Combining Conjugate and Non-Conjugate Wave Data for Faster Elastography

Roger Grimm[1], Eric Stinson[1], and Richard Ehman[1]
[1]*Mayo Clinic, Rochester, MN, United States*

Purpose: Elastography sampling with gradient echo sequences can lead to long scan times. Scan efficiency is limited by gradient heating concerns and the need to synchronize the TR to the period of motion excitation. These inefficiencies can be ameliorated by using a phase advancing TR [1]. This interleaved approach allows for TR options beyond integer multiples of the wave period and spreads the gradient heating across multiple TRs. This work uses a phase advancing TR and acquires the minimum 7 samples to provide complex sampling of the wave field along all 3 axes.

Methods: The unknown static field and the 6 wave field unknowns (x_i, y_i, z_i, x_q, y_q, z_q) with their conjugate pairs are distributed around the complex plane seen in **Figure 1b** due to the phase advancing TRs of the acquisition. Since conjugate pairs contain the same information, only one of the pair needs to be sampled. Due to Fourier conjugation rules, **Figure 1c** shows the orientation needed to sample both halves of ***k***-space using conjugate pairs. The center of ***k***-space is oversampled with 8 extra samples and is acquired with a 3D gradient echo acquisition with 60Hz motion excitation and a TR = $5\lambda/4$ = 20.8ms. The conjugate pair data sets are combined and reconstructed as explained in **Figure 2**. All scans were performed on a GE 1.5T HDx scanner.

Results: A standard acquisition, using 12 samples, performs a phase difference of a plus and minus motion encoding. This will provide twice the amplitude of the proposed method resulting in the phase wrap seen in **Figure 2**. The proposed method shows little or no blurring in the phase direction from the half-NEX like reconstrucion used for image reconstruction and produces comparable results to the standard acquisition which acquires almost twice the data. Due to inter-voxel phase dispersion, the virtual shim had difficulties in areas of high motion and the resulting low magnitude signal.

Conclusions: This paper has presented a novel approach to reduce the number of samples acquired in Elastography imaging. Combining conjugate and non-conjugate data into a single image requires full knowledge of any underlying phase. The results here show that this is feasable; though, further work remains. Having phase ramps after ΔB_0 and Maxwell correction suggest that an actual shim of each encoding direction could eliminate this from the acquired data. Alternatively, a calibration scan could be used to sample these. Additionally, the SNR characteristics of this method need to be verified and compared to other approaches.

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References: [1] Grimm RC, Proceedings of the ISMRM, 2446, 2013. [2] Xiang QS, Proceedings of the ISMRM, 789, 2001. [3] Bioucas-Dias JM, IEEE Trans. Image Process., 16:3, 698, 2007.

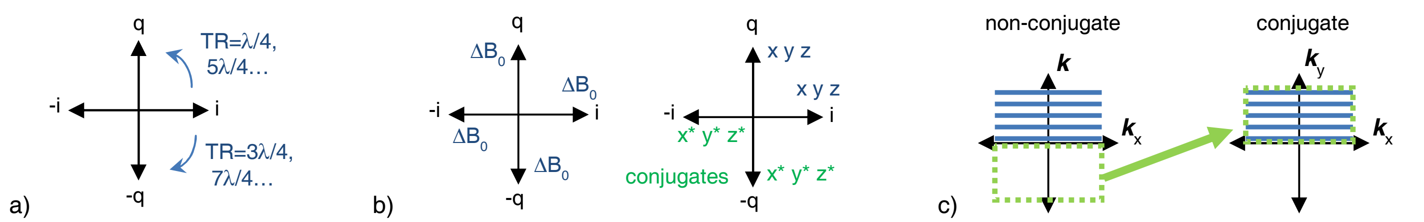

Figure 1a) TR values with odd multiples of ¼ of the applied motion period, λ, advance around the complex plane of the wave field. **b)** The background static phase, ΔB_0, is sampled without motion encoding gradients and does not change relative to motion timing. Interleaving the 3 motion encoding polarizations will distribute the samples around the complex plane filling both conjugate and non-conjugate positions. **c)** The Fourier conjugate theorem indicates the conjugated image data is flipped in ***k***-space. At the end of acquisition, there are 6 conjugate pairs of ***k***-space samples. These are the in-phase and out-of-phase samples for each polarization: (x_i, x_i^*), (y_i, y_i^*), (z_i, z_i^*), (x_q, x_q^*), (y_q, y_q^*), (z_q, z_q^*).

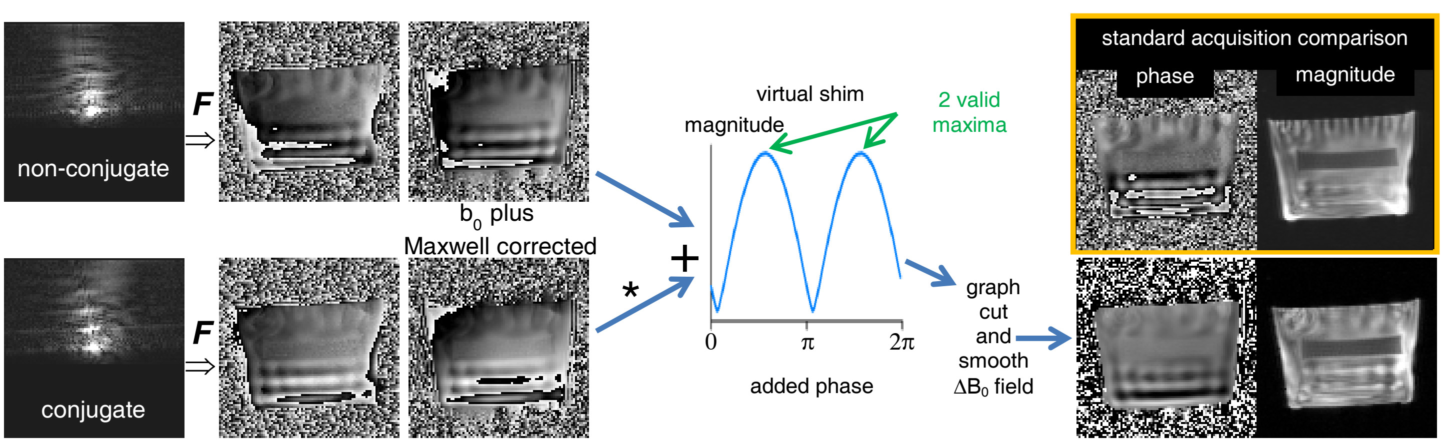

Figure 2 The oversampled center of ***k***-space is windowed with a ramp to produce uniform weighting. After the Fourier transform, the phase from the ΔB_0 sample and Maxwell terms are removed. At this stage, phase ramps still exist in the data that are removed with a virtual shim [2]. A range of phase values are added to both data sets on a pixel basis prior to conjugation and addition of the images. Due to the conjugation, the maxima occur where the motion induced phase is centered about 0 and π in the wave data of the 2 image pairs. The calculated spatially varying shim field is fed into a graph cut algorithm [3] to remove phase discontinuities and then fit to a 3D linear ramp before being used.