**COST EMF - MED (Action BM1309):**
**European network for innovative uses of EMFs in biomedical applications**

STSM Report:

Analysis of EEG and MEG signals using

Empirical Decomposition Phase Locking method

**Researcher:** Pawel Stepien email: pstepien@mail.ibib.waw.pl

**Home Institution:** Institute of Biocybernetics and Biomedical Engineering. Contact: Wlodzimierz Klonowski. email: wklonowski@gmail.com

**Host Institution:** AAI Scientific Cultural Services Ltd.. Contact: Andreas A. Ioannides.

email: a.ioannides@aaiscs.com

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## Abstract:

Magnetoencephalography (MEG) and electroencephalography (EEG) are the only techniques available today capable of capturing direct correlates of changes in brain activity at timescales short enough to correspond to transitions between brain areas. These methods have high potential in helping us understand neurological disorders (dystonia, Parkinson, Alzheimer, depression, etc.). Development of these techniques requires new methods of analysis of brain response to repeated stimulation. Empirical Mode Decomposition Phase Locking (EMDPL) is a promising method of such an analysis.

In this project we test the ability of using EMDPL for analysis of EEG and MEG signals corresponding to different kinds of stimulations. In EEG or MEG raw signal each time series has contributions from many generators. Continuous probabilistic estimates throughout the brain were extracted from raw data with inverse problem. Each obtained time series describes the activation from specific brain areas (ROI). Such signals are decomposed into its monocomponents (modes) with Empirical Mode Decomposition. Next the synchronization between corresponding modes through the epochs (stimuli repetition) is calculated with Phase Locking Value (PLV) parameter and then mean value of PLV is calculated through the EMD modes. EMDPLV parameter is visualized as the map across time and ROIs.

## A. Purpose of the STSM

The goal of the collaborative project between the two Institutions is to explore methods of analysis of EEG and MEG raw time series either of the raw signals (signal space applications) or in the source space. In the signal space analysis the actual MEG and EEG signal is used either in their raw form or after some preprocessing. In the source space analysis the estimates of regional activation is analyzed, usually obtained after the EEG and/or MEG signal is analyzed using magnetic field tomography (MFT) or its recent adaptation for EEG Electric Field Tomography (EFT). The resulting time courses represent estimates of activity within a specific region of interest (ROI) in the brain. Methods already studied under the collaboration include non-linear measures of the signal complexity (e.g. Higuchi Fractal Dimension) and Empirical mode decomposition (EMD), with the later showing better results.

The specific objective of the STSM project was to test the EMD primarily for source space time analysis of NFT solutions and establish a basis for an efficient long-term collaboration that will generate not only routine analysis of data but also new breakthroughs in the methodology. The tangible output from the project were a set of software tools that allow easier pipe-lining of analysis, the identification of some theoretical problems that need to be clarified and the application of the method to a set of MFT solutions. result of the project will be software platform for analysis of response to repeated stimuli based on Empirical Mode Decomposition Phase Locking method and several publication.

## B. Work Description

During STSM Visit we:

- Discuss the theoretical underpinnings of the EMD method and practical questions regarding how the results are interpreted.
- exchanged experience in the analysis of time series data
- prepared Python environment with necessary libraries for running EMDPL software code of the STSM research within at the hardware and overall software support environment of the Host Institution
- Discussed possible choices for statistical analysis of the results and implementing in the EMDPL software a statistical analysis of the results based on permutation test
- Discussed ways of improving the visualization of EMDPL results and implementing them with emphasis on the analysis of brain response to repeated stimuli
- Generate binary format of output data in EMDPL software that can be directly fed to the software of the host institution, allowing new techniques already available at the Host Institution to be used for data mining of both EMD and EMDPL results,
- During the STSM the software of the AAISCS was adapted for the analysis of EMD components from single trials and for the display of thee results.
- The new software combinations were tested on different sets of data available in the host institution.

- Some tests were also performed for raw EEG and MEG signal, but these were of exploratory nature, simply demonstrating that the methodology can be applied to a wide ranging set of data, both for source and for signal space analysis.

## C. Results

The theoretical discussions brought up important questions about the pre-processing of data that researchers usually employ before applying the method. It had also raised questions about how the EMD components are classified as noise or signal. Using prior knowledge (about the latencies of the expected responses it became clear that some of the fast components that would normally be labelled as noise actually carried significant information about early processing. The requirement to further analyze these components was one of the strong motivations for linking the existing software of the STSM researcher with the single trial statistical analysis software of the host institution and it is one of the areas expected to produce significant results as this work develops.

The creation of working software platform for analysis of response to repeated stimuli based on Empirical Mode Decomposition Phase Locking method allowed us to apply the method over a short time period to a range of data. However the intensity demanded by single trial analysis did not allowed us to complete the work for any one application; it was deemed essential to demonstrate the tolls could be equally well applied to signal as well as source space timeseries and to a range of such cases. The choice of examples aimed to furnish evidence that the method indeed produced good results.

Created software platform decomposes the signal into its monocomponents with Empirical Mode Decomposition method for each repetition of stimuli (epochs). For selected components Phase Locking Value is calculated through epochs (PLV is a measure of signals' synchronization) according to the formula:

$$PLV_i(t) = \frac{1}{N}\left|\sum_{k=1}^{N} e^{j\phi_{i,k}(t)}\right|,$$

where $\phi_{i,k}$ *(t)* phase of *i*-th mode of *k*-th epoch in time point *t* and *N* is number of epochs. The EMDPLV parameter is calculated as mean value of selected modes' $PLV_i$. Next 1000 windows ( 200 ms length) of EMDPLV before stimulation are permuted from all epochs and ROIs. The mean value of EMDPLV and its standard deviation is calculated from permuted windows - their sum is the level of significance. EMDPLV (thresholded by level of significance) parameter is visualized as the map across time and ROIs.

Figure 1. shows examples of visualization of propagation of response to visual stimulation by the picture of a check-board. Fig 1a) shows response to stimulation presented in left visual field (at 0 time point). 80 ms after the stimulation a statistically significant rise of PLV parameter is observed in r_V1 region (the significance level is represented with dark blue color). The response is propagated immediately to r_V4 and r_OFA regions. Fig 1b) shows response to stimulation presented in right visual field; propagation of response in regions of the left side of brain is visible.

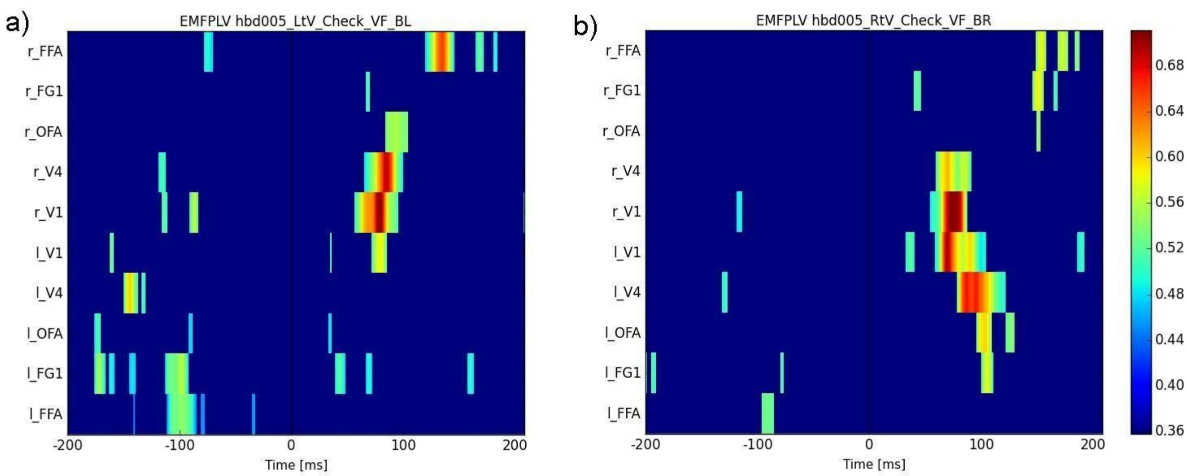


Fig. 1. Visualization of propagation (through brain areas -vertical axis) of response to visual stimulation with EMDPL method, a) stimulation in left visual field, b) stimulation in right visual field

The data displayed in Fig. 1 are for stimuli presented in the attended part of the visual field; they are from only 6 epochs. The corresponding results when identical stimuli were presented to the same visual field, but when attention was directed to the opposite hemi-field showed marked decrease. The plan is to identify which areas are involved and use the EDM to reconstruct them in single trials - we already demonstrated that the method produces similar effects in the same EDM components across trials, but because software development took too much time and we did not manage to analyze enough data to finalize the work . We also found that in analysis of brain response to repeated stimuli the “rate of phase change” may be useful instead of Phase Locking parameter.

## D. Future collaboration with host institution

Working (in Laboratory for Human Brain Dynamics) software platform for analysis of response to repeated stimuli based on Empirical Decomposition Phase Locking method gives possibility to test usability of this method on big database in the near future and give materials for publications. We are going to test ability of using the “rate of phase change” parameter instead of Phase Locking in connection with Empirical Mode Decomposition method.

## E. Expected Publications

After testing of Empirical Decomposition Phase Locking method on data from several experiments we should have material for several publications

**Confirmation by the host institution of the successful execution of the STSM:**

We confirm that (Researcher’s Name) has performed the research work as described above.

Contact Person of Host Institution:
Prof. Andreas A. Ioannides

Signature

Name of researcher:
Pawel Stepien

Signature