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Control Design Methods for Platooning in Robot Car

Ryo TAKAKI, Xin ZHAO, Harutoshi OGAI

Waseda University, 2-7 HIBIKINO, WAKAMATSU-KU, KITAKYUSYU CITY, FUKUOKA, 808-0135, Japan
(Tel: 81-93-692-5147; Fax: 81-93-692-5147)
(Email address: takaki@akane.waseda.jp, zhaoxin_19870121@yahoo.co.jp)

Abstract: Platooning technology is becoming a future task which suggests as a way of reducing carbon dioxid e emissions and realizing safe driving at a high speed velocity. This paper describes a few control methods f or vehicle-platooning. The conventional control method improved fuel consumption by shortening the distance between vehicles. By contrast, the method we proposed improves it by controlling the velocity at the time of acceleration gently. The velocity is controlled by generating the desired value of inter-vehicular distance corres ponding to the leading vehicle velocity. Another method which is planned to realize a highly efficient arterial traffic distribution system includes reducing aerodynamic drag by minimizing the distance between vehicles to allow drafting. In this paper, the two degrees-of-freedom control system is applied for it. These proposed met hods were evaluated by simulation and some experiments.

Keywords: Platooning, control method, two degrees-of-freedom, distance

I. INTRODUCTION

Platooning is considered as one of the innovations in the automotive industry that aim to improve the safety, efficiency, mileage, and time of travel of vehicles while relieving traffic congestion, decreasing pollution and reducing stress for passengers[1]. Also, platooning makes it possible for vehicles to travel together closely and safely. This leads to a reduction in the amount of space used by a number of vehicles on a highway. Thus more vehicles can use the highway without traffic congestion [2].

In our research, we use the equipment of robot car which is a kind of electric cars carrying the laser range sensor and CCD camera. By robot car, we can carry out the research of automation driving and platooning.

In this paper, it designs the model for the robot car platooning system and develops two degrees-of-freedom control system to control the distance of vehicle-platoon.

II. OUTLINE OF PLATOONING SYSTEM

2.1 Modeling of Robot car

In this research, the response characteristic of acceleration from target value to actual value is given by equation (1).

$$G_a(s) = \frac{a(s)}{u_a(s)} = \frac{1}{T_m s + 1} \tag{1}$$

Where, T_m is the time constant of the acceleration response characteristic. The acceleration response characteristic is controlled by model matching control system shown in Fig.1 [3]. This control system consists of model matching compensator, robust compensator and plant. The model matching compensator generates a signal to match the actual response characteristic and ideal response characteristic shown in equation (1). Furthermore, robust compensator generates a signal to reduce the effect of fluctuation of plant characteristic. In this research, we defined the time constant as T_m=1.0 in the same way as reference [4].

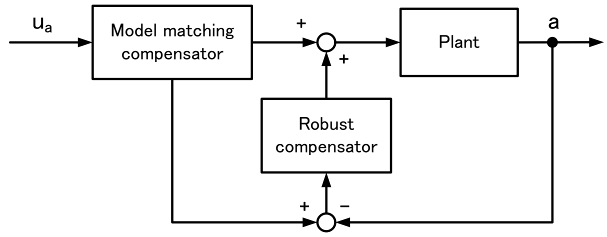


Fig.1. Robust model matching control system

2.2 Constitution of vehicle-platoon

The constitution of platoon is shown in Fig.2. In this research, we deal with three robot cars as a vehicle-platoon. Each robot car detects distance between two cars by radar sensor. The variable's numbers shown in Fig.2 corresponds to each robot car's number. For example, v_2 represents the velocity of robot car 2.

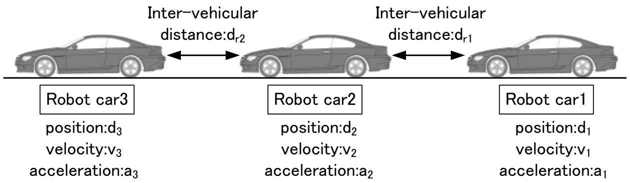


Fig.2. Constitution of platoon

III. DESIGN OF CONTROL SYSTEM

3.1 Object of the system

When the leading car moves quickly, it is necessary to control the velocity of following robot car rapidly for remaining the target inter-vehicular distance. However, the fuel consumption is also increased rapidly. In order to solve this problem, it is necessary to determine the target inter-vehicular distance corresponding to the leading car's driving situation. Moreover, the control system which can regulate the inter-vehicular distance without influencing ride quality is required.

3.2 Constitution of control system

Two degrees-of-freedom control system shown in Fig.3 is designed to attain the design requirements, [6]. The control system consists of controlled object P(s), target inter-vehicular distance generator $G_{ref}(s)$, model matching compensator $G_M(s)$, feed forward compensator $C_{FF}(s)$ and feedback compensator $C_{FB}(s)$. And this kind of control system is carried in each robot car.

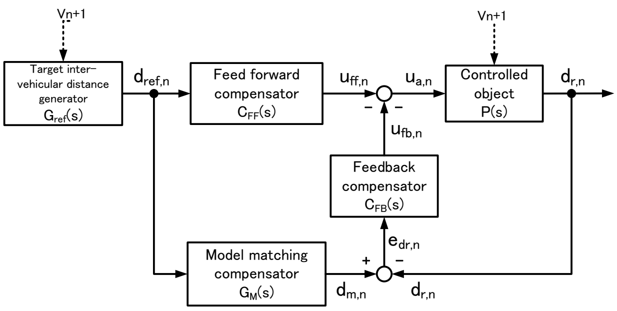


Fig.3. Constitution of control system

3.3 Control objective

The block diagram of the controlled object is shown in Fig.4. The transfer function of the control objective P(s) from target acceleration $u_a(s)$ to actual inter-vehicular distance $d_r(s)$ is given by equation (2).

$$P(s) = \frac{d_{r,n}(s)}{u_{a,n}(s)} = \frac{1}{s}\left(v_{n+1}(s) - v_n(s)\right)$$

$$= \frac{v_{n+1}(s)}{s} - \frac{u_{a,n}(s)}{T_m s^3 + s^2} \tag{2}$$

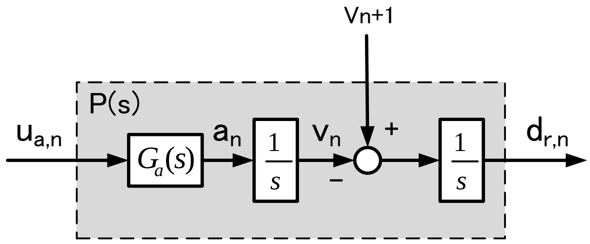


Fig.4. Block diagram of control objective

3.4 Inter-vehicular distance generator of target

Inter-vehicular distance of target $d_{ref,n}(s)$ is calculated by equation (3).

$$d_{ref,n}(s) = d_{ref-v,n}(s) + d_{ref-a,n}(s) \tag{3}$$

Where, $d_{ref\text{-}v}(s)$ represents the element of inter-vehicular distance of target correspond to leading car's velocity and $d_{ref\text{-}a}(s)$ represents another element of target inter-vehicular distance correspond to the leading car's acceleration. $d_{ref\text{-}v}(s)$ and $d_{ref\text{-}a}(s)$ are given by equation (4), (5), respectively.

$$d_{ref-v,n}(s) = h\, v_{n+1}(s) \tag{4}$$

$$d_{ref-a,n}(s) = h\frac{s}{\lambda_{a,n} + s} v_{n+1}(s) \tag{5}$$

Where, h represents inter-vehicular time coefficient and λ_a represents control parameter. Therefore, $d_{ref\text{-}v}(s)$ increases as leading car's speed increases. In my research, we defined the inter-vehicular time coefficient as h=2.0 in the same way as reference [5]. When leading car moves quickly, $d_{ref\text{-}a}(s)$ also increases quickly. Due to long target inter-vehicular distance, it is not necessary for subsequent robot car to accelerate rapidly.

3.5 Model matching compensator

The transfer function of the model matching compensator $G_M(s)$ from inter-vehicular distance of target $d_{ref}(s)$ to inter-vehicular distance response $d_m(s)$ is given by equation (6).

$$G_{M,n}(s) = \frac{d_{m,n}(s)}{d_{ref,n}(s)} = \frac{\omega_n^{\,2}}{s^2 + 2\zeta_n\omega_n s + \omega_n^{\,2}} F(s) \tag{6}$$

Where, ζ represents attenuation coefficient and ω represents character frequency. F(s) is a filter given by equation (7).

$$F(s) = \frac{1}{T_F s + 1} \tag{7}$$

Where, T_F represents time constant. In this research, time constant is defined as T_F =0.1.

3.6 Feed forward compensator

A block diagram of feed forward control system is shown in Fig.5. In order to match the actual inter-vehicular distance $d_r(s)$ and inter-vehicular distance response $d_m(s)$, it is necessary to equalize the transfer function of feed forward compensator from target inter-vehicular distance $d_{ref}(s)$ to actual inter-vehicular distance $d_r(s)$ and the transfer function of model matching compensator. Therefore, transfer function of feed forward compensator is given by equation (8), (9).

$$\frac{d_{r,n}(s)}{d_{ref,n}(s)} = C_{FF,n}(s)P(s) = G_{M,n}(s) \tag{8}$$

$$C_{FF,n}(s) = \frac{G_{M,n}(s)}{P(s)} \tag{9}$$

Feed forward compensator can control actual inter-vehicular distance $d_r(s)$ similar to inter-vehicular distance response $d_m(s)$. However, due to disturbance and fluctuation of plant characteristic, feedback compensator is also necessary.

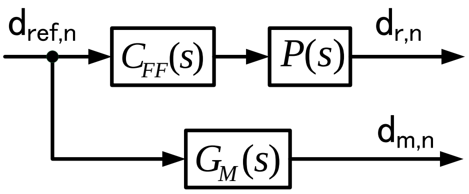


Fig.5. Feedforward control system

3.7 Feedback compensator

A block diagram of feedback control system is shown in Fig.6. This compensator controls transfer characteristic from a disturbance to actual inter-vehicular distance shown in equation (10).

$$\frac{d_{r,n}(s)}{d_{d,n}(s)} = \frac{1}{1 + C_{FB}(s)P(s)} \tag{10}$$

Feedback compensator can control disturbance response without influencing desired value response. In this research, sensitivity function for disturbance is given by equation (11).

$$S(s) = \left(\frac{s}{\lambda_S + s}\right)^3 \tag{11}$$

Where, λ_S represents a parameter of sensitivity function. From equation (10) and (11), transfer function of feedback compensator is calculated as equation (12).

$$C_{FB}(s) = \frac{1 - S(s)}{S(s)P(s)} = \frac{3T_m\lambda_S s^3 + 3\lambda_S(T_m\lambda_S + 1)s^2 + \lambda_S^{\,2}(T_m\lambda_S + 3)s + \lambda_S^{\,3}}{s} \tag{12}$$

In my research, the parameter of sensitivity function is defined as λ_S=3.0.

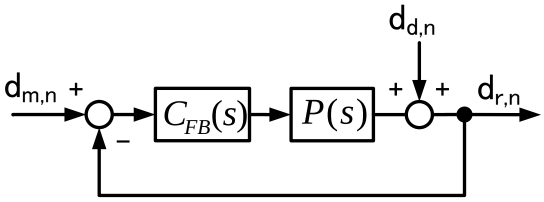


Fig.6. Feedback control system

IV. SIMULATION

4.1 Simulation condition

Initial position of the vehicle-platoon is shown in Fig.7. The vehicle-platoon contains one leading robot car4 and three robot cars 1,2,3 and each initial inter-vehicular distance is 3[m] and each initial velocity is 0[m/s]. The velocity of robot cars1,2,3 are controlled by proposed control system and the velocity of robot car4 is given as Fig.8. Simulation parameters of each Robot car are given by Table.1. Under above conditions, Inter-vehicular distance and velocity of each robot car are simulated.

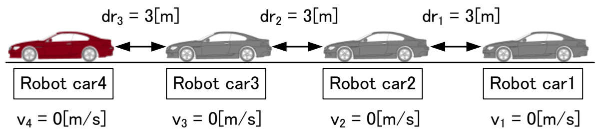


Fig.7. Initial position of Robot car

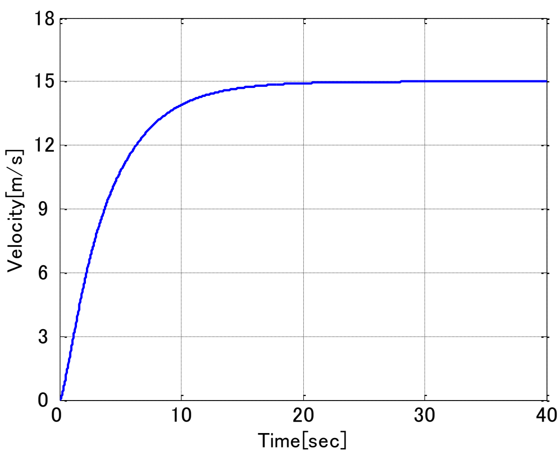


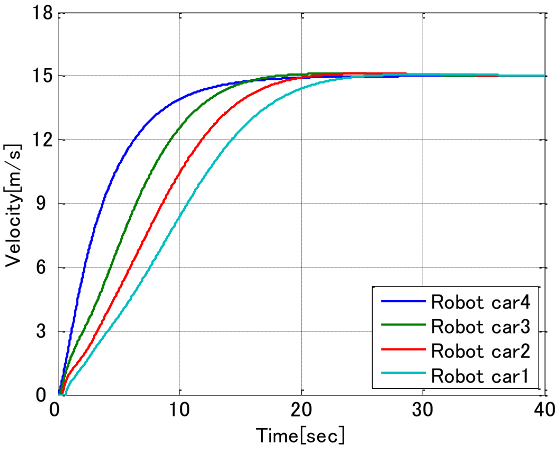
Fig.8. Speed fluctuation of leading-robot car4

Table.1:Simulation parameters

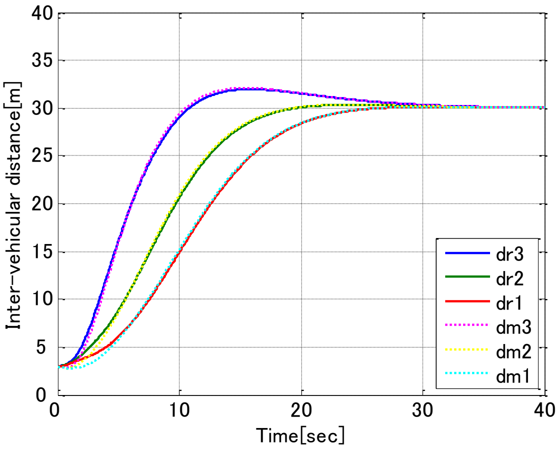
Parameters	Robot car1	Robot car2	Robot car3
λ_a	0.65	0.45	0.25
h	2.0	2.0	2.0
ζ	1.5	1.5	1.5
ω	0.7	0.7	0.7

4.2 Simulation results

The calculated value of robot car's velocity and each inter-vehicular distance is shown in Fig.9(a), Fig.9(b), respectively. From simulation results, it is verified that the velocity of subsequent robot car is controlled more gently than that of leading robot car. This result indicates that the proposed method can prevent subsequent following vehicles from accelerating rapidly. Moreover, Fig.9(b) indicates that actual inter-vehicular distance $d_r(s)$ is controlled accurately to match the inter-vehicular distance response $d_m(s)$.



(a)Velocity



(b)Inter-vehicular distance

Fig.9. Simulation results

5. CONCLUSION

In our research, it presents a two degrees-of-freedom control system to control the platooning. The system controls the velocity of vehicle-platoon smoothly and keeps the distance of vehicle-platoon accurately.

The future plan is to carry out the simulation of model predictive control and do the comparison. And we will lead the control system into robot car.

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