TIME VARYING CURRENT DENSITY DISTRIBUTIONS IN A HUMAN HEART AND BRAIN

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A new method for visualizing and post-processing 3D time varying vector fields is presented. This method is based on equivalent ellipsoids fitted to these fields. The new technique has been tested on vector fields representing current density reconstruction results based on biomagnetic data from a cardiac patient and a neurological patient. Multiple foci in the vector fields are extracted by multiple ellipsoids, which are fitted in an iterative manner. The new method enables visualization of even very complex vector fields, as well as statistical post-processing.

INTRODUCTION

Current density reconstructions (CDRs) are used to assess cardiac activation[1] and brain function[2] based on non-invasively obtained bioelectromagnetic data. CDRs are vector fields where each vector represents the current density in a volume element or on a surface element. Often CDRs are very complex and a method is needed to visualize these CDRs. Moreover, for statistical data analysis (e.g. in group studies) a method is needed which enables a comparison of time varying CDRs within groups of patients or volunteers. Previously, e.g. a parameterization based on the visual inspection of up to 8 sub-areas of the heart has been applied[3]. These sub-areas have been classified manually into active or not active ones and statistics have been computed about the number of classified sub-areas. One clear disadvantage of this method is that it yields only a very rough statistical description of the location and extent of the activation maximums and minimums. In this paper, we expand a new technique, which has been previously introduced for 2D planes[4] to full 3D time varying problems. This technique is based on the parameterization of CDRs with the help of equivalent ellipsoids. The usefulness of our new technique is demonstrated through CDR data from a cardiac patient and a neurological patient.

EQUIVALENT ELLIPSOID TECHNIQUE

An equivalent ellipsoid has been defined as a 3D ellipsoidal object fitted to a current density distribution region in which the magnitude of the currents is above a certain threshold[4]. The equivalent ellipsoid is defined by its three orthogonal semi-axes in a local coordinate system. First, the center of gravity (COG) of the marked region has been calculated. The position of the COG has been used as a new origin of the local coordinate system. The direction of the main axis has been computed on the basis of the weighted longest distance (LD) from the COG according to:

$$d_{\max} = \max_{i=1,\ldots,N_T} M_i \left| \mathbf{P}_i - \mathbf{P}_{COG} \right|, \tag{1}$$

where M_i denotes the magnitude of the moment of i-th current density vector and N_T is the number of current density vectors in the thresholded region. Alternatively, a second approach of the estimation of the main axis based on the dominant direction (DD) of the vectors has been

tested. In the next step, the local coordinate system has been rotated so, that the main axis represents the *z*-axis. In the rotated coordinate system, the normalized position of the current density vector with the maximal distance from COG on the new *x-y* plane has been used as the direction of the second semi-axis of the equivalent ellipsoid. The direction of the third axis has been determined by the cross product of the first two axes. For multi-focal distributions the basic algorithm is applied iteratively, including an additional parameter, the separation radius R_s. R_s selects a certain part of the thresholded CDR to which the equivalent ellipsoid is fitted. Using a local COG and R_s, only the current density vectors within this restricted region are included into the fit of the equivalent ellipsoid. After the first equivalent ellipsoid fit, the second local maximum is searched in the rest of the thresholded CDR. Based on the separation radius and the new position of the local maximum the new local COG has been computed, and the next equivalent ellipsoid is estimated. The procedure is repeated until user break or up to the last current density vector in the thresholded distribution. The algorithm described above is currently applied to each time step separately in order to visualize time varying 3D CDRs.

CARDIAC EXAMPLE

The measurements have been taken in a magnetically shielded room (AK3b, Vacuumschmelze, Hanau, Germany) at the Biomagnetic Center in Jena, Germany. The magnetic field has been recorded with a twin dewar biomagnetometer system (2×31 channels) with first order axial gradiometers (Philips, Hamburg, Germany). We have measured the magnetocardiagram of a patient aged 70 years who had non-sustained ventricular tachycardia that developed after anterior left ventricular myocardial infarction and apical aneurysm. We have recorded 600 s of signals at a sampling rate of 1000 Hz. The last 40 ms of the bi-directional 30 Hz highpass filtered depolarization signal (late potentials, LP) have been used for inverse computations. A 3D MRI data set of the chest of the patient has been obtained. A Boundary Element model consisting of the left and right lungs as well as the outer torso surface has been applied for the magnetic field computations. The surface of the *lv* has been segmented from the MRI data set and subsequently used for the restriction of the source space. The current density vectors have been determined through a minimum norm least squares algorithm (L_2 norm) for all time points.
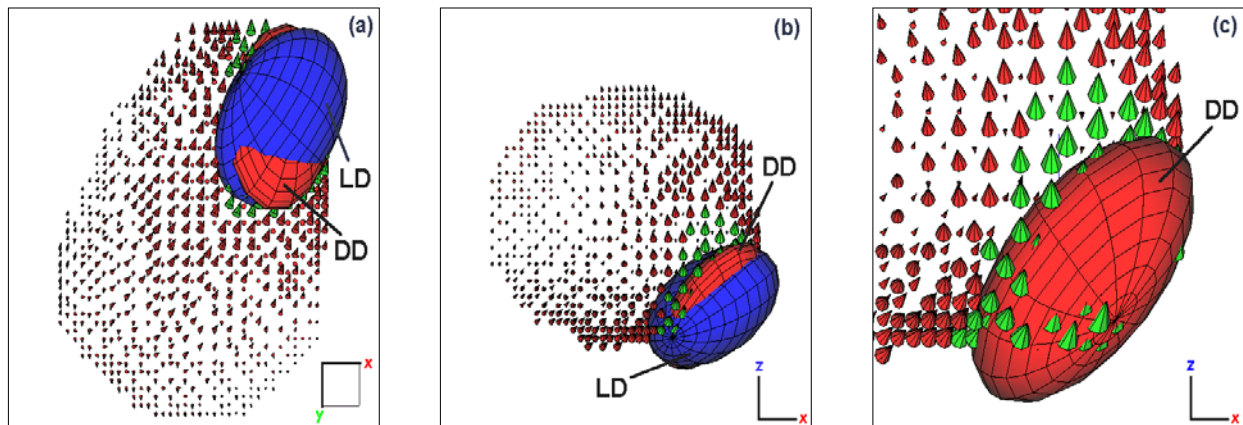
Fig. 1. Equivalent ellipsoids fitted to the reconstructed current density distribution located on the surface of the *lv*. Diaphragmal view (a), apical view (b), and magnified apical view for DD approach (c). The thresholded distribution is indicated by light cones.

NEUROLOGICAL EXAMPLE

As a part of a larger study we have measured 31 channel DC MEG using the biomagnetometer described above in a patient with pharmacological induced migraine (nitroglycerin spray). The biomagnetometer has been positioned above the parietal-occipital cortex and one hour of continuous data with a sampling rate of 40 Hz (0 – 15 Hz bandwidth) has been obtained. Large amplitude waves have been identified in the raw data and have been used for minimum norm estimation as described above. A 3D MRI data set of the head has been obtained, the inner skull surface has been segmented and triangulated, and a one compartment Boundary Element model has been constructed and applied for source reconstruction. The source model has consisted of 23564 current density vectors on the segmented brain surface (3.2 mm average distance).
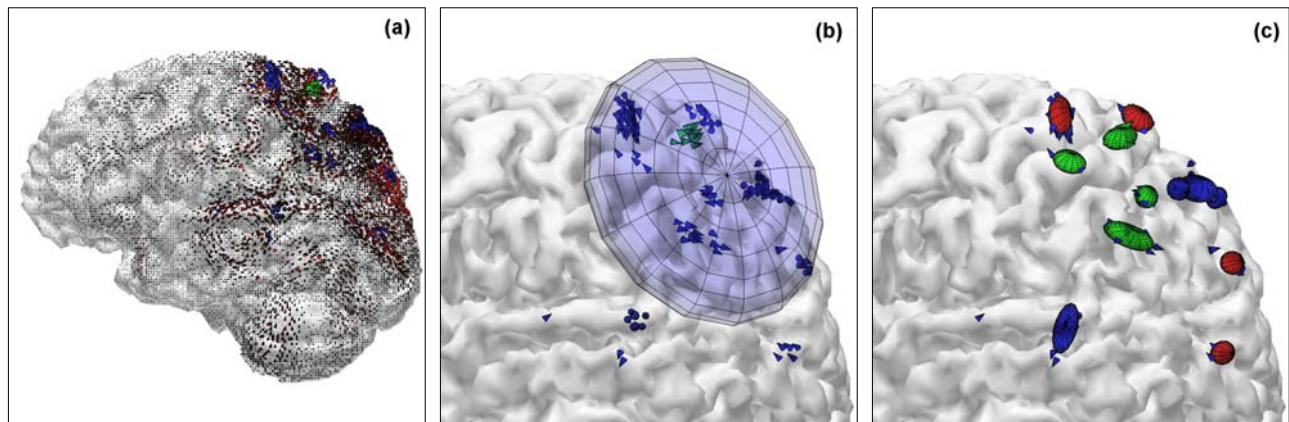
Fig. 2. Results of the current density reconstruction for a patient with pharmacological induced migraine in side view (a) and enlarged side view (b,c). An equivalent ellipsoid with $R_s=\infty$ (b) and ellipsoids with $R_s=12$ mm (c) fitted to the CDR.

CONCLUSION

We have presented a new technique for post-processing CDRs which will support visualization and statistical analyses. Although we have presented only examples from the field of biomagnetism, it is possible to apply our technique to other types of vector fields.

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