Specification and Design of Cyber Physical Systems Based on System of Systems Engineering Approach

Lichen Zhang
Faculty of Computer Science and Technology
Guangdong University of Technology
Guangzhou 510090, China
zhanglichen1962@163.com

***Abstract*—Cyber-physical Systems of Systems (CPSoS) are large complex systems where physical elements interact with and are controlled by a large number of distributed and networked computing elements and human users. A SoS is an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal. In order to specify and model such kind of systems, we need develop specification and modeling methods which would be capable to encompass the systems of systems (SoS) specific properties of cyber physical systems. In this paper, we propose a new paradigm for specifying and modeling cyber physical systems based on system-of-systems approach. We propose an approach to support specification and modeling cyber physical systems based on systems of systems engineering by integrating AADL, Modelicalml and other modeling language. On the basis of the hierarchical concept of industrial CPS system, a hierarchical design scheme of industrial CPSoS system based on OPC UA heterogeneous data integration processing is proposed. This paper will also use AADL for modeling CPS on three levels: 1). robot on the unit level; 2) workshops of smart factory on the system level 3) intellectual factory on the SOS level. For the physical aspect of cyber physical system, this paper will propose a method to combine modelical, Simulink and AADL model to model a unit robot which can interaction with real environment.**

***Keywords*-Cyber Physical Systems; Systems of Systems; Specification; Modeling; AADL; Modelicaml; Smart Factory**

I. Introduction

Cyber-physical Systems of Systems (CPSoS) are large complex systems where physical elements interact with and are controlled by a large number of distributed and networked computing elements and human users [1]. A SoS is an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal [2].

System of systems (SoS) have five key characteristics of SoS [3]:

- Operational independence of the components of the overall system
- Managerial independence of the components of the overall system
- Geographical distribution
- Emerging behaviour
- Evolutionary development processes.

Complex cyber physical systems rely heavily on the interplay of dozens of individual physical systems, communication systems and computing systems. Complex cyber physical systems aim to dramatically improve the autonomous capabilities of a collection of individual sub-systems. When each of the system in the collection becomes entirely independent, complex cyber physical systems are typical systems of systems.

Cyber-physical Systems of Systems are cyber-physical systems which exhibit the features of systems of systems [4]:

- Large, often spatially distributed physical systems with complex dynamics
- Distributed control, supervision and management
- Partial autonomy of the subsystems
- Dynamic reconfiguration of the overall system on different time-scales
- Continuous evolution of the overall system during

Some important issues and challenges on tools and methodologies for CPSoS are [5]: collaborate environments for competing companies, Integration of legacy systems from different subcontractors, requirements and model-based engineering of the system's full life cycle, exploration of the design space, taking into account heterogeneity , control and verification of CPSoS, analysis how the type (hierarchical, decentralized, distributed) of control influences performance, new dedicated algorithms for CPSoS control and verification, challenges in modeling and simulation of CPSoS, challenges in whole-system modeling: multiple scales, already available models of subsystems may, integrating system evolution, model management, model integration), modeling of human interaction with systems by behavioral patterns, Fault management and performance under degraded conditions of subsystems, dealing with dynamic reconfiguration and resilience in CPSoS, heterogeneous data, data integration, synchronization, feature extraction. big data is important (only) as an enabling technology.

Modeling and simulation are key to improved design, operation and continuous improvement of cyber-physical systems of systems. The design of complex systems is increasingly built upon models, but building reliable and sufficiently precise models of a system often requires significant efforts. The challenges in modeling include the high cost for building and maintaining mod-

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els and the difficulty of model re -use, modeling, simulation and analysis of stochastic behavior, coupling tools of different strengths without the need for re-modeling, the consistency of detailed and abstract models, and the effort needed for setting up models that include failure states and the reaction to abnormal situations for validation and verification purposes. Challenges in simulation include large-scale simulation of heterogeneous systems, efficient hybrid (continuous discrete) simulation, simulation of systems with many different time scales, and integrated simulation of the physical part of the system and the management strategies for performance analysis including abnormal situations [6].

Thus, due to their increased size and complexity relative to real time systems, complex cyber physical systems present numerous developmental challenges. The long-term viability of complex cyber physical systems confronts these challenges through the development of new specification, modeling, design, composition, verification, and validation techniques.

In this paper, we propose a new paradigm for specifying and modeling cyber physical systems based on system-of-systems approach. We propose an approach to support specification and modeling cyber physical systems based on systems of systems engineering by integrating AADL, Modelicalml and other modeling language. On the basis of the hierarchical concept of industrial CPS system, a hierarchical design scheme of industrial CPSoS system based on OPC UA heterogeneous data integration processing is proposed. This paper will also use AADL for modeling CPS on three levels: 1). robot on the unit level; 2) workshops of smart factory on the system level 3) intellectual factory on the SOS level. For the physical aspect of cyber physical system, this paper will propose a method to combine modelical, Simulink and AADL model to model a unit robot which can interaction with real environment.

II. The Proposed Method for Specification and Modeling of Cyber Physical System Based on Systems of Systems Approach

One class of systems of systems with the additional challenge of integrating different system types are cyber-physical systems (CPS). Cyber physical systems are integrations of computation and physical processes. By approaching a collection of complementary CPSs in a shared environment as systems of systems, emergent behavior can be explored without prior knowledge of the internals of each constituent system. Specifying and modeling a set of CPSs as systems of systems is beneficial where sub-systems exhibit traits of managerial and/or operational independence. With some groups of cyber-physical sub-systems, a subset of sub-systems may be useful outside the context of the entire collection. Similarly, a subset of sub-systems is able to satisfy some useful goal outside of the entire collection. Moreover , evolutionary development and emergent behavior are both common traits of cyber-physical sub-systems exhibiting behaviors of self-organization. In order to model such characteristics using systems of systems approach, subsets of sub-systems can be modeled as constituents of an overall system. This approach is useful in that it can be applied to give indication of structural approach alternatives, and emphasizes possible interaction behavior between constituents.

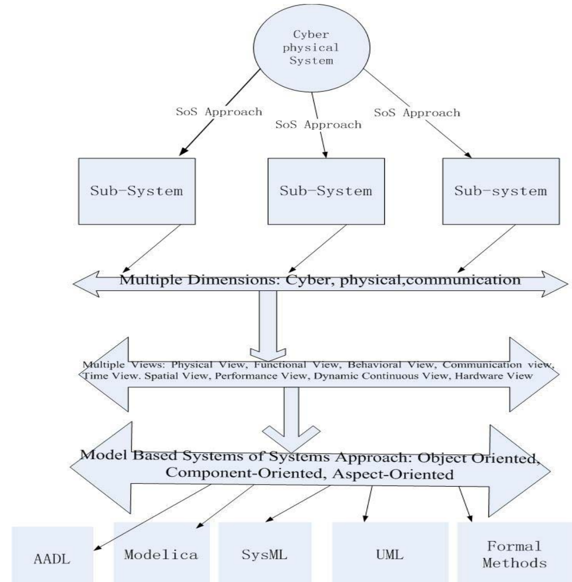

Figure 1. The proposed methodology for cyber physical system development base on Systems of Systems approach

In this paper, we propose a design methodology for cyber physical systems based on Systems of System approach as shown in Fig.1 First, The requirements of cyber physical systems are specified as either systems-of-systems requirements which are properties of the overall system-of systems that are described using the capabilities of the constituent systems, or constituent system-level requirements which are allocated to particular constituent system(s). These types of requirements are constantly changing and this makes the partitioning very difficult. This means the traditional concept of static, signed-of requirements is not suitable for systems-of-systems. New requirements engineering processes, management methods, techniques and tools that can dynamically respond to unstable, fragmented, continually changing requirements are needed. The proposed methods and tools should not only be able to deal with problems that are associated with influence requirements, cascades effects, epidemics but also be able to handle problems associated with partitioning a large-scale system-of-systems into multiple autonomous independently evolving constituent systems.

Second, in this paper we proposes the description of CPS architecture based on the research and understanding of CPS in multi-dimension, multi-domain, multi-view. We first divide CPS into three dimensions: physical world dimension, communication dimension and cyber computation dimension.

Third, in this paper, we propose a view oriented approach to integrated different models to specify and model cyber physical systems as a whole Using multi-view modeling, it is possible to describe different aspects of cyber physical system being designed and thus support system development process phases such as requirements analysis, design, implementation, verification, validation and integration. Especially, multi-view modeling approach supports mathematical modeling with equations since equations specify behavior of physical world of aerospace cyber physical system. In the specification, analysis, design and implement of cyber physical systems, multi-views on the system to be developed are often used. These views typically composed of models in different formalism. Different views usually are suitable to various partial aspects of the complex cyber physical systems in a multi-view approach, individual views are simpler than a single model representing all aspects of the system. As such, multi-view modeling, like modular, hierarchical modeling, simplifies system development. Most importantly, it becomes possible for individual experts on different aspects of a system develop to work in isolation on individual, possibly domain specific views without being encumbered with other aspects. These individual experts can work mostly independently, thereby considerably speeding up the development process.

Finally, in this paper, we propose an approach to support specification and modeling cyber physical systems based on SOS engineering in the well established modeling language AADL, Modelicaml, Modelica, SysML, UML and forml techniques.

The Architecture Analysis & Design Language (AADL) [7] was approved and published as SAE Standard AS-5506 in November 2004. Version 2.1 of the standard was published in Sept 2012. The AADL is designed for the specification, analysis, automated integration and code generation of real-time performance-critical (timing, safety, schedulability, fault tolerant, security, etc.) distributed computer systems. It provides a new vehicle to allow analysis of system designs (and system of systems) prior to development and supports a model-based, model-driven development approach throughout the system life cycle. The SAE AADL standard can lower development and maintenance costs by 1) providing a standard, precise syntax and semantics for performance-critical systems, so that documentation can be well defined 2) providing the ability to model large-scale (multi-contractor) architectures from many aspects in a single analyzable model that can be incrementally refined 3) capturing the "architectural API" needed to evaluate the effect of change, such as the emergent properties of integration (e.g., safety, schedulability, end-to-end latency, and security) 4) allowing early and life-cycle tracking of modeling and analysis 5)analyzing the system structure and runtime behavior, complementing functional simulation 6)providing a great complement to reference architectures and component-based or product-line development. [8]

III.Case Study: Specification and Modeling of Smart Factory

The smart factory is a flexible system that can self-optimize performance across a broader network, self-adapt to and learn from new conditions in real or near-real time, and autonomously run entire production processes. Smart Factory will need to consider some technologies as well, including transaction and enterprise resource planning systems, IoT and analytics platforms, and requirements for edge processing and cloud storage, among others. This could require implementing the various digital and physical technologies inherent in Industry 4.0—including analytics, additive manufacturing, robotics, high-performance computing, AI and cognitive technologies, advanced materials, and augmented reality—to connect assets and facilities, make sense of data, and digitize business operations [9].

The AADL modeling architecture of CPSoS in Smart factory based on cloud platform as shown in Fig.2

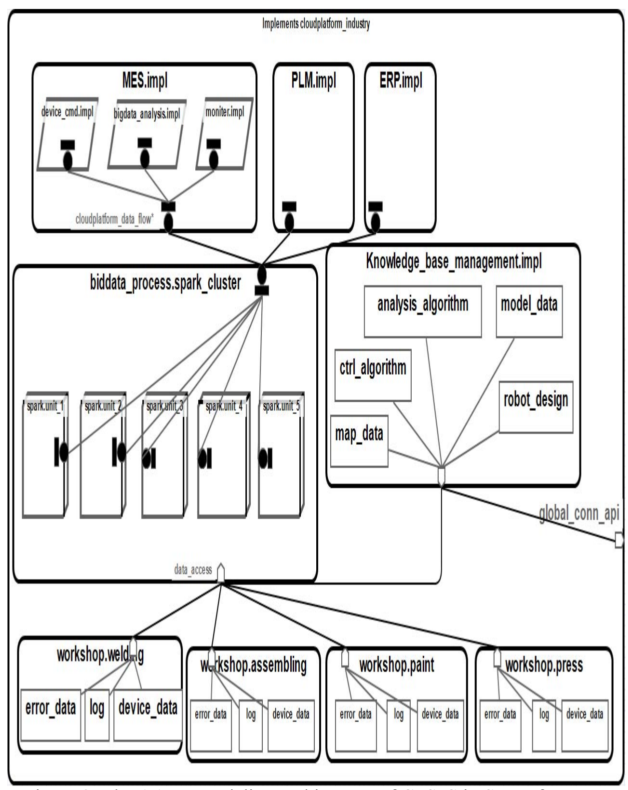

Figure 2. The AADL modeling architecture of CPSoS in Smart factory based on cloud platform

The AADL modeling architecture of CPS in robot workshop is shown as Fig.3.

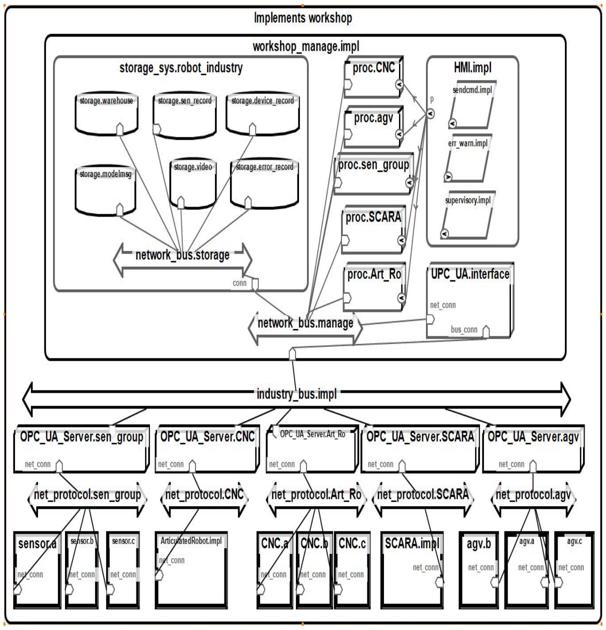

Figure 3. The AADL modeling architecture of CPS in robot workshop

AADL model diagram of the mobile robot system is shown as Fig.4.

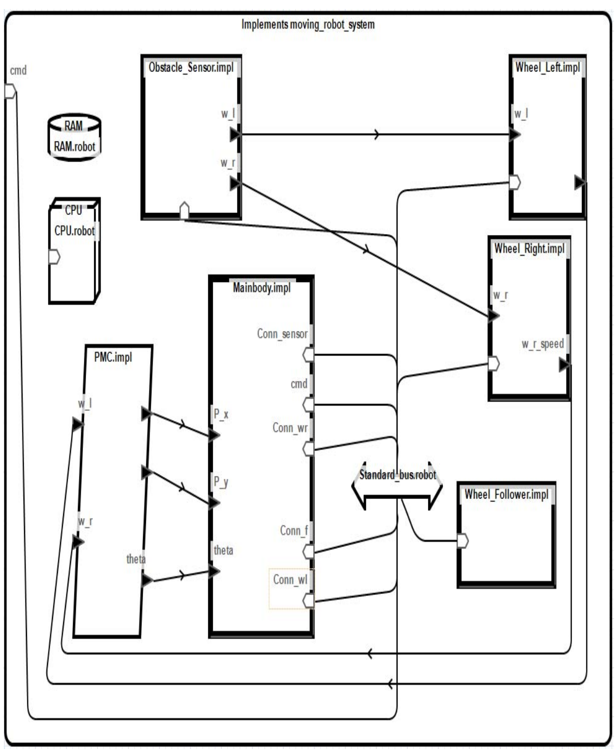

Figure 4. AADL model diagram of the mobile robot system

IV. CONCLUSION

In this paper, we proposed a paradigm for specifying and modeling cyber physical systems based on system-of-systems approach. We developed a multi-dimension, multi-domain, multi-view modeling methods for Cyber-physical Systems of Systems. We proposed an approach to support specification and modeling cyber physical systems based on systems of systems engineering by integrating AADL, Modelicalml and other modeling language. On the basis of the hierarchical concept of industrial CPS system, a hierarchical design scheme of industrial CPSoS system based on OPC UA heterogeneous data integration processing is proposed. This paper will also use AADL for modeling CPS on three levels: 1). robot on the unit level; 2) workshops of smart factory on the system level 3) intellectual factory on the SOS level. For the physical aspect of cyber physical system, this paper will propose a method to combine modelical, Simulink and AADL model to model a unit robot which can interaction with real environment.

Future work will focus on verification of the models that are used for modeling Cyber-physical Systems of Systems.

ACKNOWLEDGMENT

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