TRAFFIC SIGNAL CONTROL BASED ON FUZZY LOGIC AND RADIAL BASIS FUNCTION NEURAL NETWORK

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Abstract: Traffic signal control is an important means used to control urban traffic. The paper presents a method of four-phase traffic signal control based on fuzzy logic and radial basis function network. Its main idea is: Firstly, we give an initial phase a constant green time. When the green time is over, a fuzzy controller will determine either prolong the green time or turn to another phase. The fuzzy controller is realized by radial basis function network. This method proved by MATLAB' simulation is more accurate in running accuracy and shorter in running time than BP network. This method is more adapted to real condition than BP network.

This paper also introduces some research of area control based on single control coupled with Chinese traffic conditions.

Key Words: fuzzy logic, radial basis function network, signal control, area control

1. INTRODUCTION

Traffic signal control is usually used to command urban traffic by assigning passing right for traffic in time domain at plane intersection. Isolated control is often used to control a single intersection, but area control considers all intersections' control in some certain area in order to obtain minimal delay when vehicles pass the area. In general, there are two kinds of isolated control measures: isolated pre-timed control and actuated-control. Isolated pre-timed control cannot adapt to the random variance of traffic flow. Actuated-control can adequately utilize green time and enhance capacity by minimizing the possibility of vehicles stopping. Therefore, actuated-control is safer and more reliable than isolated pre-timed control.

In actuated control system, green time is determined by the traffic demand detected by detectors. In most conditions, the time-phase of system is pre-determined. The green time phase will go on running when the red time phase has no waiting vehicles. Control logic is used to adjudge whether changing time-phase or prolonging green time when next conflicting time-phase has waiting vehicles. In some degree, the performance of system is determined by controlling parameters. In general, there are at lease three basic parameters: minimal green time; prolonged green time ; signal period. At present, some actuated-control models are used in many countries, such as NEMA in American (basic control model), basic flow-density control model , MOVA in Britain and AWA in Australia (interval-density control model). The comparison among these models is shown in table 1.

Table 1: The comparison among above actuated-control models

Control Models	Advantage	Disadvantage
Basic control models	Control parameters and control logic is simple	Values of parameters are fixed. It is difficult to get best values. I f parameters or detectors are configured incorrectly, performance of system will be effected greatly.
Basic flow-density control model	1 basic green time is adjustable; 2 prolonged green time is adjustable; 3 it is adept for section of high critical velocity;	It is easy to close green lamp earlier than real required time if ignoring the passing demand of green time-phase.
MOVA	1. Besides traditional control model, it also has decision-making logic for two parameters 2. Between adaptive control and actuated-control 3. Compared with traditional actuated-control, it can reduce delay by 13 percent.	1. It needs a large number of detectors. 2. Section which has large range of critical velocity will effect the validity of PL.
Interval-density control model	1 Critical interval is used to determined whether vehicles group is over or not 2. Reduce prolonged time by adding losing time	1. It is easy to make a wrong adjudication when the change of vehicles' interval is large. 2. It is easy to close green lamp earlier than real required time if the flow is low.

Dongling Xu[1] brought forth a method used to realize actuated-control of signal by using BP network and fuzzy logic. But BP network has local minimal value and its convergence is slow. Besides above two kinds of disadvantage, two time-phase does not fit for the urban' real conditions and the method of counting the number of vehicles is not very reasonable. Zhiyong Liü[2] presented a fuzzy control method that is used to control traffic signal with three or more phases at isolated intersection.

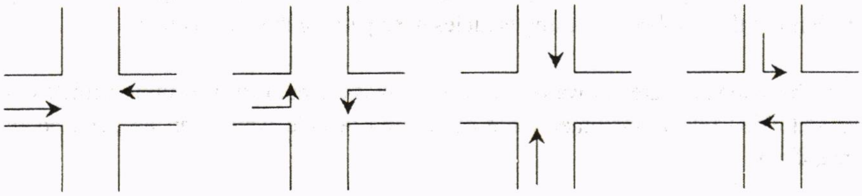
Because traffic system is random , fuzzy and uncertain, classical control algorithms can not get satisfied result. Radial basis function network has ability of local approaching. Its ability of approaching, classification and learning rate have advantages over those of BP network. Therefore, this paper brings forth a control method of traffic signal at isolated plane intersection using fuzzy algorithm and radial basis function network. Prove by MATLAB simulation, it has obviously advantages.

With the development of traffic control theories, communication, computer and detection, area control attracts more and more researchers. At present, several area control system, such as SCOOT, SCATS and so on, are in use. Because the background of these systems is not same to that of China, these systems are not very suitable for China. This paper will present some ideal about area control.

We know from traffic management department of Changsha that over 90% interactions of Changsha City are adopted two-phase control. Only interactions of the Wuyi road are adopted four-phase control. Many people are dissatisfied with the current traffic condition.

2. CONTROL THEORIES

This paper considers signal control with four time-phases according to the real condition of urban traffic. Figure 1 shows the distribution of four time-phases.



(a) Time-phase 1 (b) time-phase 2 (c) time-phase 3 (d) time-phase 4

Figure 1: distribution of four time-phases

At the entrance of actuated-control intersection, detectors are installed to detect the number of waiting vehicles. The distribution of detectors for one lane is shown in figure 2.

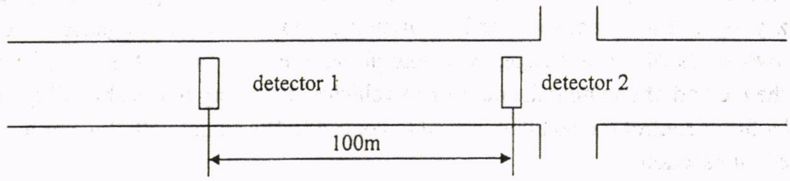


Figure 2. Distribution of detector for one time phase

The number of waiting vehicles group is the differences of the number vehicles detected by the two detectors at the same moment. Suppose the distance between the detector1 and the detector2 is 100m, the maximal number that can be detected by the two detectors is 13.

At the beginning of a time-phase, controller gives the time-phase a minimal green time. When the minimal green time is over, controller will make a decision: changing time-phase or prolonging green time according to the number of waiting vehicles in this time-phase and the next conflicting time-phase, the vehicles' waiting time of the next conflicting time-phase. If there has none waiting vehicles in current time-phase, controller will change phase. If there has waiting vehicles, controller will determine whether change time-phase or prolong green time by using fuzzy rules and fuzzy reasoning. In this paper, the minimal green time is 15 seconds, the maximal green time is 60 seconds, and the maximal period is 180 seconds. Besides, the paper also does not consider losing green time and the public bus stop in detected area.

3. FUZZY REASONING AND CONTROL LOGIC

Fuzzy reasoning is used to adjudge whether changing time-phase or not. In this paper, fuzzy reasoning has three kinds of inputs; the demand degree of waiting vehicle flow of green time-phase; the demand degree of waiting vehicle flow of the next conflicting time-phase and waiting time of the time-phase next to green time-phase. The demand degree of waiting vehicle flow denotes the number of waiting vehicles need passing the intersection.

Definition 1: The demand degree of waiting vehicle flow is the number of waiting vehicles in detecting area divided by the maximal value of waiting vehicle which can be detected in detecting area, that is

$$q = \frac{r_i}{\max(b_i)} \qquad (i=1,2,3,4) \qquad (1)$$

Where,

q represents the demand degree of waiting vehicles flow

r_i represents the number of waiting vehicles of its time-phase in the detecting area,

b_i represents the maximal value of waiting vehicles of i time-phase which can be detected in the detecting area.

Definition 2: The coefficient of waiting time equals to the waiting time divided by historical maximal period.

3.1 The demand degree of waiting vehicle in green time-phase

The demand degree of waiting vehicle flow of green time-phase represents the number of waiting vehicles group which needs to pass the intersection. The number of waiting vehicles in green time-phase determines it.

3.2 The demand degree of waiting vehicle in next conflicting time-phase

The demand degree of waiting vehicle in next conflicting time-phase represents the number of waiting vehicles group which needs to pass the intersection. It is determined by the number of waiting vehicles in next conflicting time-phase.

3.3 The waiting time of vehicles in next conflicting time-phase

Besides demand degree of waiting vehicles flow, waiting time of next conflicting time-phase is necessary to adjudge whether change time-phase or not when a minimal green time is over. Waiting time starts to calculate from time when a first vehicle begins to waiting. This paper considers waiting time because it can affect driving safety and we take account of drivers' tolerance for waiting.

After establishing a set of rules and input the three parameters, we can obtain demand degree of changing time-phase by fuzzy reasoning. In order to enhance the flexibility of fuzzy control, the paper classifies the demand degree of changing time-phase into five sets: extreme low, low, rather low, high, extreme high. Because the value of demand degree of changing time-phase is fuzzy, we have to transform it into an accurate value that is between zero and one. If the value is more than 0.5, controller will change time-phase. When any one of the following conditions is satisfied, controller will change time-phase:

- there is no waiting vehicle when minimal green time is over;
- Current green time is the maximal green time;
- When demand degree of current green time is low and demand degree of next conflicting time-phase is high, it needs to change time-phase by reasoning.

Figure 3 show the detailed control logic.

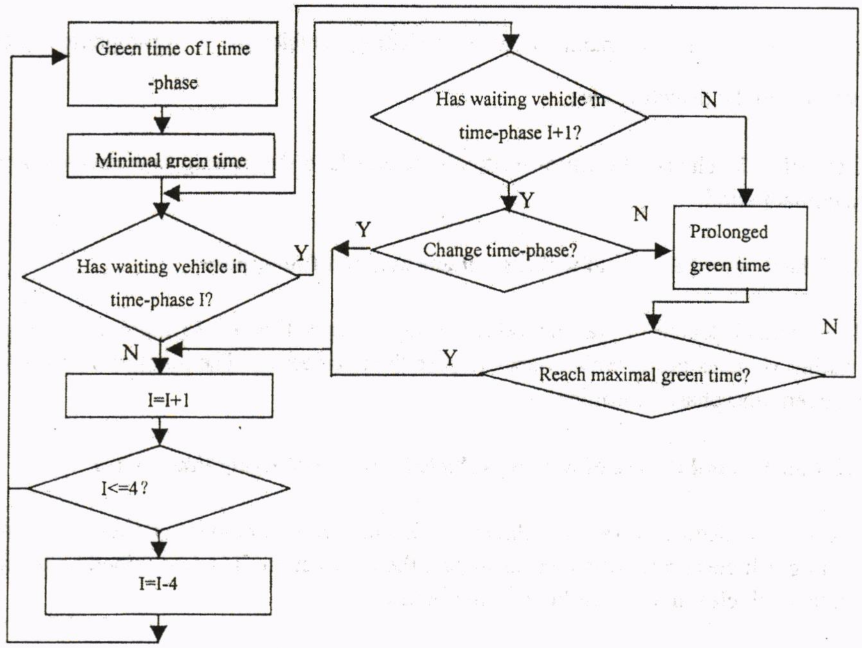


Figure 3. The detailed control logic

In figure 3, a radial basis function network according to fuzzy subset of waiting vehicles calculates prolonged green time. Table 2 is fuzzy subset of waiting vehicles. The fuzzy subset of prolonged green time is shown in table 3. To deciding whether change time-phase or not is a key part in this paper. Decision-making is accomplished by fuzzy reasoning. The rules used in fuzzy reasoning are established according to experts' experiences and related papers. Rules are used to describe controlling strategy and controlling destination. The detailed rules are shown in table 4.

Table 2: fuzzy subset of waiting vehicles

IF	F \ G	2	8	14	20	25	32	38
IF1	Extreme Few	1	0.5	0.2	0	0	0	0
IF2	Few	0.5	1	0.5	0.2	0	0	0
IF3	Rather few	0.2	0.5	1	0.5	0.2	0	0
IF4	Some	0	0.2	0.5	1	0.5	0.2	0
IF5	Rather Many	0	0	0.2	0.5	1	0.5	0.2
IF6	Many	0	0	0	0.2	0.5	1	0.5
IF7	Extreme many	0	0	0	0	0.2	0.5	1

Table 3: The fuzzy subset of prolonged green time

V / Q / LF		1	3	5	7	9	11	13
LF1	Extreme Few	1	0.7	0.3	0	0	0	0
LF2	Few	0.7	1	0.7	0.3	0	0	0
LF3	Rather few	0.3	0.7	0	0.7	0.3	0	0
LF4	Some	0	0.3	0.7	1	0.7	0.3	0
LF5	Rather Many	0	0	0.3	0.7	1	0.7	0.3
LF6	Many	0	0	0	0.3	0.7	1	0.7
LF7	Extreme many	0	0	0	0	0.3	0.7	1

Table 4: Rules of fuzzy reasoning

Rules	The demand degree of waiting vehicle flow of next conflicting time-phase	The demand degree of waiting vehicle flow of green time-phase	The waiting time of next conflicting time-phase	The demand degree of changing time-phase
Rule1	0	0, L, M, H	S, M, L	N
Rule2	L, M, H	0	S	PY
Rule3	L, M, H	0	M, L	Y
Rule4	L	L	S	PN
Rule5	L	L	M	M
Rule6	L	L	L	PY
Rule7	L	M	S	N
Rule8	L	M	M	PN
Rule9	L	M	L	M
Rule10	L	H	S, M	N
Rule11	L	H	L	M
Rule12	M	L	S	M
Rule13	M	L	M	PY
Rule14	M	L	L	Y
Rule15	M	M	S	PN
Rule16	M	M	M	M
Rule17	M	M	L	PY
Rule18	M	H	S	N
Rule19	M	H	M	M
Rule20	M	H	L	PY
Rule21	H	L	S	PY
Rule22	H	L	M, L	Y
Rule23	H	M	S	M
Rule24	H	M	M, L	PY
Rule25	H	H	S	M
Rule26	H	H	M	PY
Rule27	H	H	L	Y

Notes:

- The demand degree of waiting vehicle vehicles: high(H), Middle(M), Low(L), Zero(0).
- Waiting time: Long(L), Middle(M),Short(S).
- Demand degree of changing time-phase: Extreme low(N), Low(PN), Middle(M), High(H), Extreme High(Y).
- Q is the number of waiting vehicles in detecting area, V is fuzzy vector, LF and IF are elements of fuzzy subset, G is prolonged green time.

4. NEURAL NETWORK CONTROL OF TRAFFIC ACTUATED SIGNAL

It is well known that the weight adjustment of BP Neural Network adopts minus gradient decreasing methods when it is used in function approaching. And this leads to some drawbacks, such as local minimum and slow convergence. Radial basis function neural network is made up of three layers, the nodes of input layer transmit input signal to Perdue layer, which is constituted by radiation-shaped basis functions, for instance, Gauss Function. In general, the nodes of output layer are simple linear functions. The basis functions will produce response to input signal in local area. That is, when input signal is abet to the central scope of basis function, it will result in big output in the Perdue nodes. Radial basis function network is advantageous in approaching ability, classifying ability and learning rate. So we adopt radial basis function network to affect the control of actuated traffic signal.

4.1 Structure of Radial Basis Function Network

The structure of radial basis function network is illustrated in Fig. 4. It is feed by R inputs, generally the cell transformation function is Gauss Function, there are s2 cells in output layers, and the input of radial basis layer is b times the distance of input vector and weight vector, where b is the threshold.

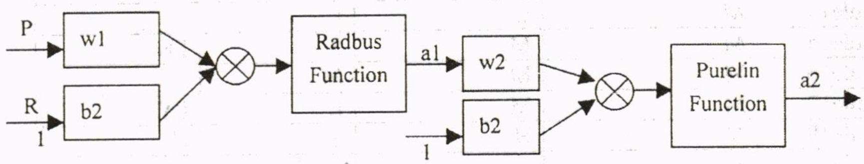


Fig.4 Structure of Radial Basis Function Network

Where

a1=radbasis(dist(w1,p),b1)
a2=purelin(w2*a1,b2)

In radial basis function network, training function 'solverb' produces a neural cell one time. In such a way, the number of cells is increased till it is up to error target or maximum training steps.

5. RESULTS AND DISCUSSIONS

Given that error target is err_goal=0.02 and the arrived vehicles in green direction is from 1 to 13 respectively, we can obtain corresponding prolonged green time in Table 4 by MATLAB program.

It is proved by simulation that three radial basis functions all reaches appointed error when the cells increase to 6, and the training error is shown in Fig. 5. Let us solve the same problem by training BP neural network with L-M method, suppose the maximum training step is 4,000, the nodes of Perdue layer is 6, hence we can obtain the results listed in Table 5.

Table 4. Arrived vehicles-prolonged green time corresponding table
(By RBF neural network)

Arrived vehicles(v)	1	2	3	4	5	6	7
Prolonged green time(sec)	2.0000	4.5641	8. 0000	10. 9902	14. 0000	17. 4536	20. 0000
Arrived vehicles (v)	8	9	10	11	12	13	
Prolonged green time (sec)	22. 7185	25. 0000	26. 5298	32. 0000	32. 1880	38. 0000	
Run time (sec)	2. 14						

Table 5. Arrived vehicles-prolonged green time corresponding table(sec)
(By BP neural network)

Arrived vehicles (v)	1	2	3	4	5	6	7
Prolonged green time (sec)	2.2177	-4. 8409	8.1234	4.9014	13. 7300	19. 4708	19. 8954
Arrived vehicles (v)	8	9	10	11	12	13	
Prolonged green time (sec)	22. 8985	24. 9941	25. 0154	32. 0112	32. 9555	38. 0472	
Run time (sec)	4. 23						

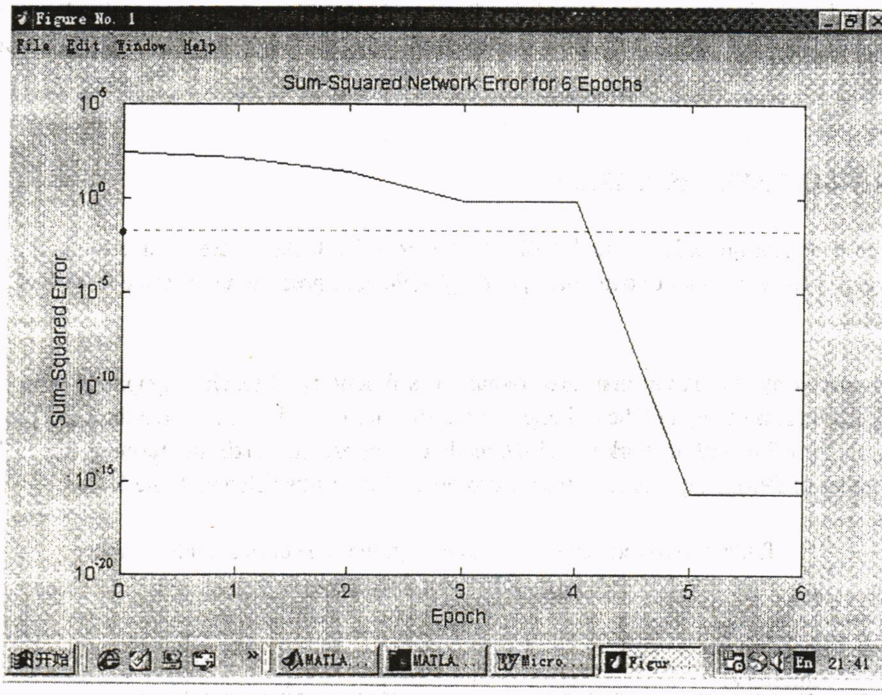


Fig. 5. Training error of radial basis network (for Prolonging green time)

Consequently, radial basis function network is more adaptive in the control of traffic signal. We can come at the same conclusion by the contrast of error figure. Control logic must decide if there are necessities to change time-phase when vehicle is detected in the conflicting time-phase. There are 4 parameters: arrived vehicles in green time-phase (Ga); arrived vehicles in next conflicting time-phase (Ra); maximum green time (Maxg); waiting time of vehicles in next conflicting time-phase (Wt). We may obtain the results, change direction or prolong green time, listed in Table 6 by MATLAB simulation in 8 typical cases.

Table 6: Part of results of traffic signal control system by MATLAB simulation

	1	2	3	4	5	6	7	8
Ga (v)	9	9	3	5	5	0	5	13
Ra (v)	3	3	9	5	5	5	0	7
Maxg (sec)	60	60	60	60	60	60	60	60
Wt(sec)	20	50	15	15	50	20	0	20
Cd	0	1	1	0	1	1	0	0
Et(sec)	25	\	\	14	\	\	14	38

In the column of Cd, 1 indicates changing direction and 0 denotes prolonging green time. It is clearly that when the vehicles in both directions are equal, the control logic prefers to prolong green time in case of short waiting time, and in other case, the traffic signal is changed. When there is no vehicle in green-lamp direction, system decides to change direction. If no vehicle is detected in time-phase next to current time-phase, the green time is prolonged.

6.1 AREA CONTROL MODELS

6.1 Minimum delay model

The minimum delay model emphasizes that the total runtime in the traffic network is minimum. Suppose that n intersections are distributed in the area, then the model can be presented by

$$\text{Min} \qquad \sum_{i=1}^{n} \lambda_i \int_0^{r_i(t)} q_i(t) r_i(t) dt \qquad (2)$$

$$\text{st.} \qquad \sum_{i=1}^{n} \lambda_i = 1;$$

$$0 \leqslant q_i(t) \leqslant 13$$

$$a \leqslant r_i(t) \leqslant b$$

Where

$\lambda_i(t)$— weight of Intersection i; (i=1,2,···,n)

$q_i(t)$—function of arriving vehicles in green time-phase;

$r_i(t)$— red time of intersection i;

a—minimum of green time
b—maximum of green time

6.2 Key intersection model

Select one or several intersections as key intersections, and the signal controlling of the remaining intersections are mainly determined by selected key intersections. The distance between neighboring intersections, the volume, mean traffic speed are also in consideration. It is simple in case of one intersection, when two or more intersections are selected as key intersections, the circumstance could be more complex. It is prosperous that two key intersections represent most cases.

There are 5 possible layouts which are shown in Fig. 7 in case of two key intersections.

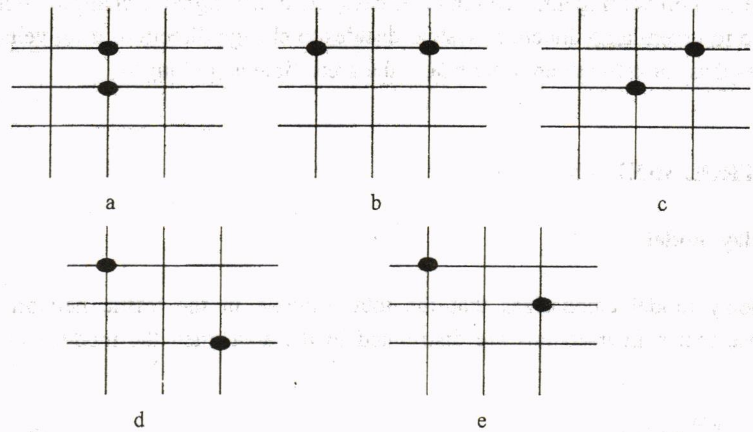


Fig. 6 possible layout of two key intersections

Corresponding controlling strategies are listed in Table 7.

Table 7: Control strategy of two key intersections

No.	Control strategy
A	Consolidated time-phase in neighboring intersections
B	Consolidated time-phase in neighboring intersections
C	Interlaced time-phase in neighboring intersections
D	Interlaced time-phase in neighboring intersections
E	Interlaced time-phase in neighboring intersections

7. CONCLUSION

Neural network fuzzy controlling of traffic actuated signal is discussed in this paper, according to input parameters, such as ga, ra and wt, firstly the control system decide whether it is necessary to change direction, then calculate the prolonged green time in case of no changing time-phase. It is proved by simulation that the method is obvious advantageous. The followings are its main advantages over other methods:

First, by contrast to traditional fixed-time method, the ANN one is more adaptable in determine the green time. So the delay in intersections is greatly reduced.

Second, the method is fair and valid, and so it prevents the radical behaviors of the drivers.

Third, combining of fuzzy logic and radial basis function network enhances the cluster accuracy and velocity of computing dramatically.

Fourth, for the input of the system is from real time sampling data and there is no need for predicting, it is good in real time performance.

In the same time, we make some research in the field of area control, two models are presented in the final part.

8. REFERENCES

[1] Dongling Xu. (1994)Fuzzy controlling and neural network realization of traffic system. **Information and control, Vol. 21 ,No. 2,**74~78.

[2] Zhiyong Liu. (1999)Multi-phases fuzzy control of single intersection. **Information and control, Vol. 28 ,No. 6,** 453~457.

[3] Shuntian Lou. (1999)**System analyses & designing based on MATLAB—Neural Network**. Xi'an Electron Science & Technology University Press,

[4] Puyin Liu. (1998)**Fuzzy Theories and Its Applications**. National Defense Science & Technology University Press.

[5] Zhiqiang Su.Researches (2000)On Fuzzy Actuated Controlling Mode. Civil & Water Conservancy **Engineering Periodical of China, Vol. 11,No. 2,** 365~376.

[6] Wei Wei. (1995)**Intelligent Control Technology**. Mechanics Industrial Press.

[7]John Spence,R.A. Vincent. (1995)Benefits Of Mova Control At A Partially signaled Roundabout. **Traffic Engineering & Control, July/August,**383～385.

[8] Teruki Sigitani, Youji Liguni, (1999) Hagime Maeda. Image Interpolation For Progressive Transmission By Using Radial Basis Function Networks. **Neural Networks(IEEE),March,**381-390.