ESTIMATION OF ELECTRIC FIELD MAPS FROM B1+ AND TRANSCEIVE PHASE MEASUREMENTS FOR LOCAL SAR EVALUATION

Alessandro Sbrizzi[1], Hans Hoogduin[2], Jan J Lagendijk[2], Peter R Luijten[2], and Cornelis A van den Berg[3]
[1]*Imaging Division, UMC Utrecht, Utrecht, Utrecht, Netherlands,* [2]*UMC Utrecht,* [3]*UMC Utrecht, Netherlands*

Introduction SAR estimation is an important topic in high field MRI, since it is directly related to patient safety. To compute the SAR, the electric fields generated by the RF coil should be estimated. Recent work [1,2,3,4] shows the possibility to partially extract this information from the magnetic fields (B_1^+). Here, an improvement of the method employed in [1,2] is demonstrated. The reconstruction of the complex *z*-component of the electric fields is done on the basis of a 3D model. The electromagnetic fields can be efficiently expressed in terms of few ad hoc constructed basis functions. The expansions coefficients are found by fitting the measured data to the model. Numerical simulations and in vivo measurements confirm the validity of the method for a 2ch 7T transceive birdcage headcoil.

Methods The method employed in [1,2] made use of the explicit relationship between B_1^+, B_1^- and E_z fields when they are projected into the space of Bessel/Fourier functions. Exploiting this relationship, a fitting procedure could be derived to recover ph(B_1^+) and complex E_z from measured $d_1=|B_1^+|$ (the B_1^+ map) and d_2=ph($B_1^+B_1^-$), that is, the transceive phase [5]. The central idea there was to introduce the vector potential A and exploit the fact that B=curl A assuming that $A=(0,0,A_z)^T$ [6]. Since A is a solution of the Helmholtz equation [6], it can be efficiently represented as a Bessel/Fourier functions expansion. Furthermore, it can be shown that also B_1^+, B_1^- and E_z can be represented by similar expansions, which share the same coefficients. Generalizing the same idea to $A_x\neq0$ and $A_y\neq0$ and arbitrary basis functions, we can approximate each component of A as expansion of few basis functions f_ℓ (Eq. (1), for small L). Since B=curl A and $B_1^+=(B_x+iB_y)/2$ and $B_1^-=(B_x-iB_y)/2$, expansions for B_1^+ and B_1^- in terms of f_ℓ can be derived (Eq. 2). These last expressions can be discretized and written in matrix-vector notation (Eq. 3) where $\mathbf{F}^+$ and $\mathbf{F}^-$ are the encoding matrices and $\mathbf{c}_{tot}$ is the concatenation of the common coefficients vectors $\mathbf{c_x}$, $\mathbf{c_y}$ and $\mathbf{c_z}$. Once the generalized model is fitted to the measured datasets d_1 and d_2, the derived coefficients $\hat{\mathbf{c}}_{tot}$ can be used to reconstruct B_x and B_y. The electric fields can be reconstructed from E=curl$B/(\sigma+i\omega\varepsilon\varepsilon_0)$ [4]. The SAR estimation follows from its definition in Eq. 4.

Materials The new method was tested for a 2ch 7T birdcage headcoil for a human head model. First, full electromagnetic fields were computed with SEMCAD [7]. From these fields, datasets d_1 and d_2 were assembled and used as input for the fitting procedure. Then, data from an in vivo measurement was employed. The spherical functions were used for the expansions (Eq. 5) where j_m denotes the spherical Bessel function of the first kind of order m, and Y_n^m is the spherical harmonic of degree n and order m. These functions arise naturally from the solution of the Helmholtz equation in the spherical coordinates system. The expansion was truncated at N=3 resulting into 16 basis functions. The scaling factor κ depends on the conductivity σ and the permittivity ε. These values were set to be equal to 0.3 S/m and 50, respectively [1,2].

(1)
$$A_x = \sum_{\ell=1}^{L} c_{x,\ell} f_\ell \qquad A_y = \sum_{\ell=1}^{L} c_{y,\ell} f_\ell \qquad A_z = \sum_{\ell=1}^{L} c_{z,\ell} f_\ell$$

(2)
$$B_1^+ = 1/2 \sum_{\ell=1}^{L}\left[c_{z,\ell}\left(\frac{\partial f_\ell}{\partial y} - i\frac{\partial f_\ell}{\partial x}\right) - c_{y,\ell}\frac{\partial f_\ell}{\partial z} + ic_{x,\ell}\frac{\partial f_\ell}{\partial z}\right]$$
$$B_1^- = 1/2 \sum_{\ell=1}^{L}\left[c_{z,\ell}\left(\frac{\partial f_\ell}{\partial y} + i\frac{\partial f_\ell}{\partial x}\right) - c_{y,\ell}\frac{\partial f_\ell}{\partial z} - ic_{x,\ell}\frac{\partial f_\ell}{\partial z}\right]$$

(3)
$$\mathbf{b}_1^+ = \mathbf{F}^+\mathbf{c}_{\text{tot}} \qquad \mathbf{b}_1^- = \mathbf{F}^-\mathbf{c}_{\text{tot}}$$

(4)
$$\text{SAR} = \frac{\sigma}{2\rho}|E|^2$$

(5)
$$f_\ell = j_m(\kappa\rho)Y_n^m(\theta,\phi), \quad 0\le n\le N, \quad -n\le m\le n, \quad \ell=n^2+n+m+1, \quad \kappa=\epsilon_0\epsilon\mu_0\omega^2 - i\sigma\omega\mu_0$$

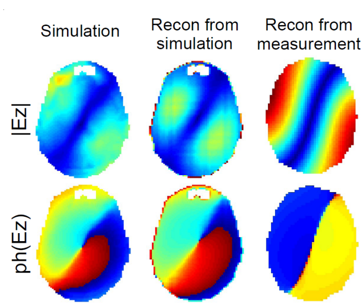

Figure 1 The simulated and the reconstructed E_z fields for the simulation and the measurement.

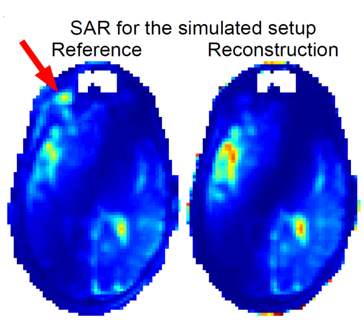

Figure 2 SAR for the simulation

Results The reconstructed E_z and the estimated SAR for a transverse slice are shown in Fig. 1 and 2, respectively. Apart from the hotspot in the left occipital region (see arrow), the overall similarity between the reference and the predicted SAR is good. Note that from the same coefficients we can reconstruct the B_1^+ and B_1^- fields (Fig. 3).

Conclusions The generalized 3D model based on the spherical basis functions is able to give a good estimate of the E_z fields and the local SAR. The model can be easily expanded to incorporate information about B_z and hence to quantify the transverse components of the E fields for a more accurate SAR evaluation. For this scope, B_z values at the head-air interface should be measured and used as additional input.

References [1] Sbrizzi A et al. ISMRM 2011 p. 3855 [2] Sbrizzi A et al. ISMRM 2011 p. 3889 [3] Katscher U. et al. ISMRM 2011 p. 494 [4] Buchenau S. et al. ISMRM 2011 p. 493 [5] Voigt T et al. MRM 66: 456-466 (2011) [6] van den Berg CAT et al. http://www.staff.science.uu.nl/bisse101/Articles/proc2007.pdf [7] Speag, Switzerland

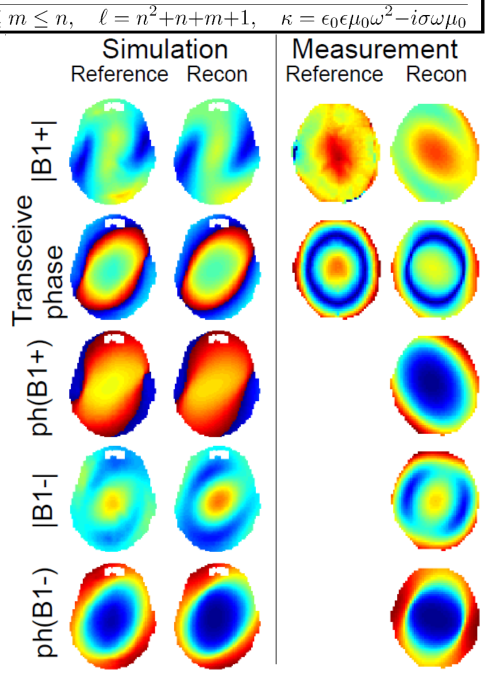

Figure 3 The simulated and the reconstructed B_1 fields for the simulation and the measurement.