Directional Filtering for Multiple-Driver Magnetic Resonance Elastography Data

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Introduction

Magnetic resonance elastography (MRE) is a phase contrast based MRI imaging technique that can directly visualize and quantitatively measure propagating acoustic strain waves in tissue-like materials subjected to harmonic mechanical excitation [1]. The data acquired allows the calculation of local quantitative values of shear modulus and the generation of images that depict tissue elasticity or stiffness. The shear waves are typically produced by an electromechanical, pneumatic or piezoelectric driver, applied to the surface of the object. In some applications, adequate displacement may not be present in regions of an object due to attenuation and shadowing effects. It has been shown that excitation with multiple, phased array drivers can provide more uniform illumination of an object [2]. However, the wave field from such a driving system can be very complex, with interference patterns yielding areas of low wave amplitude and hence low SNR. A spatio-temporal directional filter can in principle separate interfering waves traveling in different directions so they can be processed separately [3]. We investigate the effect of such filtering on multiple driver MRE data sets and on stiffness results derived from these with three different inversion techniques.

Materials and Methods

A 1.5 T whole body scanner(GE Signa, Milwaukee, WI) and Helmholtz surface coil were used for the experiments. A cylindrical gel phantom of 20 cm diameter and 7 cm height was made with 2% agar. A rectangular inclusion of 4% agar gel of dimensions 2.8 cm × 2.3 cm × 7 cm and a cylindrical inclusion of 2.1 cm diameter x 7 cm were also included in the phantom. A setup of eight electromechanical drivers, with 2 Ω resistance in each coil, was placed in the phantom. All eight drivers were driven simultaneously, using a commercially available 8-channel 16 bit analog output board (PD2-AO-8/16). In a preliminary set of wave images, the response of the phantom to a waveform from each driver was measured. Eight different phase offsets between the mechanical driving and the motion sensitizing gradient were obtained. Eight directional filters with preferred orientations evenly spaced around a circle were applied to the data, and three different inversion algorithms [4] were applied to the filtered and unfiltered data sets. Under certain assumptions that are good approximations in practice (linearity, incompressibility, local homogeneity), the equation of harmonic motion simplifies to the Helmholtz equation. Direct inversion (DI) uses filtered estimates of displacement and its Laplacian in a local neighborhood to directly solve for shear modulus at each point in the image or volume. Local frequency estimation (LFE) combines local estimates of instantaneous frequency over several scales. Phase gradient (PG) assumes propagation of a single shear wave and simply calculates the gradient of its phase. This technique breaks down in the presence of wave reflection or interference, and its use is normally limited to specialized situations.

Results

Fig. 1 shows a magnitude image of the phantom, the wave field from the eight drivers simultaneously, the amplitude of the frequency component of the data at the driving frequency for the unfiltered data, and the effective combined amplitude for the eight filtered data sets (right). Note that the unfiltered amplitude has many areas of interference that are largely removed in the filtered amplitude, and how well the inclusions are visualized as areas of low amplitude. Fig. 2 shows the results of the three inversion techniques for the unfiltered and filtered data sets. The LFE result shows only modest improvement with directional filtering; this is expected since the filters resemble processing already present in the LFE. The DI results are significantly improved by directional filtering. The PG results are very poor for the unfiltered data, which is expected since PG explicitly assumes a single wave and simply tracks its phase, and this assumption is strongly violated. Interestingly, the directional filter provides sufficient wave separation that the "single wave" assumption is now closer to reality, and the filtered results are very comparable to the other techniques.

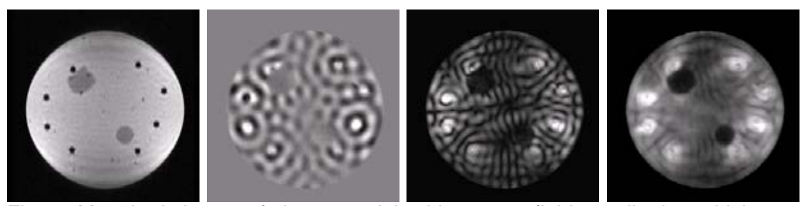

Fig. 1. Magnitude image of phantom, eight-driver wave field, amplitude at driving frequency, and combined amplitude at driving frequency after directional filtering.

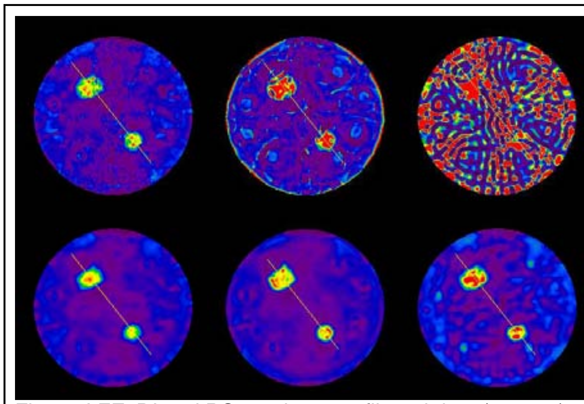

Fig. 2. LFE, DI and PG results on unfiltered data (top row) and filtered data (bottom row).

Discussion

Multiple driver excitation yields improved MRE wave illumination throughout objects, but with potentially very complicated wave fields that can negatively impact inversion algorithms. Spatio-temporal directional filtering can dramatically improve inversion results. All three inversion algorithms considered gave very similar (and accurate) inversion results when applied after directional filtering.

References

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