Localization of vortex shaped current sources in a physical torso phantom

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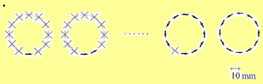
INTRODUCTION

The first experimental study of the influence of increasing vortex currents on electric and magnetic signals in a human torso phantom [1] proved the well known fact that vortex currents can be detected only by the magnetic measurements. They found out that source reconstruction with unconstrained focal source models performed well for a single dipole only, while minimum norm source reconstruction yielded reasonable results only for a few of the dipole configurations.

In this study, we applied a source model with a constant current along the circular arc [2] to explain the measured data from [1]. The current was approximated from magnetic data by uniformly distributed current dipoles positioned tangentially along the arc (Fig. 3). From the electric data the best fitting equivalent single current dipole was found. In both cases, we applied boundary element method (BEM) using model in Fig. 2.

MEASUREMENTS

The active vortex currents in [1] were modeled by a set of twelve single current dipoles positioned 15 mm apart and arranged in a circle with a circumference of 180 mm. Magnetic (33 magnetometers perpendicular to the chest and 2x33 planar gradiometers) and electric (56 electrode, see Fig. 2) data were recorded simultaneously while the dipoles were switched on stepwise one after the other..



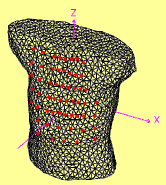


Fig. 2. BEM model: 3606 triangles, 56 electrodes.

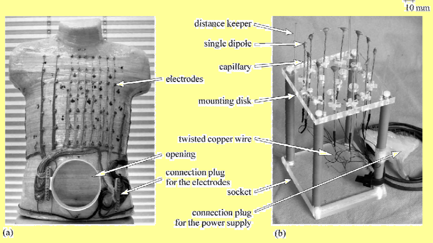
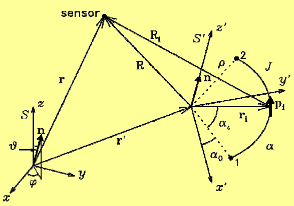


Fig. 1:(a) The realistic torso phantom with Ag/AgCl-electrodes. (b) The vortex shaped dipole source consisting of 12 single current dipoles.

MODEL DESCRIPTION



The current source is completely described by nine parameters $\beta = (\mathbf{r}', \rho, \alpha_0, \alpha, \vartheta, \varphi, p)$:

$\mathbf{r}'$ – arc origin and ρ – arc radius

α_0 – arc starting angle and α – arc length

ϑ – polar and φ – azimuth angle of the normal $\mathbf{n}$

p – strength of each dipole $\mathbf{p_i}$ ($p = J\rho\alpha/N$)

Rotation $S \longrightarrow S'$
$$\begin{pmatrix} \cos\vartheta\cos\varphi & \cos\vartheta\sin\varphi & -\sin\vartheta \\ -\sin\varphi & \cos\varphi & 0 \\ \sin\vartheta\cos\varphi & \sin\vartheta\sin\varphi & \cos\vartheta \end{pmatrix}$$

Normal $\mathbf{n} = (\sin\vartheta\cos\varphi, \sin\vartheta\sin\varphi, \cos\vartheta)$

Fig. 3: Schematic view of the curved current source in the sensor coordinate system S and the source coordinate system S'. The transformation from S to S' is defined with the translation by $\mathbf{r}'$, rotation by φ around z-axis and rotation by ϑ around y'-axis.

The current J is flowing from the point 1 to the point 2 and is estimated with $N+1$ uniformly distributed tangential dipoles $\vec{p}_i = p_t\vec{t}_i$ and magnetic field is calculated as

$$\vec{B}(\vec{r}) = \sum_{i=0}^{N} \vec{B}_i(\vec{r},\beta) = \frac{\mu_0 p_t}{4\pi} \sum_{i=0}^{N} \frac{(\vec{t}_i \times \vec{R}_i)}{R_i^3}, \quad \vec{R}_i = \vec{R} - \vec{r}_i, \quad \vec{R} = \vec{r} - \vec{r}' = (X,Y,Z),$$

where $\vec{R}_i$ connects the origin of local (arc) coordinate system S' in $\vec{r}'$ with the magnetic sensor in $\vec{r}$. Above equation has to be expressed with the source parameters β

$$B_{xi}(\vec{r},\beta,p_t) = \frac{\mu_0 p_t}{4\pi} \frac{\left[\sin\alpha_i(Y\sin\vartheta + Z\cos\vartheta\sin\varphi) + Z\sin\varphi\cos\alpha_i + \rho\sin\vartheta\cos\varphi\right]}{R_i^3},$$

$$B_{yi}(\vec{r},\beta,p_t) = \frac{\mu_0 p_t}{4\pi} \frac{\left[\sin\alpha_i(X\sin\vartheta + Z\cos\vartheta\cos\varphi) + Z\sin\varphi\cos\alpha_i + \rho\sin\vartheta\sin\varphi\right]}{R_i^3},$$

$$B_{zi}(\vec{r},\beta,p_t) = \frac{\mu_0 p_t}{4\pi} \frac{\left[\cos\vartheta\sin\alpha_i(X\sin\varphi - Y\cos\varphi) - \cos\alpha_i(X\cos\varphi + Y\sin\varphi) + \rho\cos\vartheta\right]}{R_i^3},$$

and can be applied in the fitting procedure where the best parameters β are determined.

[1]Liehr M, et al. Vortex shaped current sources in a physical torso phantom, Ann Biomed Eng 33:240-247, 2005

[2]Jazbinsek V, et al. Localization of curved current sources in magnetocardiography, Biomed Tech 46(Suppl 2):141-143, 2001

DISCUSSION AND CONCLUSIONS

Goodness of fit was estimated by the relative error (RE). Localization error (LE) was estimated by the difference between center of gravity (COG) of dipoles in the original source and COG of dipoles in the arc model. Reconstruction results show (see, selected examples in FIgs. 4-6) that the arc model gives excellent results (RE<0.02 for magnetometer data) for all sources with 2 or more dipoles switched on. However, the LEs show that the arc model can be effective only when a half of the circle or more is switched on (LE<10 mm and reconstructed radius higher than a half of the original source radius). For other sources with less dipoles activated, the reconstructed arc tends towards small closed loop (radius<3 mm).

RESULTS

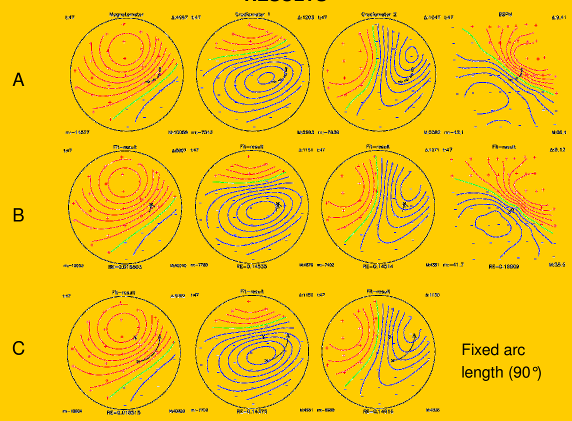


Fig. 4 A – measured data with 4 dipoles switched on for all modalities: 33-magnetoneters (Bz), 33-planar gradiometers 1 (∂Bz/∂x) and 2 (∂Bz/∂y), 56-lelectrodes (BSPM). B – unconstrained reconstruction of the arc source for the magnetic data and singled dipole source for the electric data. For this case the reconstructed arc has very small diameter (<3 mm) and it is almost closed. C – reconstructions of the arc source with the fixed length. In this case, we obtained diameter of almost twice the original one.

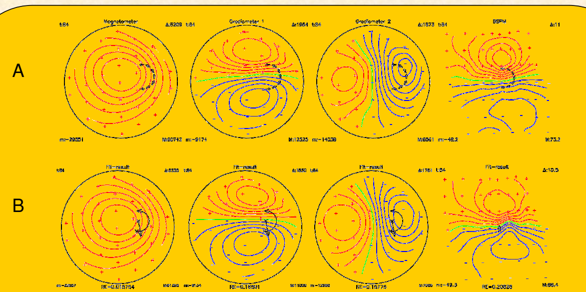


Fig. 5 A – measured data with 7 dipoles switched on (half a circle). B – unconstrained reconstruction of the arc source for the magnetic data and singled dipole source for the electric data. In this case, the reconstructed arc almost perfectly fits the original source configuration.

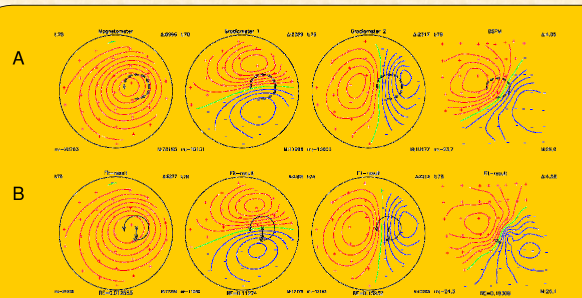


Fig. 6 A – measured data with 10 dipoles switched on (3/4 of a circle). B – unconstrained reconstruction of the arc source for the magnetic data and singled dipole source for the electric data. Like in Fig. B, the reconstructed arc almost perfectly fits the original source configuration.