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Imaging results of multi-modal ultrasound computerized tomography system designed for breast diagnosis

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ABSTRACT

Nowadays, in the era of common computerization, transmission and reflection methods are intensively developed in addition to improving classical ultrasound methods (US) for imaging of tissue structure, in particular ultrasound transmission tomography UTT (analogous to computed tomography CT which uses X-rays) and reflection tomography URT (based on the synthetic aperture method used in radar imaging techniques). This paper presents and analyses the results of ultrasound transmission tomography imaging of the internal structure of the female breast biopsy phantom CIRS Model 052A and the results of the ultrasound reflection tomography imaging of a wire sample. Imaging was performed using a multi-modal ultrasound computerized tomography system developed with the participation of a private investor. The results were compared with the results of imaging obtained using dual energy CT, MR mammography and conventional US method. The obtained results indicate that the developed UTT and URT methods, after the acceleration of the scanning process, thus enabling *in vivo* examination, may be successfully used for detection and detailed characterization of breast lesions in women.

1. Introduction

The most widely applied diagnostic tests used for early detection of breast cancer lesions currently include palpation (manual), X-ray mammography, ultrasonic B-mode imaging (US), and magnetic resonance (MR) mammography [1]. In the case of suspected malignancy of the breast cancer, cytology or histopathological examination is performed on material obtained through biopsy. There are other diagnostic methods which can be used for preventive examinations of breast, such as [2]: elastography (USE), thermography, electrical impedance tomography (EIT), single photon emission computed tomography (SPECT) and positron emission tomography (PET). In particular, ultrasound transmission tomography (UTT) and reflection tomography (URT) may be used for imaging and early detection of neoplastic lesions of female breast [2–7]. Recently, several research centres around the world (including the Laboratory of Ultrasound Technology at the Chair of Acoustics and Multimedia at the Faculty of Electronics, Wroclaw University of Technology) carry out work to build a prototype of the ultrasound computer tomography device for breast screening imaging tool in women (with the ability of *in vivo* scanning, measuring, data acquisition, image reconstruction and processing) [2–12]. The design, operation and imaging methods of each device are specific and varied.

The group of Nebojsa Duric and others (Karmanos Cancer Institute, Detroit, USA) [4] has developed the Computed Ultrasound Risk Evaluation (CURE) prototype with the vertical moved ring-shaped ultrasonic transducer array (consisting of 256 elements used ultrasound frequency of 1.5 MHz), which surrounds female breast submerged in a water tank. The CURE system is capable to provide two types of UTT images (the speed of ultrasound and the ultrasound attenuation), and two types of URT images performed by migrating the time-dependent signals and their envelopes.

The group of Nicole Ruiter and others (Karlsruhe Institute of Technology, Karlsruhe, Germany) [5,9,10] is working on 3-D Ultrasound Computer Tomograph (USCT) in two versions, with the sparse-aperture 3-D ultrasonic transducer array of a cylindrical shape [9], and a semi-ellipsoidal shape [10]. Both of these systems

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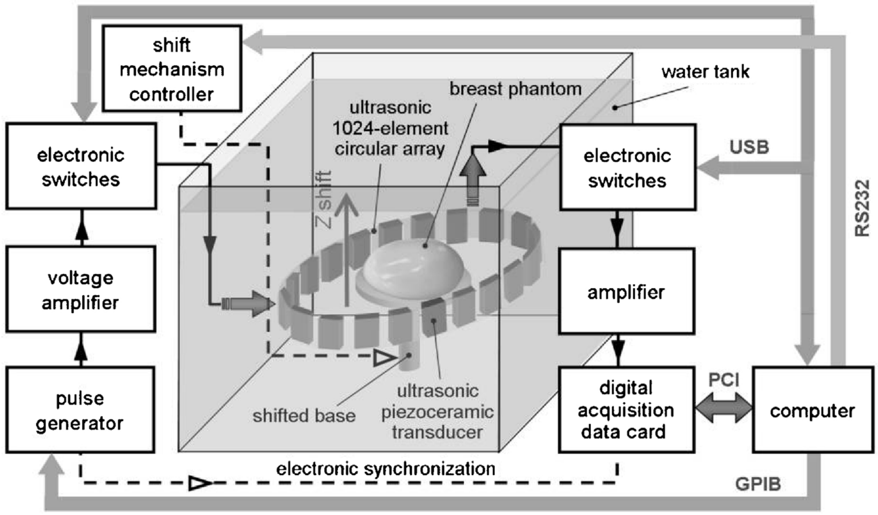

Fig. 1. Block diagram of the developed multi-modal ultrasound computerized tomography system.

are equipped with many advanced assembled transducer array systems (TAS) [5,9]. The 3-D USCT I system consists of 48 transducer arrays arranged equidistantly in three parallel circles on the inner cylindrical aperture filled with water. Each array consists of eight transmitter- and 32 receiver-transducers. The aperture can be rotated to increase the number of transducer positions. The 3-D USCT II is equipped with 628 ultrasound senders and 1413 receivers, grouped into 157 transducer array systems, mounted at the inner semi-ellipsoidal surface of the measurement basin [10]. The aperture can be rotated and lifted in arbitrary steps. Pulses of 2.4 MHz center frequency are applied for both USCT systems. The USCT systems can operate with the same imaging modalities as the CURE prototype.

The group of Michael Andre, Steven Johnson, James Greenleaf and others (TechniScan, Inc., Salt Lake City, USA) [6] has developed clinical prototype of Computerized Volumetric Ultrasound System (CVUS) consists of a circular water tank with the tri-arm containing the linear transmitter array, the linear receiver array (with 1536 elementary transducers operating at a frequency of 1 MHz), and the three linear reflection arrays (with 192 elements) focused at 2.5, 4 and 7.5 mm and operate at a frequency of 6 MHz [6,12]. The scanner can provide data in both transmission and reflection mode using several imaging arrays. All arrays are mechanically rotated describing a full circle. The transmission mode data are acquired with two arrays (the transmission and the receiving one) facing one another at opposite sides of the tank and operating at a nominal center frequency of 1 MHz. The data were used for constructing tomographic images of speed of ultrasound. The reflection mode data are acquired with three arrays located at approximately 45°, 90° and 135° from the transmitter array.

The group of Vasilis Marmarelis, Jeong-Won Jeong and others (Alfred E. Mann Institute for Biomedical Engineering of University of Southern California, Los Angeles, USA) [11] has developed an experimental prototype of the High-resolution Ultrasonic Transmission Tomography (HUTT) system, which employs transmit-receive pairs of linear ultrasonic arrays by which the data collection is performed in transmission mode over successive elevation planes. The arrays are rotated around and moved vertically along an examined breast submerged in a water tank. In order to reduce scanning time, several elementary transducers of the transmitting and the receiving array are simultaneously activated. The concept of orthogonal coding (code-division multiplexing) is utilized to alleviate problems arising from cross-talk between different transmit-receive elements. Because of wide band ultrasonic transducers, which operate at 8 MHz center-frequency, the HUTT system provides a set of 2-D tomographic images (termed multi-band images) corresponding to the various frequency bands of interest at each elevation plane. This set of images provides the potential capability of "multi-band" analysis of the constituent parts of the image for the purpose of tissue differentiation.

This paper presents and analyses the results of ultrasonic tomography transmission imaging of the internal structure of the female breast biopsy phantom CIRS Model 052A (designed to train biopsy assisted with ultrasonic B-mode imaging) and the results of the ultrasonic tomography reflection imaging of the wire sample cross-section. Imaging was performed using a multi-modal ultrasound computerized tomography system developed with the participation of a private investor [8]. The results were compared with the results of imaging using dual energy CT (X-ray Computed Tomography), MR mammography, and conventional US method (B-mode scanning). Such comprehensive comparison is hard to find in the world-wide literature, because of difficulties associated with measurements of the same phantom using different expensive imaging systems with different scanning methods, in different locations. It requires the cooperation of several medical and technical centers. Particular aspect of novelty in our paper is to present the possibility of ultrasound tomography imaging in comparison to other known and used methods in relation to the breast tissue examination. The advantages of our system is very good compromise between high quality images and simple and short scanning time, fast data acquisition, signal processing and image reconstruction, as well as ultrasonic transducer array and electronics are not so expensive and not very difficult to mass production. Our methods, algorithms and system have been developed since 1993. Finally, a very important advantage is multi-modality, which can be realized using the same electronics: three UTT sub-modalities [7,8], URT modality, classical real-time US imaging from sectors around breast cross-section and automated full angle ultrasound spatial compound imaging (FASCI) [13].

2. Materials and methods

2.1. Measurement setup

Block diagram of the developed multi-modal ultrasound computerized tomography system is shown in Fig. 1.

Circular array of piezoelectric transducers [14,15] with the internal diameter of 260 mm (Fig. 2) is the main element of the