Canonical Decomposition of scalp EEG in epileptic seizure localisation

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Abstract - When patients with epilepsy cannot be helped with medication, they stay one week in an epilepsy monitoring unit in order to localise the part of the brain that is causing the seizures. The electroencephalogram (EEG) is then recorded over several days as it is the direct measurement of electrical brain activity. We developed a method to extract localising information out of the EEG, even at low signal-to-noise ratios or when the ictal EEGs are severely contaminated. In this survey-paper, we write a manual how to apply the method and illustrate it.

1 Introduction

Epilepsy is one of the most common, severe neurological diseases. People suffering from epilepsy, who are not helped by medication, can potentially benefit from epilepsy surgery. In order to remove the epileptogenic region, a precise localisation of the epileptic focus is mandatory. One of the diagnostic tools to localize this region of seizure onset zone is recording of ictal scalp electroencephalogram (EEG) [10]. The EEG measures electric potential distributions at discrete recording sites on the scalp. These potential distributions are the direct consequence of internal electrical currents associated with the synchronous firing of neurons. EEG recordings have an excellent temporal resolution, but a rather poor spatial accuracy due to the limited number of recording sites and the shielding effect of the skull. Visual analysis of EEG recordings aims to determine which lobe or which electrodes are activated. A challenging problem in neuroscience is to estimate in a more objective and precise way the regions of the brain that are active, given only the measured potential distributions.

The seizure discharge is a very complex pattern. Mainly artifacts, such as electromyogram, movement, eye blinks and eye movements artifacts, render seizure localisation difficult [4]. Even visual analysis of seizure onset can be significantly improved by removing muscle artifacts. Moreover, the low signal to noise ratio of the seizure signal can render the correct localisation very diffuse. However, when source localisation of seizure onset would be possible, it can reduce the need for invasive intracranial EEG recordings.

A possible way to localise brain activity is assuming that an equivalent dipole generates the EEG. The localising value of dipole modeling of ictal EEG can be improved by first removing artifacts and afterwards estimating the sources [5]. Another possibility is to decompose the measured EEG in a sum of individual contributions of distinct brain sources and localising the epilepsy-related source in order to estimate the epileptic focus. Space-time decomposition techniques like Principal Component Analysis (PCA) and Independent Component Analysis (ICA) of multichannel EEG can be used for extracting activities of interest [6]. However, in order to obtain a matrix decomposition like PCA and ICA, assumptions like orthogonality or independence - which are physically maybe irrelevant - have to be imposed. Recently, we have shown that a space-time-frequency decomposition of a three way array containing wavelet transformed EEG by the Canonical Decomposition (Candecomp), also known as Parallel Factor Analysis (Parafac), reliably separated a seizure atom from the noise and background activity with a sensitivity of more than 90 % [3]. This work was inspired by [8]. In [1], Candecomp was also used to localise seizures. The main advantage of this decomposition is that no extra assumptions have to be imposed. After the decomposition, the potential distribution over the electrodes of the epilectical activity was obtained, and displayed as a 2D image. Electrodes with large potential amplitudes could be considered as close to the focus. Afterwards [2], we also showed in a large simulation study several advantages of our approach with respect to previous methods.

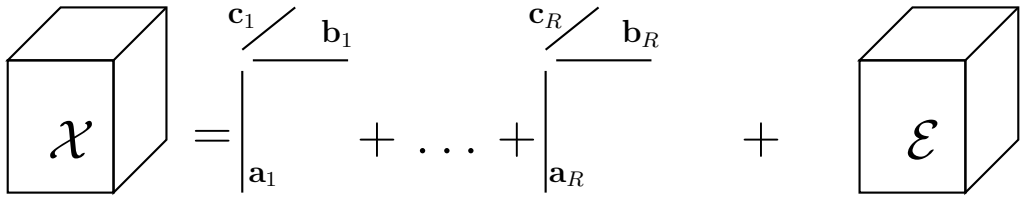

Figure 1: The Candecomp model with R components.

As we explained already in detail the theory behind the method in the previous publications we resume here the method in a clear manual and illustrate it.

2 Method

- Acquire EEG data with electrodes placed according to the 10-20 system [9] and additional electrodes T1 and T2 on the temporal region.
- Rereference the data into average montage.
- Determine the start of the seizure in the EEG.
- Compute the continuous wavelet transform of all the channels during 2 seconds at the start of the seizure in order to obtain a three-way tensor.
- Compute a Candecomp decomposition (figure 1) of the obtained tensor with the appropriate number of components.
- Select the atom in the decomposition that represents the ictal activity based on its characteristic signature. The ictal atom should have a rhythmical time series and a focal spatial distribution.
- The spatial distribution of the ictal atom contains the potential distribution of the epileptic signal over the electrodes.
- Compute the parameters (coordinates and orientation) of an equivalent current dipole that best generates the given potential distribution in a least squares sense.

3 Illustration

We illustrate this approach with an example. EEG containing clear ictal activity in the right temporal lobe is given in figure 3. The seizure starts at second 3, and the EEG between second 3 and 5 is wavelet transformed and decomposed with Candecomp (figure 2). Corcondia [11] indicated that a decomposition in two atoms would be appropriate. The first atom is recognized as seizure atom. The frequency component peaks around 3 Hz and the time component is a rhythmical waveform that increases in amplitude. When this component is reconstructed in EEG settings by means of the inverse continuous wavelet transform (ICWT) [7], pure ictal activity can be seen (figure 4). Because the atoms in the Canonical Decomposition have a very simple, trilinear structure, we only fit 1 dipole for every atom. We expect that, when a patient suffers from multifocal epilepsy, different atoms will be related to activity generated by the different dipoles.

4 Discussion

In [3], we introduced the described method as an automatic, fast and sensitive method for visualizing the ictal onset zone. The method was both validated on simulations and on a large number of *in vivo* seizures, and was not influenced by the presence of strong artifacts.

In the future, we plan to validate our method on *in vivo* seizures with a gold standard. This gold standard can be intracranial EEG, ictal SPECT, or the site of epilepsy surgery in patients who were rendered seizure free. We anticipate that the higher sensitivity and objectivity of our Candecomp method as compared with visual assessment of the ictal EEG's will improve and streamline the non-invasive presurgical evaluation of patients with refractory partial epilepsy.

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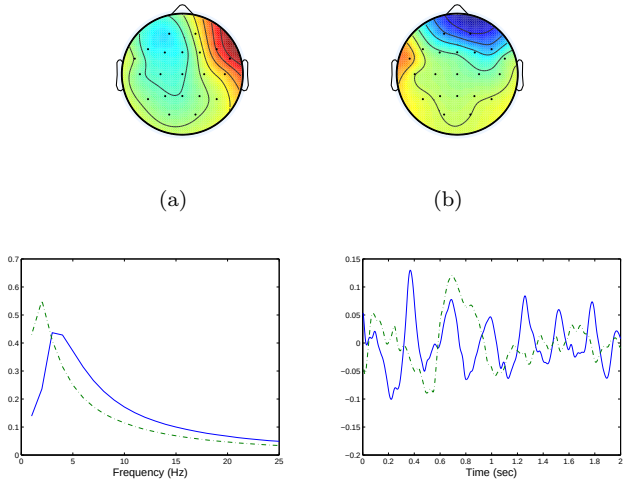

(a) (b) (c) (d)

Figure 2: Seconds 3 to 5 of the seizure shown in figure 3 are decomposed with the Canonical Decomposition with 2 atoms. (a) (b) the spatial potential distributions of the two atoms. (c) The frequency content of the atoms. (d) The time course of the atoms. First atom drawn in solid line correspond with (a). Dash-dotted line correspond with (b). First atom is seizure atom.

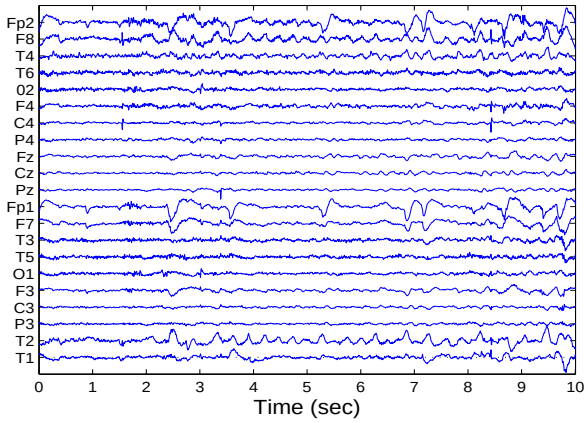

Figure 3: 10 seconds of EEG containing the start of a seizure

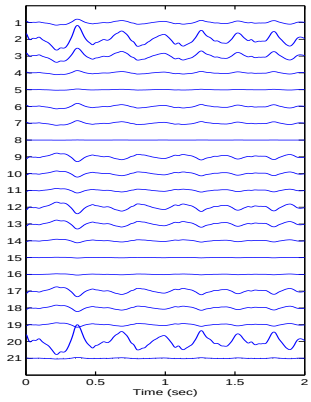

Figure 4: The seizure atom from figure 2 is reconstructed in EEG coordinates after Canonical Decomposition.