Student project: Seismic breast cancer screening

This project will allow you to delve into the field of medical ultrasound tomography. Seismology has provided us with a very broad and powerful toolbox to analyze and understand wave phenomena at any scale. Therefore, the application of theses methods is not limited to geophysics, but can be transferred to many different fields of research dealing with wave propagation problems. A particularly active synergy has developed between seismology and medical ultrasound (Duric et al. 2009, Hopp et al. 2019, Korta Martiatu et al. 2020). Gerhard Pratt presents a very nice overview of the differences and similarities of the two fields in (Pratt et al. 2017). In both fields of research, ultrasonic waves are used to probe an unknown medium and to acquire some data from which one would like to infer the structure of this medium. In geophysics, the medium of interest is the Earth (or some part of it), whereas in medical ultrasound one is interested in obtaining tomographic images of the human body, for instance quantitative speed-of-sound maps that display the structure of human tissue and that allow the differentiation of different tissue types.

The focus of this project is to obtain speed-of-sound maps of human breast tissue. The application is targeted at breast cancer screening with Ultrasound Computed Tomography (USCT), which is a rather new method in that domain. This is envisioned as an alternative to mammography, currently considered the state-of-the art method in hospitals. The approach to obtain a speed-of-sound map is conceptually formulated very similar to the steps involved in a seismic transmission experiment. First, travel time data between an ultrasonic source and a receiver are collected. These data are then used to invert for the speed-of-sound structure of the breast tissue. A particular challenge that one is facing with data acquired by USCT devices is that the datasets are usually very large. This has mainly two reasons, the first one being that commonly employed frequencies are much higher than what we are used to in seismology (medical ultrasound usually operates in the range of 1MHz to several tenth of MHz). Moreover, in order to be able to resolve small-scale features such as small tumors, a dense sampling of the domain is needed, which means that there are many source-receiver pairs. The challenge is then to construct a computational framework that is able to generate high quality reconstructions within a short time frame.

In this project, you will have the opportunity to explore a very interesting, but very large dataset containing transmission data from a 3D USCT scanner developed at the Karlsruhe Institute of Technology (Gemmeke et al. 2017). Figure 1 presents a sketch of the device and a close-up of the ultrasonic sources and receivers. For each source-receiver pair, a time series is recorded at a sampling frequency of 2.5 MHz. The interesting part here is that the dataset consists of *real* laboratory measurements of different tissue-mimicking breast phantoms. Furthermore, there has not been a successful attempt to reconstruct speed-of-sound images from these data. The question that we would like to answer is: what is the best image that we can obtain from the data given our knowledge about the physics of the problem and our knowledge of the geometry of the device? Therefore, the focus will lie on **inverse modelling** and finding solutions to the acoustic inverse problem. In more detail, we are interested in **testing different inversion schemes** and different formulations of the inverse problem. The latter includes the question of how to incorporate prior knowledge in the inversion problem. There has been some previous work on this topics within our group, so you won't start from zero.

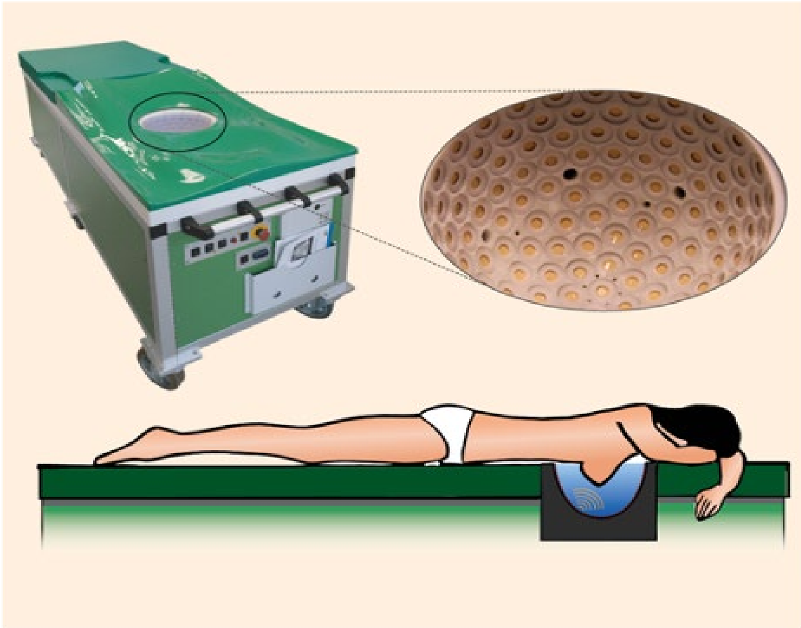

Figure 1: Sketch of the 3D scanner developed at the KIT. The close up shows the water tank in which thebreast is emersed. The ultrasonic sources and receivers are visible on the inside of the tank.

A road map for this project includes an initial phase of getting familiar with the data set and to **preprocess the data**. In a second stage, you will design **optimization schemes** that invert for the speed-of-sound of the tissue, given the observed travel time data. You are free and even encouraged to experiment also in the implementation step. If you like or have an interest in parallel computing, high performance computing and the like, then this is the stage where you can get creative and use your computation powers!

Contact: ines.ulrich@erdw.ethz.ch