Referee's report concerning PhD Thesis of Ing. René Labounek entitled „Simultaneous EEG-fMRI Data Fusion with Generalized Spectral Patterns“

Ing. René Labounek submitted the above named doctoral thesis dealing with analysis of human electrophysiology (EEG) or combined EEG and functional magnetic resonance (fMRI) data. The topic of this thesis is highly relevant for an important area of experimental neuroscience.

The broadly defined aim of the thesis is to try to design and find the optimal EEG-fMRI data processing pipeline which would be able to blindly estimate and visualize the task-related brain networks from the captured data, without any prior knowledge about the stimulus timings. After brief Introduction, the problem context and state of the art is reviewed. The main scientific contribution of the thesis is then structured around two specific results corresponding to chapters 3 and 4. The thesis is concluded with brief chapter Outcomes and conclusions, detailed Bibliography, List of Symbols and Appendices including some detailed visualization of results and description of included program code. The core of the theses has 107 pages, while including the References and Appendices it builds up to 142 pages.

From the formal point of view the thesis is generally well organized. However, I have noticed a variable quality of language and style. In fact, there is a typo even on the front cover („Elektrical“), and also as early as in the abstract (both in the Czech and English language mutation) one can notice multiple language/style errors or typos, such as:
'general liner model'
'actual state of art'
'puts a goal'
'povodní'
'aktuální současný stav'
'pásma zobrazily'
'10 vzorů vypadají'

Chapter 3 introduces a novel approach denoted 'Generalized EEG-fMRI spectral heuristic model', which moves beyond an previously proposed method for EEG-fMRI fusion, that consisted of modeling BOLD signal by a convolution of instantaneous EEG energy with a kernel representing the haemodynamic response function. The innovation proposed by Ing. Labounek is to use specific frequency bands, based on the observation that the power in different frequency bands can be only weakly (if not negatively) correlated, because they reflect different neuronal processes. Using this frequency separation, spatial topographic maps can be constructed, that visualize brain networks that show fMRI signal related to distinct EEG bands. The chapter systematically explores the effect of working with absolute or relative spectral powers (a choice which is shown to have a key role, with the relative spectral powers concluded to be probably more informative), and the role of choice (of a set) of electrodes to compute the representative spectra (which is suggested to be less important, as the power time-courses seem to be relatively highly correlated across electrodes).

Chapter 4 describes a generalized approach named 'EEG-fMRI spatiospectral heuristic model', which moves further in two directions. Firstly, it includes back the spatial resolution of the EEG by considering signals from all individual electrodes instead of the representative average signal of a subset of them. Moreover, to deal with the high-dimension of the incoming signal in a data-driven manner, and to provide applicability to groups of subjects, the 4-D data (electrodes x frequencies x subjects x time) is decomposed using a multi-step procedure, in a manner similar to procedures commonly applied to analyze fMRI data. The resulting 'group-level EEG components' are discussed, and the meaningfulness of the obtained patterns is advocated through the comparison of its activation time series to the underlying task paradigm, or relating it (after convolution with HRF) to the concurrently measured fMRI data.

As a side note, based on reading the detailed list of publications of Ing. Labounek, the dedications in the Doctoral Thesis as well as several encounters at conferences, I firmly believe that he has long-term experience with collaborative scientific work that had a beneficial impact on his scientific maturation.

A few questions for discussion:

- How robust/reproducible are the obtained EEG spatiospectral components? What is the expected level of reproducibility if the method was applied to a different dataset obtained using the same or different equipment?
- In what sense is the obtained data analysis pipeline "optimal"? (see aims of the thesis)
- How much would the spatiospectral results differ if the analysis was applied to individual subjects?
- There seems to be some contradiction between the results in the third chapter suggesting that the choice of the electrodes does not matter much, and proposing to carry out spatiospectral decomposition in the next chapter. Can you comment on the subtle issue of the actual role of the spatial component, and probably also the sensitivity of the results with respect to choice of the reference electrode, or any re-referencing?

In summary, the thesis deals with an important topic within the field of the candidate's study. The work includes novel scientific contribution, in particular the methodology for extraction of group-level spatiotemporal electrophysiological patterns and their subsequent relation to concurrently measured fMRI data. The core of the work was published in a satisfactory way (most notably, the key results were published in 2 first-authored journal articles with impact factor, and further related results were published in other journal publications or conference proceedings).
The evidence of the overall scientific achievements of the applicant is further supported by his participations in other research projects related to neuroimaging data analysis. The weakest part of the submitted thesis is its variable quality of language and style.

Notwithstanding the critical comments included above, I believe that the thesis fulfills the generally accepted scientific community criteria for a dissertation thesis and I recommend it for defense.

Praha, 29. června 2018 Ing. Mgr. Jaroslav Hlinka, Ph.D.