Introduction to the Special Issue on Novel Embedded Systems for Ultrasonic Imaging and Signal Processing

Ultrasonic technology and sensors play a vital role for a diverse field of industrial and medical applications. The global market for ultrasonic equipment in 2011 was estimated at $17.5 billion and will reach $27.7 billion by 2016 according to market analysts BCC Research. Demand for ultrasonic testing and imaging devices is expected to increase, however, sustaining high growth requires innovative and novel ultrasonic sensors, devices, and testing methodologies. Therefore, this special issue of *IEEE Transactions on Ultrasonics, Ferroelectric and Frequency Control* (IEEE TUFFC) presents a timely assessment of the research landscape in real-time ultrasonic testing and imaging systems. The main objective of this special issue is to bring the latest advances in ultrasonic sensor arrays, micro electromechanical systems (MEMS), embedded computing, and signal processing and imaging hardware of interest to the ultrasonic research community into a common platform that falls within the scope of the IEEE TUFFC.

In recent years, the semiconductor industry has been going through an important evolutionary step called "More-than-Moore" for devices with functionalities that do not necessarily conform or scale according to Moore's law. These new devices can incorporate heterogeneous and parallel processing cores, and will allow sensors and actuators to be integrated into package- [system in a package (SiP)] or chip- [system on a chip (SoC)] level solutions. Similarly, reconfigurable technologies based on field-programmable gate arrays (FPGAs) have matured to a level where they are now considered viable for use in consumer products, offering great cost for performance and unmatched flexibility. More recently, general processing with graphics processing units (GPGPU) has gained momentum for scientific and industrial applications. GPUs offer tremendous parallel processing capability with a largely software-based design flow, making them attractive solutions for computationally complex problems. These devices are poised to make a significant impact in many fields, including the next generation of ultrasonic systems and devices. In fact, research and development of real-time ultrasonic testing and imaging systems is very active, as evidenced by the great interest in this special issue. A substantial number of papers were submitted, and after rigorous peer-review process, 22 were selected to be included in this content-rich special issue. We believe that these contributions are likely to have long-term impact on the future of novel ultrasonic devices. It is our hope that bringing together the research in this special issue will introduce readers to the latest breakthroughs in distinct fields of ultrasonic testing, signal processing, and embedded system design. The selected papers cover important topics in ultrasonic systems with medical and industrial applications; capacitive micromachined ultrasonic transducer (CMUT) and MEMS devices, FPGA-based embedded systems, reconfigurable hardware, front-end sensor electronics, integration of sensors and SoC devices, array systems, and GPGPU processing.

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The first group of 9 papers discusses ultrasonic system development for imaging and signal processing. These papers are concerned with achieving optimal design constraints such as hardware efficiency, system adaptability, low cost, and high throughput. The first paper by Owen *et al.,* (Charlottesville, VA) presents a computationally efficient, separable 2-D array beamforming method for increased frame rate and battery life for hand-held devices. The paper by Alqasemi *et al.* (Storrs, CT) introduces a reconfigurable processor system for real-time, co-registered ultrasound and photoacoustic imaging. A system-on-chip platform for ultrasonic target detection using neural networks is presented by Saniie *et al.* (Chicago, IL). Steckel and Peremans (Antwerp, Belgium) developed an FPGA-based biomimetic sonarhead to mimic echolocation behavior of bats. The ULtrasound Advanced Open Platform (ULA-OP), recently developed in Firenze, Italy by Boni *et al.,* is shown as a reconfigurable platform that can be adapted to applications such as vector Doppler, quasi-static elastography, flow-mediated dilation, pulse compression and high-frame-rate imaging. A cost-effective and portable FPGA-based ultrasound imaging embedded system is developed for point-of-care applications by Kim *et al.,* (Seoul, Korea). Another ultrasonic system with industrial application is described by Ricci *et al.* (Firenze, Italy, and Zurich, Switzerland). Here, an embedded Doppler system is designed for rheological fluid behavior characterization using FPGAs. Martin-Arguedas *et al.,* (Madrid, Spain) describe a new ultrasonic synthetic aperture technique using a GPU beamformer for accelerated execution and reduced hardware cost. The last paper in this group, by Cheng *et al.,* (Taipei, Taiwan), examines the MPEG compression of ultrasonic RF data to evaluate the compression efficiency.

The next 8 papers describe ultrasonic medical imaging systems with novel hardware components and methodologies. Kamimura *et al.,* (Sao Paulo, Brazil, and Rochester, MN) demonstrate the use of reconfigurable arrays for vibro-acoustography beam formation and conduct a parametric study for performance evaluation. Qiu *et al.,* (Hong Kong SAR, China) present a real-time, compact, and open platform for ultrasound biomicroscopy using FPGA devices. Bochud and Rus (Granada, Spain) report a numerical method by combining the solution of a probabilistic inverse problem with signal-processing techniques to monitor tissue formation processes in real-time. A 1024-element half-ring transducer array for ultrasound tomography is designed by Rouyer *et al.,* (Marseille, France) for anatomical breast inspection. Litniewski *et al.,* (Warsaw, Poland) present a low-cost FPGA-based ultrasonic scanner for *in vivo* measurement of trabecular bone. Abhilash and Sunita (Nanyang, Singapore) introduce a correlation-based motion prediction technique to address the movement of urological organs, which can be integrated into an image-guided noninvasive robotic surgical system with high targeting accuracy. Hemmsen *et al.,* (Lyngby, Denmark) describe a versatile and open data-acquisition platform using a medical ultrasound scanner. Multiple applications are examined including beamformation, blood velocity estimation, and acquisition of spectral velocity data. Finally, Yu *et al.,* (Delft, The Netherlands) present the development of an ultrasonic matrix transducer with more than 2000 elements to be used for 3-D trans-esophageal echocardiography.

The next 3 papers present the latest developments in system integration of capacitive micromachined ultrasonic transducers (CMUT) for imaging and detection applications. Wong *et al.,* (Waterloo, Canada) report the design of an FPGA-based real-time ultrasonic imaging system that uses a 16-element phased array CMUT, fabricated using the fusion bonding process. Lemmerhirt *et al.,* (Ann Arbor, MI, and Medford, MA) present a 32 × 32 ultrasound array manufactured using a CMUT-in-CMOS approach whereby transducer elements and readout circuits are integrated on a single chip. Berg and Rønnekleiv (Trondheim, Norway) compare the acoustic properties of CMUT 3-D stacks bonded with three different bonding techniques to reduce the impact of surface acoustic waves.

The last two papers are related to electronic subsystems required for high-voltage power amplifiers and for pulse generators used in high-frequency ultrasound imaging systems. Gao and Gui (Dallas, TX) show a new digital predistortion technique implemented on FPGAs to improve the linearity and power efficiency of a high-voltage power amplifier for ultrasound transmitters. Finally, Qiu *et al.* (Hong Kong SAR, China), present the development of a multi-functional, reconfigurable pulse generator for high-frequency ultrasound imaging. This pulse generator can be used for B-mode imaging, Doppler measurement, and modulated excitation imaging.

We believe that the articles in this special issue highlight both the current advances of ultrasonic systems and the key emerging solutions which can stimulate more research for innovative products in ultrasound-based medical or industrial applications. Moreover, it is our strong belief that the techniques discussed in this issue illustrate clearly how to map complex ultrasonic sensing and signal processing applications for real-time systems while meeting critical constraints such as system speed, power consumption, overall cost, and time-to-market.

We acknowledge the participation of many dedicated individuals who have made this special issue possible. We are deeply grateful to the authors for their contributions and to the reviewers for their insightful and constructive comments. We thank current IEEE TUFFC Editor-in-Chief Dr. Marjorie Yuhas and Editor-in-Chief Elect Dr. Steven Freear, who encouraged and guided us for this special issue. We also thank the editorial staff of the IEEE TUFFC for their efforts in editing and assembling this issue.

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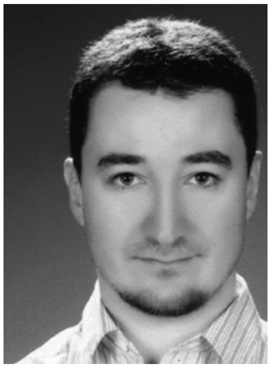
Jafar Saniie (S'80–M'81–SM'91–F'10) was born in Iran on March 21, 1952. He received his B.S. degree in electrical engineering from the University of Maryland in 1974. He received his M.S. degree in biomedical engineering in 1977 from Case Western Reserve University, Cleveland, OH, and his Ph.D. degree in electrical engineering in 1981 from Purdue University, West Lafayette, IN. In 1981, Dr. Saniie joined the Department of Applied Physics, University of Helsinki, Finland, to conduct research in photothermal and photoacoustic imaging. Since 1983, he has been with the Department of Electrical and Computer Engineering at the Illinois Institute of Technology, where he is a Filmer Endowed Professor, Associate Chair, and Director of the Embedded Computing and Signal Processing (ECASP) Research Laboratory.

Dr. Saniie's research interests and activities are in ultrasonic signal and image processing, statistical pattern recognition, estimation and detection, embedded digital systems, digital signal processing with field-programmable gate arrays, and ultrasonic nondestructive testing and imaging. In particular, he has performed extensive work in the areas of frequency-diverse ultrasonic flaw detection techniques, embedded signal processing architectures and system-on-chip design for ultrasonic imaging, ultrasonic data compression, nonlinear signal processing in target detection, ultrasonic imaging of reverberant multilayer structures, morphological processing and pattern recognition in ultrasonic imaging, time-frequency analysis of ultrasonic signals, and applications of neural networks for detecting target echoes and classifying microstructural scattering. Dr. Saniie has been a technical committee member of the IEEE Ultrasonics Symposium since 1987 (currently he is the chair of Sensors, NDE, and Industrial Applications), Associate Editor of the *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* since 1994, IEEE Branch Counselor (1983–1990), Program Coordinator and Local Chair of the Conference on Properties and Applications of Magnetic Materials (1985–2005), and Editorial Advisory member of the *Nondestructive Testing and Evaluation* journal (1986–1996). He is a member of Sigma Xi, IEEE, Tau Beta Pi, and Eta Kappa Nu. He is the 1986 recipient of the Outstanding IEEE Student Counselor Award. He is the recipient of the 2006 Outstanding Faculty Award and 2007 University Excellence in Teaching Award. Dr. Saniie is an IEEE Fellow for his contributions to "Ultrasonic Signal Processing for Detection, Estimation and Imaging."



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