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ASSESSMENT OF SOURCES OF ERROR IN A CYBER-PHYSICAL TEST BENCH FOR ELECTRIC MOTORS

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ABSTRACT

Model-Based System Testing (MBST) consists in the combination of computer simulation and physical experimentation in the assessment of component behavior. Cyber-physical test benches (CPTBs) are one of the most challenging applications of this approach, in which physical system components are tested through their real-time interaction with a virtual environment that replicates their real-life operating conditions. CPTBs enable the evaluation of component behavior before a full system-level prototype is available, reducing the costs associated with testing procedures and shortening the product development cycle. In order to deliver useful results, CPTBs need to achieve real-time performance and to be able to represent the system under study up to a reasonable level of accuracy. A number of sources of error, however, can decrease this accuracy, introducing divergences between the desired simulation conditions and practical ones. These include communication issues between the simulation and the physical components, modelling errors, and sensor and actuator limitations. Besides, CPTBs can be considered a particular case of real-time co-simulation environments, and they are subjected to the numerical issues that are inherent to explicit co-simulation setups. In the present work, a test bench for electric motors was used to identify and quantify the impact of different error sources in cyber-physical experiments. The effects of these errors were measured and compared against reference data obtained from experimental tests in which the motors used in the bench were assessed through the motion of physical inertias.

1 INTRODUCTION

Model-Based System Testing (MBST) is a methodology for the testing of components that combines physical experimentation with computer simulation [1]. Cyber-Physical Test Benches (CPTBs) are a particularly relevant application of MBST in which physical components are assessed through their interaction with a real-time simulation of their operation environment. Through CPTBs, developers can obtain a deeper insight into the behavior of a particular component without the need of having a full-system prototype. Since the experiments can be performed in a controlled environment, the component under study can be tested in multiple situations while keeping the consistency of the testing conditions and for a fraction of the cost.

In order to deliver useful results, CPTBs need to achieve real-time performance and be realistic enough to represent the system-level environment up to a reasonable level of accuracy [2]. These goals may conflict with each other; moreover, other issues affect the performance of CPTBs as well. These include modelling uncertainties, communication issues between the different components of the simulation and testing environment, and sensor and actuator limitations. Besides, CPTBs suffer from the same numerical inaccuracies as other explicit co-simulation applications [3], which may lead to the alteration of the energy balance of the overall system and the introduction of high-frequency components at the time-discrete coupling interface. Determining the relative importance of these sources of error and quantifying their impact on simulation steps is necessary to define and enable correction actions to ensure the quality of the experimental results obtained in CPTBs [4].

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2 METHODS

In this work, a CPTB for low-power electric motors [2] was used as assessment platform to identify and measure the impact of different sources of error in cyber-physical experiments. This test bench mounts two motors in a back-to-back configuration: motor 1 is the device under test (DUT), to which motor 2 transmits the load evaluated by the computer simulation of its environment. The bench can be connected to a digital twin of the DUT and to a human-in-the-loop simulator to reproduce driving maneuvers, as shown in Fig. 1.

FIGURE 1. Cyber-physical bench for testing electric motors in a driving simulation.

In the back-to-back configuration, the DUT is actuated by an external command input torque u_c. The simulation environment predicts the dynamics of the physical load that the motor would move in a real application and provides the angular velocity ω of the assembly; this velocity is commanded to motor 2. To close the simulation loop, the CPTB uses a sensor to measure the torque exerted by the DUT. This initial configuration was modified, so that motor 2 could be replaced by a physical load in some tests, to obtain a data to verify the results delivered by the CPTB.

The initial co-simulation scheme used to connect physical components and simulation is shown in Fig. 2. The details of the implementation of this scheme lead to different time delays in the transfer of information betweeen subsystems. In Fig. 2, the information flow is sequential. The first operation in each macro-step, of size h, is sending the speed ω determined by the simulation to motor 2. Once motor 2 processes the command, which requires a time lapse Δt_1, the simulation requests the torque measured at the bench. Reading this signal requires an interval Δt_2, after which the torque is received and the next time step can be executed. Other schemes, however, can be followed. Besides the effect of co-simulation schemes, imperfections in data transmission and modelling uncertainties, as well as the limitations of sensing and actuation capabilities in the bench, have a critical effect on the accuracy of the CPTB results.

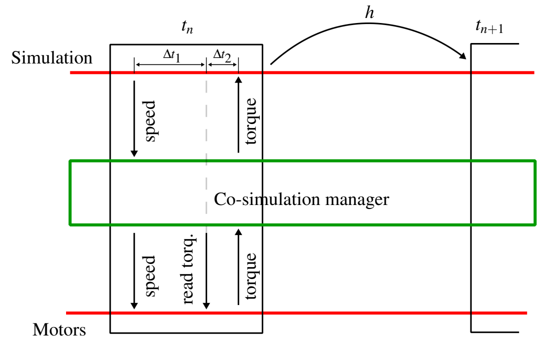

FIGURE 2. Initial communication scheme.

A set of experiments was developed in order to evaluate the effects of these sources of error, which were studied and compared against the reference data obtained from experimental tests in which a single motor was used to move an inertial load.

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