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An important feature of the method is the evaluation of nonlinear components whose spectra are folded back into the transmission band. All odd order nonlinearities can create such echo components. The reception of these components eliminates the high bandwidth requirements encountered in second harmonic imaging. Higher-order even harmonics may also be detected by taking advantage of the harmonic fold-back process. Folded frequency components will be centered around DC and at two times the transmit frequency ($2f_0$). This still requires a bandwidth sufficient to detect signals at $2f_0$ but eliminates the reception at higher multiples of f_0.

The polynomial model makes assumptions about the wave propagation that are not met exactly. The conditions under which the approximation is valid are discussed. The method has been evaluated on a contrast phantom. Imaging results demonstrate the separation of the linear, second, third and fourth order nonlinearity. The results also indicate that a higher SNR than currently available is required to extract components past the forth order. The experimental data have been acquired with a commercial General Electric LOGIQ 700 system. Since the data acquisition chain by itself generates a small amount of nonlinear distortion, a processing scheme has been devised to compensate for the nonlinearity of the system.

6. ELASTICITY/TISSUE MOTION

6.1 **Tumor volume estimation using 3D sonoelastography,** L.S. Taylor, B. Porter, D.J. Rubens, and K.J. Parker, *Department of Electrical Engineering and Department of Radiology, Rochester Center for Biomedical Ultrasound, University of Rochester, Rochester, NY 14627.*

Vibration amplitude sonoelastography differentiates between hard tumors and normal tissue by detecting the relative vibration amplitude between the regions of tissue. Low frequency shear waves (less than 0.1 mm displacement and 1 kHz frequency) are propagated through the tissue, while real time Doppler techniques are used to image the resulting vibration pattern. A discrete hard inhomogeneity, such as a tumor, will produce a localized disturbance in the vibration pattern which forms the basis for tumor detection. A three-dimensional image of the vibration pattern in the tissue is produced by assembling sequential tomographic slices. Segmentation techniques can then be applied to determine the shape and extent of the tumor.

In order to establish the accuracy of this technique, a tissue-mimicking phantom containing a stiff lesion was imaged using both 3D sonoelastography and 3D MRI. Segmentation techniques were applied to both data sets. A tumor volume was obtained in the known location of the lesion for both modalities. The images were then registered using a correlation technique. Visual comparison of equivalent 2D slices in both data sets show that the MRI and the sonoelastography renderings of the tumor agree as to the location of the tumor. The MRI image produced a better rendering of the smooth outline of the ellipsoidal lesion. The tumor volume was calculated in both modalities and the tumor volume estimate from the sonoelastogram measured 85% of the MRI tumor volume. The factors affecting MRI and sonoelastic US accuracy are discussed.

6.2 **Solution of the inverse problem in sonoelastography using an iterative forward approach**, Dongshan Fu,[1] Stephen Levinson,[1,3] Sheryl Gracewski[2] and Kevin Parker[1], *De-*

partments of [1]Electrical & Computer Engineering, [2]Mechanical Engineering and [3]Physical Medicine and Rehabilitation, University of Rochester, Rochester, NY 14627.

Finite-element methods have previously been presented for elastic reconstruction from displacement data in sonoelastography. Standard methods for solution of the inverse problem, however, rely on the use of first, second and even third-order spatial derivatives. Ultrasonic speckle tracking data contains noise from speckle decorrelation, quantization error and various other sources. Because even a small noise component will result in significant errors in the spatial derivative terms, we have found it necessary to apply regularization and filtering techniques that have the potential to introduce bias into the resulting elasticity formulation.

We have recently explored an alternative approach to vibration sonoelastography that does not rely on the estimation of spatial derivatives of measured displacements. In our experiments, three or more consecutive frames of image data are recorded. The 2-D displacements between each pair of consecutive frames are estimated using a mesh-based speckle tracking method previously presented. Motion estimates are obtained only from nodes that have high feature energies, minimizing the risk of speckle decorrelation. The amplitude, phase and direction of the motion vectors are calculated using a least-square estimator. Elastic reconstruction is then formulated as a forward problem based on finite element theory. The region of interest is subdivided into sample blocks in which the elasticity and viscosity are assumed to be constant. Given boundary conditions consisting of the measured amplitude and phase values on the boundary of each sample block, the motion vectors for the internal nodes can be estimated from finite element theory, given an assumed elasticity and viscosity. The predicted motions are then compared to the measured data and the sum-squared difference (SSD) is calculated. This procedure is repeated iteratively with different viscoelastic moduli until the minimum SSD is obtained.

Because both ultrasonic tissue motion estimation and elastic reconstruction are mesh-based, their integration provides a systems approach by which the mechanical properties can be measured directly from vibrating ultrasonic image sequences. The approach has been tested on both synthetic data and experimental data from a two layer tissue-mimicking phantom. The preliminary results are very encouraging and centimeter-level resolutions (1x1cm block size, 2 cm spatial resolution) have been realized.

6.3 **New trends in transient elastography,** Laurent Sandrin, Mickael Tanter, Stefan Catheline and Mathias Fink, *Laboratoire Ondes et Acoustique, E.S.P.C.I., Université Paris VII, U.R.A C.N.R.S 1503, Paris, France.*

Elastography is used in different ways to characterize soft tissues. J. Ophir uses static elastography to estimate strains in the tissue after a quasistatic compression. Strains can also be measured by sonoelasticity using mechanically forced low frequency vibrations and the ultrasonic pulsed Doppler method (Parker and Sato). These techniques are subjected to bias due to unknown boundary conditions and to diffraction effects. In this article, we present a technique called transient elastography that is not sensitive to boundary conditions and to various diffraction limitations. It uses a low frequency pulsed vibration (~ 100 Hz) and a cross-correlation technique to measure displacements on the order of 1 μm. This technique is now used with an array of 64 transducers to get time-dependent, two-dimensional displacements at a rate of 2,000 frames per second. Movies of the shear wave propagation through homogeneous, inhomogeneous phantoms and biological tissues have been obtained. We shall discuss how to inverse near-field data in order to recover the medium shear viscosity and elasticity fields.

6.4 **Kinetic acoustic vitreous examination: phantom studies,** W.F. Walker,[1,2] T.J. Mondzelewski,[1] M.J. McAllister,[1] F.J. Fernandez,[1] and C.A. Toth[3], *[1]Department of*

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