Fuzzy Control of Traffic Signals Accompanying Pedestrian Crossings

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Abstract: - In this paper, a fuzzy logic control system was constructed for controlling the green time length for a real single intersection with multiple lanes, turns, and two pedestrian crossings. Control of pedestrian crossingd was achieved by assigning pedestrian crossingd into related light phases, which were controlled by a fuzzy logic controller. An evolutionary algorithm was employed to generate the fuzzy logic rule base, using real statistical traffic data of the intersection. Simulation results showed that the fuzzy controller system performed better than a pre-cycle controller system which is currently used at the intersection.

Key-words: - Fuzzy logic, Time length, Light Phases, Pedestrian Crossings, Evolutionary Algorithms

1 Introduction

As the demands for transportation have increased over the last few decades, traffic lights were widely installed in intersections to improve efficiency of traffic flow and to avoid vehicle accidents. Due to the randomness and uncertainty of traffic flow, fuzzy logic controllers have been developed and applied to control of traffic lights.

A number of traffic controllers using fuzzy logic have been developed. Pappis and Mamdani [1] made the first attempt using fuzzy logic in traffic control for a single intersection after Zadeh [2] introduced the idea of fuzzy logic. They constructed a fuzzy controller for a one-way single intersection, and obtained shorter waiting time than that of traditional signal control using optimal loop time length. Chiu [3] developed fuzzy decision rules to adjust cycle time, phase split and offset for signal control and tested the model using a traffic flow simulation model. Kelsey and Bisset [4] simulated an isolated north-south and east-west intersection using a fuzzy logic controller and a pre-timed controller. In their simulation, two-phase signal and turning movements were considered. Kim [5] presented a fuzzy controller considering turning phases at an isolated intersection by taking into account possible blockage in heavy traffic conditions. Nittymaki et al. [6] developed a pedestrian crossing controller for a two-way two-lane vehicle roadway.

Some fuzzy controllers have been developed based on an assumed traffic intersection and traffic data. The reality is that the development of such controllers should be used on real traffic data. Most real complex intersections have multiple lanes, turns, and pedestrian crossings and these factors will have a direct bearing on the performance of the fuzzy controller.

This paper presents a fuzzy control system for a real traffic intersection that consists of five approaches, 14 lanes including 6 turns, and two two-way pedestrian crossings near the Stockland Shopping Fair, North Rockhampton. These lanes were divided into 10 groups controlled by 10 independent traffic lights, which were further arranged into 7 lane phases. The two pedestrian crossings were grouped into the 4 related lane phases. The minimum green times (walking times) for a pedestrian were considered as constraints to the traffic green time length. A fuzzy controller is used to generate green time for each light phase. This controller is learnt using an evolutionary algorithm from a simulation of the traffic based on real statistic data for the intersection. A comparison is made between the proposed fuzzy controller and the precycle controller which is currently serving in the intersection.

2 Traffic Signal Control

The considered intersection shown in Figure 1, has 2 pedestrian crossings, 14 lanes, in which 7 lanes are straight lanes, 6 lanes are turns, and one lane is both a straight lane and turn. These 14 lanes and 2 pedestrian crossings are arranged in 10 groups controlled by 10 traffic lights. Table 1 lists the lane group and corresponding lights. As lane 2 is both a straight and turning lane, the first three lanes are controlled by light one. Lights 2, 4, 6, and 8 control turning lanes. Lights 3, 5, and 7 control straight lanes.

Lights 9 and 10 control the two pedestrian crossings.

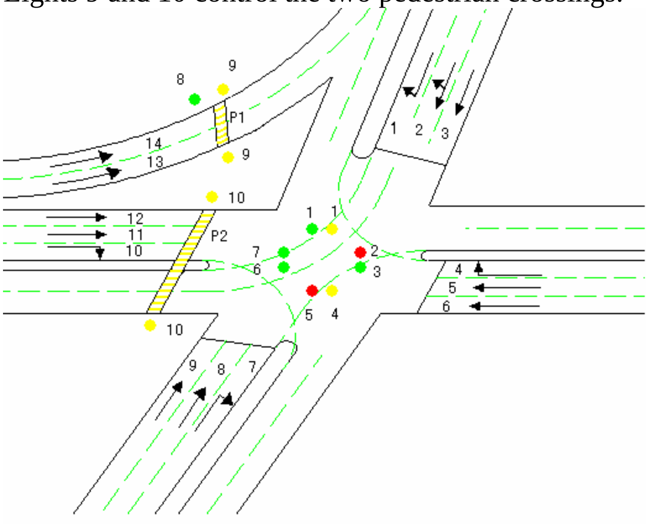


Figure 1 Intersection layout

Table 1 Lane groups and corresponding lights

Group No	Light No	Lanes	Group No	Light No	Lanes
1	1	1,2,3	6	6	10
2	2	4	7	7	11,12
3	3	5,6	8	8	13,14
4	4	7	9	9	P1
5	5	8,9	10	10	P2

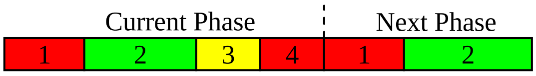
The fuzzy traffic light system is controlled in light phases. 7 light phases with maximum compatible lanes are arranged as listed in Table 2. The 7 light phases cover all 10 sets of traffic lights. The first three phases consist of only vehicle lanes, and the last four phases include vehicle lanes and the pedestrian crossings.

Table 2 Light phases and lane groups

Phase No.	Lights	Lanes	Late Start(s)	All Red (s)
1	3,7,8	5,6,11--14	2	2.5
2	6,7,8	10,11--14	2	2.5
3	1,8	1,2,3,13,14	3	2.5
4	2,3,9	4,5,6,P1	3	2.5
5	4,8,10	7,13,14,P2	0	2.5
6	4,5,9,10	2,6,P1,P2	0	3.5
7	7,8,9,10	4,10,P1	3	2.5

The fuzzy controller employs a competitive phase sequencing method. Once the green light of current phase finishes, the controller will take the phase that has the maximum number of waiting vehicles as the next phase.

Time sequences of each light phase are arranged as late start, green, yellow, and all red as shown in Figure 2 [7]. Late start and all red are arranged for clearing safety at the red light. The late start and all red time for each phase are listed in Table 2. During late start, all lights are red except the lights that are green in both last phase and the current phase. At the beginning of the green phase, the controller will turn on all green lights and calculate the green light time length using the fuzzy controller. Once the green light finishes, the controller will determine the phase that has the maximum number of waiting vehicles as the next phase. If the next phase is still the current phase, the light state remains unchanged, and the controller continues determining the next phase. Once a different phase from the current phase is determined, the yellow lights turn on. If a green light in the current phase is still a green light in the next phase, the green light will stay green all the way from the yellow light of the current phase to end of green light of the next phase. After 5 seconds of yellow light, all the yellow lights will turn red. After all red and late start, the green lights of the next phase will commence.



1: Late Start, 2: Green, 3: Yellow, 4: All red

Figure 2 Time sequences of a light phase

3 Traffic and Pedestrian Simulation

Traffic and pedestrian simulation models are needed for the simulation of the traffic intersection data.

All vehicles in the front of red lights, and vehicles which can't safely stop behind the stop line when the yellow light turns on, have to decelerate and stop. This group of vehicles is simulated by the deceleration model developed in this study

$$a(t) = \begin{cases} 0.2(v_{free} - v(t)), & \Delta x(t) > d_{sa}(t), \\ 0, & d_{sa}(t) \geq \Delta x(t) > d_{sb}(t), \\ -4.5, & \Delta x(t) \leq d_{sb}(t), \end{cases} \quad (1)$$

in which all the distances are defined as

$$\begin{aligned} \Delta x(t) &= x_f(t) - x(t), \\ d_{sb}(t) &= 1 + \tfrac{1}{7}(v^2(t) - v_f^2(t)), \\ d_{sa}(t) &= 1.5 + 2\max(d_{sb}(t),\ 0). \end{aligned} \quad (2)$$

In this model, movement of a vehicle is dependent on the vehicle immediately in front. The vehicle will accelerate if the distance Δx between the two vehicles is longer than the safe acceleration distance d_{sa}; the vehicle will keep its original speed if the distance is shorter than the safe acceleration distance but longer than the safe break distance d_{sb}; the vehicle will decelerate if the distance is shorter than the safe break distance. In this study, the breaking acceleration is assumed a constant value of 4.5 for simplicity. After the acceleration is determined, the velocity and position of the vehicle can be calculated forward using

Equations

$$v(t+\Delta t) = v(t) + a(t)\Delta t\,, \quad (3)$$

$$x(t+\Delta t) = x(t) + v(t)\Delta t + \tfrac{1}{2} a(t)\Delta t^2\,, \quad (4)$$

When the vehicle velocity decreases, two adjacent vehicles become very close. The velocity of the following vehicle is mainly dependent on the velocity of the front vehicle. To mimic reality, another relation is assumed,

$$\begin{aligned} &v(t+\Delta t) = v_f(t),\ a(t)=0, && \text{if } \Delta x \le 1.0\text{m},\ v(t) < 0.2\text{m/s}, \\ & && \text{and } v(t) < 0.2\text{m/s}, \\ &v(t) = 0, && \text{if } v(t) < 0. \end{aligned} \quad (5)$$

Thus, all the vehicles in the queue keep a spacing of about 1 metre.

Vehicles in the front of green lights, and vehicles which can safely pass the stop line when the yellow light is on, will accelerate to speed-limit of the road. This group of vehicles is simulated using the acceleration model developed in this study. The accelerating vehicles can be divided into two groups according to their movement state. The first group is the front waiting vehicles characterized by $v(t) \le v_f(t)$. This group of vehicles accelerates one vehicle after another. The second group of vehicles characterized by $v(t) > v_f(t)$, is the later approaching vehicles coming forward with high speed behind the first group of vehicles.

Movement of the first group of vehicles is simulated by

$$a(t) = \begin{cases} 0, & \Delta x(t) < 3.7\text{m and } v(t) < 2\text{ m/s}, \\ 0.2(v_{free} - v(t)) - \exp(12.4 - 22.4\Delta x(t)/d_{sca}(t)), & \text{other wise} \end{cases} \quad (6)$$

where the the safe clearance d_{sca} is determined from testing data as

$$d_{sca}(t) = 3.7 + 0.1v(t)\,, \quad (7)$$

After the acceleration of the vehicle is determined, its velocity and location can calculated using Eq.(3) and (4).

The second group of vehicles is simulated by the deceleration model until $v(t) \le v_f(t)$ condition is met.

A pedestrian is simulated by constant speed movement. When the pedestrian green lights are on, a pedestrian will move at a constant speed of 3m/s. When the pedestrian red light is on, or there is no enough time left to pass when the yellow lights turn on, the pedestrian will stop and wait in the front of the lights.

4 Fuzzy Controller

A fuzzy logic traffic controller having two inputs and one output, comprising twenty five fuzzy rules, is used to adjust the green light duration. Once the green lights of a given phase are on, the controller will calculate the green light duration. The first input is the maximum queue length among the lanes of the current phase. The second input is the maximum queue length among the lanes in the other phases. The output is the green light duration of the current phase. The two input variables use the same fuzzy sets, with linguistic values - very low, low, medium, high, and very high, and the same membership functions describing the densities of the two phases as shown in Figure 3. As the maximum number of vehicles capable of detection by the sensors is twenty, the maximum value of the input variable is 20. The output variable used another five fuzzy sets, with linguistic values - very short, short, medium, long, very long, and with membership functions describing green phases duration as shown in Figure 4. From the road test and simulation [8], the time for 20 waiting vehicles passing through a stop line is 34.7 seconds. So, the maximum value of output variable is set to 35 seconds.

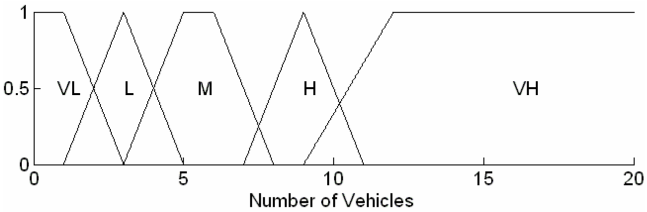


Figure 3 Input member functions

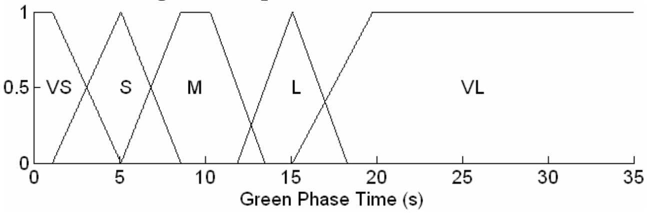


Figure 4 Output member functions

Two inputs of the fuzzy controller do not consider the pedestrian calls. But green light duration is subjected to minimum duration constraints. If the current light phase has P1 calls, the minimum green light duration is 6 seconds, if it has P2, or P1 and P2 calls, the minimum green light duration is 10 seconds.

The fuzzy rule base used for the traffic light fuzzy controller will be taken as the best rule base found by an evolutionary algorithm using the test data.

5 Fitness Function and Evolutionary Algorithm

To evaluate the best fuzzy rule base, a fitness function is defined as the following to characterize performance of the fuzzy controller

$$Fitness = T_{mw} = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=0}^{T}\Delta T_w^{ij}\,. \quad (8)$$

It is the averaged waiting time over the whole simulation time T and all vehicles. The waiting time is defined as

$$\Delta T_w = \begin{cases} \frac{v_{\text{limit}} - v(t)}{v_{\text{limit}}}\Delta t, & v(t) < 0.8 v_{\text{limit}}, \\ 0, & v(t) \geq 0.8 v_{\text{limit}}, \end{cases} \quad (9)$$

in which the waiting time during deceleration is considered.

In using the evolutionary algorithm, it is necessary to encode the fuzzy rule base as an individual in the population. By numbering the output fuzzy sets, very short, short, medium, long, and very long by integers 1, 2, 3, 4 and 5 respectively, a rule base can be encoded as an individual which a linear string of integers of length 25.

The architecture of algorithm for this study is shown in Figure 5. Given two initial individuals whose corresponding entries in the rule bases are generated randomly, one point crossover is used to generate 500 individuals. Then 4% of the individuals are randomly chosen to take mutation at one random point. At the mutation point, the corresponding element in the string is set to a random integer in the range 1 to 5. During the traffic simulation, the fitness of each individual is calculated. Based on the fitness, two new individuals are selected to generate the new population by crossover and mutation using the same procedure that was used to generate the initial population. These two individuals are chosen to be the best individual and the next best individual based on ranking of the fitness function. After repeating the procedure for 50 generations, the individual with the best fitness value is obtained as the best rule base.

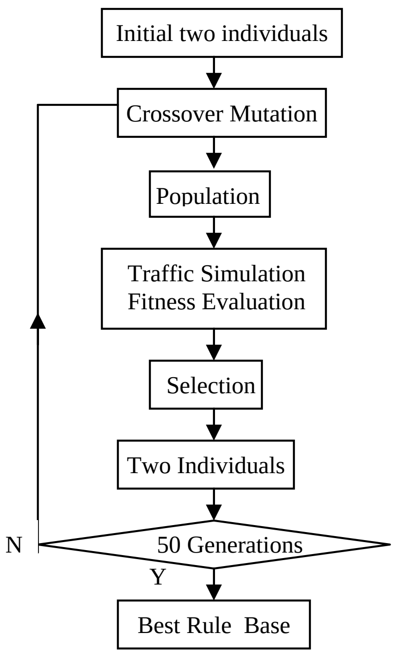


Figure 5 Architecture of fuzzy rule base generator

6 Simulation Results

Traffic simulations are carried out using two light controllers. The first is the precycle controller that is currently being used the Department of Main Roads at the intersection. The second is the fuzzy controller developed above. The first controller has four phases (A, B, C, and D) as listed in Table 3. The sequence is fixed as A, B, C and D. Phase C has three different choices depending on certain conditions. The green light duration for each phase is fixed at 20 seconds.

Table 3 Four pre-cycle light phases

Phase	Light No.	Lane
A	1, 8	1,2,3,13,14
B	4, 5	7,8,9
C_0	2, 6	4,10
C_1	2, 3	4,5,6
C_2	6, 7, 8	10--14
D	7, 8	11--14

The real statistic vehicle data of the intersection was provided by the Queensland Department of Main Roads. The total traffic volume shown in Figure 6. The traffic has two peak hour periods at 9am and 5pm and trough hour at 4 am. The maximum and minimum traffic density are about 3000 and 100 vehicles/hour.

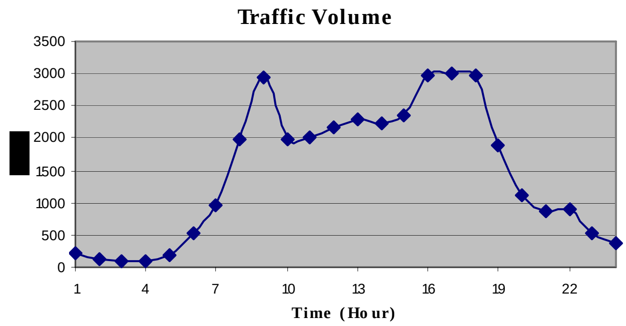


Figure 6 Traffic volume against time

The time average queue lengths over the 14 lanes of the intersection are shown in Figure 7. The time variations in queue length for the two controllers have the same shape as that of the traffic volume shown in Figure 6. When traffic density is low, the queue lengths are shorter. When traffic density is high, the queue lengths are longer. The average queue length of the fuzzy controller is much shorter than that of the precycle controller. At the peak hour of 9 am, these queue lengths for the two controllers are 1.5 and 2.5, respectively.

The average waiting time for each hour is shown in Figure 8. The waiting time for the fuzzy controller is shorter than that for the precycle controller throughout the whole day. At peak hours, the average waiting time for the fuzzy controller are 20 and 21 seconds, which are nearly half of that for the precycle controller (38 and 37 seconds). During non-peak hours, the fuzzy controller has further better performance. For example, the waiting time at 1am is 5 second, which is five times shorter than that of the precycle controller (32 seconds).

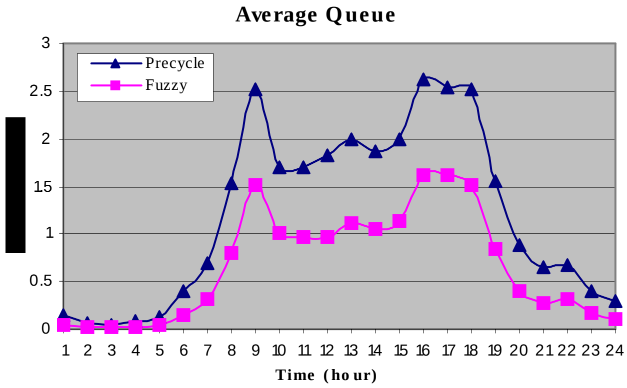


Figure 7 Average queues for two controllers

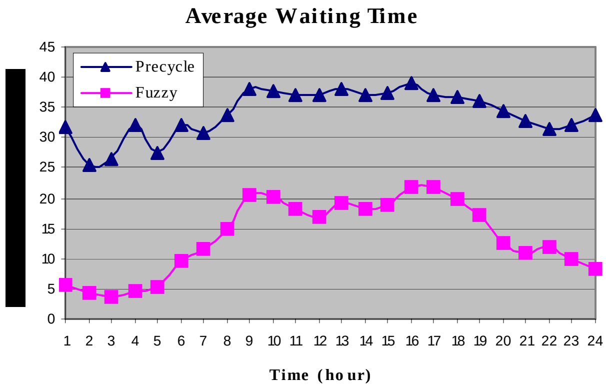


Figure 8 Average waiting for two controllers

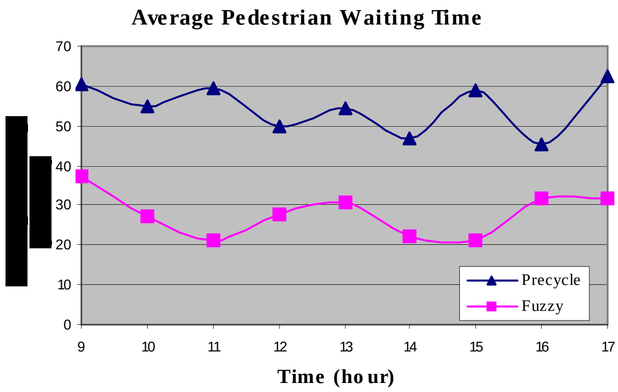


Figure 9 Average pedestrian waiting time for two controllers

The average pedestrian waiting times for the two controllers are shown in Figure 9. Similar to the results found from vehicle waiting time, the pedestrian waiting time for the fuzzy controller is shorter than that for the precycle controller. During non-peak hours, the average waiting time for fuzzy controller is around half of that for the precycle controller.

7 Conclusions

In this paper, a fuzzy traffic light controller was developed for a real intersection. Traffic simulation was carried out using vehicle acceleration and deceleration movement models developed in this study. The fuzzy controller was chosen as the best fuzzy rule base learnt by evolutionary algorithm using real statistic data of the intersection for performance evaluation.

From simulation results, it was found that the developed fuzzy controller had better performance than the precycle controller which is currently employed to control traffic at the intersection. It produces shorter average queue length than that of precycle controller, and about half of the average waiting time for the precycle controller for both vehicle and pedestrian traffic.

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