Connected testbeds for connected automated vehicles

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Connected automated vehicles (CAVs) hold significant potential for improving fuel economy and emissions in future transportation. High-fidelity evaluations of CAV technologies in the early stages of their design can accelerate their development and deployment. However, state of the art tools can be insufficient to provide this capability. On the one hand, purely simulation based studies could be off by as much as 27% in terms of fuel economy and as much as 350% in terms of emissions. While fidelity of traffic simulators is improving, the computing power that is required for integration of high-fidelity and multi-physics models of modern powertrains continues to be prohibitively high for this application. On the other hand, experimental studies can provide invaluable real-world data, but performing an affordable, controllable, repeatable, and scalable evaluation of CAV technologies is difficult in on-road experiments. Therefore, in pursuit of a high-fidelity, cost-effective, repeatable, and scalable evaluation tool for CAVs, a novel concept called *connected testbeds* is under development, which refers to integrating powertrain testbeds, such as engine or battery test cells, over the Internet to enable hardware-in-the-loop evaluation of CAV technologies even if the powertrain components are geographically dispersed. One of the main research challenges to realize this vision is handling the time delay that is introduced into the connected testbeds due to the Internet. In particular, the delays that are introduced into the coupling signals, i.e., the signals that are exchanged between the remote locations to establish the integration, can distort the dynamics of the connected testbed, reducing its fidelity and even jeopardizing its stability. Therefore, to ensure a high-fidelity coupling of the testbeds, these delays may need to be compensated. To this end, we adopt and further develop a predictor framework to predict the current coupling signals given their delayed measurements. The dynamics of the predictors are described by first order delay differential equations with only a couple of tuning parameters similar to the proportional-integral control concept. Hence, the predictor framework does not require mathematical models of the systems that generate the coupling signals and is thus suitable as a component-agnostic solution for connected testbeds. We present an analysis for the stability and performance of the predictors. Preliminary simulations and experimental results show the utility of the connected testbeds concept and the predictor framework.

Keywords: networked engineering testbeds; delay compensation; hardware-in-the-loop simulation; connected automated vehicles

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