Referenceless Multi-Coil Reconstruction

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Introduction Referenceless proton resonance frequency (PRF) shift thermometry [1] is inherently robust to tissue motion because the subtraction of a baseline phase image acquired prior to heating is not necessary. Instead, the background phase is estimated in every individual image from a frame region of interest (ROI) surrounding the heating region. The background phase is estimated by fitting a polynomial to the phase in the frame region or by fitting a complex polynomial to the complex data [2]. It is necessary that the phase vary slowly without discontinuities (2π-phase wraps can be easily removed by phase unwrapping). Phase images from single coils generally meet this requirement and can be processed with referenceless reconstruction.

Referenceless processing of phase images acquired with multiple coils is problematic if a coil is not sensitive over the whole frame region. In this case, the polynomial is fit preferentially to the high signal region within the frame ROI. This problem is avoided if the phase images of the different coils are combined into a single image before referenceless reconstruction. However, unknown, per-scan phase offsets are expected between each receiver channel, due to coil geometry and position, coil electrical properties, such as opposing-phase wiring, and receiver time delays. Predetermined solutions are undesirable, as coil loading will change phase offsets, and are incompatible with coil arrays that are flexible or are not in a fixed geometry. Therefore, the data of the different coils has to be combined taking the offsets into account such that the combined image has a smooth phase without phase discontinuities.

Here, we demonstrate a coil combination that determines and eliminates the coil dependent phase offset and generates combined images with a smooth background phase that can be used for temperature estimation with the referenceless method.

Methods Focused ultrasound (FUS) heating spots were created in an ultrasound gel phantom using an InSightec ExAblate 2000 system installed on a 3T GE Signa magnet. Temperature images of the heating region were acquired with a flexible 2-channel coil and a 4-channel cardiac phased array in axial and coronal planes. Imaging parameters were TE=12.7 ms, TR=25.5 ms, flip angle = 30°, FOV=24 cm for coronal images and 32 cm for axial images, matrix size 256x128, BW = 11.3 kHz.

The multi-coil combination and referenceless processing was performed in MatLab. Receiver coil phase offsets $R=(\theta_1\ \theta_2 \ldots \theta_{N-1})$ from an arbitrarily chosen individual coil in an N coil array were determined using a least-squares solution. In an ideal system, the phase offset between any pair of coils can be determined by estimating the constant phase difference for all pixels where both coils have sufficient signal. However, better noise tolerance and coil phase estimation between coils that do not have much, or any, sensitivity overlap can be achieved by using a linear differential model of coil phase offsets. That is, the offset from coil 1 to coil 4 is also the difference between coil 1 and 3 and 3 and 4. For N coils this results in $N(N+1)/2 - 1$ comparisons. Once the differential coil offsets of the individual coils are determined, the offset is removed by multiplying each image with the corresponding complex conjugate of the phase offset. After the correction, the data may be combined into a single complex image. For a combination that minimizes the temperature uncertainty in the resulting temperature maps, the phase can be combined with a weighting by the magnitude squared [3]. Temperature maps from the combined images were reconstructed with the referenceless method and compared to temperature maps reconstructed with baseline subtraction.

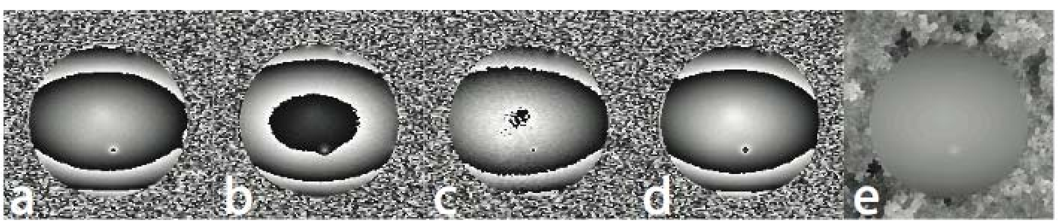

Figure 1: Phase images of the individual coils of a 2-channel array (a,b) and the combined phase without (c) and after removal of the coil dependent phase offset (d). After phase unwrapping (e), the smooth background allows processing with the referenceless method.

Results and Discussion Figure 1 shows the individual phase images of the 2-channel coil and their combination using the described phase combination. The resulting phase is smooth and can, after unwrapping, be used for referenceless temperature estimation. Figure 2 shows temperature maps through the FUS heating region reconstructed with referenceless reconstruction and baseline subtraction. The measured temperatures with both methods are virtually identical.

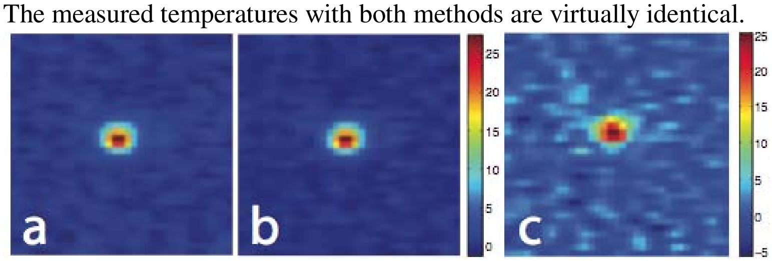

Figure 2: Coronal temperature images showing the FUS heating in the transverse direction. Image (a) is reconstructed with baseline subtraction and image (b) with referenceless reconstruction using the proposed phase combination. The estimated temperature of this heating spot is virtually identical in both methods. Adding the phase without removing the coil dependent phase offset results in poor temperature estimation with the referenceless method (c).

Conclusions Combining the phase of multi-coil acquisitions after removing the coil dependent receiver phase offset generates phase images without discontinuities that can be processed with the referenceless method. This allows referenceless reconstruction to be utilized for temperature estimation without restriction of the coil types used for imaging.

References 1. Rieke V, Vigen KK, Sommer G, Daniel BL and Pauly JM and Butts K. Referenceless PRF shift thermometry Magn Res Med. 51(6), 1223-31, 2004.
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3. Bernstein MA and Grgic M and Brosnan TJ and Pelc NJ. Reconstructions of phase contrast, phased array multicoil data. Magn Reson Med 32(3):330-4, 1994.

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