Generalized Reconstruction of Multi-Spectral MR Acquisitions for Imaging Near Metal Implants

D. Hernando[1], K. M. Koch[2], K. F. King[2], and Z-P. Liang[1]

[1]Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, United States, [2]Applied Science Laboratory, General Electric Healthcare, Waukesha, WI, United States

Introduction

MR imaging near metal implants is a challenging problem due to the presence of very large induced B_0 field dispersions (~ 20 kHz). Several techniques have been recently developed, that effectively divide the large spectral range into smaller bins, dramatically reducing B_0-related distortions [1,2,3]. The MAVRIC technique [1,2] acquires several 3D datasets using different transmit/receive frequencies (with each dataset covering a narrow spectral band). These datasets are then independently reconstructed, and combined using sum-of-squares (SOS). One of the main limitations of this reconstruction is the presence of residual image intensity distortions in regions of rapid field variation, which can produce both characteristic signal pile-up and intensity attenuation artifacts. In this work, we develop a generalized reconstruction method for multi-spectral acquisitions, where the true image and B_0 field map are directly estimated by solving the corresponding inverse problem.

Methods

For a 3D acquisition without slab selection gradients, the signal obtained using each transmit/receive frequency ν_0^{RT} can be modeled as:

$$s(k_x,k_y,k_z,\nu_0^{\mathrm{RT}}) \propto \int_{\mathbb{R}^3} \rho(x,y,z)p(\nu_0(x,y,z)-\nu_0^{\mathrm{RT}})e^{i2\pi\left[k_x\left(x+\frac{\nu_0(x,y,z)-\nu_0^{\mathrm{RT}}}{\bar{\gamma}G_r}\right)+k_y y+k_z z\right]}dx\,dy\,dz \quad (1)$$

where k_x is the readout dimension and k_y, k_z are the phase-encoding dimensions, G_r is the amplitude of the readout gradient, $p(\cdot)$ is the excitation/refocusing spectral profile, $\rho(x,y,z)$ is the desired image and $\nu_0(x,y,z)$ is the frequency offset due to B_0 inhomogeneity. The spectral profile $p(\cdot)$ is assumed known or calibrated from the data (in this work it is modeled as a Gaussian with FWHM ~2 kHz and linear phase). Therefore, the only unknown parameters in the signal model are $\rho(x,y,z)$ and $\nu_0(x,y,z)$. These parameters are estimated using a nonlinear least-squares (NLLS) fitting procedure [4] after discretizing Eq. (1). We include regularization of $\rho(x,y,z)$ and $\nu_0(x,y,z)$ in the NLLS procedure to prevent excessive noise amplification in regions of rapid field variation (where the conditioning is worst).

Data acquisition: Data were obtained on a phantom containing a cobalt-chromium component of a total knee replacement as well as a plastic replica, using a standard MAVRIC acquisition, with ν_0^{RT} separation of 1 kHz between consecutive spectral bands, 256 readout points and readout bandwidth of +/-125 kHz. An in vivo acquisition with similar parameters was performed on a human subject with total knee replacement.

Results and Discussion

Results from the proposed method are shown in Figs. 1 and 2 (phantom and in vivo results, respectively).

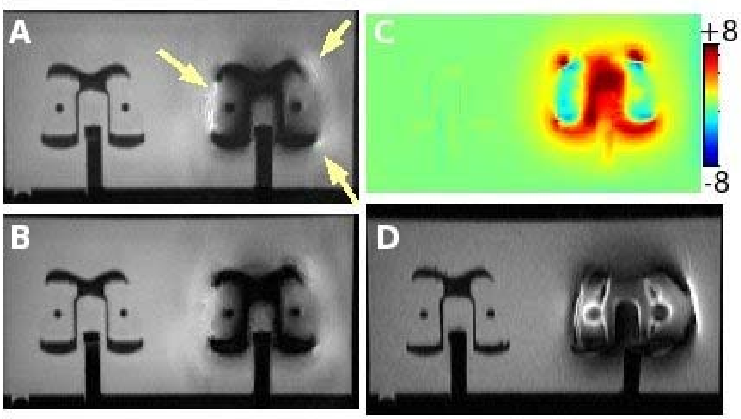

Fig. 1. Phantom results. (A) SOS reconstruction. (B) Proposed reconstruction. (C) Estimated field map (kHz). (D) 2D FSE image containing extreme distortions, shown for comparison. Arrows in (A) indicate regions of rapid field variation where standard reconstruction results in pile-up intensity distortions.

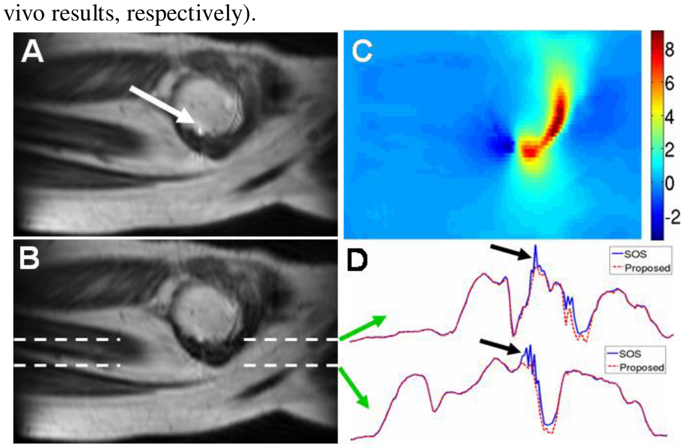

Fig. 2. In vivo results (sagittal view of total knee replacement). (A) SOS reconstruction. (B) Proposed method. (C) Field map (kHz). (D) 1D profiles of the SOS and proposed reconstructions, highlighting (see black arrows) the regions of signal pile-up due to rapid field variation.

The proposed method presents some additional challenges with respect to the SOS reconstruction: firstly, it is more computationally demanding. However, since the modeled distortions occur only in the readout direction, the method can be decoupled for each *(y,z)* location, resulting in a (parallelizable) set of small problems. Secondly, it requires accurate knowledge of $p(\cdot)$, which in this work is estimated from the data itself.

In addition to allowing distortion-free reconstructions, the proposed method has two important properties: (a) it removes the constraints on the choice of offsets (ν_0^{RT}) and spectral profile ($p(\cdot)$), whereas the SOS method requires these parameters to result in a flat "combined" profile [2] (this added flexibility can result, e.g., in faster acquisitions by acquiring fewer spectral bands), and (b) it allows precise characterization of the properties of different sampling schemes using the Cramer-Rao bound [5], which can be used for choosing optimal parameters.

Conclusions

This abstract presents a novel method for the reconstruction of multi-spectral acquisitions such as MAVRIC, based on estimating the image and field map directly from the data. The proposed method overcomes important limitations of current reconstruction methods.

References: [1] Koch K et al, ISMRM, 2008, p 1250 [2] Koch K et al., Magn Reson Med, 2008, in press. [3] Lu W et al., ISMRM 2008, p. 838. [4] Bertsekas DP, *Nonlinear Programming*, Athena Scientific, 1999. [5] Scharf LL et al., Proc of the IEEE Workshop on Stat Signal and Array Proc, 1999, pp 5-8.