Three-level verification and validation approach for motorcycle subsystem testing using physical/ virtual co-simulation

Author(s):
Tsokanas, Nikolaos; Thielemans, Laurane; Sputh, Bernhard; Pastorino, Roland; Stojadinovic, Bozidar

Publication date:
2021

Permanent link:
https://doi.org/10.3929/ethz-b-000473432

Funding acknowledgement:
764547 - Dynamic virtualisation: modelling performance of engineering structures (EC)

Three-level verification and validation approach for motorcycle subsystem testing using physical/virtual co-simulation

Nikolaos Tsokanas[1], Laurane Thielemans[2], Bernhard Sputh[2], Roland Pastorino[2], Božidar Stojadinović[1]

[1] *Dept. of Civil, Environmental and Geomatic Engineering, ETH Zurich, Stefano-Franscini Platz 5, 8093 Zurich, Switzerland, {tsokanas, stojadinovic}@ibk.baug.ethz.ch*
[2] *Siemens Industry Software NV, Interleuvenlaan 68, 3001 Leuven, Belgium, {laurane.thielemans, bernhard.sputh, roland.pastorino}@siemens.com*

Hybrid simulation (HS) is a co-simulation method used to investigate the dynamic response of a physical subsystem subjected to a realistic loading scenario. HS is also known as Hardware-in-the-Loop (HiL) for mechanical systems. It is one of the techniques to combine test and simulation for Model-based System Testing (MBST). The complete system consists of multiple loading-rate-sensitive sub-components, some of which must be tested physically, i.e. the physical subsystems (or substructures) (PS), and the remaining are numerically simulated, the numerical subsystems (or substructure) (NS). The coupling of PS and NS forms the so-called hybrid model. HS is conducted based on a step-by-step numerical solution of the hybrid model governing equations of motion, combining in each time step experimental responses obtained from the PS [1]. The corresponding NS and PS are coupled via transfer systems, e.g. servo-controlled motors, responsible for synchronizing the dynamic boundary conditions of each subsystem in every time step of the HS. The advantage of HS over conventional experimental or purely numerical techniques is that it can be used to test specific sub-components beyond their linear regime without risking to damage the entire full-scale system. Therefore, realistic testing is performed at lower cost.

Although attractive, HS is a complex procedure incorporating many challenges that can compromise the simulation fidelity, such as network communication interruptions and time delays between subsystems. Even though various methods have been developed to cope with such challenges (see for example [2]), trust in HS outcome fidelity is paramount. To this regard, a verification and validation (V&V) approach for HS is presented in this study. This approach facilitates quantification of differences between the hybrid model responses and the responses of the prototype and identification of the components most accountable for such differences.

V&V consists of a series of actions used to ascertain whether a computational model can accurately describe the underlying equations of its respective mathematical model, i.e. verification, and to determine the level it represents its corresponding real world system, i.e. validation [3]. The proposed V&V approach for HS involves three levels, namely: i) Model-in-the-Loop (MiL), ii) Software-in-the-Loop (SiL) and iii) Hardware-in-the-Loop (HiL). In the MiL, all hybrid model subsystems are developed in a simulation software environment and their responses are evaluated offline by exchanging data with each other. In the SiL, all hybrid model subsystems are still numerically simulated, however in this case they are integrated in the environment of a real-time PC thus exchanging data in real-time with each other. This real-time PC is an essential component of HS as it is responsible for data exchange between subsystems and for implementing the HS numerical integration scheme. Finally, in the HiL, the actual HS is conducted using the real-time PC, simulating the NS and also interfaced to the PS for physical bench testing. Prior to MiL, verification of each subsystem must also be done. Between each step, validation of the obtained results is made to identify potential misbehavior of sub-components and to rectify their response. When the acquired responses are acceptably similar, advancement to the next step occurs. Fig. 1 illustrates the structure of the presented approach.

To demonstrate the proposed HS V&V approach, a case study is employed. The prototype system is a motorcycle. The hybrid model consists of four NS: i) the engine crankshaft, ii) the motorcycle body dynamics, iii) the rear and iv) front wheel braking systems. The PS includes the electrically continuously variable transmission (eCVT) of the motorcycle. Specifically, the eCVT PS consist of a multi-input-multi-output (MIMO) model with two sets of inputs/outputs. The first set is connected to the engine crankshaft NS and the second to the motorcycle body dynamics NS. The latter connection corresponds to the transmission output shaft of the motorcycle. The

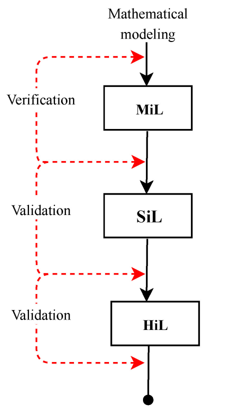

Figure 1: V&V framework.

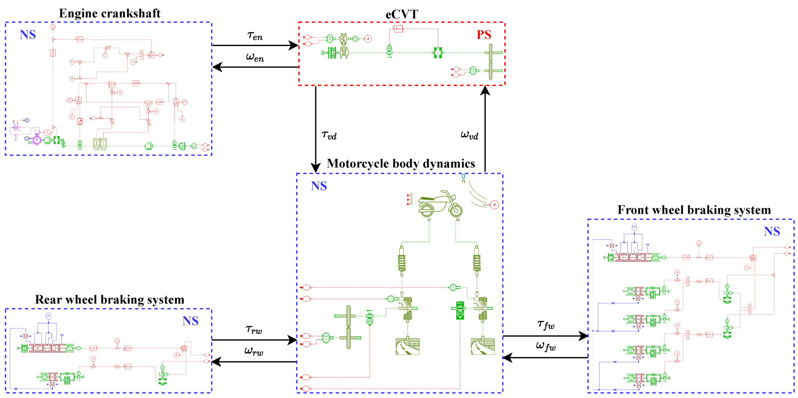

Figure 2: Hybrid model block diagram.

engine crankshaft NS aims to simulate the behavior of the combustion engine and it is a single-input-single-output (SISO) model, with input and output the angular velocity ω_{en} and torque τ_{en} of the engine crankshaft respectively. The motorcycle body NS addresses the inner body dynamics of the motorcycle along with the dynamics of the suspension and the tires. It is a MIMO model with 3 sets of inputs/outputs. The first set is connected to the eCVT PS with input and output the torque τ_{vd} and angular velocity ω_{vd} of the transmission output shaft respectively. The second and third sets are connected to the rear and front wheel braking system NSs. Both braking system NSs are SISO models with input and output the angular velocity and torque of the rear ω_{rw}, τ_{rw} and front ω_{fw}, τ_{fw} wheel respectively. Fig. 2 illustrates the block diagram of the hybrid model and subsystem interconnections. A real-time PC is used to co-simulate in hard real-time all the subsystems of this HS. The case study results make it possible to compare the different levels of the proposed HS V&V approach and reveal configurations with lacking calibration. Future work aims at validating the HiL HS V&V results with responses obtained from physically testing the complete prototype system, the motorcycle itself.

References

[1] A. H. Schellenberg, S. A. Mahin, and G. L. Fenves, “Advanced Implementation of Hybrid Simulation,” Tech. Rep. PEER 2009/104, Pacific Earthquake Engineering Research Center, University of California, Berkeley, 2009.

[2] N. Tsokanas, D. Wagg, and B. Stojadinovic, “Robust Model Predictive Control for Dynamics Compensation in Real-Time Hybrid Simulation,” *Frontiers in Built Environment*, vol. 6, 2020.

[3] L. E. Schwer, “An overview of the PTC 60/V&V 10: guide for verification and validation in computational solid mechanics,” *Engineering with Computers*, vol. 23, no. 4, pp. 245–252, 2007.