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Source Localization Algorithm based on Topographic Matching Pursuit

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Kurzfassung

Räumlich-zeitliche Zerlegungsmethoden können in Kombination mit Quellenlokalisationsalgorithmen zu einer besseren Beschreibung und Zuordnung von neuronaler Aktivität aus mehrkanaligen elektrischen und magnetischen Messungen beitragen. Wir stellen einen neuen Algorithmus vor, der Topographic Matching Pursuit als räumlich-zeitliches Zerlegungsverfahren mit einer Dipol-Quellenlokalisationsmethode kombiniert. Der neue Algorithmus wird auf EEG Daten aus einem photic driving Experiment an elf Probanden angewendet. Im Vergleich zur bisher publizierten Multikanal-Matching Pursuit (MMP) Quellenlokalisation zeigt der neue Algorithmus bei einer Mirrored-Dipole Konfiguration höhere Goodness-of-Fit Werte, wenn temporale Asynchronität in EEG-Kanälen vorliegt. Wir schlussfolgern, dass der vorgeschlagen Algorithmus im Falle temporaler Asynchronität besser für eine Quellenrekonstruktion geeignet ist als bisherige MMP basierte Verfahren.

Abstract

Spatio-temporal decomposition methods in combination with source localization algorithms can contribute to an improved description and allocation of neural activity from electrical and magnetic multichannel measurements. We introduce a new algorithm, which combines Topographic Matching Pursuit as spatio-temporal decomposition method with a dipole-source localization. The new algorithm is applied to EEG-data obtained from a photic driving experiment with eleven volunteers. In comparison to a hitherto published Multichannel Matching Pursuit (MMP) source localization the new algorithm shows, for a Mirrored-Dipole configuration, higher Goodness-of-Fit values, if temporal asynchrony exists in the EEG-channels. We conclude that the suggested algorithm is more appropriate for source reconstruction in case of temporal asynchrony than MMP-based procedures used so far.

1 Introduction

In neuroscience, the description of time-frequency parameters of a signal and the localization of centers of activity are of high importance. In order to unravel overlapping sources and also noise components, often preprocessing steps are carried out before source reconstruction is performed. These preprocessing steps include e.g. filtering and spatio-temporal signal decomposition. For instance, [1] applies an Independent Component Analysis (ICA) before the actual source localization.

A further decomposition method is the Multichannel Matching Pursuit (MMP), which was applied prior to the localization algorithm LORETA [2]. However, MMP imposes temporal synchrony for all channels, thus limiting the description of multi channel data such as EEG.

Consequently, we introduce a new source localization algorithm based on Topographic Matching Pursuit, which overcomes the constraint of channel-wise temporal synchrony. For our purpose we use a mirrored dipole fit with three concentric spherical shells as head model. We apply this framework to EEG-data, obtained from an alpha-entrainment experiment using flickering light.

2 Materials and Methods

2.1 Experiment

We exposed eleven volunteers to flickering light, flashing at frequencies of a fixed ratio (0.4-1.6) to their individual alpha frequency. Each frequency was presented in 20 trials each consisting of 40 flashes. The response-EEG was recorded with 10-20 system over the frontal region and with a 10-10 system over the occipital region at a sampling rate of 1 kHz.

As this stimulation leads to alpha entrainment, the main response frequencies are not in all cases equal to the stimulation frequency. In a close interval around half the individual alpha frequency (0.5*alpha), the main response was approximately 1*alpha. In a narrow interval from 0.9*alpha to 1.1*alpha, the response frequencies remained stable at around 1*alpha [3]. We found high similarity among the EEG response-topographies inside the above mentioned intervals and dissimilarity to the responses outside the interval.

Furthermore we observe that the topographies show two maxima which do not develop symmetrically over both hemispheres. We assume that more than one source creates the topographies, since, due to the type of stimulation, the visual cortex is activated in both hemispheres.

Prior to Matching Pursuit decomposition we filter the data with a zero phase Butterworth band pass filter of order 4 between 2 and 20 Hz. Then the filtered data are averaged over the 20 trials and over the 40 stimuli for each stimulation frequency, thus only one representative train per volunteer and stimulation frequency remained.

Next we decompose the representative train with the Topographic Matching Pursuit (TMP) algorithm and localize the sources described by the TMP parameters. The next section provides a short introduction to Matching Pursuit.

2.2 Matching Pursuit

The single channel Matching Pursuit (MP) [4] iteratively creates an approximation $f(t)$ of signals with a sum of weighted time-frequency representations called atoms.

$$f(t) = \sum \mathrm{a_n} * g_{\gamma_n}(t),$$

where a_n represents the weights and $g_{\gamma_n}(t)$ are atoms.

Atoms are scaled s, translated u and modulated ξ Gaussian functions $\mathrm{g}(t)$ and are chosen from a highly redundant set called dictionary. The Gauss function is modulated by a cosine function, where the phase ϕ parameter is expressed explicitly:

$$g_{(\gamma,\phi)}(t) = \frac{\mathrm{K}_{(\gamma,\phi)}}{\sqrt{\mathrm{s}}} * \mathrm{g}\left(\frac{\mathrm{t-u}}{\mathrm{s}}\right) * \cos(\xi t + \phi),$$

where the constant $\mathrm{K}_{(\gamma,\phi)}$ ensures $\|g_{(\gamma,\phi)}\| = 1$.

Topographic Matching Pursuit (TMP) [5] is an extension to the standard MP and uses the same dictionary. The algorithm chooses the atom which has the highest simultaneous correlation in all channels. The descriptive atom in each channel is the same in s, u, ξ and t, and only differs in the parameters amplitude and channel phases $\Phi_{TMP,Chan}$. Thus, in this approximation the amplitudes and the phases vary across the channels.

The first TMP-Atom of the representative train for each stimulation frequency and volunteer represents the basis for the dipole atoms and thus for the algorithm which we present in section 2.3.

2.3 Source Localization

2.3.1 Source and Head Model

In our model assumption the EEG is produced by two mirrored neural sources. For our source localization approach, we combine qualities of TMP atoms and dipoles to what we call dipole atom. This combination adds three new parameter sets to the standard TMP atom. Thus, besides the standard TMP parameters the new dipole atom comprises spatial coordinates, the direction/moment as well as the phases ϕ_{DA} and $\phi_{\mathrm{DA,Mirr}}$ for the dipole atom and the mirrored dipole atom. The latter ones are calculated independently from the TMP phases $\Phi_{TMP,Chan}$. Since a TMP-Atom provides phases for 30 channels, it is impossible to allocate TMP phase information to two dipole atoms only. Therefore the phase parameters of the TMP-Atom are discarded for the construction of the dipole atoms.

The parameters obtained from the MP-atom e.g. frequency are identical for the dipole atom and the mirrored dipole atom. However, with regard to the new parameter sets the dipole atom and its mirrored counterpart differ. The spatial coordinates of the dipole atom mirrored at the midsagittal plane yield the coordinates for the mirrored dipole atom. The direction parameters of the two dipole atoms are independent. The same holds true for their phase parameters. All parameters are static for the duration of an atom.

The gain transfer matrix (lead-field) of the head model is calculated based on a spherical 3-shell-model [6] by using the computation method introduced by [7].

The algorithm of the inverse calculation is portrayed in the following section.

2.3.2 Inverse Computation

We construct a cubic grid inside the boundaries defined by individually obtained anatomical electrode positions. Next the electrode positions are projected onto a spherical surface. Accordingly, the cubic grid is transformed resulting in a grid with uneven distances between the grid points. For this transformed grid we calculate a lead-field based on the head model. Thus, the grid points inside the inner shell of the 3-shell-model are the spatial coordinates for which the (mirrored) dipole atom(s) are defined.

The inverse problem is solved by a Differential Evolution optimization routine. Two phase parameters, two direction sets, one dipole magnitude and one coordinate set are employed to minimize of the L_2 error norm (i.e. the root mean square) between the TMP-atom and the forward calculation.

After an optimal solution is found, the search is continued in a finer sub grid, which is created in the untransformed grid. More specifically this finer grid is constructed in the space spanned by the 26 neighboring grid-points surrounding optimal location of the grid. The sub grid is then transformed similar to the grid. Subsequently the L_2 error norm is minimized further. The best forward solution is then subtracted from the original signal. Based on the resulting residuum a new TMP-atom is calculated, which allows for the localization of further sources.

3 Results

3.1 Signal Approximation with TMP

Figure 1 shows a representative train and the first TMP approximation. Major amplitudes and frequency of the representative train are approximated. In contrast to a MMP approximation also the time offset of the EEG-channels are maintained with the TMP method.

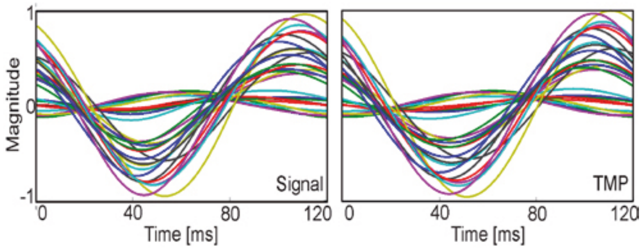

Figure 1 Left: a representative train of one volunteer obtained by averaging; right: the approximation by one TMP-atom.

3.2 Reconstruction with Mirrored Dipoles

Figure 2 shows the localization result of the TMP-based method, the mirrored dipoles are localized in the occipital region. Although the directions of the dipoles are estimated independently the reconstruction indicates that the directions are mirrored at the midsagittal plane.

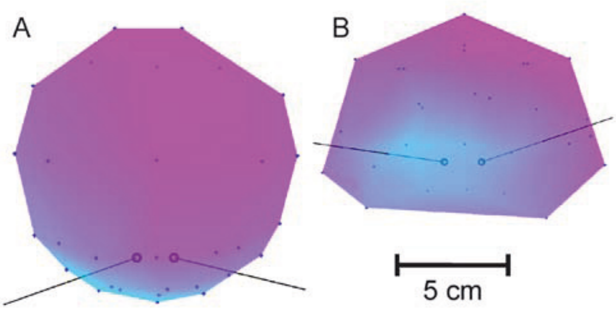

Figure 2 Subfigure A: the occipital dipoles as seen from above; Subfigure B: the dipoles as seen from behind.

As stated in section 2.3.1 the phases $\Phi_{TMP,Chan}$ are modeled by dipole atoms of unequal phases. As a result of source reconstruction based on TMP and variably phased dipole atoms we observed for the narrow intervals around 0.5*alpha and 1*alpha, that the phase difference ϕ_{DA} - $\phi_{\mathrm{DA,Mirr}}$ varies across the volunteers from 3.5° (0.9ms) to 95.4° (27ms). For stimulation frequencies outside these intervals the phase difference ranged from 15.8° (3.2ms) to 251.1° (92.0ms). Table 1 lists the GOF calculated between the EEG-data and TMP- or MMP-based source localization of one atom.

Table 1 The GOF of the TMP-based reconstruction method are higher than for the MMP-based reconstruction, suggesting a better estimate.

Stimulus as alpha multiple		**0.5**	**0.9**	**0.95**	**1**	**1.05**	**1.1**
GOF of Method	MMP	82.8	56.8	54.6	89.9	50.6	84.7
	TMP	83.8	82.1	83.8	91.8	91.8	93.7

4 Conclusion

We conclude that our suggested algorithm is more appropriate for source reconstruction in case of temporal asynchrony than MMP-based procedures used so far. Future work will consider realistic volume conductor models.

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