Correlation Coefficient Scanning to Identify Localised Activity

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INTRODUCTION

In this paper we suggest a method of approaching one biomagnetic modelling problem where subjective judgements are common; the identification of the number and locations of discrete regions of activity. These regions are often modelled as current dipoles.
In multi-dipolar systems several different modelling approaches may be adopted. If there is *a-priori* evidence for a particular set of fixed local generators it is appropriate to use a model comprising a limited number of fixed dipoles of time varying activity [1]. However such a simplification may not be justified. Then there is some difficulty as the full multiple-dipole inverse problem has poor convergence. In this paper, we describe a method in which a preliminary distributed current solution that has minimal *a priori* assumptions is subsequently analysed to identify individual dipole patterns.
A preliminary algorithm [2] was based on the observation that the distributed current algorithm that we use [3] produces a characteristic extended current image $< \mathbf{J} >$ if the source is a dipole. A simple template $\mathbf{T}$, which mimicked this pattern, was scanned over the image to produce a map of the cross-correlation between $\mathbf{T}$ and $< \mathbf{J} >$. This algorithm was robust and discriminating. Carrying on from this work, we have improved the template function and have extended the method to three dimensions.

THE CORRELATION COEFFICIENT METHOD

The present method is based on a distributed current algorithm [3] that produces the expectation value of the current density associated with given field data. To a first approximation, the current image is instrument-independent. The algorithm consists of the following steps:

1. The expectation value $< \mathbf{J_m} >$ of the current density is computed from the data [3].
2. For each point on a grid in source space the forward problem is solved for orthogonal current dipoles at that point.
3. The optimum dipole is found by maximising the cross correlation between the measured signal and the signals computed in the previous step.
4. Using the signal generated by the optimum dipole, a second expectation value $< \mathbf{J_t} >$ of the the current density is calculated.
5. The cross correlation between $< \mathbf{J_m} >$ and $< \mathbf{J_t} >$ is calculated.
6. Steps 2 to 5 are repeated for all other grid points.
7. A map of the optimised cross coefficient is displayed.

(a) (b) (c)

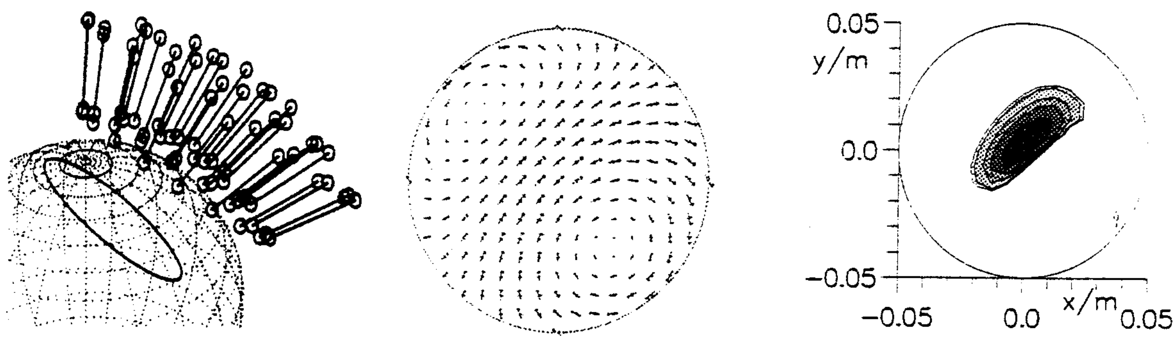

Figure 1: (a) The experimental geometry showing source disk, conducting sphere and gradiometer positions. (b) $< \mathbf{J_m} >$ computed from the data generated by a single (central) dipole. (c) The cross correlation map for the plane containing the source dipole. The dipole is at the origin.

The method is not restricted to any particular experimental geometry but, for present purposes, we have used that shown in Figure 1a. The detectors are as in the BTi 37 channel system. The patient's head is modelled as a sphere and the source space (i.e. the volume where sources are allowed) consists of either a tangential 2-d disk (as in this case) or a 3-d cylinder. The dipole in sphere model is used in all calculations.
The expectation value of the computed current density $< \mathbf{J} >$ consists of a region of large magnitude at the dipole position lying between two current vortices of opposite handedness (Figure 1b). This extended pattern results from the finite number and the forms of the functions used in the reconstruction algorithm. The output of our correlation coefficient algorithm is given in Figure 1c. The contour lines range from 90% to 100% of the maximum value in steps of 2%. This scale is used in all figures.
In step 3, we have chosen to identify the optimum dipole for each grid position by calculating the correlation coefficient r in measurement space because, framed in this way, the maximisation problem is linear in the coordinates of the dipole moment. An alternative and simpler method of choosing the optimum dipole is by aligning it along the local direction of $\mathbf{J_m}$. This yields similar results.

RESULTS

All of the data used in this paper is computer generated from a small number of dipoles: random noise equal to a specified percentage of the peak to peak signal value is added. The method has been tested on single and multiple (up to three) dipole data sets using the instrument shown in Figure 1a. Typically we are able to locate dipoles to about 5 mm in three dimensions. There is insufficient space here for more than two examples.

(a)

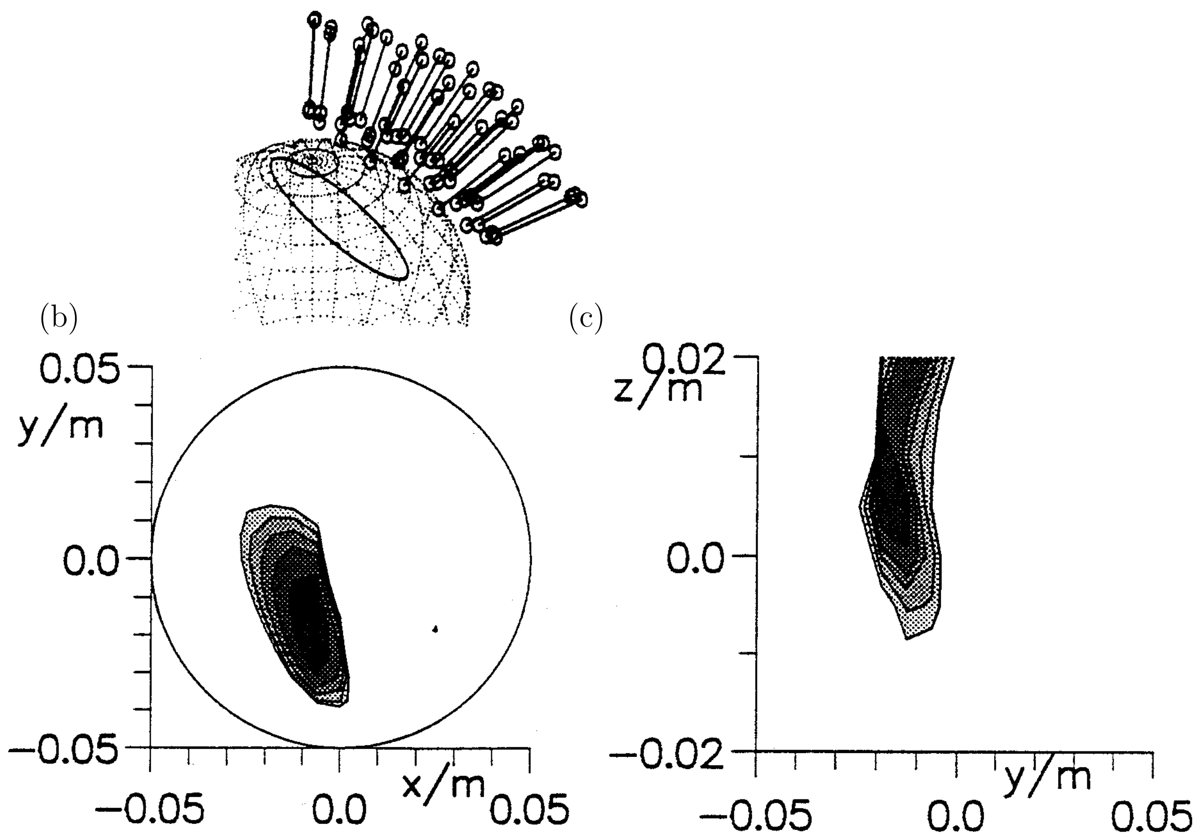

Figure 2: (a) The signal map for the 37-channel system and a single dipole source with 30% noise added. (b) The 2-d cross-correlation map (for a 2-d disk source space). The true dipole position is (-1,-1,0). (c) An y-z section of the 3-d cross-correlation map (for a cylindrical source space).

The first is a single dipole problem in which 30% noise has been added to the data (Figure 1a). The cross-correlation map for a planar source disk intersecting the true dipole position is shown in Figure 2b. Figure 2c shows a cross section through the output 3-d cross-correlation map when the source space consists of a 3-d cylinder. The depth (the most difficult parameter) is found quite accurately, i.e. with an error of less than 5mm.

In Figure 3 we illustrate the discrimination of the method by applying it to data generated by two dipoles of at the same depth. Once again 30% noise has been added. The correlation coefficient map distinguishes clearly the two sources, although it exaggerates their separation and, in 3-d studies, underestimates their depth. These effects originate in the low-pass spatial filtering properties of the distributed current algorithm and the inherent context sensitivity of the dipolar patterns.

(a) (b)

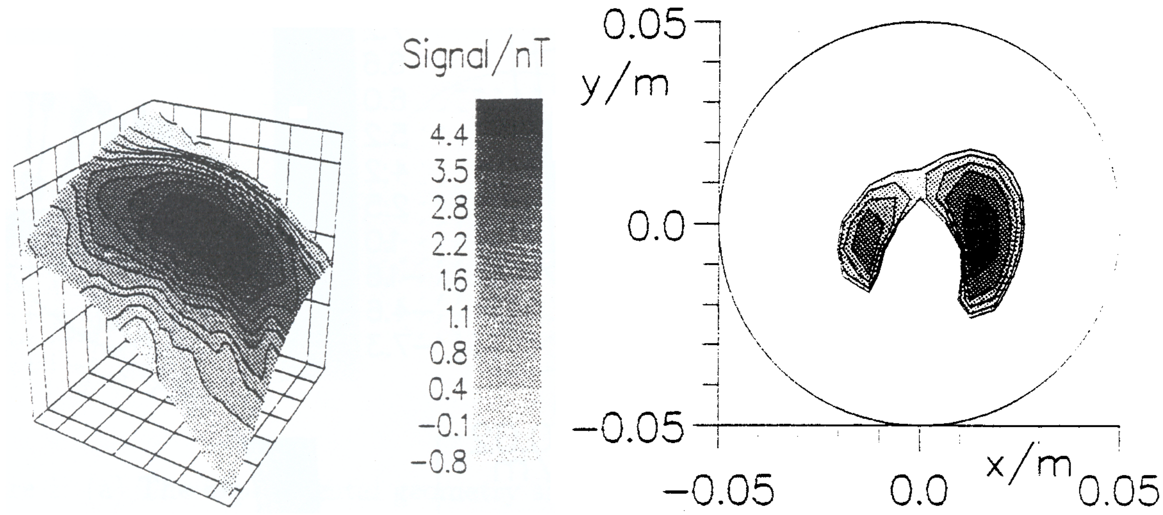

Figure 3: (a) The signal map for two anti-parallel dipoles 2 cm apart with 30% added noise. (b) The 2-d cross-correlation map (assuming a 2-d disk source space) at the correct depth. The dipoles are at (1,0) and (-1,0).

CONCLUSIONS

The method is aimed at providing an objective means of deciding whether a signal is generated by a number of current dipoles and at estimating their parameters. As such it will be a useful tool in handling data where there is some difficulty in deciding the appropriateness of dipole analyses. For such cases, we would suggest that an initial analysis in terms of a distributed current image [3] can be developed into a localised generator representation after scrutiny using our algorithm.

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