Functional-Level Design Space Exploration of the Multi-domain Cyber-Physical Systems

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EXTENDED ABSTRACT

Software-integrated multi-domain systems also referred to as Cyber-Physical Systems (CPS) consists of various interacting domains (software, hardware, multi-physics, communication, etc.). As an example of CPS, this talk will mainly focus on cyber-physical automotive systems. Related to this talk, the speaker refers to his recent publications [2,3,4].

In automotive CPS, design decisions in one domain may completely change the constraints and requirements in the other domains, e.g. adding more functions in a modern automotive CPS may require changes to thousands of lines of software code or even the mechanical architecture [1]. Existing CPS design methodologies are siloed in a specific domain and therefore have limited design space exploration capabilities, because only one domain can be tested at a time. This talk will present our recent work on functional-level cyber-physical co-design technique starting from the functional model of the CPS capable of concurrently expressing (multi-)physics and control in automotive applications. Moreover, we have developed a high-level synthesis algorithm capable of selecting a set of optimized executable system architectures using various simulation components and cost metrics. The talk will demonstrate the technique with a realistic automotive use case and explore various design alternatives for implementing the control systems in pure continuous domain (e.g. traditional automotive subsystems without ECUs) or hybrid domain (e.g. Brake-By-Wire (BBW), Steer-By-Wire (SBW), Drive- By-Wire (DBW), etc.) under power, performance, and **reliability** constraints.

Cyber-Physical Systems (CPS) are hybrid (continuous and discrete dynamics), heterogeneous (component variations), multi-domain systems consisting of various embedded systems, and physical processes connected through communication networks. The complexity in modern automotive design is attributed, for the most part, to the high-levels of software integration. Today, 90% of all the automotive innovations come from the electronics and software; and 40% of the development costs come from the Electronic/Electric (E/E) systems. Unfortunately, the software integration in the automotive design is performed after the physical architecture has been decided. This is not an optimal process for various domains and a counter-intuitive approach for the design of CPSs because, in principle, CPSs are supposed to be tight integrations of “cyber” and “physical” processes. In our opinion, the state-of-the-art automotive design methodologies should be revisited in such a way that the software integration is validated as early as possible and in parallel with the design of the rest of the system. This means that new design tools should provide the cyber-physical design capabilities to fully exploit the benefits of software integration for increased performance, reliability, and decreased power, price, and time-to-market.

During the early design stage, detecting and fixing errors is 5X to 10X less expensive and problematic than in the latter detailed design stages. Therefore, it is highly desirable to validate CPS design as early as possible. However, the existing CPS design tools stay at the domain-specific level and this inhibits the possibility of appropriately handle the cross-cutting concerns that characterize CPS at the early stage. For example, the early design of an automotive requires an experienced designer with a broad multi-domain knowledge to manually make decisions such as: should the control be implemented in traditional continuous domain architecture or in E/E discrete-domain architecture? If E/E architecture is selected, what will be the minimum cost for the digital hardware implementation? What are the additional costs of sensors and actuators? Are additional continuous-domain electro mechanical components required for implementing this control strategy?

Therefore, to answer these questions as early and as accurately as possible in the early design stage, system-level automotive CPS co-design tools are currently missing but heavily desired by automotive industry. This talk will present our current work on functional level co-design technique that emphasizes breadth – knowledge that spans across disciplines – rather than depth – knowledge that focuses on a particular domain – as it is the focus of the existing design tools. The co-design technique starts with the functional models which formalize the requirements of a new automotive CPS that defines what the system does in terms of energy, material, and signal flows at the early design stage. We have shown that from a design automation perspective, the high abstraction level in the functional models makes them a suitable formalism for CPS co-design. For example, an engine system has the functionality that converts chemical energy contained in the fuel into mechanical energy and hot gases. Given this functionality, several architectures, such as the traditional mechanical control system with driver and pedals or the modern E/E systems with many sensors and ECUs, from multiple domains could be applied.

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