

Velocity Control Model in Vehicle Platoon

Eisuke KITA, Masaki Takahashi, Tatsuhiro Tamaki

Abstract—In the vehicle platoon, vehicles drive in a row with a short vehicle distance by the help of the mechanical and the electric control systems. The aim of this paper is to discuss the velocity control model of the vehicles in a platoon. The velocity control model is defined by means of the vehicle following model. The parameters are determined by minimizing the objective function. The validity of the model is discussed firstly in computer simulation and then, applied for the experiment of robot vehicles. The validity of the model is discussed in the computer simulation and the experiment of robot vehicles.

Keywords—vehicle platoon, vehicle following model, simulation, experiment.

I. Introduction

Annual loss time due to traffic jam in Japan is about 5 billion hours for each person, which is about 40% of travel time. Considering that the loss of major cities in Europe and the United States is about 20% of the travel time, the situation of Japanese traffic jam is serious. Each research institute conducts research aimed at traffic jam, one of which is research on platoon vehicles. In platoon vehicles, the vehicles drive in a row with a short vehicle distance by the help of the mechanical and electric control systems. The vehicle platoon can realize an increase in traffic capacity and reduction in fuel consumption [1-3]. In this study, the control model of vehicle velocity is defined by the help of the vehicle following model [4-10]. The model parameters are determined by minimizing the objective function. The validity of the model is discussed in the computer simulation and the experiment of robot vehicles. Especially, in the experiment, the validity is discussed from the viewpoints of the similarity of the simulation and experiment, the platoon length and the ride comfort level.

The remaining part of this paper is organized as follows. The simulation model is explained in section II. The computer simulation results and the experimental results are shown in section III and IV, respectively. The results are summarized again in section V.

II. Simulation Model

The vehicle platoon is composed of four vehicles. The vehicles are named as lead (P1), first follower (P2), second follower (P3) and third follower (P4) vehicles, respectively. While a first follower vehicle has only on leader vehicle, the other follower vehicles have two leader vehicles. Therefore, a first follower vehicle control its velocity according to single-leader vehicle following model. The other follower vehicles depend on two-leader vehicles following model.

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A. Single-Leader Vehicle Following Model

Helly model is adopted as the single-leader vehicle following model, which is given as follows [7].

$$\dot{x}_n(t + \Delta t) = \alpha \dot{x}_{n-1}(t) - \dot{x}_n(t) + (x_{n-1}(t) - x_n(t) - D) \quad (1)$$

where the parameter α and β denote the sensitivity for the velocity difference between the vehicle n and its nearest forward vehicle $n - 1$ and the sensitivity related to the vehicle head differences of the vehicle n and its nearest forward vehicle $n - 1$, respectively. Helly model controls the acceleration rate according to the velocity difference $\dot{x}_{n-1}(t) - \dot{x}_n(t)$ and the difference between the vehicle head distance $x_{n-1}(t) - x_n(t)$ and its desires value D .

B. Two-Leader Vehicles Following Model

Vehicle following model adopts only nearest forward vehicle data for controlling the acceleration or the velocity, which are referred as to single-leader vehicle following model. The single-leader vehicle following model can be extended to the multiple-leader vehicles following model. This study uses the following two-leader vehicles following model;

$$\ddot{x}(t + \Delta t) = \alpha(\dot{x}_A(t) - \dot{x}_n(t)) + \beta(x_A(t) - x_n(t) - D) + \gamma(x_B(t) - x_n(t)) \quad (2)$$

where the notation A and B denote the first and the second leader vehicles, respectively.

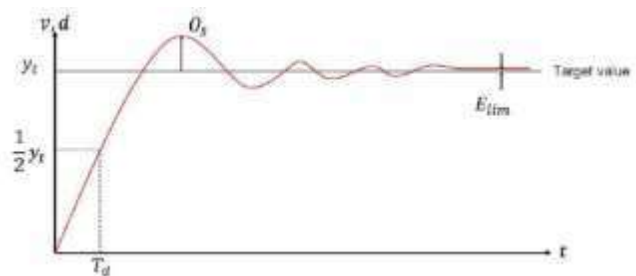


Figure 1: Definition of control parameters

C. Parameter Design

Parameter Design of Vehicle Following Model are determined by minimizing the objective function

$$= w_1 T_d + w_2 O_s + w_3 E_{lim} + w_4 I \quad (3)$$

where the variables T_d , O_s , E_{lim} and I denote the delay time of control, the overshoot of control, the steady-state deviation of control and the difference between the desired and actual vehicle distances, respectively. The definition of the variables O_s and E_{lim} is shown Fig.1. The parameters w_1, \dots, w_4

are weight parameters, which are taken as equal values as $w_1 = w_2 = w_3 = w_4 = 1$.

D. Ride Comfort Level

Since the ride comfort of vehicle driver largely depends on human senses, it is difficult to explain by expression and numerical values. Therefore, in this study, we evaluate based on the ride comfort level (L_t) which is used for evaluating the ride comfort of high-speed railway. The lower the value of L_t is, the better the ride comfort is. The value L_t is calculated from effective value of frequency component of the running vibration weighted by the riding comfort filter (W_t), which is given as follows.

$$L_t = 10 \log 10 \frac{1}{\omega_{ref}} \int_{f_1}^{f_2} P_{L_t} df \quad (4)$$

III. Computer Simulation

A. Simulation Condition

The vehicle platoon starts at the constant velocity and the lead vehicle performs the deceleration and the acceleration once.

Initial velocity and acceleration are 20 cm/s and 0 cm/s², respectively. The initial distances between vehicles are 30 cm. The initial values are summarized in Table 1.

Total number of simulation steps is 300 time-steps. Since one time-step is 0.1 [s], total simulation time is 30[s]. The lead of the platoon vehicle starts at velocity of 10 cm/s. It constantly decelerates to 0 cm/s from 100 time-step to 120 time-step. After stopping until 200 time-step, it constantly accelerates to 20 cm/s. The velocity of the lead vehicle v_{P1} is given by the function of the time-step t as follows.

$$v_{P1} = \begin{cases} 20 & 0 \leq t \leq 100 \\ 120 - t & 100 < t \leq 120 \\ 0 & 120 < t \leq 200 \\ t - 200 & 200 < t \leq 220 \\ 20 & 220 < t \leq 300 \end{cases} \quad (5)$$

The first follower vehicle controls its velocity according to the following model;

$$\dot{x}_1(t + \Delta t) = \alpha(\dot{x}_0(t) - \dot{x}_1(t)) + \beta(x_0(t) - x_1(t) - D) \quad (6)$$

The other follower vehicles depends on the following model;

$$\dot{x}(t + \Delta t) = \alpha(\dot{x}_{n-1}(t) - \dot{x}_n(t)) + \beta(x_{n-1}(t) - (t) - D) + \gamma(\dot{x}_0(t) - \dot{x}_n(t)) \quad (7)$$

The vehicle head distance D in the velocity control model is taken as

$$D_c = 4, 6, 8, 10 \text{ (cm)} \quad (8)$$

B. Model Parameters

The model parameters are determined according to the algorithm in section IIc. The sensitivity γ for the vehicle P2 is specified to be $\gamma = 0$ because the vehicle P1 is only leader vehicle for P2. The sensitivities of the follower vehicles for the different parameter D_c are summarized in Table 2. The sensitivities of the vehicles P2 and P3 are relatively large. However, in the sensitivities of P4, only sensitivity γ takes relatively large.

The simulation results of the vehicle velocities are shown in Fig.2. Figures are plotted with the time [0.1s] as the horizontal axis and the velocity as the vertical axis, respectively. The labels P1, P2, P3 and P4 denote the lead, the first, the second and the third follower vehicles, respectively.

During 0 to 100 time-steps, bigger the value D_c , smaller the maximum velocity of vehicle P3. In case of $D_c = 8$ and 10, the maximum velocity of vehicle P3 is smaller than that of vehicle P2.

During 100 to 200 time-steps, the minimum velocity of P2 and P3 becomes smaller than that of P1. The velocity of P4 does not undertake that of P1. Therefore, it is late for the vehicle P4 to catch up on the vehicle P3, especially, in case of $D_c = 10$.

The simulation results of the vehicle trajectories are shown in Fig.3. Figures are plotted with the time [0.1s] as the horizontal axis and the position as the vertical axis, respectively. The labels P1, P2, P3 and P4 denote the lead, the first, the second and the third follower vehicles, respectively. Since the vehicle P4 accelerates slower than the others, the distance between P3 and P4 is bigger than the others.

The accuracy of the vehicle control, the vehicle head distances from vehicles to their lead vehicles are calculated. Their average values and errors are listed in Table 3. The error is calculate as follows.

Table 1: Initial condition of vehicles

Vehicle	Acceleration	Velocity	Position
P1	0	20	-100
P2	0	20	-130
P3	0	20	-160
P4	0	20	-190

Table 2: Sensitivities of velocity control models

(a) $D_c = 4 \text{ cm}$			
Vehicle	α	β	γ
P2	1.98	1.32	0
P3	2.00	1.87	1.83
P4	0.03	0.01	1.43
(b) $D_c = 6 \text{ cm}$			
Vehicle	α	β	γ
P2	2.00	1.67	0
P3	2.00	1.97	1.9
P4	0.03	0.01	1.57
(c) $D_c = 8 \text{ cm}$			
Vehicle	α	β	γ
P2	1.64	2.00	0
P3	2.00	2.00	2.00
P4	0.03	0.01	1.75
(d) $D_c = 10 \text{ cm}$			
Vehicle	α	β	γ
P2	1.53	2.00	0
P3	2.00	1.53	1.95
P4	0.01	0.01	0.69

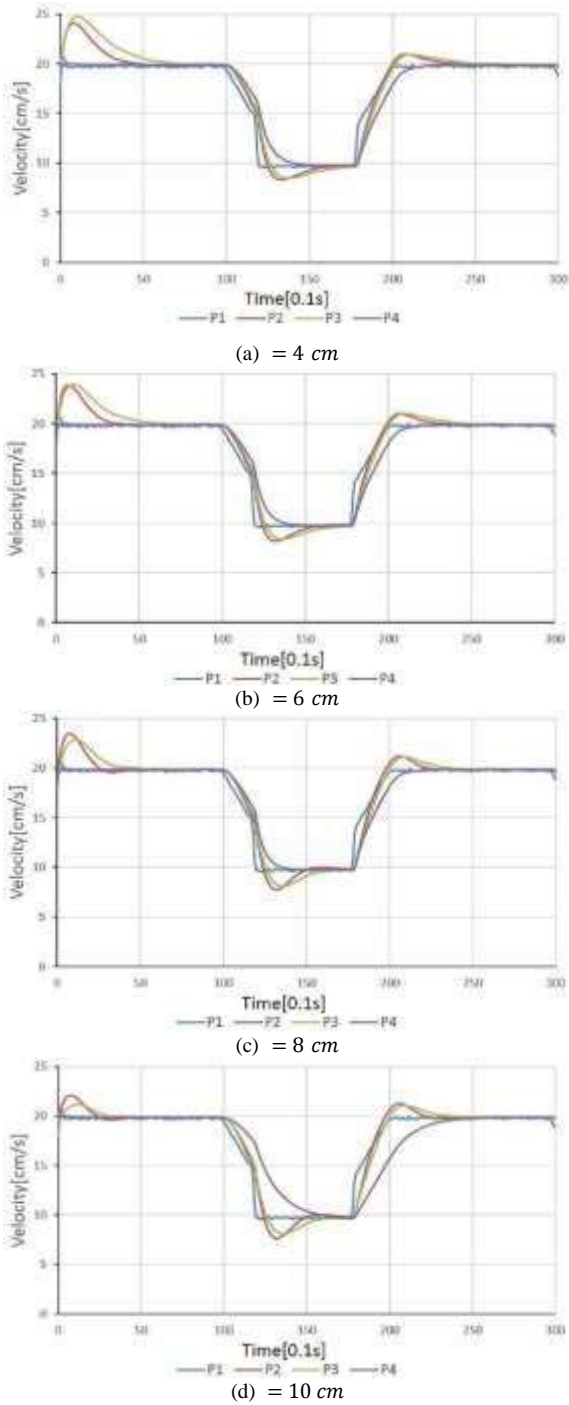


Figure 2: Velocity fluctuations in simulation.

$$E = \sum_{n=2,3,4}^1 \sum_{k=1}^m |(x_{(n-1)k} - x_{nk} - l) - D_c| \quad (9)$$

where the variable x_{nk} and the parameter l denote the vehicle position and vehicle length, respectively.

In case of $D_c = 10 \text{ cm}$, the average vehicle head distance and the error becomes smallest.

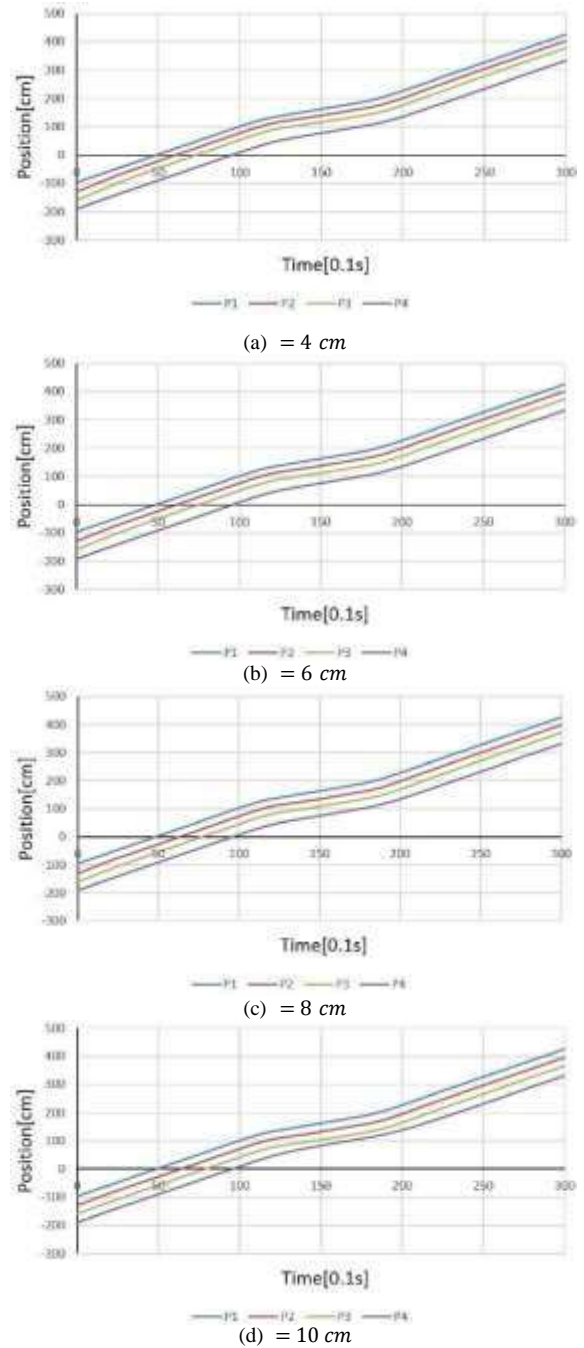


Figure 3: Vehicle trajectories in simulation.

Table 3: Average vehicle distance and error
(a) $D_c = 4 \text{ cm}$

Vehicle	Average distance	Error
P2	4.578	1.029
P3	4.778	1.063
P4	21.25	17.25

(b) $D_c = 6 \text{ cm}$

Vehicle	Average distance	Error
P2	6.382	0.7508
P3	6.565	0.8428
P4	18.47	12.47

(c) $D_c = 8 \text{ cm}$

Vehicle	Average distance	Error
P2	8.208	0.5783
P3	8.381	0.6578
P4	15.58	7.578

(d) $D_c = 10 \text{ cm}$

Vehicle	Average distance	Error
P2	10.14	0.5176
P3	10.23	0.571
P4	10.19	4.211

IV. Experiment

A. Vehicle Robot and Experimental Course

A vehicle robot is LEGO MINDSTORMS EV3, which has ARM9 300MHz processor, 16Mbfush memory, 64MB RAM, Bluetooth communication, motor, supersonic sensor and so on [11,12].

The overview of an experimental course is shown in Fig.4. An experimental course is compose of wood materials. There is a guideline on the road. Vehicles drive along the guidelines.

A vehicle platoon is composed of four vehicles, which are named as lead, first follower, second follower and third follower vehicles, respectively. A lead vehicle starts at constant velocity and decelerates suddenly and accelerates again at the same velocity as at the start. The follower vehicles estimate the distance from the nearest forward vehicle by supersonic sensor and calculates the velocity difference between its vehicle and the nearest forward vehicle as

$$x_{n-1}(t) - x_n(t) \equiv \Delta x_{n-1}(t) \approx \Delta \frac{\Delta x_{n-1}(t) - \Delta x_{n-1}(t - \Delta t)}{\Delta t} \quad (10)$$

The experimental results of vehicle robots are shown in Figs. 7 and 8. Figure 7 is plotted with the time [0.1s] as the horizontal axis and the velocity as the vertical axis, respectively. Figure 8 is plotted with the time [0.1s] as the horizontal axis and the position as the vertical axis, respectively. The velocity and position histories are similar to them in simulation.

The simulation and experimental results are compared in Table 5. The correlation coefficient η , the position difference E_p and the velocity difference E_v are estimated between the simulation and the experimental results. The correlation coefficients are very good for all cases. The velocity errors are with 5%. The position errors are within 10 cm. The results show that the experimental results agree well with the simulation ones.

The ride comfort level is estimated. The values are taken as follows $f_1 = 0.5[Hz]$, $f_2 = 5[Hz]$ and $T = 256 [0.1s]$. The acceleration data is multiplied by 100/9 to transform into the actual vehicle scale. The ride comfort level L_t is calculated from the transformed data in different vehicle distances. The results are summarized in Table 6.

The platoon length is estimated by the distance between P1 and P4. The platoon lengths, which are calculated for all cases, are listed in Table 7.

The results show that the adequate vehicle distance is $D_c = 4$ or 10 cm. Shorter the platoon length is, higher the traffic density is. Therefore, it is concluded that the vehicle distance of 4 cm is best, which is equivalent to 4m in the case of an actual vehicle.



Figure 4: Overview of experimental course

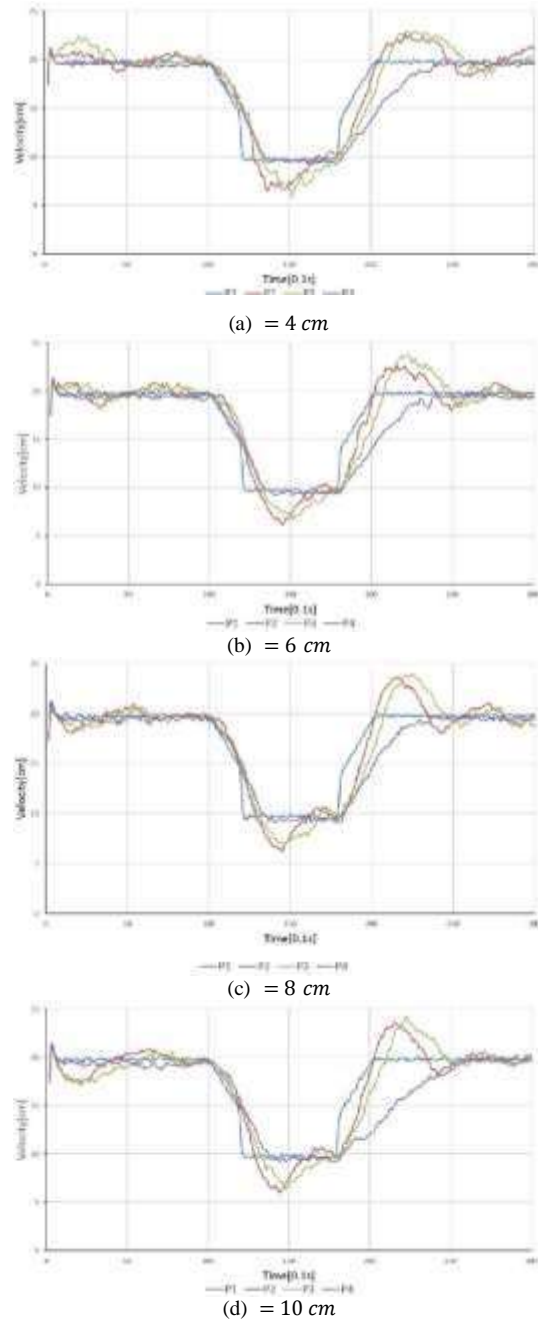


Figure 5: Velocity fluctuations in experiment.

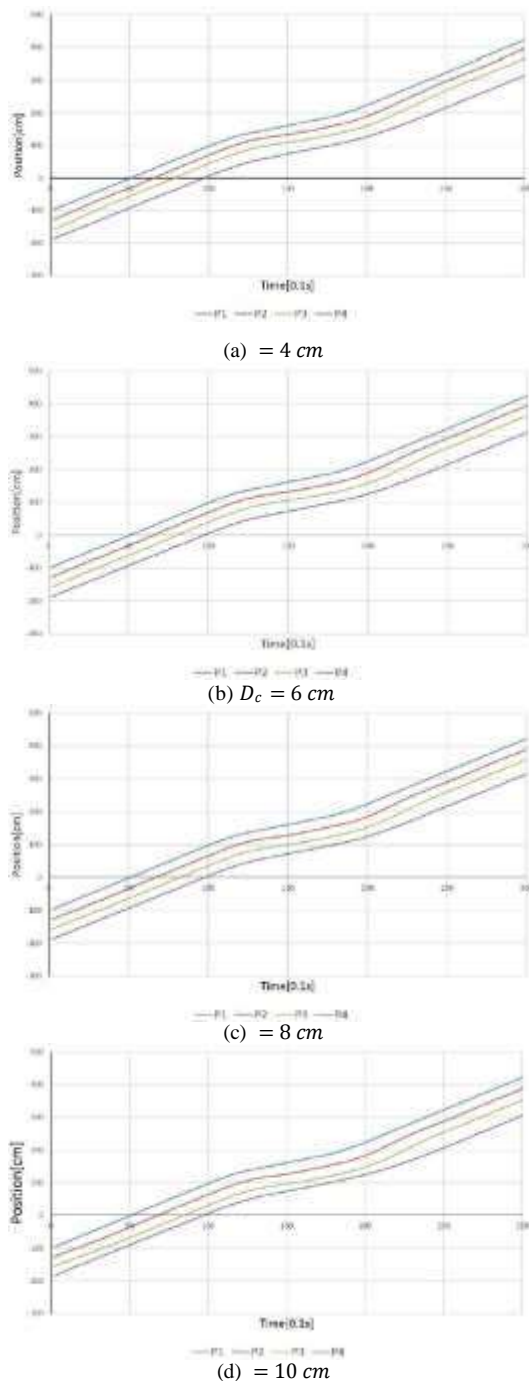


Figure 6: Vehicle trajectories in experiment.

v. Conclusion

The velocity control model of vehicles in a platoon was discussed in this study. The platoon is composed of four vehicles. The model is defined as the Helly model and its extension. The model parameters are determined by minimizing the objective function of the velocity control. The validity of the model was confirmed in the computer simulation and then, applied for the experiment of vehicle robots. Finally, the adequate length of the vehicle distance was discussed from the viewpoints of the comparison of the simulation and experiment, the platoon length and the ride comfort level. In the future study, the validity of the models is discussed in the other use cases.

Table 5: Comparison of simulation and experiment

(a) = 4 cm

Vehicle	η	E_p	E_v
P2	0.9999	7.387	1.245
P3	0.9999	9.775	1.340
P4	0.9997	8.380	0.9001

(b) = 6 cm

Vehicle	η	E_p	E_v
P2	0.9999	6.907	1.114
P3	0.9998	9.713	1.346
P4	0.9998	1.987	0.8603

(c) = 8 cm

Vehicle	η	E_p	E_v
P2	0.9999	7.357	1.227
P3	0.9998	10.27	1.304
P4	0.9998	7.213	0.7509

(d) = 10 cm

Vehicle	η	E_p	E_v
P2	0.9999	7.411	1.254
P3	0.9998	10.73	1.338
P4	0.9988	10.90	1.029

Table 6: Ride comfort level

D_c	P2	P3	P4
4 cm	74.59	74.73	72.74
6 cm	74.19	74.70	72.79
8 cm	73.59	74.42	73.44
10 cm	73.25	74.31	73.07

Table 7: Platoon length

D_c (cm)	Platoon length (cm)
4	75.62
6	76.51
8	75.89
10	77.89

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