IFC-based modeling of cyber-physical systems in civil engineering

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Abstract. The term "cyber-physical system" (CPS) refers to a new generation of engineering systems integrating computing, networking, and physical processes. Traditional building information, such as geometry, material or cost, can be represented based on the Industry Foundation Classes (IFC), an open standard used for building information modeling (BIM). However, information representing cyber-physical systems cannot be fully described with the IFC standard. Focusing on CPS applications in structural health monitoring and control, this paper presents an extension of the current IFC schema, enabling BIM-based modeling of cyber-physical systems in compliance with the IFC standard. BIM-based, IFC-compliant CPS modeling facilitates the design process, the documentation, and the information exchange of cyber-physical systems. In this study, a semantic model is developed, serving as a technology-independent metamodel to formally describe cyber-physical systems deployed in structural health monitoring and control applications. Supporting BIM-based, IFC-compliant modeling of cyber-physical systems, the semantic model is mapped into the IFC schema. Validating the BIM-based CPS modeling approach proposed herein, a CPS prototype for structural health monitoring and control is designed, implemented, and tested in laboratory experiments.

1. Introduction

The incorporation of quasi-automated self-regulating optimization technologies in engineering, leveraging features from the fields of embedded systems and the Internet of Things, has been gaining increasing attention in an attempt to enhance the efficiency and the sustainability of engineering applications (Smarsly et al., 2013). In this context, cyber-physical systems have been introduced as an approach to merge the digital and the real world, integrating physical processes with computational and networking processes (Sanfelice, 2016). Examples include smart structures instrumented with active or semi-active tuned mass dampers (Casciati & Chen, 2012) or wind turbines instrumented with intelligent monitoring and control systems that are online accessible through cyber infrastructures (Smarsly & Hartmann, 2009a, 2009b; Smarsly et al., 2012).

In many engineering applications, the inherent dynamic physical processes are optimized utilizing information obtained by computational models created to describe the physical processes (Bilek et al., 2003; Smarsly, 2013). Computational models are typically based on data collected from the physical processes (data-driven models) and/or on the principles characterizing the physical processes (physics-based models). Moreover, by integrating additional physical elements (e.g. actuators) or virtual elements (software) into the physical processes, computational models are extended to computational processes that facilitate the automated control of physical processes or automated decision making (Legatiuk et al., 2017). The application of cyber-physical systems has been widespread in several engineering fields, such as civil engineering (Huang et al., 2010), construction (Yuan et al., 2016), aerospace engineering (Atkins & Bradley, 2013), and aviation (Sampigethaya & Poovendran, 2013).

From a civil engineering perspective, cyber-physical systems are predominantly associated with computer-aided monitoring and control of structural systems, falling essentially within the scope of structural health monitoring (SHM) and control (Bhuiyan et al, 2016). Here, owing to the automation intrinsic to cyber-physical system (CPS) operation, the requirement of high levels of intelligence in the computational and networking processes comes to the