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Study on Collaborative Control of Vehicle System at Road Intersection in Dynamic Competitive Environment

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Abstract. By analyzing the conflict form of the road intersection, the time and space trajectory diagram was used to analyze the area where the vehicle may collide through the intersection. The vehicle coordination control model of the road intersection was established by using the safety index and the fastness index weighted processing. The model was used to construct the fitness function by using the penalty function method. The particle swarm optimization algorithm was used to solve the model, and the optimal acceleration of the vehicle was obtained.

Key-words: Dynamic competitive environment, vehicle system, road intersection, collaborative control.

1. Introduction

In the traffic network, the road in all directions through the intersection and outward extension, the intersection is the direction of the traffic flow in all directions, it is for this reason, and the road near the intersection is often occupied by a large number of vehicles and congestion, resulting in a traffic accident. In the dynamic traffic environment, the vehicle in the traffic network is very easy to run in the vicinity of the intersection stagnation or even conflict, which greatly reduces the traffic capacity of the intersection, reducing the operational efficiency of the transport system. Therefore, how to realize the cooperative control of vehicle intersections, to ensure the safe and orderly passage of vehicles through the intersection, to improve the safety capacity of the road intersection area vehicles, and then to achieve efficient operation of the traffic system has become the focus of current research and focus.

In recent years, domestic and foreign scholars have proposed a variety of vehicle safety collaborative control methods: such as Del Vecchio and others proposed based on the partial sequence of cross-intersection collision algorithm, an effective solution to the intersection of collision avoidance problems [1-2]. Proposed the automatic navigation of vehicles under dynamic traffic environment, proposed and designed dynamic traffic controllers to realize the collision avoidance at intersections [3]. Alonso *et al.* proposed a priority-based control strategy and a conflict-based control strategy for the no-signal road intersection [4]. In order to solve the problem, the rectangular collision area is introduced, and the force field function and the early warning function are introduced to complete the multi-vehicle intersection [5]. Although most of the methods are feasible in theory but are less practicable in practical applications. In view of this, the study, based on a large number of related literature and specific operational experiments, first analyzes the conflict form of the vehicle in the road intersection area, establishes the safety index and the fastness index of the multi-vehicle cooperation in the intersection area, Weighted control is used to obtain the vehicle cooperation control model of the intersection area, and the constraints of the model are given. Then the constraint function is transformed into the unconstrained optimization problem by the penalty function method. The particle swarm optimization algorithm is used to solve the example, and finally get the optimal acceleration of the multi-vehicle cooperation in the intersection area, and realize the cooperative control optimization of the intersection vehicle system.

2. Analysis of Vehicle Conflict at Road Intersection

Crossroads are one of the most typical and common intersections in the traffic network. The conflict forms include cross conflict, confluence conflict and shunt conflict. Among them, the cross conflict is mainly caused by the conflict between the straight and straight, straight and left and left turn and left turn vehicles of the intersection area, which has the greatest impact on the intersection traffic. This paper mainly aims at the intersection of multi- To study, as shown in Fig. 1.

The dots in Fig.1 indicate possible cross-collision points between vehicles. In general, the right turn of the vehicle has little effect on the traffic system. Therefore, this paper does not consider the right turn of the vehicle, only considering the cross conflict caused by the left turn and the straight vehicle. Among them, A, C, E, G on behalf of the straight flow, B, D, F, H on behalf of the left turn traffic.

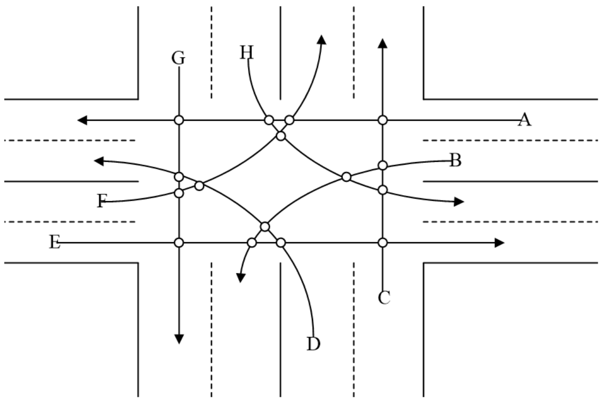

Fig. 1. Crossroads at the crossroads.

3. Construction of Vehicle Cooperative Model at Road Intersection

In the high traffic flow at the road intersection, mainly through the traffic lights to control the vehicle in turn through the intersection. In this paper, the main consideration is in the case of lower traffic flow, by adjusting the speed of vehicles to control the vehicle in the state of non-stop through the cross in turn. The vehicle system real-time transmission and reception of vehicle speed, location and other state information, through the workshop communication to perceive each other's operating state, the system may adjust the speed of the vehicle collision, to ensure vehicle safety through the intersection, and to minimize time delay, improve traffic efficiency The Therefore, safety and rapidity are the two target indicators established by the vehicle interaction control model at the road intersection.

3.1. Safety indicators

The author introduces the method based on the time and space trajectory to predict the potential collision of the vehicle to analyze the safety problem of the vehicle through the crossroads. Vehicle AI, BJ space and time trajectories, as shown in Figure 2:

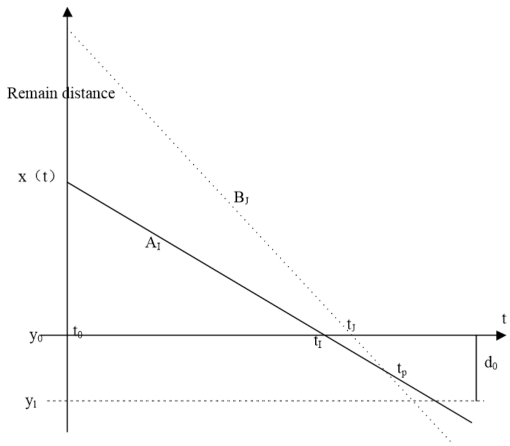

Fig. 2. Vehicle AI, BJ space and time trajectory map.

In Fig. 2, the horizontal axis is the time, and the vertical axis is the remaining distance, that is, the distance of the vehicle from the crossing entrance. The real slash and the dashed line indicate the temporal and spatial trajectories of the vehicle A_I and B_J, respectively. y_0, and y_l respectively represent the intersection entrance and outlet positions, and the distance between them indicates the distance from the intersection (d_0). t_I, t_J respectively indicate the time at which the vehicle A_I and B_J enter the intersection. t_p said the two cars due to lack of car from the collision. In order to avoid collision, you can adjust the speed near the intersection to reduce or even avoid the occurrence of collision events.

If the A_I travel speed is V_I, the acceleration is a_I, the distance between the vehicle and the cross entrance X_I (0). The distance of the car at the cross entrance is:

$$X_I(t) = X_I(0) - V_I t - \frac{1}{2} a_I t^2 \tag{1}$$

Vehicles A_I, B_J at the intersection at the same time, there may be collision conflict, as shown in Fig. 3.

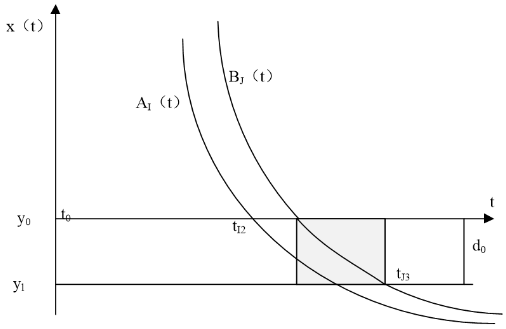

Fig. 3. Prone to collision shadow diagram.

Shadows in the figure indicate that A_I and B_J appear at the intersection at the same time, easily lead to a collision, A_I, B_J in the shadow area of the curve length are:

$$L_I = \int_{t_{J3}}^{t_{I2}} \sqrt{(1 + X'_I(t)^2) dt} \tag{2}$$

$$L_J = \int_{t_{J3}}^{t_{I2}} \sqrt{(1 + X'_J(t)^2) dt} \tag{3}$$

If $t_{j3} \geq t_{I3}$ so L_I L_J are all less than zero, the shadow part does not exist, the vehicle A_I, B_J will not appear in the shadow area, two cars cannot be a collision.

It can be seen that the smaller the curve length of the space-time trajectory in the shadow, the less the vehicle in the intersection area is less prone to accidents and the more secure the vehicle. Therefore, the problem of vehicle safety cooperation in the intersection area can be transformed into the curve length of the space-time trajectory in the shadow area.

When the intersecting area intersects the two unidirectional straight lanes of the number of vehicles with N_1 and N_2 respectively, the sum of the curvilinear lengths of the spatiotemporal trajectories in the overlapping areas of the two vehicles on both lanes are L:

$$L = \sum_{I-1}^{N_1} \sum_{J-1}^{N_2} \int_{t_{J3}}^{t_{I2}} \sqrt{(1 + X'_I(t)^2) dt} \tag{4}$$

The smaller the L, the less the collision occurs in the intersection area. Therefore, the security problem of vehicle cooperation in the intersection area can be transformed into an optimization problem to solve the minimum total length of the curve in the shadow area. The model is:

$$\text{Min} L = \sum_{I-1}^{N_1} \sum_{J-1}^{N_2} \int_{t_{J3}}^{t_{I2}} \sqrt{(1 + X'_I(t)^2) dt} \tag{5}$$

$X'_I(t) = -A_I - a_I t$, the speed of the vehicle can be measured by the vehicle sensor and sent to the system in real time via the wireless communication network, thus selecting the acceleration as the variable to be optimized for the model.

3.2. Fastness indicators

In order to ensure the safety of the vehicle at the intersection of the road intersection, in order to improve the traffic efficiency, the vehicle is set up as soon as possible through the intersection, the vehicle speed of the intersection is established, and the model is established as follows:

$$\text{Min}t = Vt_{A_I} + Vt_{B_J} \tag{6}$$

In the above formula, t represents the total time of the vehicle A_I, B_J through the road intersection $Vt_{A_I} = t_{d,I} - t_{o,I}$, $Vt_{B_J} = t_{d,J} - t_{o,J}$ are respectively, and said the vehicle A_I, B_J through the road intersection time.

3.3. Model constraints

(1) Speed constraints. Vehicles in the city transport network, to meet the corresponding speed limit requirements. Take the vehicle A_I as an example: the maximum and minimum values of the speed limit, S_{max} and S_{min} are respected. The following constraints can be obtained by derivation:

$$\frac{S_{min}^2 - A_I^2}{2(X_I - X_I(t))} \leq a_I \leq \frac{S_{max}^2 - A_I^2}{2(X_I - X_I(t))} \tag{7}$$

(2) Acceleration constraints. Due to the limitation of the vehicle's own structure and the power system, the acceleration of the vehicle AI is obeyed to $a_{min} \leq a_I \leq a_{max}$, In order for $X_I(t) = 0$ to have positive real solutions, Need to obey $A_I^2 + 2a_I X_I \geq 0$, and then get the constraints:

$$a_I \geq -\frac{A_I^2}{2X_I} \tag{8}$$

(3) Safety time constraints. When crossing the road through the road, the vehicle must maintain a corresponding safety distance to avoid rear-end events occur. The distance between the adjacent vehicles A_{I-1} and A_I and the cross entrance are respectively is $X_{I-1}(t), X_I(t)$, and the safety distance of the front of the two vehicles is h, in order to avoid rear-end, to meet the following safety time constraints:

$$\left(X_I - v_I t_r - \frac{1}{2} a_I t_r^2\right) - \left(X_{I-1} - v_{I-1} t_r - \frac{1}{2} a_{I-1} t_r^2\right) \geq h\left(v_I + a_I t_r\right) + \frac{1}{2} a_I h^2 \tag{9}$$

On the type of simplified to get:

$$\begin{aligned}
&\frac{1}{2}(a_{I-1}-a_I)t_r^2-(v_I-v_{I-1}+a_Ih)t_r+S\geq 0,\\
&S=X_I-X_{I-1}-v_Ih-\frac{1}{2}a_Ih^2,\\
&t_r=\frac{-v_I+\sqrt{v_I^2+\frac{1}{2}a_{I-1}X_I}}{a_I}
\end{aligned} \tag{10}$$

3.4. The establishment of the model

The above two indexes are weighted to obtain the objective function and the constraint condition of the vehicle interaction control model at the road intersection:

$$MinB=\mu\sum_{I-1}^{N_1}\sum_{J-1}^{N_2}\int_{p_{I,J}}^{q_{I,J}}\sqrt{(1+X_I'(t)^2)dt}+(1-\mu)\left(\sum_{I-1}^{N_1}Vt_I+\sum_{J-1}^{N_2}Vt_J\right)$$

$$s.t.\begin{cases}
a_I\geq max\left(a_{min},-\frac{v_I^2}{2X_I},\frac{S_{min}^2-v_I^2}{2(X_I-X_I(t))}\right)\\
a_I\geq max\left(a_{max},\frac{S_{max}^2-v_I^2}{2(X_I-X_I(t))}\right)\\
\frac{1}{2}(a_{I-1}-a_I)t_r-(v_I-v_{I-1}+a_Ih)t_r+S\geq 0
\end{cases} \tag{11}$$

3.5. The solution of the model

The above model contains integral term is not conducive to Matlab programming, in order to facilitate the calculation [6].

(1) First, the fitness function is constructed by the penalty function method

The penalty function method is to combine the constraint function into the penalty item and apply the penalty item to the original objective function, which makes the iterative point approach the feasible domain and finally solve the optimization problem with the constraint condition [7]. The above model contains integral term is not conducive to Matlab programming, in order to facilitate the calculation. I use the penalty function method for processing. Define the following functions:

$$
\begin{aligned}
E_I &= a_I - max\left(a_{min}, -\frac{v_I^2}{2X_I}, \frac{S_{min}^2 - v_I^2}{2(X_I - X_I(t))}\right)\\
E_J &= a_J - max\left(a_{min}, -\frac{v_J^2}{2X_J}, \frac{S_{min}^2 - v_J^2}{2(X_J - X_J(t))}\right)\\
F_I &= min\left(a_{max}, \frac{S_{max}^2 - v_I^2}{2(X_I - X_I(t))}\right) - a_I\\
F_J &= min\left(a_{max}, \frac{S_{max}^2 - v_J^2}{2(X_J - X_J(t))}\right) - a_J\\
G_I &= \frac{1}{2}(a_{I-1} - a_I)t_r - (v_I - v_{I-1} + a_I h)t + S\\
G_J &= \frac{1}{2}(a_{J-1} - a_J)t_r - (v_J - v_{J-1} + a_J h)t + S
\end{aligned}
\tag{12}
$$

This translates the problem into an unconstrained optimization problem, let

$$
\begin{aligned}
p = &\sum_{I-1}^{N_1}\left[\big(min(0, E_I)\big)^2 + \big(min(0, F_I)\big)^2 + \big(min(0, G_I)\big)^2\right]\\
&\sum_{I-1}^{N_1}\left[\big(min(0, E_J)\big)^2 + \big(min(0, F_J)\big)^2 + \big(min(0, G_J)\big)^2\right]
\end{aligned}
\tag{13}
$$

Combine equations (12) and (13) to obtain the fitness function for unconstrained optimization problems Fitness:

$$
Fitness = B + \sigma P \tag{14}
$$

(2) Then, expand the Particle Swarm Optimization algorithm

The method is solved from the random solution and the optimal solution is found by iteration. In each iteration, the particle is updated by the individual extremum Pbest and the population extremum Gbest. Here we use the linear recursive factor of the particle swarm optimization algorithm to solve the minimum value of the process is as follows:

The first step, to determine the initialization algorithm parameters: particle size, particle velocity X_n and location X_m .

The second step, to determine the fitness of each particle fitness (m);

The third step, compare Fitness (m) with Pbest (m), if Fitness (m) <Pbest (m), then Fitness (m) instead of Pbest (m);

The fourth step, compare Fitness (m) with Gbest (m), if Fitness (m) <Gbest (m), then Fitness (m) instead of Gbest (m);

In the fifth step, the speed and position of each particle are updated as follows:

$$
\begin{aligned}
&V_{mn}(k+1) = wv_{mn}(K) + C_1 r_1\big(p_{mn}(k) - x_{mn}(k)\big) + C_2 r_2\big(p_{gn}(k) - x_{gn}(k)\big)\\
&x_{mn}(k+1) = x_{mn}(k) + v_{mn}(k+1)
\end{aligned}
\tag{15}
$$

The sixth step, update the inertia weight w:

$$w = w\,max - i \times \frac{w\,max - w\,min}{max\,gen} \tag{16}$$

$w\,max$ and $w\,min$ are respectively, the maximum value of the inertia weight, the minimum, $max\,gen$ For the number of iterations

The seventh step, if the end of the algorithm is satisfied, otherwise return to the second step.

4. Case analysis

The author takes the intersection of two unidirectional single lanes as an example and solves the vehicle coordination control model of the intersection. The vehicle condition is as follows:

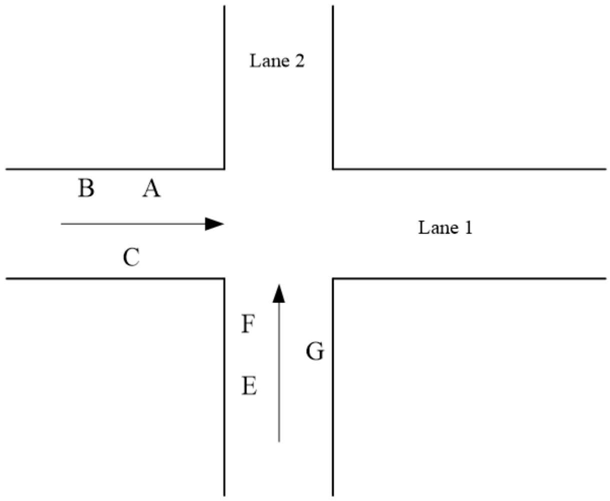

Fig. 4. Schematic diagram of six vehicles passing through the intersection.

In the lane 1, vehicles A, B, C and lane 2, the distance between the vehicle E, F, G and the cross entrance is (in meters): $x_1 = [25, 35, 45]$, $x_2 = [35, 45, 55]$.

The speed is (in m/s): $v_1 = [8, 8, 8], v_2 = [10, 10, 10]$. The speed of the vehicle running on the road is $5m/s \leq v_1, v_2 \leq 15m/s$, Acceleration is $-0.5m/s^2 \leq a_1, a_2 \leq 0.5m/s^2$.The length of the intersection is d = 25m.Constraints, speed limit requirements: $S_{max} = 13m/s$, $S_{min=7m/s}$. Front safety time h2s. In the objective function $\mu = 0.5$, in Penalty function $\sigma = 1000$. The particle swarm optimization algorithm is used to solve the particle swarm optimization. Speed update parameters $c_1 = c_2 = 2$, $w\,max = 0.9$, $w\,min = 0.4$, $max\,gen = 100$.

According to the steps of particle swarm optimization algorithm, the optimal acceleration of six vehicles at the intersection can be obtained as follows: 0.5000, 0.1928, -0.1099, 0.5000, 0.1810, 0.0596 (m/s^2).

5. Conclusion

The safety function index and the quickness index are used to establish the vehicle cooperation control model of the road intersection, and the fitness function is constructed by the penalty function method. The particle swarm optimization algorithm is used to analyze the case, and finally, the optimal acceleration of the six vehicles is obtained. At the intersection of vehicle control model is established, with a certain degree of practicality. In order to make the model and algorithm better applied in real life, a large number of cases to be verified, and ultimately have the operability.

References

[1] DEL VECCHIO D., *Observer-based control of block-triangular discrete time hybrid automata on a partial order*, International Journal of Robust and Nonlinear Control, **19**(14), 1581–1602, 2009.

[2] DEL VECCHIO D., *Computational tools for the safety control of a class of piecewise continuous systems with imperfect information on a partial order*, SIAM Journal on Control and Optimization, **49**(6), 2463–2493, 2011.

[3] SALEH Y., TOFIGH A., ZAHRA A., *Transportation Routing in Urban Environments Using Updated Traffic Information Provided through Vehicular Communications*, Journal of Transportation Systems Engineering and Information Technology, **14**(5), 23–36, 2014.

[4] ALONSO J, MILANÉS V, PÉREZ J., *et al. Autonomous vehicle control systems for safe crossroads*, Transportation research part C: emerging technologies, **19**(6), 1095–1110, 2011.

[5] WEI Han, LU Xiong, YIMENG Hou , *et al. Optimization and control of yaw stability based on wire controlled braking system*, Journal of Tongji University (Natural Science Edition), **45**(5), 732–740, 2017.

[6] JUHÁS M., JUHÁSOVÁ B., *Sorting system with buffer stock visualisation using Matlab GUI and VRML*, Technical Gazette, **24**(1), 1–5, 2017.

[7] YUPING W., ZHE X., YOUFANG H., *et al. Study of Continuous Berth Allocation Algorithm Based on Fairness Maximization*, Journal of Engineering Science and Technology Review, **10**(5), 116–127, 2017.