Session 4aBAb

Biomedical Acoustics and Signal Processing in Acoustics: Novel Ultrasound Beamforming Techniques and Their Applications I

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Chair's Introduction—9:00

Invited Papers

9:05

4aBAb1. Spatial-coherence-based beamforming for image quality enhancement in high frame-rate ultrasound imaging. Giulia Matrone (Dept. of Elec., Comput. and Biomedical Eng., Univ. of Pavia, Via Ferrata 5, Pavia 27100, Italy, giulia.matrone@unipv.it) and Alessandro Ramalli (Dept. of Information Eng., Univ. of Florence, Florence, Italy)

Several high frame-rate ultrasound imaging techniques have been recently proposed which allow to increase image acquisition rates by transmitting multiple focused beams simultaneously or defocused waves, and reconstructing multiple scan lines in parallel. These methods, which include for example multi-line transmission, plane/diverging wave imaging, and parallel beamforming, have proved to be successful in increasing the frame-rate, but on the other hand they have also showed some limitations in terms of the achievable image quality, partly degrading image contrast and resolution. Different solutions have been proposed to address this problem so far, such as the use of advanced receive beamforming algorithms able to improve the beam shape and the quality of the obtained image. Among these, beamformers based on backscattered signals spatial coherence, as e.g. Filtered Delay Multiply and Sum beamforming, Coherence-Factor-based methods, and Short Lag Spatial Coherence Imaging, have gained increasing attention for their ability to enhance image contrast and suppress clutter. In this presentation, an overview of some recent results obtained by jointly exploiting high frame-rate ultrasound imaging and coherence-based beamforming methods will be presented, showing through experimental tests the performance improvement achievable with these techniques.

9:25

4aBAb2. Adaptive beamformer with echo statistics. Hideyuki Hasegawa (Univ. of Toyama, 3190 Gofuku, Toyama 9308555, Japan, hasegawa@eng.u-toyama.ac.jp), Takumi Akamatsu, Masaaki Omura, and Ryo Nagaoka (Univ. of Toyama, Toyama, Japan)

Delay-and-sum (DAS) beamforming is commonly used in commercial scanners and computationally efficient for real-time imaging. However, the ability to suppress off-axis signals is limited. A minimum variance (MV) beamformer realizes a superior performance in suppression of off-axis signals and improves lateral resolution significantly. On the other hand, MV degrades the contrast-to-noise ratio (CNR) compared to DAS because it alters speckle statistics. In this study, we developed a method for improvement of CNR in MV beamforming by evaluating envelope statistics of echo signals. It is well known that the envelope statistic of speckle echoes from a random medium obeys the Rayleigh distribution. The echo envelope statistics were evaluated using the shape parameter of the Nakagami distribution. The proposed beamformer is worked as DAS for speckle echoes and MV for non-speckle echoes by referring to the Nakagami shape parameter. In the phantom experiment, the lateral resolution of MV was 0.18 mm, which was significantly better than 0.53 mm obtained by DAS. However, CNR was degraded from 6.73 dB to 4.05 dB by MV. The proposed beamformer realized a lateral resolution of 0.25 mm, which was significantly better than DAS, with a CNR value of 6.03 dB, which was comparable to DAS.

9:45

4aBAb3. High-frame-rate limited-diffraction beam imaging. Jian-yu Lu (Bioengineering, The Univ. of Toledo, 2801 West Bancroft St., Toledo, OH 43606, jian-yu.lu@ieee.org)

Limited-diffraction beams such as Bessel beam, X wave, and array beam are a class of beams that in theory do not spread as they propagate to infinite distance. When realized with a finite aperture, these beams have a large depth of field. In this paper, limited-diffraction beams and their applications to high-frame rate imaging are reviewed and further studied. Using a limited-diffraction beams (in either transmission or reception, or both, or with spatial Fourier transform of received signals), images can be reconstructed in Fourier domain. This significantly reduces the amount of computation in 3D imaging since FFT can be used. As the bandwidth of the transducer is increased, the image reconstructed can cover a larger field of view since a frequency in limited-diffraction beam corresponds to one angular direction of the beam (similar to the "frequency encoding" in the magnetic resonance imaging or MRI). Using the angular

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dependence with frequency, focused limited-diffraction beams can be used for high-frame-rate and high-resolution tissue property imaging. When limited-diffraction beams are used in transmissions, no time delay (only amplitude weighting) is needed, which simplifies imaging system hardware. Also, flow vector imaging can be obtained with limited-diffraction beams using sine and cosine (quadrature) aperture weighting.

10:05

4aBAb4. Beamforming of 3D ultrasound signals with full or sparse probes: New perspectives for volumetric imaging. François Varray (Univ. Lyon, INSA-Lyon, Université Claude Bernard Lyon 1, UJM-Saint Etienne, CNRS, Inserm, CREATIS UMR 5220, U1294, 21 Ave. Jean Capelle, Bat Leonard de Vinci, Villeurbanne 69621, France, francois.varray@creatis.insa-lyon.fr)

The advances of 2D arrays and 3D ultrasound systems open new perspectives for volumetric US imaging. Coupled with the ultrafast acquisitions, the quantity of acquired data to process expand and the beamforming could become a bottleneck in the processing, especially if volumes are reconstructed in real time. In this work, we propose to study the impact of the beamformer on 3D volumetric images, such as coherence factor, sign coherence factor, phase coherence factor or pDAS. Indeed, such beamformers, adaptive or not, can be easily transfer to 3D but their studies are limited in 3D volumetric situation. Moreover, the introduction of fully populated array required the used of advance and expensive systems. To this end, the utilisation of sparse probes is a promising solution to reduce the number of signals to manage and the complexity of the used hardware. However, the impact on the reconstructed volumes have to be evaluated and the presented beamforming strategies will be presented in both fully and sparse probes.

10:25–10:40 Break

10:40

4aBAb5. On the use of denoing algorithms for ultrasound beamforming. Sobhan Goudarzi (Dept. of Elec. and Comput. Eng., Concordia Univ., Montreal, QC, Canada), Adrian Basarab (CREATIS, Univ. of Lyon, Université Claude Bernard Lyon 1 CREATIS UMR 5220 Bât. Léonard de Vinci, 21 Ave. Jean Capelle, Villeurbanne Cedex 69621, France, adrian.basarab@creatis.insa-lyon.fr), and Hassan Rivaz (Dept. of Elec. and Comput. Eng., Concordia Univ., Montreal, QC, Canada)

Beamforming in receive, whose objective is to estimate an image from raw RF data acquired by the probe piezoelectric elements, plays a crucial role in ultrasound imaging. The standard method, called delay and sum (DAS) and implemented in most of the commercial scanners, consists in coherently summing the RF signals, providing the backprojection solution of the inverse problem of beamforming. Despite real-time properties, DAS results into images with limited spatial resolution and contrast. The literature of ultrasound beamforming is rich and mainly consists in alternatives to DAS based on non-adaptive or adaptive (e.g., minimum variance, coherence factor) methods or image reconstruction algorithms in the Fourier domain. Furthermore, inverse problem formulations have been shown to be well-adapted to ultrasound beamforming. They consist in minimizing a cost function formed by two terms: a data fidelity term modelling the acquisition setup, and a regularization term. The choice of the latter is not straightforward in ultrasound imaging, mainly because of the need to conserve statistical properties of the speckle. In this paper, denoising algorithms are shown to be good regularizers for ultrasound beamforming, providing a good performance in spatial resolution and contrast gain, without deteriorating the quality of the speckle texture.

11:00

4aBAb6. Correlation-based ultrasound imaging: A diagnostic enabler. Maxime Bilodeau, Tamara Krpic, Nicolas Quaegebeur (Mech. Eng., Universite de Sherbrooke, Sherbrooke, QC, Canada), and Patrice Masson (Mech. Eng. Dept., Universite de Sherbrooke, 2500 blvd Universite, Sherbrooke, QC J1K 2R1, Canada, Patrice.Masson@USherbrooke.ca)

Correlation-Based (CB) ultrasound imaging relies on the correlation of measured signals with signals from a simulated or measured database. The CB imaging algorithm *Excitelet* has demonstrated better ultrasound image quality in Non-Destructive Testing (NDT) applications. In medical applications, ultrasound imaging is characterized by weak image dynamics when compared with Magnetic Resonance Imaging (MRI) or Computed Tomography (CT). However, portable, low-cost, and reliable diagnostic tools based on ultrasound imaging could help reducing the delays between patient assessment and treatment. In order to see more ultrasound-based diagnostics, collective research efforts are still required.Recent work on the use of the CB framework in medical imaging has enabled new diagnostic modalities. Indeed, CB imaging extends the field of view due to the near perfect compensation of the intrinsic properties of the transducers (directivity, dynamics, imperfections, lenses). New automated tools allow using a measured signal database, as opposed to simulated database previously required in CB imaging. Due to its frequency formulation, a realistic signal database enables local acoustical impedance estimation through the reconstruction of the reflectors/diffusers local phase. It is herein proposed to overlay this color-coded phase information, as typically done in Doppler imaging, to enrich the ultrasound image, and facilitate image interpretation.

11:20

4aBAb7. From ultrafast ultrasound imaging to "matrix imaging". Mathias Fink (Langevin Inst., ESPCI Paris, 1 rue Jussieu, Paris 75005, France, mathias.fink@espci.fr)

Both ultrasound medical imaging and NDT requires reflection-mode detection. As tissues, as well as many metallic samples, are complex disordered media, containing random distribution of scatterers, these techniques suffer various limitations as distortion induced by aberrating layers. A multi-illumination strategy is the solution to solve these problems. It was first used in the context of ultrafast imaging with multiple plane wave illumination. I will show that, recording a "reflection matrix" provides enough information to greatly improve beam-forming techniques. I will describe how to extract from the coherence properties of this reflection matrix enough information both to compensate the effects of aberrating layers and to provide quantitative information. Various strategies to measure this matrix and to exploit it will be discussed. This is the domain of "matrix imaging" recently developed for ultrasound imaging.