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Intelligent Intersection Management using Fuzzy Logic control and PI control

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Abstract

Traffic congestion is one of the leading causes of loss of productivity and low living standards in urban areas. The effectiveness of transport systems is a priority for modern society. The regions with the highest traffic density in cities are those with traffic intersections. Intelligent traffic light applications reduce waiting time in traffic. Therefore, as these practices become widespread in big cities, quality of life increases. Therefore, control of traffic lights in these areas is a crucial factor in reducing traffic congestion. In this study, a single intersection simulation environment is made by using Simulation of Urban MObility (SUMO) program. Fuzzy logic control based and Proportional Integral (PI) type control based traffic light controllers are designed for controlling a basic road junction. Simulations for the designed controllers and conventional traffic light controllers are performed and the results are compared.

Keywords: Fuzzy Logic, Intelligent Intersection Management, Intelligent Transportation Systems, Traffic Light Controller (TLC) .

1. Introduction

With the development of technology, the development and advancement of transportation technology is inevitable (Kumar, Albert and Deeter, 2005). With the development of science and technology, Intelligent Transportation Systems (ITS) have been developed to reduce people's thinking or decision-making responsibility by providing innovative services such as high technology, traffic control and different modes of transport (Ezell, 2010). Technological advances have enabled transport systems to collect unprecedented amounts of data. With the help of such data, the development of intelligent transportation systems is increasing rapidly.

Intelligent Transportation Systems (ITS) can be called as systems consisting of technologies such as electronic, data processing and wireless networks that provide a level of security and efficiency in the transportation network. ITS enable communication and exchange of information between each unit of transportation. These units can be centers that provide control of people, vehicles, infrastructure and transportation. As the development process of ITS systems continues, it is thought that the expectations and benefits of these systems may change over time or focus on different areas.

ITS based on Multi Agent technologies has become an important approach to solve complex transportation problems (Deakin, 2003). Structurally dispersed nature of components in heterogeneous environments causes application difficulties, such as interoperability between agents forming a demand for a unified software platform as an underlying infrastructure. Therefore, it is preferable to use centralized solutions for relatively simple problems such as the one considered in this paper. For both transport decision makers and drivers, ITS have a great potential for efficient and intelligent traffic management, threat identification, driving comfort and safety (Wang, Ren and Li, 2010). ITS can also provide a flexible approach for effective management of complex networked transportation systems letting traffic management decision-makers to control signal changes, regulate route flows, and broadcast real-time traffic information. As much as route scheduling, weather forecasting, emergency services, etc. for drivers, ITS can also facilitate reducing driving loads and improve safety.

ITS implementation can produce positive results in many areas, from environmental issues to national security issues, from emergency management to transportation. ITS applications can reduce time spent on the road. Short travel times provide economical savings for both individual and commercial vehicles, and usually mean less environmental pollution. Intelligent Intersection Management (IIM) technology has started to develop in traffic intersections as part of Traffic Light Control (TLC) systems.

Traffic light control is an important way to reduce traffic congestion. In this study, Webster proposed the optimal traffic light cycle length to minimize waiting times for vehicles at the traffic junction (Webster, 1958). There are basically two types of Traffic Light Control (TLC) methods. The first is the periodic change of traffic lights at predetermined times. The second method is to change traffic lights automatically according to the data from the sensors. Most traffic intersection signal controllers are of the fixed cycle type (conventional), ie there are constant green / red phase times for each traffic signal cycle. Implementation of this method is very simple. However, it usually results in poor performance. With the development of technology, intelligent controllers started to be used instead of fixed-time traffic light control systems (De Schutter and De Moor, 1998; Wiering, 2000; Wiering *et al.*, 2004; Tubaishat, Shang and Shi, 2007). Because they have many advantages, intelligent traffic lights can offer undeniable benefits, especially in metropolitan areas. In particular, fuzzy control technique was widely used in many applications on traffic light control after Zadeh described the theory of indefinite sets in 1965 (Zadeh, 1965), (Pappis and Mamdani, 1977; Favilla, Machion and Gomide, 1993; Kim, 1997)(Kulkarni and Waingankar, 2007)(Trabia, Kaseko and Ande, 1999).

Pappis and Mamdani presented a Fuzzy Logic Control (FLC) at the traffic intersection of two one-way streets (Pappis and Mamdani, 1977). The FLC obtains an output based on the three inputs. Fuzzy input variables, elapsed time of the current interval, number of vehicles passing through the junction at green light, and number of vehicles waiting at red light. The green phase duration calculated using FLC is fuzzy output. Five rules were used for each ten-second intervals. Favilla et al. proposed a FLC with adaptive strategies (Favilla, Machion and Gomide, 1993). The FLC adjusts the membership functions according to traffic conditions to optimize the performance of the control function. There are statistical and fuzzy adaptation strategies. The FLC determines the green phase and red phase duration. In this study, Traffic light control was performed by using fuzzy logic and PI control methods and their performances were compared. (Tunc and Söylemez, 2019).

In this paper, Fuzzy Logic Control simulation is performed to control the timing (green / red) of traffic light phases.

In addition, the simulation (green / red) of the timing control of traffic light phases was performed using a Proportional Integral (PI) based control method, a conventional control method in control engineering. The simulation of these two methods are performed using Simulation of Urban MObility (SUMO) and the results were compared. A simulation environment is created using SUMO. The SUMO program is an open source, highly portable, microscopic road traffic simulation package designed to handle large road networks (Centre for Applied Informatics (ZAIK) and the Institute of Transport Research at the German Aerospace Centre: Simulation of urban mobility - sumo website., 2019).

This paper is organized as follows. First, an overview of the traffic light control system is presented and the characteristics and limitations of the generated simulation environment are outlined. Then, features and operating principles of FLC and PI type controllers and traffic light controllers are explained. Then, the simulation results of the fuzzy traffic light controller and the PI type traffic light controller are shown comparatively. Finally, simulation results are discussed in the conclusion section.

2. Traffic Light Control System

The general structure of the simulation environment of the traffic light control system controlled by the Traffic intersection agent method is shown as in Figure 1(a). There are two detectors placed on the road for each strip. The detectors in each lane are used to determine the number of vehicles in the lane. The traffic light controller is responsible for controlling the duration of the green or red status of the traffic lights at the intersection according to the traffic conditions. The optimum cycle time was calculated by Webster's method. As the traffic density increases in the simulation, the optimum cycle time can exceed 120 seconds. Cycle time selected to 120 seconds to minimize delay and driver frustration.

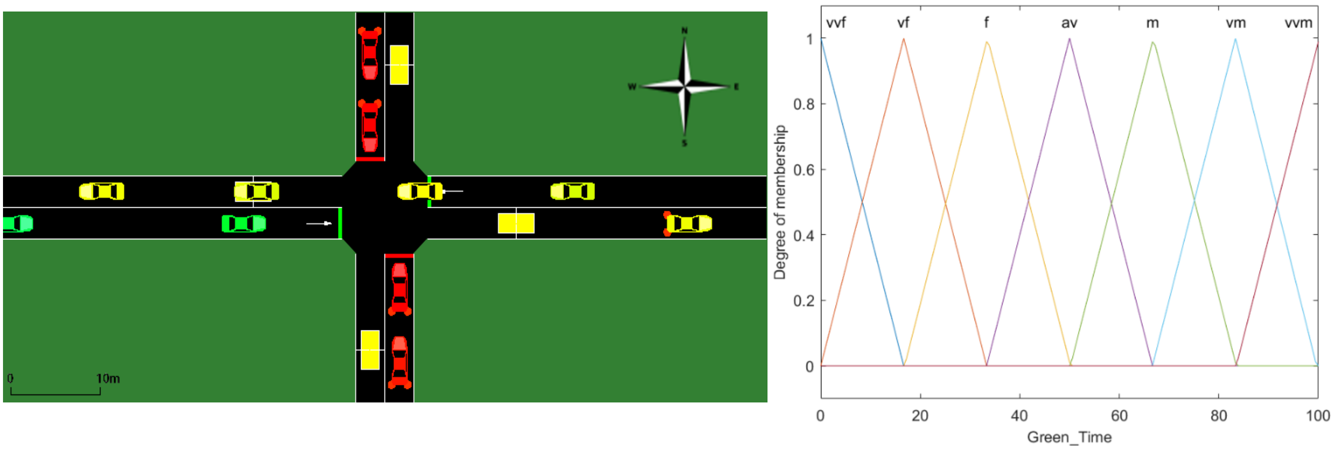

Fig. 1 (a) Traffic intersection model; (b) Traffic light green phase time member function

The traffic light control system at the intersection is designed according to the following assumptions and limitations:

- Traffic moves from north to south, from west to east and vice versa.
- When the green light is on for the vehicles from the north and south, the red light is on for the vehicles from the east and west, and vice versa.
- Right and left turns are not allowed at the intersection.
- Number of lanes on the roadway is one.
- Cycle length of the signal program is 120 sec.
- The minimum and the maximum durations for green light on both directions are 6 seconds and 60 seconds, respectively.
- No amber time
- Table 1 shows Order of phases.

Table 1: Order of phases

	North	***South***	***East***	***West***
Phase 1	-	-	Straight	Straight
Phase 2	Straight	Straight	-	-

3. Traffic Light Design with Fuzzy Logic Controller

Fuzzy logic technology allows the implementation of real-life rules similar to the way humans would think. For example, humans would think in the following way to control traffic situation at a certain junction: “if the traffic is heavier on the north or south lanes and the traffic on the west or east lanes is less, then the traffic lights should stay green longer for the north and south lanes”. Such rules can be easily accommodated in the fuzzy logic controller. The beauty of fuzzy logic is that it allows fuzzy terms and conditions such as “heavy”, “less”, and “longer” to be quantized and understood by a computer. It is possible to show that fuzzy logic-based TLC systems can achieve better results in comparison to conventional ones. In junction management based on fuzzy logic, the junction agent changes the traffic lights depending on the number of vehicles at the junction. Fuzzy logic controller is designed for 4-way traffic junction: north, south, east and west as shown in Figure 1(a).

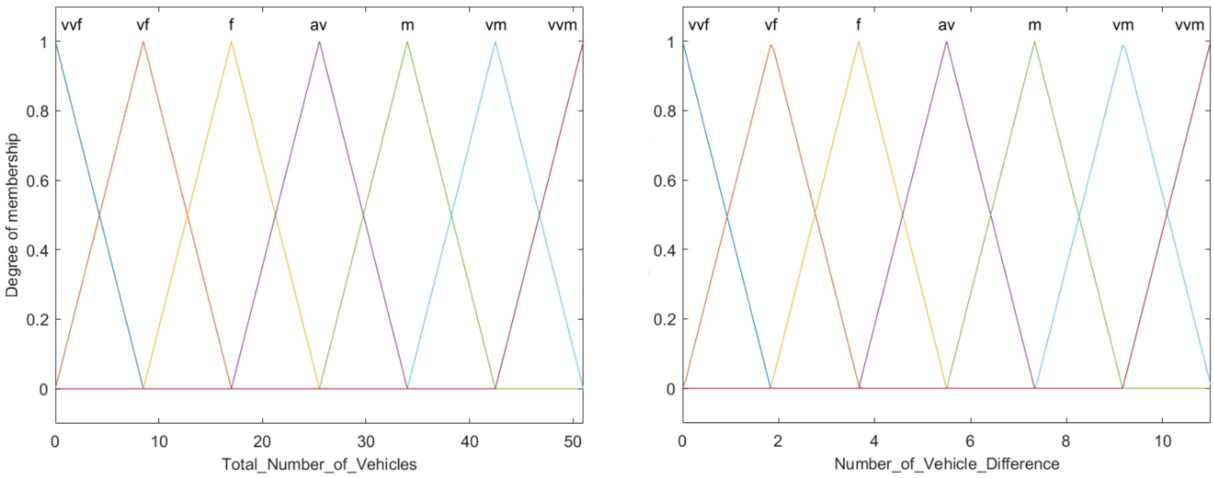

Fig. 2 Fuzzy Logic inputs member functions

Two fuzzy input variables have been selected in the traffic lights controller. The first is the total number of vehicles (TNV) at the intersection. The other variable is the difference between the number of vehicles (VND) coming from the east and west and the total number of vehicles coming from the north and south. It includes 7 membership functions which are very very few (vvf), very few (vf), few (f), average (av), much (m), very much (vm) and very very much (vvm). Based on the fuzzy rules as given in Table 2, the fuzzy controller produces an output according to current traffic conditions to determine the green light duration. The direction in which the green phase will be active is determined according to the difference in the number of vehicles. For example, if the difference in the number of vehicles (the difference between total vehicles from east and west and the total vehicles from north and south) is negative, the green phase is effective for vehicles from north and south. If the difference is positive or zero, the green phase is active for vehicles from the east and west. The green phase duration, which is the fuzzy logic output value, is then calculated according to the fuzzy logic input values. The green phase is recalculated in every second, so the green phase times change dynamically. However, it is expected that the time will be complete when the sign of the difference in the number of vehicles changes (from positive to negative or vice versa). In this case, the green phase will remain active for the last value before the signal change, then the green phase will be active for the other direction. The cycle continues in this way. While there are five members for the graph to control the traffic lights, there are nine member functions for the output. A graphical representation of the membership functions of the output value is given in Figure 1(b) and input values are given in Figure 2.

Table 2: Rule Table for Fuzzy Logic

TNV \ VND	vvf	vf	f	av	m	vm	vvm
vvf	vvf	vvf	vf	vf	f	f	av
vf	vvf	vf	vf	f	f	av	m
f	vf	vf	f	f	av	m	m
av	vf	f	f	av	m	m	vm
m	f	f	av	m	m	vm	vm
vm	f	av	m	m	vm	vm	vvm
vvm	av	m	m	vm	vm	vvm	vvm

4. Traffic Light Design with PI Controller

When performing PI type traffic light control, the difference in the number of vehicles on both directions is considered as the error of the traffic intersection system. The green phase times in the PI type Traffic Light Controller are determined by the multiplication of the K_p coefficient by error and the multiplication of the K_i coefficient by the total error. Here, the green phase times can be negative or positive. This helps the determination of the direction of the green phase. For example, when the green phase time is positive, there will be green phase for vehicles from the east and west directions. When the green phase time is negative, the green phase will be for vehicles from north and south. The total error of the system does not increase much because the error values can be positive or negative. The duration of the green phase is recalculated in every second, so the green phase times change dynamically. However, when the sign of the green phase time changes (from positive to negative, or vice versa), the time is expected to complete. In this case, the green phase will remain active for the last value before the signal change, then the green phase will be active for the other direction. The cycle continues in this way. PI parameters K_p and K_i values were determined by considering the effects of proportional and integral coefficients on the system.

Table 3: Simulation results

	Vehicle Density	**Traditional Control**	**Fuzzy Control**	**PI Control**
CO_2 Emission (kg/s)	*0.5*	*32,54*	*25,86*	*25,28*
	1	*80,23*	*67,52*	*80,68*
	1.5	*177,18*	*156,34*	*172,99*
	2	*270,45*	*235,14*	*260,63*
	2.5	*356,88*	*304,60*	*347,79*
Average Speed (km/h)	*0.5*	*35,73*	*43,38*	*44,09*
	1	*29,22*	*32,94*	*29,58*
	1.5	*19,92*	*21,89*	*21,15*
	2	*17,05*	*18,77*	*18,38*
	2.5	*16,15*	*18,51*	*17,44*

5. Simulation Results

A simulation environment is designed and implemented using SUMO. The CO_2 emission outputs and average speed values of the vehicles were taken directly from the SUMO program. Simultaneous vehicles produced for 300 seconds during simulation. In the simulation, the ratio of the number of vehicles coming from east-west direction to the number of vehicles coming from north-south direction is 1,5. In the simulation, half, one, one and a half, two and two and a half vehicles are produced per second to determine the vehicle density. Therefore, during simulation, 150, 300, 450, 600 and 750 vehicles were produced for vehicle density of 0.5, 1, 1.5, 2 and 2.5, respectively.

Figure 3 shows the average speed values for different traffic light control techniques relative to the change in vehicle density. Figure 4 shows the total CO_2 emission values according to vehicle density for different control techniques. Table 3 shows the results of CO_2 emission and the average speed of vehicles. It can be stated that the Fuzzy logic type traffic light controller and the PI type traffic light controller give much better results than the traditional traffic light controllers shown in figure 3 and figure 4.. In the methods we propose, efficiency is seen more clearly in average speed values. However, as shown in Figure 4 The sum of CO_2 emission was less changed for either FLC and PI. The reason for this is that vehicles do not emit CO_2 emissions when they wait at the traffic junction, i.e. when their speed is 0. An important advantage of the PI type controller over the Fuzzy logic type controller is that the process load is less. Indeed, this was also observed during the simulation. In addition, it is seen that Fuzzy Logic TLC system gives slightly better results than PI type TLC system as the density of vehicles increases.

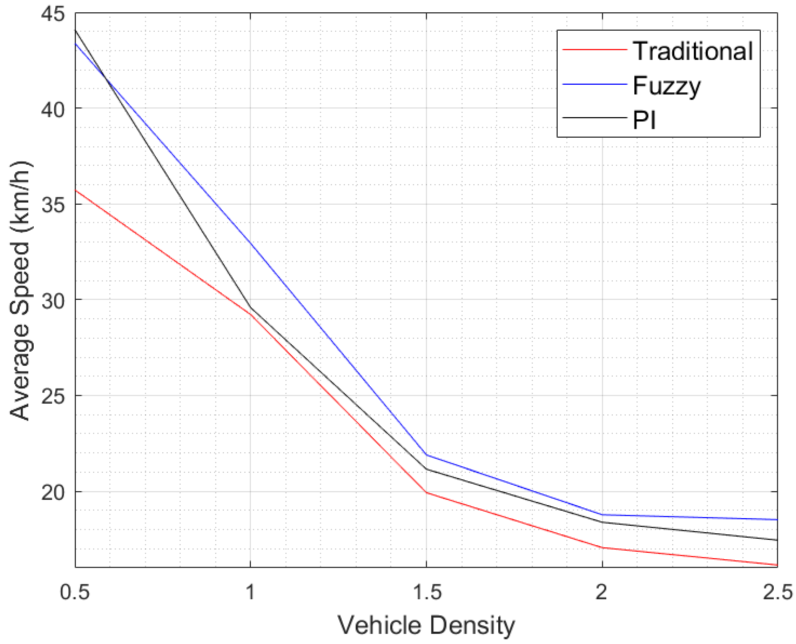

Fig. 3 Average speed values according to changes in the number of vehicle density.

Each vehicle crossed the intersection once. In the traditional method, the green light is steadily lit for 60 seconds for each phase. Traffic lights are calculated dynamically according to fuzzy logic input values with constraints of minimum 6 seconds and a maximum of 100 seconds for both proposed methods.. Also, there is no amber time in the traffic junction system.

6. Conclusion

In this study, Fuzzy logic and PI control methods are proposed to be used in the Intelligent Intersection method which is an alternative method to the classical traffic lights, which are the places where the most traffic is experienced. Traffic intersection and vehicles were made by using SUMO traffic simulation program. When planning the routes of the vehicles, the vehicle density from the east-west direction is thought to be higher. As can be seen from the simulation results, the proposed methods give better results than the traditional methods.

In future studies, it is aimed to investigate the problems of more complex intersection systems and control of junctions in a region instead of a single junction. In addition, with the support of Multi-Agent control theory, it is aimed to develop appropriate control methods in intersection where vehicles can communicate with each other and intersection agents.

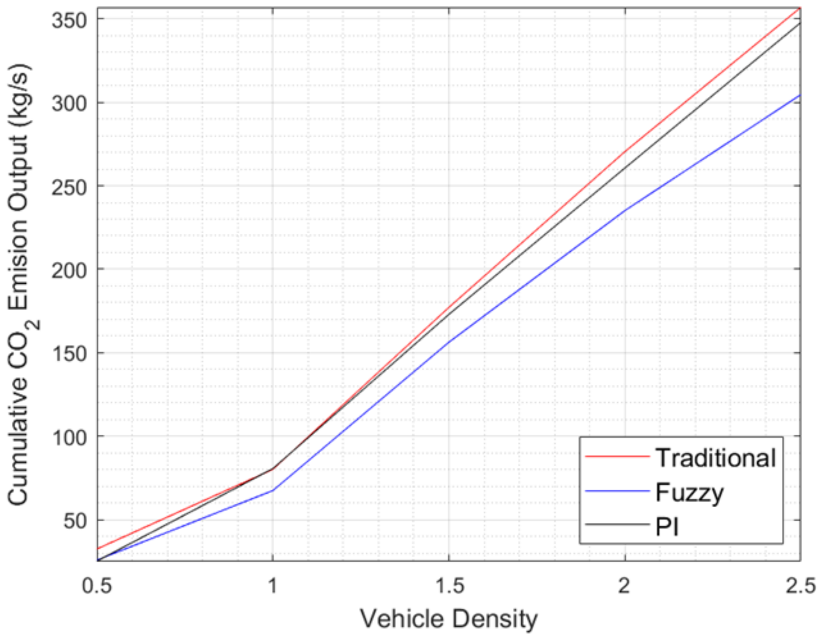

Fig. 4 Total emission values according to changes in the number of vehicle density.

References

Centre for Applied Informatics (ZAIK) and the Institute of Transport Research at the German Aerospace Centre: Simulation of urban mobility - sumo website. (2019).

Deakin, E. (2003) 'Mainstreaming Intelligent Transportation Systems: Findings from a Survey of California Leaders', in *Transportation Research Board 82nd Annual MeetingTransportation Research Board*.

Ezell, S. (2010) 'Intelligent Transportation Systems. The Information Technology & Innovation Foundation. January 2010'.

Favilla, J., Machion, A. and Gomide, F. (1993) 'Fuzzy traffic control: adaptive strategies', in *[Proceedings 1993] Second IEEE International Conference on Fuzzy Systems*. IEEE, pp. 506–511.

Kim, J. (1997) 'A fuzzy logic control simulator for adaptive traffic management', in *Proceedings of 6th International Fuzzy Systems Conference*. IEEE, pp. 1519–1524.

Kulkarni, G. H. and Waingankar, P. G. (2007) 'Fuzzy logic based traffic light controller', in *2007 International Conference on Industrial and Information Systems*. IEEE, pp. 107–110.

Kumar, M., Albert, S. and Deeter, D. (2005) 'A summary of rural intelligent transportation systems (ITS) benefits as applied to ODOT region 1', *Oregon Department of Transportation Region*, 1.

Pappis, C. P. and Mamdani, E. H. (1977) 'A fuzzy logic controller for a trafc junction', *IEEE Transactions on Systems, Man, and Cybernetics*. IEEE, 7(10), pp. 707–717.

De Schutter, B. and De Moor, B. (1998) 'Optimal traffic light control for a single intersection', *European Journal of Control*. Elsevier, 4(3), pp. 260–276.

Trabia, M. B., Kaseko, M. S. and Ande, M. (1999) 'A two-stage fuzzy logic controller for traffic signals', *Transportation Research Part C: Emerging Technologies*. Elsevier, 7(6), pp. 353–367.

Tubaishat, M., Shang, Y. and Shi, H. (2007) 'Adaptive traffic light control with wireless sensor networks', in *2007 4th IEEE Consumer Communications and Networking Conference*. IEEE, pp. 187–191.

Tunc, İ. and Söylemez, M. T. (2019) 'Simulation of Fuzzy Logic and PI Control Methods in Intersection Management'.

Wang, D., Ren, L. and Li, J. (2010) 'Modeling intelligent transportation systems with multi-agent on SOA', in *Intelligent Computing and Integrated Systems (ICISS), 2010 International Conference on*. IEEE, pp. 717–720.

Webster, F. V. (1958) *Traffic signal settings*.

Wiering, M. A. (2000) 'Multi-agent reinforcement learning for traffic light control', in *Machine Learning: Proceedings of the Seventeenth International Conference (ICML'2000)*, pp. 1151–1158.

Wiering, M. A. *et al.* (2004) 'Intelligent traffic light control'. Utrecht University: Information and Computing Sciences.

Zadeh, L. A. (1965) 'Fuzzy sets', *Information and control*. Elsevier, 8(3), pp. 338–353.