



System-level model integration of design and simulation for mechatronic systems based on SysML

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ABSTRACT

The design of a mechatronic system (MTS) is not a trivial task due to the complexity of the systems. The evaluation of various design scenarios for the given requirements of a specific MTS is also difficult. Currently, model-based systems engineering (MBSE) and the modeling language SysML provide a novel means for the systematic design of MTSs. However, the specific requirements of MTS behavior modeling, i.e., continuous dynamics or even discrete/continuous hybrid behavior modeling, and automatic simulation and evaluation of the behavior models, are not supported by SysML which intends to create descriptive static design models. Therefore, extension should be made for SysML to support detailed hybrid behavior modeling and the transformation between hybrid models in SysML and executable simulation models in certain simulation environment. For this study, a meta-model based method is proposed to integrate the system design and simulation models of MTSs. First, a set of stereotypes is defined to facilitate the designer to explicitly model hybrid dynamic behavior based on SysML. The necessary simulation information is also formalized in SysML to support an analysis of the system dynamic behavior with the aid of simulations. Finally, the SysML-based system dynamic behavior, and the related simulation information are integrated with the platform-specific simulation model through a bidirectional model transformation approach based on a triple graph grammar (TGG), which facilitates the automatic model consistency and traceability between system design and simulation. The proposed method is implemented and illustrated by using an Inverted Pendulum System (IPS).

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1. Introduction

A mechatronic system (MTS) is the synergistic integration of physical systems, sensors, actuators, electronics, controls, and computers through the design process, from the very start of the design process, thus enabling complex decision making [1]. It requires a complex combination of multiple disciplines such as mechanical, electrical, hydraulic and control to accomplish the entire requisite functionality [2]. Additionally, the sub-systems of different disciplines are interwoven together, which causes the design of MTSs to be a difficult task. A new level of complexity (i.e., system design) to integrate the mechanical, electrical, electronic, control and software components together is added to the development of MTSs [3]. Generally, MTSs can be regarded as special complex systems that are characterized by continuous or hybrid dynamic behavior. Therefore, the methods that are devised for the design of general complex systems should be further specialized for the

design of MTSs with the consideration of the specific properties of MTSs.

Currently, model-based systems engineering (MBSE) [4] is the mainstream method for complex system design. Additionally, a standard systems modeling language, the Systems Modeling Language (OMG SysML™) [5], has been established based on unified modeling language (UML) to support the MBSE by the International Council of Systems Engineering (INCOSE) and the Object Management Group (OMG). One of the greatest advantages of MBSE is that the knowledge can be expressed and shared unambiguously between the engineers and different stakeholders with the help of the models. Also, the MBSE facilitates dependency tracing between different models and the reuse of knowledge.

Although SysML supports the specifications, analysis, design, verification and validation of a broad range of complex systems, including hardware, software, information, processes, personnel and facilities, it is still a general-purpose modeling language for complex system modeling. For MTSs modeling, two specific requirements should be considered. First, the behavior of the MTS may be continuous, discrete or even hybrid. Therefore, the approach for modeling the three types of behavior should be provided. The other is that it is difficult to determine if the system

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