Beamforming-deconvolution: A novel concept of deconvolution for ultrasound imaging

Zhouye Chen*, Adrien Besson†, Jean-Philippe Thiran†‡ and Yves Wiaux*

*Institute of Sensors, Signals and Systems, Heriot-Watt University, Edinburgh, United-Kingdom

†Signal Processing Laboratory (LTS5), Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

‡Department of Radiology, University Hospital Center (CHUV) and University of Lausanne (UNIL), Lausanne, Switzerland

***Abstract*—In ultrasound (US) imaging, beamforming is usually separated from the deconvolution or some other post-processing techniques. The former processes raw data to build radio-frequency (RF) images while the latter restore high-resolution images, denoted as tissue reflectivity function (TRF), from RF images. This work is the very first trial to perform deconvolution directly with raw data, bridging the gap between beamforming and deconvolution, and thus reducing the estimation errors from two separate steps. The proposed approach retrieves both high quality RF and TRF images and exhibits better RF image quality than a classical beamforming approach.**

The deconvolution problem for ultrasound (US) imaging has been intensively considered to enhance the image quality after Jensen *et al.* [1] introduced a convolution model from the standard wave equation. According to such a model, the *radio-frequency* (RF) image, obtained from the *raw data* after the beamforming operation, can be represented as a convolution between the *point spread function* (PSF) of the US system and the *tissue reflectivity function* (TRF). The TRF image can thus be recovered from the RF image using deconvolution algorithms. The quality of the RF image, which has an impact on the recovered TRF, is linked to the beamforming technique. In classical US systems, the delay-and-sum (DAS) method is used which results in a relatively poor quality RF image.

Recently, we have expressed a linear forward model which relates the raw data to the RF image [2]. Formally, if we denote by $\boldsymbol{y} \in \mathbb{R}^M$ the raw data and by $\boldsymbol{r} \in \mathbb{R}^N$ the RF image, we have formulated a linear operator $\mathsf{G} \in \mathbb{R}^{N\times M}$ such that $\boldsymbol{y} = \mathsf{G}\boldsymbol{r} + \boldsymbol{n}$ [2].

In this study, we propose a new method, recalled as beamforming-deconvolution framework, which bridges the gap between the two techniques described above and aims at obtaining both higher quality RF and TRF images. The direct model of the beamforming-deconvolution framework is expressed as $\boldsymbol{y} = \mathsf{GH}\boldsymbol{x} + \boldsymbol{n}$, where $\boldsymbol{x} \in \mathbb{R}^N$ stands for the TRF, $\mathsf{H} \in \mathbb{R}^{N\times N}$ represents the PSF and $\boldsymbol{n} \in \mathbb{R}^M$ is the additive Gaussian noise.

Instead of estimating the RF image and TRF sequentially, we hereby propose to recover the TRF and RF images altogether. With the US adapted assumption that TRF is general Gaussian Distributed, the corresponding ℓ_p - minimization ($p > 0$) problem is formulated as:

$$\min_{\boldsymbol{x}\in\mathbb{R}^N} \quad \alpha \parallel \boldsymbol{x} \parallel_p^p + \parallel \boldsymbol{y} - \mathsf{GH}\boldsymbol{x} \parallel_2^2 \tag{1}$$

where α is a hyperparameter. In order to avoid the computation of the inverse of G, the forward-backward splitting (FBS) algorithm with a proximal operator of the ℓ_p-norm is adopted to solve Problem (1).

We provide a basic comparison between the proposed algorithm and a sequential method, which performs beamforming and deconvolution sequentially and separately. The method of DAS is used for beamforming and the deconvolution step was processed with FBS by minimizing $\alpha \parallel \boldsymbol{x} \parallel_p^p + \parallel \boldsymbol{r} - \mathsf{H}\boldsymbol{x} \parallel_2^2$. As a preliminary investigation, we should note that the PSF for both methods was estimated in a preprocessing step. A 128-elements linear probe, with a central frequency of 5 MHz, has been simulated with Field II, a state-of-the art ultrasound simulator. The anechoic cyst shown in figure below is composed of a 8-mm diameter anechoic occlusion at 4 cm depth embedded in a medium with high density of scatterers (30 per resolution cell) and insonified with one plane wave (PW) with normal incidence. No apodization is used neither at transmission nor at reception.

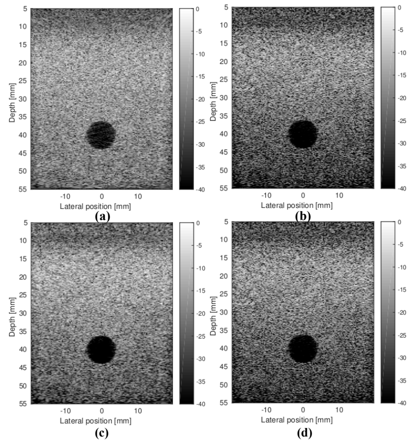

Figure 1 Comparison with a sequential method. (a) RF image with DAS (CNR=7.50 dB), (b) TRF image with sequential method (CNR=3.93 dB), (c) RF image with proposed method (CNR=7.71 dB), (d) TRF image with proposed method (CNR = 5.01 dB).

Figure 1 confirm that the proposed method is capable of recovering both high quality RF and TRF. The door from raw data to TRF is thus opened, bringing us many possibilities in the near future. On the one hand, we can perform some other post-processing techniques such as super-resolution directly to raw data. On the other hand, the compressive sampling with raw data can be introduced by including an undersampling oprator and the reconstruction of enhanced US image from compressed measurements will thus become true [3, 4]. Our future work will also include the consideration of blind deconvolution techniques with variant PSFs.

References

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