High resolution fast 3D ultrasound imaging with deep learning based adaptive beamforming

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Introduction

Achieving high resolution fast volumetric ultrasound imaging is challenging because spatial resolution is reduced by:

- The use of plane-or divergent transmit fields
- For matrix probes, implementation of micro-beamforming techniques, needed to achieve a manageable data rate and channel count

To improve image quality powerful receive data processing is needed.

Recently, deep learning-based beamformers have been employed to improve resolution. The deep learning based adaptive beamformer ABLE [1] and the Delay-And-Neural-Network (DANN) [2] method both showed improved resolution in 2D ultrasound images w.r.t. the conventional delay-and-sum (DAS).

Here we used simulations to create a high-resolution training target for large 3D arrays, that is not limited by the capability of current beamformers. We propose a modified ABLE beamformer with increased receptive field, trained on the high-resolution targets.

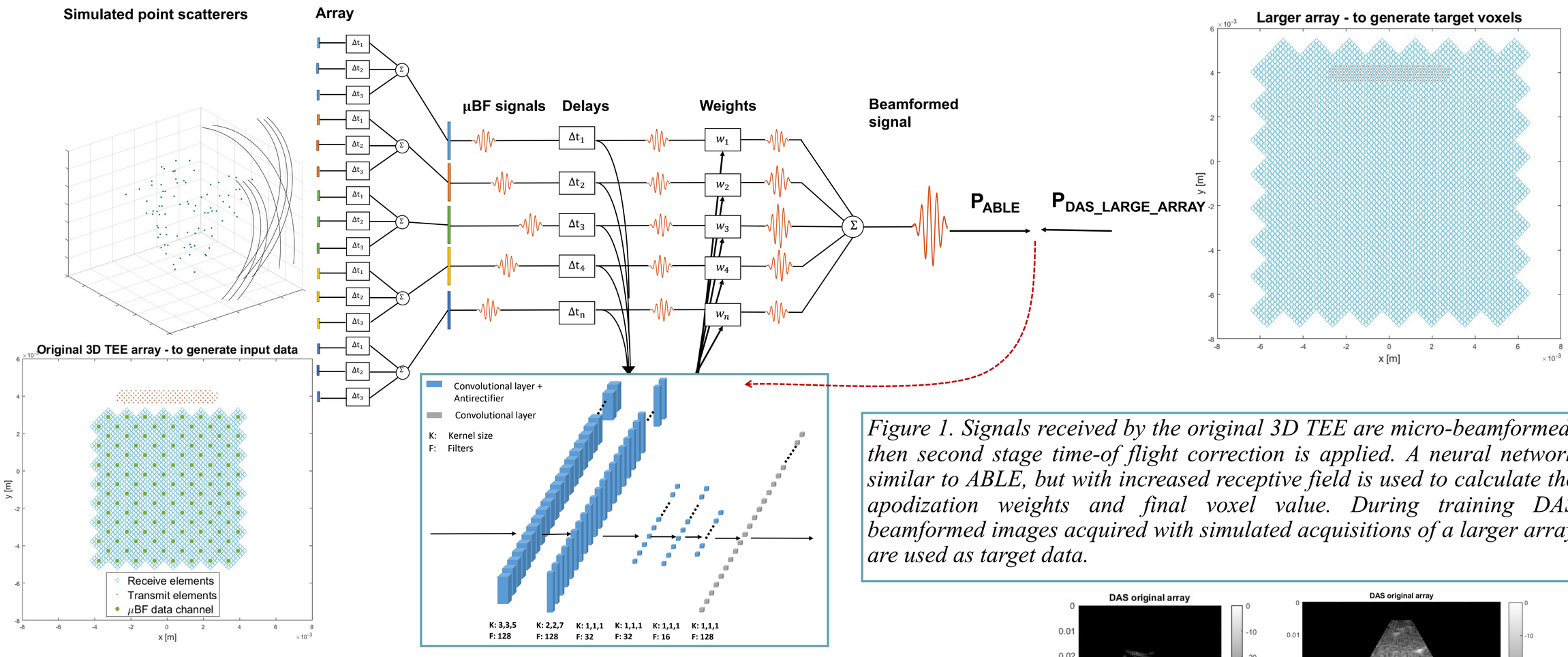

Figure 1. Signals received by the original 3D TEE are micro-beamformed, then second stage time-of flight correction is applied. A neural network similar to ABLE, but with increased receptive field is used to calculate the apodization weights and final voxel value. During training DAS beamformed images acquired with simulated acquisitions of a larger array are used as target data.

Methods

- A real adult matrix TEE probe with split transmit receive design [2] consisting of 2048 receive elements grouped in 128 sub-arrays of 4x4 elements was used to acquire in vitro images of the CIRS phantom.
- The original 3D TEE probe and a larger array with 2.25 times the number of receive elements were simulated in Field II with 3 different volumes of point scatterers.
- The ABLE network is modified by increasing the kernel size such that apodization weights for a voxel are adaptively calculated based on the time-of-flight corrected signals of a small region of voxels.
- Voxels reconstructed with the DAS beamformed data of the larger array are used as training targets and time-of-flight corrected micro-beamformed channel data of the simulated original 3D TEE array is used as the input.

Results

ABLE improves resolution compared to DAS in simulations and in the CIRS phantom (Fig. 2), without decreasing the GCNR (0.67 for (modified) ABLE, 0.6 for DAS).

Conclusion

The resolution improvement obtained with a (modified) ABLE network trained on simulation data generalizes to in vitro imaging.

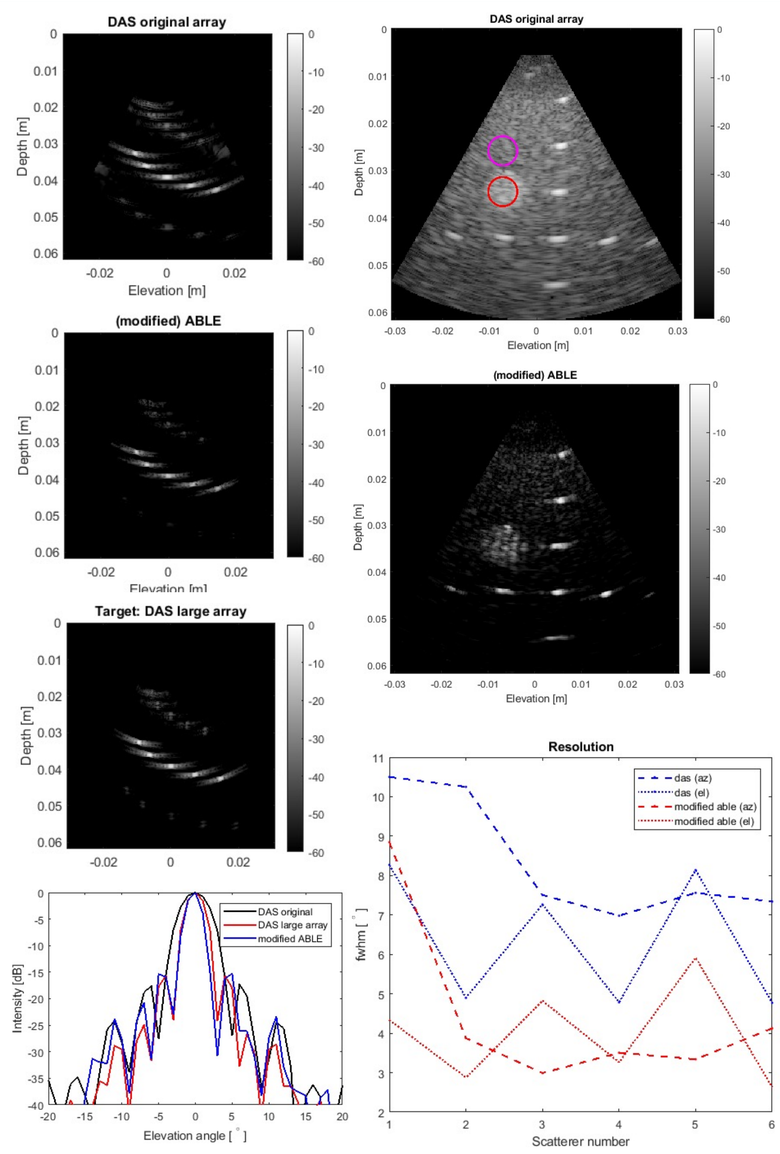

Fig 2. Left column) Results on simulated data and FWHM of the middle scatterer. Right column) Results on the CIRS phantom, circles indicate the high and low intensity region used to determine GCNR. The FWHM of the scatterers is shown for DAS and (modified) ABLE

References

[1] B. Luijten et al., "Adaptive Ultrasound Beamforming using Deep Learning," in IEEE Transactions on Medical Imaging, doi: 10.1109/TMI.2020.3008537.
[2] F. Vignon et al. "Resolution Improvement with a Fully Convolutional Neural Network Applied to Aligned Per-Channel data," 2020 IEEE International Ultrasonics Symposium (IUS) doi:10.1109/IUS46767.2020.9251482.
[3] D. Bera et al., "Fast Volumetric Imaging Using a Matrix Transesophageal Echocardiography Probe with Partitioned Transmit–Receive Array," UltrasoundMed. Biol., vol. 44, no. 9, pp. 2025–2042, 2018

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