Guest Editorial Leveraging Design Automation Techniques for Cyber-Physical System Design

The research on cyber-physical systems (CPSs) addresses the close interactions between the embedded cyber components and the dynamic physical components that could involve mechanical components, energy systems, human activities, and surrounding environment. Some example CPSs include automotive systems, energy systems, robot systems, and cyber-physical biochip systems.

The design of CPS involves the consideration of multiple factors such as timing, energy, reliability, fault tolerance, and security. Developing high performance CPS necessitates design automation tools, including large-scale analytical modeling and analysis methods, efficient simulation, synthesis and verification techniques, and methodologies for real-time data analytics and system control, etc.

This special section of the IEEE TRANSACTIONS ON COMPUTER-AIDED DESIGN OF INTEGRATED CIRCUITS AND SYSTEMS examines a number of aspects addressing the emerging CPS research problems from the design automation perspective. It serves as a stimulus to promote the highly interdisciplinary research and development in CAD for CPS. The selected papers span a variety of CPS topics ranging from automotive, energy harvesting, and biochip to robot systems. These papers showcase how CAD approaches developed for traditional IC design problems can be adapted to handle the new CPS research challenges such as how to improve CPS security considering performance constraints and how to manage power consumption in storage-less energy harvesting systems. CAD techniques have been leveraged to optimize different metrics, including timing (efficiency), schedulability, power, reliability, and security for CPS, which can be elaborated as follows.

The paper titled "Cross-Layer Codesign for Secure Cyber-Physical Systems" proposes a cross-layer design automation framework for addressing the security issues in resource-constrained CPSs. Security has become a pressing concern for CPSs due to the fact that attacks to such systems are difficult to defend due to many different attack surfaces and could lead to significant social and economic losses. The proposed framework combines control-theoretic methods with cybersecurity techniques while optimizing performance considering timing and resource constraints. Such a codesign framework is validated using an automotive case study.

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The paper titled "LSCD: A Low Storage Clone Detection Protocol for Cyber-Physical Systems" addresses the communication security challenges facing wireless sensor networks of a CPS. It proposes a novel low storage clone detecting protocol for witness-based clone detection, where a network node sends its identity to witness nodes such that cloning is identified if multiple nodes at different locations share the same identity. The proposed protocol organizes witness nodes into witness routing ring paths surrounding a sink node and set up a detection route along the perpendicular direction of a witness path. Such a protocol enables high detection rates while optimizing network lifetime and energy efficiency.

The paper on "Solar Power Prediction Assisted Intra-task Scheduling for Nonvolatile Sensor Nodes" proposes a storage-less and converter-less nonvolatile sensor node to achieve high energy efficiency, while leveraging more sensibilities to solar variations by intratask scheduling. Solar-powered sensor nodes are widely used since they are free of battery maintenance. However, the unstable and intermittent solar energy supply affects the quality of service of tasks executed on these nodes. This work describes a system model for intratask scheduling together with an online intra-task algorithm to obtain an optimal schedule. The proposed priority-based intratask scheduling algorithm determines task priorities based on solar power classification and two-level artificial neural networks. A prototype of nonvolatile sensor node is built and demonstrates significant reduction in deadline miss rate with energy efficiency improvement.

The paper titled "Graceful Performance Modulation for Power-Neutral Transient Computing Systems" presents a new power-neutral paradigm to tackle the power supply challenge for the transient computing system whose operation is solely based on harvested power. Such a paradigm enforces the well match between the instantaneous power consumption and the harvested power through using an innovative control algorithm exploring dynamic frequency scaling. The system is empirically validated using a microcontroller powered directly from energy harvesters, showing that it can operate for a much longer time with significant speedup compared to some alternatives.

The paper titled "A Formal Approach to Power Optimization in CPSs With Delay-Workload Dependence Awareness" addresses a new power optimization challenge in CPSs, which is the dependence between the delay and workload resulting from the interactions between cyber components and physical components. The paper proposes a provable asymptotically optimal power management policy. It leads a system to enter into certain steady state, characterized by the same workload, delay and processing speed across iterations, so as to achieve optimal power consumption.

The paper titled "Synthesis of Application-Specific Fault-Tolerant Digital Microfluidic Biochip Architectures" discusses the architecture level design of a digital microfluidic biochip system. It presents a new synthesis technique for nonrectangular application-specific architectures considering cost minimization subject to timing constraints. Due to the existence of faults, there can be failure in biochemical applications. This motives the work to use redundant electrodes in architecture synthesis for failure reduction. This synthesis technique has been validated using existing benchmarks.

The paper on "CPS Oriented Control Design for Networked Surveillance Robots With Multiple Physical Constraints" addresses one of the most important issues in networked robotics. In such CPSs, in the control design stage conventional algorithms usually ignore physical constraints, e.g., the interference between robots, the nonholonomic restriction of individual robots, and the existence of obstacles. This paper aims to bridge this gap, and through taking physical constraints into consideration it presents a cyber physical interaction model to perform formation control and tracking in the presence of other robots and static obstacles. It also explores how hardware acceleration can be utilized to improve system efficiency. This is an interesting demonstration of applying CAD techniques to tackle research challenges in the networked robot CPS.

The CAD community has started to embrace the emerging CPS research especially from our unique design automation perspective. The success of this TCAD special section, together with various regular and special sessions organized at our leading conferences such as the IEEE/ACM DAC and the IEEE/ACM ICCAD, further validates this trend. This TCAD special section has received a significant number of submissions while only a small portion of them can be selected for publications. In addition to the problems considered in the above selected papers, there are many interesting and challenging CPS aspects which need CAD techniques such as CPS synthesis, verification and big data analytics, as well as CPS applications in smart home, building and grid systems, transportation systems, and smart health systems. It is our belief that research dedicated to leveraging advanced design automation techniques for tackling emerging CPS design challenges will keep growing and eventually take the CPS research to a new level.

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