Experimental Study of the Effect of Co-Simulation Schemes on Cyber-Physical Testing

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EXTENDED ABSTRACT

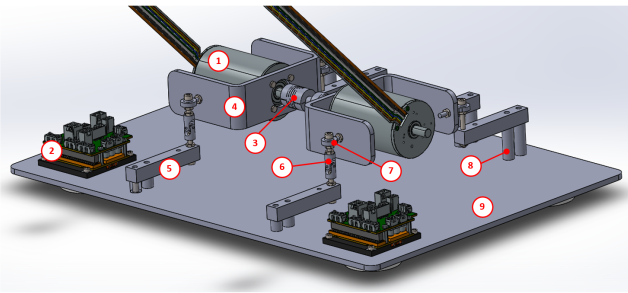
1 Introduction

Model-based system testing (MBST) is an enabling technology in the context of industry 4.0 that introduces model-based computer simulation into the testing process of physical components [1]. Cyber-Physical Test Benches (CPTBs) are an application of MBST of particular interest for the industry, in which physical components under test interact in real-time with a digital representation of their real-world environment. CPTBs can enable the test and validation of physical components in realistic operation conditions while avoiding the need for an operational full-system prototype; they also provide consistent repetitive component testing under a given set of operation conditions, which will be necessary to validate new components and software required by novel technologies. When the test manoeuvres involve emergency actions or the evaluation of component response to failure modes, CPTBs decrease not only the cost but also the risk of the experimental campaigns.

A fundamental requirement of CPTBs is that the experimental results that they deliver must be representative of the real-world behaviour of the tested component. A first condition for this is that the computational models used in the virtual environment describe faithfully their physical counterparts, but the fulfillment of this point is not enough to guarantee realistic results. An additional requirement stems from the fact that cyber-physical systems naturally involve a discrete-time communication between the physical device under test and its simulated environment. Such a communication can be considered a particular case of co-simulation, in which the tested component and the simulation would be two different subsystems. The presence of a physical system makes this co-simulation explicit, preventing integration steps from being retaken to improve numerical convergence and, in most cases, imposes the use of constant communication step-sizes. This means that the numerical results of the CPTB suffer from the accuracy and stability issues of explicit co-simulation setups [2]. The quality of the coupling scheme, accordingly, needs to be monitored to guarantee the reliability of the obtained results and to carry out corrections if necessary, e.g., through the modification of the bench actuation [3]. Moreover, physical communications in the setup introduce sources of error that do not exist in the co-simulation of software on a single processing unit, such as delays and information loss, whose effects on the results must be considered as well.

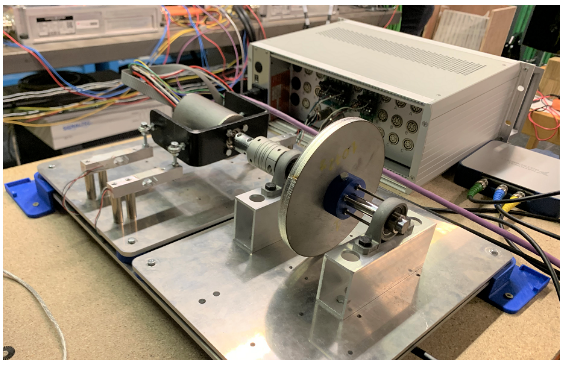
2 Experimental setup

To gain insight into the above-mentioned issues and how they affect the quality of co-simulation results in cyber-physical devices, we have built a scaled-down prototype of a cyber-physical test bench for automotive-grade electric motors. The prototype is built following a back-to-back configuration, in which a motor is the device under test (DUT) and the other one replaces the real-world environment with which the DUT would interact (Figure 1a). The initial prototype was subsequently modified to enable the test of the DUT directly against physical loads, rotational masses in this case (Figure 1b). This modification makes it possible to directly compare simulation, experimental, and CPTB results.



1-	Motor	4-	Bracket	7-	Ball joint
2-	Controller	5-	Load cell	8-	Spacer sleeve
3-	Flexible coupling	6-	Cardan joint	9-	Base plate

(a) Initial back-to-back configuration.



(b) Modification to enable tests with physical loads.

Figure 1: Test bench design.

A preliminary step in the evaluation process is the characterization of the electric and mechanical properties of the DUT and its environment. Appropriate co-simulation models for the cyber-physical device must be formulated and implemented as well, including the explicit consideration of the actuation and sensing strategies used in the test bench.

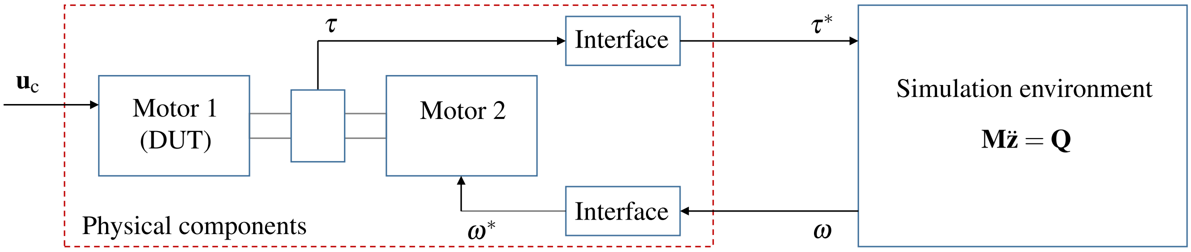


Figure 2: Diagram of the co-simulation scheme in a cyber-physical test.

Figure 2 shows a simplified model of the cyber-physical testing device. The DUT is actuated by means of an external command input $\mathbf{u}_c$, in this case the specification of the current that it receives. The simulation environment performs the forward-dynamics prediction of the motion of the DUT environment, and provides the angular velocity ω as the actuation command for motor 2. The test bench measures the torque τ transmitted between the axles of the two motors, and feeds it back to the simulation environment. The physical-virtual interface between both subsystems may introduce nonideal phenomena such as delays and information loss, which result in modifications in the coupling variables received as input by the subsystems, τ^* and ω^*.

A set of relevant configuration parameters, namely the communication step-size, the formulation and integrator of the virtual subsystem, and the input extrapolation approach used in the simulation environment, have been chosen to investigate the influence of the co-simulation configuration on the results delivered by the test bench [4]. These results will be compared to a reference solution, obtained from experimental tests using physical loads, as shown in Fig. 1b. In a second research stage, the effect of imperfect information transmission at the co-simulation interface will be characterized as well.

Acknowledgments

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