Tensor Field Model for Phased-Array Imaging: Application for Phase Sensitive Inversion Recovery Reconstruction

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INTRODUCTION

Phase sensitive inversion-recovery (PSIR) has clinical applications ranging from myocardial infarction detection, brain tumor imaging, to fat/fluid suppression [1-3]. MR images acquired using phased-array coils can be viewed as a tensor field, i.e., each pixel is associated with a length-L complex vector where L is the number of receive channels. Conventional sum-of-squares (SOS) reconstruction is near optimal in terms of signal-to-noise ratio (SNR) but loses the phase information and the potential contrast. PSIR reconstruction overcomes the problem by retrieving the spin polarity. Existing methods usually require an additional phase reference scan (without inversion pulse), or need correcting phase inconsistency among coil images [1,3-5]. This paper presents a new PSIR recon method based on random tensor field modeling, which simultaneously corrects image phase of all channels, automatically guarantees the consistency between channels, and is robust against the image noises even in the low sensitivity areas of particular receive coils.

METHOD

The method obtains the spin polarity information directly from acquired coil images. Denote $\mathbf{I}(\vec{r}) = |\vec{I}^{l}(\vec{r})|\exp[j(\theta^{l}(\vec{r})+\phi(\vec{r}))]$, $l=1,2,...,L$, as a tensor field where $\vec{r}$ is the coordinate, $\theta^{l}(\vec{r})$ the background phase of the l^{th} coil image, and $\phi(\vec{r})$ the polarity phase (0 or π) due to spin relaxation common to all coil images. An example of a partial tensor field from a 8-ch image is shown in Fig. 1. Due to its physical nature, the background phase is a smooth, spatially-slow-varying field, i.e., it is Markovian. Using this property, the desirable polarity phase term $\boldsymbol{\psi}(\vec{r})=\{\exp[j\phi(\vec{r})]\}$ is determined by minimizing a cost function defined on the tensor field, i.e., $\arg\min_{\psi}\sum_{\vec{r}}\sum_{\vec{p}\in \mathrm{N}(\vec{r})}\langle\hat{\mathbf{I}}_{\psi}(\vec{r}),\hat{\mathbf{I}}_{\psi}(\vec{p})\rangle$, where $\mathrm{N}(\vec{r})$ is the set of spatial neighbors of the point $\vec{r}$ inside an $M\times M$ region, $\hat{\mathbf{I}}_{\psi}(\vec{r})=\hat{\mathbf{I}}(\vec{r})\boldsymbol{\psi}(\vec{r})$, and $\langle\cdot\rangle$ stands for the vector inner product. Since the inner product incorporates complementary data from all channels, the low sensitivity regions of a particular coil will be covered by other more sensitive channels. Thus the algorithm is more robust than processing individual coil images which is prone to error is the low SNR regions. In addition, the new method guarantees phase consistency across channels. No polynomial-time global optima algorithm for this problem is known. Therefore, a fast local optimization algorithm is developed to obtain a suboptimal solution. The binary optimization problem (only two possible polarities at each pixel) is solved based on a highest-confidence-first principle, where the pixels with the largest contribution to the cost function is optimized first [6].

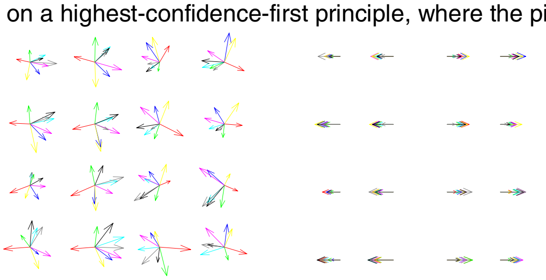

Fig. 1: Partial tensor field: (Left) before phase correction; (Right) after phase correction. Channels are color coded. Opposite tensor directions are due to different polarities.

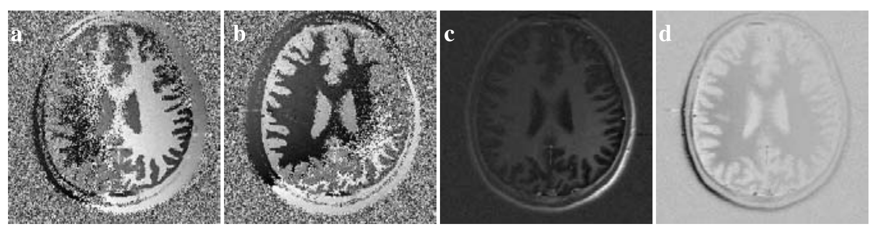

Fig. 2: Phase maps of (a) the 3rd and (b) the 6th coil images acquired by an 8-ch phase-array head coil. (c) and (d): PSIR recon corresponding to (a) and (b) using conventional phase correction. Note the polarity inconsistency between the two PSIR images.

RESULTS AND DISCUSSION

Inversion recovery data sets were collected on a GE 1.5 Tesla whole body MR system with a 8-ch head coil using a fast spin-echo sequence with TR/TE/TI/ETL/BW =2000/8.5/450/16/32K and data matrix of 256×256. Figure 2 (a-b) show the phase maps from two of the eight channels. Figure 2 (c-d) shows the PSIR recon from isolated coil-by-coil phase correction using the algorithm in [3]. The inconsistency as shown were automatically corrected by the new method using the tensor field modeling (partial field is shown in Fig. 1). Figure 3 compares the SOS recon and the PSIR recon using the new method. These results show that the tensor random field method yields phase sensitive inversion recovery images from phased-array coils without the need for reference scan and it inherently guarantees the channel consistency. The algorithm is computationally efficient and robust to noise. It can be straightforwardly extended to other phase-sensitive clinical imaging applications such as Dixon water/fat imaging.

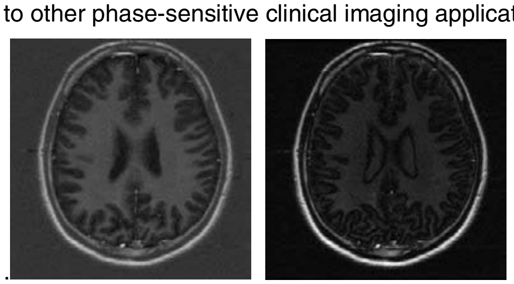

Fig. 3: Comparison of (a) the phase sensitive recon using the new method and (b) the SOS recon. Because the new method using tensor model to accurately determine the polarity information, PSIR image shows enhanced T1 contrast.

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