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Editorial

Special Issue on Computational Ultrasound Imaging and Applications

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Scientific and technical progress is driven particularly by the ability to "look" into new areas. Imaging technologies such as optical and electron microscopy, X-ray, positron emission tomography, magnetic resonance imaging, and most recently gravitational wave astronomy have each provided humanity with a window into a new world. Ultrasound (US) imaging, which emerged in the last century, has enabled us to probe otherwise opaque media in a non-invasive, safe, and cost-efficient manner. This has led to a multitude of new applications, particularly in the fields of medical diagnostics and non-destructive testing. However, some practical limitations of ultrasound imaging have held some very desirable applications just out of reach:

1. **Susceptibility to aberrations**: The quality of a US image degrades if there are deviations from the assumed speed of sound or reflections that are not accounted for during beamforming. In the context of process metrology, for instance, having a multi-mode wave guide in the acoustical path to shield the transducer array from hot melts prevents in situ flow imaging [1]. In medical context, the strong aberrations induced by the skull bone hinder transcranial US imaging and therapy [2]. This limitation impedes non-invasive, pre-hospital or bed-side diagnostics and continuous monitoring of the brain.
2. **Limited processing bandwidth**: The bandwidth of capturing and processing the information conveyed in the sound field is often limited by the ultrasound device. This makes it very hard to simultaneously achieve real-time 3D imaging with high spatial and temporal resolution over a large field of view. As a result, it is still challenging to comprehensibly capture fast-moving volumetric objects with complex structures, such as the beating heart [3].
3. **Diffraction limit**: The diffraction of sound waves limits the resolution of classical US imaging and hinders the ability to visualize sub-wavelength objects or structures. By overcoming this limitation, anatomical and functional imaging of microvasculature in vivo [4] or high-resolution flow mapping in technical processes [5] becomes feasible. In the future, this may even enable imaging and tracking of medical microrobots, which is essential for their application in vivo [6].
4. **Manual decision-making process**: Deriving diagnostic decisions from ultrasound images is a complex and to date mostly manual process. Augmenting or automating parts of the decision-making process through advanced statistical or machine learning methods could potentially lead to faster and more objective diagnostic results [7].
5. **Limited modalities:** Restriction to the classical modalities of US imaging, such as brightness mode (B-mode) and Doppler, reduces its diagnostic value. Acquiring additional modalities through computational or physical methods can provide more information. For example, shear wave elastography can infer the mechanical stiffness of tissues and materials [8], and photoacoustic imaging can reveal their optical properties [9].

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Citation: Nauber, R.; Büttner, L.; Czarske, J. Special Issue on Computational Ultrasound Imaging and Applications. *Appl. Sci.* **2024**, *14*, 964. https://doi.org/10.3390/app14030964

Received: 16 January 2024
Accepted: 18 January 2024
Published: 23 January 2024

In recent decades, enormous computational resources have become available and cost efficient. This allows addressing the aforementioned challenges with a combination of novel methods; for example, computational, software-defined ultrasound imaging allows for the use of more complex signal processing algorithms. Such methods enable super-resolution imaging, correction of strong aberrations, and reconstruction of the shear wave speed of the insonified medium. Further down the signal processing pipeline, machine learning methods can assist in interpreting the acquired data. This Special Issue comprises a total of nine papers that address the aforementioned challenges.

1. Mozaffarzadeh et al. show that geometry-based phase aberration correction enhances the contrast and resolution of transcranial images [10]. Nguyen Minh et al. show that US-based estimation of the thickness and speed of sound of the human tibia bone is improved through phase aberration correction [11]. Doveri et al. establish reflection-mode ultrasound computed tomography for accurately mapping anatomical features despite strong reflections and speed of sound differences [12].
2. Kaddoura et al. develop a novel parallel transmission scheme that can decrease the acquisition time for 2D and 3D synthetic aperture imaging [13]. Zhang et al. introduce algorithmic improvements in a basic building block of US data processing for real-time applications [14].
3. Weik et al. achieve super resolution flow imaging in liquid metals by utilizing ultrasound localization microscopy [15].
4. Kerdegari et al. automate the detection and localization of pulmonary abnormalities through deep learning with spatiotemporal attention in ultrasound videos [16]. Del-Canto-Fernández et al. establish image texture analysis as a US-based diagnostics protocol to gain insight into low back pain [17].
5. Olteanu et al. use shear-wave elastography for diagnosing high-risk varices in non-alcoholic fatty liver disease based on the mechanical properties of the spleen [18].

In summary, this Special Issue covers a multitude of computational ultrasound approaches to address the limitations arising from restricted processing bandwidth, diffraction, manual decision making, and restricted modalities. The nine papers primarily target applications in medical diagnostics, as well as technical and basic research uses. Computational technologies are currently revolutionizing US imaging and extending its reach towards new applications. Given the high rate of adoption of machine learning technologies across the ultrasound processing pipeline, there is a growing demand for interpretable results, particularly in the case of high-stakes decisions. Future research should be directed to provide reliable indicators of uncertainty to supplement any quantitative measures and diagnostic results derived from ultrasound data.

Funding: This research was partially funded by the German Research Foundation (DFG), project numbers 411799900 and 512483557, as well as by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 853609, "Micro-GIFT").

Acknowledgments: The authors thank the many people who contributed to this Special Issue by either submitting manuscripts, reviewing or handling them.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Grüter, L.; Nauber, R.; Czarske, J. Ultrasonic Bubble Imaging in Molten Salt Using a Multi-Mode Waveguide and Time Reversal. *IEEE Trans. Instrum. Meas.* **2022**, *71*, 1–10. [CrossRef]
2. Lindsey, B.D.; Nicoletto, H.A.; Bennett, E.R.; Laskowitz, D.T.; Smith, S.W. 3-D Transcranial Ultrasound Imaging with Bilateral Phase Aberration Correction of Multiple Isoplanatic Patches: A Pilot Human Study with Microbubble Contrast Enhancement. *Ultrasound Med. Biol.* **2014**, *40*, 90–101. [CrossRef] [PubMed]
3. Papadacci, C.; Pernot, M.; Couade, M.; Fink, M.; Tanter, M. High-contrast ultrafast imaging of the heart. *IEEE Trans. Ultrason. Ferroelectr. Freq. Control.* **2014**, *61*, 288–301. [CrossRef] [PubMed]

4. Christensen-Jeffries, K.; Couture, O.; Dayton, P.A.; Eldar, Y.C.; Hynynen, K.; Kiessling, F.; O'Reilly, M.; Pinton, G.F.; Schmitz, G.; Tang, M.X.; et al. Super-resolution Ultrasound Imaging. *Ultrasound Med. Biol.* **2020**, *46*, 865–891. [CrossRef] [PubMed]
5. Kupsch, C.; Feierabend, L.; Nauber, R.; Buttner, L.; Czarske, J. Ultrasound Super-Resolution Flow Measurement of Suspensions in Narrow Channels. *IEEE Trans. Ultrason. Ferroelectr. Freq. Control.* **2021**, *68*, 807–817. [CrossRef] [PubMed]
6. Nauber, R.; Goudu, S.R.; Goeckenjan, M.; Bornhäuser, M.; Ribeiro, C.; Medina-Sánchez, M. Medical microrobots in reproductive medicine from the bench to the clinic. *Nat. Commun.* **2023**, *14*, 728. [CrossRef] [PubMed]
7. Liu, S.; Wang, Y.; Yang, X.; Lei, B.; Liu, L.; Li, S.X.; Ni, D.; Wang, T. Deep Learning in Medical Ultrasound Analysis: A Review. *Engineering* **2019**, *5*, 261–275. [CrossRef]
8. Garra, B.S. Elastography: history, principles, and technique comparison. *Abdom. Imaging* **2015**, *40*, 680–697. [CrossRef]
9. Lin, L.; Wang, L.V. The emerging role of photoacoustic imaging in clinical oncology. *Nat. Rev. Clin. Oncol.* **2022**, *19*, 365–384. [CrossRef]
10. Mozaffarzadeh, M.; Verweij, M.D.; de Jong, N.; Renaud, G. Comparison of Phase-Screen and Geometry-Based Phase Aberration Correction Techniques for Real-Time Transcranial Ultrasound Imaging. *Appl. Sci.* **2022**, *12*, 10183. [CrossRef]
11. Nguyen Minh, H.; Muller, M.; Raum, K. Estimation of Thickness and Speed of Sound for Transverse Cortical Bone Imaging Using Phase Aberration Correction Methods: An In Silico and Ex Vivo Validation Study. *Appl. Sci.* **2022**, *12*, 5283. [CrossRef]
12. Doveri, E.; Sabatier, L.; Long, V.; Lasaygues, P. Reflection-Mode Ultrasound Computed Tomography Based on Wavelet Processing for High-Contrast Anatomical and Morphometric Imaging. *Appl. Sci.* **2021**, *11*, 9368. [CrossRef]
13. Kaddoura, T.; Zemp, R.J. Hadamard Aperiodic Interval Codes for Parallel-Transmission 2D and 3D Synthetic Aperture Ultrasound Imaging. *Appl. Sci.* **2022**, *12*, 4917. [CrossRef]
14. Zhang, C.; Geng, X.; Yao, F.; Liu, L.; Guo, Z.; Zhang, Y.; Wang, Y. The Ultrasound Signal Processing Based on High-Performance CORDIC Algorithm and Radial Artery Imaging Implementation. *Appl. Sci.* **2023**, *13*, 5664. [CrossRef]
15. Weik, D.; Grüter, L.; Räbiger, D.; Singh, S.; Vogt, T.; Eckert, S.; Czarske, J.; Büttner, L. Ultrasound Localization Microscopy in Liquid Metal Flows. *Appl. Sci.* **2022**, *12*, 4517. [CrossRef]
16. Kerdegari, H.; Phung, N.T.H.; McBride, A.; Pisani, L.; Nguyen, H.V.; Duong, T.B.; Razavi, R.; Thwaites, L.; Yacoub, S.; Gomez, A.; et al. B-Line Detection and Localization in Lung Ultrasound Videos Using Spatiotemporal Attention. *Appl. Sci.* **2021**, *11*, 11697. [CrossRef]
17. Del-Canto-Fernández, A.; Calleja-Martínez, P.; Descalzo-Hoyas, B.; Rodríguez-Posada, S.; Cuenca-Zaldívar, N.; Fernández-Carnero, S.; Naranjo-Cinto, F.; Gallego-Izquierdo, T. The Application of Image Texture Analysis Techniques on the Effects of Dry Needling versus Placebo in Low-Back Pain Patients: A Pilot-Study. *Appl. Sci.* **2022**, *12*, 5556. [CrossRef]
18. Olteanu, V.A.; Sfarti, C.V.; Balan, G.G.; Timofte, O.; Gologan, E.; Mitrică, D.E.; Gilca-Blanariu, G.E.; Dascalu, C.G.; Sandu, I.; Ştefănescu, G. The Role of Shear-Wave Elastography of the Spleen in Ruling out the Presence of High-Risk Varices in Non-Alcoholic Fatty Liver Disease (NAFLD). *Appl. Sci.* **2023**, *13*, 5764. [CrossRef]