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Minimizing the inter-vehicle distance of the time headway policy for platoons control in highways

ALI, Alan
Mél: Alan.Ali@irccyn.ec-nantes.fr

Résumé:
Variable and constant spacing are the two spacing policies in longitudinal control of platoons. Variable spacing doesn't require very much information from other vehicles, what's more, we can get string stability using only onboard information, but inter-vehicle distances are very large and hence low traffic density. Constant spacing can assure string stability with high traffic density, but it requires at least information from the leader. We propose an important modification for the time headway spacing policy. This modification is effective to decrease the distance between the cars, to become nearly equal to the constant spacing policy. Also, it doesn't require heavy communication between the cars. Simulation results show the effectiveness of the proposed modification and its potential effect on traffic density. Simulation was made under Matlab and TORCS.

Keywords: *Platoon, control, time headway, constant spacing, string stability, inter-vehicle distance, highways.*

1 Introduction

As the number of cars increases the traffic congestion becomes a more and more important problem. Many solutions have been proposed, most of which try to benefit from advances in technology, and especially in the domain of automated electric cars.

One of these solutions is to drive in platoon, so that all cars in the platoon run automatically together, with the same speed and with desired inter-vehicle spacing. This can increase traffic capacity, security, and decrease fuel consumption and driver tiredness.

The most recent platooning project is the SARTRE Project, which was tested and finished in Sep 2012 using a big truck as a leader and three follower vehicles. Beside this project, there are many others, like the CHAUFFEUR 2 project and the platooning project in the PATH program (California Partners for Advanced Transportation Technology). All previous projects concentrated on platooning in highways, where we concentrate on the problem of longitudinal control at high speed.

Variable spacing and Constant spacing are the two policies in longitudinal control. Variable spacing doesn't require a lot of information from other vehicles, what's more, it can assure string stability just by using on-board information [1], but inter-vehicle distances may be very large, and hence traffic density is low. Constant spacing can assure string stability with high traffic density, but it requires inter-vehicle communications.

Although variable spacing may give large spacing distances, the previously mentioned advantages attracted researchers to try to reduce the spacing to make it more practical. One of the most important variable spacing policies is the time headways policy, in which the inter-vehicle distance is a function of the velocity of the vehicle.

Constant time headways (CTH) is the simplest and most common time headway policy [2,3,4,5], while others use variable time headway, which varies linearly with the velocity or with relative velocity [4] ,or even with the vehicle dynamics and the road conditions [4]…

[5] Has proved that the string stability decreases when the headway decrease. [8] Showed that the desired control torques are inversely proportional to the headway time. This can produce torque saturation when choosing small headway. It was concluded that for high capacity small vehicle to vehicle spacing, the constant spacing law is necessary at the price of inter-vehicle communication. To our knowledge, all previous research has concentrated on optimizing the time head way constant, to get good compromise between stability and inter-vehicle distance.

In this paper, we will concentrate on the longitudinal control of platoons in highways. We will propose a new modification to the time headways policy. And we will show all the benefit of this change. The security issue will not be discussed in this paper.

The paper is organized as follows: in section 2 and 3 modeling, control and stability. Then in section 4 we will present the simulations under Matlab and TORCS. Finally, in section 5 we will give the conclusion.

2 Modeling:

In this paper we concentrate on the longitudinal control. As we are dealing with highways, with small curvature, so the lateral control will not be discussed:

2.1 Car Model:

We take classical car model, obtained using exact linearization [2,9]:

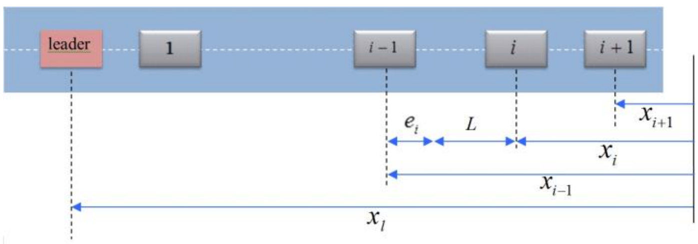
$$\ddot{x} = u \tag{1}$$

Where x : is the position of the car.
u : The control input.

2.2 Platoon Model:

As shown in figure (1) the platoon consists of many vehicles moving at the same speed with a desired inter distance L between each two vehicles. The first vehicle is the leader; it performs maneuvers (automatically or by a human), and the following vehicles are controlled to maintain a desired following distance.
We define the following parameters:

- L : Desired inter-vehicle distance.
- x_i : Position of i-th vehicle.
- $v_i = \dot{x}_i$: Velocity of the i-th vehicle.
- $\Delta x_i = x_{i-1} - x_i$: The real spacing between i-th car and its predecessor (i-1-th car).
- $e_i = x_{i-1} - x_i - L$:Spacing error of the ith vehicle.
- $\dot{e}_i = x_{i-1} - x_i$: Velocity error.
- N : Number of vehicles.



Figure(1) Platoon

3 CONTROL AND STABILITY

3.1 String Stability

We say that a platoon is string stable if the spacing error does not increase as it propagates through the platoon.
To verify this condition, we define the spacing error propagation transfer function:

$$H_i(s) = \frac{\varepsilon_i(s)}{\varepsilon_{i-1}(s)}$$

And the platoon is string stable if:

$$\|H_i(s)\|_\infty \leq 1 \quad , \quad h_i(t) > 0 \qquad i = 1,2..N \tag{2}$$

3.2 Control law

In constant spacing control, we take the following position error:

$$e_i = x_{i-1} - x_i - L$$

And the following control law:

$$u_i = k_v.\dot{e}_i + k_p.e_i$$

This control law makes $e_i \to 0$ and $\dot{e}_i \to 0$. But it needs, at least, information from leader to assure the string stability of the platoon.

While in the time headways policy we add a new term (proportional to velocity) which will reduce the communicated information and increase the string stability so we define new error:

$$\delta_i = x_{i-1} - x_i - L - h.v_i$$

With the following control law:

$$u_i = \frac{\dot{e}_i + \lambda.\delta_i}{h}$$

This new control law makes $\delta_i \to 0$ and $\dot{e}_i \to 0$, and it can ensure string stability using only on-board data. But the inter-vehicle distance in steady state will be proportional to velocity of vehicle v_i, equal to $L + h.v_i$, which is the main disadvantage of this law.

The main idea of our modification is to make δ_i proportional to velocity changes $(v_i - V)$ instead of the velocity itself. So we define new error as:

$$\delta_i = x_{i-1} - x_i - L - h.(v_i - V) \tag{3}$$

V : might be platoon velocity or the medium velocity of the vehicles in the platoon.

With the following control law:

$$u_i = \frac{\dot{e}_i + \lambda.\delta_i}{h} \tag{4}$$

We get the following spacing error propagation transfer function:

$$H_i(s) = \frac{e_i(s)}{e_{i-1}(s)} = \frac{s + \lambda}{h.s^2 + (1 + h.\lambda).s + \lambda} = \frac{1}{h.s + 1} \tag{5}$$

So

$$\begin{cases} |H_i(\omega)| = \left\{ \dfrac{1}{\sqrt{h^2.\omega^2 + 1}} \le 1 \right. \\ h_i(t) = e^{-\frac{t}{h}} > 0 \end{cases} \tag{6}$$

In other words, at all frequencies, the spacing errors do not amplify as they propagate through the platoon, so the system is string stable.

The only condition on V (to keep the platoon stable) is to make it the same for all the vehicles at the same sample time, so we can choose any value for V (e.g. leader's velocity, the medium velocity of the platoon or the minimum velocity in the platoon...).

4 SIMULATIONS

We have checked the control law under Matlab, and using TORCS to get more realistic results (as it takes much more phenomena into account) and to have visual output when applying modifications.

TORCS (The Open Racing Car Simulator) is one of the most popular car racing simulators show in figure (2). It is written in C++ and is available under GPL license.

All the simulations will be done on a straight road in Matlab, and with small curvatures in TORCS. The desired speed of the leader of the platoon is changed three times figure (3), to check the transit response of the platoon and to check the stability and the inter-vehicle distances, we take L = 5 m the desired inter-vehicle distance (bumper-to bumper distance, so we omit cars lengths from all figures).

Figure (2) TORCS

Figure (4) and figure (5) show the reduction in inter-vehicle distance using our control law, compared to the classical time headway control law. Inter-vehicle distance are greatly reduced and become equal to the desired L in steady state, and it changes to assure the platoon string stability during the dynamic changes. We can see also that our system is string stables (the error e_i decreases as i increases).

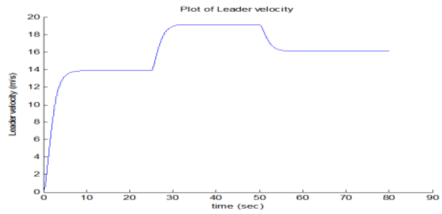


Figure (3) Leader's velocity profile

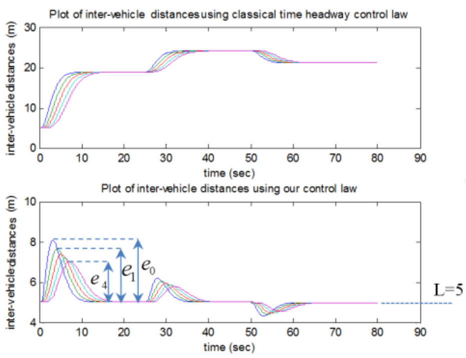


Figure (4) Inter-vehicle distance using CTH law and our law (in Matlab)

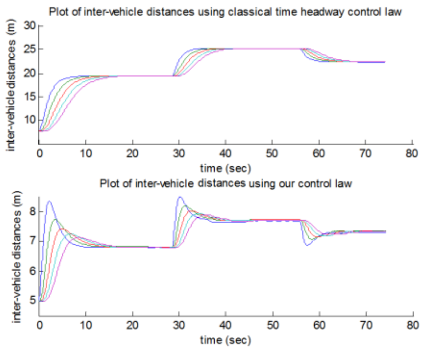


Figure (5) Inter-vehicle distances using CTH law and our law (in TORCS)

5 CONCLUSIONS

In this paper we have addressed the longitudinal control of platoons in highways. We have proposed a new modification of CTH control law, which improves the main shortcoming of that law, which are the large inter-vehicle distances. It also enables to increase the stability, the robustness, and avoid torque saturation. These benefits are obtained without the need for high rate data from other vehicles. Moreover, the platoon can still be stable even if the communication link is totally lost. All this results have been tested under Matlab and TORCS to check the validity of the modification.

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