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Optimal control based CACC: problem formulation, solution, and stability analysis

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***Abstract*— Cooperative Adaptive Cruise Control (CACC) in previous researches typically refers to the linear controller with a gap policy. The system could not be designed to fulfill multiple objectives. This inspires the concept of optimal control based CACC in this paper. The basic procedure of the proposed controller is to gather the information collected by each vehicle to the computation unit first, then plan the trajectory of all the followers by solving an optimal control problem, and dispatch the optimal motion command to each vehicle at last. This paper models CACC under optimal control framework. A numerical approach inspired by dynamic programming is adopted to solve the control problem. The stability of the proposed controller is thoroughly investigated in terms of both local stability and string stability. To verify the concept of controller, solution, and the analysis about stability, simulation is carried out. The simulation verifies that the numerical method is effective with respect to computation time. Both theoretical analysis and simulation proved that the proposed optimal control based CACC is both local stable and string stable. The low computation burden, local stability, and string stability together guarantee the future implementation of the proposed controller.**

I. INTRODUCTION

An new optinal based CACC is proposed in this paper. The basic idea is to determine the motion of vehicle by solving an optimal control problem. The proposed controller with its computation unit first collects the motion states of all vehicles in the platoon, then plans the trajectory of all the followers by solving an optimal model predictive control problem, and dispatches the optimal motion command to each vehicles at last.

II. CONTROL PROBLEM

The control logic of the optimal control based CACC could be partitioned into the following four stages.

- Data collection: the local information is firstly obtained by the vehicle sensor, which may include the distance headway, the speed of ego-vehicle, the acceleration of ego-vehicle, etc. Then, the local information is sent to the central controller via V2V communication (as the red arrows in Fig. 1).
- Motion planning: the central controller, which could be any vehicle in the fleet (Fig. 1 gives follower 1 as the central controller for instance), optimizes the motion of each vehicle in the fleet. As opposed to the state-feedback gap policy controllers that only outputs the acceleration commands at the current time, the optimal control based CACC gives optimal acceleration trajectories over a future time horizon.
- Command dispatching: the driving command for each vehicle in this stage is sent back to each non-central controller via V2V communication (as indicated by the green arrows in Fig. 1).
- Actuation: each vehicle in the CACC fleet execute according to the received command.

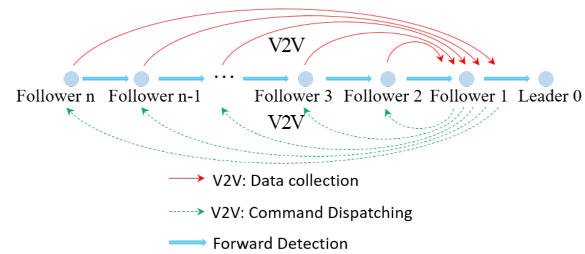

Fig. 1: Communication topology of vehicle-scale CACC.

Data flow of the proposed optimal control-based CACC is as Fig. 1.

III. CONCLUSIONS

This research proposes a cooperative adaptive cruise controller under optimal control framework. The control problem is solved by a numerical method which based on dynamic programming. The controller aims to coordinate the longitudinal maneuver of multi consecutive vehicles. The local stability and string stability is guaranteed by theoretical analysis. The computation effectiveness of the numerical solution, local stability, and string stability are all verified by simulation. Detailed analysis reveals that:

- The adopted solution is capable of controlling as many as 100 vehicles at the same time with computation time of about 650 ms.
- The proposed optimal control based CACC with any controller size is local stable.
- The proposed optimal control based CACC with any controller size is string stable.

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