Hardware in the Loop Testing of Signalized Intersection Approach and Departure with Connected and Automated Vehicles

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Abstract

CAV based hardware-in-the-loop (HIL) testing allows real test vehicles to interact with virtual vehicles from traffic simulation models – providing an excellent evaluation environment that can replicate actual field conditions at early stages of CAV development without incurring excessive costs. In this study, testing hardware includes automated vehicles controlled in real time, traffic signal controllers (TSC) and Dedicated Short Range Communication (DSRC) devices (e.g., OBU, RSU) for CV applications. Traffic simulation tool VISSIM is used to set up test environment and generate background traffic. The developed HIL system is used to test a representative early deployment applications of CAV, Eco-Approach and Departure (EAD) at signalized intersection, which aims at minimizing fuel consumption and emissions, increasing intersection throughput, and enhancing driving comfort. The algorithm generates proper speed profiles for testing connected automated vehicles (CAV) based on the vehicle’s status (e.g., location, current speed), signal phase and timing (SPaT) and MAP information, system constraints, and parameters (e.g., maximum acceleration and deceleration). The algorithm also considers status of other vehicles (CV or regular) in designing CAV’s trajectories. The experiment is conducted in the simulated environment of the test track at the Turner Fairbank Highway Research Center (TFHRC) and it successfully demonstrated this functionality with one testing CAV (and no other regular vehicles) driving through one intersection controlled by a fixed-timing traffic signal. Initial testing results show that EAD equipped vehicle can significantly save fuel and reduce emissions while ensuring system efficiency.

Features of the Hardware-in-the-Loop System

• A cost-efficient approach for evaluating CAV applications by using:
  - Critical real hardware: CAV, DSRC equipment, and traffic infrastructure
  - Field performance data: real-time logging of all vehicle and simulation data; use of customized fuel meters for fuel consumption evaluation
• Use NTCP protocol to place detector calls from virtual vehicles to real traffic signal controller.
• This approach can be used for NTCP compatible controllers from different vendors.
• Compatible with different types of real vehicles: regular vehicle, connected vehicle, automated vehicles
• Enhance data exchange between different system components by adding another communication channel through Ethernet (e.g., efficient vehicle synchronization), in addition to DSRC communication
• Integrate actual vehicle (i.e. Cadillac SRX) sensor system into HIL system
  - PinPoint GPS: better location accuracy for synchronization
  - MicroAutoBox: output sensor data at 50 Hz
• A robust, well designed, and tested vehicle control system

HIL Testing for Eco Approach and Departure at Signalized Intersections

• Experimental Scenarios: Single Intersection with fixed time traffic signal control
  - Scenario 1: Base case without EAD (Adaptive Cruise Control, ACC)
  - Scenario 2: Improved EAD algorithm by considering background traffic
  - Scenario 3: Improved EAD algorithm by considering background traffic and existing queue
• Impact Factors for Sensitivity Analysis
  - Traffic volume: light and medium,
  - Penetration rates of CAVs: low, medium, and high
  - EAD Vehicle start time: 0, 10, 20, 30, 40, 50 (cycle length: 60 seconds)

Initial Results

• Experimental Process
  - Start system – wait for vehicle start time (traffic being generated at the same time) – record data
• Initial Results shows significant improvement (16% on average) over Adaptive Cruise Control

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