A Toolbox for Real-Time Neuroelectromagnetic Source Localization

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Introduction

Electroencephalography (EEG) and Magnetoencephalography (MEG) provide insight into neuronal processes in the brain in a real-time scale. This renders these modalities particularly interesting for online analysis methods, e.g. to visualize brain activity in real-time. We present a toolbox (Neuronal Activity Online, NA-Online) which provides the online reconstruction of distributed sources on the cortical surface using individual EEG/MEG forward models. It allows to set up a signal processing chain with different algorithms by means of graphical building blocks. We performed several runtime tests to evaluate the real-time capabilities.

Methods

The toolbox consists of distinct functional units, i.e modules (Fig. 1), each of which can be loaded several times. The input/output connectors allow their flexible interconnection using graphical buidling blocks to set up the signal processing chain (Fig. 2). For example, branches in the signal flow, e.g., to use multiple processing chains, can be realized. EEG/MEG data is passed module by module starting at the beginning of the signal chain, which implies blockwise data processing. Data is stored in a hybrid structure with static and dynamic areas (Fig. 3). The latter is replaced by each module and contains, e.g., raw and processed data.
The developed modules are embedded in OpenWalnut, a software for multi-modal brain visualization [1]. An overview is given in Fig. 4. Four categories are distinguished:

1. **Data Acquisition:** interface to EEG/MEG device and recorded data (file formats).
2. **Forward Model Preparation:** modules to prepare EEG and MEG forward models (see below).
3. **Pre-Processing:** signal conditioning, preparation for event related analysis.
4. **Analysis:** actual data analysis, e.g., source localization (see below).

EEG Forward Model

Since sensor positions are only available after measurement setup, the forward model cannot be calculated in advance. We use leadfield interpolation as a technique for a time efficient forward model estimation. Virtual electrodes were densely placed on the head surface and the leadfield is calculated at each position. The leadfield at the true sensor locations is estimated by means of interpolating adjacent leadfields.

MEG Forward Model

The MEG forward model depends on the head position in the MEG device. The detection of the head position is based on evaluating the oscillatory signals generated by head position indicator (HPI) coils which are attached on the head [2]. To correct MEG data for the head position, we employ the approach proposed in [3]. It is essentially based on an inverse minimum norm procedure using a simple forward model which can easily be calculated for both the true head position and a centered reference position.

Source Localization

The Source Reconstruction module provides the reconstruction of distributed sources on a high resolution individual cortical surface using the (weighted) minimum norm method [4]. Localization is done for each data block and utilizes the graphics card (GPU) for high performance data processing.

Runtime Tests

The toolbox was tested using a previously recorded data set (auditory stimulation, trigger on sentence onset). The signal processing chain consists of a bandpass filter (order 200), epoch separation and averaging (total average), and source reconstruction for EEG data (60 channels, 500 Hz sampling rate, 244.662 sources). We examined the runtime of all involved modules for data block sizes of 250, 500, 750 and 1000 samples, epoch sizes of 150, 250 and 350 samples and for 4 configurations of the modules in the processing chain: CPU-only (all algorithms run on CPU), GPU-all (modules with CUDA support run on GPU), GPU-FIR (only FIR filter runs on GPU), and GPU-SRC (only source reconstruction on GPU). The runtime tests were performed on an Intel Xeon E5620, 2.4 GHz with a NVIDIA Tesla C2070.

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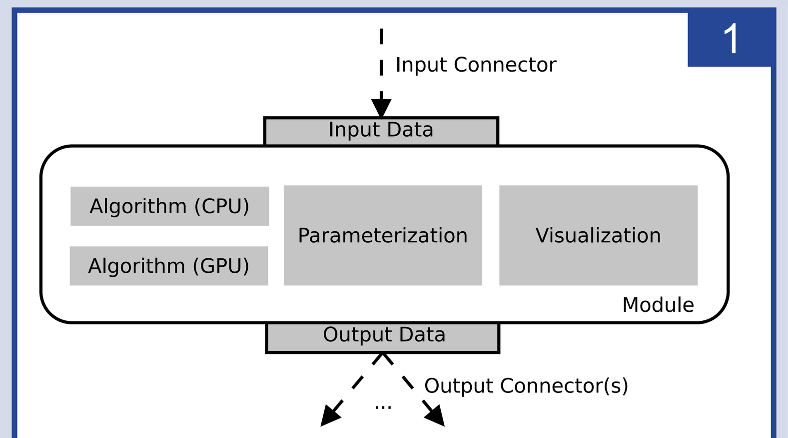

Abstract structure of a module in OpenWalnut. Gray blocks represent functions that are provided by each module.

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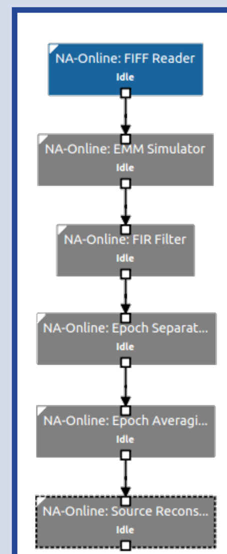

Module graph in OpenWalnut. It can be interpreted as a signal processing chain. The data flow is from top to buttom.

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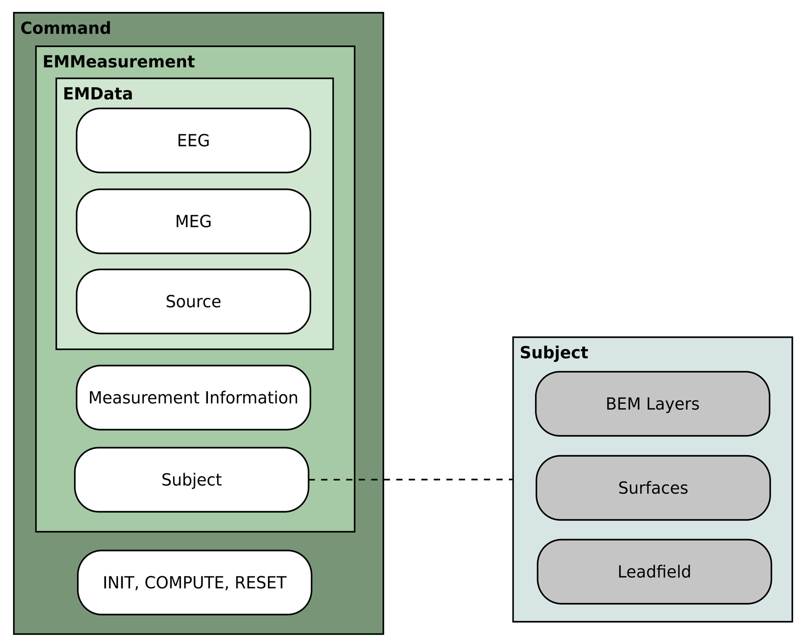

Shared command and data structure. Modules can be connected based on the EMMeasurement class, which contains any sub-data that may be needed. EMData holds dynamic data, all other parts contain static information, e.g. individual surfaces.

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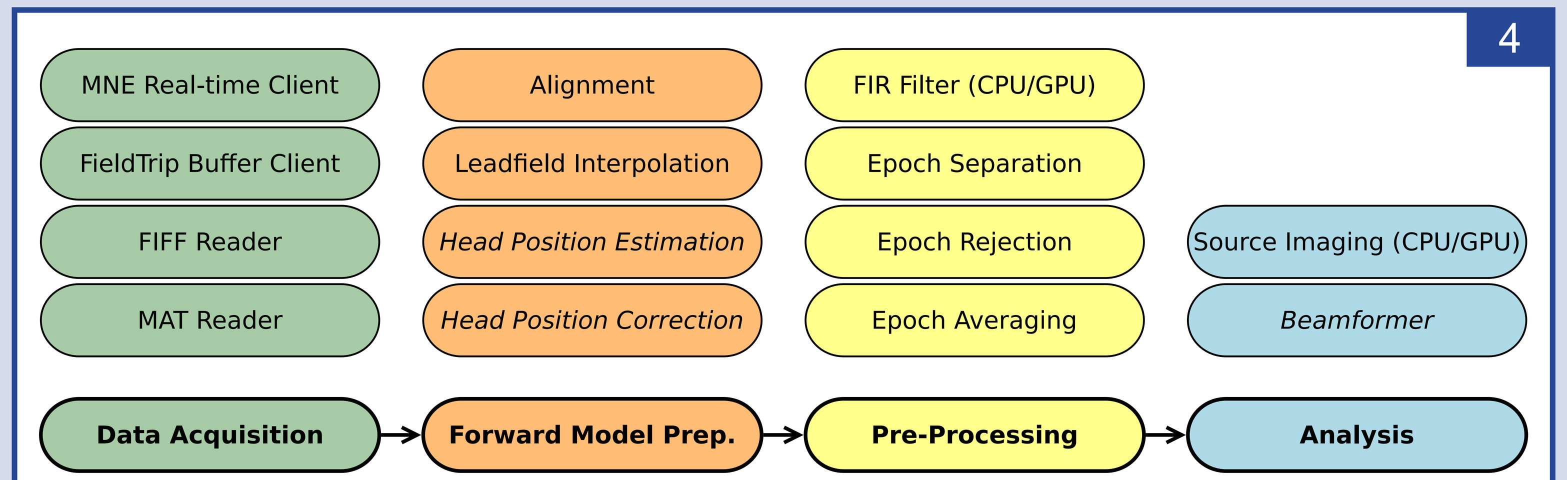

Available modules in our NA-Online toolbox. Modules formatted in *italic* style are in development.

Results

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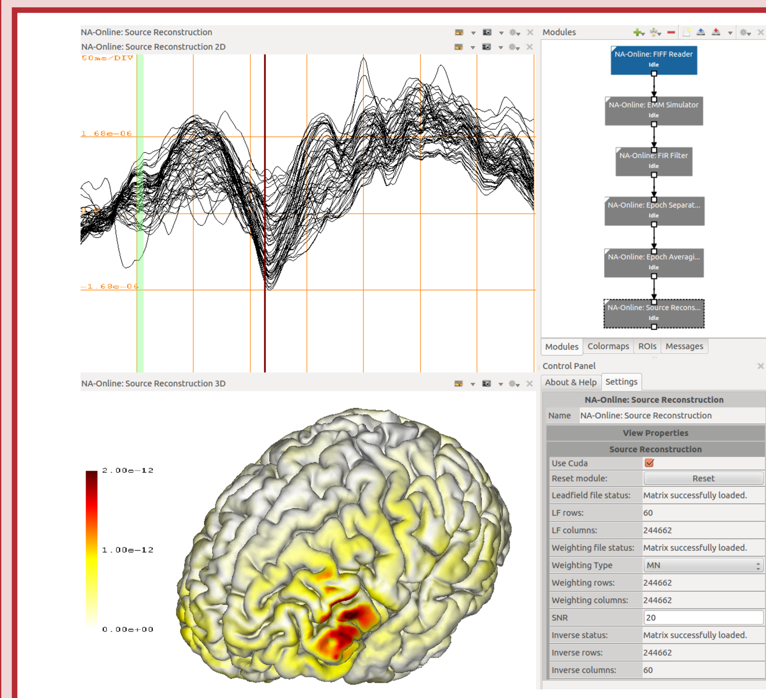

Source Reconstruction module in OpenWalnut.
Top: Averaged epochs of all 60 EEG channels.
Bottom: 3D view, estimated source strength at selected time point mapped on individual cortical surface.

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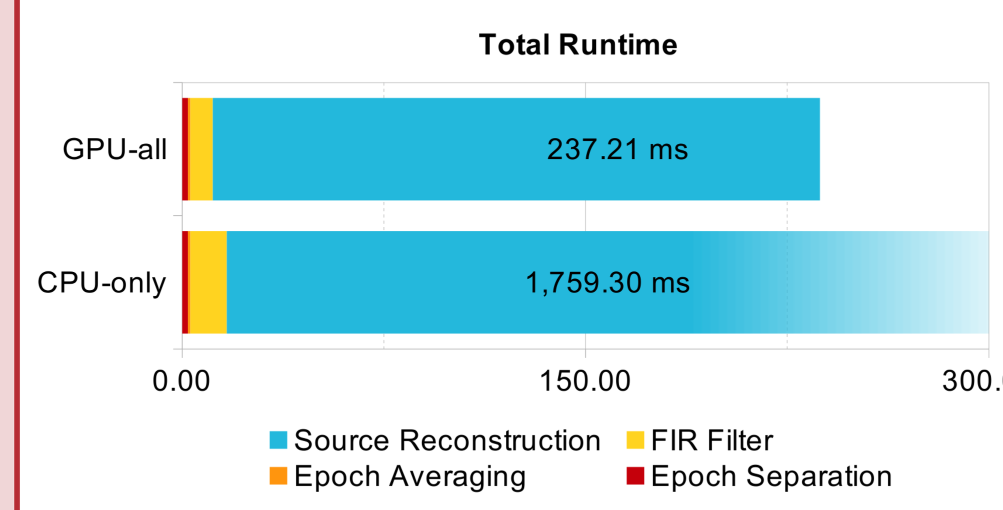

Averaged processing time per module for a block size of 1s (500 samples) and an epoch size of 300ms (150 samples). CPU-only processing exceeds the block size by more than 700ms. GPU-all setup takes 237ms to process a data block of 1s.

Runtime Results for FIR Filter

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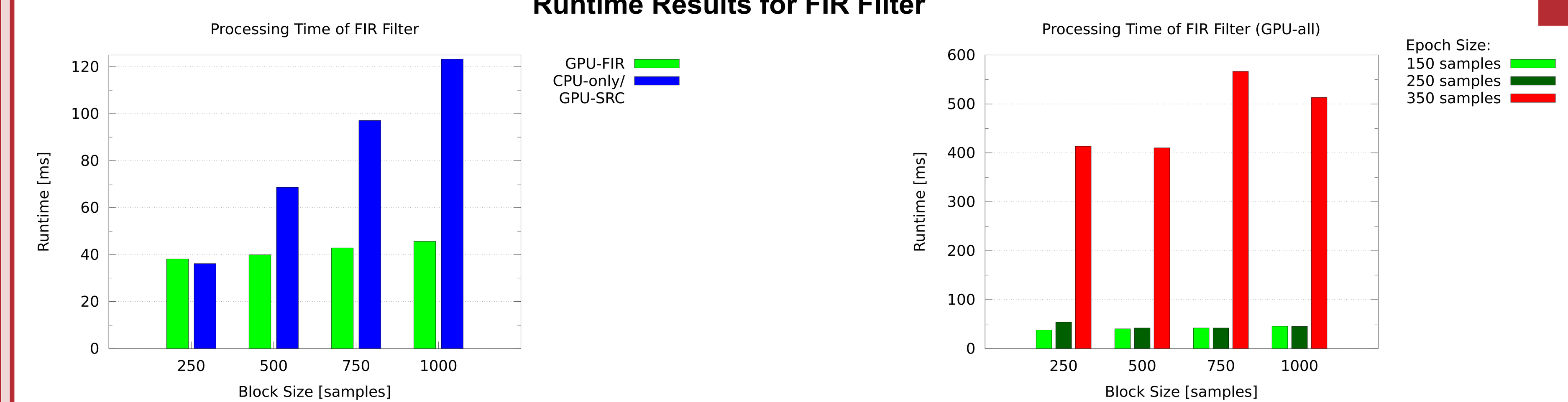

Left: Processing time of FIR Filter module depending on block size and execution on CPU or GPU. With increasing amount of data, the processing on GPU becomes more efficient.
Right: Processing time of FIR Filter module for GPU-all execution depending on block and epoch size. Although the FIR Filter only depends on block size, the processing time increases with an epoch size of 350 samples. In this configuration the CUDA execution of the FIR Filter is block by the CUDA execution of the Source Reconstruction module.

Runtime Results for Source Reconstruction

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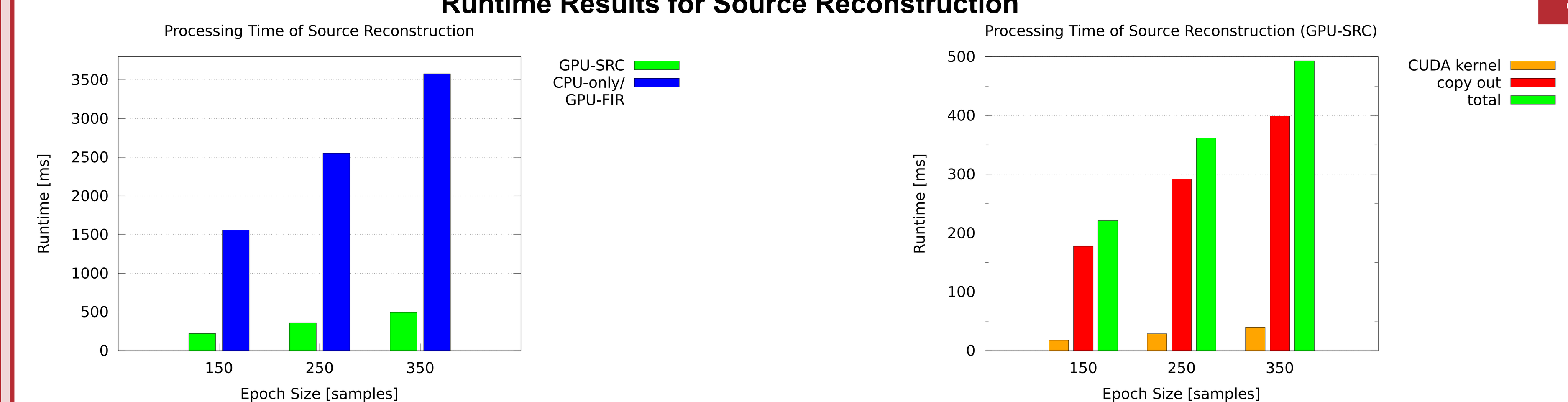

Left: Processing time of Source Reconstruction module depending on block size and execution on CPU or GPU. For 350 samples the speedup for GPU execution is 7.
Right: Processing time of different steps for Source Reconstruction (GPU). CUDA kernel is the pure processing time on GPU without any data transfers. Copy out is the transfer time which is needed to copy the result from the graphics card back to the application. The biggest part of processing is the data transfer.

Conclusion

We developed a toolbox which allows the online reconstruction of EEG/MEG sources using high resolution distributed source models which are defined on the individual cortical surface. The software allows a flexible on-demand configuration of the signal processing chain and, moreover, can easily be extended with additional algorithms such as, e.g., artifact detection and rejection.
Our runtime tests have shown that processing of data (60 EEG channels) in a typical configuration requires only 25 percent of the blocksize (1 second) when the GPU is used, while CPU-only processing exceeds this real-time limit by 70 percent. Despite possibilities of further optimizations of several algorithms as, e.g., the limitation of the source reconstruction to only a few significant samples rather than always employing the whole averaged epoch, involving the GPU provides sufficient resources to process MEG signals (306 channels), including MEG based source localization. This will be available after the complete realization of the head position correction, which is currently in progress.
The toolbox, called "NA-Online", is licensed under LGPL and freely available on Bitbucket: **www.bitbucket.org/labp/na-online_ow-toolbox**

Contact:

References:

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[2] K. Uutela, S. Taulu, M. S. Hämäläinen, "Detecting and Correcting for Head Movements in Neuromagnetic Measurements," *NeuroImage*, no. 6, pp. 1424-1431, 2001.
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