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● *Original Contribution*

ALIGNMENT AND CALIBRATION OF DUAL ULTRASOUND TRANSDUCERS USING A WEDGE PHANTOM

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Abstract—We present a novel method of aligning two orthogonal ultrasound transducers into a coincident scan plane. A wedge phantom design provides visual feedback to the user to facilitate alignment. Calibration provides the transformation from one transducer to the other as well as a measure of the residual error in alignment. Mean alignment error is shown to be under 1° in the rotation axes and 1 mm in translation after repeated manual alignments. The repeatability of wedge based calibration has similar results compared with N-fiducial based calibration. The accuracy of the calibration for mapping points from one transducer to the other is found to have a mean error of 1.6 mm. The dual transducer system is well suited to imaging anatomy such as the breast and may be used for spatial compounding for improving B-mode images and motion estimation compounding for improving elastography results. (E-mail: jeffa@ece.ubc.ca) © 2011 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Alignment, Calibration, Compounding, Dual transducer.**

INTRODUCTION AND LITERATURE

Ultrasound image features are strongly dependent on the direction of the ultrasound beam relative to the reflectors. The point spread function of an ultrasound transducer is anisotropic. Image speckle arises from the coherent ultrasound source and varies with the location of the ultrasound source. For these reasons, there have been many techniques developed to combine two or more ultrasound images of the same region-of-interest but taken from different viewpoints. Previous publications are divided roughly into two categories: improving B-mode image quality with spatial compounding and improving elastography results by compounding motion estimates.

Spatial compounding simply averages B-mode images from multiple viewpoints to reduce speckle and improve depiction of internal anatomy (Jespersen et al. 2000; Huber et al. 2002; Groves and Rohling 2004). Modern systems often electronically steer the ultrasonic beam to obtain multiple viewpoints so compounding can be done quickly on a single transducer. However, for large steering angles (*e.g.* $>\pm15°$), the effective aperture size decreases and artifacts from grating lobes may reduce image quality (Lu et al. 1994). This can be overcome by mechanically steering a transducer (Choi et al. 2008), mounting the transducer on an articulated arm (Hernandez et al. 1996), or using multiple transducers (Dick et al. 1979). When using multiple transducers, the key issue is physical alignment of the different imaging planes.

Tracking of tissue motion, such as in the field of elastography, is most accurate along the axial beam direction. Estimation of the tissue properties from a set of motion estimates is improved with the use of lateral and elevational motion components (Konofagou and Ophir 2000; Eskandari et al. 2008). Electronic beam steering can be used to measure motion in different directions and the tracking can be compounded to improve estimation accuracy (Rao et al. 2007; Zahiri Azar 2009). However, optimal steering angles are again typically limited to approximately 10° to 15° (Rao and Varghese 2009). A filtering technique has been developed to reduce grating artifacts to allow for steering angles up to ±45°, but the decreased aperture only allows for shallow imaging such as for carotid arteries (Hansen et al. 2010). Using two orthogonal transducers (dual transducers) has been proposed for approximately an order of magnitude improvement in the accuracy of tracking internal tissue

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motion (Dickinson and Hill 1982; Abeysekera and Rohling 2009). The accuracy of motion tracking is a key issue for reconstructing elasticity values (Doyley et al. 2000; Barbone and Oberai 2007). Using elastography for identifying cancerous lesions in breast has shown promise but inconsistent results have limited its clinical adoption (Pellot-Barakat et al. 2006; Burnside et al. 2007). A dual transducer set-up is well suited for scanning anatomy such as the breast and the advantages it provides may lead to an effective clinical diagnostic tool. Again, alignment of the image planes is the critical issue for dual transducers.

There are two aspects to solving the problem of creating a dual transducer system. The first is alignment, where the two transducers must be physically oriented in such a way that their image planes coincide. An image based alignment is preferred to a purely mechanical alignment of the transducer casings since the orientation of the piezoelectric crystals and, therefore, the image planes, is unknown. Alignment requires adjustment of four degrees of freedom (DOF) since two translations within the plane can be adjusted freely while still maintaining alignment. The second step in creating a dual transducer system is determining the transformation from one transducer's coordinate frame to the other, which is generally referred to as calibration. Calibration requires determination of all six DOF. This is the first article addressing two-dimensional (2-D) to 2-D ultrasound alignment and calibration.

Calibration is a well researched problem (Lindseth et al. 2003; Mercier et al. 2005). Calibration refers to the localization of the image coordinates with respect to an external coordinate system, usually with a position tracker attached to the transducer housing. The need for physical alignment of dual transducers poses a unique problem that cannot be solved by traditional calibration approaches. For example, most traditional calibrations are solved iteratively, over six DOF (three positions and three orientations) but physical alignment cannot be performed in this manner because of the lack of decoupled control of all DOF using cascaded motion stages, lack of visual feedback to guide alignment, and need for relatively few iterations. For these reasons, a new technique is required that is suitable for both alignment and calibration of two transducers. Alignment will bring the two imaging planes into approximately the same plane and calibration will determine the relative location of the image origins and axes. Calibration will also provide a measure of the residual error in alignment.

Although the alignment and calibration problem is unique, the solution can borrow aspects from previous work on calibration. Calibration typically involves scanning a phantom of known geometry, extracting features of the phantom from the ultrasound images and using an optimization algorithm to converge to a solution of the transformation matrix. For example, single-point based phantoms can be constructed with a bead or pin (State et al. 1994) or two intersecting wires (Detmer et al. 1994). The point feature is imaged from several different orientations to create an over-determined system for the calibration parameters. Single-point methods are easy to construct but can be time consuming since tens of images are needed for proper determination of the calibration matrix and locating and centering the transducer over the target point requires experience and skill. Wire-based phantoms, such as the N-fiducial phantom (Comeau et al. 1998; Pagoulatos et al. 2001), do not require as many images and can be easier to scan. One possible limitation with such phantoms is that the features do not appear as clear dots in ultrasound images but as blurred ellipses, making locating the points more difficult to localize accurately and increasing the number of points required to reduce errors.

Alternatively, planar structures can be scanned to produce lines in images. Examples include the floor of a water bath or the specialized Cambridge phantom (Prager et al. 1998). Thin plastic plates can also be used to produce line features (Viswanathan et al. 2004). Effects such as speckle, reverberation and side lobe artifacts may cause errors in feature extraction. Line features produce a large number of data points that help to average out these errors.

There are many other calibration methods and aspects of performance not listed here (see for example Lindseth et al. 2003; Mercier et al. 2005). The main point is that some aspects can be adapted to the problem of physical alignment. Some visual guide to assist the user in alignment is needed such as angled wires leading to a plane of beads (Leotta 2004). Opposing wedges provide the advantage of easily centering the beam in the elevation direction (orthogonal to the scan plane) and providing line features instead of points (Gee et al. 2005; Boctor et al. 2006).

This article investigates the problem of physical alignment of two imaging planes from dual transducers and calibration to determine the position and orientation of one image coordinate system with respect to the other. We present a new method of alignment for dual ultrasound transducers using a novel multi-wedge phantom. The phantom provides visual cues to the operator to guide the alignment process so that alignment can be achieved in a few steps. The repeatability of the alignment and calibration steps are tested and calibration results are compared with a N-fiducial phantom.