Reflection matrix approach for ultrasound tomography of speed-of-sound and multiple scattering

William Lambert[1,2], Laura Cobus[1], Mathieu Couade[2], Mathias Fink[1], Alexandre Aubry[1]
[1]Institut Langevin – ESPCI – CNRS – PSL, Paris, France,
[2]SuperSonic Imaging, Aix-en-Provence, France

Background, Motivation and Objective

Quantitative ultrasound imaging aims to provide indicators based on quantitative measurements of mechanical parameters. When such parameters are impacted by a disease, these bio-indicators become relevant candidates for assessing, monitoring and detecting the stage of the disease. For instance, non-alcoholic fatty liver diseases (NAFLD) are characterized by the accumulation of fat droplets within the liver cells. Fat tissues don't have the same speed of sound than healthy liver tissues ($c_{fat} \approx 1480\ m/s$ vs $c_{liver} \approx 1600\ m/s$). From the ultrasound point of view, those droplets are unresolved scatterers that will impact the effective speed of sound of the medium. In addition, by modifying the micro-architecture of the tissue, such a disease or any tumor are most likely to have an impact on the intensity of signals that come from multiple scattering process [1].

Statement of Contribution/Methods

In this work, a matrix approach of ultrasound imaging is developed in order to measure the medium sound speed and to assess the level of multiple scattered intensity in the ultrasound image. This method is based on the study of the reflection matrix **R** that contains all the back-scattered wave-fronts for a set of incident waves [2]. By back-propagating **R** to any focal plane in transmit and receive, a focused reflection matrix $\mathbf{R_f}$ is built between virtual transducers at each depth (fig. 1 a).

Results/Discussion

$\mathbf{R_f}$ enables a direct and local measurement of the focusing quality that can be used as a criterion (fig. 1b) for a local measurement of the sound speed (fig. 1 d). It is also well suited for discriminating multiply-scattered echoes from those that have only interacted once with the medium (fig. 1 e). Analyzing such echoes from the far-field enables the observation of a coherent back scattering peak. The latter phenomenon is a proof that extracted echoes indeed result from a multiple scattering process [3].

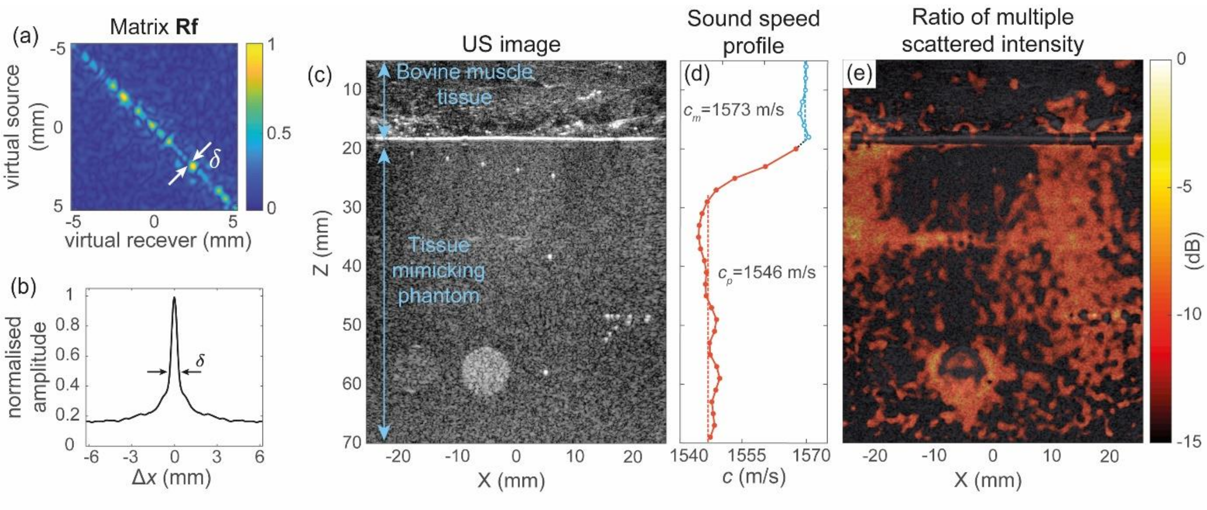

Fig. 1: Application of the matrix approach to quantitative imaging of a stratified medium. (a) Focused reflection matrix at z=30 mm. (b) Back-scattered intensity versus the distance between virtual source and recever, for z=30:32 mm. (c) Ultrasound image. (d) Sound speed profile. c_m and c_p: estimated sound speed in muscle tissue and phantom. (e) Ratio of multiple scattered intensity over backscattered intensity.

[1] K. Mohanty, J. Blackwell, T. Egan, and M. Muller, *Ultrasound Med. Biol.* **43**, **2017**, 993
[2] G. Montaldo, M Tanter, and Mathias Fink, *Phys. Rev. Lett.* **106**, **2011**, 054301
[3] A. Badon, D. Li, G. Lerosey, A. C. Boccara, M. Fink, A. Aubry, *Sci. Adv.* **2**, **2016**, e1600370