN**	**FN**	**PWT**	**RT**	**UDT**
Z	S	M	M	Z	Z	S	M	VL	Z
S	S	M	M	S	S	S	M	VL	L
M	S	M	M	M	M	S	M	VL	VL
L	S	M	M	L	L	S	M	VL	VL
VL	S	M	M	L	VL	S	M	VL	VL
Z	L	M	M	Z	Z	S	L	M	Z
S	L	M	M	S	S	S	L	M	S
M	L	M	M	S	M	S	L	M	S
L	L	M	M	S	L	S	L	M	S
VL	L	M	M	S	VL	S	L	M	M

2.5. Decision module

Input decision module is the output of the red phase module (UDP) and the green phase module (EDP). This module will make a decision either to change or extend the green signal. If UDP is higher than EDP, it means that traffic conditions for the next phase are heavier than the current green phase. Therefore, this module will give a green signal to the phase with the highest UDP value.

2.6. Signal phases proposal and schematic diagram of the controller

Basically, controlling traffic signals is a process to determine, which phase should be activated in the next cycle and how long it should take [5]. In the case of a four-way intersection, 16 alternative phases are possible to choose as shown in Fig. 4. To create a complete cycle of traffic signals, only a few phases were selected from the 16 phases so that all traffic flows have an opportunity to move forward. The fuzzy system will choose, which phase will be activated in one cycle adaptively, adjusting to existing road density conditions. Figure 5 shows an example of a schematic controller diagram if phase 1 in Fig. 4 is the green phase now.

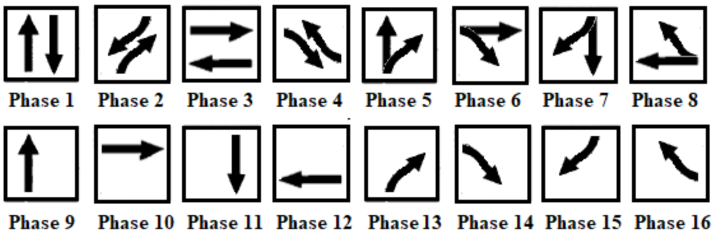

Fig. 4. Possible phases in a four-way intersection.

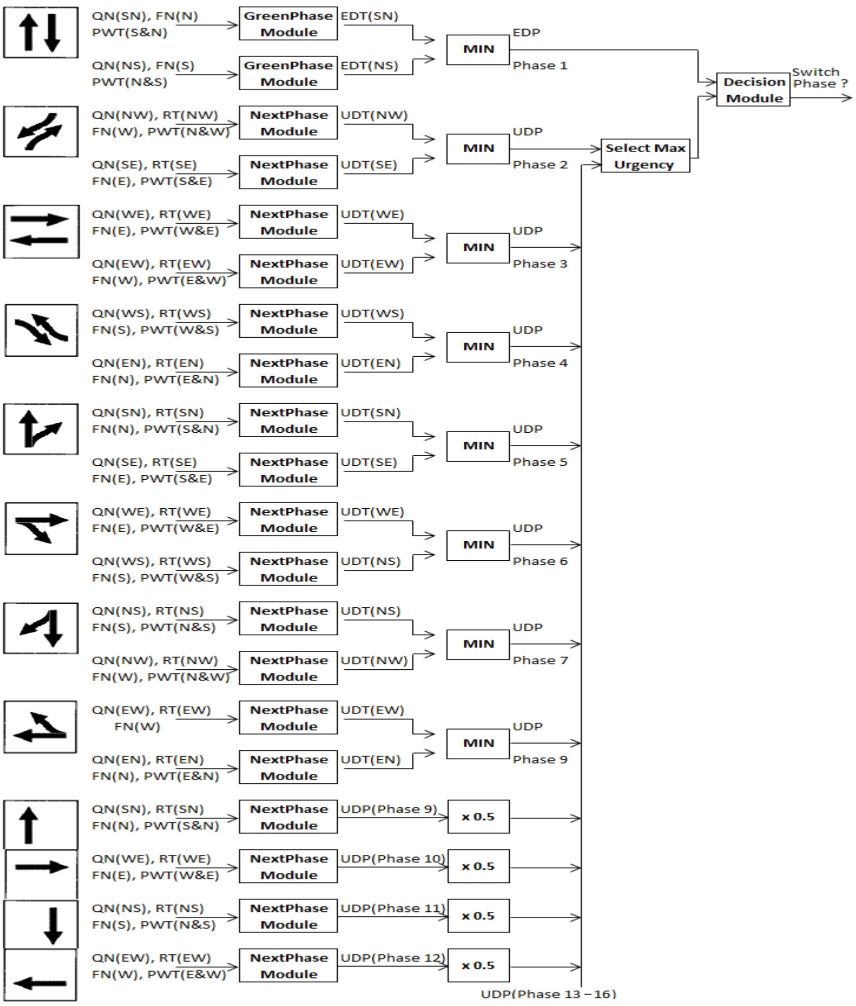

Fig. 5. Schematic diagram example of controller if green phase is phase 1 of Fig. 4.

3. Results and Discussion

3.1. Simulator

To test the proposed controller, a simulator consisting of nine intersections was developed. Every intersection was connected with other intersection in four directions. Each link had two directions. Meanwhile, the simulator had four input links: northern input link (top), south input link (bottom), eastern input link (right), and western input link (left). The vehicles and pedestrian were generated according to the plan provided from the input links entered into the links. In testing the simulator, the following assumptions were used:

- 30% of the number of vehicles on a link will turn right
- In addition to vehicles, there are also pedestrians crossing.
- For every intersection, the number of pedestrians generated on each link is 5 pedestrians /minute.

To generate traffic flow, the following car model proposed by General Motors Inc. was used [13]. In the model of implementation, the study employed the following conditions:

- The driver will react to the change in vehicle speed in front of it after a time gap called reaction time.
- The acceleration, speed, and position of the vehicle will be updated at certain time interval
- The speed and position of the vehicle is governed by Newton's laws of motion

The equations used are as follows:

$$v_n^t = v_n^{t-\Delta t} + a_n^{t-\Delta t} \times \Delta t \quad (1)$$

$$x_n^t = x_n^{t-\Delta t} + v_n^{t-\Delta t} \times \Delta t + \tfrac{1}{2} a_n^{t-\Delta t} \Delta t^2 \quad (2)$$

$$a_{n+1}^t = \left[\frac{\alpha_{l,m}\left(v_{n+1}^t\right)^m}{\left(x_n^{t-\Delta T} - x_{n+1}^{t-\Delta T}\right)^l}\right]\left(v_n^{t-\Delta T} - v_{n+1}^{t-\Delta T}\right) \quad (3)$$

where v is the vehicle velocity, x is movement distance, a is the vehicle acceleration, Δt is the time interval, ΔT is the reaction time, m is the speed exponent with intervals -2 to +2, l is the distance headway exponent with intervals from -1 to +4, and α is the sensitivity coefficient. The parameters are then calibrated using real data.

3.2. Simulation results and discussions

The proposed controller was compared to PCT Controller and VA Controller. The simulation was conducted in 9 traffic conditions:

- Cases that the traffics of all input links are the same:
  - 600 vehicles/hour
  - 700 vehicles/hour
  - 800 vehicles/hour
  - 900 vehicles/hour
  - 1000 vehicles/hour

  - 1100 vehicles/hour
- Cases where traffic conditions change every 20 minutes
  - Case with light traffic

    Table 3 shows the number of vehicles generated on each input link for light traffic conditions.
  - Cases with normal traffic

    Table 4 shows the number of vehicles generated on each input link for medium traffic conditions.
  - Cases with heavy traffic (vehicles/hour)

    Table 5 shows the number of vehicles generated on each input link for heavy traffic conditions.

Table 3. Case with light traffic conditions (vehicle/hour).

Time	0 - 20	20 - 40	40 - 60	60 - 80
North	700	700	700	700
West	600	600	500	600
East	500	500	600	500
South	700	700	700	400

Table 4. Case with medium traffic conditions (vehicle/hour).

Time	0 - 20	20 - 40	40 - 60	60 - 80
North	900	850	900	900
West	800	950	800	800
East	900	950	750	900
South	750	850	900	950

Table 5. Case with heavy traffic conditions (vehicle/hour).

Time	0 - 20	20 - 40	40 - 60	60 - 80
North	1100	1100	1100	1100
West	1000	1050	1000	1000
East	1100	1000	1050	1000
South	1000	1100	1100	1100

The measured performance index is the amount of the average delay time of the vehicles and the pedestrians. Tables 6 and 7 summarise the obtained simulation results. Each table displays the average delay time in seconds.

The proposed method has shown good performance in all cases. In steady traffic conditions, the proposed controller showed some improvements of average delay time from 3.50 to 8.60% through the VA controller and from 4.90 to 16.40% through the PCT controller. In time-varying conditions, improvement of average delay time from 3.90 to 7.90% was obtained through VA controller and from 5.70 to 12.40% through PCT controller. Only in heavy traffic conditions, the proposed method only showed a small improvement (3.50 - 5.70%). This indicates that the vehicles will wait with shorter waiting time at the intersection that applies the fuzzy controller.

From the findings, it can be concluded that the simulation results of the proposed fuzzy controller have shown better performance compared to those of the PCT and AV controllers in light and medium conditions. Previous reports also reported similar results regarding the superiority of fuzzy controllers compared to PCT and AV controllers [5, 6, 8, 9]. This is also in accordance with Shinde [14] who reported that the AV and PCT Controllers could cause unnecessary waiting times.

However, in intersections with heavy traffic conditions, only the proposed controller made a few improvements. This is because the number of vehicles has reached maximum capacity from intersections so that only a few possibilities for improvements can be made. Similar things were reported by Lee and Lee-Kwang [5] and Aria [8, 9]. Fuzzy controllers then will choose the most optimal phase from the 16 available phase options (as shown in Fig. 4) and its duration to minimize the waiting time of vehicles and pedestrians.

Table 6. Average delay time for case 1.

Case	Fuzzy controller	VA controller	PCT controller	Improvement than VA controller	Improvement than PCT controller
1*a*	44.9	49.1	53.7	8.4%	16.4%
1*b*	53.1	57.3	58.2	7.3%	8.8%
1*c*	61.1	66.4	68.8	8.0%	11.2%
1*d*	65.7	71.3	73.8	7.9%	11.0%
1*e*	90.4	94.4	95.1	4.2%	4.9%
1*f*	99.6	103.2	105.3	3.5%	5.4%

Table 7. Average delay time for case 2.

Case	Fuzzy controller	VA controller	PCT controller	Improvement than VA controller	Improvement than PCT controller
2*a*	49.0	53.2	54.6	7.9%	10.3%
2*b*	63.7	68.8	72.7	7.4%	12.4%
2*c*	94.9	98.8	100.6	3.9%	5.7%

4. Conclusions

This paper has proposed a fuzzy logic system traffic controller to control several adjacent intersections in optimizing the rate of the vehicle going straight or going right. In addition, this fuzzy controller also optimized the opportunity for pedestrians to cross. The controller not only managed local traffic but also worked with their neighbours from which, the controller gets information besides the detectors.

The simulation results in light and medium conditions revealed that the proposed controller showed better performance than the AV and PCT controllers. Data gained dealing with measured performance index showed that the proposed controller performed improvements of average delay time from 3.5% to 8.6% through the VA controller and from 4.9% to 16.4 % through the PCT controller in steady traffic conditions. In time-varying conditions, the improvement of average delay time is from 3.9 % to 7.9 % through VA controller and from 5.7% to 12.4% through the PCT controller. However, under heavy traffic conditions, the proposed controller showed only a small improvement.

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