A Fuzzy Control Method of Traffic Light with Countdown Ability

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Abstract

Based on intelligent traffic system idea and fuzzy logical, a fuzzy control method of the traffic light signal with full countdown function is proposed which can effectively solve the randomness problem in the dynamic system. The method overcomes limitation of traditional mathematical control method and does not build a complex traffic flow model. It makes the action of controlling green light time into a series of roles and these roles can be optimized off-line. This paper studies the deviation in traffic flow data and data bottleneck production problem, and provides a solution based on conjunction of mathematical statistics and time series analysis. Using the conception of flow quantitative to fuzz traffic flow to implement self-adapted fuzzy controller controls intersection signal. Finally, simulation results verify the performance of our proposed method.

Keywords: *Traffic light signal, fuzzy logic control, countdown, prediction, self-study*

1. Introduction

The fact that classical feedback control method can not get a satisfactory control effect results from its fuzziness and uncertainty. Fuzzy logic is a powerful tool to handle uncertainty and nonlinear complex problems. It is similar to some of the characteristics of the human mind, which will get a favorable effect when it is embedded into reasoning technology. Some researchers like Kelsey, Bisset, Niittymaki, Pursula, Trabia, Kaseko, Ande have done research into fuzzy control problem of single intersection [1-4]. Their research suggests that fuzzy control can reduce the time delay effectively. Fuzzy logic is a mature reactive traffic signal control method, which is successfully used for all kinds of theoretical research and practical application. The fuzzy control method in this article is that instantaneously adjust the time of green light on the basis of the comparison between current green light phrase and other red green light phrase, so that the method will get relatively efficient scheme of time allocation.

However, this type of intelligent traffic control method often conflicts with the work of lights countdown card. The time allocation cycle is adjusted by the real detected traffic flow of every intersection, each duration time of traffic light is different from last time. So, the countdown devices do not know the traffic duration time and end point in advance. So far, the these self-adaption traffic control systems used all over the world like SCOOT, SCATS and so on all cannot implement count down in whole day.

The sufficient condition of implementing the signal with countdown ability is to get time allocation result of next cycle. If we use mathematical statistics and nature network to predict future traffic flow data, simulate signal time allocation by fuzzy control computing, we can complete countdown single intersection intelligent control [5, 6]. According to actual requirement of control of intersection, this article does some following research: structure of fuzzy controller, traffic flow prediction method which meets countdown requirement, green light duration decision-making matrix, simulation and conclusion [7-11].

2. Overall Structure of Fuzzy Controller

Fuzzy controller is the core of fuzzy control. The fuzzy control idea in this article is that according to the comparison between objective green phase and all objective red light phase, the controller adjusts green light time instantaneously as we can see in Figure 1, which shows overall structure of fuzzy control model. Fuzzy control implements point control function while controlling traffic signal, responsible of adjusting green-signal rate, it can cooperate with area control.

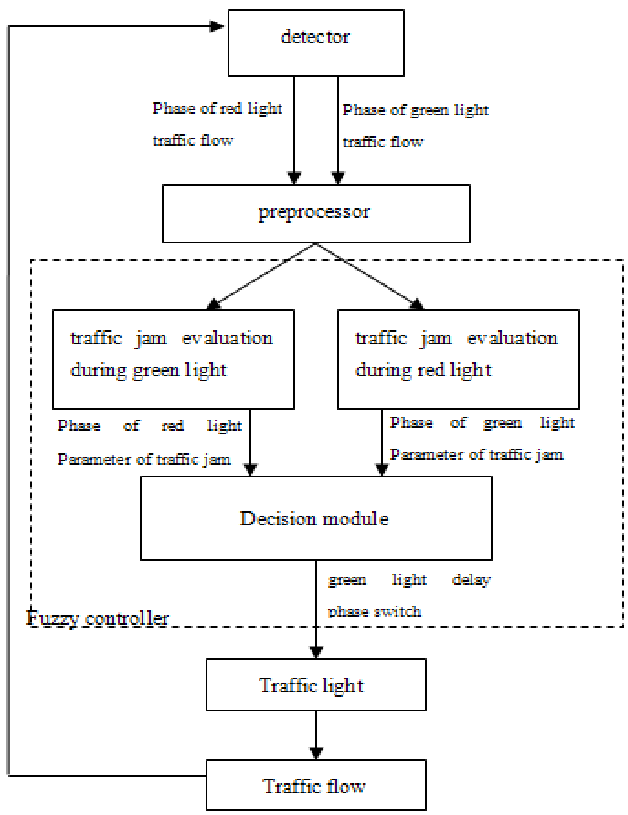

Figure 1. Fuzzy Controller Structure

The operation process is as follows:

1) Get ID of intersection and its time allocation information.
2) Determine a running model.
3) Preprocessing required traffic flow data. (Prediction)
4) Transform traffic flow data to traffic intension by membership function.
5) According to traffic intension to do fuzzy decision.
6) Update time allocation information.

3. Data Bottleneck and Time Offset Problem

Data bottleneck problem stems from limitation of car detection. Because of downstream intersection traffic flow depends on upstream intersection data of car detection, this problem is always exists in the case of single line with single car detection installed. Downstream intersection has numerical upstream intersections whose travel time has different length. Thus, the data of lower travel time becomes the bottleneck. However, time offset is a derived problem from data bottleneck problem. There are some biases against travel time and predicted time, while travel time directly affects time window width of downstream traffic flow, which has a major effect on providing traffic flow predicting data.

3.1. Intersection Geometrical Model and Car Detection Position

As we can see in Figure 2, car detection is allocated at the exit of stop line. The upstream car detection produces pulled out traffic flow, which is corrected to pulled-in traffic flow by function of discrete with rate.

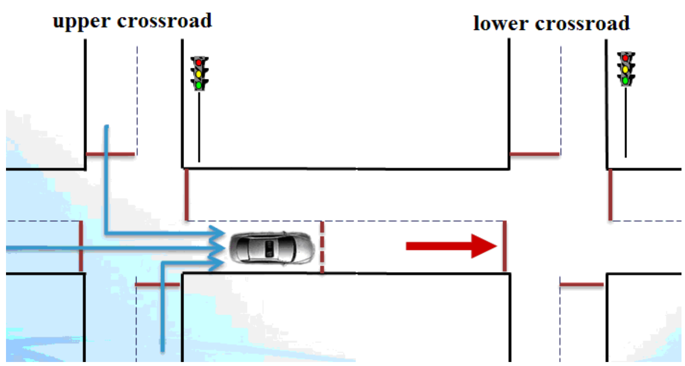

Figure 2. Intersection Geometrical Model

We cannot get the data of pulled-in traffic flow only relying on case of installing car detection at the lane exit. As we get the pulled-in traffic flow data by calculating the data of upstream intersection car detection, so here exists a problem that each directional data will be affected by the minimum travel time data, as each lane's traffic flow comes from different intersection, whose distance are different, which means travel time is different.

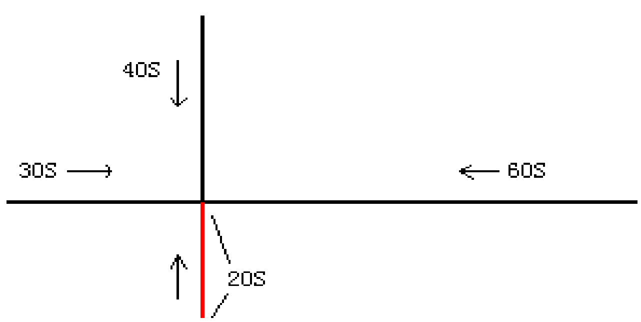

Figure 3. Bottleneck of Traffic Flow Data

In Figure 3, we abstract an intersection model, 20s, 30s, 40s, 60s are travel time of each directional traffic time of traffics drive from intersection entry to intersection center. The data whose travel time is 20s become the bottleneck data, which limits the 'prediction' time distance of current intersection.

3.2. Appearance of Time Offset

As we can see in Figure 3, we can get traffic flow data after as early as 20s (the traffic flow data of red lane is data bottleneck), but to implement time countdown function, its gap between travel time and predicted time makes time offset, as is shown in Figure 4. In this figure, the given cycle is 120s, 0 second is decision ending time, which will end before 0s moment. Data of 20s is the furthest data we can get. The two cycles between 0-240s is time allocation destination. We can see that there is 220s' gap between data and time allocation and cannot use these data to make decision.

In summary, the blank of traffic flow data between actual data time we get and time allocation destination must be predicted and filled with traffic flow data between 20s and 40s.

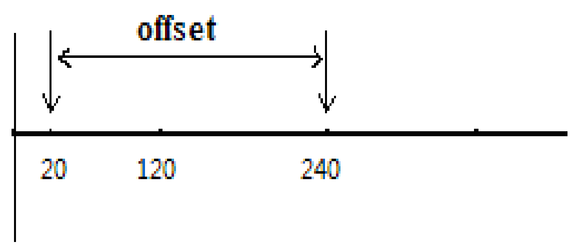

Figure 4. Offset between Data Time and Time Allocation Destination

3.3. Data Prediction

Data prediction method uses traffic flow prediction method which based on the conjunction of mathematical statistics and time series analysis. Mathematical statistics uses method of moving average, which is shown in Eq. (1). In the function: M_t is moving average number of t cycles, N is the number of moving average items.

$$M_t = \frac{\sum_{i=t-N+1}^{i=t} x_i}{N}, N \leq t \tag{1}$$

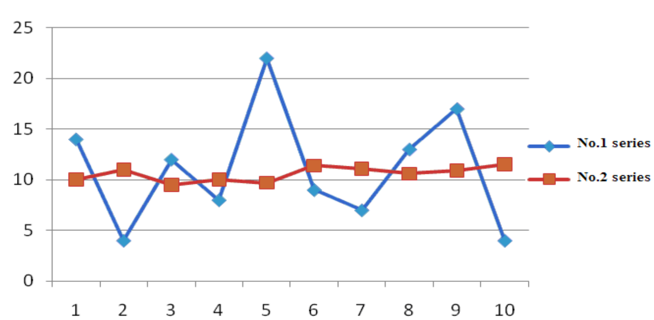

Figure 5. Comparison between Real Car Number and the Predicted Number

Figure 5 shows the comparison between vehicle data (No.1 series in Figure 5) of 10 cycles by single car detection and prediction data (No.2 series in Figure 5) predicted by method of moving average, in which time series analysis uses neural network tool.

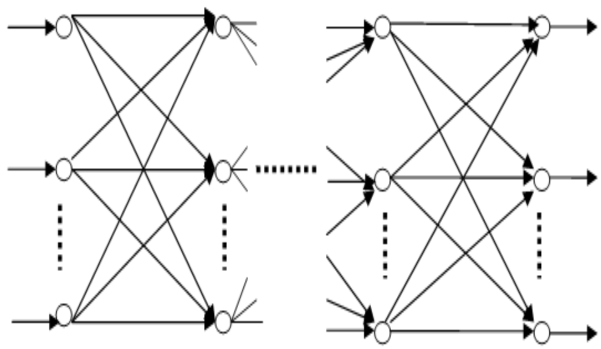

Figure 6. BP Neural Network Structure

Neural network tool in Figure 6 can easily implement nonlinear mapping process by simulate the powerful learning ability of human brain and have large-scale computing ability. Traffic flow data is a series of nonlinear function affected by many factors. Predicted by BP neural network with mathematical statistics is a desired way for solving extraction and approximate nonlinear function. Here we use BP neural network as a prediction tool for traffic flow time series. We use actual data as input for network, use the result of mathematical statistics as corrected parameter of data and use the traffic flow data of future 2 weeks as output.

4. Traffic Intension Estimate

We use the conception of flow ratio to describe green light phase lane congestion parameter and use the occupation ratio of lane to present red light phase congestion parameter. Calculate the current green light phase congestion parameter b0 and red phase lane congestion parameter b1 based on Eq. (2)

$$b = max \frac{\sum_{x}^{G} q_i}{\frac{s_i \times G}{3600}} \quad (2)$$

where q_i is real time detected traffic flow diagram of lane i, which is consisted of number of every 5 second traffic flow, G is current decision green light ending time and s_i is saturation flow of lane i.

Parameter b is sensitive to green light time and traffic flow, while is not sensitive to location of lane and time interval. b0 and b1 represent phase destination phase lane congestion parameter and other red phase lane congestion parameter. In the membership calculation, although s_i which acts as denominator is saturation flow, we can not insure that the value of q_i will not succeed denominator. So we can set the range of b as (0, 1.2).

5. Membership Function

To given a domain of discourse, we can call an entirety which is consisted of some objects that have certain attributes and can be distinguished as a set. Normal set a special form of fuzzy set, so fuzzy set is a conception extension of normal set, also Membership function is an extension of characteristic function and characteristic function is a special form of membership function. Traffic intension evaluation function are presented by vehicle congestion parameter b0 (destination green light phase congestion parameter) and destination red phase lane congestion parameter b1. Divide b0 and b1 into five fuzzy subset as B0 and B1, recorded as B∈{VB, B, N, F, VF}, in which VB is very blocking, N is normal, F is free and VF very free. When determining the endpoint of fuzzy subset, we make each subset not mixed, which is a special form of fuzzy set, so that membership calculation can be omitted, accelerates the processing speed effectively, and extracts only fuzzy conception in membership function.

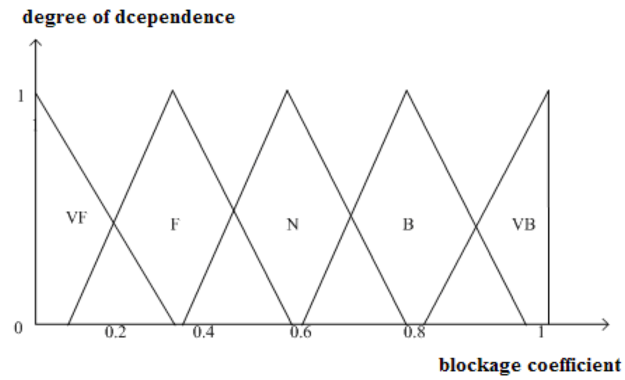

Figure 7. Membership Function Curve of B

The boundary of each fuzzy subset of lane congestion parameter, as we can see in Figure 7, is VF(0,0.2), F(0.2,0.4), N(0.4,0.6), B(0.6,0.8), VB(0.8,1).

6. Decision Module

Orthogonal matrix provides knowledge service for fuzzy decision where there exists many possible pairs and any one pair among them can get a one and only result from orthogonal matrix and lead the program to make a decision. b0 and b1 will get a result every stage, which is said that every cycle in one stage will make a decision based on traffic intension evaluation result. The decision process begins when green stage is beginning, and make sure it will end before next stage begin. Decision result will find corresponding action from orthogonal matrix table based on mapping results.

6.1. Orthogonal Matrix of Stage Time Allocation

Parameters b0 and b1 are mapped to B0 and B1 by membership function, both of them make up a two-dimension orthogonal matrix (shown in Table 1). MUL, ADD, EQ, MIN, DIV in the matrix are corresponding to five different rules (shown in Table 2), expressing “green light time+8”, “green light time+4”, “invariant green light time”, “green light time-4” and “green light time-8”.

Different macroscopic strategy may use different orthogonal matrix. Different module may use different orthogonal matrix and it may be mapped to different role according to requirement of different intersection.

Table 1. Stage Time Allocation Orthogonal Matrix

$B_0 \backslash B_1$	VB	B	N	F	VF
VB	MUL	MUL	MUL	MUL	MUL
B	EQ	ADD	ADD	ADD	ADD
N	MIN	MIN	EQ	EQ	EQ
F	DIV	MIN	EQ	EQ	MIN
VF	DIV	DIV	DIV	MIN	MIN

Table 2. Roles Library

Rule_id	Premise	Action	Active	Used
1	MUL	G0= G0+8		0
2	ADD	G0= G0+4		0
3	EQ	G0= G0		0
4	MIN	G0= G0-4		0
5	DIV	G0= G0-8		0

6.2. Rule Library Self-study

Single fuzzy control system is lack of self-study ability. It can only make a decision based on current phase and next phase lane jams without considering whole intersection average delay. However, fuzzy control rule, which often derived from early experience of experts, are objective and may be not optimum for complicated traffic flow. Thus, the control rule must be adjusted to adapt to complex traffic situation to get a satisfied control effect. The model improves the rule library through modify it periodically or non-periodically. If the effect after using this model can be feedback, we can improve the rule library by value of Active field.

Every intersection maps to a table in rule library, every rule records using time and reliability. Whether reliability is augmented or decreased depends on the effect after rule executing. When reliability lowers to the certain extent, the corresponding rule in fuzzy matrix will be modified.

7. Simulation and Evaluation

We use VISSIM simulation tool to produce simulated analysis by timing control and fuzzy logical control method which based on index of verticals waiting time in different traffic flow intension, the result is shown in Table 3. The simulation result shows that when traffic intension is little and normal, the effect of fuzzy logic control is better than timing control, evaluation index decreased 28.3%, while the result of fuzzy control is close to the result of timing control with the increase of traffic flow. When traffic flow become saturated, the result of fuzzy control is slightly better than the result of timing control. Overall, the delay of saturated intersection controlled by fuzzy logic control method is 16.5% lower than that of timing cycle allocation method. The fuzzy control method can make sure the function of traffic signal time allocation; in the meantime, it can gain a satisfied Microscopic signal timing strategies.

Table 3. Comparison between Two Effects of Signal Control Method at Intersection

Traffic intension (n/h)	Timing control stop waiting time (s)	Fuzzy logic control stop waiting time (s)	Improvement of fuzzy logic control method
500	5125.4	3672.5	28.3%
1000	9623.1	7695.6	20%
1500	13510.5	10451.8	22.60%
2000	16866.7	13954.8	17.30%
2500	20483.3	18645.5	9%
3000	24938.1	24550.2	2%

8. Conclusions

The method to simulate traffic police with orthogonal decision matrix gets a significant effect in saturated and over saturated traffic flow, reduces verticals waiting time compare with timing control and does not need to build complex traffic model. The countdown function can bring real convenience to resident, while contradicts self-adapted. This paper uses the method of fuzzy logical control to predict in advance with prediction data to solve the problem. The method implements intersection signal control and precise countdown timing function during the whole journey.

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