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Platoon Control of Mixed Vehicles with External Disturbances via Delay-Based Spacing Strategy

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Introduction

This paper proposes a delay-based spacing strategy aimed at optimizing the driving efficiency and stability of mixed vehicle platoons (cooperative automated and human-driven vehicles). In response to the limitations of traditional spacing strategies in complex traffic environments, a control scheme is designed that incorporates radial basis function neural network for disturbance compensation.

Research Questions

This paper adopts the predecessor-following topology, to represent the information exchange among CAVs. The characteristic of this topology is that each CAV only receives the state information from its adjacent preceding CAV. The CAV, as the controlled object, achieves its control objectives by acquiring the state information of adjacent vehicles.

Methodologies

The optimization problem of MPC for the leading vehicle is expressed as follows:

$$\min_{u_0} J_0(x_0,u_0,x_0^a)=\sum_{\ell=0}^{N_p-1} L\left(x_0(\ell+1\mid k),u_0(\ell\mid k),x_0^a(\ell+1\mid k)\right)$$
$$x_0(\ell+1\mid k)=f_d(x_0(\ell\mid k),u_0(\ell\mid k)),$$
$$d_{min}\le \Delta s_0(\ell+1\mid k)\le d_{max},$$
$$u_0(\ell\mid k)\in\mathcal{U},\quad x_0(0\mid k)=x_0(k)$$

Figures

This paper addresses the energy-saving platooning problem in a longitudinal single-lane mixed traffic driving environment, as shown in Figure 1.

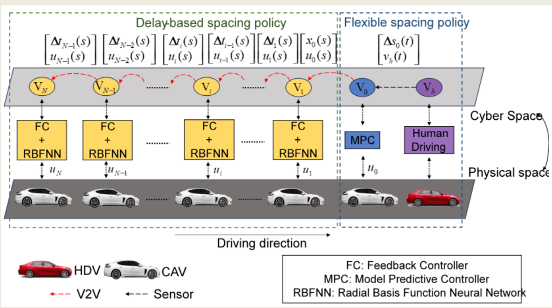


Figure 1. E-CACC scheme

Mathematical Formulas

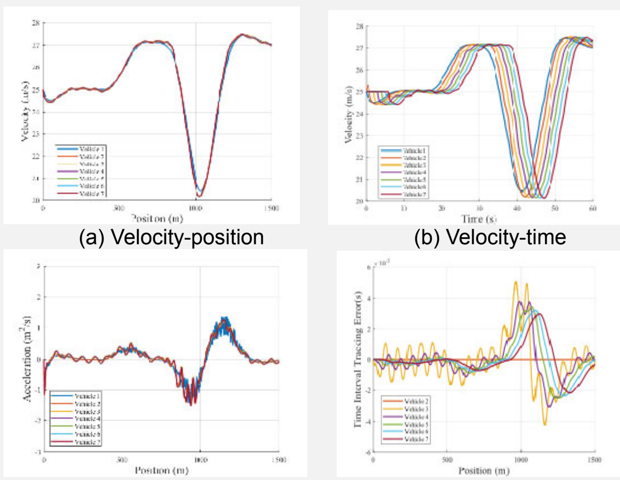
The longitudinal kinematic model of a vehicle with disturbances in the time domain can be described as

$$\begin{cases}\dot{p}_i(t)=v_i(t)\\ \dot{v}_i(t)=a_i(t)\\ \tau_i\dot{a}_i(t)+a_i(t)=u_i(t)+\omega_i(t)\end{cases}\tag{1}$$

$$t_{i,ref}(s)=t_{i-1}(s)+\Delta t_{i-1}(s)-h\left(\frac{1}{v_i(s)}-\frac{1}{v_{i-1}(s)}\right)\tag{2}$$

$$u_i(s)=u_i^{nom}(s)+u_i^{RBFNN}(s)\tag{3}$$

Figures



(a) Velocity-position (b) Velocity-time

(c) Acceleration-position (d) Time interval tracking error-position

Figure 2. Mixed platoon control without disturbance compensation

Conclusion

This paper presents a delay-based spacing strategy and control scheme for mixed vehicle platoons, achieving energy-efficient and smooth driving. It addresses external disturbances affecting platoon performance by employing an RBFNN for disturbance approximation and a compensation mechanism to enhance robustness. Numerical simulations validate the strategy's stability and safety, offering potential for real-world applications. Future work will enhance the framework with detailed vehicle dynamics models to reflect realistic motion and evaluate the strategy in complex scenarios, including lateral lane changes and curved roads, to extend its utility across diverse traffic conditions.