Ultrasound computer tomography for breast cancer diagnosis

Rainer Stotzka, Tim O. Müller, Klaus Schlote-Holubek, Hartmut Gemmeke

Forschungszentrum Karlsruhe, Institute for Data Processing and Electronics, Germany
Phone: +49 7247 82-4738, email: rainer@stotzka.de

Purpose: Ultrasound is the most available and most frequently used diagnostic imaging modality. In breast cancer diagnosis, ultrasound examination provides useful additional diagnostic information. Moreover ultrasound does not harm biological tissue and can be applied frequently. But conventional ultrasound imaging methods lack both high spatial and temporal resolution. The contrast and the resolution depend highly on the frequency used, as well as on the distance between the transducer array and the region of interest within the breast. Usually, the scanner is operated manually and the tissue is deformed while getting as close as possible to the region of interest. Therefore, image content and quality depend strongly on the operator. Exact measurement of tissue structures, like tumor size, is not possible.
The intention of the development of ultrasound computer tomography is to increase the reliability of ultrasound imaging and to supply standardized images similar to other imaging modalities like computer tomography (CT) and magnetic resonance imaging (MRI).
At Forschungszentrum Karlsruhe, we are developing an ultrasound computer tomography system for breast imaging.

Methods and Materials: Ultrasound computer tomography (USCT) is a new imaging method which allows the recording of reproducible images with higher resolution and tissue contrast [1,2]. In conventional ultrasound imaging a linear transducer array is operated manually and only the tissue reflections are recorded.
In USCT the transducers are arranged in a fixed geometry (figure 1) around the object to be examined. For breast examinations the breast is placed in a tank filled with water as coupling medium. The transducers are mounted in a cylindrical array at the tank walls.

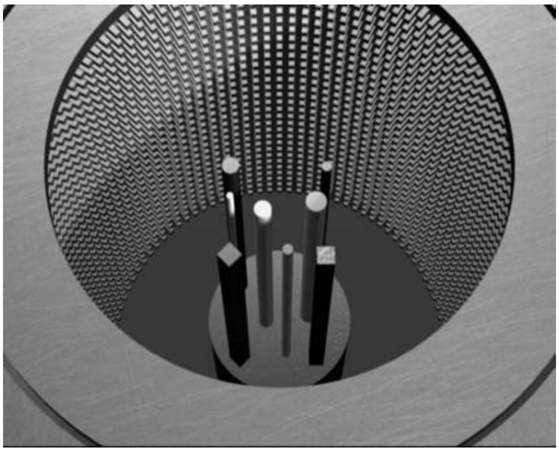

FIGURE 1: Fixed arrangement of transducers for 3D ultrasound computer tomography. The transducers are arranged in a cylindrical array around a tank containing the object and water as the coupling medium.

One transducer is acting as transmitter and emits a short pulse, which is scattered by the structures inside the object. Every transducer is small, emitting a nearly undirected beam (spherical wave front). All other transducers measure the transmitted, reflected and scattered signals (A-scans) simultaneously. The received signals are amplified, digitized and stored. Then the next transducer will transmit an ultrasound pulse while all others receive the signals and so on. Figure 2 shows the ring architecture of a two-dimensional ultrasound computer tomography system and an A-scan of one receiving element.

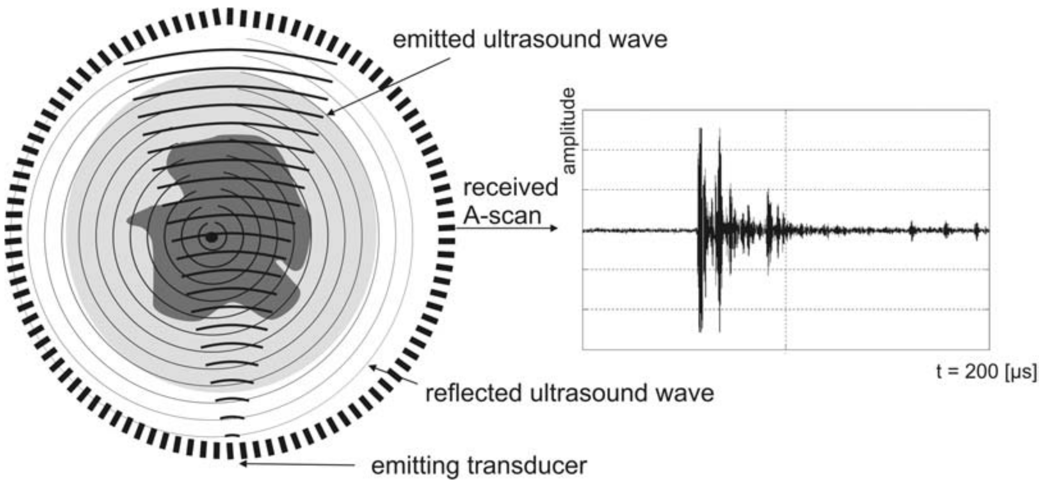

FIGURE 2: Architecture of the USCT system built in our institute, shown in 2D. A ring (cylinder) of ultrasound transducers encloses the object (left). One transducer emits a short ultrasound pulse, all other transducers receive simultaneously. The A-scan at the right side shows the directly transmitted and scattered signals.

We have built an experimental setup to evaluate a multi-sensor system which regards transmitted, scattered and reflected waves at the same time.. It consists of two transducer arrays (2.5 MHz) in a water tank, a pulse generator, an amplifier and a digital data acquisition system connected to an external computer. The signal processing and image reconstruction is done by the computer. Both transducer arrays can be positioned independently on the ring to emulate a full circular array (1600 elements, diameter 12 cm). An array consists of 16 elements each 0.2 mm wide, 10 mm high with a pitch of 0.25 mm. One array is used as the emitter, the other as the receiver. Every receiving element is treated separately. For every emitter position, all possible receiver positions on the circle are evaluated and the correspondent signals are recorded successively.
Based on the data recorded by our experimental setup we are able to reconstruct two-dimensional tomographic images. The reconstruction is based on a full aperture sum-and-delay algorithm [1] on the assumption of constant sound speed in the water and the object. Furthermore, no corrections of the angle-dependent sensitivity of the transducers have been applied.

Results: Since the measuring time for the simple prototype takes up to 10 hours, we needed fixed phantoms mimicking biological tissue. We created several phantoms from of a galantine and olive-oil emulsion with straws and threads as inner structures.
The whole imaging system is two-dimensional in a cylindrical slice with a height of about 1 cm and a diameter of 12 cm . For the phantom, we built a model sketched in figure 4 which we submerged inside a plastic cup with very thin walls. The smallest structures within the phantom are nylon threads with a diameter of 0.1 mm each, corresponding to approximately 0.2 wavelengths of the emitted ultrasound signal.
We have recorded the ultrasound signals of the phantom for 100 emitter positions and 1440 receiving positions each, gathering approximately 5 GBytes ultrasound data. Figure 3 shows the results of an image reconstruction. Two different types of images can be reconstructed: one using only the amplitude information of the scattered signals and the other including the phase information. Amplitude images show high contrast and low noise but their image resolution is limited to the length of the ultrasound pulse (approx. 1 - 1.5 mm). By inclusion of phase information the quality of imaging allows the visualization of structures as small as 0.1 mm, but the overall image is getting noisy.

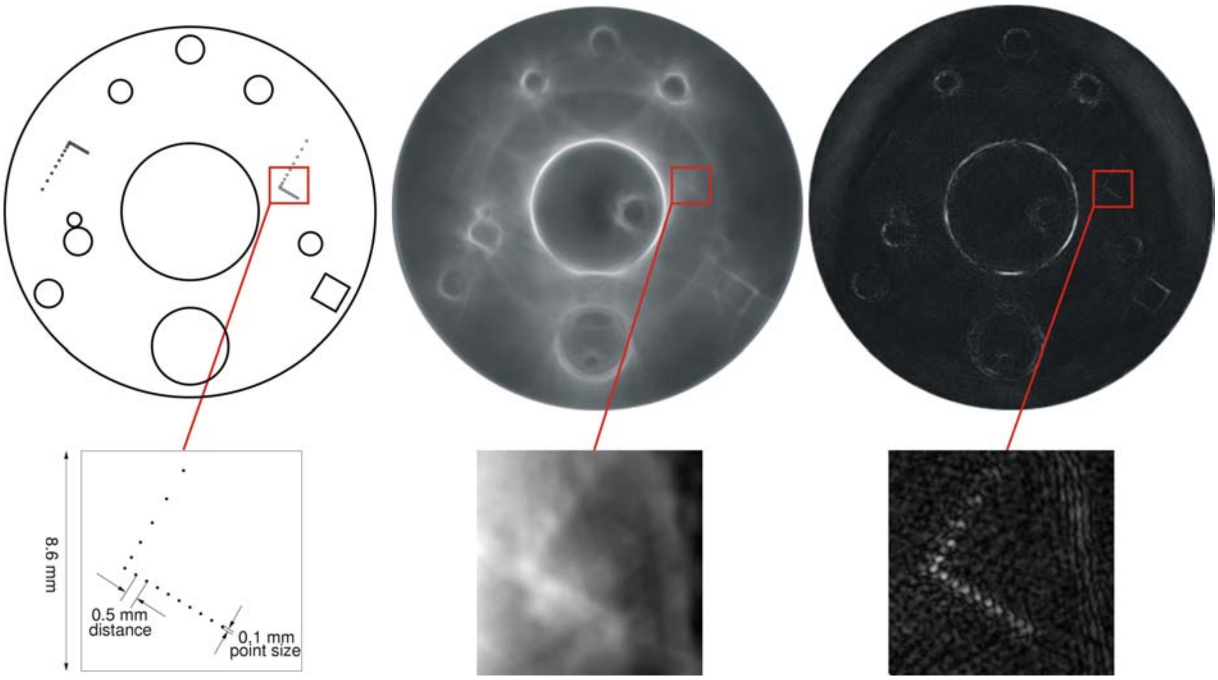

FIGURE 3: Phantom and reconstructed images. Left: Rough plan of the phantom. The diameter is 8.5 cm. The smallest structures consist of nylon threads with a diameter of 0.1 mm and a spacing of 0.5 mm shown in the region enlargement below. Middle: Reconstruction using only amplitude information. Right: Reconstruction including phase information. The nylon threads are clearly visible.

Conclusions: Ultrasound computer tomography allows an operator independent and 3-dimensional imaging of tissue structures. The reconstructed images are of superior quality in comparison to common ultrasound imaging systems. More detailed structures are visible and there are no shadows hiding the view of remote tissue features. A measurement of geometric structures is possible with an accuracy of approximately 0.25 mm.

In future we will set up cylindrical geometry consisting of 1920 transducer elements [4] and a parallel data recording system to image biological tissue in vivo. Applied to breast tissue, ultrasound computer tomography promises high quality three-dimensional images without ultrasound shadowing artifacts. For the first time the premises for multimodal registration of 3D ultrasound images to other imaging modalities are fulfilled. It is now possible to register US images of the breast to MRI, CT and positron emission tomography or even X-ray mammograms using our algorithm proposed in [3].

[1] R. Stotzka, J. Würfel, T. Müller. Medical imaging by ultrasound computer tomography, in SPIE's Internl. Symposium Medical Imaging 2002, pp. 110 - 119, 2002

[2] M. Ashfaq, H. Ermert. Ultrasound spiral CT for the female breast: First phantom imaging results, in 35. Jahrestagung der Deutschen Gesellschaft für Biomedizinische Technik, 2001.

[3] T. Müller, N.V. Ruiter, R. Stotzka, H. Gemmeke, J. Reichenbach, W. Kaiser. Model based fusion of X-ray mammograms and MR-volumes of the female breast, Third Congress on MR mammography 2003, 2003.

[4] R. Stotzka, G. Göbel, K. Schlote-Holubek. Development of transducer arrays for ultrasound-computertomography, SPIE's Intern. Symposium Medical Imaging 2003, 2003.