A NEW 3D ULTRASOUND COMPUTER TOMOGRAPHY DEMONSTRATION SYSTEM

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Abstract— *Ultrasound computer tomography is a new imaging method capable of producing volume images with both high spatial and temporal resolution. The promising results of a 2D experimental setup of an ultrasound computer tomography system with at least 0.25 mm resolution encouraged us to build a new 3D demonstration system.*
It consists of three parts: a tank containing the sensor system, a data acquisition hardware and a computer workstation for image reconstruction and visualization.

Keywords— *Ultrasound, computer tomography, breast cancer, transducer, image reconstruction*

Introduction

Ultrasound computer tomography (USCT) is a new medical imaging method which allows the recording of reproducible images with high resolution and tissue contrast [1-4]. In conventional ultrasound imaging a linear transducer array is operated manually and only the reflections are recorded. In USCT the object is placed in a tank filled with water as coupling medium. The tank walls are covered with transducers in a fixed geometry (fig. 1), building a cylindrical array surrounding the imaged object.

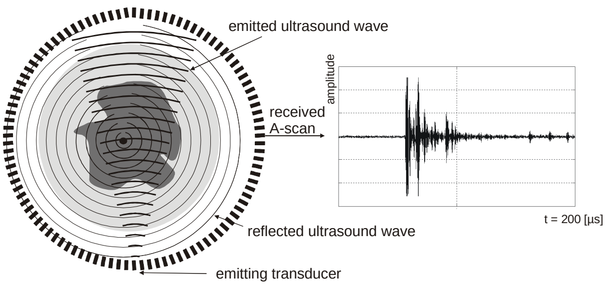

Figure 1: Architecture of the USCT system built in our institute, shown in 2D. A ring of ultrasound transducers encloses the object (left). One transducer emits a short ultrasound pulse, all other transducers receive simultaneously. The A-scan (right) shows the directly transmitted and scattered signals.

One transducer acts as a sender and emits a short pulse which is scattered by the structures inside the object. Every transducer emits 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 a different transducer will emit an ultrasound pulse while all others receive the signals and so on. Fig.1 shows the ring architecture of a two-dimensional ultrasound computer tomography system and an A-scan of a receiving element
At Forschungszentrum Karlsruhe we built a 2D experimental setup [4] which regards transmitted, scattered and reflected signals at the same time. We created several phantoms from a galantine emulsion with straws and threads as inner structures. The whole imaging system is two-dimensional in a cylindrical slice with a height of approx. 1 cm and a diameter of 12 cm. For the phantom, we built a model as sketched in fig. 2 which we submerged inside a plastic tube 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.

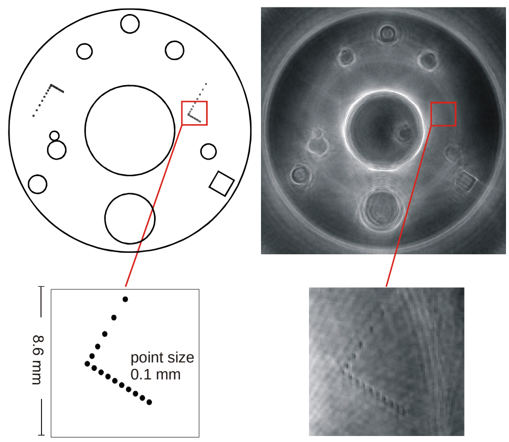

Figure 2: Phantom and reconstructed images. Left: Rough blueprint of the phantom. The diameter is 8.5 cm. The smallest structures consist of nylon threads with a diameter of 0.1 mm and a spacing of 0.5 mm shown in the region enlargement below. Right: Reconstructed cross-section. The nylon threads are clearly visible.

We recorded the ultrasound signals of the phantom for 100 emitter positions and 1000 receiver positions each, gathering approximately 5 GBytes ultrasound data. The signals were preprocessed using a low-pass filter and a blind deconvolution method similar to Jensen [5] to sharpen the scattered signals.
The reconstruction itself is based on a full aperture sum-and-delay algorithm 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. Fig. 2 shows a reconstructed cross-section of the phantom. The nylon threads with a diameter

of 0.1 mm and a spacing of 0.5 mm are clearly visible and discernible, resulting in a spatial resolution superior to 0.25 mm.
Since the measuring time for the experimental setup takes up to 10 hours, it is not possible to image living biological tissue. Yet the promising results encourage us to develop a new ultrasound computer tomography demonstration system which is capable to record the ultrasound data in real-time and in three dimensions.

The 3D demonstration system

The new 3D ultrasound computer tomography system consists of three parts: a tank containing the sensor system, a data acquisition hardware and a computer workstation.

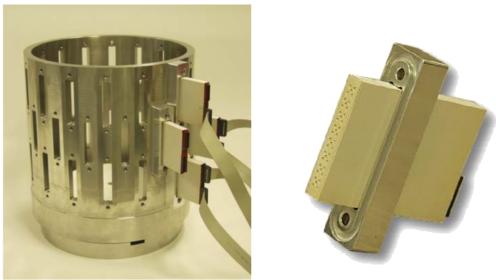

Figure 3: Tank with connected transducer array systems (left) and single transducer array system (right) made in Forschungszentrum Karlsruhe

The tank has a diameter of 18 cm and a height of 15 cm. 48 transducer array systems will be mounted into the tank walls carrying each 32 receiving and 8 emitting elements. The transducer elements can be accessed individually. The resulting cylindrical array will be rotated in 6 steps to fill the gaps between the transducers. Thus a fully covered cylindrical array will be emulated, resulting in a total of 9216 receiver and 2304 emitter positions. The received signals and the control signals are gathered in four blocks containing preamplifiers, address generation and control logic.

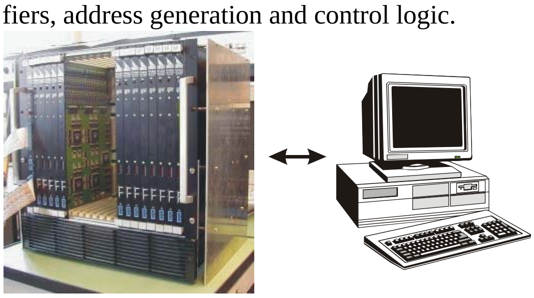

Figure 4: Data acquisition system with 192 parallel channels. The recorded data is transferred to a computer workstation for image reconstruction.

The data acquisition electronics is a modified design of the system for the Auger fluorescence detector [6]. It is based on 9 9HE-card boards connected by a modified VME-bus. One board controls the data acquisition process, the data storage and the transfer to the computer workstation. The other 8 boards are carrying 24 data recording channels each. A channel consists of the analog signal processing, an A/D converter (10 MHz, 12 Bit) and the digital signal processing. The digital processing is based on an array of four FPGAs executing the online data storage, noise reduction and simple data reduction.
While one emitting transducer is activated with coded excitation, all receiving transducers receive simultaneously the scattered signals. 192 channels are sampled and recorded in parallel. 48 multiplexing steps are needed to record an A-scan from every receiver. The data is transferred to a computer workstation and the next emitting transducer is selected. The data storage, the image reconstruction and the visualization of the results are accomplished on the computer workstation.

Discussion

Our new 3D ultrasound computer tomography demonstration system is currently under construction. The ultrasound transducer array systems are designed and currently manufactured in our hybrid laboratory. The almost entire automatic manufacture process guarantees high quality and high reproducibility of the transducer characteristics (±2%) and low costs (~100 € per transducer array system including front-end electronics).
The development of the data acquisition boards and the corresponding control software will be completed in summer 2004. The reconstruction algorithms for 3D ultrasound computer tomography are already implemented in Matlab.
In summer 2004 we start our first measurements. The data recording for a quick cross section consisting of 96 different emitting positions and 60 receiving positions each will take less than 15 seconds. This quick mode will allow to image living biological tissue.
The signal-to-noise ratio of the A-scans will be increased significantly by the embedded amplifiers of the new transducer array systems. The decreased number of recorded A-scans (compared to the 2D experimental setup) will lead to a reduced image quality, but will be partly compensated by the higher quality of the recorded signals.

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