Powertrain and Chassis Hardware-in-the-Loop (HIL) Simulation of Autonomous Vehicle Platform
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ABSTRACT
The autonomous industry is moving towards the goal of autonomy with the development of autonomous vehicles. Ford Motor Company is currently working on researching prototypes autonomous vehicles. The Autonomous Vehicle Platform (AVP), which is an acquired version of the vehicle platform, mandates for HIL Level 4 autonomous vehicles is currently under development. The AVP consists of the vehicle itself and its corresponding subsystems which encompass all the hardware aspects of the physical vehicle which are responsible for vehicle motion such as the engine, brakes and steering subsystems along with their corresponding controls. For HIL Level 4 autonomous vehicles, when an automated driving system is responsible for all the dynamic driving tasks including the fallback driving performance in case of system failure, redundant mechanical systems and controls are required as part of the AVP. Since the driver is completely out of the loop with respect to driving, an in-vehicle seating for autonomous vehicles will be considered expensive, time-consuming, and unsafe due to the number of scenarios and drive test laboratory required for validation, a simulation platform which can provide a safe and cost-effective way to test the performance and robustness of the hardware and software components of the AVP. This research focuses on a powertrain and chassis hardware in the loop (HIL) simulation of the AVP and the validation of the performance of the corresponding subsystems with those of the HIL portion of the actual research prototype autonomous vehicle. This approach includes powertrain control and actuation, redundant brakes and steering controls, along with full brake and hydraulic hardware. The 2017 Ford Fusion Hybrid was used as the vehicle platform for simulation. The simulations of other subsystems and controls were achieved by using a simulink® Carlessons® co-simulation environment representative of the 2017 Ford Fusion Hybrid.

INTRODUCTION
An autonomous vehicle consists of two main high-level components:
- Virtual Driving System (VDS):
  - This consists of the algorithms for localization, path planning, computer vision, and high-level features. HIL along with the sensor hardware for radars, cameras, LiDAR, and INS (Inertial Navigation System)
- Autonomous Vehicle Platform (AVP):
  - This consists of the upgraded versions of the vehicle itself and its corresponding subsystems which encompass all the hardware aspects of the physical vehicle which are responsible for vehicle motion such as the engine, brakes and steering subsystems along with their corresponding controls.

The simulation of on-board electronic systems using real-time Simulink® Carlessons® co-simulation environment representative of the 2017 Ford Fusion Hybrid. An HIL-level platform model of the power-split powertrain comprising an engine, motor-generator, high voltage battery, and planetary gear set driveline was defined in Simulink®, which formed the basis of the vehicle level plant model simulations. The Simulink® model representation also included high voltage battery and auxiliary subsystem controller and plant models. The steering, energy, and vehicle dynamic plant models were simulated using the CAR Lessons® representation of the 2017 Ford Fusion.

The simulation of HIL-based virtual vehicle behavior is an integral part of the virtual vehicle development in the automotive product development cycle due to the following benefits:
- Controller test in a simulated environment
- Scalability and reusability of scenarios
- Improvement in test consistency
- Reduced in test variation

The objectives of this research were as follows:
- Develop a HIL simulation for the AVP for powertrain and chassis, including redundant systems for brakes and steering in the event of failure
- Emulate virtual vehicle behavior allowing the AVP to be simulated in the full vehicle level in the HIL environment with those on the vehicle to understand the fidelity and accuracy of the HIL simulation.

MATERIALS & METHODS
A hardware in the loop (HIL) simulation provides a test platform where the system under test consists of actual hardware components with the remainder of the system simulated with mathematical or physics-based plant models of the processes via a real-time simulation platform.

The HIL hardware setup of the vehicle level HIL simulation consisted of:
- Engine Control Module (ECM)
- Hybrid Powertrain Control Module (HPCM)
- Powertrain actuation such as throttle body and spark plugs/valves
- Gear Shift Module (GSM)
- Transmission Range Control Module (TRCM)
- Gearbox Module (GBM)
- Seats Up Display (SUD)
- Primary and Secondary Electronic Power Assisted Steering (EPAS)
- MHP® Microshocks® (MHS)

MATERIALS & METHODS
More electronic systems, such as EPAS and EPAS (post-event) have inherent infinities in places due to the presence of the driver. If EPAS or EPAS fails, the driver is still able to operate the brakes or steering physically with the loss of electronic assist features. For HIL Level 4 autonomous vehicles, redundancies will be required to mitigate the failure of important components and systems due to:
- Driver not being in the loop at all
- All vehicle control handled by autonomous system

SAE Level 4 autonomous vehicles must be designed such that the chassis controls are independent of real functional, i.e., a single controller or software fails, the controllability of the vehicle is maintained, however, with degraded performance. In this design, the chassis control systems and their corresponding actuation must have independent and separate units.

- Components
  - Powertrain

CONCLUSIONS
- Control and assisted test environment for repetitions
- Different disturbance conditions between for robustness analysis
- Unsafe driving scenario tested in a safe simulated environment
- Testing & validation continues to time HIL level vehicle

FUTURE WORK
- Addition of more high-fidelity systems
  - High-Voltage Battery Subsystem HIL
  - Steering Subsystem HIL
- Addition of VDS hardware and software

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SIMULATIONS & TEST RESULTS
The simulations were conducted on the Simulink® Carlessons® HIL platform representation of 2017 Ford Fusion.

SIMULATIONS & TEST RESULTS (CONT.)

VALIDATION OF DISTRIBUTION AND NOISE FACTORS
- Normal distribution
- Uniform distribution
- Lognormal distribution
- Exponential distribution

VALIDATION OVER VARIATIONS OF DISTRIBUTIONS AND NOISE FACTORS
- Normal distribution
- Uniform distribution
- Lognormal distribution
- Exponential distribution

Validation over Variations of Distributions and Noise Factors

Where:
- A1 = Normal value
- A2 = Normal value
- n = Total number of data points

$\text{r} = 1 - \frac{\sum_{i=1}^{n}(y_i - \bar{y})(\hat{y}_i - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$