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區域交通網路口號誌之智慧型控制(2/2)

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行政院國家科學委員會專題研究計畫結案報告

區域交通網路口號誌之智慧型控制(2/2)
Intelligent Traffic Junction Signal Control for a Junction Group

計畫編號：NSC94-2213-E-216-003

執行期限：94 年 8 月 1 日至 95 年 7 月 31 日

主持人：周智勳　　中華大學資訊工程系

***Abstract* - In this project, a traffic junction signal controller (TJSC) for a junction group is proposed. The design procedure contains two parts: the construction of the initial fuzzy TJSC and the application of the genetic algorithm to tune the parameters of the fuzzy TJSC. Simulation results with respect to 2×2 and 3×3 junction groups display the satisfactory performances of the proposed controller.**

I. INTRODUCTION

Due to the economic development, the increases of populations and vehicles make the urban traffic jam more and more serious. The congested traffic wastes time and energy, populates environment, and hinders the economic development, which reduces the quality of our life. Traditional fixed-cycle traffic junction signal controllers [1, 2], i.e., constant time ratio of green phase in traffic signal cycle, are unable to give a satisfactory performance when the traffic load is heavy. It is necessary to develop an automatic system [2, 3], managing the light phases according to the traffic loads, in place of the fixed-cycled as well as the police manpower.

Modern intelligent controllers, designed by using fuzzy logic, genetic algorithm and neural networks, have the characteristics of integrating the expert's knowledge, robust to uncertainty and model-free. They were extensively applied in many fields [4-7] including the traffic junction signal control. The most pioneering study was proposed by Pappis and Mamdani [8] and was extended by Nakatsuyama[9], Favilla [10]. Traffic junction signal controllers (TJSCs) can be categorized into two types, a single arterial road and a traffic junction group, depending on the complexity of the junction topology.

Traffic signal control of a junction group is much more complex than the arterial one [11]. The researches about it are still few, of which fuzzy logic [12-14], genetic algorithm [15-16] and neural networks [16-17] are the artificial intelligence approaches. In addition to the interrelation between junctions, much more factors such as the turns of vehicles, the topology of the junctions are needed to consider.

One of the main purposes of designing a TJSC is to replace the manpower of the traffic police. So a TJSC can be viewed as an expert system for enhancing the traffic flow. The fuzzy logic theory is very suitable for designing such a controller. The interrelations between traffic junctions, however, make the design procedure for a junction group much more harder. So in this study, not only the fuzzy logic theory but also the genetic algorithm is applied in the development of an intelligent TJSC.

The remaining of this report is organized as follows. Section 2 describes the simulation environment. The developed approach for TJSC design is proposed in section 3. Simulation results are shown in section 4. Section 5 gives the conclusion.

II. THE SIMULATION ENVIRONMENT

In this study, a parabolic function is utilized as the probability index to simulate the vehicle movement of each lane, and four sensors around each junction are used to acquire the vehicles flow data.

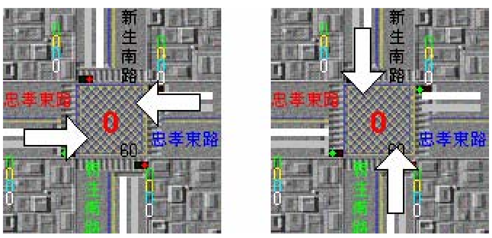
A. *The Traffic Model*

To model the vehicle flow, a parabolic equation $f(t) = at^2 + bt + c$ is applied to determine the arrival of a vehicle over a time unit (1 sec). Assume the vehicle number of a particular lane over some fixed time interval T be VN, the maximum flow occurs at time $T/2$, and the initial condition $f(0)$ is given, then the three parameters, a, b, and c, can be obtained. The procedure for determining the vehicle occurrences of each lane is as follows:

1. For each traffic junction, let the total vehicles of a direction over time interval T be TV, then the VN of each lane in the time interval is about TV/N. (N is the number of lanes in the direction).
2. The probability threshold at time T' is $f(T')$.
3. Generate a random number $r \in [0,1]$, if $r < f(T')$ then one vehicle occurs at the time unit, else none.

B. *The Simulation Environment*

Each junction is composed of four ways: east, west, north and south directions (See Fig. 1). Four data of each direction are measured. They are queue length, vehicle's waiting time, total vehicles generated from the direction and total vehicles pass through the junction. In addition to the adjustable green light and red light phases, the yellow light phase is set as 3 seconds. Following is the detailed procedure for simulating a vehicle passing:



(a) East-West direction (b) North-South direction

Fig.1 The composition of a junction

1. For an observed junction, determine whether a vehicle comes from some lane by using the parabolic probability index.
2. The road length of each direction is defined by time interval. A length of 18 seconds means that a vehicle must spend 18 seconds to drive through the road.
3. As the vehicle arrives at the junction and waits for passing through, the queue length and waiting time are recorded.
4. If the junction is in green light phase and the front vehicles are passing through, then this vehicle will also pass, otherwise keep waiting.
5. Calculate the turn probability (left turn, right turn or forward), determine the turn direction of the vehicle.
6. If the vehicle leaves the junction group then end, else repeat steps 2 to 6.

C. *Sensor Detecting Method for Vehicle Flow*

Four sensors are set around each junction (see Fig. 2). The totally passing vehicles and the turn probability can then be calculated. For example of junction B, the accumulated entering vehicles of the east-west direction (*aev_ew*) at time t can be detected by sensors c1 and a3:

$$aev\_ew(t) = av_{c1}(t) + av_{a3}(t), \tag{1}$$

where $av_{kj}(t)$ denotes the accumulative vehicles passing through sensor j of junction k at time t. The accumulated leaving vehicles of the east-west direction (*alv_ew*) can be detected by sensors b0, b1, b2 and b3:

$$alv\_ew(t) = av_{b0}(t) + av_{b1}(t) + av_{b2}(t) + av_{b3}(t), \tag{2}$$

then

$$\Delta v(t) = alv\_ew(t) - aev\_ew(t), \tag{3}$$

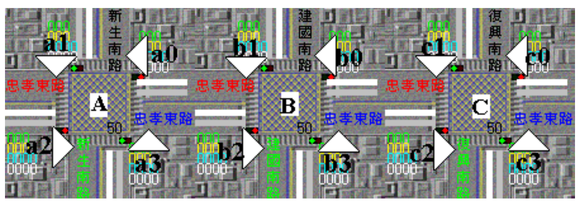
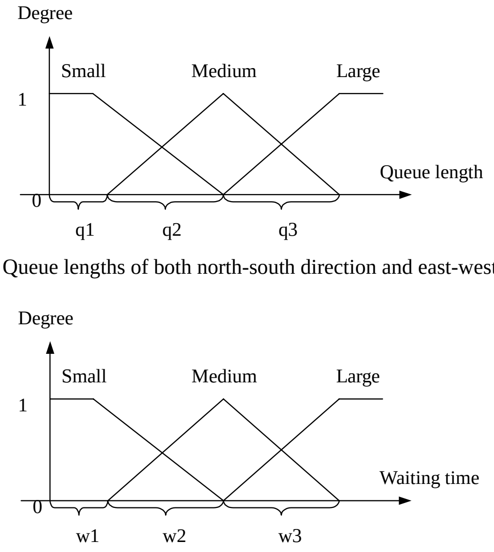


Fig. 2 Sensor locations



(a) Queue lengths of both north-south direction and east-west direction

(b) Waiting time of both north-south phase and east-west phase

Fig. 3 Membership functions of the input fuzzy variables

denotes the number of vehicles stop at ($\Delta v(t) < 0$) or come from ($\Delta v(t) > 0$) the region between junctions *A* and *C*. The accumulative vehicles come from east and west directions are $av_{c1}(t) + \Delta v(t)/2$ and $av_{a3}(t) + \Delta v(t)/2$. The turn probabilities are $av_{bi}(t)/aev\_ew(t)$ for north ($i = 0$), west ($i = 1$), south ($i = 2$) and east ($i = 3$) directions.

III. Fuzzy Genetic Algorithm Approach for the TJSC Design of a Junction Group

The proposed hybrid system integrates the fuzzy logic system and the genetic searching algorithm. We first describe the fuzzy logic part and then explain the application of genetic algorithm to search the parameters of the expert system.

A. The Fuzzy Logic Part of the Hybrid TJSC

In constructing the fuzzy logic system, queen lengths and waiting times of both directions of all junctions are considered. The membership functions for both queue length and waiting time are shown in Fig. 3, in which three fuzzy sets, Small (light load), Medium (middle load) and Large (heavy load), are defined. For output fuzzy variable, the modification rate, seven fuzzy singletons called NL (negative large), NM (negative medium), NS (negative small), ZE (approximately zero), PS (positive small), PM (positive medium) and PL (positive large) are defined as shown in Fig. 4. All the parameters used in these membership functions will be determined by applying the genetic algorithm.

By using the above membership functions, the fuzzy control rule for each junction can be constructed such as

If max(N_Q, S_Q) is (L, M or S),
max(N_W, S_W) is (L, M or S),
max(E_Q, W_Q) is (L, M or S),
and max(E_W, W_W is (L, M or S),
then the green-light phase of the north-south direction is extended (NL, NM, NS, ZE, PS, PM or PL).

The terms N_W, S_W, E_W and W_W denote the waiting time of north, south, east and west direction, respectively. Since the junctions are managed individually by the hybrid TJSC, the expression max(N_Q, S_Q) compute the maximum value of N_Q and S_Q of the corresponding junction. By this way the green-light ratio of each junction is adjusted according to its traffic status so that the junction group is managed in an asynchronous manner.

B. The Genetic Algorithm Part of the Hybrid TJSC

There are eighty-one possible rules, which are too complicated for human being to construct well. So the genetic algorithm is applied to solve it. That is, to optimally fulfill the fuzzy rule table shown in Table I. Refer to Figs. 3 and 4, there are 9 parameters, q1, q2, q3, w1, w2, w3, e1, e2 and e3, used in the membership functions. Adding the 81 empty consequent parts, r_i, $i = 1,2,...,81$, of the rules in Table I, there are 90 unknowns to be determined by the genetic algorithm.

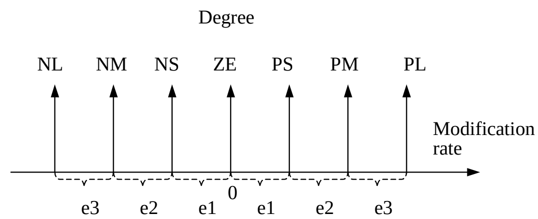


Fig. 4 Membership function of the output fuzzy variable

Table I Empty fuzzy rule table

		max(E_Q,W_Q)/max(E_W,W_W)								
		L/L	L/M	L/S	M/L	M/M	M/S	S/L	S/M	S/S
max(N_Q,S_Q)/max(N_W,S_W)	L/L									
	L/M									
	L/S									
	M/L									
	M/M									
	M/S									
	S/L									
	S/M									
	S/S									

For the applied genetic algorithm, the population size is 20, and the individual is coded as shown in Fig. 5. Among the parameters in Fig. 5, q1, q2, q3, w1, w2 and w3 are coded by using 8 bits each, the parameters e1, e2 and e3 are 6 bits each, while 3 bits are used to code each of r_i , $i = 1,2,...,81$. Since there are seven possible fuzzy sets in the consequent parts of the rules, the three bits used to represent the consequent part r_i has the mapping relation as shown in Table II.

To enhance the evolution, the rule part of one of the 20 initial individuals is initialized intuitively as the one shown in Table III. Setting such an initial individual has the purpose of ensuring an acceptable fitness value at the first generation. The reproduction process at every generation is accomplished by saving the 10 top-ranking individuals with the rest 10 replaced by new individuals. The operations of the genetic operators are described in details in the following. For crossover operation, a binary individual *S* is randomly generated to determine the inheritance of the parents' genes. Let the four strings *A*, *B*, *C* and *D* denote the parent and child individuals. The crossover operation is defined by the following equations.

$$C_i = \begin{cases} A_i, \text{ if } S_i = 0 \\ B_i, \text{ if } S_i = 1 \end{cases}, \; i = 1, 2, \ldots, 24 \cdot N \tag{4}$$

$$D_i = \overline{C_i}\,, \; i = 1,2,3,...,24 \cdot N\,, \tag{5}$$

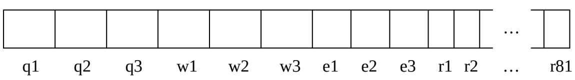


Fig. 5 Coding of the individual

Table II Code mapping of r_i

Coding	Fuzzy set
000	ZE
001	NS
010	NM
011	NL
100	ZE
101	PS
110	PM
111	PL

In this procedure, one parent is selected from the 10 top-ranking individuals and the other is randomly selected from the remaining in the population. The child individuals replaced two of the 10 down-ranking individuals. To accomplish the mutation process, some individuals are randomly selected from the population for duplication. The mutation operation is achieved by randomly altering the binary bits of the duplicated individuals. These new individuals replace some of the 10 down-ranking individuals. Both of the crossover and mutation processes are reiterated if a duplicated child appears. Besides, a new individual is randomly generated to replace one of the 10 down-ranking individuals at every generation to increase the ability of avoiding the premature convergence.

The termination condition is defined according to the number of junctions. Since the individual length is equal to 24 times of the junction number, the size of the search space is proportional to the junction number. In this study, the termination condition is set as 100 generations for 2×2 case and 250 generations for 3×3 case.

Table III The specific initial individual

$$q1\; q2\; q3\; w1\; w2\; w3\; e1\; e2\; e3\; \underbrace{r_1 \cdots r_{81}}$$

		max(E_Q,W_Q)/max(E_W,W_W)								
		L/L	**L/M**	**L/S**	**M/L**	**M/M**	**M/S**	**S/L**	**S/M**	**S/S**
max(N_Q,S_Q)/max(N_W,S_W)	**L/L**	ZE	ZE	ZE	PS	PS	PS	PM	PM	PM
	L/M	ZE	ZE	ZE	PS	PS	PS	PM	PM	PM
	L/S	ZE	ZE	ZE	PS	PS	PS	PM	PM	PM
	M/L	NS	NS	NS	ZE	ZE	ZE	PS	PS	PS
	M/M	NS	NS	NS	ZE	ZE	ZE	PS	PS	PS
	M/S	NS	NS	NS	ZE	ZE	ZE	PS	PS	PS
	S/L	NM	NM	NM	NS	NS	NS	ZE	ZE	ZE
	S/M	NM	NM	NM	NS	NS	NS	ZE	ZE	ZE
	S/S	NM	NM	NM	NS	NS	NS	ZE	ZE	ZE

IV. EXPERIMENTAL RESULTS

Two junction groups with topology 2×2 and 3×3 as shown in Figs. 5 and 6 are applied in the simulations. The 2×2 junction group is composed of 忠孝東路(Zhong Xiao East Rd.), 仁愛路 (Ren Ai Rd.), 新生南路 (Xin Sheng South Rd.) and 建國南路 (Jian Guo South Rd.). For 3×3 case, two more roads, 信義路 (Xin Yi Rd.) and 復興南路 (Fu Xin South Rd.), are included. The traffic data for both 2×2 and 3×3 cases are shown in Tables IV and V, which contain the road name, the lane number, the lengths between junctions, the expected vehicle number and the turn probabilities. These traffic data were acquired from the local government. The performance of the proposed approach is compared with that of the fixed-ratio type. The performance index is defined as a function of the maximum queue length, maximum waiting time, average queue length and average waiting time of the junctions as

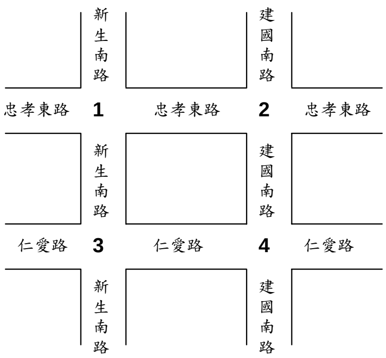


Fig. 5 The applied 2×2 junction groups

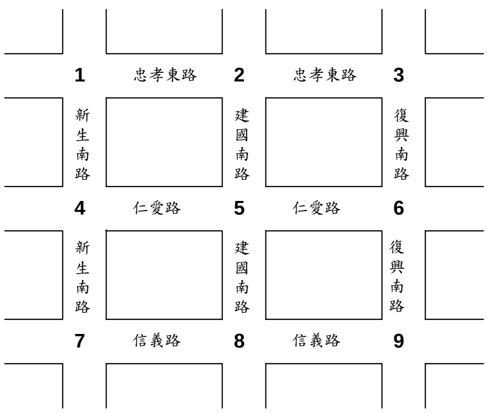


Fig. 5 The applied 3×3 junction groups

Table IV The simulation data - 2×2 junction group.

Junction	Road name	Lanes	Length of the direction	Expected vehicle number	Connected junction number	probability	
						Turn right	Go straight
1	新生南路	3	11	4070	None	0.11	0.12
	忠孝東路	3	12	1700	None	0.25	0.33
	新生南路	3	13	7000	2	0.12	0.35
	忠孝東路	3	14	1500	1	0.18	0.25
2	建國南路	3	11	4300	None	0.11	0.12
	忠孝東路	3	12	4500	0	0.33	0.45
	建國南路	3	13	2300	3	0.32	0.31
	忠孝東路	3	14	1700	None	0.44	0.19
3	新生南路	3	11	1630	0	0.11	0.12
	仁愛路	3	12	2200	None	0.33	0.45
	新生南路	3	13	250	None	0.32	0.31
	仁愛路	3	14	4400	3	0.44	0.19
4	建國南路	3	11	4300	1	0.32	0.41
	仁愛路	3	12	100	2	0.31	0.44
	建國南路	3	13	5600	None	0.32	0.31
	仁愛路	3	14	4000	None	0.18	0.35

Table V The simulation data - 3×3 junction group

Junction	Road	Lane number	Length of the direction	Expected vehicle number	Connected junction number	probability	
						Turn right	Go straight
1	新生南路	3	15	7320	None	0.09	0.91
	忠孝東路	3	15	5284	None	0.16	0.84
	新生南路	3	15	0	3	0.23	0.77
	忠孝東路	3	15	0	1	0.08	0.92
2	建國南路	3	15	6062	None	0.35	0.64
	忠孝東路	3	15	0	0	0.17	0.83
	建國南路	3	15	0	4	0.20	0.80
	忠孝東路	3	15	0	2	0.24	0.76
3	復興南路	3	15	4122	None	0.09	0.91
	忠孝東路	3	15	0	1	0.10	0.90
	復興南路	3	15	0	5	0.06	0.94
	忠孝東路	3	15	4793	None	0.09	0.90
4	新生南路	3	15	0	0	0.29	0.71
	仁愛路	3	15	1064	None	0.09	0.91
	新生南路	3	15	0	6	0	0.71
	仁愛路	3	15	0	4	0.16	0.71
5	建國南路	3	15	0	1	0.61	0.39
	仁愛路	3	15	0	3	0.01	0.99
	建國南路	3	15	0	7	0	0.66
	仁愛路	3	15	0	5	0.32	0.60
6	復興南路	3	15	0	2	0.26	0.74
	仁愛路	3	15	0	4	0.01	0.99
	復興南路	3	15	0	8	0	0.74
	仁愛路	3	15	9261	None	0.07	0.85
7	新生南路	3	15	0	3	0	0.76
	信義路	3	15	6509	None	0.02	0.81
	新生南路	3	15	5973	None	0.15	0.85
	信義路	3	15	0	7	0.01	0.99
8	建國南路	3	15	0	4	0	0.13
	信義路	3	15	0	6	0.21	0.70
	建國南路	3	15	6269	None	0.21	0.78
	信義路	3	15	0	8	0.21	0.79
9	復興南路	3	15	0	5	0.19	0.80
	信義路	3	15	0	7	0.06	0.94
	復興南路	3	15	4680	None	0	0.70
	信義路	3	15	2152	None	0.26	0.74

Table VI The comparison between the hybrid approaches and the fixed-ratio method.

(a) The 2×2 case.

	MaxQueue	MaxWait	AvgQueue	AvgWait	Fitness
Fixed-ratio	2641	581	209.2	9.2	3603
Hybrid	613	199	72.8	0.8	900

(b) The 3×3 case.

	MaxQueue	MaxWait	AvgQueue	AvgWait	Fitness
Fixed-ratio	1577	384	84.8	1.9	2084
Hybrid	1199	292	75.4	1.3	1591

$$\begin{aligned} &PI(Max\_queue, Max\_delay, Avg\_queue, Avg\_delay) \\ &= Max\_queue + Max\_delay \\ &\qquad + Avg\_queue + 20 \cdot Avg\_delay \end{aligned} \tag{6}$$

The simulation results upon the same traffic data are compared with those of the fixed ratio. The fixed ratio method is achieved by optimally setting the fixed green time ratio as well as the fixed light cycle. The comparison of simulation results of both 2×2 and 3×3 cases are shown in Table VI. Both results show that the hybrid method displays preferable performances in all indices. It not only balanced the traffic loads of different directions but also reduced the waiting time of each vehicle, making the traffic flow much more smoothly.

V. Conclusion

In this study, a hybrid TJSC for a junction group is proposed. The design procedure integrates the fuzzy system structure and the searching ability of genetic algorithm. The simulations are performed with respect to 2×2 and 3×3 junction groups. The performance of the proposed method is displayed by comparing with that of the fixed-ratio one.

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