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VEHICLE CONTROL OF VEHICLES SEPARATING FROM VEHICLE PLATOON

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Vehicle platoon is very important techniques for increasing the traffic flow safely and effectively. The electric and mechanical systems are necessary for effective vehicle platoon. Several systems have been studied for control vehicles in the platoon. This paper focuses on the velocity control of the vehicles separating from the vehicle platoon. The velocity control model is defined according to the vehicle following model and then, the parameters are determined by minimizing the objective function. The model with the optimized parameters is applied for the vehicle platoon experiment of LEGO Mindstorms NXT. The experimental results are compared with the simulation results in order to confirm the validity of the model. Although the experimental results finally converge to the simulation results, there exists the difference between the computational simulation and the experimental results because of the error of the sensor and the others.

Keywords: Separation, Vehicle following model, Simulation, Optimization, Lego® Mindstorm®.

1 INTRODUCTION

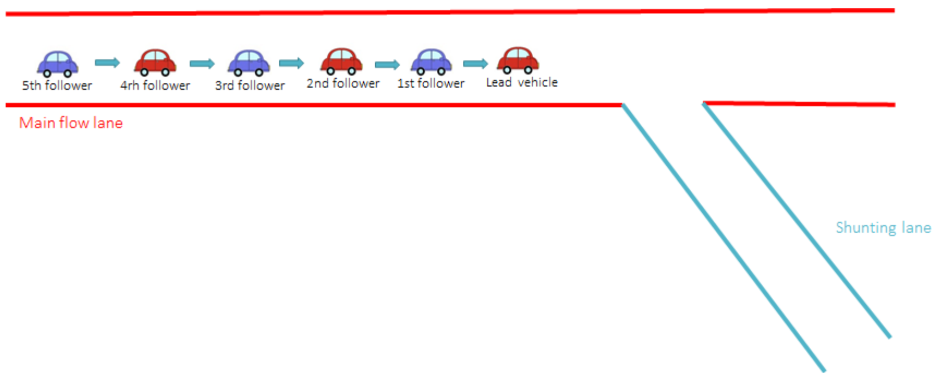
Vehicle platoon is the very important technique for increasing the traffic capacity safely. Vehicle platoons decrease the distances between cars or trucks using electronic, and possibly mechanical, coupling. This capability would allow many cars or trucks to accelerate or brake simultaneously. The previous studies in this field focus on the velocity control of the vehicles for stably keeping the vehicle platoon (Kita *et al.* 2014). However, this study focuses on the velocity control of the vehicles when the vehicles are separated the vehicle platoon. One large platoon moving on the road separates two small platoons at the intersection.

The velocity control model in this study is based on the vehicle following model (Bierley 1963, Chandler *et al*. 1958, Gazis *et al*. 1961, Helly 1959). The vehicle following model controls the vehicle velocity from the information from the nearest frontal vehicle such as the vehicle head distance, the velocity distance, the acceleration rate and so on. Gazis model (Gazis *et al*. 1961) is adopted in this study. This model controls the velocity according to the vehicle head distance and the vehicle velocity difference between the vehicle and the nearest frontal vehicle. The model parameters are determined by solving the optimum problems. The model with the optimized parameters is applied for the vehicle velocity control in the vehicle platoon experiment of Lego® Mindstorms® NXT (LEGO® Education 2016). The experimental results are compared with the simulation results in order to confirm the validity of the model.

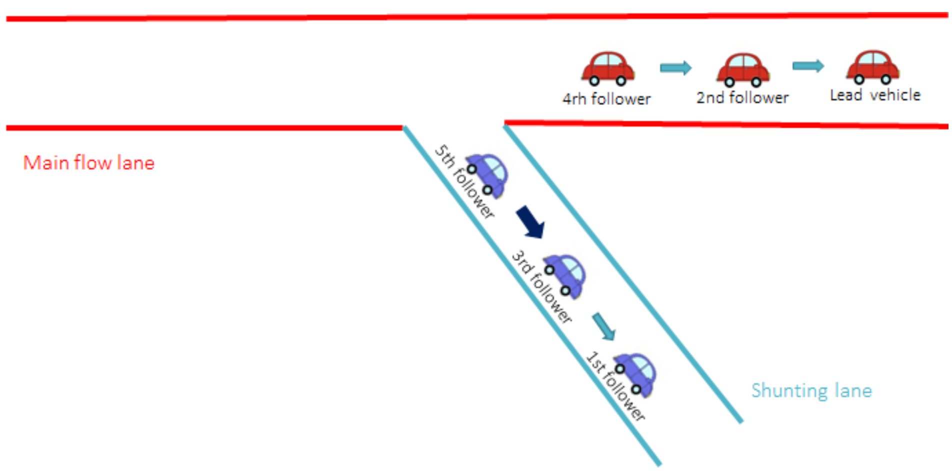
2 VELOCITY CONTROL MODEL

2.1 Vehicle Platoon

The vehicle platoon is composed of six vehicles. From the head vehicle of the platoon, the vehicles are named as the lead, 1st follower, 2nd follower, 3rd follower, 4th follower and 5th follower vehicles, respectively. The large platoon of six vehicles separates into two short platoons of three vehicles (Figure 1) at the intersection. One and the other short platoons are composed of the lead, the 2nd follower and the 4th follower vehicles and the 1st, the 3rd and the 5th follower vehicles of the large platoon, respectively.



(a) Before separation.



(b) After separation.

Figure 1. Separation of vehicles from vehicle platoon.

2.2 Vehicle Following Model

The vehicle following model controls the vehicle velocity according to the mathematical model with the information from the frontal vehicles. Several parameters are adopted as the control information; such as the vehicle head distance, velocity distance, acceleration rate, and so on.

The vehicle following model controls the vehicle velocity from the information from the nearest frontal vehicle such as the vehicle head distance, the velocity distance, the acceleration rate and so on. In this study, the vehicle following model is defined according to the advanced Gazis model (Gazis *et al*. 1961).

The advanced Gazis model is given as follows. The velocity of the 1st follower vehicle is controlled with the Eq. (1) and the velocity of other follower vehicles are with the Eq. (2).

$$\ddot{x}_1(t+\Delta t) = \frac{1}{x_{n-1}(t)-x_n(t)}\left[\alpha\left(\dot{x}_0(t)-\dot{x}_n(t)\right)+\beta\left(x_{n-1}(t)-x_n(t)-D_n(t)\right)\right] \tag{1}$$

$$\ddot{x}_n(t+\Delta t) = \frac{1}{x_{n-1}(t)-x_n(t)}\left[\alpha\left(\dot{x}_{n-1}(t)-\dot{x}_n(t)\right)+\beta\left(x_{n-1}(t)-x_n(t)-D_n(t)\right)\right.$$
$$\left.+\gamma\left(\dot{x}_0(t)-\dot{x}_n(t)\right)\right] \qquad (n=2,3,4,5) \tag{2}$$

The variables $x_0(t)$, $x_1(t)$, $x_2(t)$, $x_3(t)$, $x_4(t)$ and $x_5(t)$ denote the positions of the lead, the 1st, the 2nd, the 3rd, the 4th and the 5th follower vehicles of the large platoon, respectively. Therefore, the vehicle $n-1$ is the nearest frontal vehicle of the vehicle n. The terms $x_{n-1}(t)-x_n(t)$ and $\dot{x}_{n-1}(t)-\dot{x}_n(t)$ denote the vehicle head distance and the velocity difference between the vehicle $n-1$ and the vehicle n, respectively. The parameters α, β and γ are the sensitivity parameters. The function $D_n(t)$ is the desired vehicle head distance.

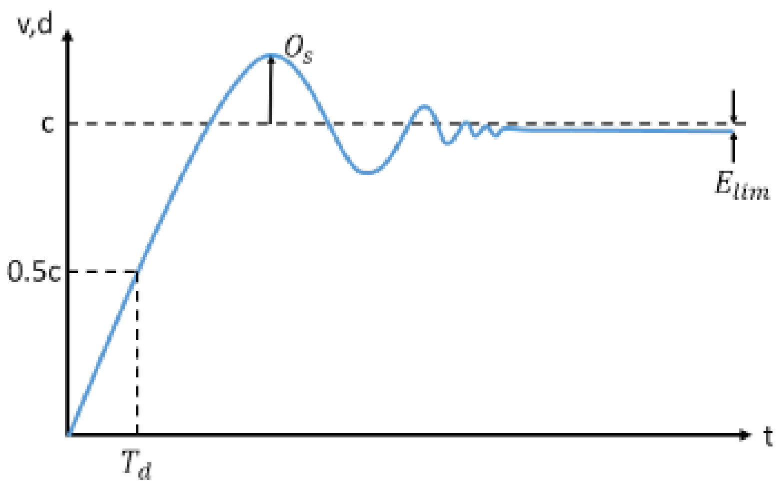


Figure 2. The convergence history.

2.2 Parameter Design

When the vehicle position $\boldsymbol{d}$ or the vehicle velocity $\boldsymbol{v}$ is controlled to their target values $\boldsymbol{c}$, the convergence history is shown in Figure 2. The values T_d, O_s and E_{lim} denote the delay time of the control, the overshoot value and the steady-state variation, respectively.

The control parameters are determined by minimizing the following objective function J.

$$J = w_1 T_d + w_2 O_s + w_3 E_{lim} + w_4 D \tag{3}$$

The value D is the time-integration of the difference between the actual and the desired vehicle head distances. The parameters w_1, w_2, w_3 and w_4 are the weight parameters.

Table 1. Initial position, the initial velocity and the initial acceleration rate of the vehicles.

	Lead	1st follower	2nd follower	3rd follower	4th follower	5th follower
$\ddot{x}_n(t)\,[cm/s^2]$	0	0	0	0	0	0
$\dot{x}_n(t)\,[cm/s]$	11.8	11.8	11.8	11.8	11.8	11.8
$x_n(t)\,[cm]$	-90	-130	-170	-210	-250	-290

Table 2. Sensitivity parameters.

	Before separation			After separation		
	α	β	γ	α	β	γ
1st follower	0.91	1.0	0	0	0	0
2nd follower	1.0	0.73	0.59	0.02	0.01	0
3rd follower	1.0	1.0	0.55	0.99	0.82	0
4th follower	1.0	0.51	0.98	0.98	0.62	0.24
5th follower	1.0	0.61	0.98	1.0	0.01	1.0

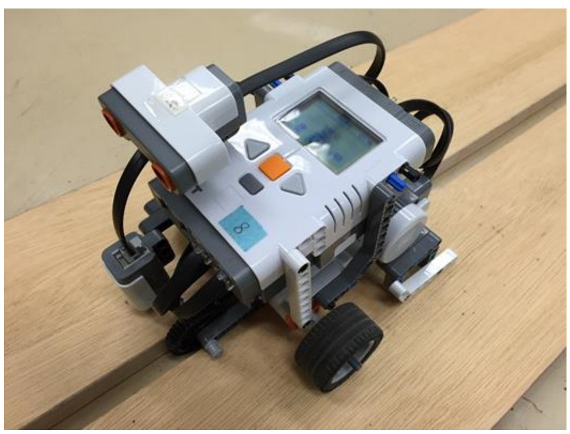


Figure 3. Lego® Mindstorms® NXT.

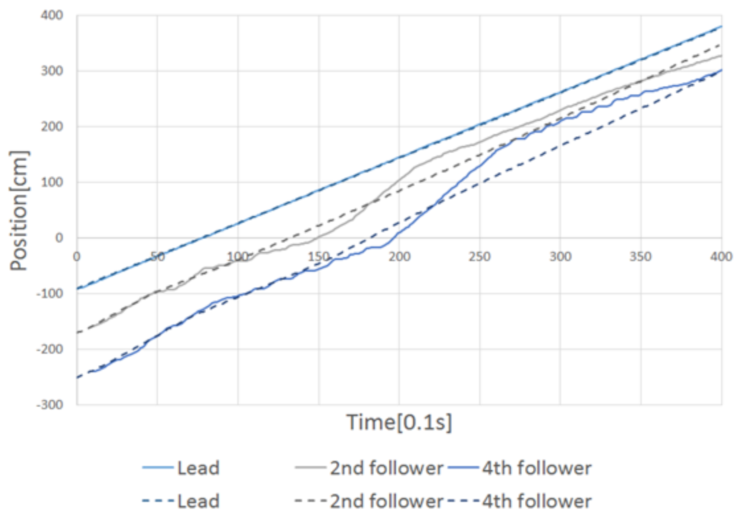
3 NUMERICAL SIMULATION

The vehicle platoon is composed of six vehicles. Three vehicles separates from the platoon. The computer simulation program is written in C language. The experimental results are obtained from the vehicle platoon simulation of the Lego® Mindstorms® NXT (Figure 3). The initial position, the initial velocity and the initial acceleration rate of the vehicles in the platoon are shown in Table 1. The lead vehicle and the 1st follower vehicles after separation of the platoon move at the uniform velocity.

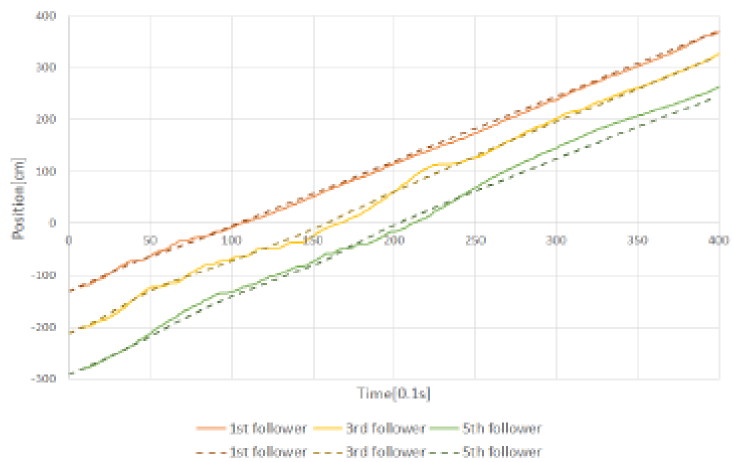
The weigh parameters in Eq. (3) are specified as follows:

$$w_1 = w_2 = w_3 = w_4 = 1 \tag{4}$$

Minimizing the Eq. (3) leads to the sensitivity parameters shown in Table 1.



(a) Lead, 2nd follower, and 4th follower vehicles.



(b) 1st, 3rd follower, and 5th follower vehicles.

Figure 4. Comparison of computational simulation and experimental results.

The comparison of the numerical simulation and the experimental results is shown in Figure 3. Figure 3 (a) shows the position of the lead, the 2nd follower and the 4th follower vehicles. Figure 3 (b) shows the position of the 1st, the 3rd follower and the 5th follower vehicles. The figures are plotted with the time as the horizontal axis and the position as the vertical axis, respectively. The solid and the broken lines denote the experimental result of the LEGO MINDSTORMS NXT and the computational simulation result, respectively. Although the experimental results finally converge to the simulation results, there exists the difference between the computational simulation and the experimental results. The difference is caused from the sensor error, the delay time of the control, etc.

4 CONCLUSION

The vehicle platoon is very important technique for safely increasing the traffic capacity of the road network. This study focused on the velocity control of the vehicles separating from the vehicle platoon. The sensitivity parameters in the velocity control model were defined as the vehicle following model and the sensitivities were determined by minimizing the objective function. The velocity control model was used for the computational simulation and the experiment of the Lego® Mindstorms® NXT. Although the experimental results finally converge to the simulation results, there exists the difference between the computational simulation and the experimental results. The difference is caused from the sensor error, the delay time of the control, etc. The reasons of the difference should be discussed in the future works.

Acknowledgements

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References

Bierley R. L. Investigation of an Intervehicle Spacing Display. *Highway Research Record*, Vol. 25, pp. 58-75, 1963.

Chandler R. E., Herman R., and Montroll E.W., Traffic dynamics: studies in car following. *Operations Research*, Vol. 6, No. 2, pp. 165-184, 1958.

Gazis, D. C., Herman, R., and Rothery, R. W., Non-linear Follow-the-Leader Models of Traffic Flow. *Operations Research*, Vol. 9, pp. 545-567, 1961.

Helly, W., Simulation of Bottlenecks in Single-Lane Traffic Flow. *Theory of Traffic Flow*, pp.207-238, 1959.

Kita, E., Sakamoto, H., Takaue, H., and Yamada, M., "Robot Vehicle Platoon Experiment Based on Multi-leader Vehicle Following Model," *2014 Second International Symposium on Computing and Networking*, pp. 491-494, 2014.

LEGO® Education, 2016. Retrieved from http://www.legoeducation.jp/mindstorms/ on May 1, 2017.