The Use of an Adaptive Reconstruction for Array Coil Sensitivity Mapping and Intensity Normalization

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Abstract
Extraction of coil sensitivity information in vivo is a challenging problem in MRI. Coil sensitivity mapping is important in parallel imaging techniques, as well as in intensity normalization of array coil images. In this abstract, it is demonstrated that the adaptive reconstruction previously presented by Walsh et al can be used to provide both coil sensitivity information and furthermore intensity normalized images. Example of both applications are presented.

Introduction
Over the past decade, a variety of phased-array reconstruction techniques have evolved to address specific problems in MRI [1-2]. In general, multi-coil arrays are used to increase signal to noise ratio. Recently, many parallel acquisition (PPA) techniques have been presented which focus on increasing acquisition speed [3–4].

Most MRI images using array coils are reconstructed using a sum of squares (SOS) reconstruction [1]. In general, the SOS reconstruction is nearly optimal in terms of SNR and requires no extra information in terms of coil sensitivity information. However, undesired large intensity variations can be present when using an SOS reconstruction. In order to correct for this intensity variation, some information about the coil sensitivities must be provided. In general, this is obtained using a body coil reference [4]. Coil sensitivity information is also critical in all PPA applications, and many methods have been proposed to obtain this information.

Walsh et al [2] have proposed an adaptive method for SNR & CNR optimization in conventional array imaging. The array measurement is considered to consist of a desired stochastic signal process *s(*)*, and an undesired stochastic noise process *n(*)*. The array response to each process is characterized by the array correlation matrix

$$\mathbf{R}_s(j,k) = E\left[s_j s_k^{\ *}\right] \quad , \quad j,k = 1,\ldots,N \qquad (1)$$

$$\mathbf{R}_n(j,k) = E\left[n_j n_k^{\ *}\right] \quad , \quad j,k = 1,\ldots,N \qquad (2)$$

where N is the number of elements in the array.

The array filter vector that maximizes the power contrast between *s(*)* and *n(*)*, denoted by the **m**, is the eigenvector of

$$\mathbf{P} = \mathbf{R}_n^{-1}\mathbf{R}_s \qquad (3)$$

having the maximum corresponding eigenvalue [2].

Coil Sensitivity Mapping

The reconstruction vector **m** can be simply used itself as a reasonable approximation to the coil sensitivities as long as the number of pixels used in Eq. 1 is large enough to remove the influence of the spin density variations. However, in general, the original method [2] suffers from errors in the phase of the coil sensitivities including severe phase discontinuities. This problem can be easily avoided by modulating the phase of all the coils by the phase of a single coil of the array. This provides only relative phase information, but this is normally adequate for most applications. This correction also allows the reconstruction vectors, **m**, to be calculated on a coarse grid which can then be interpolated to the final image matrix for rapid reconstructions.

Intensity Normalization

The vector **m** is proportional to the normalized RF sensitivity of each coil, due to the correlation matrix calculation. Therefore, the sum of the reconstruction weights roughly represents the total amount of sensitivity contributed at each point. This can be used to normalize the intensity of the resulting image. In general, we have found the following intensity correction factor to be optimal:

$$F = \left(\sum_N |m|\right)^2 \qquad (4)$$

Although this normalization factor isn't as perfect as a correction based on a body coil reference, it is typically good enough for most applications based on visual examination.

Conclusion
These extensions to the adaptive reconstruction method presented here provide robust in vivo coil sensitivity maps as well as images with normalized sensitivity. This method could have impact in both normal array reconstructions and in the emerging field of parallel imaging.

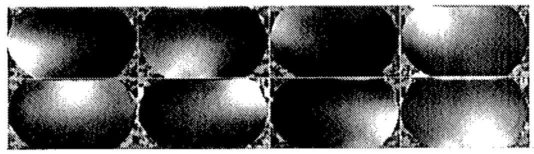

Figure 1. A demonstration of in vivo coil sensitivity mapping. These data were acquired using a single shot HASTE sequence and an 8-element flexible body array in the abdomen of a volunteer.

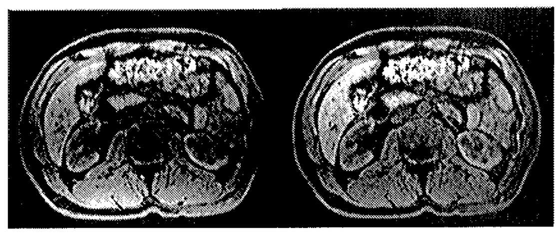

Figure 2. Example of intensity normalization applied to gradient echo imaging in the abdomen **Left:** SOS **Right:** adaptive matched filter with intensity normalization. Data were acquired using a 4-element flexible body array. Both images are shown with the same intensity scale.

Figure 3. Normalization factor for the images of Figure 2 calculated using Eq. 4.

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