A Computational Model for Rapid Development and Testing of Ultrasound Elastography Systems: Ultrasound Simulation Framework

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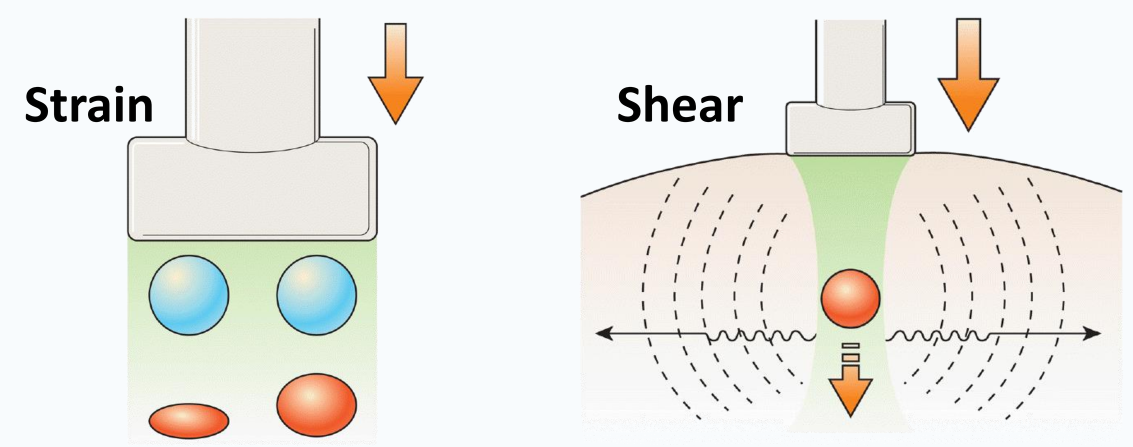
Introduction

Ultrasound elastography



In the past several years, the emerging field of ultrasound elastography has become a major tool in the evaluation of multiple diseases by allowing us to noninvasively map out the stiffness of imaged tissue. However, it faces a number of hurdles…

- Widespread clinical application is primarily limited to liver fibrosis
- Currently relies on assumptions that don't hold true in most tissues

Thus, there is an impetus to develop more robust and accurate elastographic methods, but their evaluation is currently reliant on…

- Tissue mimicking phantoms – difficult to develop and construct
- Clinical human trials – costly, with significant logistical constraints

There is a clear need for a reliable and efficient means of testing novel elastography techniques.

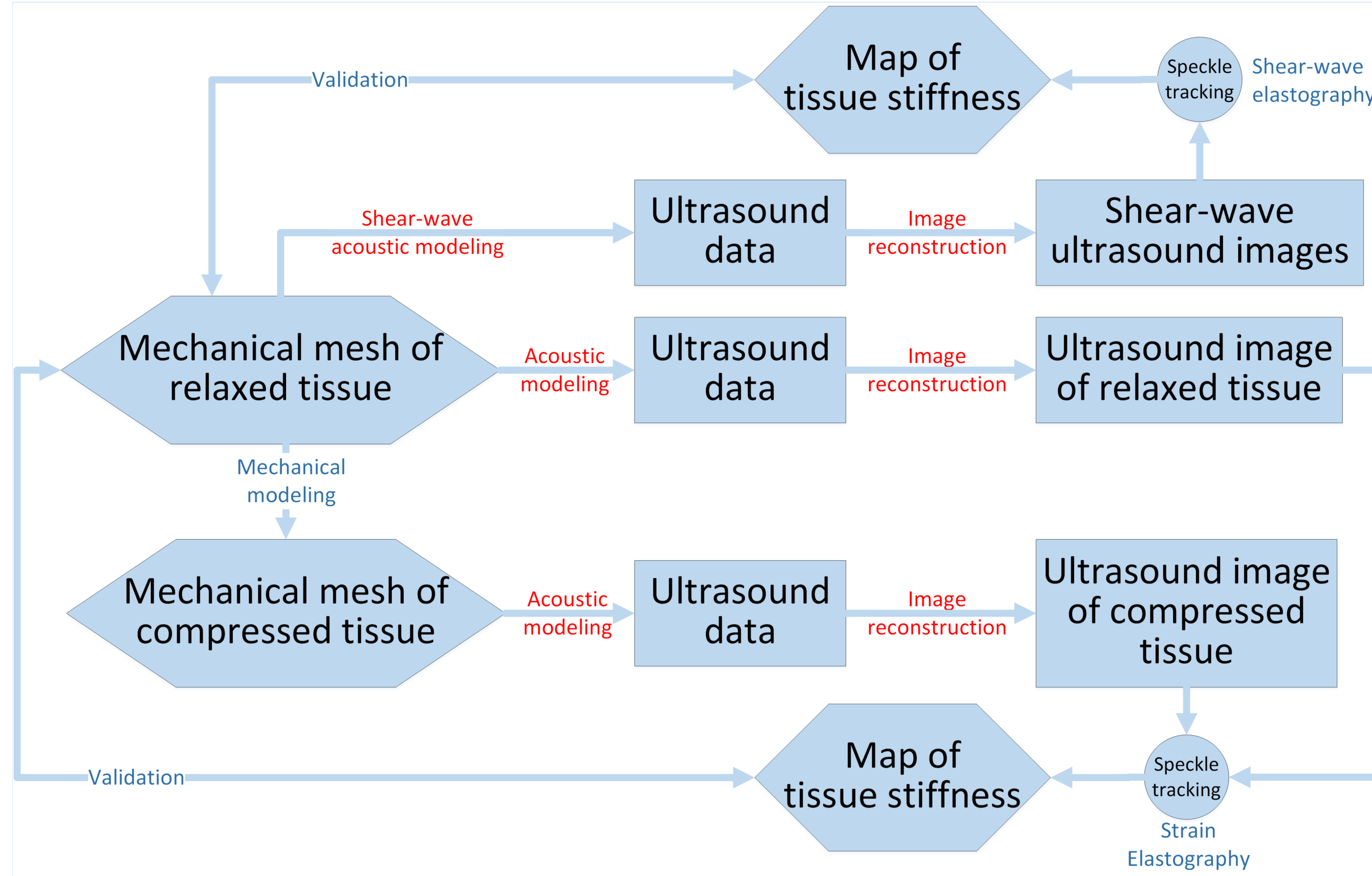
Computational modeling

Computational modeling is a powerful tool that can be used to quickly investigate elastographic phenomena *in silico*. In this project, we aim to develop a complete computational model of elastography by combining models of tissue mechanics and acoustic imaging. The resulting model can be used to simulate ultrasound elastography systems and validate their performance.

Current Development

Development of the ultrasound simulation platform is ongoing, and has thus far progressed through…

- Translation of an existing fat/glandular breast tissue phantom to an easily modified *in silico* phantom.
- Creation of a pipeline for readily generating and running *k-Wave* simulations on this phantom for incremental testing.
- Development of a versatile delay-and-sum beamformer for 2D or 3D image reconstruction from raw ultrasound data.



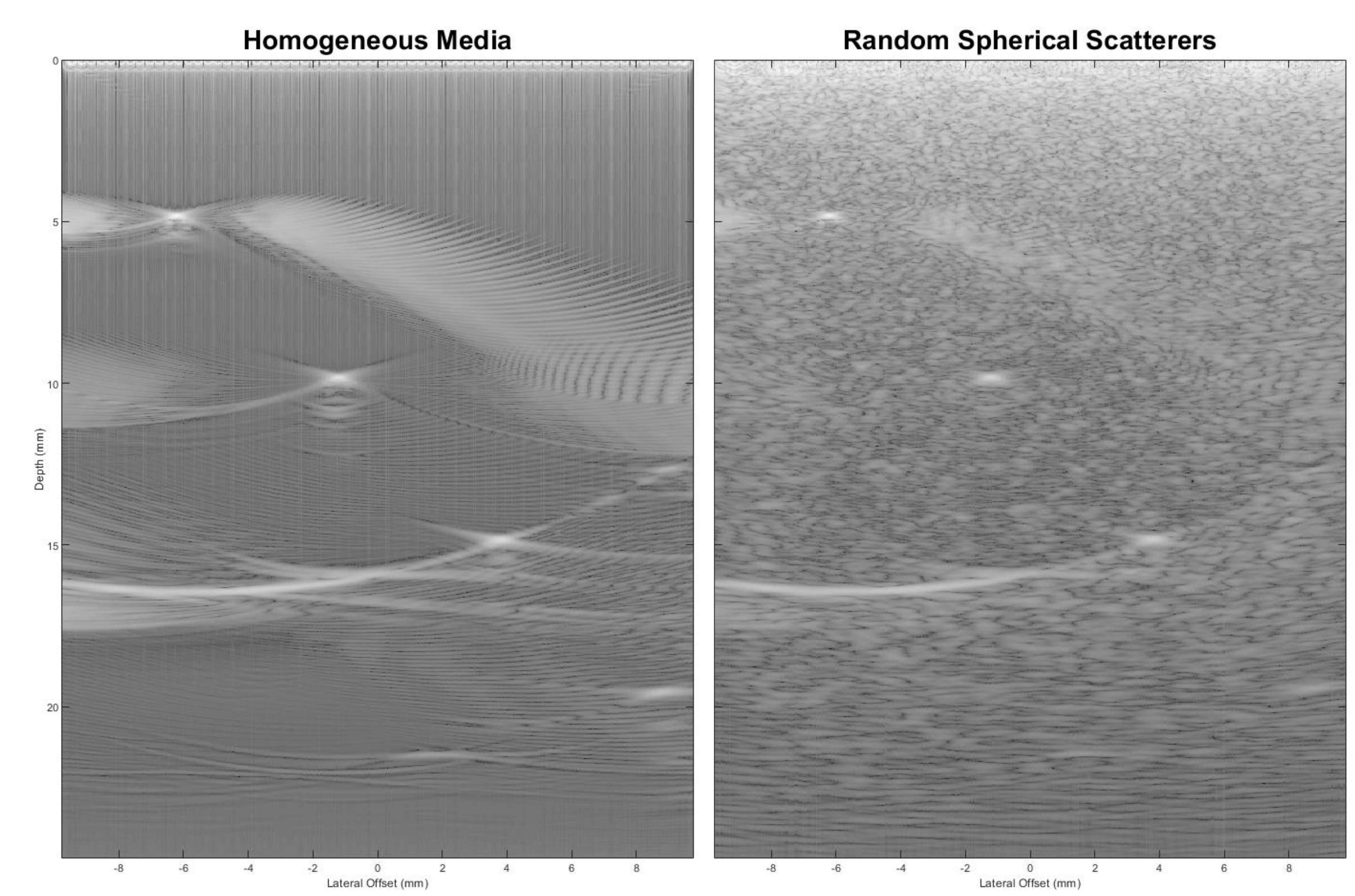
The overall end-goal of this project is a framework for validating elastographic measurement techniques *in silico*. This requires both mechanical modelling of elastic deformation, and acoustic modelling of ultrasound signal propagation. This work is focused on implementing an accurate acoustic model for strain elastography using output from the mechanical model.

Scattering and Heterogeneity

Shown to the right are images from two test simulations of ultrasound imaging, with and without the presence of randomly distributed scatterers. The simulated medium is based on a two-layer breast phantom developed here at the FDA[1] for photoacoustic imaging, which we've recreated *in silico* as a testing ground for work on the simulation. In the homogeneous case (left), the acoustic properties –implemented in terms of sound-speed and density – are uniform within each layer. Thus, the only apparent noise in the image is due to image reconstruction artifacts. In the heterogeneous case (right), a number of glass microspheres of varying sizes were randomly dispersed throughout each layer, in accordance with the physical phantom the model is based on. In this case there is clearly visible speckle, though it differs in texture and intensity from the speckle observed in actual ultrasound images of the phantom. The sparsity and uniformity of the scatterers dispersed is likely responsible for this, and work is currently progressing on a more thorough approach based on the quantitative metrics mentioned in the 'Ultrasound Modeling' section.

Ultrasound Modeling

This portion of the project is focused on developing a platform to translate the results of mechanical tissue modelling into an *in silico* acoustic phantom for ultrasound imaging simulation using the open- source software, *k-Wave*. In order to serve as a useful validation mechanism, all relevant features of clinical ultrasound imaging must be properly reflected in the simulation. The overall acoustic properties of various tissues are well-characterized in literature, and their implementation is fairly straightforward. A more significant challenge is speckle – an interference pattern due to incoherent scattering of the acoustic signal by microscale variations in the medium. Because speckle arises from tissue microstructure, it is useful for tracking tissue deformation, and is often used for this purpose in elastography. As such, proper modelling of speckle – and thus proper modelling of sub-resolution scatterers – is a necessity. Fortunately, speckle is frequently used for tissue classification in the field of quantitative ultrasound, and speckle-relevant features of the tissue microstructure – such as effective scatterer diameter and acoustic concentration – can be approximated from backscattered signals. Using typical ranges of these features for various tissue types, we can introduce sub-resolution heterogeneities to the in silico phantom that will produce realistic scattering in the acoustic simulations.



Next Steps

The next steps towards improving simulation accuracy include…

- Developing an algorithm to introduce sub-resolution scatterers throughout the simulation media that yield accurate speckle and background intensity.
- Compiling a list of typical values of quantitative speckle metrics in various tissues, and translating it into tissue-specific scatterer generation.

Once the simulation provides an accurate reflection of clinical ultrasound images, the next step would be to integrate the platform with the output of mechanical models; first in line is an open-source compressible breast phantom model also developed at DIDSR[2].

[1] Jia et al., "Two-layer heterogeneous breast phantom for photoacoustic imaging," J. Biomed. Opt. 22(10) 106011 (19 October 2017)

[2] Graff, "A new, open-source, multi-modality digital breast phantom," Proc. SPIE 9783, Medical Imaging 2016: Physics of Medical Imaging, 978309 (22 March 2016)