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An Intelligent Fuzzy Logic Based Traffic Controller

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ABSTRACT

Increasing road congestion, travel time, number of accidents, carbon dioxide emissions, and fuel consumption are some of the consequences of growth in the vehicle population. Therefore, intelligent traffic controllers are required to solve road traffic congestion problems. The results of prevalent methods, including preset cycle time controller and vehicle-actuated controller, indicated that they do not effectively perform at traffic peak moments. Therefore, due to the deficiency of common methods, fuzzy logic based traffic signal controllers have attracted a lot of attention among researchers. In this article, a fuzzy logic based algorithm for 4-way intersections is proposed and it consists of two main stages for sorting the phase and determining the green light duration. The proposed system is simulated in the MATLAB programming environment and the performance of the designed controller and a conventional controller is compared for some of the presumed conditions. The results of applying the proposed system indicate that this algorithm has a better performance in different traffic conditions in contrast to a preset cycle time controller and it can reduce the number of vehicles behind traffic lights at intersections and the waiting time of passengers.

Keywords: Fuzzy logic, Fuzzy rule-based system, Traffic controller, Traffic phase sorting, Membership functions

Introduction

Many countries around the world have confronted with traffic congestion problems in the last decades. In traditional traffic signal controllers, the traffic lights change based on a preset time and a constant cycle time and do not have optimal performance for different conditions [1]. Hence, a considerable amount of time is wasted behind red signal of traffic lights. Therefore, drivers have to wait behind a red light while there is little or no cross traffic and this often makes them impatient or frustrated, which is very perilous and may cause more accidents. In general, traffic signal controllers work based on a pre-timed or vehicle-actuated mechanism. In a pre-timed controller (conventional), the phases of each traffic signal cycle are constant. Due to the simple operation of this type, its performance is not appropriate for heavy traffic. A vehicle-actuated controller works based on real-time conditions of traffic congestion using complete data of current condition obtained from detectors located at the intersection. Traffic flow can usually not be determined with certainty, therefore proposing an intelligent traffic controller would be a good alternative. Fuzzy logic has been shown to be a good solution for such situations [2]. The concept of fuzzy logic has been introduced by Zadeh [3] and it has shown many considerable results in solving engineering problems.
The structure of this paper is as follows. Section 2 provides a review of related works. Problem description and the proposed fuzzy control system are given in section 3. In section 4 the simulation of the proposed controller is presented. Section 5 discusses the research findings and compares the performance of traditional and proposed controllers for the defined conditions. Finally, section 6 concludes the article.

Literature Review

Fuzzy logic based traffic signal controllers have attracted a lot of attention among the researchers in the last decades. Mamdani and Pappis [4] proposed the most famous fuzzy logic based traffic light controller. They considered a two-way traffic junction where each way has a single lane and proposed their solution according to these conditions. To estimate traffic flows,

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they used vehicle loop detectors to collect traffic data. The gathered data were used to determine whether the regular time intervals were extended or the current phase of the traffic signal was terminated. Bisset and Kelsey [5] designed a traffic signal controller with two phases for a single intersection with one lane. Pursula and Niittymaki [6] considered a 4-way intersection and simulated their traffic signal controller. Trabia et al. [7] used some detectors located at the intersection to estimate traffic flow and queue length of vehicles and considered right and left turns to design the fuzzy based traffic controller. Niittymaki and Kikuchi [8] proposed a fuzzy logic controller to control the pedestrian movement on sidewalks. Their results showed that the fuzzy logic based controller has a better performance compared to the actuated controller. Chen [9] considered a freeway and studied the fuzzy controller. The results of their study showed that it reduces traffic congestion and the number of accidents. Chiu [10] studied the application of a fuzzy controller for multiple intersections and considered a two-way street without any left or right turns. Indrabayul et al. [11] observed Indonesia's most complex intersection for months using some cameras and designed an adaptive traffic signal controller. The results showed a substantial reduction in congestion.

Mohanaselvi et al. [12] considered an isolated four lane intersection and designed a fuzzy controller to manage the traffic flow. Motwakel et al. [13] proposed a fuzzy traffic controller by considering both vehicles and pedestrians. Mahmood et al. [14] proposed a two-stage fuzzy traffic controller and performed their proposed system using a SUMO traffic simulator. Collotta et al. [15] considered an isolated intersection and represented a new approach to manage the traffic signals and phases dynamically. Their proposed algorithm used wireless sensor networks to monitor the existing volume of traffic and after sorting the phases based on their priority, it used multiple fuzzy logic controllers to determine the run time of the green light for each phase and implemented the green light for all phases according to the specified order and time. It seems it will be a better solution to check the traffic condition at the intersection after each implementation of the green light for the most important phase, because the priority of the defined phases may be changed during the green light running. It means after the phase sorting stage, it would be more appropriate to specify the green time of just the most important phase and after the run time of the green light for the selected phase, check the traffic condition at the intersection again and perform phase sorting and green time determination based on the updated data. Therefore, in this article, we have considered a 4-way intersection with 2 lanes for each way. Right and left turns are allowed for north and south lanes. In the first stage, a phase selector is designed to determine the most important phase to be implemented and in the next stage, the required run time of the selected phase is calculated using a fuzzy logic controller. Finally, the proposed system is simulated in the MATLAB programming environment and the performance of the designed controller and a conventional controller is compared for some of the presumed conditions.

Proposed Fuzzy Control System

First of all, we want to explain the expressions and definitions that are used in the proposed control system. "Time Cycle" is used to refer to the time that is passing for a traffic light to turn all four routes ON or OFF. "Phase" is used to denote the allowed directions for a vehicle during a time cycle. "Queue" is used to denote the number of vehicles of a lane that are behind a red light. "Arrival" refers to the number of vehicles passing an intersection during a green light [16]. The number of traffic phases and the directions allowed for each phase can be defined arbitrarily. Hence, we considered 3 phases shown in Fig. 2.

Design criteria and constraints

- The intersection is isolated and traffic in the north, west, south and east directions is considered;
- The main approach is considered north-south direction;
- The vehicles in east and west directions are not allowed to turn left.

Figure 1 represents the proposed fuzzy control system. As can be seen, this system consists of two main stages called "Phase sorting" and "Green time duration". In the first stage, the phases are sorted based on the priority of the phases and the phase with the highest priority will be considered as the green phase. The second stage involves a fuzzy logic controller that specifies the green phase duration. The structure of this traffic signal controller is shown in Fig. 1. We also defined a parameter to prevent the excessive green phase prolonged. The control parameter which is used in this algorithm is T_{max} = maximum duration of green light for each phase.

The steps of the proposed system are as follows.

- Step 1: The detectors located at the intersection collect the input data of the control system.
- Step 2: The next green phase is specified based on the priority of each phase (fuzzy phase selector stage).
- Step 3: The fuzzy controller computes the duration of the green phase (Green time duration stage).
- Step 4: If the duration is more than T_{max}, the green light time is T_{max} , else the green light runs according to calculated duration.

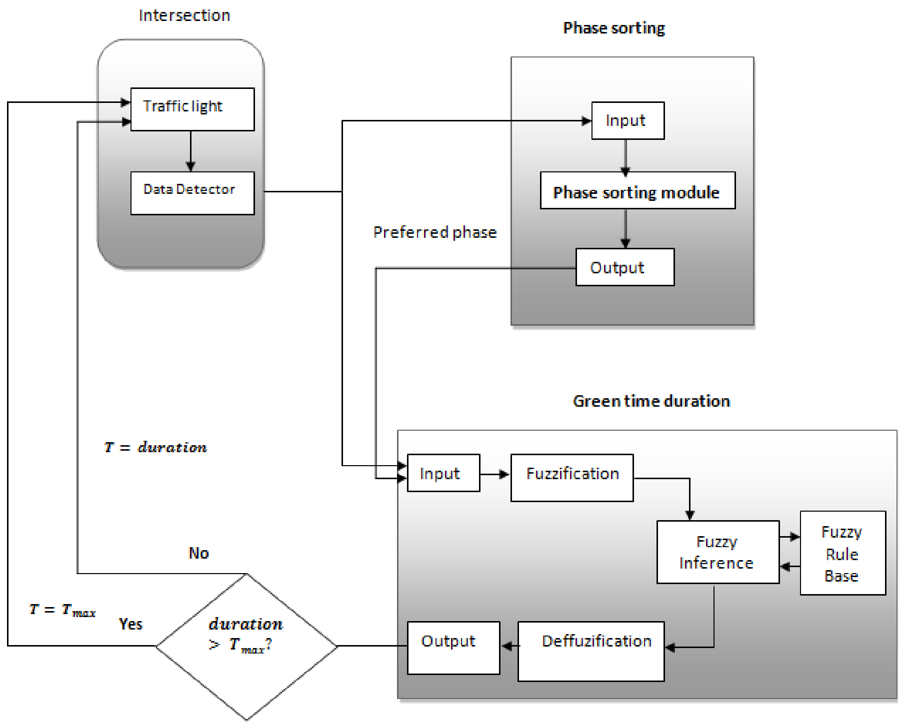

Figure 1. Structure of the proposed fuzzy control system.

Phase selector stage

In this stage, the priority of each defined phase is calculated based on the total number of waited vehicles behind the red light on the respective lanes, as shown in Equations (1) - (3). This stage is aimed to determine the most appropriate phase order to be implemented. The phases of the simulated intersection are illustrated in Fig. 2.

$$\text{Phase1\_priority} = \text{queue\_len}_{A1} + \text{queue\_len}_{C1} \quad (1)$$
$$\text{Phase2\_priority} = \text{queue\_len}_{B1} + \text{queue\_len}_{D1} \quad (2)$$
$$\text{Phase3\_priority} = \text{queue\_len}_{A2} + \text{queue\_len}_{C2} \quad (3)$$

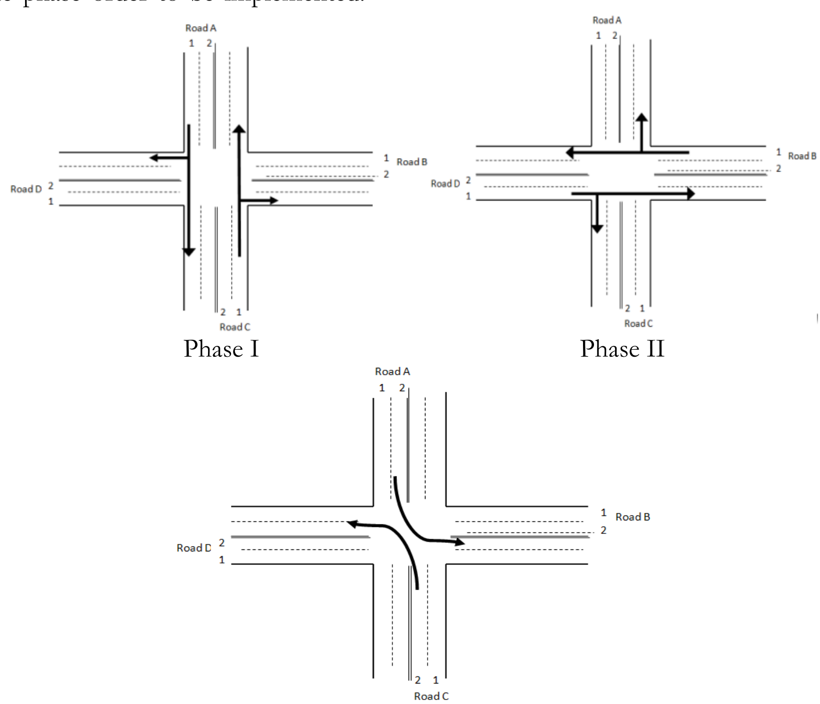

Figure 2. Traffic lights phases.

Green phase duration stage and fuzzy rule-based system

Since Fuzzy logic technology contains some concepts to handle uncertainties, it can be used to permit real-life rules to be implemented in a manner similar to human thinking. Thus, real conditions in traffic control often using fuzzy logic would be a suitable solution for this domain. Fuzzy logic uses imprecise data and linguistic statement in signal timing design. Also, fuzzy logic can convert 'If-Then' statements into a control algorithm.

In this stage, the signal control is a process that uses collected data by detectors for specifying the duration of the selected green phase based on a set of fuzzy rules. In this article 27 fuzzy rules have been defined based on the opinion of an expert as shown in Table 1. For example, the first rule states that if the length of arrival and both queues are small, the green phase time should be short.

Table 1
Fuzzy rules of green light duration.

Rule No.		Arrival length		Queue1 length		Queue2 length		Green phase time
1	IF	Small	AND	Small	AND	Small	Then	Short
2	IF	Small	AND	Small	AND	Medium	Then	Short
3	IF	Small	AND	Small	AND	Large	Then	Short
4	IF	Small	AND	Medium	AND	Small	Then	Short
5	IF	Small	AND	Medium	AND	Medium	Then	Short
6	IF	Small	AND	Medium	AND	Large	Then	Short
7	IF	Small	AND	Large	AND	Small	Then	Short
8	IF	Small	AND	Large	AND	Medium	Then	Short
9	IF	Small	AND	Large	AND	Large	Then	Short
10	IF	Medium	AND	Small	AND	Small	Then	Medium
11	IF	Medium	AND	Small	AND	Medium	Then	Medium
12	IF	Medium	AND	Small	AND	Large	Then	Medium
13	IF	Medium	AND	Medium	AND	Small	Then	Medium
14	IF	Medium	AND	Medium	AND	Medium	Then	Short
15	IF	Medium	AND	Medium	AND	Large	Then	Short
16	IF	Medium	AND	Large	AND	Small	Then	Medium
17	IF	Medium	AND	Large	AND	Medium	Then	Short
18	IF	Medium	AND	Large	AND	Large	Then	Short
19	IF	Large	AND	Small	AND	Small	Then	Long
20	IF	Large	AND	Small	AND	Medium	Then	Long
21	IF	Large	AND	Small	AND	Large	Then	Medium
22	IF	Large	AND	Medium	AND	Small	Then	Long
23	IF	Large	AND	Medium	AND	Medium	Then	Medium
24	IF	Large	AND	Medium	AND	Large	Then	Long
25	IF	Large	AND	Large	AND	Small	Then	Medium
26	IF	Large	AND	Large	AND	Medium	Then	Medium
27	IF	Large	AND	Large	AND	Large	Then	Medium

Simulation of the Proposed Fuzzy Traffic Controller

In this section, the simulation of the designed fuzzy controller is represented. First, the design steps are modeled and then the final output is compared to the output of a conventional traffic controller. As explained in the previous sections, the fuzzy logic controller is used to specify the green light duration. As shown in Figure 3, the three inputs of 'Green phase length', 'Length of queue1' and 'Length of queue2' have been connected to the inference machine to determine the green phase duration. The membership functions of inputs and output are shown in Figures 3 to 5. The rules are defined in Matlab according to Figure 6. Moreover, Figure 7 illustrates the output of some of the arbitrarily chosen inputs.

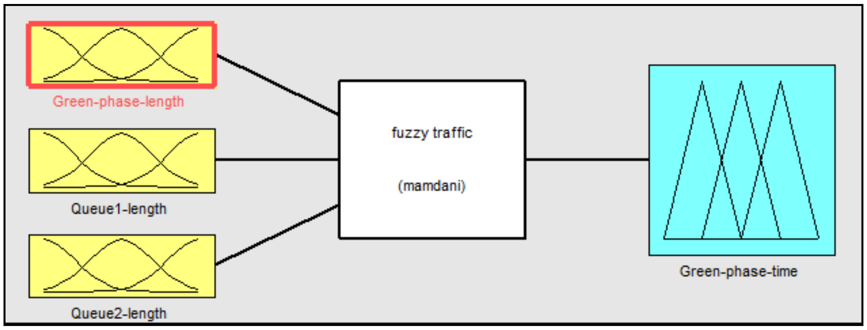

Figure 3. Structure of the fuzzy controller.

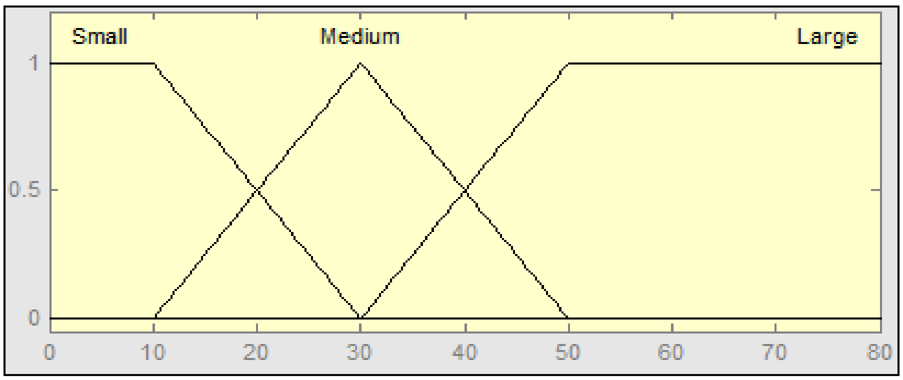

Figure 4. Membership functions for the number of vehicles (input variables).

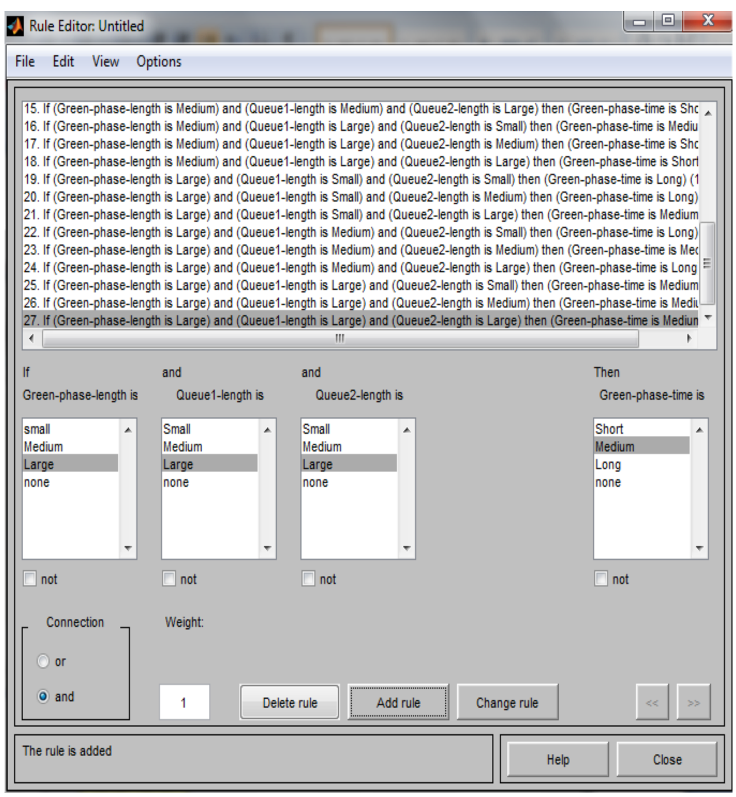

Figure 6. Rules definition in Matlab.

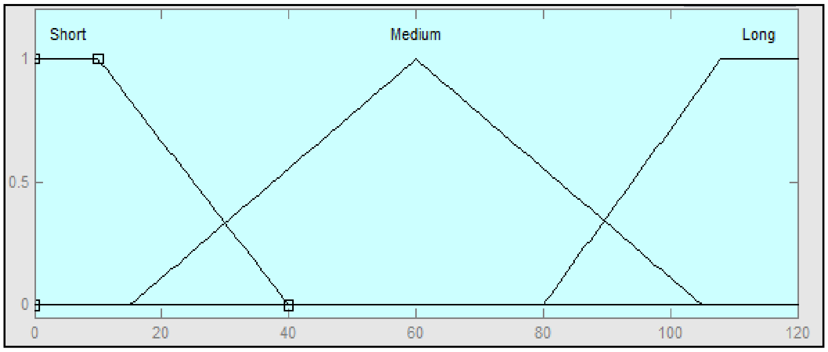

Figure 5. Membership functions for the green light duration (output variables).

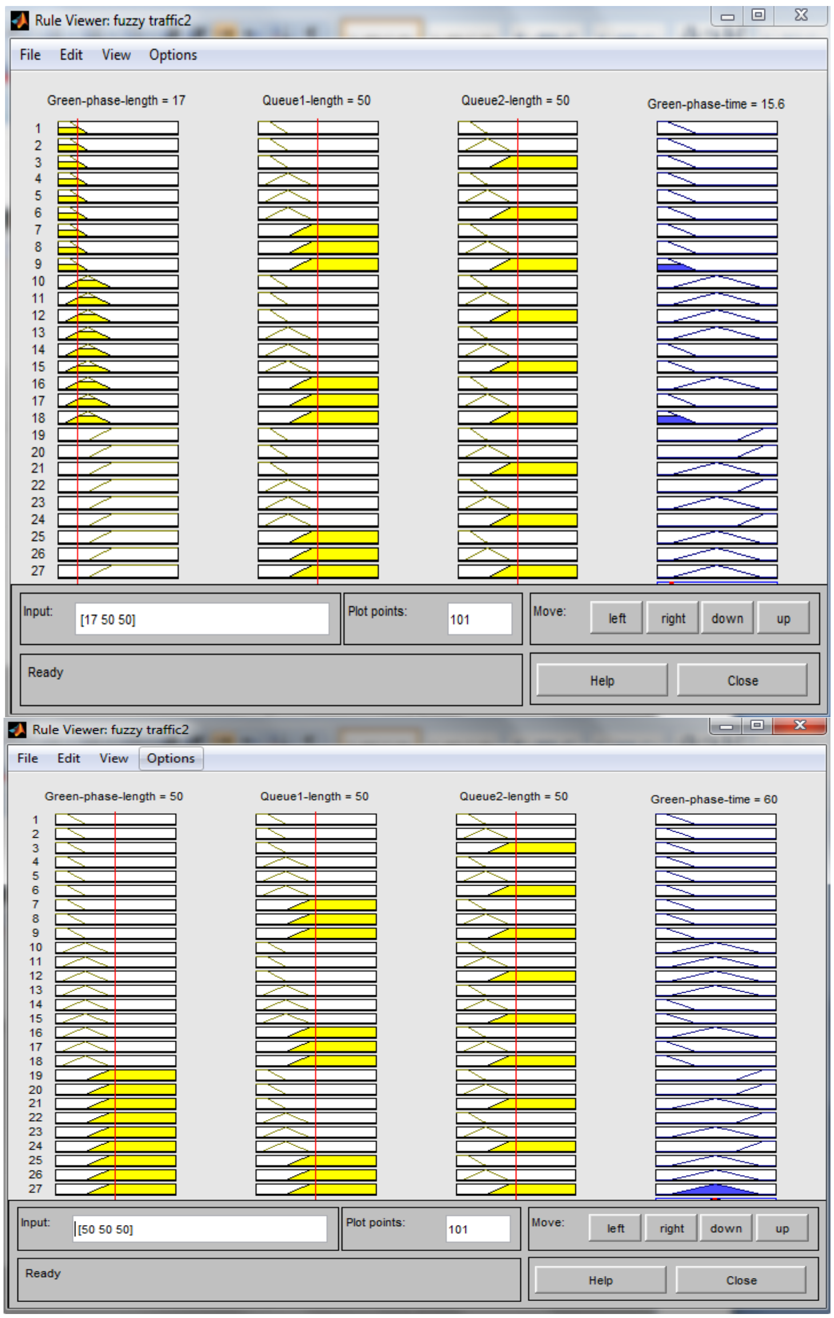

Figure 7. Difference output by changing the input.

Discussion

A conventional traffic light is assumed with a sequence of phases as (1,2,3) and each phase is implemented for about 70 seconds. The output of the proposed fuzzy traffic controller is counted according to Figure 6 and compared to the conventional (pre-set) output under different presumed situations, and the results are shown in Table 2.

Table 2
Comparison of a conventional (pre-set) and the fuzzy traffic controller.

Length (priority) of phase 1	Length (priority) of phase 2	Length (priority) of phase 3	Phase sequence in the conventional controller	Phase sequence in the fuzzy controller	First green light time in the conventional controller	First green light time in the fuzzy controller
12	10	7	1-2-3	1-2-3	70	16.8
12	7	10	1-2-3	1-3-2	70	16.8
48	20	30	1-2-3	1-3-2	70	70.8
14	20	33	1-2-3	3-2-1	70	58.8
23	16	33	1-2-3	3-1-2	70	57.6
28	53	68	1-2-3	3-2-1	70	60
19	64	7	1-2-3	2-1-3	70	104
22	83	47	1-2-3	2 -3-1	70	62.4
39	69	42	1-2-3	2 -1-3	70	75.6

According to Table 2, in conventional traffic controllers (pre-set), the phase sequences and the green time duration are constant in different traffic conditions. While the proposed fuzzy logic based controller can analyze the real-time traffic condition and can also make different decisions for different traffic conditions. As shown in Table 2, the proposed algorithm can select the most important phase and determine the required running time based on the existing traffic conditions. It is therefore clear that to manage and control the traffic congestion based on the real-time intersection conditions, the proposed fuzzy controller has a good and efficient performance and it can also reduce the waiting time and the number of vehicles behind a traffic light.

Conclusion

Traffic congestion has become a major concern in recent decades. To deal with this problem, it is important to design an intelligent traffic control system that can make decisions based on the real-time traffic flow conditions. Hence, we proposed a fuzzy control system for a full intersection with two-way streets and left-turn lanes, except for the east-west directions which are not allowed to turn left. The proposed system makes decisions based on real-time traffic information and fuzzy rules. The proposed fuzzy control system includes phase sorting and green phase duration stages. The phase sorting is performed by computing the priority of each phase and the duration of the green light specified using the designed fuzzy. In the pre-time controller, the green time is not specified according to the density of the cars at the junction. In the fuzzy logic controller, the duration is not constant for each situation. The computing of duration is performed according to the rule-based system in a manner of how a human would use. Finally, comparing the output of the fuzzy controller and a presumed conventional traffic controller indicated that the performance of fuzzy controller is more suitable for the different traffic congestion conditions. In future studies, it would be interesting to focus on data collection methods that can discern the emergencies and trying to manage these types of situations can be another research topic.

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