Karlsruhe Institute of Technology

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3D Ultrasound Computer Tomography

Nicole Ruiter, Torsten Hopp, Michael Zapf, Hartmut Gemmeke et al.

Aim and motivation

- To build a 3D imaging device based on ultrasound for early breast cancer diagnosis

Advantages & prominent features

- Full 3D imaging ("holography") with a sparse system
- Ultrasound-based method without exposure to radiation
- No compression of the breast necessary
- Sub-millimeter resolution images
- Three different modalities at once: images of reflectivity, speed of sound and attenuation

Challenges of the 3D USCT

- Large number of ultrasound sensors for high resolution and image quality
- Low cost sensors for a low overall price
- Reproducible sensor characteristics
- High signal to noise ratio with a small active area
- High signal dynamics
- Short data acquisition time to prevent patient movement
- Large amount of raw data at high data rates
- Time consuming image reconstruction
- Phase abberation correction

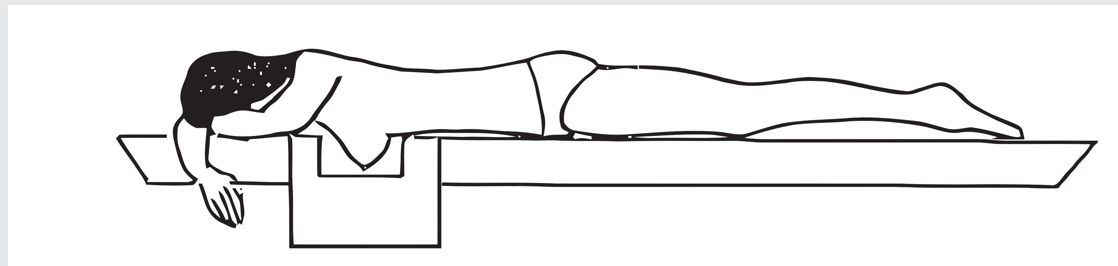
Sensor Technology

- 157 proprietary transducer array systems (TAS)
- 4 emitters, 9 receivers per TAS
- Integrated amplification,multiplexing 3
- Programmable excitation
- Reproducible and cost effective due to automatic batch production
- Sparse aperture with overall 628 emitters and 1413 receivers
- Up to 46 aperture movements resulting in 28888 virtual emitters and 64998 virtual rececivers

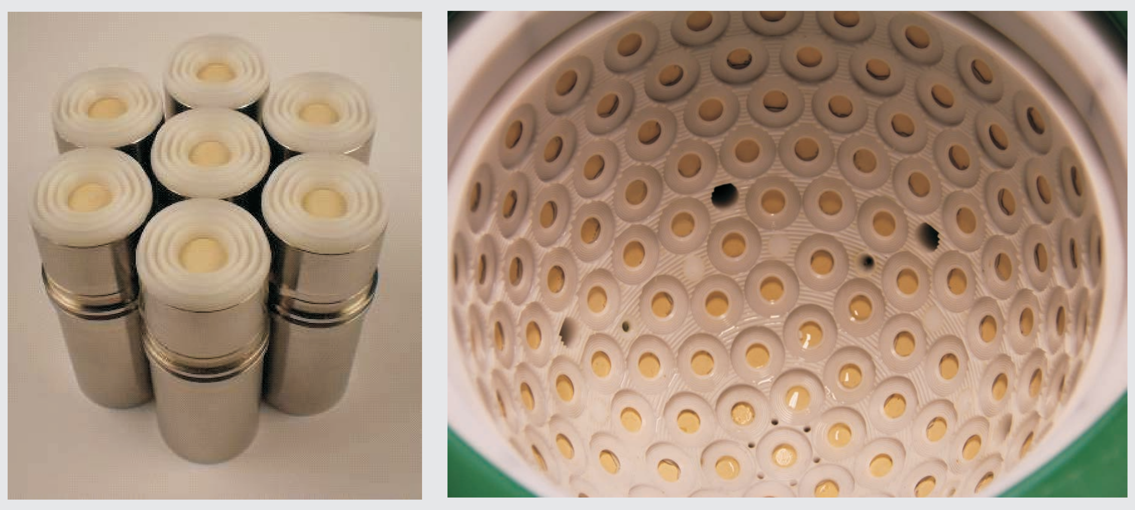
Data Acquisition

- 480 parallel channels
- 80 GB internal memory
- Data acquisition time: 10s per aperture movement

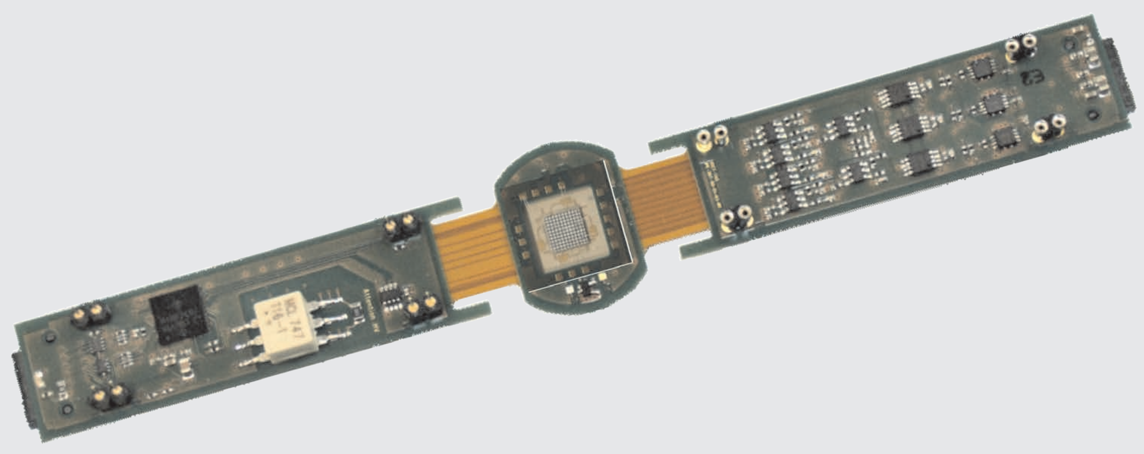
3D Ultrasound Computer Tomograph open (left) and with patient bed (right)



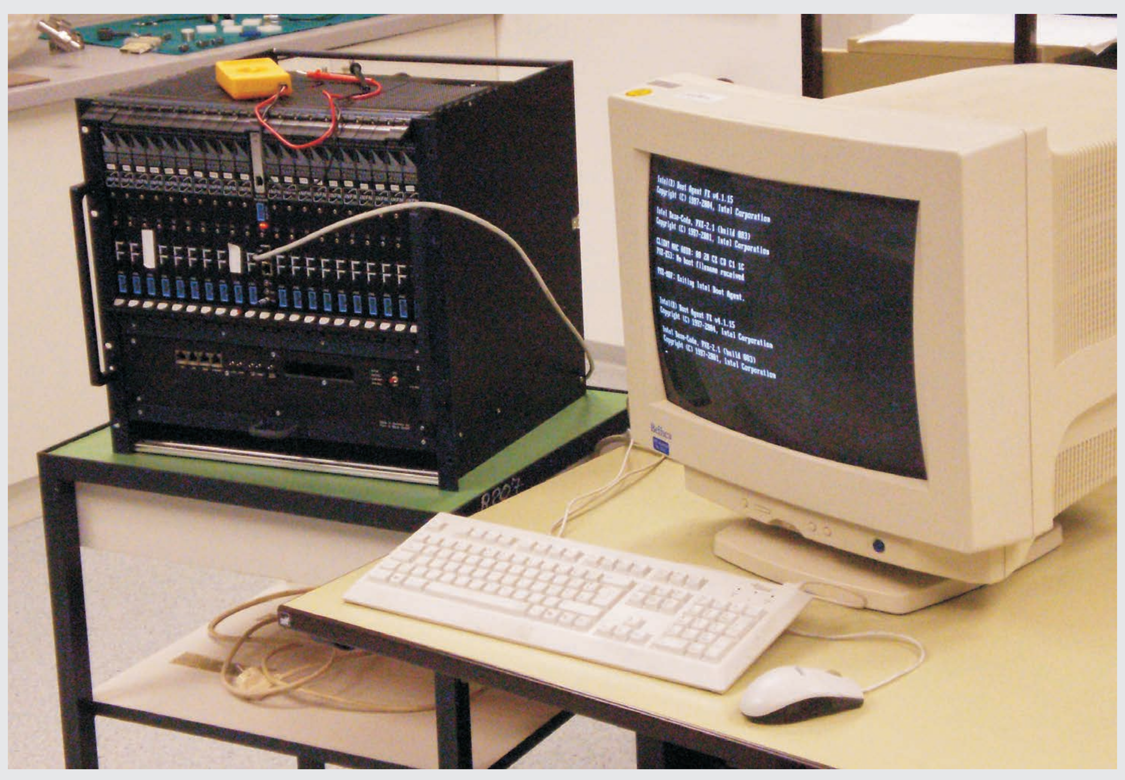
Patient positioning during examination.



Transducer Array Systems (left) and measurement basin with 157 TAS mounted on its surface.



Sensor electronic within each TAS.



Data acquisition system

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Signal processing

- Application of frequency coded chirps
- Matched filter
- Signal detection and reduction

Image reconstruction

- Reflectivity volumes: synthethic aperture focusing technique (SAFT) with speed of sound correction, 3D isotropic point spread function with maximum $(0.2\ \text{mm})^3$ resolution
- Speed of sound and attenuation volumes: total variation based numerical minimization algorithm with maximum $(2\ \text{mm})^3$ resolution

Acceleration of image reconstruction

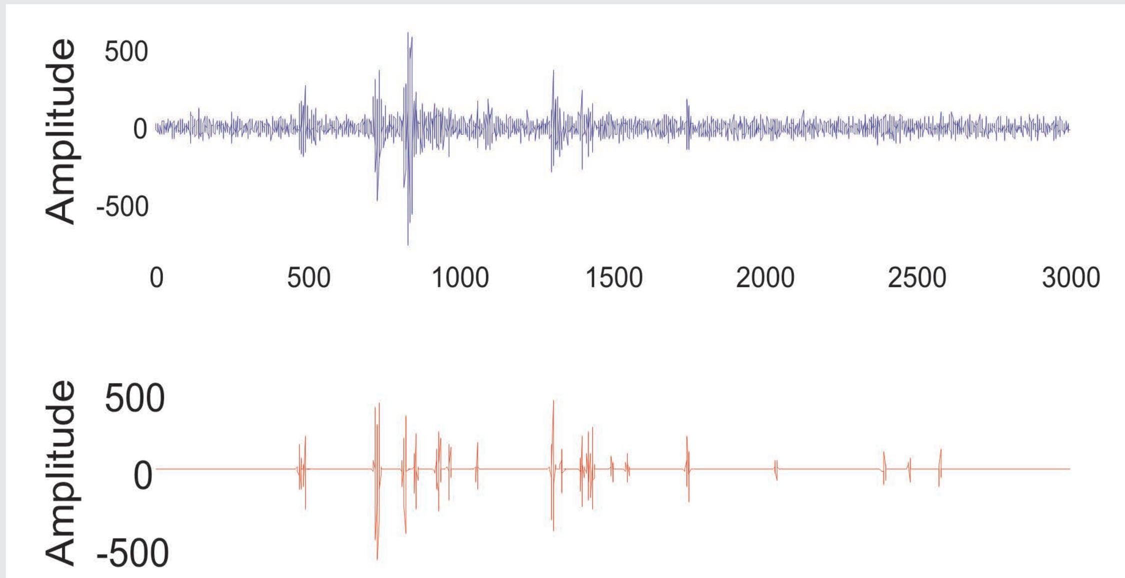
- Reuse of FPGAs in data acquisition system for signal processing
- Extension of PC with multi-GPUs
- Optimization of bottle neck data transfer
- Reconstruction core was moved to GPUs: acceleration of factor 100.
- Example: 64 slices of 1024^2 can now be calculated in 21 minutes: clinically applicable

Patents

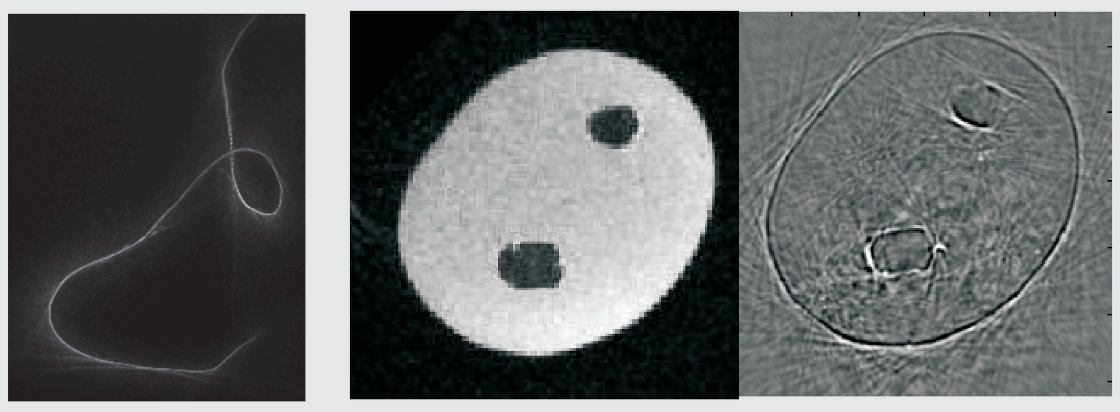
- Ultrasonic Tomograph: US.6.786.868, 2003
- Ultrasound transducers: EP 1 755 837, 2004
- Aperture Optimization for 3D Ultrasound Computer Tomography: EP 2 056 124, 2009
- Method for reconstruction of the internal structure of a sample body by means of reflection and scattering signal: EP 2539870 A2, 2011
- Method for reducing ultrasonic data: PCT/EP2012/000640 (pending)

Cooperations

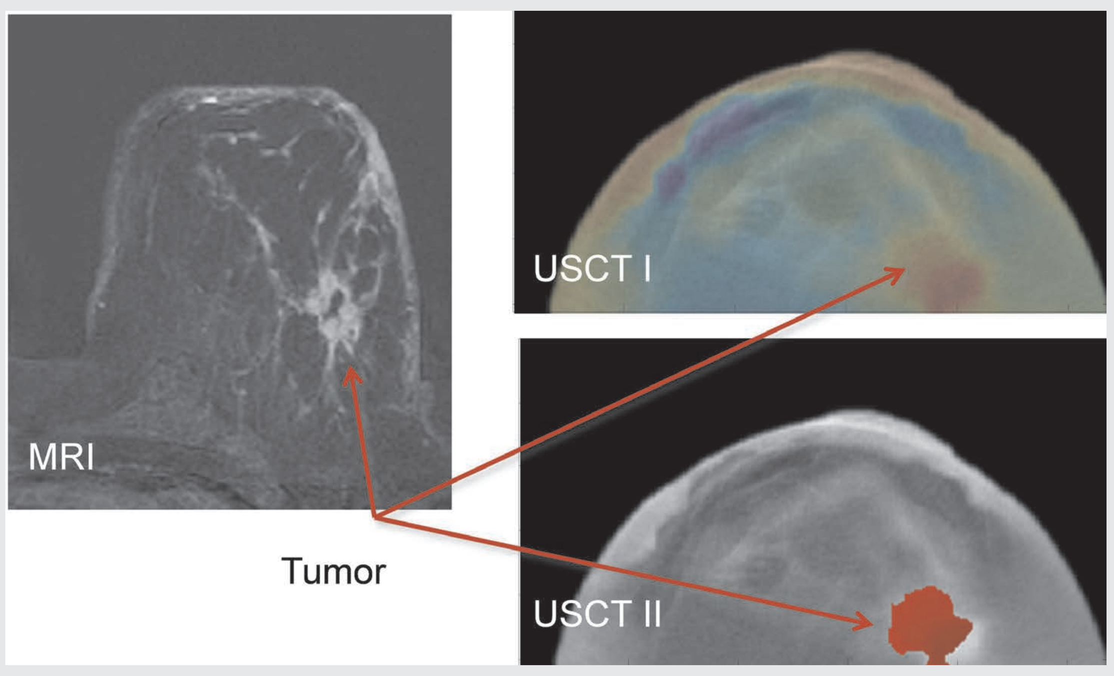
- KIT, Steinbuch Centre for Computing, Germany
- KIT, Institute for Information Processing Technology, Germany
- University Hospital Jena, Institute of Diagnostic and Interventional Radiology, Germany
- University Brno, Department of Biomedical Engineering, Czech Republic
- University Delft, Laboratory of Acoustical Imaging and Sound Control, The Nertherlands
- Karmanos Cancer Institute, USA



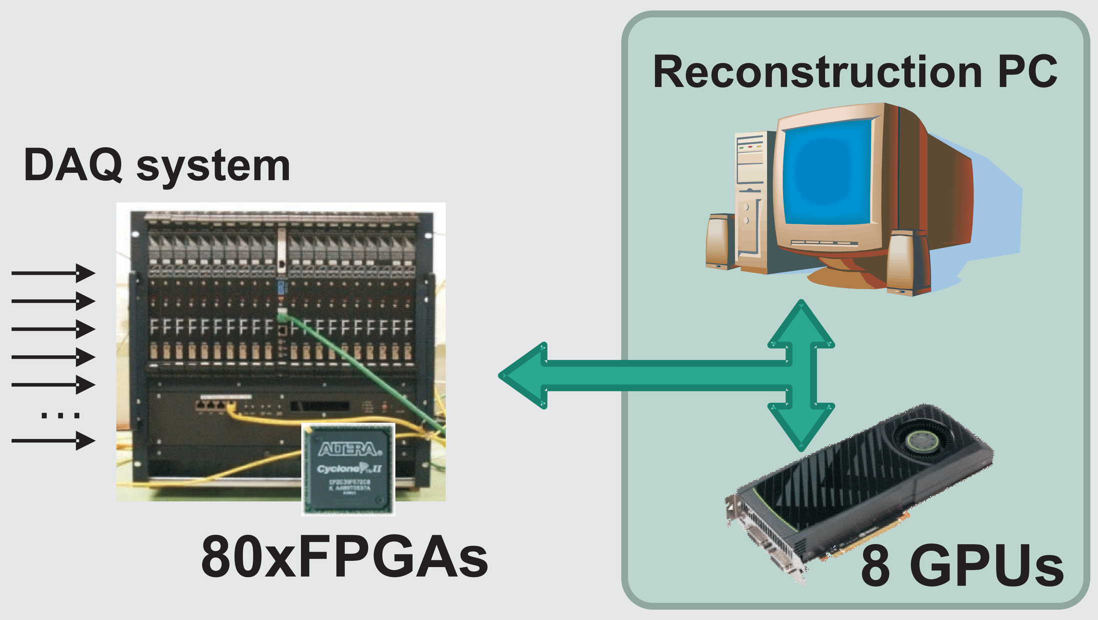
Signal Processing of A-Scans: original (blue) and result of signal detection (red).



Reconstructions of phantoms: maximum intensity projection of a 0.07 mm thread with $(0.2)^3$ mm point spread function (left). Clinical breast phantom in MRI (middle) and USCT (right).



Clinical case: MRI slice of a 64 year old patient with a large tumor (left) and fused multimodal USCT images (right).



Third generation of the USCT hardware includes FPGAs and GPUs for acceleration of the signal processing and image reconstruction

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