MICROWAVE IMAGING VIA SPACE-TIME BEAMFORMING FOR BREAST CANCER DETECTION: EXPERIMENTAL STUDIES USING BREAST PHANTOMS

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Abstract: We have recently proposed a method of microwave imaging via space-time (MIST) beamforming for early-stage breast cancer detection. This approach exploits the significant dielectric-properties contrast between normal and malignant breast tissue. An ultrawideband pulse is transmitted sequentially from each antenna in 2-D antenna array located near the surface of the breast. A MIST beamformer is designed to focus the received backscattered signals in both space and time to form an image of backscattered energy as a function of location. The feasibility of the MIST method is demonstrated using both FDTD-computed backscatter data and experimental data obtained from simple breast phantoms.

Motivated by the critical need for complementary or alternative modalities to X-ray mammography for early-stage breast cancer detection, we have recently proposed a method of microwave imaging via space-time (MIST) beamforming for detecting and localizing backscattered energy from small malignant breast tumors [1]. Our efforts have been guided by published data in the literature and our own preliminary measurements which suggest that a substantial contrast exists between the dielectric properties of normal and cancerous breast tissue at microwave frequencies [2-4]. The enhanced dielectric properties of breast carcinomas appear to arise in part from increased protein hydration. The contrast is further enhanced by the vascularization of malignant tumors. As a result, malignant tumors have large microwave scattering cross-sections relative to comparably sized heterogeneity in normal breast tissue. Since microwaves offer an estimated 2:1 or greater contrast compared to the few-percent contrast exploited X-rays, microwave imaging techniques have the potential to overcome some of the limitations of conventional mammography.

In our MIST approach each antenna in an array sequentially transmits an ultrawideband microwave pulse into the breast and receives the backscatter. Spatial focusing of the backscattered signals is required to discriminate against clutter caused by the heterogeneity of normal breast tissue. This focus can be achieved synthetically by applying robust space-time beamforming techniques to the recorded signals. A beamformer time shifts the received signals, passes them through a bank of finite-impulse response (FIR) filters, and sums the filter outputs to produce the beamformer output. The beamformer output is time gated and then the energy is calculated. A display of energy as a function of location provides an image of backscattered signal strength. Locations of high energy indicate the presence of significant scatterers, i.e. malignant lesions.

In our previous investigations we demonstrated the performance of the MIST technique by applying 2-D space-time beamformer designs to simulated backscatter data obtained from anatomically realistic FDTD breast models. In this paper, we present our preliminary experimental investigations of a 3-D beamformer design using simple breast phantoms. For this initial testing stage the breast phantom is composed of a tank filled with a liquid simulating the dielectric properties of normal breast tissue and a small suspended synthetic tumor immersed in the liquid. A specially designed ultrawideband antenna is sequentially repositioned using a mechanical x-y scanner to virtually synthesize an antenna array placed above the breast phantom. The antenna is connected to a commercial vector network analyzer (VNA) to transmit and receive microwave energy. At each antenna location in the synthetic array, a frequency sweep is performed over a wide band of frequencies. The frequency-domain backscattered signals are transformed to synthesize ultra-short time-domain pulses. After obtaining the backscattered waveforms at all antenna locations, the recorded signals are time-shifted, passed through a bank of finite-impulse filters, and summed to produce the beamformer output at a specific candidate location in the breast phantom. The beamformer output is time gated and then the energy is calculated and displayed as a function of location.

Performance of the 3-D MIST beamformer approach to detecting small malignant lesions is demonstrated by successfully imaging backscattered energy for a variety of breast phantom scenarios, such as different tumor sizes, shapes and locations, and variations in the dielectric properties of the tissue simulants. Our results suggest that microwave imaging via space-time beamforming offers the potential of detecting small breast tumors using state-of-the-art but readily available hardware and robust signal processing algorithms.

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