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Special Section on RFID

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Guest Editorial

Special Section on RFID

RADIO FREQUENCY IDENTIFICATION, or RFID, is a rapidly growing technology with applications in a number of industries. At the very core of RFID systems is the RFID chip, where cost and power are primary considerations. The chip, packaged with an inexpensive antenna, forms the basic passive RFID tag which can, when affixed to a logistical unit enable a myriad of applications related to tracking, tracing, and authentication. The basic passive tag has no battery, but draws power from the field generated by the reader. The use of batteries enables longer range communications. The tag communicates with a reader through a defined communication protocol over an appropriate frequency band. Issues of power limitations, bandwidth limitations, and varying regulations come up against the read-ranges, read rates, and tag functions demanded by the application. The RFID reader “inventories” a population of tags in its field, and the inventory is then analyzed by the software stack that resides above it. The software must analyze this stream of RFID data and extract business meaning from it. Application software must then generate business actions from this data and drive business processes which have been constructed around the capabilities of RFID.

Uniquely amongst communication technologies, RFID must be viewed as a tightly designed system stitching together a number of disciplines: semiconductor manufacturing, RF devices, chip packaging, signals and communication, networking, security, software, logistics, supply chain, and business processes. The theme of this Special Section is component technologies and applications related to RFID systems. This Special Section presents eight papers describing state-of-the-art technologies and tools and one application of RFID which were selected from 19 submissions. We are hopeful that this section will illustrate the breadth of opportunities for research and innovation in RFID.

RFID protocols, though simple, offer a surprising number of parameters which can be adjusted to achieve maximum performance. Since RFID systems are often operated at the edge of feasibility, the optimization of these parameters is essential. For example, a reader attempting to inventory hundreds of cases on a pallet as it is driven through a dock door has only a couple of seconds to quickly communicate with as many tags as it can. Any inefficiency might result in a significant drop in system per-

formance. The ISO/IEC 18000-6C is based on the so-called the “Q” algorithm, where Q is the number of slots in a variant of the slotted Aloha Algorithm. Maguire and Pappu calculate the best Q value for a round and describe a recursive algorithm to read all available tags in the shortest amount of time. While this paper deals with the algorithmic aspects of RFID, simulation of the physical and logical layers of RFID can prove equally important. In the Floerkemeier and Sarma paper, we present an RFID simulation engine, RFIDSim, which implements the ISO 18000-6C communication protocol and supports path-loss, fading, backscatter, capture, and tag mobility models.

RFID can be viewed as a surrogate for computer vision. Placing RFID tags on objects enables a computer to “view” the movement of physical objects without line-of-sight in a somewhat reduced but more pervasive way. So while an RFID system might be able to detect objects which cannot be seen, some simple conclusions that a line-of-sight vision system can draw are more difficult with RFID, such as the orientation of the object or its relative location. A significant opportunity exists for innovating in such areas. Roh and Choi describe the concept of a 3-D tag: a 3-D arrangement of tags attached to a cube. By exploiting the anisotropic responses of individual tags, it is possible to infer what the orientation of the 3-D tag is. Kim and Chong describe an RFID reader which determines the direction-of-arrival (DOA) of signals from a transponder by comparing the signal strength at adjacent antennae. The DOA can be used to infer the approximate bearing of a tag.

RFID is being used in a wide range of applications around the world today. Most of these uses are well within the capabilities of commercial systems, but a few require cutting-edge enhancements and analysis. Lehto *et al.* describe novel tag antenna designs for paper and board reel identification and propose solutions for reader and reader antenna integration in a paper handling machinery chain of paper and board reels.

RFID is a new and promising research field which combines systems-level issues with disciplinary challenges. We are excited to bring this Special Section forward to highlight this mosaic of activities.

We would like to thank all the authors and the anonymous reviewers for their outstanding work. We would also like to thank Editor-in-Chief Emeritus Peter Luh, Editor-in-Chief N. Viswanadham, Editorial Assistants Tatiana Janowycz and Amit Chakravarty, and all Guest Editors for their efforts in putting this issue together.

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Sanjay Sarma received the B.S. degree from the Indian Institute of Technology, Kanpur, the M.S. degree from Carnegie Mellon University, Philadelphia, PA, and the Ph.D. from the University of California, Berkeley.

In 1999, he was one of the founders of the Auto-ID Center, and until 2003, Chairman of Research of the five labs worldwide. He has over 50 papers and chapters in various journals, books, magazines, and conferences. He has done research with over 100 companies around the world. He serves on the boards on EPCglobal and OATSystems and is a past trustee of the New England Technology Leadership Council. His research includes RFID, computational geometry, automation, robotics, and manufacturing.

Prof. Sarma received several recognitions including the MIT MacVicar Fellowship, the Den Hartog Excellence in Teaching Award, and the Keenan Award for Innovation in Teaching, both at MIT, the NSF CAREER Grant, the New England Business and Technology Award, and a place in Business Week's E-Business 25.



Marlin H. Mickle (M'62–SM'86–F'96–LF'02) received the B.S.E.E., M.S.E.E., and Ph.D. degrees from the University of Pittsburgh, Pittsburgh, PA.

He is Nicholas A. DeCecco Professor holding appointments in electrical and computer engineering (primary), computer engineering, telecommunications, and industrial engineering at the University of Pittsburgh. He is the Executive Director of the RFID Center of Excellence and received the Carnegie Science Center Award for Excellence in Corporate Innovation in 2005 along with several other national and international awards. He has over 125 refereed publications and is coauthor and coeditor of more than 20 books. His academic research has been supported by over 35 different government agencies, corporations and foundations through 100+ funded projects. He is currently active in the areas of energy harvesting and high technology RF applications focused on RFID. In the past 36 months, five companies have been spun-off with licenses from Mickle *et al.* RFID related patents with additional filings in process.



Duncan McFarlane received the B.Eng. degree from Melbourne University, Victoria, Australia, in 1984 and the Ph.D. degree in the design of robust control systems from Cambridge University, Cambridge, U.K., in 1988.

He is Professor of Service and Support Engineering at the Department of Engineering, Cambridge University, and Head of the Distributed Information and Automation Laboratory within the Institute for Manufacturing. He is also Director of the Cambridge Auto-ID Lab and Research Director of two industrially supported activities: the Service and Support Engineering Programme and the Aero ID Program. He has been involved in the design and operation of automation and information system for the manufacturing supply chain for 20 years. He worked industrially with BHP Australia in engineering and research positions between 1980 and 1994. His work is focused on distributed automation strategies for the industrial supply chain including manufacturing, distribution, and service and support systems. From 2000 to 2003, he was the European Research Director of the Auto-ID Center, a center investigating the development of standard, low cost, networked RFID solutions for the retail supply chain. In 2001, he also became a coinvestigator in the EPSRC funded Innovative Manufacturing Research Centre based in the Institute for Manufacturing. In 2004, he became head of the Cambridge Auto ID Laboratory and in 2005 co-founded the Aero ID Program, examining the role of RFID in the aerospace industry. He is involved in numerous European projects and activities relating to RFID and distributed automation. He was appointed to the Professorship of Service and Support Engineering on October 1, 2006.

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Peter Cole received his undergraduate education from the University of Sydney, Sydney, Australia, obtaining the B.Sc. and B.E. degrees, the latter with the University Medal, and also obtained in 1964 the Ph.D. degree from the University of Sydney.

He was then engaged in three years postdoctoral study at the Massachusetts Institute of Technology, researching nonlinear behavior of ferromagnetic and anti-ferromagnetic materials. After moving to the University of Adelaide, he has pursued interests in radio frequency identification, electromagnetic engineering, microcircuit design, signal processing, and technology transfer to industry. He is a world renowned expert on radio frequency identification systems, and is the inventor of many important principles in the practice of RFID technology, for which he holds many patents. His inventions include the mixed field article surveillance tag, the one port acoustic surface wave tagging system, the near-field reactive power conservation principle, the data recording homodyne receiver, the rectifier capacitance resonating tag, the precursor-based adaptive round multiple tag reading system, the tag excitation level collision detection system, the parasitic antenna tagging system, a metal screened tagging system, and security systems based on publicly rechargeable one time codes. He was the founder and from 1984 to 1999 the Chairman of Directors of Integrated Silicon Design Pty. Ltd., a company specializing in radio frequency identification systems. This Company is now part of TAGSYS RFID known worldwide in the RFID industry. In 2002, he was invited to join the Auto-ID Center established by MIT. He is now Professor of Radio Frequency Identification Systems and Director of the Auto-ID Laboratory at the University of Adelaide.

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