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Guest Editorial

Physical System Modeling

Simulation is a key tool for everyday engineering practice, and its use is rapidly increasing with the development of powerful, inexpensive computing hardware and integrated simulation environments. This is due in part to the plethora of design and control techniques (e.g., design optimization, internet distributed hardware-in-the-loop simulation, and model predictive control) that require simulation. It is also due to the cost and time savings associated with virtual experiments. Simulation is used in many aspects of the product cycle from concept development to final production.

However, despite its advantages, the effectiveness of a simulation-based design depends on the "quality" of the models imbedded in the simulations. Use of "inadequate" models leads to inaccurate predictions, which in turn can lead to designs that are suboptimal. It is the goal of this special issue of the JDSMC on Physical System Modeling to collect and present the latest research on modeling of physical systems. More specifically, it aims to present work in the areas of modeling methodologies, modeling for control, model validation and identification, and some models of cutting edge engineering applications.

Modeling is the procedure of developing a representation of a system that can be used to answer specific questions about that system. Therefore, the first step in modeling is to define the context as shaped by the engineering task and the available simulation tools. For example, during the design process, one may be interested in a wide range of issues such as power consumption, dominant dynamic response, vibration, stress analysis, controller design, hardware-in-the-loop simulation, and dynamic programming. Given these different perspectives of the system, it is not realistic to have a single model that can be used to assess the system from these multiple perspectives. The common requirement for the models from each of these perspectives is to predict the specific physical quantities of interest, e.g., forces, velocities, natural frequencies, and stresses, to the accuracy level required for each of these perspectives. There is probably no model that accurately predicts all these quantities sufficiently and at the same time has acceptable computational efficiency. Clearly, the same system can have different models depending on the physical quantities that need to be predicted and the context or perspective for assessing the accuracy of these predictions.

The model context provides the framework for selecting the physical phenomena to be included. However, even with a given context, this step is perhaps the most challenging in the modeling procedure, especially for complex systems, because there are few formal tools to help determine, a priori, the correlation between the quantities (variables) of interest and the physical phenomena taking place during the system operation. Traditionally, this obstacle is overcome by engineers with years of experience in specific fields of engineering. However, this solution has limitations for innovative system design or emerging technologies where there is little domain system knowledge. In addition, some companies experience a sufficient turnover, and often modeling knowledge is not archived adequately. This serves as the motivation for developing modeling methodologies and tools to assist engineers in selecting the appropriate physical phenomena to include in the model.

The computational efficiency of simulating a model is another constraint that has high importance for real time implementations and design optimization. For real time applications, i.e., simulators, hardware-in-the-loop simulation, and model-based controllers, computational efficiency is paramount to a stable simulation. Models in this context often need to be evaluated approximately ten times faster than real time. A similar but softer constraint exists in models used in design optimization where the model is evaluated thousands of times before reaching an optimal design, and so a real practical constraint is imposed on engineers who have to wait weeks for a single optimization result.

Selecting the proper level of physical phenomena in the model to achieve the desired accuracy with acceptable computational efficiency is even more difficult when addressing new areas of technology. For example, areas such as hybrid vehicle systems, with the issues of grid interconnectivity, battery chemistry, nanotechnology, biosystems, biomechanics, and prosthetic implants, may lack the archived domain knowledge of how to represent these systems for the design and control of a new generation of products.

It is the combination of the above described challenging modeling issues that motivates the creation of this special issue on physical system modeling. This effort has resulted in 14 research papers and 1 technical brief. These 15 papers are organized in the following four groups: Modeling Methodologies, Modeling for Control, Model Validation and Identification, and Modeling Applications. The order of the groups and papers is arbitrary.

In the Modeling Methodologies group, two papers focus on modeling algorithms that assist engineers in identifying the necessary physical phenomena to be included in a model (Rideout and Haq; Louca et al.). The third paper presents work on the assembly of system models with component models coming from different suppliers (Motato and Radcliffe). The last paper introduces a software tool for the simulation of thermodynamic systems with fluid flow and phase change (Brown).

The Modeling for Control papers present recent work on model development approaches for models to be used in a controller design of dynamic systems. The paper by Krauss and Book presents a modeling methodology for a controller design that includes noncollocated feedback. There are also two papers that deal with modeling issues of hybrid vehicle systems and, in particular, with the state of charge estimation of lithium-ion batteries (Di Domenico et al.) and the controllability and observability analysis of fuel cell systems (McCain et al.). The models developed in the two previous papers are intended for controlling the highly complicated and sensitive hybrid vehicles. Modeling of system uncertainty is an important issue for controller design, and the last paper addresses this issue (Templeton et al.).

The first two papers under Model Validation and Estimation introduce new metrics for the comparison of time histories that result from the simulation of dynamic systems (Sarin et al.; McCusker et al.). The next paper investigates the validity of different models of a magnetorheological fluid damper as it operates over a range of dynamic conditions (Sandu et al.). The last paper proposes a computational estimation procedure that can be used for systems with uncertainties in their parameters (Blanchard et al.).

In the last group of papers, Modeling Applications, the authors present their modeling approaches as they are applied to different dynamic systems. The first paper uses the versatile bond graph formulation in order to model the dynamic behavior of an active differential system (Deur et al.). This model is used for a theoretical analysis of drivability and time response characteristics of vehicles with active differentials. The next paper also uses the bond graph formulation for modeling and stability analysis of a rotating flexible shaft (Samantaray et al.). The last paper addresses the problem of modeling and estimating an effective force field directing cell movement (Milutinovic and Garg). This model is developed using the analysis of intravital video microscopy.

As Associate Editors of this special issue, we wish to thank the enthusiastic and unending support of the Modeling, Identification, and Intelligent System Technical Committee. We hope that you find the papers in this issue interesting, helpful, and ultimately the basis for further work in the evolving area of physical system modeling. Finally, we welcome your feedback about this issue and look forward to seeing the research that is spawned from its publication.

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