Virtual testing of powertrain systems

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Who are Claytex?

• Model-based engineering analysis consultancy
  – Innovators in CAE process
  – Leading the way on zero-prototype development
  – Specialists in high-fidelity real-time simulation
  – Users of Dymola and Modelica since 1999

• Provider of software solutions for systems engineering
  – Dymola distributors since 2003
  – Dassault Systemes partner since 2008
  – rFpro system integrator and distributor since 2009

• Modelica library and FMI tool developers
• Dassault Systemes Certified Education Partner
• Offices in the UK, USA and South Africa
• Major customers include Automotive OEMs, suppliers and Motorsport teams (Formula 1, NASCAR, Indycar, Formula E)
Virtual Testing

- Simulation of the complete vehicle system in a virtual environment
- Allow interaction with the driver (human or AI) as Driver-in-the-Loop simulator
- Create complex test scenarios combining
  - Real world locations
  - Traffic
  - Pedestrians
  - Weather effects
- rFpro provides a scalable solution from single PC to full motion platform
- Wraps around your vehicle model supporting multiple tools such as Dymola
System complexity and test demands

- Researchers have estimated that autonomous vehicles need to be driven 5 billion miles to prove they are safe
  - Estimate is targeting making the AV 20% safer than a human driver
  - Each software/hardware release will have to be validated
  - This is not physically possible

- “The complexity of our systems has already outgrown our ability to guarantee their safety in classical ways”
  - UBER exec on restarting AV testing, Keynote at IEEE, October 2018

Source: Rand Corporation

Figure 3. Miles Needed to Demonstrate with 95% Confidence that the Autonomous Vehicle Failure Rate Is Lower than the Human Driver Failure Rate

Source: Rand Corporation
Testing Continuum

Simulation
- Huge number of scenarios can be considered
- Full control of virtual environment: traffic, pedestrians, weather, etc.

Test beds & proving grounds
- Recreate critical scenarios
- Limited control of the environment
- Robot controlled targets
- Pedestrian targets
- No control of weather and light

Field Tests
- Investigation of real driving situations
- No control of the environment
Sensor modelling for AVs

- Claytex are developing sensor models for rFpro
- Generic set of idealised sensor models
  - Camera, LiDAR, Radar and Ultrasound
  - Built on a common framework to allow easy adaptation to model specific devices
  - Supports TCP/IP and UDP outputs
- Developing a library of models that represent real sensors
  - Produce the same output message format
  - Capture the dynamics of the sensor e.g. rotation of sensor with time
- Active R&D projects to increase fidelity of sensor models
  - Weather and interference effects
rFpro ParisStreets digital road model
rFpro hosted LiDAR sensor model
Real-time data stream visualised in native software
Traffic objects controlled by IPG CarMaker
Vehicle Physics

- rFpro Wraps around your vehicle model
  - Supports Dymola, CarMaker, CarSim, SIMPACK, Dynaware, AVL_VSM, VI-Grade, dSPACE_ASM, Simulink and C++
- Supports integration with HIL
  - Off-the-shelf implementations for Concurrent Realtime, dSPACE, Speedgoat
- Claytex uses Dymola with multi-domain vehicle models
  - Combine vehicle dynamics with powertrain, thermal management, electric drives, batteries, etc.
Vehicle Systems Modelling and Analysis

- Suite of Modelica libraries for Vehicle Systems Modelling and Analysis
- Core platform enables performance, fuel economy and energy analysis
  - Drive cycle simulation
- Application specific extensions provide detailed models across many areas
  - Engines, powertrain, vehicle dynamics, driver-in-the-loop
- Used for modelling conventional, hybrid and electric vehicles
- Real-time capable
• The vehicle models and controllers also need to respond to hardware and software faults.
  – Having the facility to inject physical system model faults using representative fault scenarios and physical description of the fault:
    • Sensor and actuator faults (Injector clogging, variable cam timing actuator malfunction, throttle control circuit issues).
    • Electrical open and short circuits (controller, sensor and actuator electrical connection interruption/anomaly).
    • Fluid leaks (air paths, cooling systems, hydraulic actuation systems).
    • …and many more.

• The controllers can therefore be developed whilst the physical prototypes do not exist and physical testing can be reduced and scenario investigation dramatically increased.
  – vs. physical testing, we can run 1000….s of scenarios in parallel in the time it takes to prepare a vehicle, transport it, wait for the test slot and test it.
Examples of fault insertion projects for ICE powertrain:

- Integration of physical throttle body system:
  - Sliding contact potentiometers. (4,9)
  - Magnetic field inducing coil spindle actuation (6,7,8).
  - Signal feedback (4).
  - Ability to test for variations in supply voltage and circuit breaks (5, 10, 12).
  - Ability to inject external disturbances and model shaft bearing binding, coil-magnet binding and spindle magnet degradation (6,8,11).
  - Effects of limp home / fast idle mode on vehicle test scenarios and AI decision making.

Throttle body model test prior to ICE integration
**Fluids system faults: Injector clogging**

- **Examples of fault insertion projects for ICE powertrain:**
  - **Misfire detection:**
    - Injection fault through hole clogging using including a cam-driven high pressure fuel pump:
      - Reduced fuel flow.
      - Altered combustion.
      - Crank acceleration anomaly detection.
      - Limp home trigger.

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**Graphs:**

- **In-cylinder pressure**
- **Crank acceleration (blue)**
- **Crank acceleration min (red)**

**Diagram:**

- Engine and ECU-on-dyno test prior to vehicle integration
Concluding Remarks

• Practical testing of autonomous vehicles for hardware and software sign-off is not feasible.
• The tool chain for AV virtual development and testing exists.
  – Vehicle models:
    • Fully physical representations of the vehicles and their subsystems incl. AVs and ADAS
  – Environments:
    • Virtualisation of real environments for fully immersive testing.
  – Faults:
    • Triggering of faults in the systems through physical modelling of sensors and actuators
• The validity of the virtual tests will depend on how well the vehicle and environment are modelled. This is crucial for virtual hardware and software sign-off.
• For example: The vehicle dynamics is often neglected through use of oversimplified models.
  – Limit handling is not captured accurately, therefore the controller development for critical scenarios is compromised.

AV and ADAS virtual development and testing has to be the way forwards.
We support the future of virtual testing.

Visit our stand in the exhibition area for more information.

Thank you for your attention!

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