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Study on Cooperative Vehicles Infrastructure Collision Avoidance in Unsignalized Intersection using Simplified Conflict Table

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Abstract: Focusing on the problem that accidents frequently happen in unsignalized intersection, this study is about the collision avoidance technology in unsignalized intersection based on cooperative vehicles infrastructure technology. First, a simplified conflict table model is established to solve the problem that the traditional conflict table algorithm has so many conflict points which make it difficult to implement and the confluence conflict in simplified model is resolved. Then, the virtual traffic light mechanism is introduced and the fuzzy control model of intersection collision avoidance is constructed using the traffic intensities of green and red phase as input and the extension time of green phase as output. Finally, based on the technology of RFID and Zigbee, the vehicle-road-center intelligent cooperative control platform is built and the algorithm validation is conducted on the platform. The result shows that the algorithm can effectively prevent the occurrence of traffic crashes in unsignalized intersection.

Key words: Cooperative vehicles infrastructure system, conflict table, fuzzy control, collision avoidance, unsignalized intersection

INTRODUCTION

Intersection is an important node in the road network and the accident occurred at the intersection in the United States accounted for 50% (FHA, 2004), 30% in urban road traffic in China (Guan, 2007), more than 20% in the EU personnel casualty accident (ERSO, 2012). In recent years, many scholars around the world carry out the study on collision avoidance in the unsignalized intersections utilizing the cooperative vehicles infrastructure technology. Morioka *et al*. (2000) adopt differential GPS and gyro to gain the information about precise position and velocity of test cars and warn the driver if the relative distance of the vehicles is less than the safety distance. Chan and Bougler (2005) investigated the fusion method of the detecting information about road traffic and vehicles and designed the intersection decision support systems with safety warning threshold. Bouraoui *et al*. (2006) proposed a new communication algorithm between cars based on Cybercars smart car, designed partial motion planner algorithm and carried out the multi-vehicle collaborative experiment in intersection through CyCab platform. Ammoun and Nashashibi (2009) proposed collision prediction algorithm between vehicles, utilized GPS and Wife to gain and share vehicle motion state information and adopted Kalman filter algorithm to predict vehicles running track. Alonso *et al*. (2011) studied the cooperative driving strategy between three vehicles and proposed two kinds of vehicles conflict resolution decision-making algorithms in unsignalized intersections based on conflict table and access priority. The experiments show that the vehicle can obtain the expected driving locus under the two algorithms. Guo (2012) designed the game theory coordination algorithm for the conflict vehicles in unsignalized intersections and utilized electromagnetic navigation smart car to verify the reliability of the algorithm. Basma *et al*. (2011) adopted the magnetic sensor to obtain the information of vehicles on the road such as position, velocity and acceleration. The information can then be transmitted to the intersection base station and used for trajectory prediction of vehicles, with which accidents can be detected and corresponding control information can be generated. Sun (2007) proposed a multi-vehicle coordination algorithm based on the conflict table in intersections. The driving rules of the conflict table were derived from 3 different situations, a vehicle in conflict zone, a vehicle in a lane and many vehicles in a lane. Besides, passage efficiencies of

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T-shaped junctions and crossroads were analyzed and compared based on the simulation on INTERSIM platform. Wenjuan (2012) established a rule base for unsignalized intersections by utilizing conflict table method. According to her theory, conflicts can be resolved by comparing the priority of vehicles. Simulation was performed on Prescan to verify the algorithm as well.

Reviewing the literature, vehicle infrastructure cooperative collision avoidance system is divided into two modes, central control station and vehicle-vehicle cooperative control. Most of the collision avoidance system is by the vehicle-vehicle communication mode but the control algorithm is complex in the large traffic and the research is in its infancy involving just 2 or 3 vehicles. The central control station mode can regulate the vehicles in the overall through the wireless communication between the control station and the vehicle and effectively solve the large traffic problem. In the algorithm, the conflict table algorithm is used more often which has characteristics of high security and good controllability. But there are still some problems: the conflict points are as many as 32 which will lead to the situation, when a lane is occupied, the other lanes conflicted with it are impassable; Furthermore, the frequently switch of lanes resulting from the rules of first-come, first-pass will cause a large waste of time; in addition, the intersection collision avoidance system in literatures is mostly achieved through simulation and does not have the actual verification. Therefore, in order to solve the above problems, some work has been done. First of all, the conflict table is simplified by dividing the intersection into 2 parts, east-west direction and north-south direction and establishing the rules of the high-priority passage for non-conflict vehicles. Second of all, aiming at avoiding the collision of vehicles from the cross directions and reducing the intersection delay time, a fuzzy control algorithm (Trabia *et al*., 1999; Xizheng and Yaonan, 2011; Yang *et al*., 2012) based on red-green light model is introduced to adaptively optimize the duration of the phases of 2 lights. Last but not least, a small vehicle-road-center intelligent cooperative control platform is built to validate the algorithm.

CONFLICT TABLE SIMPLIFYING

Traditional conflict table: The traffic from different directions converges in intersection, where the overlapping portion of the east-west and north-south direction forms the conflict zone. In conflict table algorithm, the passage of vehicles in intersections is regarded as a competition where different vehicles enter the conflict zones and compete for the access lines. From this angle, the conflicts can be avoided by rationally formulating and planning the access order of the vehicles from each line. Consequently, the collision in the intersection can be avoided. When the vehicles pass through the intersection, there will be three different routes (turn left, go straight, turn right) and the driving route from different directions will conflict. Figure 1 shows the conflict point distribution of intersection for each

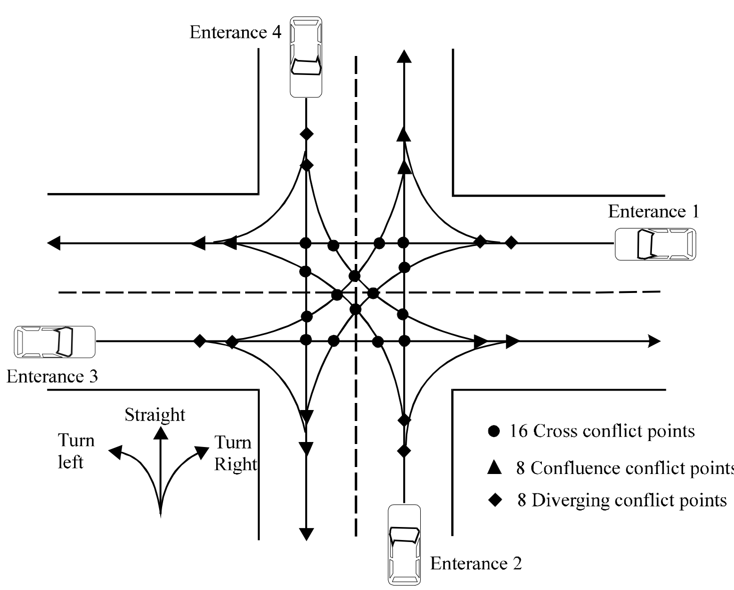

Fig. 1: Distribution map of conflict point in intersection

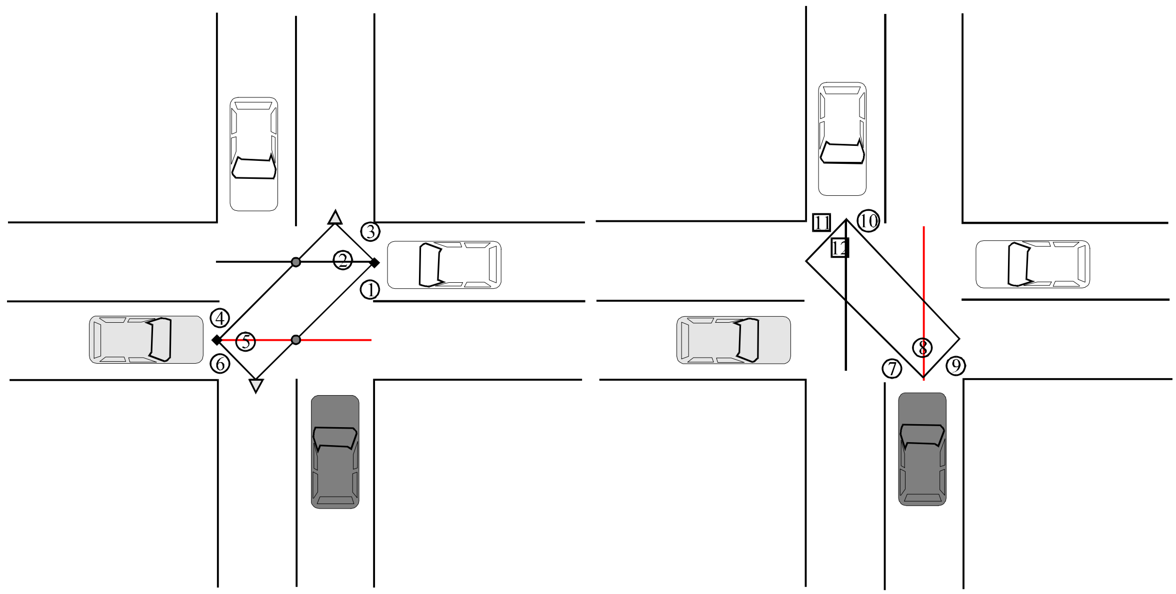

Fig. 2: Conflict distributions of vehicles from east-west and south-north direction

route. In the intersection, there are 4 entrances from 4 directions, east, west, south and north and vehicles from each entrance have three routes. Hence, there will be 12 different lines totally which produce 32 conflict points. These 32 conflict points consist of 16 cross conflict points, 8 confluence conflict points and 8 diverging conflict points.

Simplified conflict table: As Fig. 1 shows, since there are many conflict points in the intersection, the conflict rule becomes complex. The rule of first-come, first-served will cause the frequent switching of the occupied lane, whereas the rule of conflict-free vehicle first-served will cause the problem that the one driveway resources will be always occupied and the vehicle from the other lane cannot pass. Therefore, according to the traffic light model, the intersection is divided into two phases-east-west and south-north and it will simplify the intersection model and greatly reduce the probability of occurrence of the above problems. Simplified conflict points of the vehicles from east-west and south-north direction are shown in Fig. 2. There are 6 conflict points for each direction, including 2 in each cross, confluence and split and the total number of the conflict point is only 12 which is convenient for the follow-up research of the conflict resolution.

There are three driving directions, turn left, go straight and turn right (without the situation of U-turn), for each vehicle at intersection; There are three driving directions for each vehicle at intersections, turning left and right and going straight (without the situation of U-turn). Thus, all possibilities of vehicles from 4 directions, north, south, west and east, can be indicated by the number 1-12. More specifically, vehicles that are coming from 4 directions and turning left can be indicated by 1, 4, 7 and 10 whereas, turning-right vehicles can be indicated by 3, 6, 9 and 12. Finally, vehicles that are going straight can be indicated by 2, 5, 8 and 11:

- Use number 0, 1, 2 to indicate the means of conflict. 0 is conflict-free; 1 is cross conflict; 2 is confluence conflict
- When there is a conflict between turning around cars and going straight cars, going straight cars will have the high priority, indicated by positive number while turning around is indicated by negative number; confluence and cross conflict are treated in the same way
- It is not considered as a conflict if multiple vehicles enter the same route

Based on the above rules, the conflict tables of east-west direction and south-north direction are established which is shown in Table 1 and 2.

Conflict judgment based on the resource lock: There are 12 kinds of routes when vehicles go through the intersection. Each route can be seen as a resource and a resource lock is set to each resource to manage the driveway resources, so the system totally has 12 resource locks. Conflicts in the intersection could be determined by resource lock and conflict matrix.

The resource lock matrixes of east-west and north-south direction are respectively established. They are represented by R, R = [r1, r2, r3, r4, r5, r6], in which 0 represents that the lane is idle, whereas 1 represents the driveway is occupied. The vehicle conflicts matrixes represented by C, C = [c1 c2 c3 c4 c5 c6], whose values can be obtained from the conflict table. Collision can be judged by Eq. 1, where Co represents collision flag, 0 represents no conflict, 2 represents confluence conflict. When Co is 2, it means that this collision can be resolved according to the next section; whereas, the other value represents mixture of confluence and cross-conflict, the collision cannot be resolved; C' represents the transpose of conflicts matrix:

$$C_O = R \bullet C' \quad (1)$$

Table 1: Conflict table of cars on L1-L6 from east and west

	L1	L2	L3	L4	L5	L6
L1	0	0	0	0	-1	2
L2	0	0	0	1	0	0
L3	0	0	0	2	0	0
L4	0	-1	2	0	0	0
L5	1	0	0	0	0	0
L6	2	0	0	0	0	0

L1 to L6 are the routes in Fig. 2. Values represent the conflict type

Table 2: Conflict table of cars on L7-L12 from north and south

	L7	L8	L9	L10	L11	L12
L7	0	0	0	0	-1	2
L8	0	0	0	1	0	0
L9	0	0	0	2	0	0
L10	0	-1	2	0	0	0
L11	1	0	0	0	0	0
L12	2	0	0	0	0	0

L7 to L12 are the routes in Fig. 2. Values represent the conflict type

Confluence conflict resolution turning right and left: Concerning conflicts in intersection, cross conflicts resolution is more complex; therefore, the confluence conflict resolution is studied first in this study. The study is based on the small smart car model and the assumptions are as follows:

- Consider its characteristics of low speed and quick startup and assume the small smart car goes through the intersection at a uniform speed
- When the smart car goes through the intersection, the initial speed is $v = 10$ cm sec^{-1}

Confluence conflicts happening when turning left and right are shown in Fig. 3, where two cars turn left into the conflict zone and at the same time, a car turns right into the zone which probably causes a confluence conflict. The following conflict resolution is based on this scene.

Vehicles in the same route are not considered to have conflicts, so the confluence conflict resolution only needs to consider the vehicles in its confluence route. The distance of vehicles in conflict route from the confluence point are represented by L = [L1 L2······ Ln], where1, 2, N represent the number of vehicles in conflict zone sorted by the distance from the conflict point. l represents the distance between vehicles that are about to enter the conflict zone and the conflict point; l_{vhicle} represents the

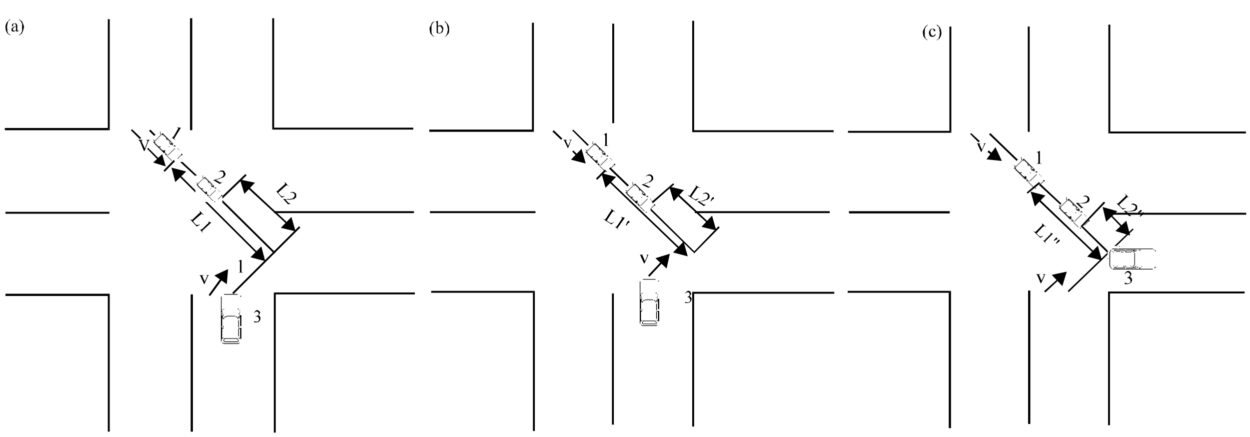

Fig. 3(a-c): Sketch Map of conflict resolution, (a) Vehicle is about to enter the conflict zone, (b) Head of vehicle reaches the point and (c) Rear for vehicle go through the conflict point length of the vehicle; t_1 and t_2 represent the time that the head and rear of vehicle go through the conflict point calculated by Eq. 2 and 3:

$$t_1 = l/v \tag{2}$$

$$T2 = (l+l_{vehicle})/v \tag{3}$$

When the head and rear of vehicle reaches conflict point, the distance of vehicle in conflict zone from the conflict point is represented by matrix L_1 and L_2, calculated by Eq. 4 and 5:

$$L_1 = L\text{-}v{\bullet}t_1 \tag{4}$$

$$L_2 = L\text{-}v{\bullet}t_2 \tag{5}$$

After the above calculations, the conflict resolution strategies can be determined by judging L_1 and L_1. Firstly, get the vehicles position information of the nearest vehicles in and out the conflict zone to the conflict point after t_1 and t_2.

After time t_1, the nearest vehicle in conflict zone in distance set L_1 to the conflict point is denoted as a: After time t_1, according to the distance set L_1, the vehicle that is closest to the conflict point among all vehicles in the conflict zone is denoted as a:

$$L_a = \min\{L1', L2'\cdots LM'\} = L_1^+ \text{ s.t. } L1', L2'\cdots Lm'>0 \tag{6}$$

According to the distance set L_1, the vehicle that is closest to the conflict point among all vehicles going out from the conflict zone is denoted as b:

$$L_b = \min\{Lm', L(m+1)'\cdots Ln'\} = L_1^- \text{ s.t. } Lm', L(m+1)'\cdots Ln'<0 \tag{7}$$

Similarly, determine the distance of vehicle c and d after time t_2:

$$L_c = \min\{L1'', L2''\cdots Lm''\} = L_2^+ \text{ s.t. } L1'', L2''\cdots Lm''>0 \tag{8}$$

$$L_d = \min\{Lm'', L(m+1)''\cdots Ln''\} = L_2^- \text{ s.t. } Lm'', L(m+1)''\cdots Ln''<0 \tag{9}$$

The condition where 2 cars are not crashing is shown in Eq. 10. The equation implies that after t_1, at which the head of vehicles reaches the conflict point, the minimum distance of vehicles in the conflict area from the conflict point should be greater than the provided distance. Moreover, after t_2, at which the rear of vehicles reaches the conflict point, the minimum distance of vehicles leaving the conflict area should be bigger than the provided distance as well:

$$\begin{cases} L_1^+ > (l_{vehicle}+l_{safe}) \\ L_1^- > (l_{vehicle}+l_{safe}) \\ L_2^+ > l_{safe} \\ L_2^- > (2*l_{vehicle}+l_{safe}) \end{cases} \tag{10}$$

If the distance does not meet the conditions in Eq. 10, then the conflict resolution is needed. The resolution strategy is to reduce the vehicle speed of vehicle a (according to formula Eq. 11), increase the vehicle speed of vehicle b (according to Eq. 12). In another word, it can reduce the vehicle speed that would hit the head of vehicle and increase the speed that would hit the rear of vehicle:

$$v_a < v - \frac{l_{vehicle}+l_{safe}-L_1^+}{t_1} \tag{11}$$

$$v_b > v + \frac{l_{vehicle}+l_{safe}-L_1^-}{t_1} \tag{12}$$

After using the above resolution policy, vehicle that is about to enter the conflict zone will go through the conflict zone between vehicle a and b; after the rear of the vehicle reaches the conflict point, a and b correspond to c and d, so it is not necessary to adjust the speed of c and d.

TRAFFIC LIGHTS MODEL BASED ON FUZZY CONTROL

Intersection model: The intersection studied is two-way-one-lane. Vehicles turning left, going straight and turning right at the same direction are in the same lane, so the requirements of the system can be met only by two phases. The four directions, east, south, west and north, are marked as 1, 2, 3 and 4, respectively. Based on vehicles-road cooperative system, it is convenient and efficient to acquire information of traffic flow, queue length and average waiting time of each direction in time interval Δt. The number of queuing vehicles d_i, the total waiting time tw_i in each direction and arriving vehicles c_i in unit interval time Δt can be computed through the control center database (i is direction 1, 2, 3, 4). Average waiting time (atw_i) is:

$$atw_i = \frac{tw_i}{d_i} \tag{13}$$

The arriving traffic flow of green light phase is defined as:

- If the green phase is east-west, then:

$$c = \max [c_1, c_3] \quad (14)$$

- If the green phase is south-north, then:

$$c = \max[c_2, c_4] \quad (15)$$

- Queue length of east-west is defined as:

$$d = \max [d_1, d_3] \quad (16)$$

- Average waiting time of east-west is:

$$atw = \max [atw_1, atw_3] \quad (17)$$

- Queue length of north-south is defined as:

$$d = \max [d_2, d_4] \quad (18)$$

- Average waiting time of north-south is:

$$atw = \max [atw_2, atw_4] \quad (19)$$

Fuzzy control method: According to the intersection traffic flow data, fuzzy controller determines whether to have an extension or termination of the current green light phase in the time interval $\Delta t = 10$ sec. In order to ensure that vehicles of the green light phase can go through the intersection smoothly, fuzzy controller begins to control at the beginning of green light phase $t_{min} = 20$ sec and total green light time is no more than $t_{max} = 60$ sec.

The traffic intensity of green light phase and red light phase can be obtained through fuzzy control, the green light time of extension or termination can be controlled through the traffic intensity of two directions. The traffic intensity of green light phase is determined by queue length d and arriving traffic flow c is expressed by triangular membership functions. Considering that the length of existing vehicles-road system entrance is 120 cm, the length of vehicles is 20 cm. Therefore, the domain is {0, 1, 2, 3, 4, 5, 6} and fuzzy language is {None, Less, Medium, Large}; Assignment table is shown as Table 3. Using the fuzzy language of d and c as input, the traffic intensity of green phase (TR_{green}) can be determined by fuzzy rules in Table 4 and fuzzy language is {None, Mild, Moderate, Serve}.

Traffic intensity of red light phase can be acquired through the quantity of queue d and average waiting time atw. The traffic intensity of red light phase is determined by the parameters d and atw expressed by triangular membership function. The assignment table of d is the same as queue length of green light phase, that is shown as Table 3. The domain of atw is {0, 10, 20, 30, 40, 50, 60} and fuzzy language is {None, Short, Medium, Long}; Assignment table is shown in Table 5. Using the language of d and atw as input, the traffic intensity of red light (TR_{red}) can be determined by fuzzy rules in Table 6.

After traffic intensity of green light phase and red light phase are determined, fuzzy controller determines whether to have an extension or termination on the current green light phase, by using the language of TR_{green} and TR_{red} in two directions as input, according to the fuzzy rules in Table 7.

Table 3: Assignment table of the fuzzy quantity of queue length and arriving traffic flow

	d/c veh/10 sec						
d	0	1	2	3	4	5	6
None	1	0.5	0	0.0	0	0.0	0
Less	0	0.5	1	0.5	0	0.0	0
Medium	0	0.0	0	0.5	1	0.5	0
Large	0	0.0	0	0.0	0	0.5	1

Table 4: Fuzzy rules of green light phase traffic intensity

	c			
d	None	Less	Medium	Large
None	None	Mild	Moderate	Serve
Less	Mild	Moderate	Serve	Serve
Medium	Moderate	Serve	Serve	Serve
Large	Serve	Serve	Serve	Serve

Table 5: Fuzzy quantity assigument table of average waiting time

	atw /s						
	0	10	20	30	40	50	60
None	1	0.5	0	0.0	0	0.0	0
Short	0	0.5	1	0.5	0	0.0	0
Medium	0	0.0	0	0.5	1	0.5	0
Long	0	0.0	0	0.0	0	0.5	1

Table 6: Fuzzy rules of red light phase traffic intensity

	dveh/10 sec			
atw	None	Less	Medium	Large
None	None	None	None	None
Short	Mild	Mild	Moderate	S
Medium	Moderate	Moderate	S	S
Long	S	S	S	S

Table 7: Fuzzy rules of traffic lights switch

	TR_{green}			
T_{Red}	None	Mild	Moderate	Serve
None	0	10	10	10
Mild	0	10	10	10
Moderate	0	5	10	10
Serve	0	5	5	10

Vehicles-road-center cooperative experiment system: In order to verify the effectiveness of the algorithm, the vehicle-road-central intelligence cooperative hardware simulation platform based on self-developed Radio Frequency Identification (RFID)© and Zigbee technology is built. Figure 4 and 5 represent vehicles-road-center control platform system diagram and physical map, respectively.

Vehicles-road-center cooperative experiment system consists of control center, intelligent car and digitized road, both defined based on RFID. Firstly, intelligent car can acquire the location information of digitized road through RFID identification technology. Secondly, road information, car's ID information and speed are sent to control center through Zigbee wireless communication by intelligent car. Thirdly, in order to overall regulate and control intelligent car, control center stores the information from intelligent car in corresponding data sheet. Finally, control center localizes the intelligent cars by enquiring established digitized road information and displays the information in system map (Fig. 6). Control center can compute the vehicles quantity arriving intersection, waiting time and other traffic information which will be used by fuzzy algorithm.

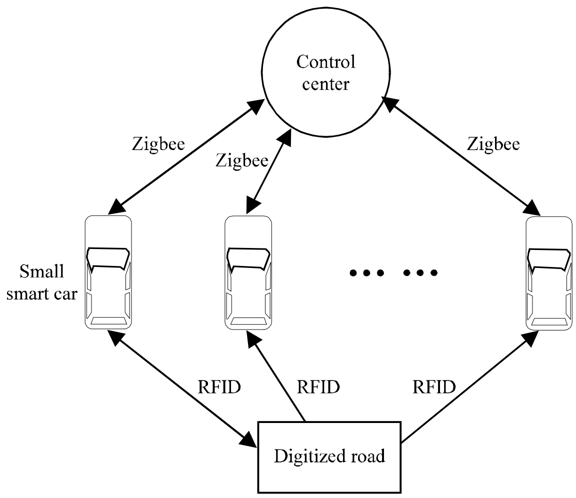

Fig. 4: Vehicles-road-center control platform system

Fig. 5: Platform physical map

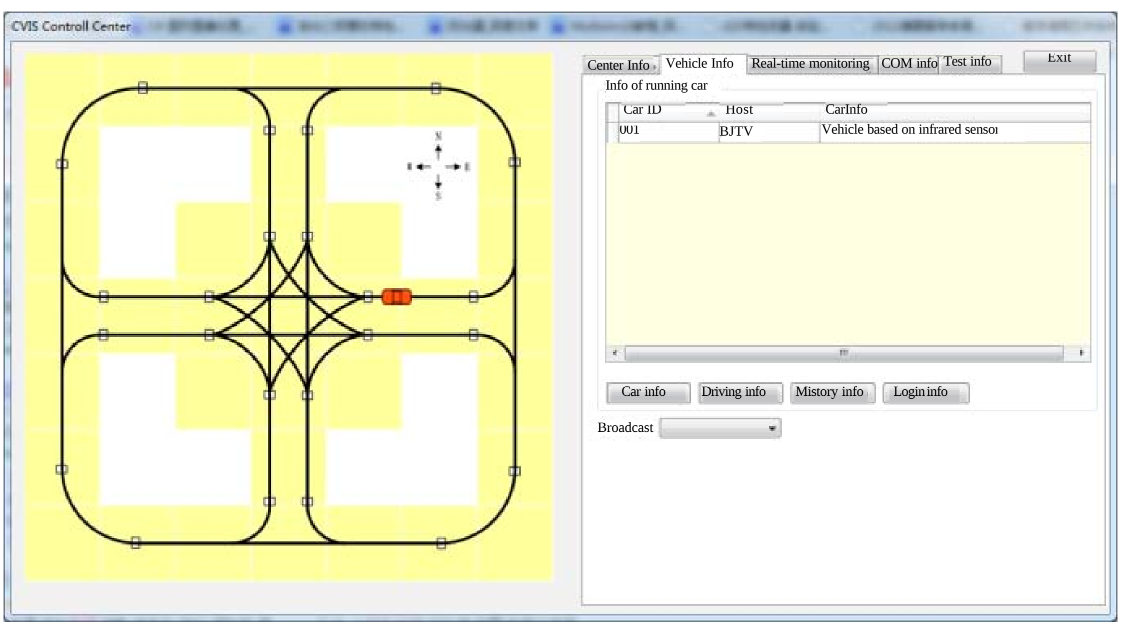

Fig. 6: Location of intelligent car

Verification of the traffic light fuzzy control algorithm: Width of the intersection is 1 m. The current green phrase is the east-west direction and the vehicles of north-south direction are waiting for green light under red light. Three vehicles are waiting for red light in south and north direction entrance in control system. Among them, the average waiting time of south entrance is 20 sec and the average waiting time of north entrance is 15 sec. At the moment, 2 vehicles arrived east entrance in 10 sec and 1 vehicle arrived west entrance in last 10 sec. So:

- **Traffic intensity of the green phase:** Green phase is for the east-west direction and the parameters can be shown as follows:

$$d_1 = 1,\ d_3 = 0;\ c_1 = 1,\ c_3 = 1;$$
$$d = \max\,[d_1, d_3] = 1;\ c = \max\,[c_1, c_3] = 1$$

The membership of fuzzy queue length is:

$$\mu_{None}(1) = 0.5;\ \mu_{Less}(1) = 0.5$$

The membership of arriving traffic flow in last 10 sec is:

$$\mu_{None}(1) = 0.5;\ \mu_{Less}(1) = 0.5$$

It is known that 4 control statements can be used by checking the control Table 4, so the traffic intensity of green phase (TR_{green}) are as follows:

$$\text{None} = \mu_{R1}(1,1) = \min\{\mu_{None}(1), \mu_{None}(1)\} = \min\{0.5, 0.5\} = 0.5$$

$$\text{Mild} = \mu_{R2}(1, 1) = \min\{\mu_{None}(1), \mu_{Less}(1)\} = \min\{0.5, 0.5\} = 0.5$$

$$\text{None} = \mu_{R2}(1, 1) = \min\{\mu_{None}(1), \mu_{Less}(1)\} = \min\{0.5, 0.5\} = 0.5$$

$$\text{Moderate} = \mu_{R4}(1, 1) = \min\{\mu_{Less}(1), \mu_{Less}(1)\} = \min\{0.5, 0.5\} = 0.5$$

The all membership of the traffic intensity of green phase "None", "Mild" and "Moderate" are 0.5.

- **Traffic intensity of the red phase:** Red phase is for the east-west direction and the parameters can be shown as follows:

$$d_2 = d_4 = 3,\ tw_2 = 20\text{ sec},\ tw_4 = 15\text{ sec};$$
$$d = \max\,[d_2, d_4] = 3;\ tw = \max\,[tw_2, tw_4] = 20$$

The membership of fuzzy queue length:

$$\mu_{Less}(3) = 0.5;\ \mu_{Medium}(3) = 0.5$$

The membership of waiting time:

$$\mu_{Short}(20) = 1$$

Through checking the control Table 6, the traffic intensity of red phase (TR_{red}) are:

$$\text{Mild} = \mu_{R1}(3, 20) = \min\{\mu_{Less}(3), \mu_{Short}(20)\} = \min\{0.5, 1\} = 0.5$$

$$\text{Mild} = \mu_{R2}(3, 20) = \min\{\mu_{Medium}(3), \mu_{Short}(20)\} = \min\{0.5, 1\} = 0.5$$

The traffic intensity of the red is "Mild" and its membership is 0.5.

- **Green delay time:** After acquiring the traffic intensity of the red and green, it is known that 3 control statements can be used through checking the Table 7. So, the delay time of each control statement and its membership are:

$$0 = \mu_{R1}(\text{None, Mild}) = \min\{0.5, 0.5\} = 0.5$$

$$10 = \mu_{R2}(\text{Mild, Mild}) = \min\{0.5, 0.5\} = 0.5$$

$$10 = \mu_{R3}(\text{Moderate, Mild}) = \min\{0.5, 0.5\} = 0.5$$

The green light delay time can be obtained by using weighted average method:

$$\Delta t_{green} = \frac{\sum_{i=1}^{n} \mu(u_i) u_i}{\sum_{i=1}^{n} \mu(u_i)} = 7\,\text{sec}$$

The result shows that the green phase will delay 7 sec which is less than the control interval 10 sec. Therefore, this result indicates that the algorithm can be used to realize the adaptive control in unsignalized intersection.

Verification of collision judgment and its resolution: The vehicle's speed is 10 cm sec^{-1} (constant speed) and the following two scenes are assumed to judge the collision and resolution.

Scene 1 (Conflict-free experiments): At this moment, there is a vehicle named vehicle 1 goesfrom east entrance in conflict zone, with destination direction 1 which means the second lane is occupied. So, the resource lock matrix

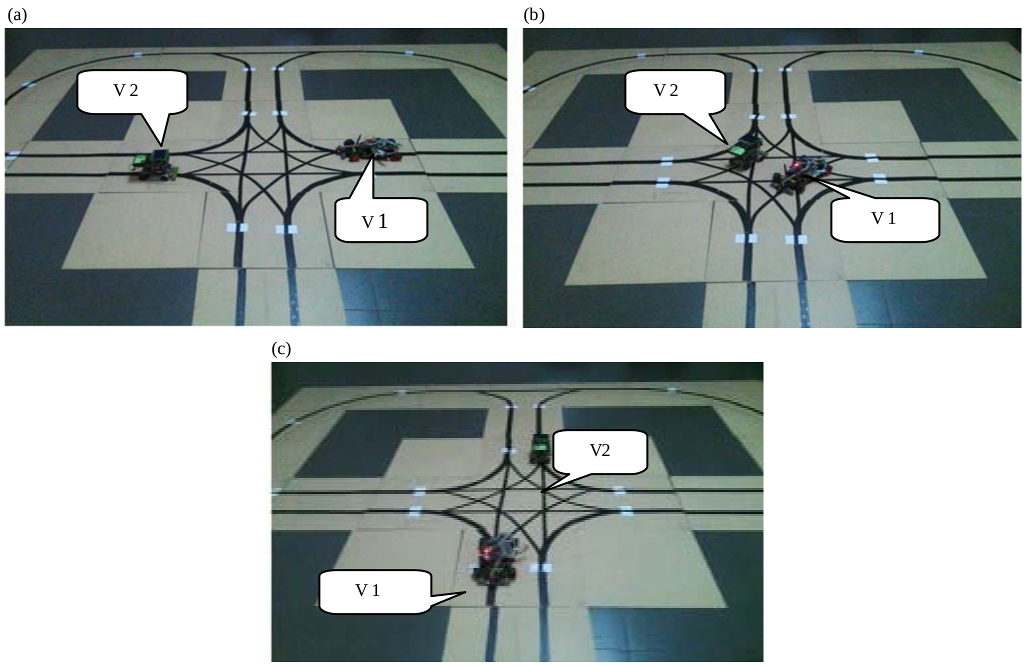

Fig. 7(a-c): Scene of conflict judgment, (a) Vehicle is about to enter the conflict zone, (b) Head of vehicle reaches the conflict point and (c) Rear of vehicle goes through the conflict point

of conflict zone lane is R = [1 0 0 0 0 0]. At the same time, there is a vehicle arrived from west entrance in conflict zone, named vehicle 2, whose route is 4 in Fig. 2. So, the conflict matrix of vehicle 2 is C_1 = [0 -1 2 0 0 0]. It is obtained that Co = 0 according to Eq. 1 which shows that there is no conflict, so the vehicle 2 goes through the conflict zone. The scene of the experiment is shown in Fig. 7.

Scene 2: The destination of vehicle 1 and vehicle 2 both have destination direction 1. The resource lock matrix of conflict zone is R = [1 0 0 0 0 0], the driving route of vehicle 3 is named 6 and the conflict matrix is C_1 = [2 0 0 0 0 0]. So, It is obtained that Co = 2 according to Eq. 1 which shows that conflict is the confluence conflict. According to the algorithm, the confluence conflict can be resolved as follows:

- The distance set of the vehicles from the conflict point in the conflict zone is L = {L_1, L_2} = {20, 55} the distance of vehicle 3 from the conflict points is l_1 = 30 cm; the length of vehicle is $l_{vehicle}$ = 30 cm; the safety length is l_{safe} = 10 cm. So:
- The time of the vehicle's head arriving the conflict point is:

$$t_1 = \frac{30}{10} = 3\text{sec}$$

- The time of the vehicle's tail arriving the conflict point is:

$$t_2 = \frac{30+20}{10} = 5\text{sec}$$

When the vehicle's head arrives at the conflict point, the location set of the vehicles from the conflict point in the conflict zone is L_1 = {-10, 25}.

When the vehicle's tail arrives at the conflict point, the location set of the vehicles from the conflict point in the conflict zone is L_2 = {-30, 5}.

According to Eq. 6-10, the following data can be obtained:

$$L_a = L_1^+ = 25; L_b = L_1^- = 10;\ L_c = L_2^+ = 5;\ L_d = L_2^- = 30$$

So:

$$l_{vehicle} + l_{safe} = 30 > L_1^+$$

If vehicles pass conflict zone at 10 cm sec^{-1}, there are existing dangers according to Eq. 10. According to Eq. 11, the conflict can be resolved and the speed of vehicle 2 is:

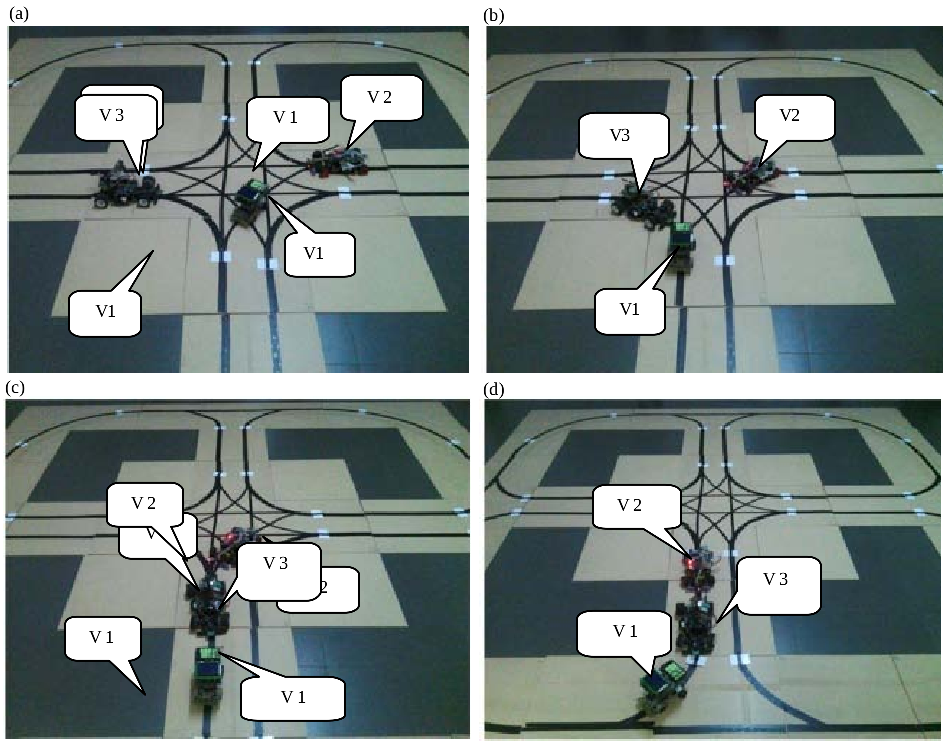

Fig. 8(a-d): Digest scene of conflict, (a) Vehicle is about to enter conflict zone, (b) Head of vehicle 3 reaches the conflict point, (c) Rear of vehicle 3 goes through the conflict point and (d) Three vehicles drive out of the conflict zone

$$v_a < 10 - \frac{20+10-25}{3} \approx 8\,\text{cm sec}^{-1}$$

At this moment, Vehicle 1 should accelerate. According to Eq. 12, the speed of vehicle 1 is:

$$v_b > 10 + \frac{20+10-10}{3} \approx 17\,\text{cm sec}^{-1}$$

The scene of the resolution experiment is shown in Fig. 8.

DISCUSSION

The result in verification of the traffic light fuzzy control algorithm shows that the algorithm can be applied to adaptive control which can meet the demand of the collision avoidance system. Figure 7 and 8 show that the system can be applied to realize the collision judgment and conflict resolution which indicates the algorithm and the system both have better reliability.

There are many studies on the collision avoidance system in unsignalized intersection which shows that the cooperative vehicle-infrastructure style can realize collision avoidance. The conflict table algorithm is discussed by Sun (2007). Wenjuan (2012) adopts simulation to verify the conflict table algorithm but the conflict point is up to 32. Therefore, the conflict table is simplified to one with only 12 conflict points in this study. At last, the small vehicles-road-center cooperative control platform is built based on RFID and Zigbee which is different from any other collision avoidance systems.

CONCLUSION

This study involves following work for the collision avoidance problem in unsignalized intersection:

- The conflict model of unsignalized intersection is simplified and the conflict table rules are set
- The virtual red-green light model is introduced to establish the fuzzy control model of intersection collision avoidance, in which inputs are traffic intensities of light phases while outputs are durations of light phases. The target is to avoid the cross-direction collision in the simplified model and optimize the waiting time in the intersection

- Based on the technology of RFID and Zigbee, a set of small vehicles-road-center cooperative control platform is built, where the small intelligent car can read the road information and do the information exchange with the center. The algorithm validation is performed on this platform and the result shows that the algorithm and system both have better reliability

The study can provide guidance for practical applications, but the vehicle in this intersection is controlled by ideal uniform speed model. Hence, the acceleration and deceleration process need to be considered to improve the vehicle model in the future.

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