Development of processing and analysis methods for Biomedical data.

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1. Research Theme

- Development of MEG data processing and analysis methods for neural decoding
- Development of fNIRS data processing and analysis methods
- Development of tools for data processing and analysis

The purpose of these studies is to develop robust and reliable methods that allow for a more accurate analysis of Biomedical data than those produced by the currently available techniques. This in turn will help us to better understand the mechanisms of speech production, language development, effects of brain disorders and more.

2. Main Research Outcomes

Development of fNIRS data processing and analysis methods

Functional Near Infrared Spectroscopy (fNIRS) signals are composed from multiple sources, such as cardio-vascular activity, motion artifacts and cerebral hemodynamics along with other contributors. Motion artifacts are one of the major hurdles of fNIRS analysis. It is very hard to separate the effects of these artifacts from hemodynamic activity of the brain. Many studies simply discard any data segments containing motion artifacts. Some studies attempt to reduce the effects of these artifacts using state of the art algorithms which aim to rectify any unusual patterns within the fNIRS signals. One of the major issues of such approach, is the distortion of the recorded signals, since these methods are usually applied to the entire signal rather than the artifact afflicted areas. To address these issues, we have developed an algorithm for targeted motion artifact suppression. Our proposed method, the Selective Mode Suppression (SMS), is applied specifically to the signal segments which contain the motion artifacts. This way it does not distort any hemodynamic information in the remaining segments. At the motion artifact segments, the algorithm decomposes the signal into many different components and attempts to disassociate the motion artifact from the hemodynamic information. It automatically detects components that were distorted by the artifact and suppresses the distortion effect only within these components. Thus, reducing distortion of the hemodynamic information within the artifact afflicted segment. When we combine this algorithm with our previously proposed filtering method, Cumulative Curve Fitting Approximation (CCFA), the resulting Signal to Noise Ratio (SNR) is improved significantly. The quality of the resulting data is improved two-fold, when compared to the filtration without the use of our proposed artifact suppression algorithm. More details can be found in our work titled: *"fNIRS Artifact Removal Using Selective Mode Suppression"*, by Patashov et.al.
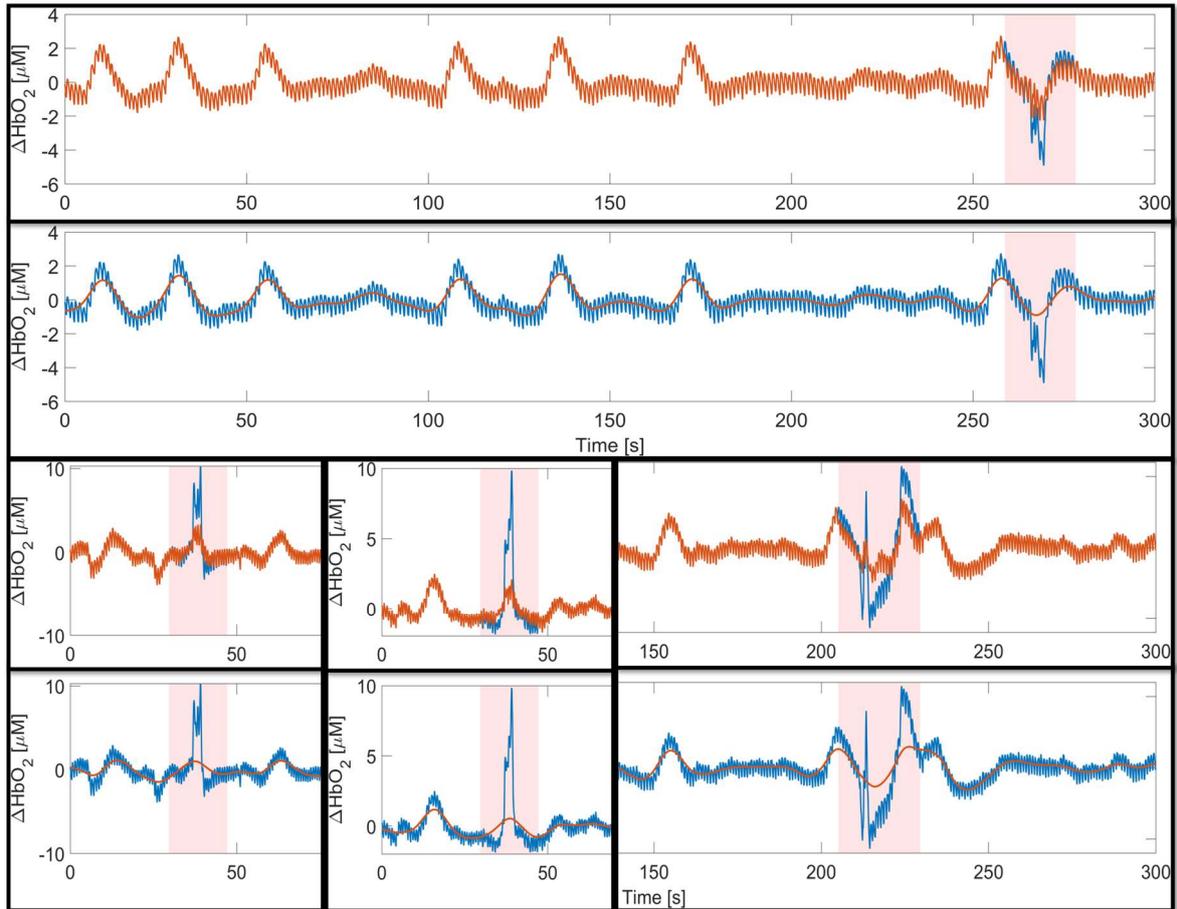
Figure 1: Top panel shows the performance of SMS on a signal containing a motion artifact between 250ms and 300ms, marked as pink area. In blue is the raw signal. In orange is the result of SMS application. Any parts of the signal where blue line is not visible, mean that the orange and the blue lines are completely overlapping. The second panel from the top shows the raw signal in blue and the CCFA filtered signal after SMS application, in orange. The bottom section of the figure shows three other examples of artifact suppression using SMS and a full filtration using SMS and CCFA together.

In Figure 1, the top pair shows an example of a full-length signal which first undergoes artifact suppression using SMS and then filtration using CCFA. We can clearly see that the raw signal is completely unaffected by the SMS outside of the motion artifact segment (the orange line covers the blue one completely). Within the artifact afflicted area, we can clearly see a strong reduction of the artifact effect. Once CCFA is applied on top of the SMS procedure, we receive a very clean signal following the wave-patterns of the fNIRS signal, but not being affected by the artifact presence at all. The bottom half of Figure 1 shows three additional examples from different subjects. It is clear that SMS is performing well in motion artifact suppression. Even though that is some examples we may see some small high-frequency noise remaining after the suppression, we can see that the final result after CCFA filtration is clean and unaffected by these small noise. As can be seen in the examples, SMS performs well in the task of artifact suppression and CCFA cleans any remaining noise from the data. This allows us to analyse the signals even if they contain motion artifact.

Development of tools for data processing and analysis

Matrix-valued time series arise naturally in signal processing and biomedical data analysis (e.g. covariance/correlation/precision matrices, diffusion tensors, functional connectivity estimates, etc.). They are especially common in multi-channel system such as fNIRS, EEG, MEG, etc. These tensors containing matrices that change in time, are often related to a single system (e.g. the brain) that changes its states in time. Analysing such data structures is not an easy task, therefore, almost always the analysis is done either on the separate matrices of the tensor (samples in time) or on the separate signals (vector of samples in time for a specific matrix index). The main issue with this approach is that when analysing the separate matrices, we lose the information residing within the dynamics of the system in time. Whereas when we analyse separate signals, dependencies and relations of sensor/source locations are completely ignored. When analysing neuroimaging data, it is clear that human brain is a single system and that its patterns change both in time and in space. It is also important to understand that these are continuous processes which rely on an exact timing of activations within different brain regions. Some activate in parallel, some activate sequentially, and some activate independently of one another. Therefore, it makes sense to analyse the data as a single system, rather than a collection of independent matrices (location relations) or independent signals (time relations). To analyse both location and time relations together, a new mathematical approach is required. In this approach, we treat our data as a tensor-based signal, where a single time sample is not a value, but an entire matrix. To analyse these tensor signals, we have developed a wavelet procedure that is performed on a Riemannian manifold. Our algorithm is able to perform a full wavelet transform on the tensor signal and is capable of a complete and exact inverse of the transformation. Since it is applied to the entire tensor, rather than independent parts of information, it allows for the analysis of the recorded system as whole. Our approach allows for an analysis of the tensor signal in wavelet domain. Which grants us access to the time-frequency analysis of the recorded system. In addition, it allows for filtering of the tensor signal. This type of filtration is a novel approach, allowing us to consider the activity through the entire system (e.g. brain) when filtering our noise or uninformative patterns. In Figure 2 we can see examples of tensor signals (top panel), where each sample is a matrix. Both signals (first and second row) were restricted to 11 samples for easier visual examination. First row shows the original signal before our tensor-wavelet application. Fourth sample of that signal was altered to emulate a spike (high-frequency) noise. The signal was transformed into wavelet domain and a time-frequency analysis was performed. The resulting time-frequency heatmap is the upper result in the lower panel of Figure 2. We can see a very high frequency (around 150Hz) activation, as we would expect from a strong spike. The bottom signal of the top panel, corresponds to the bottom heatmap of the bottom panel. It shows the result of filtration using the Riemannian wavelet approach. We can clearly see that the spike sample matrix became more similar to the neighbouring samples, thus the effect of smoothing (low pass filtering). When examining the time-frequency domain, we can still see the high frequency response, however, it is clear that its effect has spread, and the change is more gradual. These results show that our approach is in fact working and it can be used for the system level filtering and analysis.
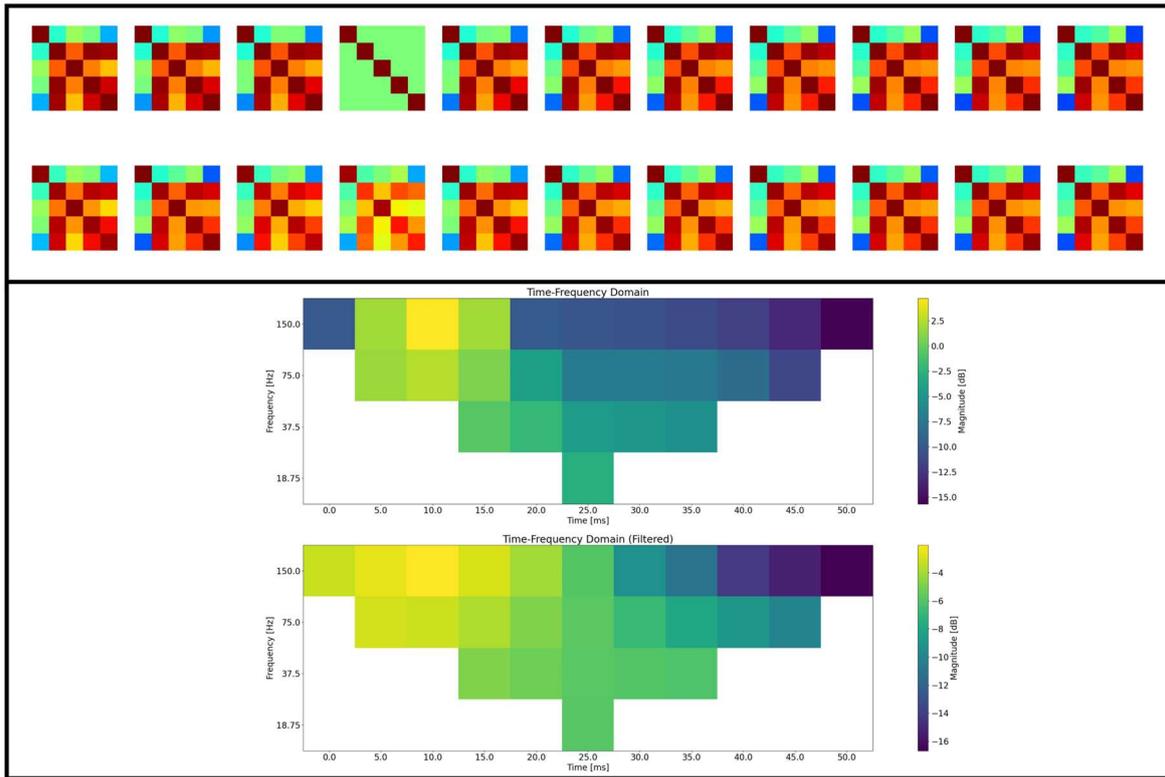
Figure 2: Top panel shows a small segment of two tensor-signals. Each matrix is a sample in time. First row is the original signal, to which a high-frequency noise (spike) was added at the fourth sample. The second row is the same signal after preforming a low pass filter using the proposed wavelet filter. The bottom panel shows a time-frequency analysis of the signals from the top panel. Upper one is before the application of the low pass filter, and lower one is after.

3. Collaborating Researchers

Prof. Hiromu Sakai – Waseda Research Institute for Science and Engineering, Waseda University, Tokyo, Japan

Prof. Reiko Mazuka – Laboratory for Molecular Mechanism of Brain Development, RIKEN Center for Brain Science, Saitama, Japan

Dr. Dmitry Goldstein - Multimodal and complex Data Analysis Center, Holon Institute of Technology, Holon, Israel

Dr. Michal Balberg – Faculty of Engineering, Holon Institute of Technology, Holon, Israel

4. Research Achievements

Reviews and Books

I have reviewed conference proceedings papers for the International Symposium on Brain Function and Cognition (ISBFC) 2025, which were published in The Institute of Electronics, Information and Communication Engineers (IEICE).

Academic and Social Activities

I was one of the primary initiators of an international conference, ISBFC 2025.

International Symposium on Brain Function and Cognition 2025; ISBFC 2025 – Neural Codes of Language and Action;

Workshop: Neural Codes Seminar 2025;

Conference Website: https://isbfc.com;

Organizing Committee: Prof. Hiromu Sakai, **Dr. Dmitry Patashov**, Dr. Refael Barkan, Dr. Michal Balberg, Prof. Mana Tanifuji, Dr. Revital Marbel, Dr. Michal Eisenberg Pasand, Ms. Ira Guetta, Ms. Marina Michaeli, Ms. Yuri Hatano;

Dr. Dmitry Patashov's roles: Conference Operations Lead, Speakers Program Lead, External Relations Lead;

Proceedings Publisher: The Institute of Electronics, Information and Communication Engineers (IEICE); (All submitted papers were peer reviewed).

Workshop: Karuizawa Prince Hotel West, Karuizawa, Nagano, Japan; 02–05.09.2025; Conference: Waseda University, Tokyo, Japan; 08–09.09.2025;

I am also a core member of the organizing committee for the International Symposium on Brain Function and Cognition (ISBFC) 2026, which is scheduled to take place at Holon Institute of Technology, October 2026. More information can be found at: https://isbfc.com.

5. Issues and Future Prospects of Research Activities

Development of tools for data processing and analysis

The preliminary results of Riemannian wavelet application are very promising. However, a few points still require attention. The control of how to filter specific bands, needs to be carefully examined and formalized. Current mathematical solution seems to have little effect when attempting to filter large matrices. A stricter formulation is required to increase filtering effect size of large matrices while maintaining the proper effects for the small ones. Currently, we are carefully examining the mentioned issues and formulating mathematical models that should resolve them. We have achieved some progress in the formal mathematical formulation of the solutions, but have yet to test their performance on a real data. We will further concentrate on testing of the mathematical models which may mitigate the issues at hand.