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An Analysis of the Value Specification Language Applied to the Requirements Engineering Process of Cyber-Physical Systems

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Abstract: Development of cyber-physical systems include analysis and comprehension of multiple disciplines including mechanical engineering, electronic engineering, systems engineering and computer science. In this research, two consolidated approaches of Model-Based Engineering are used in a combined way for proposing a methodology for requirements analysis, modeling and formal specification of cyber-physical systems. At first, it presents the analysis and classification of the overall system requirements, at high level of abstraction, in order to relate them with the semantics of the MARTE profile. Subsequently, graphical models are presented in the proposed methodology in accordance with formalization of restrictions, annotations and stereotypes through MARTE/VSL. First results of the application of the proposed methodology are presented by means of a case study in the Industrial Packing System domain.

Keywords: Embedded Systems, Cyber-Physical Systems, Manufacturing Control, Requirement Engineering, SysML, MARTE, Value Specification Language.

1. INTRODUCTION

Cyber-Physical Systems (CPS) are characterized as intelligent systems that are composed of digital virtual/cyber technologies, software, and physical components, that intelligently interact with other systems by information exchange and their physical interfaces (Ollinger et al., 2013). These systems are able to interact with external environment and generate immediate responses to the environment. Analysis and specification activities are important for enabling definition of the main functionalities, restrictions and response times imposed on these systems (Hu et al., 2016). Thus, requirements engineering processes for CPS need to obtain knowledge about the dynamics and functionality of the system.

Model-Based Engineering (MBE) is an approach which intends to raise the level of abstraction through the use of models in systems development activities. MBE can be seen as a trend in the design of embedded systems applications in the field of automation. Several approaches have been proposed in recent years as, for example, in the field of automotive systems (www.autosar.org, 2013), (Wozniak et al., 2014), (Walter et al., 2015), traffic control systems (Soares and Vrancken, 2012), (Ribeiro and Soares, 2013a), unmanned aerial vehicle systems (Wehrmeister et al., 2014), among others. MBE approaches can be employed under different perspectives and interests, allowing to analyze and describe mechanical components which are usually integrated with electronic and software components (Wehrmeister et al., 2014), as well as providing high relevance to handle semantic gap between specification and system design and the actual features of an application.

Activities covered by MBE strengthen the understanding and design of CPS, since these same activities contribute to the analysis, design, verification and validation of their properties. MBE adoption, in this context, has as objective to address the complexity of these systems and to enable the analysis of systems of systems while reducing time, cost and possible faults in their development. Currently, manufacturing systems have high degree of automation and consist of smart physical and logical components. Therefore, they need to control physical and logical components and consider quality aspects such as efficiency and reliability.

SysML is a standard language for specification, analysis, design and verification and validation of multidisciplinary systems (OMG, 2015). However, as highlighted in (Vogel-Heuser et al., 2014), limitations of SysML to represent mechanical and physical components, and for description of system resources, through their behavioral and struc-

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tural diagrams, makes it difficult to apply this language in embedded real-time domains.

This research proposes a MBE methodology which employs SysML together with annotations of the MARTE profile that are able to describe requirements for CPS. Thus, a specific approach describes system requirements and models in a case study of Industrial Packing System. The proposed methodology presents itself as generic for proposing the joint use of SysML and MARTE profiles with focus on analysis and specification of real-time characteristics of these CPS. In addition, the formalization of annotations in model elements is performed by Value Specification Language (VSL) in order to describe a formal manner to express constraints values, properties and stereotypes.

2. RELATED WORKS

MBE has been applied in different domains such as, for example, in (Russell, 2012) to describe traceability between requirements and design processes while providing support to decision making. A methodology is presented in (Barbieri et al., 2014) for integrated design of mechatronic systems, in which the W model and SysML are employed to compose the design methodology that will be evaluated on a case study of the filling system of a Tetra Pak Packaging Solution.

Some works describe model-based approaches in the scope of industrial, mechanical and assembly automated systems. These researches are important to be introduced for describing similar approaches to our research proposal.

In (Ollinger et al., 2013) MBE approaches are used to describe a production cell of the SmartFactory System. In the case study the assembly modules, the material identification and the flow control are presented using SysML Blocks diagram (Service Structure Model). SysML was extended in (Vogel-Heuser et al., 2014) to the development of SysML-AT (SysML for automation). SysML was used to describe the hybrid characteristics of a manufacturing system focusing in the centralized, decentralized and distributed hardware architectures.

An aspect-oriented MBE approach, named as Aspect-Oriented Model Driven Engineering for Real-Time systems (AMoDE-RT), was presented in (Wehrmeister et al., 2014). AmoDE-RT is applied in the design of industrial mechatronic systems, more specifically for controlling a product assembler industrial cell. The research uses MARTE profile combined with UML diagram for requirements modelling (through DERAF Aspect Framework) and RT-UML specification. In this research, the design processes aims for the representation of a specific functional requirement: periodicity.

Research presented here differs from the previously mentioned works due to three main reasons. First, the proposed MBE approach aims to integrate a SysML based design for specification of complex systems, with domain-specific concepts of real-time embedded systems (by using MARTE profile constructors). Second, this approach aims to be initially tailored for analysis processes, textual and graphical requirements specification which are relevant to CPS. Finally, for allowing future validation and verification processes of the models, in this research formalized descriptions are employed in modelling elements for the non-functional requirements of the IPS system.

3. BRIEF INTRODUCTION TO VALUE SPECIFICATION LANGUAGE

Within VSL, semantics and syntax is presented to describe DataTypes (primitive DataTypes and enumeration), literal value (real literal, DateTime and default literal), expressions, composite values (for example, interval collections, tuples and choices), and also expressions of time, which allows specifying temporal values and expressions.

VSL extends the UML simple time model by adding the capabilities to improve the properties for description of different data types, provides criteria for specification of literal constant values, offers support to describe different types of expressions in order to allow the description of references to variables, allows to represent different types of expressions and, still, it describes, through package Time-Expressions, a specialized syntax for writing expressions and specifications of time values in the model elements. Concepts presented above characterize abstract syntax and semantics of VSL. A concrete syntax is described by means of the value specifications for an expression, being the construction of an expression as shown in expression 1:

$$\begin{aligned} <value-specification>:: \quad & =<literal>| \\ & =<interval>| \\ & =<enum-specification>| \\ & =<collection>| \\ & =<tuple>| \\ & =<choice>| \\ & =<expression>| \\ & =<time-expression>| \\ & =<obs-call-expression> \end{aligned} \tag{1}$$

Value specification could be a simple literal, such as a number, or it could be a complex expression that involves variables and operations. In VSL proposed specification, a full form of atomic definition for formulation of expressions is presented in 1. Understanding each value specification becomes important to define functional constraints in modeled elements, as well as to formulate more complex temporal expressions which usually groups one or more expressions of a value specification.

Time Expression, presented in 2, allows to formalize different temporal and non-functional expressions on elaborated models and are important for providing different and rigorous standards for representation of expressions. In general, a **Time Expression** enables the description of intervals (minimum and maximum) and the duration of an event, as well as the distance considered between consecutive events to make explicit the specific moments of occurrence of an event, to detail specific event durations, describe occurrence of conditional events and, also,