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ACC performance and design

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Abstract

Introduction
Adaptive Cruise Control (ACC) enables automatic following of a vehicle. The relative distance \(x_r\) is controlled (see Fig. 1). A driver dependent part determines the desired host vehicle acceleration \(a_{dh}\), while a vehicle dependent part controls the longitudinal dynamics via actuation of the throttle \(u_{th}\) and brake system \(u_{br}\) (see Fig. 2).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1}
\caption{ACC system setup.}
\end{figure}

Problem statement
Focusing on the driver dependent part, nonlinear (situation dependent) driver behaviour generally is accounted for in the controller design via scheduling gains and switching logic, while disregarding stability issues. Furthermore, the lack of appropriately defined performance metrics yields time-consuming tuning by trial-and-error. Hence, performance metrics as well as a structured control framework for ACC are required.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2}
\caption{ACC control structure.}
\end{figure}

ACC performance evaluation
On the basis of literature and on-the-road experiments, metrics are determined to enable objective performance evaluation of an ACC system in a qualitative manner. In case of a passenger car, both comfort and desirability have to be considered. Comfort is mainly related to vestibularly detectable variables, whereas desirability is mainly related to visually and auditorily detectable variables.

Regarding desirability, \(x_r\), \(v_r\), and the so-called time-to-collision \(TTC = x_r/v_r\) are the most promising metrics, yet some situation dependency seems inevitable. Regarding comfort, acceleration and jerk peak values are appropriate metrics enabling objective performance evaluation.

ACC design
Besides the control objective regarding \(x_r\), the relative velocity \(v_r\) should be limited based on desirability and the acceleration and jerk should be limited out of comfort reasons. Furthermore, the nonlinear driver behaviour as well as safety considerations yield various (nonlinear) constraints on the control output \(a_{dh}\).

Model Predictive Control (MPC) is adopted as a suitable, structured framework for constrained, MIMO, nonlinear controller design. MPC minimizes a cost function \(J\) regarding the control output \(u\) over a user-defined prediction horizon; \(\min_{u} J(u, \epsilon, \mathcal{R})\), with \(\epsilon\) the error with respect to the control objectives and \(\mathcal{R}\) the performance related requirements. Adopting a closed-loop MPC synthesis enables explicit, offline optimization of the state-dependent controller gains. This yields a hybrid control synthesis, which prevents the need for significant online computational power.

Simulations as well as on-the-road experiments have been executed, showing appropriate behaviour of the ACC system.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3}
\caption{Screenshot of the simulation environment and the Audi S8 with which the ACC is tested.}
\end{figure}

Future work
Current research focusses on further integration of the performance metrics in the tuning process and the possibly automated, driver-specific tuning.