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SIMULATION OF VEHICLE PLATOONS PASSING THROUGH INTERSECTION

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The platooning of vehicles is a very important technique for enhancing the traffic capacity without additional road network and improving the traffic safety. In the platooning, vehicles travel in the row so as to keep the vehicle head distance short. The most important thing from the existing studies is to realize the stable platooning of vehicles. On the other hand, our research group focuses on the control of the platooning of vehicles in several use cases such as junction and intersection. In this paper, the control of the platooning of vehicles in the intersection or crossover point is studied. The simulation region is the intersection of two straight roads. Two groups of two vehicles travel on different roads and meet at the intersection. The velocity of the vehicles is controlled by the vehicle following model. The model parameters are first designed in the computer simulation. The validity of the velocity and the behavior control models are discussed in the experiment of LEGO Mindstorm. The results show that the model can control the vehicles in the platoons safely.

Keywords: Priority and non-priority roads, Helly model, LEGO Mindstorms, Vehicle head distance.

1 INTRODUCTION

At the intersection of the road, traffic jam is caused by various factors such as traffic signals and temporary stops at the right or left turns. Recently, the Intelligent Transport System (ITS) is studied widely according to the development of the automatic communication system between vehicles. The grouping vehicles in a platoon is also one of the important techniques in the ITS field (Bali *et al.* 2014, Guanetti *et al.* 2018, Li and Chen 2017). The vehicle platoon can increase the traffic capacity of the road network safely and efficiently. In the vehicle platoon, vehicles travel in a row so as to keep the vehicle head distance short. The aim of the existing studies is to control the grouping of the vehicles in a platoon safely. In the near future, the control models of velocity and the behavior of vehicles are necessary when vehicles travel in more complicated traffic situations. Our research group focuses on the control of the platooning of vehicles in several use cases such as the intersection and crossover point. The aim of this study is to control the velocity of the vehicles in the platoon when the platoons pass through the intersection or the crossover point. Two groups of two vehicles travel on the different roads and meet at the crossover point. The vehicle velocity is controlled according to one of the vehicle following models (Bando *et al.* 1995, Bierley 1963, Chandler *et al.* 1958, Helly 1959, Newell 1961). In this study, the Helly model is adopted as the velocity control model of each vehicle when the vehicle platoons pass through the intersection. The model parameters are first designed in the computer simulation. Then, the model is applied for the experiments of LEGO Mindstorms NXT (Bricx command center 2020, Lego Mindstorms 2020). Since the LEGO Mindstorms is programmable by the C language, it is effective for confirming the proposal algorithm.

This paper is organized as follows. In Section 1, the aim and related works of this study are introduced. The background of this study is explained in Section 2. The simulation model and the model parameters are described in Section 3. The experimental results are shown in Section 4. The results are summarized again in Section 5.

2 BACKGROUND

2.1 Chandler Model

The acceleration rate is controlled as presented in Eq. (1) (Chandler *et al.* 1958):

$$a_n(t+\Delta T) = \alpha\{v_{n-1}(t) - v_n(t)\} \tag{1}$$

where the variables $a_n = \ddot{x}_n$ and $v_n = \dot{x}_n$ denote the acceleration rate and the velocity of the vehicle n, respectively. The variables ΔT and α mean the delay time of the velocity control and the sensitivity related to the response to the vehicle behavior, respectively. Vehicle $n-1$ is the nearest forward vehicles of vehicle n.

2.2 Newell Modell

By Eq. (2), the velocity is given as the function of the vehicle head distance (Newell 1961):

$$v_n(t+T) = G_n(x_{n-1}(t) - x_n(t)) \tag{2}$$

where the function G_n is any non-linear function of the vehicle head distance.

2.3 Bierly Model

The acceleration is given in Eq. (3) as the linear function of the velocity difference and the vehicle head distance (Bierly 1963):

$$a_n(t+\Delta T) = \alpha_1\big(v_{n-1}(t) - v_n(t)\big) + \alpha_2(x_{n-1}(t) - x_n(t)) \tag{3}$$

where the parameters α_1 and α_2 are the sensitivity related to the velocity difference and the sensitivity related to the vehicle head distance, respectively.

2.4 Helly Model

The acceleration rate is defined in Eq. (4) as the function of the difference between vehicle velocities and the difference between the vehicle head distance and its desires value (Helly 1959):

$$a_n(t+\Delta t) = \alpha\big(v_{n-1}(t) - v_n(t)\big) + \beta(x_{n-1}(t) - x_n(t) - D_0(t)) \tag{4}$$

where the parameters α and β denote the sensitivity for the velocity difference between the vehicle n and its nearest frontal vehicle $n-1$ and the sensitivity related to the vehicle head differences of vehicle n and its nearest frontal vehicle $n-1$, respectively. The function $D_0(t)$ denotes the optimal head distance between, which is generally defined in Eq. (5) as the function of velocity and acceleration.

$$D_0(t) = a + bv_n(t) + ca_n(t) \tag{5}$$

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In this study, however, the function $D_0(t)$ is specified to be constant.

The Helly model and its extension model are adopted in this study. At the intersection, the vehicle head distance between the vehicles in the platoon should be controlled to the adequate distance. Since the Helly model includes the term of the vehicle head distance, it can control the vehicle head distance adequately.

2.5 Parameter Design

The model parameters are assumed first and then their validity is confirmed in the computer simulations. After that, the parameters are applied for the velocity control in the experiments.

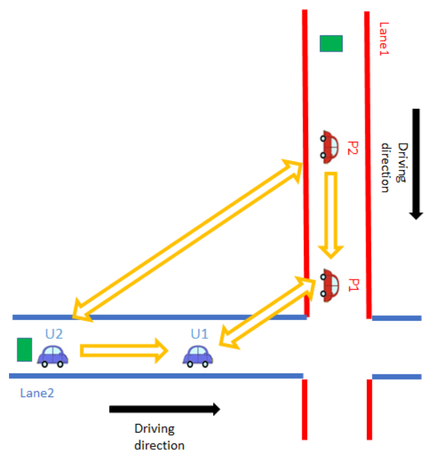

Figure 1. Traffic situation.

3 SIMULATION MODEL

3.1 Traffic Situation

The intersection is composed of two straight roads (Figure 1). Lanes 1 and 2 denote the priority road and the non-priority road, respectively. The vehicles on lane 1 are referred to as P1 and P2 and on lane 2, as U1 and U2. P1 travels in a straight line on lane 1, and P2 travels according to P1. U1 travels according to P1, and U2 travels according to U1 and P2. While P1, P2, and U1 control their velocity according to the single-leader vehicle Helly model, the velocity of U2 is changed according to the two-leader vehicles Helly model.

3.2 Velocity Control

Vehicle P1 travels at a constant velocity $\boldsymbol{v_0}$ as shown in Eq. (6):

$$v_{P1}(t) = v_0 \tag{6}$$

where variable $\boldsymbol{x_{P1}(t)}$ means the position of **P1** at time $\boldsymbol{t}$.

Vehicles P2 and U1 travel according to the Helly model (Eq. 7 and Eq.8):

$$a_{P2}(t + \Delta t) = \alpha_0\big(v_{P1}(t) - v_{P2}(t)\big) + \beta_0(x_{P1}(t) - x_{P2}(t) - D_0) \tag{7}$$

$$a_{U1}(t + \Delta t) = \alpha_0\big(v_{P1}(t) - v_{U1}(t)\big) + \beta_0(x_{P1}(t) - x_{U1}(t) - D_1) \tag{8}$$

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where variables $x_{P2}(t)$ and $x_{U1}(t)$ mean the positions of P2 and U1 at time t, respectively. The parameters D_0 and D_1 denote the ideal vehicle head distances. α_0 and β_0 denote the sensitivities for the differences of the vehicle velocities and the difference between the vehicle head differences and their desired values, respectively.

Vehicle U2 travels according to the multi-leader vehicle Helly model (Eq. 9):

$$a_{U2}(t+\Delta t) = \alpha_1\big(v_{U1}(t) - v_{U2}(t)\big) + \beta_1(x_{U1}(t) - x_{U2}(t) - D_0) \\ +\alpha_2\big(v_{P2}(t) - v_{U2}(t)\big) + \beta_2(\bar{x}_{P2}(t) - \bar{x}_{U2}(t) - D_2) \quad (9)$$

where variable $x_{U2}(t)$ denotes the position of U2 driving at time t. Variables $\bar{x}_{P2}(t)$ and $\bar{x}_{U2}(t)$ denote the distances from the intersection to P2 and U2, respectively. Parameters α_1 and α_2 denote the sensitivities for the velocity differences, and parameters β_1 and β_2 denote the sensitivities related to the vehicle head differences.

3.3 Vehicle Behavior

The vehicles' behaviors are summarized as follows.

Vehicle P1 travels at a constant velocity according to Eq. (6) and sends its position to vehicle U1.

Vehicle P2 estimates the distance to vehicle P1 to change its velocity according to Eq. (7) and then, sends its position to vehicle U2.

Vehicle U1 receives the position of vehicle P1 and changes its velocity according to Eq. (8).

Vehicle U2 receives the position of vehicle P2 and estimates the distance to vehicle U1 and then, changes its velocity according to Eq. (9).

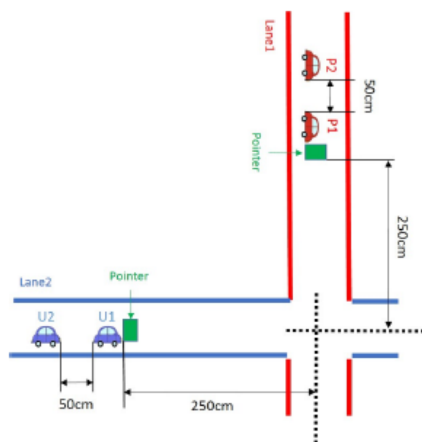

Figure 2. The initial positions of the vehicles.

Table 1. The model parameters.

Vehicles P1, P2, and U1	$\alpha_0 = 0.5\,, \beta_0 = 0.1, D_0 = 50, \Delta t = 1$
Vehicle U2	$\alpha_1 = \alpha_2 = 0.25, \beta_1 = \beta_2 = 0.05, D_1 = 50, D_2 = 35, \Delta t = 1$

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4 NUMERICAL EXPERIMENT

The intersection of two one-lane roads is considered as the object domain (Figure 2). The intersection area is defined as the area within a 250 cm radius from the intersection. The vehicles on the priority lanes P1 and P2 reache the intersection faster than the vehicles on the non-priority lanes U1 and U2. P1, U1, P2, U2 can communicate with each other. Therefore, the vehicles arrive at the intersection according to the order of P1, U1, P2, and U2. The parameters of the vehicle following model are specified in Table 1. The experimental overview is shown in Figure 3.

The results in the computer simulation and experiment are shown in Figures 4 and 5, respectively. The figures are plotted with the vehicle position [cm] as the vertical axis and the time [s] as the horizontal axis, respectively. The curves in these figures denote the vehicle positions. The correlation coefficient of the vehicle positions in the numerical simulations and experiments are compared in Table 2. The correlation coefficients of the vehicles on the priority road are better than those of the vehicles on the non-priority road because the vehicles on the non-priority road have to follow the ones on the priority road.

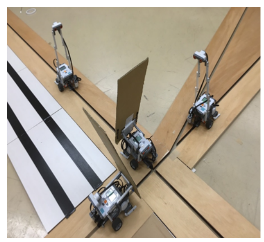

Figure 3. Experimental overview.

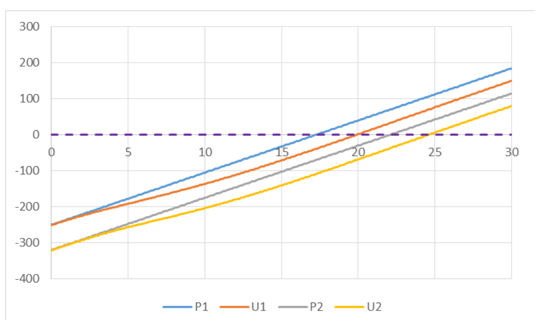

Figure 4. Numerical simulation result.

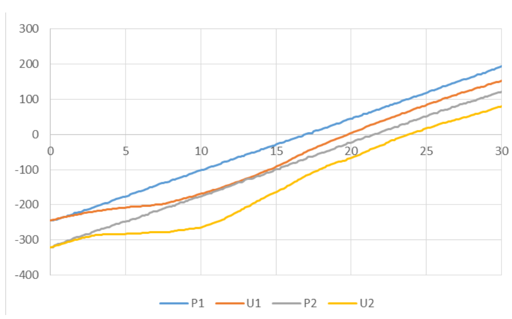

Figure 5. Experiment result of LEGO MINDSTORMS.

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Table 2. Correlation coefficient of the vehicle positions.

Vehicle	P1	U1	P2	U2
Correlation coefficient	0.99997	0.99632	0.99991	0.99198

5 CONCLUSIONS

The paper focuses on the control models of the behavior and velocity of vehicles when the platoons meet at the intersection. The velocity control model is the extension of the Helly model. The model parameters were determined in the computer simulation, and the validity of the control model was discussed in the experiments of LEGO Mindstorm NXT. The results in the computer simulation and experiment were compared. Comparison of the vehicle positions in the simulation and experiment show that the positions of the vehicles on the non-priority road are different, although the positions of the vehicles on the priority road are similar. Since the vehicles on the non-priority road have to follow the vehicles on the priority road, the ones on the non-priority road are affected by noise not only of the vehicles on the same road, but also of the vehicles on the priority road. In the future plan, it is necessary to improve the velocity control model in order to do more adequate velocity control.

Acknowledgments

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