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Guest Editorial: Special Section on Air-Coupled Ultrasound

AIR-COUPLED Ultrasound is a challenging field dominated by the drastic impedance mismatch between air and all condensed matter, the low ultrasound velocity in the air, and the rapidly increasing attenuation with frequency. These factors severely limit the applicability of air-coupled ultrasound; however, the potential is enormous. Ongoing research in this field continues to advance in the understanding of novel transduction systems and in the optimization of existing ones, by incorporating novel materials and designs. The emergence of improved transduction systems with better sensitivity, lower noise levels, wider bandwidth, higher frequency, lower cost, smaller size, and lower power consumption together with innovative signal processing and analysis methods, enables improvements of existing applications of air-coupled ultrasound in many different fields and, what is more interesting, the proposal of fully innovative use cases.

The seven articles included in this special section showcase the diversity of current research on air-coupled ultrasound. The authors are engaged in transducers design, optimization and manufacturing, dedicated electronic systems and signal processing methods and their use in different applications. This includes theoretical development, optimization methods, inverse problem solution, numerical modeling, experimental techniques, manufacturing techniques and applications. Two of the contributions focus on technological innovation—introducing new hardware platforms and measurement methods—while another offers a robust theoretical modeling approach that supports device design and optimization. The remaining four papers emphasize applied research, with use cases ranging from non-destructive testing in con-struction and food inspection to biomedical and plant science applications. Notably, one article explores the integration of machine learning for ultrasonic 3-D object reconstruction in complex outdoor environments, highlighting a significant trend: the convergence of ultrasonics with artificial intelligence.

The paper by Liu et al. [A1] introduced a novel approach to air-coupled ultrasonic transducer design by leveraging sol-gel PZT thin films for rapid prototyping. It marks the first demonstration of a piezoelectric micromachined ultrasonic transducer (pMUT) using this material to effectively emit ultrasound into the air. The study not only showcases promising performance from individual devices but also demonstrates the potential of scalable arrays for mid-air ultrasound applications.

The study by Ohara et al. [A2] explores the innovative use of air-coupled ultrasound for 3D object reconstruction in outdoor environments where optical methods like cameras or LiDAR are unreliable. By integrating ultrasonic imaging with a variational autoencoder (VAE), the authors demonstrate a robust approach for detecting and reconstructing stationary objects under real-world conditions. The work highlights the potential of combining traditional signal processing with modern machine learning to overcome longstanding challenges in ultrasonic sensing for open-air applications.

The paper by Merrien et al. [A3] presented a detailed modeling framework for air-coupled ultrasonic MEMS resonators using equivalent circuit techniques. By focusing on laterally actuated electrostatic devices with in-plane vibration modes, the authors provide a tool for predicting and optimizing device performance in applications like airborne mass sensing. The approach bridges analytical modeling with finite-element validation, offering a practical pathway for designing next-generation MEMS-based ultrasonic sensors.

Takahashi et al. [A4] introduced a novel application of air-coupled ultrasound for the non-invasive characterization of layered materials in artworks. By combining numerical modeling with experimental ultrasound transmission under varying angles, the study provides insights into the mechanical properties of materials commonly found in paintings. The approach opens new possibilities for art conservation, offering a unique way to assess structural integrity without physical contact or exposure to harmful methods.

The study by Haugwitz et al. [A5] demonstrated the use of air-coupled ultrasound for detecting hidden voids in foam-filled sandwich panels commonly used in construction. By evaluating different ultrasonic frequencies and setups, the authors show that non-contact inspection of subsurface defects is both feasible and effective. The results suggest that such techniques can be integrated into industrial quality control processes, offering a non-invasive method to ensure structural integrity and reduce material waste.

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The review by Fariñas et al. [A6] traced the evolution of air-coupled ultrasound techniques for analyzing plant leaves, highlighting their unique ability to assess tissue properties and water status non-invasively. It covers both resonant and non-resonant methods, detailing their applications in laboratory and field settings across various species. By compiling key advances, the article underscores the growing role of ultrasound in plant science, particularly in understanding hydration dynamics without damaging sensitive biological structures.

The review by Giacomozzi et al. [A7] highlighted the emerging role of air-coupled ultrasound in transforming quality control and safety monitoring within the food industry. By offering a non-invasive and real-time method to assess composition, texture, and detect contaminants, ultrasound technology addresses key challenges in modern food production. The paper surveys recent advances and demonstrates how air-coupled approaches can enhance process efficiency, traceability, and consumer safety across the food supply chain.

Importantly, all contributions in this special section are application-oriented, demonstrating the readiness of air-coupled ultrasound technologies to address real-world challenges. Whether it's ensuring food safety, supporting heritage conservation, optimizing industrial inspection, or enabling in-field biological measurements, the practical relevance of these studies makes this section particularly valuable for both researchers and industry professionals.

We hope that this collection will serve as a snapshot of ongoing progress in air-coupled ultrasound, stimulate further interdisciplinary collaboration, and inspire new innovations in both academic and industrial settings.

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APPENDIX: RELATED ARTICLES

[A1] Y.-H. Liu et al., "Development of an air-coupled piezoelectric micromachined ultrasonic transducer using sol-gel PZT thin film for fast-prototyping," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 27–36, 2024, doi: 10.1109/OJUFFC.2024.3397630.

[A2] R. Ohara et al., "3-D object reconstruction from outdoor ultrasonic image and variation autoencoder," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 140–149, 2024, doi: 10.1109/OJUFFC.2024.3466090.

[A3] T. Merrien, P. Didier, and E. Algré, "Equivalent circuit modeling of air-coupled laterally actuated electrostatic bulk-mode MEMS," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 63–76, 2024, doi: 10.1109/OJUFFC.2024.3413603.

[A4] V. Takahashi, M. Lematre, J. Fortineau, and M. Lethiecq, "Determination of elastic parameters of thin layers used in paintings by air-coupled ultrasound transmission measurements under varying incidence," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 126–139, 2024, doi: 10.1109/OJUFFC.2024.3413604.

[A5] C. Haugwitz et al., "Air-coupled Lamb wave testing of buried air-voids in foam-filled sandwich panels," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 150–159, 2024, doi: 10.1109/OJUFFC.2024.3410169.

[A6] L. Fariñas, D. Sancho-Knapik, J. J. Peguero-Pina, E. Gil-Pelegrín, and T. E. G. Álvarez-Arenas, "Origin, development, and applications of air-coupled broadband ultrasounds for the study of tissues and water relations in plant leaves: A review," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 77–88, 2024, doi: 10.1109/OJUFFC.2024.3433316.

[A7] A. Giacomozzi, J. Benedito, T. E. G. Álvarez-Arenas, and J. V. García-Perez, "Air-coupled ultrasonic inspection of foods: A review," *IEEE Open J. Ultrason., Ferroelectr., Freq. Control*, vol. 4, pp. 100–115, 2024, doi: 10.1109/OJUFFC.2024.3457503.

MATE GAAL was born in Zagreb, Croatia. He received the degree in theoretical physics from the University of Zagreb, Zagreb, and the Ph.D. degree in engineering sciences from the Brandenburg University of Technology (BTU) Cottbus-Senftenberg, Germany, in 2007. He has been working at BAM since 2003. After working on human factors and the reliability of non-destructive testing, he shifted his focus to air-coupled ultrasonic transducers based on ferroelectrets, thermoacoustics, and plasma acoustics, as well as signal processing methods for air-coupled ultrasonic testing and materials characterization.

TOMÁS GÓMEZ ÁLVAREZ-ARENAS (Member, IEEE) received the Ph.D. degree in physics from the Universidad Complutense de Madrid in 1994. After a Post-Doctoral Researcher with the Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, U.K., he joined the Spanish National Research Council, first the Institute of Acoustics in 1998, then the Institute of Physical Technologies in 2013. His research interests include design, modeling, optimization, and fabrication of ultrasonic transducers; air-coupled ultrasound transducers and applications; ultrasonic NDT; materials characterization; and wave propagation in complex materials.