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Connected and Shared X-in-the-loop Technologies for Electric Vehicle Design

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Executive Summary

The presented paper introduces a new methodology of experimental testing procedures required by designing complex systems of electric vehicles (EV). This methodology is based on real-time connection of test setups and platforms, which are situated in different geographical locations, belong to various cyber-physical domains and are united in a global X-in-the-loop (XIL) experimental environment. The proposed concept, called as *XILforEV*, allows exploring interdependencies between various physical processes that can be hardly identified or investigated in the process of EV development. In this regard, the paper discusses the following topics: global *XILforEV* architecture; realization of required high-confidence models using Dynamic Data Driven Application Systems (DDDAS) and Multi Fidelity Models (MFM) approaches; formulation of Case Studies to illustrate XILforEV applications.

1 Motivation

Overall development process of electric vehicles consists of many stages, elements and components, which are being characterized nowadays by unequal levels of technological maturity. In this regard, the following specific question, which is insufficiently addressed neither at industrial level nor in research, can be identified: *how to efficiently realize integrated development and testing of EV systems from different domains*? The problem is that here not only proper electric powertrain design but also revisiting the automotive chassis design is demanded. The EV motion control requires a blended operation of powertrain and chassis actuators (e.g. brake blending) that motivates at least the following design challenges: (i) harmonization of actuation dynamics of EV powertrain and chassis; (ii) delivering required user acceptance of new EV functionalities; and (iii) addressing more complex requirements to the fault-tolerance and robustness. Under consideration of these factors, the use of well-established processes in the design of EV systems can have some sensible limitations, for instance, co-simulation issues for software-in-the-loop (SIL) / model-in-the-loop (MIL) procedures, availability hardware-in-the-loop (HIL) test setups for different systems at the same host, tangible extension of road trial programmes with added time / cost resources to check new functionalities.

To address this scope of problems, a new approach can be proposed that aims at developing a connected and shared X-in-the-loop experimental environment uniting test platforms and setups from different physical domains and situated in different locations. The domains under discussion can cover (but are not limited to) hardware-in-the-loop test rigs, dynamometers, software simulators, driving simulators and other variants of experimental infrastructures. Real-time (RT) running of specific test scenarios simultaneously on (i) all connected platforms/devices with (ii) the same real-time models of objects and operating environments allows exploring interdependencies between various physical processes that can be hardly identified or even expected on the design development stage. In the long-term perspective, the plug-in concept of including various test platforms/devices and easy on-demand access to the test programmes for developers, engineers and researchers will bring a vast impact to the EV design community through connecting experimental environments around the world.

However, the realization of connected and shared XIL experimental environment is characterized by several steps to be solved, e.g. communication concepts ensuring real-time capability of connected experiments, reliable methods for real-time handling of big experimental data et al. Next sections introduce some solutions in this regard, which are being proposed under the *XILforEV* concept realized by several industrial and research companies under EU Horizon 2020 Framework Programme.

2 XILforEV Architecture

A conventional procedure of development of vehicles and automotive systems is successively implementing software-in-the loop, model-in-the-loop, hardware-in-the loop, and test-rig-in-the-loop (TRIL) tools, which together can be concisely referred as "X-in-the-loop". The *XILforEV* extends this approach up to collaborative experimental environments and proposes the architecture like shown on Figure 1, which is based on previous studies of authors [1].

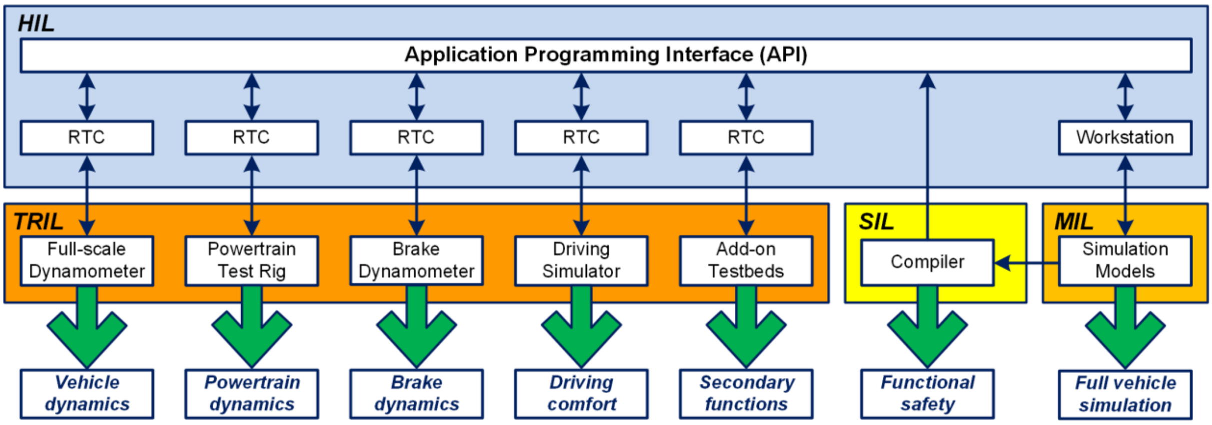

Figure 1: A variant of generic XILforEV architecture

First of all, this architecture allows developing the EV subsystem controllers in a realistic environment but leveraging the use of existing facilities. MIL tools are used for full vehicle simulation in a virtual environment. The SIL technique is applied for investigations on functional reliability of embedded software applications. TRIL is represented by different test setups, which could include in a general case dynamometers, driving simulators and other experimental devices. The TRIL and HIL components are connected using real-time communication (RTC). It should be noted that this architecture supposes a plug-in interface allowing flexible inclusion of different test devices depending on the development task.

There are two principal ways to establish the *XILforEV* framework with connected experimental setups:

- **"Distributed local"** - the setups are distributed within the narrow location, e.g. within the company site, university campus et al. Then the connection can be organized using local communication means as optic line.
- **"Distributed remote"** - the setups are distributed remotely between different geographical locations. Here the Internet-based connection is required for the establishment of *XILforEV* framework.

3 Modelling Components

Within the *XILforEV* framework, the numerical simulation is still considered as an important component. It relates to the MIL/SIL components and to RT models of HIL components. The *XILforEV* approach proposes the use of high-confidence models, which are relevant to the EV development process, on the basis of two concepts Dynamic Data Driven Application Systems [2] and Multi Fidelity Models [3]. The integration of both concepts into the XIL architecture is given on Figure 2.

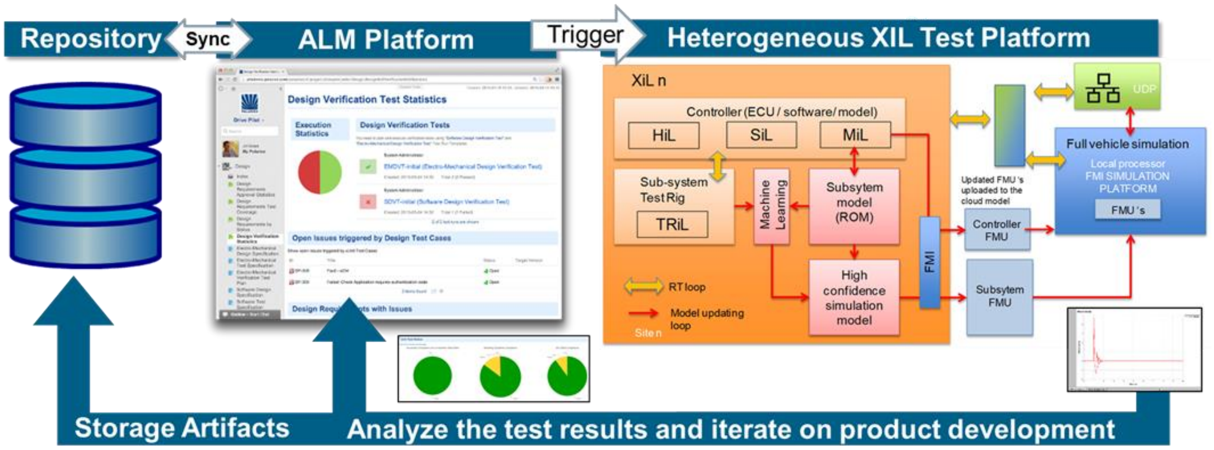

Figure 2: A variant of local XIL architecture with high-fidelity models

Table 1: XILforEV Case Studies

EV hardware	XIL configuration	Test setups	Software part	Design tasks
Use Case "Brake Blending"				
Electro-hydraulic brakes, In-wheel motors (IWM)	Distributed local	Brake dynamometer; Brake HIL test rig; Powertrain test rig	Full RT vehicle model; Co-simulation interface	Brake blending controller
Use Case "Ride Blending"				
Active suspension	Distributed remote	Shaker; Driving simulator	RT models of vehicle, powertrain and tyre/road	Ride blending controller
Use Case "Integrated Chassis Control"				
Electro-hydraulic brakes, IWMs, active suspension	Distributed remote	Shaker; Driving simulator; Brake HIL test rig; Powertrain test rig	RT models of vehicle and tyre/road; Co-simulation interface	EV integrated chassis controller
Use Case "Fail-safe and Robustness Study"				
In-wheel motors	Distributed remote	Driving simulator; Powertrain test rig	Full RT vehicle model; Co-simulation interface	Electric powertrain fail-safe control strategy

Using this modelling approach, the EV systems developers can have models based on their CAE tools with required accuracy according to their product knowledge (full order or high-fidelity models), which have to be downsized to real-time requirements established by HIL testing in the shape of low-fidelity models. Simultaneously, different testing facilities will be ready to test the project subsystems in realistic conditions but having under control the test parameters and having access to reliable data from the sensors available in the involved test benches. Here the DDDAS paradigm counterbalances the incompleteness and inaccuracy of the model by introducing reliable information from real-world objects and their operational environment. Furthermore, virtual models are usually static in the sense that they are based on defined design parameters, and with this approach they become dynamic and able to adapt to product evolution or variability.

The full text of the paper will also give extended explanation of other relevant components as (i) methodology for the high-confidence EV model based on self-validates subsystems and (ii) corresponding machine-learning applications.

4 Case Studies

The application of the XILforEV concept will be explained with four case studies to demonstrate the befits of the proposed approach. The essence of the case studies is summarized in Table 1. For each case study, the paper will give an overview of the testing environments and corresponding test scenarios. The case studies will illustrate the implementation of the XILforEV concept contributing to the cost and time efficient design of new innovative EV systems under consideration of several concurrent factors with efficient development process optimization through the networking and sharing of experimental procedures.

Acknowledgments

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