A Multilevel Sensing Adversarial Framework for Signal Recovery in Ultrafast Ultrasound

Background, Motivation and Objective

In ultrafast ultrasound with synthetic aperture and diverging waves, using as few sub-aperture transmissions as possible to achieve comparable image quality to full-aperture compounding is an active research area. However, most studies apply an end-to-end approach to the image domain and do not leverage the inherent rich information of raw signals. We hereby propose a multilevel sensing adversarial framework (MSAF) to recover raw signals from sparse sub-aperture transmissions for ultrafast ultrasound.

Statement of Contribution/Methods

Different from existing methods merely with frame-wise spatial sensing, MSAF does multi-domain (i.e., spatiotemporal) and multi-level (i.e., global-local) sensing across frames and apertures to maximize the potential of sparse sub-apertures. Our current target is to learn mapping of beamformed IQ signals between odd and even sub-apertures prior to coherent compounding. Our generator consists of two parts (see Figure). One is a complex UNet to map the odd subaperture IQ signals to the even ones in a frame-by-frame manner, thus looking for spatial information. The other is a cascaded complex Bi-ConvLSTM to refine temporal consistency. For adversarial learning, IQ signals are converted to the polar form and then fed into a discriminator. Specifically, frame-wise global discrimination constrains the intraframe cross-aperture correlation by an optimization term $\mathcal{O}_1$; aperture-wise local attribute discrimination constrains the temporal stable attributes within a sub-aperture by optimization terms $\mathcal{O}_2$ and $\mathcal{O}_3$. A total of 18,450 sub-aperture beamformed IQ frames of the human heart in vivo at 800 fps were obtained using a Verasonics Vantage system with a 2.5 MHz P4-2 phased array probe for MSAF training and evaluation. UNet and Generative Adversarial Network (GAN) were chosen as benchmarks.

Results/Discussion

MSAF achieved PSNR of 32.90±0.68, SSIM of 0.861±0.015, CNR of 2.789±0.742, and CR of 13.506±1.491. Compared with UNet/GAN, MSAF improved PSNR by 41.71/36.76%, SSIM by 65.09/47.53 %, CNR by 79.93/19.55%, and CR by 26.32/12.52%. The relative MAE and RMSE of axial displacements estimated by speckle tracking were 0.0598±0.2413 and 0.0655±0.2670. Quantitative results demonstrated excellent efficacy of MSAF in IQ signal recovery with doubled frame rates for ultrafast ultrasound.