Karlsruhe Institute of Technology

Transmission Tomography for 3D USCT

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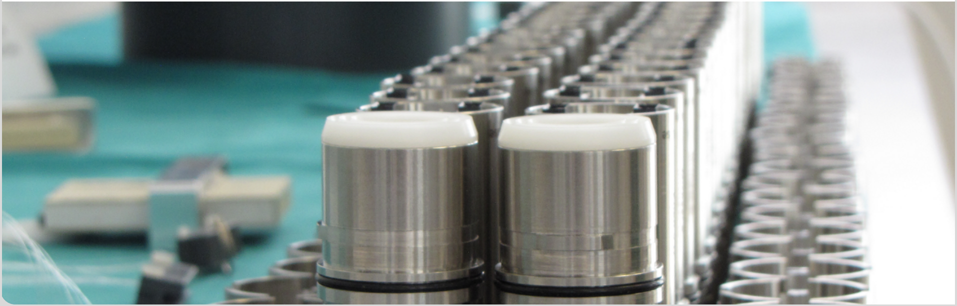
INSTITUTE FOR DATA PROCESSING AND ELECTRONICS (IPE)



3D Ultrasound Computed Tomography

- **3D USCT** – New, full 3D method for early breast cancer detection based on unfocussed ultrasound
- In contrast to established methods like MRI, CT or Mammography non-invasive, non-ionizing and inexpensive. Higher reproducibility and resolution than conventional ultrasound
- Three imaging modalities at once: Reflection, Speed of Sound and Attenuation
- Current project status: prototype operational, measurement of static phantoms successful. Clinical study with 10 patients in autumn 2012.
- Reflection tomography resolution close to theoretical limit for our system: 0.22 mm in xy, ca. 0.24 mm ±0.05 mm in z

Current System: 3D USCT II

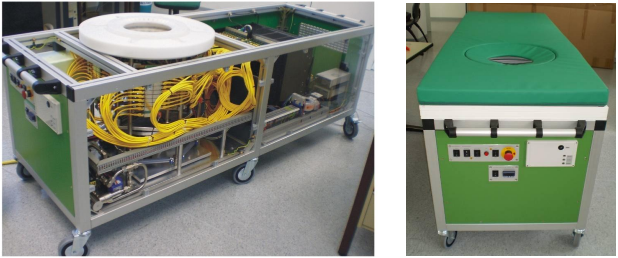


Figure : 3D USCT II w/o cover

- Second prototype 3D UCST II for clinical study

3D USCT II Measurement tank

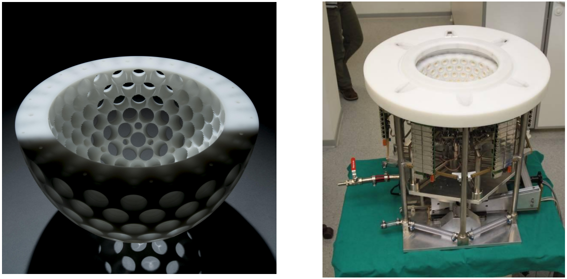


Figure : Disassembled (left) und assembled measurement ellipsoid (right), $d_{\text{top}} = 26$ cm

- 157 Transducer Array Systems (TAS), 4 Ultrasound senders and 9 receivers each, totalling 628 senders, 1413 receivers arranged in semi-ellipsoidal shape, center frequency 2.5 MHz

Signal Acquisition

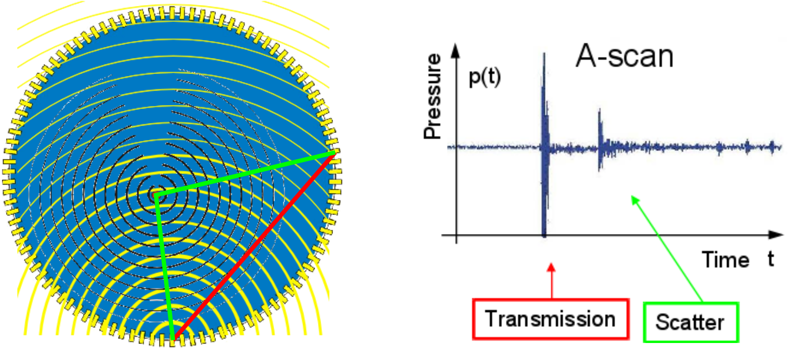


Figure : Transmission and reflection signals parts in USCT

Ultrasound Transmission Tomography

- Acoustic wave equation:

$$\nabla^2 u + k^2 u + \frac{1}{2\rho}\nabla^2 \rho u + \frac{3}{4}\left(\frac{1}{\rho}\nabla\rho\right)^2 u = 0$$

- We assume constant density:

$$\nabla^2 u + k^2 u = 0$$

- We further assume, travel time can be measured as phase difference, so $u = u_0 e^{ik_0\varphi}$:

$$ik_0 \nabla^2 \varphi - k_0^2 \left(\nabla\varphi\right)^2 + k_0^2 n^2 = 0$$

- We ignore diffraction by letting $k_0 \to \infty$ (Eikonal equation):

$$\left(\nabla\varphi\right)^2 = n^2$$

Ultrasound Transmission Tomography (2)

- Eikonal equation:

$$(\nabla\varphi)^2 = n^2$$

- From this, a line integral can be deduced

$$\varphi_{\text{receiver}} - \varphi_{\text{sender}} = \int n \, \mathrm{d}s$$

- After reformulation we obtain a formula for travel times

$$t = \int \left(\frac{1}{c(\mathbf{x})} \right) \mathrm{d}s$$

- Or in discrete space:

$$t = \sum \frac{1}{c_j} l_j$$

Linear Modelling of Travel Times

- For USCT we measure travel times T and want to reconstruct the slowness $\frac{1}{c}$ in a whole volume
- Possible by using “a lot” of integrals, i.e. senders and receivers

$$\begin{aligned} t_i &= \sum \frac{1}{c_{ij}} l_{ij} \\ t_{i+1} &= \cdots \\ &\vdots \\ T &= LC \end{aligned}$$

- **T** is a vector of travel times, **L** is a discretized model of ray propagation, **C** is the unknown slowness volume

Linear Modelling of Travel Times (2)

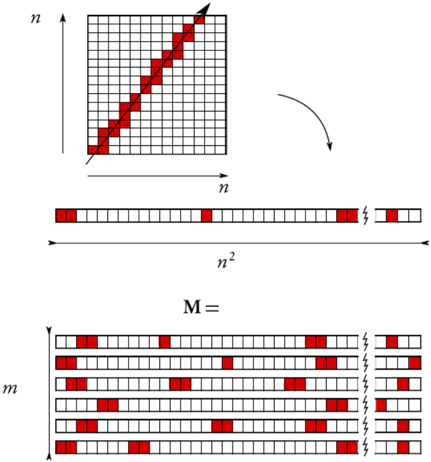


Figure : Discrete Ray Modelling

Solving the System

- We have $\mathbf{T} = \mathbf{LC}$ and want to solve for $\mathbf{C}$
- $\mathbf{L}$ is huge, approx. $3 \cdot 10^6 \times 1 \cdot 10^6$
- But: $\mathbf{L}$ is very sparse, usually $2 - 10$ GiB RAM
- Problem is ill-posed, measurements are noisy
- To solve the system we use a Lagrange optimization algorithm with Total Variation regularization (TVAL3):

$$\min_{\mathbf{C}} ||\mathbf{LC} - \mathbf{T}||_2^2 + R||\mathbf{C}||_{\text{Total Variation}}$$

Results for a Static Phantom

Figure : Triple Modality Breast Phantom (CIRS,USA)

Results for a Static Phantom

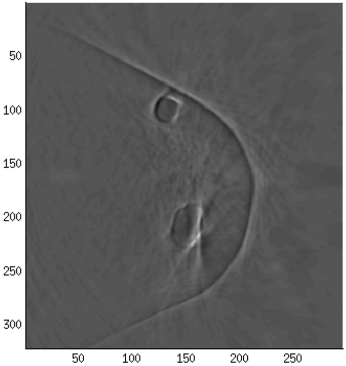


Figure : Reflection reconstruction of triple modality breast phantom

Results for a Static Phantom

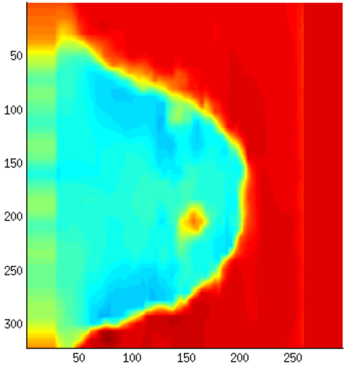


Figure : Speed of Sound reconstruction of triple modality breast phantom

Results for a Static Phantom

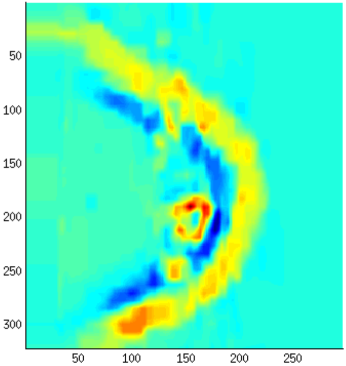


Figure : Attenuation reconstruction of triple modality breast phantom

In-Vivo Results

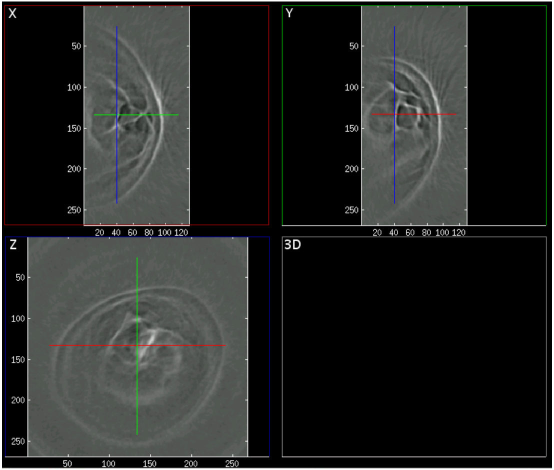
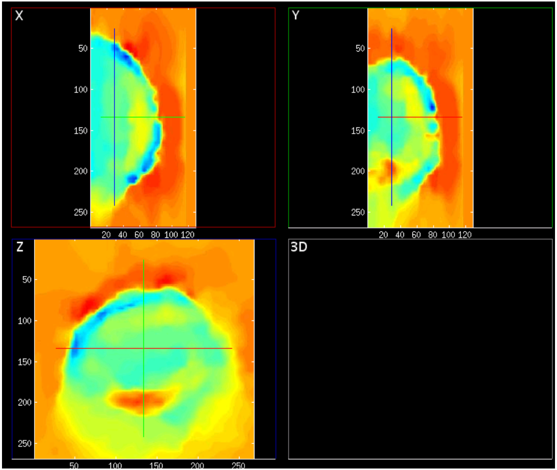


Figure : Speed of sound reconstruction of patient's breast with cancer (3 — 5 cm) from clinical study

In-Vivo Results



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In-Vivo Results (2)

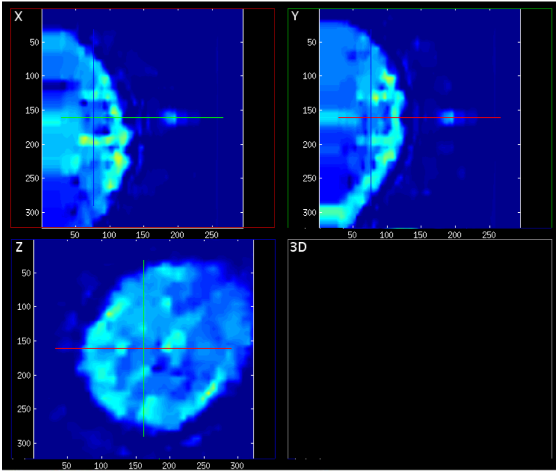

Figure : Attenuation reconstruction of healthy patient's breast

Upcoming Work

- Already working: Improve the reflection image by speed of sound estimation
- In Progress: Improve speed of sound imaging by scattering, use so-called seismologic “Banana-Doughnut” kernels
- More measurements/more data
- Improve Signal detection, seems much more important than reconstruction method
- Devise a geometry shape that is better suited to transmission tomography