Estimation of coil sensitivity profile in k-space for parallel imaging

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Introduction

A good estimation of the local coil profile is essential to reduce the wrap around artifacts in parallel acquisition technique [1]. Conventional method uses a set of low-resolution images to estimate the coil profiles. In this paper, we present an algorithm, which calculates the coil profiles directly in k-space domain. In this way, the errors of the sensitivity profiles due to sharp signal drops in the image domain can be avoided and therefore the method is more robust compared to the conventional low-resolution image method.

Methods

Consider one arbitrary array coil element kc $(1 \le kc \le nc)$ in an nc-channel array coil with the corresponding raw data set for the coil profile estimation $S_{kc}(kp,kl)$ in k-space domain (kp,kl). In addition we define a reference raw data, which can be any arbitrary linear combination of the acquired raw data set $S_{ref}(kp,kl) = \sum_{jc=1...nc} w_{jc} \cdot S_{jc}(kp,kl)$. We assume further that $s_{kc}(ip,il)$ and $s_{ref}(ip,il)$ are the Fourier transformed images in the image domain of the raw data $S_{kc}(kp,kl)$ and $S_{ref}(kp,kl)$ respectively:

$$S_{kc}(kp,kl) \Rightarrow s_{kc}(ip,il) \qquad S_{ref}(kp,kl) \Rightarrow s_{ref}(ip,il) \tag{eq. 1}$$

where we use $\Rightarrow$ to denote Fourier transforms and (ip,il) to denote the coordinate system in the image domain. The coil sensitivity profile $p_{kc}^{ref}(ip,il)$ of the coil kc relative to the reference coil in the image domain can then be given as:

$$P_{kc}^{ref}(kp,kl) \Rightarrow p_{kc}^{ref}(ip,il) = \frac{s_{kc}(ip,il)}{s_{ref}(ip,il)} \tag{eq. 2}$$

which can be also written in k-space domain as a convolution equation:

$$S_{ref}(kp,kl) \otimes P_{kc}^{ref}(kp,kl) = S_{kc}(kp,kl) \tag{eq. 3}$$

By using similar fitting algorithm as proposed in [2], the coil profile in k-space domain $P_{kc}^{ref}(kp,kl)$ can be estimated, which can be in term transformed into image domain to obtain the coil sensitivity profile in the image domain $p_{kc}^{ref}(ip,il)$. The coil profile obtained in this way is relative to the reference raw data set used. The most common way is to normalize the profile in the sum-of-squares sense (sos):

$$p_{kc}^{sos}(ip,il) = p_{kc}^{ref}(ip,il) / \sqrt{\sum_{jc=1..nc} \left| p_{jc}^{ref}(ip,il) \right|^2} \tag{eq. 4}$$

Usually the non-zero components for $P_{kc}^{ref}(kp,kl)$ needn't to be very large. Too many unknowns in the equation system eq. 3 lead to an unstable system. On the other hand, some coils need certain number of coefficients in k-space to properly describe its sensitivity profiles. Depending on coils used and the number of channels available, 10 or less than 10 pixels in each direction (readout and phase encoding) is sufficient for a good estimation.

Results

Figure 1 shows estimated coil profiles using both the conventional low-resolution approximation (dashed lines) and the k-space estimation method proposed in this paper (solid lines). In this example, the raw data is a volunteer study with a four-channel body array coil. The reference raw data is simply a linear combination of all four raw data sets with optimized SNR in the center of the image. The coil profile in k-space domain is assumed to have a size of 256x256 and only 5/11 pixels of non-zero terms in the phase encoding/readout direction. The number of continuously acquired phase encoding lines in k-space center is 24. Only 64 pixels in readout direction are used for fitting. This results in a total number of fitting equations (eq. 3) of (24-4)*(64-10) = 1080. The equation system is solved in the least-square sense.

In Fig. 1, only one data line at a particular readout position is shown. At this readout position, a significant signal drop between line number 40 and 60 exists, which causes large estimation error with conventional low-resolution image method. Because we don't use the low-resolution images, this error doesn't appear in the k-space estimation method, as can be see in Fig. 1.

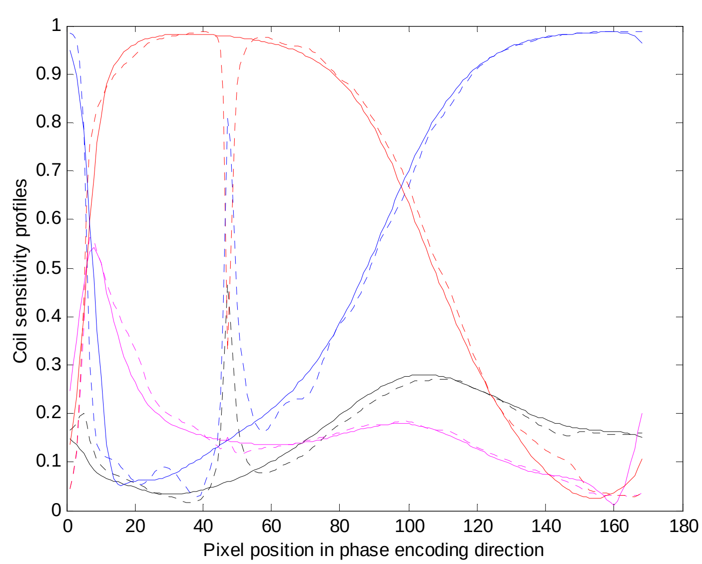

Figure 1: Estimated coil sensitivity profiles using (a) conventional low-resolution image method (dashed line) and (b) the k-space fitting method described in this paper (solid line)

Conclusions

We showed in theory and experiment a novel method to estimate coil sensitivity profiles in k-space domain without generating low-resolution images. Because the coil profiles are fitted from the raw data, the method presented here is not sensitive to strong and sharp signal drops in image domain and therefore suitable for sensitivity profile estimation for parallel imaging.

References

[1] Klaas P. Pruessmann et al, MRM 42:952–962 (1999)
[2] D. K. Sodickson et al, Magn Reson Med 1997;38:591–603