Sensors & Transducers, Vol. 156, Issue 9, September 2013, pp. 211-216

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Study on Monte Carlo Simulation of Intelligent Traffic Lights Based on Fuzzy Control Theory

ZENG Shengda, * WU Lurong, JING Lin, WU Bizhi
Computer and Information College, Fujian Agriculture and Forestry University,
Fuzhou 350002, China
* Tel.: +86 15005098168
E-mail: wulurong1@sina.com

Received: 5 June 2013 /Accepted: 25 August 2013 /Published: 30 September 2013

Abstract: Based on the traffic flow pattern in single intersection, this paper advances a design method for intelligent traffic lights in the state of stochastic dynamic change of traffic flow by employing the Fuzzy Control Theory. The application of fuzzy control technology to achieve the traffic lights control system not only breaks the traditional mechanical models but also manages to simulate intelligence control system in which the traffic is directed by the police, making possible signal conversion for different situations and optimum delay time of green light. It is proved that the fuzzy control system can effectively reduce the delay time length of waiting vehicles. In consideration of the randomness and robustness of traffic flow, this paper employs the Monte Carlo method in combination with MATLAB to simulate, which proved to be more effective than the traditional control method. It significantly increases the utilization rate of traffic, thereby generating considerable economic benefits. *Copyright © 2013 IFSA.*

Keywords: Single intersection, Fuzzy control, Intelligent traffic lights, Monte Carlo, Simulation.

1. Introduction

With the rapid development of automobile industry, more and more automobile enterprises began to set foot in the field of automobile intellectualization and apply cutting-edge Information Technology to the automobile and its control. According to relevant statistics, over 90 % of innovation in automotive industry is related to automobile intelligent system. Intellectualization is the trend of automobile's future development and is considered as a revolution in the process of automotive technology development. It is an important and effective means to gain a niche in the future automobile market. Although the automobile intelligent technology has reached a relatively mature stage, the road management cannot be reformed once and for all. The congestion problem has become increasingly prominent and the intersection is the most congested section, where traffic jam is quite often seen. Phenomenon of 2~3 hours congestion is quite common in metropolis like Beijing, Shanghai and Shenzhen. Reform of traffic rules since this year particularly poses a grave challenge to the traffic control. As a result, ideas of using high-tech systems such as intelligent, fuzzy, automation to solve the problems of road traffic are emerging.

Referring to the realistic data of China's traffic situation, considering time difference of traffic flow in different regions with periodic regularity, taking into account of length of the waiting vehicles in stop way of intersection, based on the theory of intelligent fuzzy control and with the help of computer simulation, this paper sets up an automated multiphase intelligent traffic control system and establishes a more effective control system compared with the induction time control. The control system is designed to make the vehicle at the intersections wait for the shortest time, thereby reducing their passing time. The control system has the following characteristics:

1) Adopting statistical view, combining the past traffic volume and statistical analysis of computer data to predict real-time traffic;

2) Adopting fuzzy control method, taking prediction of real-time traffic flow as input condition to control the traffic lights;

3) The control methods used have feedback self-directed learning function, and have strong sensitivity to disturbance of special time quantum.

2. Analysis of Intelligent Traffic Signal Control

Time delay distribution of traffic light in single intersection is determined by traffic flow in different intersections. Fig. 1 is the single intersection traffic flow chart.

All of the 4 directions in the three-lane road single intersection have three kinds of traffic flow direction, namely, left, right, straight on [1]. In the control of time delay distribution of traffic light in single intersection, this paper takes into account the effect of queue length of detained traffic flow at intersection during red light and the passing number of vehicles during green light on time delay distribution and draws up corresponding fuzzy control rules, constructs the traffic light intersection fuzzy controller, and achieved the delay timing control of intersections.

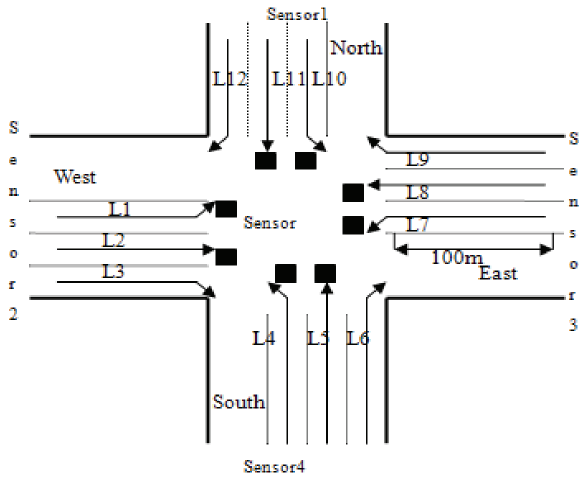

Fig. 1. Single intersection traffic flow chart.

According to the analysis of the above traffic flow structure chart of single intersection, considering the effect of queue length of detained traffic flow during red light and the passing number of vehicles during green light on time delay distribution, in realistic control, traffic flow in rush hours and in slack periods are in random change. Fig. 2 is flow chart of overall control feedback of traffic light, which enables the fuzzy controller of traffic light to accomplish intelligent artificial feedback timing regulation at different stages, so as to shorten the time of traffic congestion.

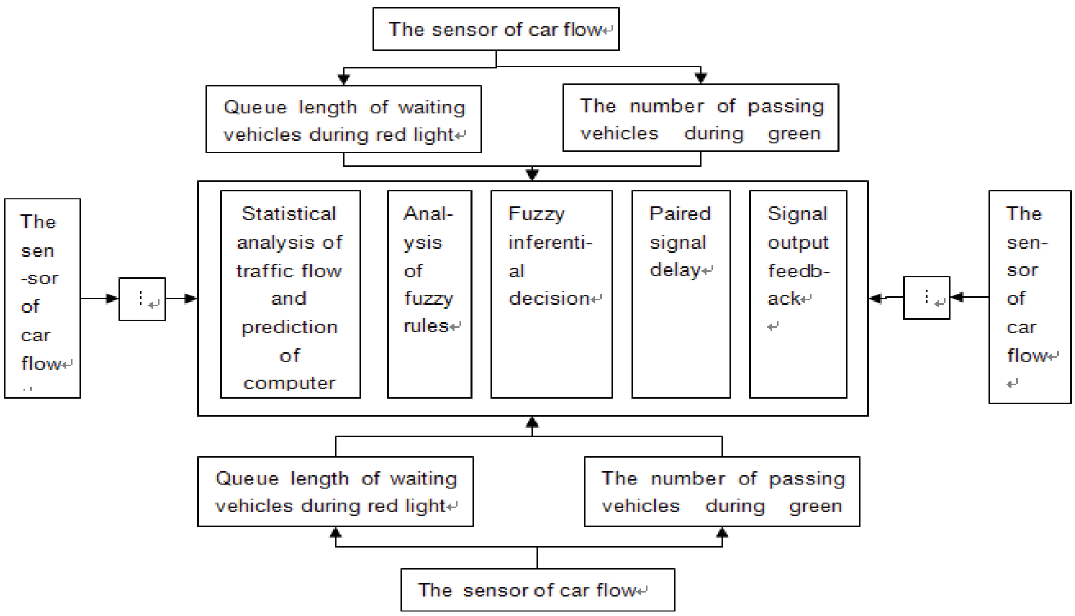

Fig. 2. Flow chart of overall control feedback of traffic light.

3. Model Design of Intelligent Traffic Light Control

3.1. Analysis of Traffic Flow Phase and the Length of Queue

Since the signal control systems of traffic light in the past generally didn't consider the phase change, we take a periodic change control of "four phase" into consideration in order to cater to the random timing distribution of intelligent automation in different states. Fig. 3 is the traffic patterns of 4 phases. This paper adopts the improved control method of 4 phases in random sequence, based on the statistical analysis of sensor traffic flow, uses phase fuzzy optimization control to calculate and analyze to determine the execution phase of the next moment [3].

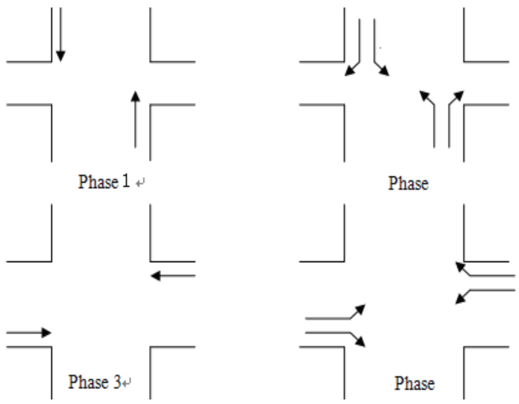

Fig. 3. Phase traffic patterns.

In Fig. 1, $Li, (i = 1, \cdots 12)$ represents the current length of fleet in different lanes. The maximal length that passes the intersection in current moment is called length of passage and the maximal length of two fleets that pass in the phase next moment is called waiting degree.

Therefore, the length of passage and value of waiting length of 4 phases can be obtained according to the traffic patterns of 4 phases [2].

3.2. The Fuzzy Delay Control Rule of Traffic Light and its Quantification

Use the theoretical achievements of fuzzy controller to turn the control strategy described by nature language into fuzzy control rules in order to realize fuzzy control.

In this regard, the variable that is used for fuzzy control has the following 3 parts: fuzzification, fuzzy control rules and defuzzification.

Use the theoretical achievements of fuzzy controller to turn the control strategy described by nature language into fuzzy control rules in order to realize fuzzy control.

In this regard, the variable that is used for fuzzy control has the following 3 parts: fuzzification, fuzzy control rules and defuzzification [4, 5].

In fuzzy control, input is decided through considering the queue length of the current phase and the next phase. The queue length consists of passing queue length and waiting queue length L; Output is the delay time T of green light. Set the distance of sensor as 100 m, load length of every queue phase as 4m and the traffic flow of each phase as 50 vehicles. It follows that the domain of discourse of the passing queue length and waiting queue length in question is [0, 54]; since the shortest delay time of green light is 8 seconds and the longest 90 seconds, the domain of discourse of delay time during green light is [8, 90].

Table 1. Passing queue length and waiting queue length of four phases.

Phase	Traffic queue length	Wait length
1	Max（L5+L11）	Max（L1+L3+L7+L9, L4+L6+L10+ L12, L2+ L8）
2	Max（L4+L6+L10+L12）	Max（L1+L3+L7+L9,L5+L11, L2+L8）
3	Max（L2+L8）	Max（L1+L3+L7+L9,L5+L11,L4+L6+L10+L12）
4	Max（L1+L3+L7+L9）	Max（L5+L11,L4+L6+L10+L12,L2+L8）

Fuzzifying the input and output, we can get:

The basic domain of discourse of passing queue length is{3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54}, the basic domain of discourse of waiting queue length is{3, 6, 9, 12, 1518, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54}, the basic domain of discourse of delay time during green light is {8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84, 88, 90}. When it comes to red light, compare the traffic flow of the east and west straight-on lanes and choose the larger one. Then, if the traffic flow at last 8 seconds is less than 5 vehicles, reduce the next-round green light time quantum by 4 seconds [6-7]; if more than 10 vehicles, increase by 4 seconds; if within 5-10 vehicles, the next-round green time quantum remains unchanged. (As shown in Fig. 2)

On the amount of input and output, we set up the model of fuzzy subset: {NB (very few), NS(few), ZE(Medium), PS(many), PB(plenty)}[8] and get Table 3.

Table 2. Time control of traffic flow before the end of green light.

Order number	Traffic flow	Green time of next round
1	Less than 5 vehicles	Reduced by 4seconds
2	5-10 vehicles	Unchanged
3	More than 10 vehicles	Increased by 4 seconds

Table 3. The rule table of fuzzy delay control.

T / L	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NB	NB
NS	NS	NB	NB	NB	NB
ZE	ZE	NS	NS	NB	NB
PS	PS	ZE	ZE	NS	NB
PB	PB	PS	ZE	ZE	ZE

3.3. The Rules of Fuzzy Delay Control and Analysis of Matlab Program

Based on the above principles, we can set the appropriate parameters and consider the probability distribution of traffic flow that accord with Queuing Theory. (Poisson distribution). Supposing that the traffic flow accords with the random quantity of Poisson distribution, then calculate the number of waiting vehicles and stopping length of time during red light in the west and the number of waiting vehicles and total stopping length of time in both the east and the west, generating the red light waiting time and number of waiting vehicles in each intersection. It's therefore defined that the next red light time quantum is the sum of green light time quantum of the rest three intersections.

This paper adopts the fuzzy inference method of Mamdani [6], the arithmetic of conjunctions "and", "or" and "also" of MATLAB fuzzy logic toolbox and fuzzy implication and comprehensive defuzzification are as follow [9]:

1) The calculation of "and"

$$\mu_{A\otimes B}(N,W) = \min(\mu_A(N), \mu_B(W))$$

2) The calculation of "or"

$$\mu_{A\oplus B}(N,W) = \max(\mu_A(N), \mu_B(W))$$

3) The calculation of Implication

$$\mu_{A\to B}(N,W) = \min(\mu_A(N), \mu_B(W))$$

4) The calculation of Aggregation

$$\mu_{A\times B}(N,W) = \max(\mu_A(N), \mu_B(W))$$

5) The calculation of Defuzzification

Employing Center of Area, that is, determine the fuzzy set membership function curve and center of abscissa surrounding area and choose the center's corresponding abscissa value as the representative value of the fuzzy set [10].

The following are some Matlab procedure codes:

```
while t1_WEST<x_1a
while v1_WEST<=x_1a
v1_WEST=v1_WEST+CAR1_WEST(i1_WES
T)
i1_WEST=i1_WEST+1
while v1_WEST>=x_1a-m
if v1_WEST>x_1a
break
end
j1_WEST=j1_WEST+1
v1_WEST=v1_WEST+CAR1_WEST(i1_WES
T)
i1_WEST=i1_WEST+1
t1_WEST=t1_WEST+1
end
end
t1_WEST=t1_WEST+1
end
…
d=d1+d2+d3+d4
s=s1+s2+s3+s4
p=(y_1a+y_2a+y_3a+y_4a)/(d+s)
l=(d+s)*60/7
y=y_1a+y_2a+y_3a+y_4a
```

Firstly, through the theoretical analysis and construction of traffic light fuzzy neural network of traffic flow, we establish the expert fuzzy control rule library; and by constant adjustment and learning in the MATLAB fuzzy system (FIS) [11]-[12], we achieve the queue length membership function and green light delay membership function value and map out the corresponding membership function diagram [4], as shown in Fig. 4:

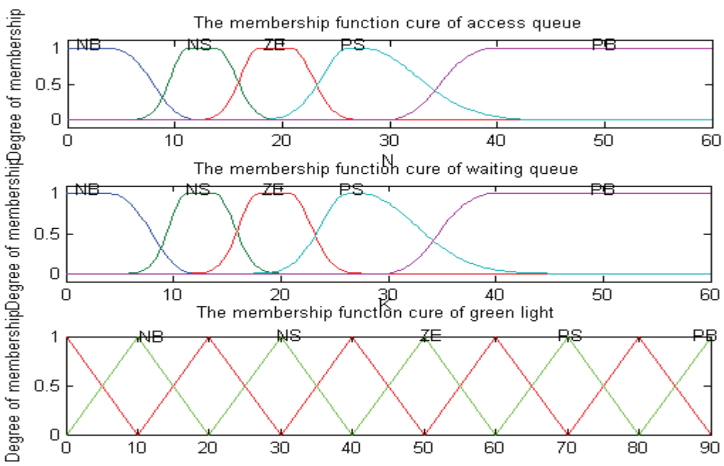

Fig. 4. The membership function diagram of queue length in traffic flow and the delay time during green light.

4. Monte Carlo Simulation

In order to reflect the advantages of intelligent traffic light control system, this paper proposes empirical method of control algorithm and combines real-time data to carry out Monte Carlo system simulation. According to the required intelligent control system features, this paper works out a Matlab simulated program and makes a simulation study on the traffic flow and control system, crystallizing the entire system to make a more direct and obvious comparison with the traditional traffic light.

At first, we use the date obtained from an intersection in Cangshan district of Fuzhou to carry out fuzzy control and compare the statistical data with the traditional control method, as shown in the following Table 4:

Table 4. Comparison of the number of waiting vehicles at the intersection for 20 minutes.

Intersection	Traditional traffic light	Intelligent traffic lights
East	50	38
South	15	12
West	128	112
North	39	30

Obviously, we find that the intelligent traffic light control is superior to traditional traffic light control. In order to reflect the uncertainty and mathematical regularity of traffic flow, we use Monte Carlo method in combination with MATLAB to carry out simulation data. Simulation of traffic flow is based on on-the-spot and long-time statistical traffic flow volume, MATLAB simulation and Poisson distribution rule, generating a large amount of simulation data. In MATLAB, we can use the function of POISSFIT (X) to obtain the sample X, and calculate the point estimate of parameter λ in Poisson distribution, thereby calculating the Poisson parameter estimation function. We can use [LAMBDAHAT, LAMBDACI] = POISSFIT(X, AL-PHA) to get the value of sample X. Calculate the parameter point estimate of Poisson distribution LAMDA and its confidence coefficient and we get interval estimation 100(1-ALPHA). Use the sample data to replace X in matrix form and we get the sample value of ALPHA and then use the formula R = POISSRND(LAMBDA,M,N) to get Poisson distribution lamda=LAMDA and random number matrix of line M and row N. Generally, the M in random number matrix is set as 1, then in the process of determine N, a certain amount of random number can be simulated. Here we set N as 10000, that is, there will be a random number of 10000 vehicles passing through the intersection.

According to the above simulation analysis, it is evident that no matter the input flow and output flow are known/certain or unknown/random, the traditional control is inferior to the intelligent fuzzy control.

5. Conclusion

The signal time delay controller of intelligent fuzzy traffic light, which is based on Monte Carlo theory and fuzzy mathematics control method, is practical in traffic control at single intersections. This paper puts forward a preferable intelligent control project of traffic light. Since this project is not subject to time, region or weather, strictly conforms to traffic rules, and has memory and learning function, it has universal practical applicability.

No matter in rush hours or slack hours of traffic, imbalance of traffic flow in different direction of the same phase will not increase the vehicle's waiting time in other phases or the average vehicle's delay time. This is a big advantage of this project. This paper just analyzes the traffic light situation at single intersections, and the design of traffic light at multiple intersections will be extended and taken as the future research.

Table 5. Monte Carlo simulation results.

The last N second of green light	Traditional traffic light		Intelligent traffic light	
	The number of stopping vehicles	The average vehicle stopping time	Number of stopping vehicles	Average stopping time
1	1086	189.3	924	147.4
2	919	148.4	813	129.5
3	853	125.4	787	108.7
4	732	109.6	642	106.3
5	658	94.7	532	84.4
6	692	95.2	586	93.5
7	774	112.1	667	90
8	832	123.2	795	109.8
9	982	152.8	960	134.6
10	1053	186.3	1024	162.4

Acknowledgements

The research work was jointly supported by National Innovation Practice of Undergraduate (Grant No. 201210389017), and Fujian province Innovation Practice of Undergraduate in China (Grant No.111ZC1258).

References

[1]. Xiaoguang Yang, Bailei Chan, Guoxiong Peng, Study on pedestrian traffic control signal settings, *Journal of China Highway and Transport,* 14, 1, 2001, pp. 73-80.

[2]. Zhiyong Liiu, Intelligent traffic control theory and its application, *Science Press*, Beijing, 2000.

[3]. Weikang Qiu, Weizhi Wang, Traffic signal control based on fuzzy neural network, *Jiangsu Electric*, 04, 2008, pp. 22-26.

[4]. Xiaoli Wu, Zhehui Lin, MATLAB aided fuzzy system design, *Xi'an University of Electronic Science and Technology Press,* Xi'an, 2002.

[5]. Jing Li, Fuzzy control and Simulation of traffic signal intersection, *Micro Computer Information*, 22, 7, 2006, pp. 33-35.

[6]. Yassine Hadjadj Aoul, Ahmed Mehaoua, Charalabos Skianis, A fuzzy logic-based AQM for real-time traffic over internet, *Science Direct,* 6, 2007, pp. 4617-4633.

[7]. Chou Chil-H Sun, Teng Jen-Chao, A fuzzy logic controller for traffic junction signals, *Information Sciences,* 143, 1, 2002, pp. 73-86.

[8] Hallapuro A., Lappalainen V., Hamalainen D., Performance Analysis of Low bit Rate H. 26L Video Encoder, in *Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP'01),* 2, May 2001, pp. 1129-1132.

[9] Tarte S. M., Talib H., Ballester M. Evaluating Partial Surface Matching for Fracture Reduction Assessment, in *Proceedings of the* 3rd *IEEE International Symposium on Biomedical Imaging: Macro to Nano,* USA, 4, 2006, pp. 514-517.

[10] Jee-Hyong Lee, Hyung Lee-Kwang, Distributed and Coorperative Fuzzy, Controllers for Traffic Intersection Group, *IEEE Transactions on System, Man and Cybernetics,* 29, 1999, pp. 263-271.

[11]. Richardon B., Rodriquez D., ITS in developing countries: strategic opportunities, *ITS Quartely*, 5, 3, 1997, pp. 7-15.

[12]. Carlsson C., Fuller R., Optimization under fuzzy if then rules, *Fuzzy Sets and Systems*, 11, 4, 2001, pp. 111-118.