VEHICLE PLATOONING SIMULATION TO AVOID COLLISION WITH PEDESTRIAN

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According to a survey by the Ministry of Land, Infrastructure, Transport and Tourism, as much as 40% of the annual travel time is wasted in traffic jams. In addition, some studies have shown that the gas emitted by idling causes air pollution, and this has become a major social problem. One of the efforts to improve these problems caused by traffic congestion is the research on platooning. Most of the conventional research assumes a straight road as the experimental condition, and there is no discussion on the behavior at intersections scattered in the general roadway. In this study, a velocity control model is studied to avoid collisions with pedestrians when platoon vehicles make a turn at the intersection. A vehicle following model is defined according to Helly model which controls the vehicle acceleration according to relative speed and distance with the vehicle in front. The validity of the model is discussed from the computer simulation. Simulations were performed in some cases. The model could control the vehicles individually without collisions with pedestrians. However, these experiments were conducted only in an ideal environment by simulation. Therefore, in the future, the effectiveness of the model should be improved in actual traffic flow by conducting experiments using real vehicles.

Keywords: Vehicle platoon, Traffic, Vehicle following model, Helly model.

1 INTRODUCTION

Due to the growing demand for road traffic, the road traffic congestion is becoming a serious problem. The economic loss due to traffic congestion amounts to about 12 trillion yen, which causes environmental problems and a decline in economic efficiency. The lost time is about 30 hours per year, and the amount is about 90,000 yen per year. From the viewpoint of energy loss, it is generally known that the traveled distance per fuel is inversely proportional to the speed. For example, when the speed becomes 1/4, the fuel consumption becomes about 2.5 times. In addition, automobile exhaust gas contains nitrogen oxides, sulfur oxides, carbon monoxide, suspended particulate matter, etc., and it has been pointed out that these substances have causal relationships with asthma, respiratory diseases, and allergic diseases. For this reason, it is necessary to improve efficiently and effectively traffic congestion for major congestion points located in the city center where congestion losses are concentrated and throughout the country. Traffic congestion wastes the time and energy required for transportation. In addition, the gas emitted by idling causes air pollution, which has become a major social problem.

vehicles travel in a row with a short inter-vehicle distance, and as a result, which can increase road traffic capacity and improve fuel efficiency due to reduced air resistance. The automatic speed control system is necessary for realizing platooning. Since there is a limit to the reaction speed of the human driver for realizing stable platooning, it is essential to develop a mechanism that automatically controls the velocity and the behavior of the vehicles. The vehicle-to-vehicle communication technology, which is being developed in Intelligent Transportation Systems (ITS), is expected to be effective useful for automatic control.

However, most of the studies on platooning assume straight roads as experimental conditions, and no discussion has been made about the behavior at intersections scattered on general roads. Right and left turns on general roads are essential for vehicle movement, and there is a problem of how to construct a speed control system to avoid collisions with pedestrians crossing pedestrian crossings.

Therefore, a speed control algorithm realizing collision avoidance with existing pedestrians is discussed in this study, when a group of vehicles platooning by vehicle-to-vehicle communication turns right. For this purpose, a vehicle following model is used for speed control and a collision avoidance model for avoiding collisions with pedestrians are combined, simulations are performed to determine whether collisions can be avoided for various pedestrian movements for discussing the model validity.

2 SIMULATION MODEL

2.1 Simulation Region

In simulation region, three vehicles are waiting to turn right on an intersection, as shown in Figure 1. After turning on the intersection, a course goes straight to the south. It is assumed that a pedestrian enters the intersection from the east side.

![Figure 1. Vehicles and pedestrians under repulsion.](image-url)
2.2 Collision Avoidance Model
According to the collision avoidance model proposed in reference (Matsuzane 2014), the acceleration $a_x$ of the vehicle $x$ is given as follows.

$$a_x(t + \Delta t) = a_{x,af} + a_{x,rf}(t)$$

(1)

where $a_{x,af}$ is determined from the actual experiments, which is as $a_{x,af} = 0.7 \text{ m/s}^2$. $a_{x,rf}(t)$ denotes the acceleration from the repulsive force, which is given in Eq. (2):

$$a_{x,rf}(t) = \frac{2a_{xh}a_{xn}}{v_x^2(t)} D + a_{xn} + a_{sn} - a_{sf}$$

(2)

where $a_{xh}$ and $a_{xn}$ denote the acceleration in the sudden deceleration and normal deceleration of the vehicle. $D$ is the vehicle head distance.

2.3 Vehicle and Pedestrian Behavior Definition
Vehicles running in a platoon are named Vehicle 1, Vehicle 2, and Vehicle 3 in order from the direction of travel. Pedestrians pass through the intersection at constant acceleration. It is verified whether the vehicle can perform appropriate speed control to avoid collision.

2.4 Speed Control Model
Each vehicle refers different pedestrian before and after passing the collision point with the pedestrian. This is because the vehicle that has passed the collision point has no risk of collision with the pedestrian and does not need to refer to the pedestrian. The reference relationship of each vehicle before passing the collision point is as follows (Figure 2). Vehicle 1 drives with reference to the pedestrian. Vehicle 2 drives with reference to Vehicle 1 and the pedestrian. Vehicle 3 drives with reference to Vehicle 2 and the pedestrian. The reference relationship of each vehicle after passing the collision point is as follows. Vehicle 1 runs with constant velocity. Vehicle 2 runs by referencing Vehicle 1. Vehicle 3 runs by referring to Vehicle 2.

![Figure 2. Reference relation of each vehicle.](image)

According to Helly model (Helly 1961) and Eq. (1), the accelerations of Vehicle 1, Vehicle 2 and Vehicle 3, which are referred to as $a_1$, $a_2$ and $a_3$, are given as follows (Eq. (3)-(6)):

$$a_x(t + \Delta t) = \begin{cases} a_{x,af} + a_b & \text{Before collision} \\ a_{x,af} & \text{After collision} \end{cases}$$

(3)

$$a_x(t + \Delta t) = \begin{cases} a(V_1(t) - V_x(t)) + \beta(D_{x2}(t) - D) + a_b & \text{Before collision} \\ a(V_1(t) - V_x(t)) + \beta(D_{x2}(t) - D) & \text{After collision} \end{cases}$$

(4)
\[ a_3(t + \Delta t) = \begin{cases} 
    \alpha \left( V_2(t) - V_3(t) \right) + \beta (D_{23}(t) - D) + a_h & \text{Before collision} \\
    \alpha \left( V_2(t) - V_3(t) \right) + \beta (D_{23}(t) - D) & \text{After collision} 
\end{cases} \]

where \( V_n \) is the velocity of the vehicle \( n \), \( D_{mn} \) is the distance between the vehicle \( m \) and the vehicle \( n \), and \( D \) is the ideal inter-vehicle distance.

### 2.5 Parameter Design

The sensitivities of the vehicle following model are determined by solving the optimization problem. The objective function \( J \) is defined by the integrated value of the difference between the delay time \( T_d \), overshoot \( O_s \), steady-state deviation \( E_{lim} \), ideal inter-vehicle distance \( D \), and inter-vehicle distance as follows (Eq. (7)):

\[ J = w_1 T_d + w_2 O_s + w_3 E_{lim} + w_4 D \]

where \( w_1, w_2, w_3 \) and \( w_4 \) denote the weights of each evaluation indexes which are defined in the range of \((0, 1]\).

### 2.6 Parameters

The sensitivities \( \alpha, \beta \) of the Helly model and other parameters are summarized in Tables 1 and 2, respectively.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>3</td>
<td>0.81</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 1. Helly model parameters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Variable</th>
<th>Value</th>
<th>Variable</th>
<th>Value</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_1 )</td>
<td>0.0 m</td>
<td>( Y_1 )</td>
<td>0.0 m</td>
<td>( X_p ) (Pass)</td>
<td>6.5 m</td>
<td>( a_h )</td>
<td>3.0 m/s²</td>
</tr>
<tr>
<td>( X_2 )</td>
<td>-2.0 m</td>
<td>( Y_2 )</td>
<td>0.0 m</td>
<td>( X_p ) (Stop)</td>
<td>7.5 m</td>
<td>( a_n )</td>
<td>1.0 m/s²</td>
</tr>
<tr>
<td>( X_3 )</td>
<td>-4.0 m</td>
<td>( Y_3 )</td>
<td>0.0 m</td>
<td>( V_p )</td>
<td>1.5 m/s</td>
<td>( D )</td>
<td>2.0 m</td>
</tr>
<tr>
<td>( X_p )</td>
<td>7.5 m</td>
<td>( Y_p )</td>
<td>-5.0 m</td>
<td>( r )</td>
<td>5.0 m</td>
<td>( D_m )</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>

Table 2. Initial values of parameters.

### 3 NUMERICAL SIMULATION

Velocity and acceleration of the vehicles are shown in Figures 3 and 4, respectively. Figures are plotted with the time as the horizontal axis and the velocity or the acceleration as the vertical axis, respectively.

Figures show that Vehicle 1, Vehicle 2 and Vehicle 3 starts in this order and then, Vehicle 2 and Vehicle 3 accelerate so that they drive at the same speed and ideal inter-vehicle distance as Vehicle 1. When approaching the pedestrian and sensing the repulsive force from the pedestrian, the acceleration of the repulsive force occurs, the acceleration of the vehicle becomes negative, and it continues until the velocity becomes zero. After the pedestrian passes the collision point and the
acceleration returns positive and the vehicle starts accelerating. After that, Vehicle 1, which has passed the collision point and no longer receives the repulsive force from the pedestrian, starts accelerating at a constant acceleration. Vehicle 2 and Vehicle 3 drive according to the similar algorithm.

![Figure 3. Velocity fluctuation.](image)

![Figure 4. Acceleration fluctuation.](image)

4 CONCLUSIONS

Most of the conventional studies on platooning assume straight roads such as highways. A method to avoid collision with pedestrians was proposed in this study when platooning vehicles turn right at an intersection. Helly model, which is one of the vehicle following models, is used for velocity
control of vehicles in the platoon. Collisions are avoided by combining the Helly model with a model that modifies vehicle acceleration based on the concept of potential fields.

In the simulation, when a vehicle platoon consisting of three vehicles turns right at an intersection, it was verified whether the vehicle velocity can be controlled appropriately while avoiding collision with pedestrians crossing the intersection. Pedestrians decelerate in preparation for actions that increase the risk of collision near the collision point, and the acceleration increases as the relative distance increases after passing, so that collision risk can be avoided appropriately for the most common pedestrian actions was verified. This made it possible to make the proposed method lack validity.

The following issues can be raised as future issues. It is necessary to verify whether this algorithm is effective in actual traffic flow by experiments using real vehicles and robots that are similar to real vehicles.

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References