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Editorial

Real-Time Embedded Systems: Present and Future

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1. Introduction

Real-time and networked embedded systems are important bidirectional bridges between the physical and the information worlds. Embedded intelligence increasingly pervades industry, infrastructure, and public and private spaces, being identified as a society and economy emerging "neural system" that supports both societal changes and economic growth. As cost/performance improves, everyday life connected objects increasingly rely on embedded intelligence in an ever-growing array of application fields, specialized technologies, and engineering disciplines.

While this process gradually builds the Internet of Things (IoT), it exposes a series of specific non-trivial timing and other extra-functional requirements and system properties, which are less common in other computing areas. For instance, most embedded systems are cost-sensitive and with real-time constraints, optimized for power and specific tasks, built around a wide array of processors, often resource-constrained, which need to operate under extreme environmental conditions, and where reliability and security can have severe implications.

The area is quite wide, with diverse computer science and engineering fields and practices involved, and the state of the art is mostly captured today in the cyber-physical systems [1] and IoT [2] evolution contexts, addressing design methods and tools [3], operating systems and resource management [4], real-time wireless networking [5], as well as safety and security [6] aspects, either horizontally or vertically along specific application domains.

2. The Present Issue

The ten articles in this special issue propose solutions to specific open problems of cyber-physical and real-time embedded systems applicable to both traditional application domains, such as industrial automation and control, energy management, automotive, aerospace and defense systems, as well as emerging domains, such as medical devices, household appliances, mobile multimedia, gaming, and entertainment systems. Specifically, they address important topics related to efficient embedded digital signal processing (DSP), security and safety, scheduling, and support for smart electric grid optimizations.

Efficient digital signal processing is an important enabler for advanced embedded applications in many domains. Of the five articles in this special issue that address efficient embedded DSP and applications, the work in Reference [7] studies feasibility options and evaluates the performance of fully embedded algorithms for real-time ventricular fibrillation detectors which can send timely alerts without requiring external processing, for applications in pervasive health monitoring. Health monitoring applications are also the focus of Reference [8] that proposes an efficient embedded hardware accelerator for long-term bio-signal monitoring and compression, which makes it suitable for various Internet of Things (IoT) applications. Hardware-assisted efficient embedded DSPs are essential in other application domains, too. An FPGA implementation of a multi-band real-time speech

enhancement system is shown in Reference [9], which includes specific architectural optimizations for speed and energy consumption. An application-specific integrated circuit (ASIC) implementation of real-time and accuracy optimizations for arctangent calculation based on a coordinate rotation digital computer (CORDIC) is shown in Reference [10] (a trigonometric function that is essential for many embedded DSP calculations), while an automated folding scheme for efficient FPGA implementation of fast Fourier transform (FFT), an algorithm widely used in many embedded application domains, is proposed and experimentally evaluated in Reference [11].

As embedded systems pervade most human activities, from households to industry, safety and security architectural and operational aspects become very important. A survey of microarchitectural attacks of embedded systems is presented in Reference [12], which emphasizes potentially very harmful hardware vulnerabilities that usually receive far less attention than the software ones. Middleware often encompasses several embedded and infrastructure systems, which may also be of different types, hence its reliability is highly relevant for the overall security of the applications. In Reference [13], the authors present a formal specification for middleware correctness and a method to thoroughly verify it at runtime. Efficient virtualization for real-time embedded systems is presented in Reference [14], with emphasis on security, safety, functionality and flexible adaptation to most embedded operating systems.

Scheduling for energy efficiency and effective real-time response of embedded systems is addressed in Reference [15], which propose static scheduling methods based on mixed integer linear programming and heuristics, for both periodic and non-periodic tasks.

Finally, as smart electric grids rely (among other requirements) on effective consumer cooperation and coordination to be able to optimize energy production and distribution, the work in Reference [16] proposes several cloud-enabled embedded solutions and provides experimental test and validation results.

3. Future

While embedded systems are not novel, they recently accelerated their permeation in most human activities, which increasingly rely on their real-time capability for, e.g., sensing, processing, communication, actuation, and composability.

Their growing importance for the operation and decision-making capability of complex systems raise significant issues regarding many other aspects of their operation. Security, safety, and reliability may directly impact on physical and data safety as embedded systems are increasingly deployed to measure and control human environments, gaining access, and processing sensitive data. Embedded systems control, validation, self-testing, and observability of their programmed or acquired operation are significant concerns for their acceptance in critical infrastructures or operations, while cost, energy, and maintenance requirements become increasingly important to economically sustain the high number of embedded systems expected for IoT applications. Edge processing, on embedded systems, gains importance over data transfer for remote processing to provide a faster real-time response, reduce dependency on data connections, improve scalability, and increase security by reducing the attack surface.

Recent hardware and software [17] advances aimed at efficiently supporting artificial intelligence (IA) applications directly on resource- and energy-constrained embedded systems for a wide class of applications, compound the importance to find effective solutions to above concerns.

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