Fuzzy Rule Based Traffic Signal Control System for Oversaturated Intersections

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Abstract – A Fuzzy Rule Based Control System is presented in this paper. This control system controls Traffic Signals for regulating traffic on oversaturated intersections with the integration of left and right turns. Based on the Fuzzy Rules, the system decides, whether to extend the current green signal or terminate it. The control system also controls the continuous and safe flow of emergency vehicles.

Keywords – Fuzzy Controller; Traffic Control; Cycle Time; Queuing Length; Emergency Vehicle.

I. INTRODUCTION

As the number of vehicles and the needs for greater transportation has grown in recent years, city streets and highways frequently face serious road traffic congestion problems. Due to this factor, traffic signals now become a common feature of cities controlling heavy traffic. Careful planning of these signals is important to increase the efficiency of traffic flow on road. Controlling traffic on oversaturated intersections is a big issue.

Conventional methods for traffic signal control based precise models fail to deal efficiently with the complex and varying traffic situations. They are modeled based on the preset cycle time to change the signal without any analysis of traffic situation. Due to fixed cycle time, such systems do not consider that which intersection has more load of traffic, so should keep green more or should terminate earlier then complete cycle time. In case of intersections, conventional control systems only consider waiting time of signals on different directions but not the vehicle directions. Such situations can be seen in various areas of Karachi like Shahrah-e-Faisal where traffic flow varies in different hours and heavy traffic flows in morning and evening timings because of large number of offices on that route. Also, in different intersections, traffic flow abruptly changes in schools timings then other daily hours. Preset Cycle Time Controllers fail in such scenarios because they could not get complete information of vehicles earlier. Also, sometimes situation arises, when some VIP movement is there, the traffic flow has to divert and control different intersections. In such situations, efficiency of human decision-making is unprecedented efficiency of human because decision-making objectives are unclear [11].

Fuzzy based controllers are proved to be well manager of traffic system in such scenarios [1, 10]. Fuzzy controllers have the ability to take decision even with incomplete information. More and more sophisticated controllers are being developed for traffic control [2, 3, 4, 5, 6, 7, 8, and 9]. These algorithms are continually improving the safety and efficiency by reducing the waiting delay of vehicles on signals [1]. This increases the tempo of travel and thus makes signals more effective and traffic flow smooth.

The key motivation towards Fuzzy Logic in traffic signal control is the existence of uncertainties in signal control. Decisions are taken based on imprecise information and the effect of evaluation is not well known [8].

The objective of this research study is to design a Fuzzy Rule Based System for oversaturated intersections with left and right turns. Also, the system controls the smooth flow of emergency vehicles.

In earlier studies, the fuzzy controllers do not consider left and right turns simultaneously. Lin Zhang and Honglong Li developed Fuzzy Traffic Controller for Oversaturated Intersections [8]. They designed an algorithm to control over-saturated intersections of two-way streets with left turning movements.

Jee-Hyong Lee and Hyung Lee-Kwang also designed a Fuzzy Control Model. The goal of controller is to decrease the average time delay in the whole traffic network. They assumed that special establishments named right-turning lane in the intersection allow right-turning traffic flow to pass the intersection without disturbing the other traffic flows at the same intersection. Under this assumption, right-turning traffic flow is out of the consideration of fuzzy control [9].

In this paper, all these limitations and assumptions have been removed. This work includes not only straight turns and single turns but all single, left and right turns. Moreover, this paper has merged the controlling of Emergency Vehicles with the intersection control algorithm to provide smooth flow to these vehicles towards their destination. This was not considered earlier. As Police Vehicle or Ambulance need flush flow, emergency vehicle control has been incorporated in this study. The signal should always be Green after sudden entrance of emergency vehicle.

This paper describes a fuzzy rule based approach designed to regulate traffic flow for oversaturated intersections. The fuzzy controller decides whether to terminate the currently Green signal or extend it for some period. These assessments are made using set of fuzzy rules. These rules consider the Queuing Lengths and Arriving Rates of current Green signal and the compared waiting signal. In this paper, rules are based on not only “Current Green Signal Arriving Rates” but also take into
consideration, the “Arriving Rates of Compared Signals”. In Lin Zhang and Honglong Li research, Arriving Rates of Current Green Signal was considered only [8]. Here, rules are made more accurate by adding new parameters and making membership functions more precise and sophisticated. This is done to achieve more demanding results and effective incorporation of Emergency Vehicle Control.

Fuzzy logic technology allows the implementation of real-life rules similar to the way humans would think. In Traffic Control System, 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 now be easily accommodated in the fuzzy logic controller. In this consideration, we can say that it is replaceable to Traffic Police Officers. Fuzzy Logic works glowing when traffic flow in different directions is highly uneven as compared to Pretimed Controller [8, 11].

II. LITERATURE REVIEW

Traffic flow is usually characterized by randomness and uncertainty. Fuzzy logic is known to be well suited for modeling and control such problems. Applications of fuzzy logic in traffic signal control has been made since the 1970s [10].

The first attempt made to design Fuzzy Traffic Controller was in 70s by Pappis and Mamdani [2]. After that Niittymaki, Kikuchi, Chui and other researchers [4, 5] developed different algorithms and logic controllers to normalize traffic flow.

Kelsey and Bisset [3] also designed a simulator for signal controlling of an isolated intersection with one lane. Same work was also done by Niittymaki and Pursula [6]. They observed that Fuzzy Controller reduces the vehicle delay when traffic volume was heavy.


Nakatsuyama, Nagahashi, and Nishizuka [7] applied fuzzy logic to control two adjacent intersections on an arterial with one-way movements. Fuzzy control rules were developed to determine whether to extend or terminate the green signal for the downstream intersection based on the upstream traffic.

Chui was the first who uses Fuzzy Logic to control traffic in multiple intersections [5]. In this attempt, only two way streets are evaluated without considering any turnings.

In recent years, Lin Zhang and Honglong Li [8] also worked on designing Fuzzy Traffic Controller for Oversaturated intersections.

Jee-Hyong Lee and Hyung Lee-Kwang [9] presented direction-varying traffic signal control but assume that right turn traffic flow do not disturb any other traffic flows in an intersection.

III. FUZZY LOGIC

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. FL is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channels PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both.

FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL’s approach to control problems mimics how a person would make decisions, only much faster. FL can be built into anything from small, hand-held products to large computerized process control systems. It uses an imprecise but very descriptive language to deal with input data more like a human operator. It is very robust and forgiving of operator and data input and often works when first implemented with little or no tuning.

IV. FUZZY TRAFFIC SIGNAL CONTROL

The aim of using fuzzy methods is attempt to model expert’s thinking ion the situations where development of an exact mathematical model of the phenomenon is very difficult or even impossible. The main goals of fuzzy logic in the traffic signal control, and a matter of fact, also in traffic signal control in general, are

1. Improving of traffic safety in the intersection.
2. Maximizing the capacity of the intersection.
3. Minimizing the delays.
4. Clarifying the traffic environment.
5. Influencing the route choices.

V. METHODOLOGY

The fuzzy logic controller determines whether to extend or terminate the current green phase based on a set of fuzzy rules. The fuzzy rules compare traffic conditions with the current green phase and traffic conditions with the next candidate green phase. The flow diagram of a controller is shown in figure 1.
Cycle Time indicates the period to which current signal is green. If the cycle time is small, it denotes that it is usual time of green signal i.e. in normal situations; the cycle time of each signal is small. If traffic situation is such that it needs extension, then it can extend to long extension. If the cycle time is medium, it denotes that some extension has already been done, and now long extension cannot be done. If cycle time is already large then no extension is allowed, no matter what the situation of traffic. This is done to avoid starvation of any signal. In case of large cycle time, short extension is allowed only when emergency vehicle is in the current green signal.

Controlling of emergency vehicle is done by investigating their presence. If the emergency vehicle is in the current green signal then extend the signal for short extension only. When there is a situation, emergency vehicles are both in current signal and any other signal then extend the current signal. If emergency vehicle is in any signal which is not green then terminate the current signal.

VI. FUZZY PARAMETERS AND THEIR MEMBERSHIP FUNCTIONS

The set of control parameters is:

- EV = Emergency Vehicle
- CT = Cycle Time of Current Green Signal
- QC = Queue Length of Current Green Signal
- QN = Queue Length of Next Signal to be Green
- ARC = Arrival Rate of Current Green Signal
- ARN = Arrival Rate of Next Signal to be Green
- CS = Current Signal
- NS = Next Signal

<table>
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<th>EV</th>
<th>CT</th>
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<th>ARC/ARN</th>
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<tr>
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TABLE 1: INPUT & OUTPUT VARIABLES AND THEIR MEMBERSHIP FUNCTIONS

VII. FUZZY RULE SET

The fuzzy controller decides an extension of current green signal on the basis of rules set. These rules will act differently on the basis of Cycle Time. As mentioned earlier, by default, the cycle time is ‘Small’ for every signal. Extension from small CT will be on certain rules. ‘Small’ CT will allow extension to ‘Long’. If the cycle time is ‘Medium’, it shows, it already had some extension, so that signal can extend only to ‘Medium’. In case of already ‘Large’ cycle time, the extension will be given only in the presence of Emergency Vehicle. When Emergency vehicle is there on any signal then it will ignore all other traffic factors and extension will be given to that signal.

Some of the rules are shown below:

1. If EV in CS is present then Short extend.
2. If EV in NS is present then Zero extend.
3. If CT is ‘Medium’ then extension can be ‘Zero’, ‘Short’ or ‘Medium’. No Long extension.
4. If CT is ‘Small’ then all values from extension set are possible i.e. extension can be done to ‘Long’.
5. Qc is V Low and ARc is low then Zero extend.
6. Qc is Medium and ARc is Low and QN is Medium and ARN is High then Zero extend.
7. Qc is V High and ARc is Low and QN is Low then Medium extend.
8. Qc is V Low and ARc is Medium and QN is V Low then Short extend.
9. Qc is L Low and ARc is High and ARN is Low and QN is V Low then Short extend.
10. QC is V High and ARC is High and QN is Medium then Long extend.
11. QC is V High and QN is V Low then Long extend.

VIII. CONVENTIONAL TECHNIQUES USED FOR INTELLIGENT TRAFFIC LIGHT CONTROL

A. EXPERT SYSTEMS

An expert system uses a set of given rules to decide upon the next action [12, 15]. The expert systems can communicate to allow for synchronization. Performance on the network depends on the rules that are used. For each traffic light controller, the set of rules can be optimized by analyzing how often each rule fires, and the success it has. The system could even learn new rules.

B. EVOLUTIONARY ALGORITHMS

Taale [14] compare using evolutionary algorithms evolution strategy to evolve a traffic light controller for a single simulated intersection to using the common traffic light controller in the Netherlands. They did not try their system on multiple coupled intersections, since dynamics of such networks of traffic nodes are much more complex and learning or creating controllers for them could show additional interesting behaviors and research questions.
C. REINFORCEMENT LEARNING

Reinforcement learning for traffic light control has first been studied by Thorpe [13], but Thorpe’s approach is different from approach in this paper. He used a traffic light based value function, and we used a car based one. Thorpe used a neural network for the traffic light based value function which predicts the waiting time for all cars standing at the junction. A neural network is used to predict the Q values for each decision, based on the number of waiting cars and the time since the lights last changed. The goal state is the state in which there are no cars waiting.

Thorpe trained only a single traffic light controller, and tested it by instantiating it on a grid of 4 X 4 traffic lights. The system outperformed both fixed and rule based controllers in a realistic simulation with varying speed.

IX. CONCLUSION

A basic fuzzy logic control algorithm for full intersections and left and right turns lanes was developed. The fuzzy logic controller makes the decision to what extent the current green phase has to be extended based on a set of fuzzy rules and real-time traffic information.

A large number of improvements are planned for the future; they include the following:

- Additional simulation tests on intersections with different levels of geometric complexity, phasing and demand.
- The cycle time may be further fuzzified to get better results.
- Expansion of the fuzzy logic controller strategy to arterial and network applications.

REFERENCES


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