Energy Harvesting and Power Management

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For over half a century, we have seen astonishing increases in the computational, storage, and communications capabilities of embedded systems. But while integrated circuit performance has, until recently, doubled every 18 months as predicted by Moore's law, the same is far from true for battery technology.

Battery performance can be evaluated in many different ways, but no matter which metric you look at, it has taken more than a decade to double performance. As a consequence, in many cases an overriding factor limiting the utility of pervasive computing hardware is battery lifetime. In addition to constraining individual, standalone devices, this limitation also encompasses the maintenance and sustainability of large-scale deployments of sensor systems.

Overcoming Battery Limitations

Although research to improve the energy density of batteries continues to be a high priority, it's often also possible for designers of mobile devices, wireless sensors, and the like to employ other approaches to extend battery lifetime. Two key techniques in this regard are energy harvesting and power management.

For this special issue, we invited authors to submit manuscripts describing new research contributions that advance the frontiers of pervasive and ubiquitous computing in the areas of energy harvesting and power management, as well as advances relating to energy storage. We selected three articles that cover a range of current research topics in this area.

In This Issue

In the first article, "Energy Provision and Storage for Pervasive Computing," David Boyle, Michail Kiziroglou, Paul Mitcheson, and Eric Yeatman at Imperial College London review various types of wireless power transfer (WPT), including inductive, RF, and acoustic WPT, and other opportunistic energy harvesting techniques and methods of energy provisioning. They introduce some key factors for consideration when designing energy harvesting systems and energy-constrained systems.

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The article also includes a discussion of modern energy storage and how it addresses or fails to address challenges in modern device ecosystems. It addresses very practical issues, such as choosing between rechargeable battery technologies and supercapacitors, the power consumption of various components and systems, the relative performance of various energy harvesting sources, and characteristics of WPT systems.

The second article in this special issue, “MIMO Wireless Power Transfer for Mobile Devices” by Daniel Arnitz and Matthew Reynolds from the University of Washington, describes a technique for controlling the amount of power delivered to mobile client devices in an RF-based WPT system. WPT has been explored by the research community for many years now, and consumer devices that incorporate some of these concepts for cord-free charging are starting to become available, although these are mainly low frequency and inductive in nature. While WPT offers tremendous benefits in terms of the convenience of powering mobile devices, the practicality of such systems depends on the ability to control the distribution of power to many clients both spatially and temporally. The authors present their research to leverage multi-input, multi-output (MIMO) techniques for controlling the distribution of power for far-field wireless power systems. In addition to describing the design of their WPT system, they present an evaluation of the system in operation. They also provide a short overview of multipath propagation and previous MIMO work in multipath environments.

The final peer-reviewed theme article describes a new approach to “Perpetual Sensing for the Built Environment.” Bradford Campbell, Meghan Clark, Samuel DeBruin, Branden Ghena, Neal Jackson, Ye-Sheng Kuo, and Prabal Dutta from the University of Michigan present an energy harvesting sensor system architecture for smart building applications. Guiding much of their work is something they refer to as the “Monjolo” philosophy—using the actual sensed signal to power the monitoring device and directly drive the transmitted information. A variety of compact Monjolostyle energy harvesting sensor systems are described and implemented. These are tailored to a wide range of applications, such as monitoring door events for occupancy, monitoring airflow, sensing the state of illumination, determining device operation via emitted heat, and performing outlet-level power metering.

In addition to these three articles, this issue’s Spotlight department also relates to energy harvesting and power management. One of us (Steve Hodges), along with Ranveer Chandra and Anirudh Badam from Microsoft Research and Jian Huang from Georgia Tech, reprise several projects over the past 10 years that have sought to more effectively manage the power consumption of mobile devices. In each case, this was done by “offloading” operations from the device’s main processor in a way that reduced the energy requirements for the mobile device in question. The article illustrates that energy savings are possible through three different forms of offloading: computation, communication, and storage.

Researchers continue to make advances in energy harvesting—both in terms of systems that capture energy naturally present in their operating environments, and in terms of scenarios where intentional energy emission is introduced by a remote power source (such as WPT). Nonetheless, to date, such systems have rarely been adopted in commercial products. For this reason, continued research into power management and optimization techniques is also vitally important. These techniques promise to improve the performance of today’s predominant battery-powered products and at the same time accelerate the viability of harvested energy sources.

We hope the theme articles in this special issue provide a useful overview of some of the current research in this field and, in so doing, inspire others to pick up the challenge of increasing battery lifetime. This work will literally fuel the next generation of mobile and embedded devices and experiences.

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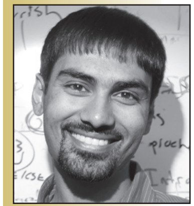

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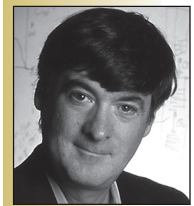

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