Signal analysis techniques for localising spikes and slow waves based on MEG/EEG data

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***Abstract* – Two abnormalities in the spontaneous magnetic brain activity of patients with tumours and epilepsy are investigated: slow waves and inter-ictal spikes. Signal analysis techniques are demonstrated to localise their underlying generators, project these sources onto the patient's MR scan and to compare their locations. The clinical importance of this study is to get insight into the question whether the (abundant) slow waves can be used as a diagnostic substitute for the (relatively rare) inter ictal spikes.**

I. INTRODUCTION

Magneto Encephalography (MEG) is the magnetic equivalent of the well-known Electro Encephalography (EEG). The spatial distribution of the magnetic field recorded from the brain can be used to localise its underlying electric generators in the brain. This localisation technique is based upon a mathematical model that predicts, for a given source (a current dipole), embedded in a conductor (e.g. a sphere), the distribution of the magnetic field at the MEG sensors. The dipole position and moment parameters are estimated from the data using a least squares criterion.

The MEG (and EEG) data of patients with epilepsy contain abnormalities, for which it is interesting to apply this dipole localisation technique. One of these abnormalities consists of inter ictal epileptic spikes, which are events during which the MEG (or EEG) signal sharply increases during a short period (<70 ms.). For patients with epilepsy who are insensitive to medication, the localisation of inter ictal spikes is potentially of important diagnostic value, when epilepsy surgery is considered. When it is assumed that epileptic spikes are generated at the epileptic zone, the dipole position indicates which area could be considered for resection.

Another abnormality in the MEG (EEG) data of patients with epilepsy, called slow wave or delta band activity, is the presence of strong oscillations between 1 and 4 Hz. The origin of these oscillations is much less clear than the epileptic spikes. They are not specific for epilepsy, but they also dominate MEG/EEG signals with other diseases, like stroke and brain tumours. Compared to spikes, which are generally rare (sometimes not more than two per hour) delta band activity, once it is present, is present almost continuously.

The goal of our study is to investigate the spatial relationship between spike and delta generators. When it can be confirmed that these generators coincide [1], delta band generators can ultimately play an important role in the pre-surgical evaluation of epilepsy. In this paper we describe the signal analysis techniques that were developed for our project and we present the first results obtained.

II. METHODS

The MEG system in Amsterdam consists of 151 sensors that record the radial component of the magnetic field. When the magnetic field recorded at sensor i, at some time sample, is denoted by B_i and the predicted magnetic field, caused by a current dipole with parameters $\mathbf{p}$ is denoted by $\tilde{B}_i(\mathbf{p})$, we have, if ε_i is the background noise:

$$B_i = \tilde{B}_i(\mathbf{p}) + \varepsilon_i \quad . \quad (1)$$

When ε_i is Gaussian noise, the maximum likelihood estimator of $\mathbf{p}$ is obtained by solving the following minimising problem

$$H = \min_{\mathbf{p}} \frac{\sum_i \left(B_i - \tilde{B}_i(\mathbf{p})\right)^2}{\sum_i B_i^2} 100\% \quad . \quad (2)$$

The minimum of (2), expressed as a percentage, is called the residual error. In [2] it is demonstrated how this minimisation problem can be solved efficiently, by exploiting the fact that the dipole moments are linear model parameters, so that they can be solved analytically from (2). For the dipole position parameters a global

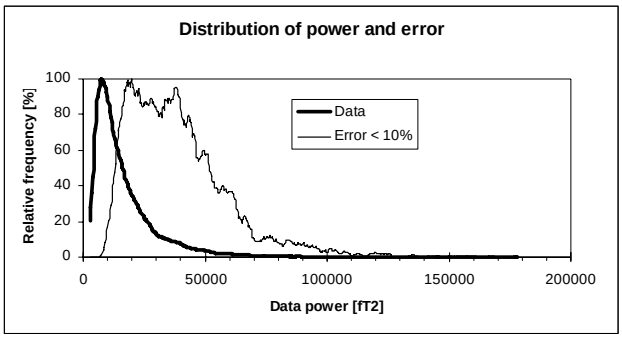

Figure 1. *The dipoles with small residual errors abound at time samples with a large data power.*

search can be performed over the region of interest (the brain). When the same global search grid is used on all time samples, forward model computations ($\tilde{B}_i$) can be performed in advance and stored in tables. In this way, the global search algorithm is not only useful in avoiding local minima problems, but it also contributes to an efficient way to solve the dipole estimation problem at multiple time samples.

A. The delta generators

To localize the delta band generators, the MEG data are band-pass filtered between 1 and 4 Hz, and the good fitting dipoles (residual error<10%) of the filtered data are detected and projected on the MR scan. By fitting a current dipole on every time sample it appears [3] that the good fitting dipoles merely coincide with time points with large data power ($=\sum_i B_i^2$), see figure 1. This finding can be used to improve the efficiency of the algorithm, when one admits the occurrence of false negative points. By skipping all samples with a data power of less than twice the average of the data set, only 10 % of the data points has to be subject to the dipole fitting procedure, whereas 50 % of the good fitting dipoles are found.

B. The spikes

Spikes were detected by visual inspection by a trained clinical neurophysiologist (MP). Before dipole fitting, the spikes were grouped based on spatial and temporal similarity of the wave shapes, using a automatic spike clustering algorithm [4]. To improve the signal to noise ratio (SNR), outliers were removed and the spikes within each group were averaged. Only the the good fitting dipoles (residual error< 10%) of each group were projected onto the MR scan.

C. The head model

Realistic models were used to describe the shape of the brain compartments of the individual subjects. These models were derived from the individual's MR scan using a semi-automatic algorithm, described in full detail in [5].

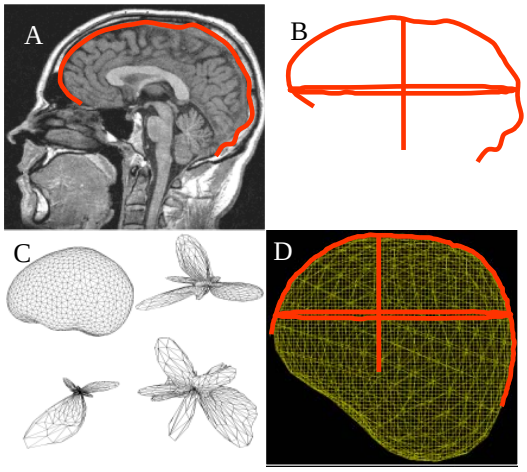

Figure 2. ***A*** *shows the MR with the manually sketched brain in the sagittal direction.* ***B*** *shows the sketched brain in three different directions and* ***C*** *shows the experimental brain shape functions that are fitted to* ***B****.* ***D*** *shows the resulting brain triangle model.*

Instead of cumbersome image processing algorithms, our method is based on the fitting of experimental brain shape functions (derived from a small data base of MR scans that were segmented very precisely) onto a rough sketch of the brain shape of each patient in three orthogonal directions, see figure 2. The main advantage of our method is that it exploits the fact that brains of different subjects are quite similar in shape.

III. RESULTS

In figure 3 the good fitting dipoles are projected upon the MR scan in the form of dipole density plots. These plots are constructed by dividing space into small voxels and counting the number of good-fitting dipoles. These numbers are auto-scaled and colour coded. In more than 50% of the patients the slow wave dipoles are clustered at one side of the lesion. An example is given in figure 3A. In the other patients the delta band dipoles are located in the mid-sagittal plane (figure 3B), similar to what is found in normal subjects.

The technique here described could in principle also be

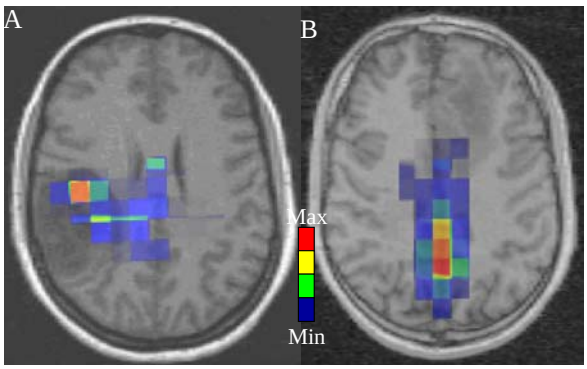

Figure 3. *Two typical examples of delta band dipoles are shown.* ***A*** *shows an example where the dipoles cluster around the lesion and* ***B*** *shows an example where this is not the case.*

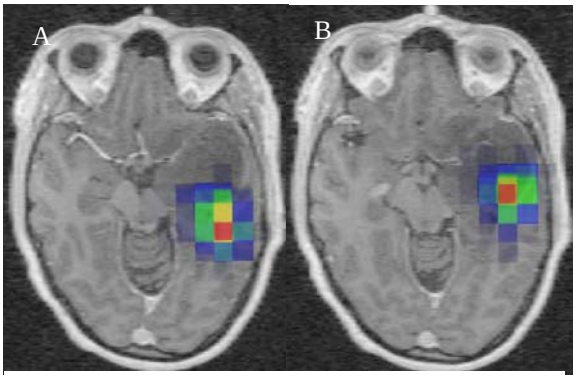

Figure 4. ***A shows the delta band dipole clusters based on MEG data and B shows the same results, based on simultaneously recorded EEG .***

applied with EEG instead of MEG. Figure 4 shows an example where EEG and MEG were recorded simultaneously, and slow wave dipoles were fit on each modality separately.

Sharp waves were analyzed only in a small subgroup of the patient population, because this part of the data analysis is based on non-automatic visual inspection of the data. One example is presented in figure 5. In that example, cluster analysis yielded two clusters that were subject to dipole fitting. It appears that the generators of both clusters are located near the tumor boundary, but at another side of the tumor than the delta cluster.

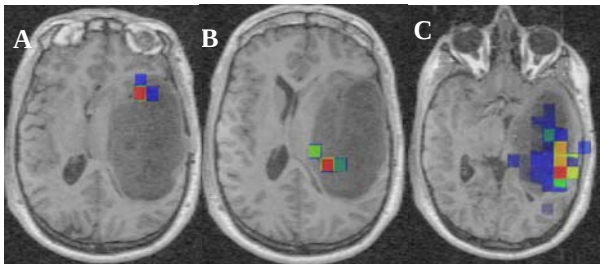

Figure 5. ***A*** *and* ***B*** *show the generators of two sharp wave clusters.* ***C*** *shows the delta band generators as a dipole density plot.*

IV. DISCUSSION

These (preliminary) results show that both sharp waves and delta band clusters are located on physiologically plausible locations. In more than 50 % of the cases the delta band dipoles are located near one side of the tumor. The sharp wave generators also border to the tumor area, but at a position which is different from the delta band dipoles. However, this finding is based on only a very few observations and more data need to be analysed before general conclusions can be drawn.

The procedure of dipole localisation is highly automated. The weak link in the analysis is the detection of sharp waves or spikes. Therefore, further improvement of our data analysis toolkit will be focussed on automatic detection of these phenomena.

V. REFERENCES

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