Estimation of Images and Sensitivities for Multi-Coil MRI

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Introduction: Estimation of array sensitivity is an important step in parallel imaging (1-3). It often requires a body coil image or assumptions on the spatial variation of the sensitivity. We present a simple method using logarithms for estimating the complex spatial sensitivity of each coil from the complex reconstructed images while simultaneously estimating the true image with a constant spatial sensitivity. This method uses a model based on a uniform sensitivity constraint that requires no body coil reference. The model is easily extendable to parallel transmit arrays (4-6). Human brain data at 3T are presented.

Theory: Let Y be the logarithm of a complex-valued reconstructed image from one of K receiver coils,

$$Y_k = \rho + R_k + \varepsilon_k , \qquad [1]$$

where ρ is the logarithm of the unknown true complex-valued image, R_k is the logarithm of the unknown true complex-valued coil sensitivity, and ε_k is complex-valued random noise. We cannot estimate both R_k and ρ without additional information. The form of the equations suggests estimating the sensitivity by introducing the constraint that

$$\sum_{k=1}^{K} R_k = 0 . \qquad [2]$$

This is a linear constraint (on the log scale) that imposes a constant sensitivity on the average. The estimates of ρ and R_k are

$$\rho' = \bar{Y} \text{ and } R_k' = Y_k - \bar{Y} . \qquad [3]$$

Here $\bar{Y}$ is the average of the Y_k's. The system is really two systems, one for the log magnitudes and one for the phases. The linear constraint will work for the phase system of equations if the phase data is unwound or varies over a small region near zero. The model can be expanded to include J transmit coils as well with the appropriate constraints:

$$Y_{jk} = \rho + T_j + R_k + \varepsilon_{jk} , \text{ where } \sum_{j=1}^{J} T_j = 0 \text{ and } \sum_{k=1}^{K} R_k = 0 . \qquad [4]$$

Here T_j is the logarithm of the complex-valued transmitter sensitivity. The estimates are now:

$$\rho' = \bar{Y} , \; T_j' = \frac{1}{K}\sum_{k=1}^{K} Y_{jk} - \bar{Y} \text{ and } R_k' = \frac{1}{J}\sum_{j=1}^{J} Y_{jk} - \bar{Y} . \qquad [5]$$

In the combined model we have JK observations but only $J + K$ - 1 parameters, therefore, there are $(J$ - 1) $(K$ -1) degrees of freedom available to, for example, estimate the variance of ε_{jk}:

$$s^2 = \sum_{j=1}^{J}\sum_{k=1}^{K}(Y_{jk} - \rho' - T_j' - R_k')^2 \Big/ (J-1)(K-1) . \qquad [6].$$

Another possibility is to use the extra degrees of freedom to estimate interactions between transmit and receive coils.

Methods: The method was tested on a brain imaging data set acquired using a four-channel array (Nova Medical) on a GE 3T scanner. A standard spin-warp GRE sequence was used for the acquisition of 16 axial 5 mm 256x256 slices with a 24 cm FOV (500 ms TR and 60^0 flip angle). The log magnitude and phase of the sensitivities were calculated using Eq. [3]. An unwrapping algorithm was used prior to solving for the phase. Note that a SENSE reconstruction using the estimated sensitivity maps and data (with reduction factors of $R = 1, 2$ and 4) synthesized from the full data will give algebraically equivalent images and is thus unnecessary.

Results: Figure 1 shows results using the four-channel receiver at 3T.

(a) (b) (c) (d) (e)
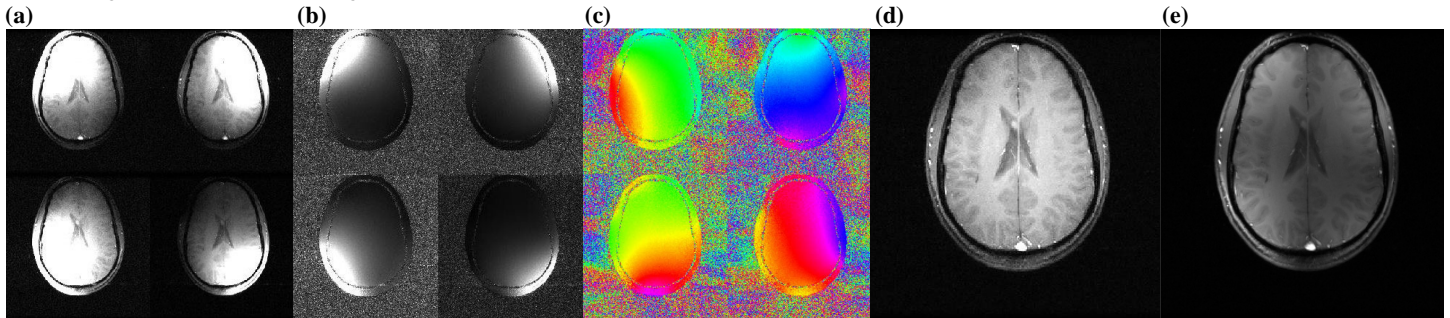
Figure 1. (a) Coil magnitude images. Estimated **(b)** magnitude and **(c)** phase sensitivities. **(d)** Estimated image and **(e)** RMS average from all coils.

Conclusions: We present a simple method using logarithms and a uniform sensitivity constraint that can be used to estimate the sensitivities and composite image for multiple-array MRI. This method is easily extendable to multiple transmitters and may be useful for parallel imaging applications including SENSE and transmit SENSE.

References: (1) Roemer PB *et al.* MRM 1990;16(2):192-225. (2) Wright SM, Wald LL. NMR Biomed 1997;10(8):394-410. (3) Pruessmann KP, *et al.* MRM 1999;42:952-962. (4) Junge S, *et al.* 12th ISMRM 2004; Kyoto. p 41. (5) Katscher U, *et al.* MRM,2003;49(1):144-150. (6) Zhu Y. MRM 2004;51(4):775-84. Work supported by the R01 MH66066 and R21 DA015900.