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Integration of topological modification within the modeling of multi-physics systems: Application to a Pogo-stick

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A B S T R A C T

The present work tackles the modeling of multi-physics systems applying a topological approach while proceeding with a new methodology using a topological modification to the structure of systems. Then the comparison with the Magos' methodology is made. Their common ground is the use of connectivity within systems. The comparison and analysis of the different types of modeling show the importance of the topological methodology through the integration of the topological modification to the topological structure of a multi-physics system. In order to validate this methodology, the case of Pogo-stick is studied. The first step consists in generating a topological graph of the system. Then the connectivity step takes into account the contact with the ground. During the last step of this research; the MGS language (Modeling of General System) is used to model the system through equations. Finally, the results are compared to those obtained by MODELICA. Therefore, this proposed methodology may be generalized to model multi-physics systems that can be considered as a set of local elements.

1. Introduction

A multi-physics system is a system containing components whose behavior involves various physics (or physical domains). The modeling of such a system is challenging, since it needs a high coordination between different types of modeling dedicated to the different physics involved. Consequently, the links and combination between different physics in the same system are handled in topological modeling of multi-physics systems.

The purpose of the present study is to find a unified tool to model multi-physics systems. The topology-based modeling is used to reach this objective. The idea of applying a topological approach for the modeling of mechanical systems was initiated by the graph theory. As shown in the works of Plateaux et al. [1] and of Björke [2], all mechatronics or multi-physics systems can be broken down into sub-systems belonging to different fields of mechatronics (i.e. electronics, mechanics, etc.). Then each field can be characterized by its topological structure and behavioral laws. Previous developments have been performed following this paradigm.

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In 2007, Plateaux et al. [1] applied the KBR topological graph (named KBR in reference to its creators Kron, Branin and Roth) to model the mechatronic systems. Indeed, the KBR topological graph allows one to obtain relationships between its elements whatever the unknown parameters and specifications of the studied systems. For more details, this graph relates the topological structures of complexes of chains and co-chains. The behavior tensor transforms the variables associated with 1-cochain in variables associated with 1-chain. Moreover, the KBR topological graph permits the distinction between the topological structure of the system and the associated physics.

Miladi in [3] made possible the separation of the topology and the physics in order to have generic local models that allow the optimization of the system behavior. She applied a topological approach for modeling mechatronic systems. With the topological approach, any model can be characterized by local relations between its elements thus making it possible to dissociate the topology from the physics. Miladi used the MGS language to implement the local behavior laws. This language is characterized by its unifying view on several computational mechanisms. MGS embeds the idea of topological collections and their transformations within the framework of a simple dynamically typed functional language [4,5]. It was initially devoted to the simulation of biological processes [6,7]. The basic MGS data structures are presented in the works of Cohen [5] and Spicher [4]. Topological collections can be defined as a set of positions, filled with values, and organized by a topology defining the neighborhood of each element in the collection. These transformations are functions acting on collections and defined by a specific syntax.

The present work aims at enhancing the previously mentioned methodology to enable the modeling of multi-physics systems with dynamically variable structure. In order to improve the modeling of multi-physics systems, a unified and a parameterized tool using the MGS language is created.

The originality of this work lies in the following aspects. First, in using analogies and the concept of changing graphs all along the methodology to validate the modeling of systems with a variable topology. Secondly, in using the MGS language to model multi-physics systems applying mechanical–electrical analogy. Finally, in the integration of the connectivity within the topological structure for multi-physics systems modeling.

Then this paper is organized as follows. Section 2 exposes a state of the art on topological approach (graph theory) and then presents the topological approach that will be used in our work. The proposed methodology consists in integrating the topological modification. Section 3 presents the case study of a Pogo-stick and the results obtained by the MGS language are compared to those obtained by MODELICA. Section 5 covers a discussion. Finally, Section 5 deals with a conclusion.

2. Topological modification

In this section, a brief overview is given on the topological graph, and then on the topological approach and its various applications in mechanical systems modeling. Then, our proposed methodology based on modeling the topological modification through a topological graph is presented.

2.1. State of the art

Given the intricacy of the suggested methodology, we start by outlining the evolution of the topological graph from the graph theory to the topological structure. Then, the topological graph approach applied in this work is detailed.

Topological graph

In 1741, the first known application of the graph theory was performed by Euler, who integrated the topological graph for the resolution of the physics of “The Bridges of Konigsberg” [8]. Later, Kron applied the topology and graph theory through a systematic methodology of decomposition of a physical system named “Diakoptic” [9]. Then, in 1955, Roth validated the work of Kron by applying algebraic topology on networks and electric machines [10]. This work was generalized by Branin [11] through the inverse analogy of Firestone [12]. Based on the Trent [13] and Kron works, Paynter established a special oriented graph, hence the creation of the “bond graph” or “link graphs” technique. Still in 1955, Trent implemented the representation of a topological structure with a linear graph.

In 1995, Björke advanced the philosophy that he had followed for 25 years consisting in the identification of scientifically based tools related to the concept of connection. In fact, he used the interconnection graph in his work while introducing the notion of a topological structure for each system [2].

In 2003, Tonti created a nodal diagram [14]. This diagram is a summary of properties and objects, and he implemented it within the framework of his first network branches and nodes [15].

Maurice dedicated his research to mathematical methods based on oriented graphs such as the topological structure [16].

In 2011, Plateaux heavily relied on the works of Kron, Branin and Roth applying the KBR topological graph to model multi-physics systems. Moreover, he used the MODELICA language that led him to apply this graph. He applied the topological graph to model multi-physics systems and had a particular interest in modeling truss structures [1].

Van der Schaft’s work [17] was devoted to the representation of Port-Hamiltonian systems through Kernel representation and Dirac structure, particularly for the Port-Hamiltonian Differential–Algebraic systems. Then in 2006, considering the overall physical system as the interconnection of simple subsystems, mutually influencing each other via energy flows, Van der Schaft established his research on the network modeling (power-based), which is the basic starting point of the

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