Title: Spatially tracked whole-breast 3DUS system toward point-of-care breast cancer screening in women with dense breasts

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Structured Abstract:

Introduction: Early detection of breast cancer has reduced mortality in women through the widespread implementation of screening mammography. However, challenges still exist in 40% of women with dense breasts, which reduces the mammographic sensitivity and detection of almost one-third of breast cancers. Automated breast ultrasound (US) has enabled whole-breast imaging, 3D visualization, improved reproducibility, and reduction in operator-dependence when compared to handheld US. However, these systems still require training for acquisition, experienced interpretation, and are costly. We propose an alternative, adaptable, and cost-effective spatially tracked system for whole-breast 3DUS imaging. This work describes the system design, optimization of spatial tracking, validation of registration and fusion of acquired 3DUS images, and the proof-of-concept whole-breast 3DUS imaging in a tissue-mimicking breast phantom and healthy volunteer study.

Methods: The system is composed of an in-house 3DUS scanner, adaptable to any US transducer, and multi-jointed manipulator and counterbalanced stabilizer, enabling 3D tracking and six degrees-of-freedom for motion. Tracking accuracy was assessed for each joint (J1-6) by comparing the spatially tracked position to its optically tracked position, using a custom stylus and external optical tracking system. Spatial-based registration of two 3DUS images acquired in a tissue-mimicking phantom with fiducial spheres was assessed and the Target Registration Error (TRE) was quantified. Whole-breast 3DUS imaging was performed in a tissue-mimicking breast phantom with simulated spherical lesions and with a healthy male and female volunteer study.

Results: The mean absolute tracking error (SD) was 0.87 ± 0.52 mm, 0.70 ± 0.46 mm, 0.53 ± 0.48 mm, 0.34 ± 0.32 mm, 0.43 ± 0.28 mm, and 0.78 ± 0.54 mm (N=4, each) for J1-6, respectively. Quadratic-based lookup table corrections minimized the error in translational J1, J2, and rotational J5. Compound motions utilizing all joints resulted in an error of 1.08 ± 0.88 mm (N=20) within the intended clinical workspace for breast imaging. Spatial-based registration of acquired 3DUS images resulted in a mean TRE of 1.28 ± 0.10 mm. In the tissue-mimicking breast phantom, multi-image registration and fusion enabled whole-breast 3DUS imaging, enabling visualization in sagittal, axial, and coronal views. The first-ever clinical exploration of the proposed spatially tracked whole-breast 3DUS imaging approach was demonstrated in a healthy male and female volunteer study.

Discussion: We demonstrated an accurate spatially tracked system for whole-breast 3DUS imaging. This work shows potential utility as a bedside point-of-care approach for whole-breast 3DUS in women with dense breasts. Current work is focused on evaluating the quality of the whole-breast 3DUS images and developing a robust 3DUS imaging protocol to address limitations in tissue deformations and motion.