A NOVEL FUZZY CONTROL MODEL OF TRAFFIC LIGHT TIMING AT AN URBAN INTERSECTION

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ABSTRACT: Despite the widespread research done on modeling, simulation and optimization of traffic flows, most applications of fuzzy logic in traffic engineering are still under development and can be frequently seen in traffic light detection, traffic situation prediction, and vehicle routing, determining transport priority, traffic assignment model, raising the degree of utility and exhibiting the group model of traffic flow. Here signal timing control, as a subclass of advanced traffic management systems, considering the native features of driving in the country (Iran), has been designed by taking two parameters in mind: Back of queue length, as the maximum extent of the queue in give-way lines at red time according to the number of stops and average waiting time along the route for both approaches so that peak hour coefficient, main and minor streets and the capacities of the lines of a given intersection have been implicitly incorporated in the parameters of this system. Provided with these four parameters in fuzzy control of signal timing using the Mamdani inference engine, 81 inference rules can be achieved, according to which changing the green phase in the next cycle will be decided.

KEYWORDS: Fuzzy Control, Intelligent Transportation Systems, Traffic Lights Timing

1. Introduction

As the population and traffic demand volumes, particularly in large urban areas grow, the issues of traffic congestion, air pollution, sound pollution, weariness, stress, time and energy waste and even damage to historical buildings have set forth a major problem. Traditional solutions such as constructing sidewalks, limiting traffic entry to the CBD, passing municipal charges, making one-way streets, redirecting traffic from congested areas and decreasing number of commutes during peak hours are not responsive to the transportation demand volumes and decreasing jam density, therefore, new technologies of intelligent traffic control have to be employed to better accommodate these increasing demands.

Traffic light is doubtlessly the most familiar, important and effective method of traffic control at intersections. Traffic lights are generally installed to ensure safety, decrease the average time of proceeding through the intersection, increase the capacity of multileg intersections, improve quality of service, quality of traffic flow and level of service for all or most traffic streams and if scheduled accurately the average delay of vehicles will be less, compared to unsignalized intersections.

Traffic situation, tightly tied to the cultural and social paradigms is a fuzzy concept itself. The sophistication of the real world aggravates its accurate description and definition. Despite the simple look of city intersections, they belong to this sophisticated world and thus cannot be controlled neglecting this feature. In this paper we will first study the intelligent traffic control systems and introduce the customary methods of timing control of traffic lights. Following the introduction of Fuzzy Control Systems, we will present the Fuzzy Control Model of Traffic Lights Timing at an urban intersection and evaluate the results.

2. Intelligent Control Systems of Intersections

Intelligent Transportation Systems, indicating the application of modern information and communication technologies in transportation systems to increase the efficiency and safety of transportation systems and decrease air pollution and its other undesirable environmental effects, are generally composed of three important components i.e. a sensor (Loop Detector), an information processor and an output device connected through a communication network. Intelligent transportation systems can be categorized into different groups, of which intelligent control systems of intersections belong to the class of advanced traffic management systems. [13]

Following the appearance of computerized traffic lights in 1960s, many researchers designed traffic light control systems which were capable of coordinating the traffic lights so that at least one of the parameters e.g. the number of stops or the delay at reaching the destination would be minimized by processing some information on the current traffic conditions. In the 1980s, the introduction of SCOOT system in Great Britain and SCATS in Australia made a major breakthrough in control systems. UTCS (Urban Traffic Control Systems) has been
employed in North America as well as SCOOT and SCATS (Sydney Coordinated Adaptive Traffic System) in Australia, Europe, Asia and recently North America.

As a result of fundamental differences between the dominant traffic behavior of the Iranian towns and the countries producing the simulation software e.g. stop density of vehicles at the beginning and the end of the approaches of signalized intersections for picking up and dropping off passengers, the conflict between the traffic flow and the pedestrians, unpredictable selection of lanes by drivers, special features of roads, driver's personality, route choice behavior and the street traffic volumes, the deployment of these applications is not appropriate and efficient prior to validation and conformance to the conditions of Iran.

3. Traffic Light Timing Control Methods

Traffic light timing using the incoming traffic conditions can be accomplished in different ways. In the pre-timed mode, each phase period and cycle duration is determined based on some predetermined values by some statistics. In traffic prediction (Actuated Signals), the future mode is estimated and decided by sensors based on the measured situation. In the pattern matching method, the information obtained by the sensors is adapted by a set of mathematical operations with the existing information, the closest pattern to the current conditions is then selected and appropriate time values are applied to the traffic lights accordingly.

In the semi-actuated control mode all times for different routes excluding the main route can be set i.e. The traffic light at the main line remains green as long as the sensors of the off-line can detect a car at the intersection. But in the full-actuated control mode, all the times of the conflicting volumes can be programmed by sensors. Full-actuated control is mostly employed where the traffic volumes of both intersecting lines are approximately equal. Full actuated control is used here to predict the future traffic flow by conforming to the designed fuzzy functions.

4. Fuzzy Control Systems

Fuzzy control systems are a special variant of non-linear control systems that describe inaccurate, ambiguous and vague phenomena. As shown in figure 1, the core of a fuzzy knowledge base/ rule base system is a knowledge database whose if-then rules are obtained from experts' knowledge by employing knowledge management techniques to be integrated into a unified system in the next stage.

Knowledge is categorized as explicit and tacit according to formation and transmission models. Explicit knowledge is the knowledge stored in documents and computers such as the statistical information on the changes of traffic parameters of a given intersection in 24 hours as opposed to tacit knowledge which is internalized by a knowledge worker during a period of time, inseparable of how the individual has gained and is using it. An example of this is the knowledge of traffic police in manual traffic light timing of many intersections in the city. We need both types to implement a fuzzy control system for traffic light timing of a given intersection. Such that explicit knowledge on domain values regarding the parameters of the fuzzy membership functions design and tacit knowledge on decision criteria for green phase change should be available.

In spite of all the research done on modeling, simulation and optimization of traffic flows [1..3], most applications of fuzzy logic in traffic engineering are still under development and can be frequently seen in traffic light detection[4], traffic situation prediction[5], vehicle routing [6], traffic assignment model [7], raising the degree of utility [8] and exhibiting the group model of traffic volume (Platoon) [9] but less employed in controlling traffic lights yet [10].

5. Fuzzy Control Model of Traffic Light Timing at an Intersection

Signal timing control, considering the native features of driving in the country (Iran), has been designed by taking two parameters in mind: Back of queue length, as the maximum extent of the queue in give-way lines at red time according to the number of stops [12] and average waiting time along the route. These parameters are calculated at red time which provides static traffic conditions and not during green display with dynamic traffic; the results are then applied in the next green phase. Therefore the resulting values of the parameters are more acceptable and usable since the route traffic conditions and obstacles are ineffective on the values of the parameters.

As opposed to similar preceding systems which merely involved the parameters of one approach at green time, intelligent timing control of intersections through this method is done by taking the parameters of both approaches with the offset of a cycle so that peak hour coefficient, main and minor streets and the capacities of the lines of a given intersection have been implicitly incorporated in the parameters of this system. In a way that peak hour is when the back of queue length in at least one of the approaches reaches its maximum; and as a result, this system allows the maximum extension to the green phase.

Involving the queue length in place of the traffic volume causes more traffic volume during green time depending on the width of the two approaches in the main street i.e. the street with more lanes. But the importance
and capacity of an approach are not taken into account in the parameter of traffic volume and number of vehicles. To compare and evaluate the traffic effect of different vehicles, passenger cars are usually chosen as the unit of measurement and vehicle traffic streams are converted to an equivalent passenger-car volume in measuring the capacities of intersections and queue length based on the number of vehicles. These coefficients are multiplied by 1.75 when used for left-turn adjustment factors.

Determining the average waiting time parameter in each approach requires the definition of a function that represents the total waiting time of all vehicles entering the intersection during the period t. For this purpose, function \( F(t) \) can be stated in short discrete intervals (e.g., 5 sec) and the product of the number of vehicles entering the intersection during the remaining time to the end of red phase based on the previous cycle.

\[ F(t) = N(t) \cdot (T_i - t) \]

Therefore, function \( F(t) \) is an almost uniform decreasing step function. If the intervals are quite long, the average waiting time can be simply calculated by means of the arithmetic mean of \( F(t) \), and otherwise, taken from the average integral formula in which \( TR_i \) is the red phase period of the previous cycle and the integral is taken from the start to the end of the red phase period of the previous cycle.

\[ T_{Ri} = \frac{1}{T_{Ri+1}} \cdot \int F(t) \, dt \]

The queue length parameter, \( L(t) \), based on the number of stopped vehicles during the red time in each approach is obtained from the sum of the possible remaining queue length of the previous cycle \( L(t_{i-1}) \) and the product of the arrival flow rate of the vehicles in the route during red time, \( V(t) \) (according to the ratio of the number of vehicles to time) and the period of this phase in the previous cycle \( (T_{R_{i-1}}) \). For this purpose, some indicators equipped with sensors installed in appropriate distances from the intersection can measure the arrival flow rate of each approach during red time.

\[ L(t) = L(t_{i-1}) + V(t) \cdot T_{R_{i-1}} \]

Obviously, a minimum amount of knowledge is required for the practical implementation of this system; the explicit and tacit knowledge can be respectively obtained from a series of minor computations on the statistical output of some traffic control software systems such as SCATS and through people-to-document approach in codification strategy for knowledge management. This technique is mostly applied to cases facing similar problems and requiring reuse of a validated solution. Efforts are made to reveal and code the hidden knowledge of people and eventually store it in knowledge databases to act as a reference for similar future attempts. But in this paper, due to lack of the tools and appropriate statistical data, required cases have been specified approximately and subjectively having no repercussion on the outcome of the system.

Waiting time parameter is considered in the interval of \([0 200]\) with 3 membership functions i.e. low \([0 0 25 75]\), medium \([25 75 125]\) and high \([75 125 200]\). Consequently, inference rules and membership functions are designed depending on the system input in every moment, appropriate fuzzy results are obtained for green time variable in the interval of \([-200 200]\) seconds for every route and therefore the red time for the opposing approach in their pertaining phases. On the basis of that, appropriate decision is made after center of gravity defuzzification for selecting any of the membership functions of decrease plus in the interval of \([-200 -200 -100]\), decrease in the interval of \([-200 -1000]\), no change in the interval of \([-100 0 100]\), increase in the interval of \([0 100 200]\), increase plus in the interval of \([100 200 200]\).

Therefore, this technique operates on the basis of changes in traffic flow conditions in this interval. Although, similar to variable traffic lights, it does not require determination of the extension period, minimum and maximum green time have to be defined for it. Figure 2 demonstrates the results of selecting the green time, as opposed to constant period.

![Figure 2. The Results of Selecting the Green Time as Opposed to Constant Period](image)

![Figure 3. Graphical Representation of the Surface of Membership Functions in 3D Combinational Mode](image)

Provided with four parameters (two parameters for each intersecting line) in the fuzzy control of signal timing using the Mamdani inference engine, 81 inference rules can be created. The graphical representation of the surface of membership functions is presented in 3D.
combinational mode in figure 3. By utilizing the proposed fuzzy model, dramatic improvement to shortening the average waiting time and queue length, shown respectively in figures 4 and 5 has been observed which explains the high efficiency of the proposed model.

![Figure 4](image_url) Figure 4. The Comparison of the Mean Waiting Time in Both Models that Shows Greater Performance in the Fuzzy Model

![Figure 5](image_url) Figure 5. The Comparison of the Mean Queue Length in Both Models that Depicts a Longer Queue in the Crisp Model

6. Conclusion

Each phase of the traffic light includes one or more traffic streams that simultaneously receive the same signal command as the priority to proceed through the intersection. In this paper, the fuzzy control of one of the states of a double-phase traffic light has been taken into account though through further research all the other phasing modes (double-phase, triple-phase, with forerunner or retrograde or forerunner-retrograde phases and timing (fixed or variable cycle length) of a traffic light can be investigated.

In regional traffic control, for further efficiency several traffic lights in a route can be coordinated using cooperative local controllers which consists of timing adjustment of some traffic lights in such a way that a car is capable of proceeding through all the intersections non-stop and at a predetermined speed [13] [14]. Therefore, issues including shortest path problem (SPP) [15][16], minimum total time path and weighted number of stops [17] are set forth in the traffic-light network.

References


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