Reconstruction of Multi-channel MR Magnitude and Phase Images Using Dual-echo Sequence at 7 Tesla

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[Introduction] The high-field magnet has many potential advantages in human brain imaging (e.g., high SNR, CNR, & high-resolution) [1,2]. And better SNR can be achieved with the multi-channel surface coil and high-field [3,4]. However, B¹-inhomogeneity and coupling between the coils and object increase at the high field [5]. As a result, the undesirable artifacts such as intensity inhomogeneity or phase dislocation could appear in magnitude and phase image, respectively. Although a couple of methods [6–8] were suggested to correct the intensity inhomogeneity in magnitude image, other side artifacts could be produced, or the extra scanning and co-registration is required. On the other hand, in the reconstructed susceptibility phase image, the phase noise and dislocation is problematic due to the phase incoherence between the channels and large local field inhomogeneity. In this study, we developed the highly efficient reconstruction algorithm for magnitude and phase image using dual-echo sequence at 7T.

[Methods] All scans were performed on a 7T scanner (Siemens Medical Solutions, Erlangen, Germany) with 9-channel (1 volume transceiver + 8 receivers) RF coil. A volunteer consented to the study approved by the IRB of the university. Dual-echo 2D GRE sequence was used to calculate the ‘coil sensitivity map’ and ‘system phase map’ (Fig. 1). (1) The coil sensitivity map of each channel was generated by compensating T²* effect remaining at PD-weighted 1 echo (and the tissue contrast was low-pass filtered), and combined with other multi-channel data using the root-square-of-sum (RSS) method [9] (Fig. 2). Then, the T²* magnitude image was generated from the T²*-weighted 2 echo using the RSS method (Fig. 3B), and was masked with the combined coil sensitivity map (Fig. 3C). (2) The acquired phase image of each channel can be modeled as the sum of three phases, i.e., the (coil-dependent) ‘susceptibility phase’ that we want to know, the (coil-dependent) ‘system phase’, and the noise term (Figs. D & E) to correct the intensity inhomogeneity field. The calculated phase map at each stage was unwrapped using fast-Fourier-transform (FFT) method [10].

[Results and Conclusions] (1) Magnitude reconstruction - The simple summation of complex data produced the severe fringe artifacts due to the phase incoherence between the channels (Fig. 3A). The RSS method can compensate an incoherent phase between the channels by neglecting all the phase information, but cannot correct the coil-sensitivity-dependent variation in the imaging space (see the right frontal hemisphere in Fig. 3B). The inhomogeneous intensity was removed by the masking process with the estimated coil sensitivity map from dual-echo sequence (Fig. 3C). Our masking method using coil sensitivity map was compared to the general high-pass filtering (Figs. D & E) to correct the intensity inhomogeneity. The corrected magnitude image by high-pass filtering of Fig. 3E improved the homogeneity particularly in the right frontal region and basal ganglia area in this sample (Fig. 3F). However, the excessive high-pass filtering can produce the intensity artifacts in the relatively large structures in the brain such as lateral body ventricle (compare white-arrowheads in Figs. 3C & F). (2) Phase reconstruction - The susceptibility phase images were compared with two categorized algorithms; (I) high-pass filtering of summed multi-channel data (in either phase or complex domain) and (II) summation of high-passed complex data (in complex domain). The first category is more sub-categorized into (I-1) summation of unwrapped phase image corrected with system phase map (SUP), and (I-2) complex summation of complex raw data (SC). The second category has (II-1) complex summation of raw data magnitude-weighting (CSMW), and (II-2) complex summation of the coil sensitivity map-weighting (CSSW). The phase by SUP and SC produced the uncorrelated artifacts (i.e., noise & phase incoherence) (see white-arrowheads in Figs. 4A & B). The CSMW method using calculated susceptibility phase & raw-magnitude-weighting, and high-pass-filtering improved the quality of susceptibility phase with less noise and no hypo-intense blob artifacts around the right frontal region (Fig. 4C). The CSSW phase with the sensitivity-weight & mapping looks comparable to that of CSMW (Figs. 4D & D). Among these phase methods, the CSSW improved SNR in most (Fig. 4E). As well, the CSSW method overcomes the artifacts in CSMW, particularly in the (almost saturated) high intensity area such as blood vessels (black-arrowheads in Fig. 4F). In conclusion, the proposed algorithm using dual-echo acquisition improved the intensity homogeneity in magnitude image, and removed the phase dislocation with a good SNR in phase image. This technique can be an effective reconstruction method for the high-resolution image at high-field magnet and multi-channel coil system. [Reference] 1. Duyn et al., PNAS, 2006. 2. Hammond et al., Neuroimage, 2007. 3. de Zwart et al., MRM, 2002. 4. Wiggins et al., MRM, 2005. 5. Ibrahim et al., MRI, 2001. 6. Wald et al., MRM, 1995. 7. Cohen et al., HBM, 2000. 8. van Gelderen et al., ISMRM, 2006. 9. Roemer et al., MRM, 1990. 10. Schofield et al., Optics letters, 2003. [Acknowledgements] We thank Dr. Z.H. Cho for the support of a 7T multi-channel head RF coil.