Combining phase information from multi-channel coils using a short TE reference scan (COMPOSER): evaluation with a range of coils and comparison with other approaches at 7T

Simon Daniel Robinson[1,2], Barbara Dymerska[1,2], Wolfgang Bogner[1,2], Markus Barth[3], Zaric Olgica[1,2], Sigrun Goluch[1,4,5], Günther Grabner[1,2], Xeni Deligianni[6,7], Oliver Bieri[6,7], and Siegfried Trattnig[1,2]

[1]High Field Magnetic Resonance Centre, Medical University of Vienna, Vienna, Austria, [2]Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Vienna, Austria, [3]Centre for Advanced Imaging, The University of Queensland, Brisbane, Australia, [4]Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria, [5]Division of Endocrinology and Metabolism, Department of Internal Medicine III, Medical University of Vienna, Vienna, Austria, [6]Department of Radiology, Division of Radiological Physics, University of Basel Hospital, Basel, Switzerland, [7]Department of Biomedical Engineering, University of Basel, Basel, Switzerland

Synopsis

A new method for combining phase images from multi-channel radio-frequency coils in the absence of a volume reference coil is presented and tested with calf, breast and head coils at 7 Tesla. This approach, called COMbining Phased array data using Offsets from a Short Echo-time Reference, or COMPOSER, is shown to yield phase matching between channels which is better than a rival, widely adopted reference-free method (MCPC-3D) and comparable with the reference-based Roemer method. COMPOSER can be used with all coil arrays, including the next generation of PTx coils where the transmit array may not be engineered to receive signal.

BACKGROUND and PURPOSE:

Phase imaging benefits from strong susceptibility effects at very high field and the high SNR afforded by multi-channel coils. Combining the information from coils is not trivial, however, as the phase that originates in local field effects (the source of interesting contrast) is modified by the sensitivity profile of each coil. This has historically been addressed by referencing individual coil sensitivities to that of a volume coil – the Roemer/SENSE method[1] - but an alternative approach is required for ultra-high field systems in which no such coil is available. A method has recently been proposed - COMbining Phased array data using Offsets from a Short Echo-time Reference, or COMPOSER[2] – which approximates the phase measured in a reference scan with a short echo time to the phase of the receiver sensitivity and other phase effects present at TE=0. In this study we assess the effectiveness of COMPOSER in phase imaging with calf and breast coils in which the local transmit coil is not capable of receiving signal (i.e. where the Roemer approach cannot be applied) and quantify its performance with respect to another reference-coil-free method, MCPC-3D, and the Roemer method in the brain.

METHODS:

Measurements of 8 healthy subjects were made with a 7 Tesla MR whole body Siemens Magnetom scanner. High resolution T_2^*-weighted gradient-echo data of the brains of six male subjects were acquired with a 32 channel ^{1}H head coil (Nova Medical) (0.3x0.3x1.2 mm^3, TE/TR = 15/28 ms, TA=12 mins), of the calf in one female subject with a two-channel ^{1}H coil[4] (0.55×0.55×2.0 mm^3, TE/TR = 10/15 ms, TA=101 secs) and of the breasts of one female subject with a four-channel dual-tuned ^{31}P/^{1}H coil (Stark Contrast) (1.6×1.6×1.3 mm^3, TE/TR = 3/7 ms, TA = 102 secs). The short echo reference (SER) data for COMPOSER were acquired with a 3D variable TE (vTE) sequence[5] (2x2x4 mm^3, vTE/TR = 0.8/5 ms, TA = 11 s). In the brain, dual-echo gradient-echo scans with 2x2x3 mm^3 resolution were also acquired for the MCPC-3D method (TE/TR = (5, 9)/606 ms), and with both the birdcage transceive coil

(AC) and the receive array (VC) for the Roemer method (TE/TR =5/606 ms).

ANALYSIS:

The real and imaginary data from the SER scan were coregistered to the high resolution scan with FSL's FLIRT[6]. A combined phase image was calculated from the single-channel magnitude (M_j) and phase images (θ_j) from each of the j coils of the high resolution data using

$$\theta_{COMPOSER} = \angle \sum_j M_j \cdot e^{-(\theta_j - \theta_{SER,j})}$$

where $\angle$ is the angle and $\theta_{SER,j}$ the phase of the SER scan in the space of M_j and θ_j. A modified Roemer reconstruction (with correction of phase only) was carried out according to

$$\theta_{Roemer\_mod} = \angle \sum_j M_j \cdot e^{-(\theta_j - (\theta_{VC,j} - \theta_{AC}))}$$

where ($\theta_{VC,j}$-θ_{AC}) is the phase correction, which was complex-smoothed and likewise in the space of M_j and θ_j.

The MCPC-3D-II reconstruction was carried out according to Ref. 3. The quality of phase matching in each voxel was assessed via the metric 'Q', where $\theta_{cor,j}$ is the corrected phase in the exponent in each method;

$$Q = 100 \times \frac{abs(\sum_j M_j \cdot e^{-\theta_{cor,j}})}{\sum_j M_j}$$

which approaches 100% for perfect matching.

RESULTS:

The absolute value of the complex sum ('Magnitude') and Q values were low for No Correction (Figure 1, top two rows) (median Q over all subjects = 19.0%) and close to 100% for the reference Roemer method (median Q=99.2%). Magnitude and Q values were generally high with MCPC-3D-II (median Q=96.9 %), although errors in unwrapping single-channel phase values led to isolated low values (Figure 1, arrows 1-3). Phase matching with COMPOSER was similar to that with Roemer, with a median Q value of 98.9%. These observations were confirmed by the histogram analysis over all voxels and subjects in Figure 2. COMPOSER was similarly effective in the calf (Figure 3) and breast (Figure 4), yielding near-perfect phase matching throughout the image and artefact-free combined phase images which could be unwrapped.

DISCUSSION AND CONCLUSION:

COMPOSER is a fast, robust method for the phase-sensitive combination of data from coil arrays. It requires no reference volume coil, making it feasible for use with all coil arrays, including PTx coils and surface arrays where the transmit part may not be engineered to receive signal. COMPOSER needs no phase unwrapping and provides phase matching which is comparable to the Roemer method and superior to that with the rival reference-coil-free approach tested.

Acknowledgements

This study was funded by the Austrian Science Fund (KLI 264).

References

1. Roemer PB, Edelstein WA, Hayes CE, Souza SP, Mueller OM. The NMR phased array. Magn Reson Med 1990;16:192-225.

2. Robinson SD, Bogner W, Dymerska B, Cardoso P, Grabner G, Deligianni X, Bieri O, Trattnig S. COMbining Phased array data using Offsets from a Short Echo-time Reference scan (COMPOSER). Proceedings of the Twenty-forth Annual Meeting of the ISMRM, Toronto 2015:#3308.

3. Robinson S, Grabner G, Witoszynskyj S, Trattnig S. Combining phase images from multi-channel RF coils using 3D phase offset maps derived from a dual-echo scan. Magnetic Resonance in Medicine 2011;65:1638-1648.

4. Goluch S, Kuehne A, Meyerspeer M, Kriegl R, Schmid AI, Fiedler GB, Herrmann T, Mallow J, Hong SM, Cho ZH, Bernarding J, Moser E, Laistler E. A form-fitted three channel (31) P, two channel (1) H transceiver coil array for calf muscle studies at 7 T. Magn Reson Med 2015;73:2376-2389.

5. Deligianni X, Bar P, Scheffler K, Trattnig S, Bieri O. High-Resolution Fourier-Encoded Sub-Millisecond Echo Time Musculoskeletal Imaging at 3 Tesla and 7 Tesla. Magnetic Resonance in Medicine 2013;70:1434-1439.

6. Jenkinson M, Bannister P, Brady M, Smith S. Improved optimization for the robust and accurate linear registration and motion correction of brain images. NeuroImage 2002;17:825-841.

Figures

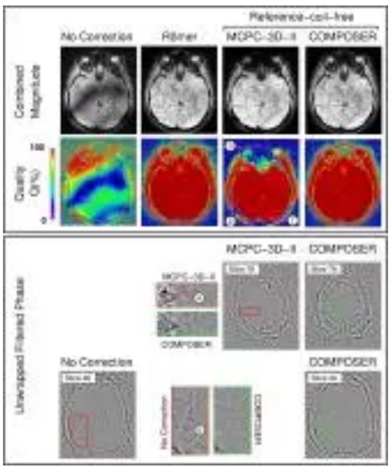

Figure 1: The quality of phase images generated with no phase correction, the Roemer method, MCPC-3D and COMPOSER (one subject). Top panel: the absolute value of the complex sum ('Magnitude') and phase matching quality (Q), the bottom panel: artefacts with 'No Correction' and 'MCPC-3D-II' in unwrapped and filtered phase images.

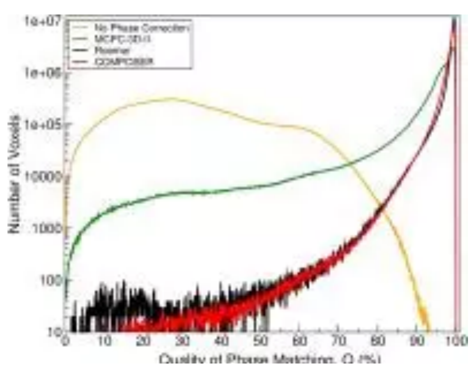

Figure 2: Quantitative comparison of the quality of phase matching (Q) achieved w ith the MCPC-3D and COMPOSER phase combination methods and the reference method, Roemer. The ordinate has been scaled logarithmically to allow comparison of the relative number of voxels w ith poor matching.

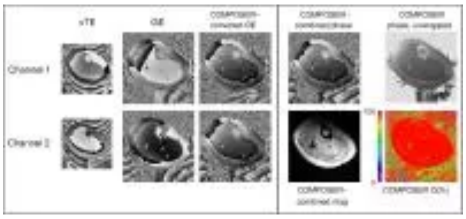

Figure 3: The quality of phase matching and reconstruction applying COMPOSER to data acquired w ith a calf coil. The phase images from the tw o proton channels ("GE") show little similarity before phase matching but appear identical after phase matching. Q values are close to 100% throughout the image.

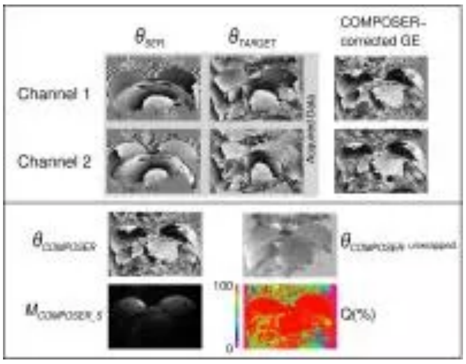

Figure 4: The quality of phase matching w ith COMPOSER w ith a breast coil w ith no volume reference and little overlap betw een the elements. The phase images from the tw o coils ("GE") appear identical after phase matching w ith COMPOSER. Q values are close to 100% throughout the image.

Proc. Intl. Soc. Mag. Reson. Med. 24 (2016)
2862