**Developing a Real-Time Feature EEG Extraction Pipeline for Resonance**

The overall goal of this project is to develop software that:

* Collects real-time EEG from two amplifiers (the 128-channel amplifier from Electrical Geodesics Inc and the DSI-24 from Wearable Sensing) using the Advanced Programming Interface (API) provided by each respective company
* Implements a real-time calculation of features of EEG related to consciousness. These features include 1) ratios of spectral power; 2) topographic distribution of alpha power; 3) phase-amplitude coupling; 4) frontoparietal phase lag index; 5) frontoparietal directed phase lag index; 6) hub locations; 7) permutation entropy.
* Outputs these features to interface with Open Sound Control

1. **Information about interfacing with the DSI-24 in real-time:**

By far the easiest is using the TCP/IP protocol (more details below), where you need to have our software open (runs on Windows), and then you open the TCP/IP socket, and it streams the data, and you can collect it using your software on ANY platform as the data can stream over the internet. (so collection on PC, but then forwards anywhere)

Then there is the API, which is a c-based .dll that runs in Linux, Mac, and Windows. It does not require our software to be running, so your software can talk directly to it, reducing a layer of complexity on the users. However, this usually takes a bit more effort to interface with. (info below).

We have an Lab-Streaming-Layer LSL implementation (which works on top of the API which supports Linux, Mac, and Windows ,

That said, here's more details on each approach:

1. TCP/IP

The Matlab sample code provided is a very good starting point.

There are two Python based approaches that can also be used.

* Here is sample codes in matlab and python and documentation:
* https://www.dropbox.com/s/hnt0ky7shle1gns/TCPIP%20Support\_20180116.zip?dl=0

2. API

dll, documentation (See demo.c) and code are at:

* https://www.dropbox.com/sh/30pyzl1cwnbsl1a/AAD889a9pAXWI0SmsuFKIEMQa?dl=0

3. LSL

* To download the Wearable Sensing module and compile it:
* https://github.com/Neuroscale-Users/dsi2lsl
* 1. Launch DSI-Streamer, check impedances, signal quality etc....
* 2. go to SOURCE tab in DSI-Streamer and click STOP to stop streaming data to DSI-Streamer
* 3. Exit DSI-Streamer and wait 5 seconds for COM port to be released by Windows (headset will start flashing green status LED)
* 4. Launch LSL GUI, select port and hit start
* 5. an LSL socket should be created
* 6. Use LSL recorder to open the stream along with any other streams such as presentation's stream, and record XDF files

I am in the process of purchasing a DSI-24 for the lab and will let you know when the order is placed.

2. **Feature Extraction**

The overall parameters for calculating these features might need to change, but please start here:

1. **Ratios of spectral power**

Calculate the spectral power of a 2 second window of EEG, for all channels, using Chronux. Step size = 0.5 s (this may increase to 1 s if it’s too computationally intensive for real-time); time-bandwidth product NW = 2; number of tapers K = 3.

Calculate overall power for theta (4-8 Hz), alpha (8-13 Hz), beta (13-25 Hz) bandwidths.

Average the power for each bandwidth over the *x* overlapping windows that span an interval of 5 seconds (e.g. if your step size is 0.5 s, 10 windows; if your step size is 1 s, 5 windows).

Every 5 seconds, output the following ratios to OSC:

* + Beta power / alpha power
  + Alpha power / theta power

1. **Topographic distribution of alpha power**

Using a 5 second window of EEG for all channels:

Calculate the scalp power distribution at 10 Hz (this will need to be an adjustable parameter) using the topoplot function. Divide the head anterior and posterior at Cz so that all of the electrodes in front of Cz are part of the “front” of the head and all of the electrodes along Cz and behind it are part of the “back” of the head.

Calculate the average power at 10 Hz for the front and the back of the head.

Output the ratio: front power / back power every 5 seconds to OSC.

1. **Phase amplitude coupling**

Using a 30-second window of EEG from these electrodes:

* For the EGI system, use the EEG data from 6 electrodes around Fz (electrodes 4, 10, 11, 16, 18, 19) and 5 electrodes around Pz (electrodes 61, 62, 67, 72, 77, 78).
* For the DSI-24 system, use the EEG data from 3 frontal electrodes (F3, Fz, F4) and 3 parietal electrodes (P3, Pz, P4).

Extract the extra low-frequency (0.1 to 1 Hz) and alpha (8-13 Hz) oscillations. Use a Hilbert transform to calculate instantaneous phase and amplitude within each bandwidth. Use the PAC code you have implemented in EEGapp to construct a phase-amplitude modulgram, assigning each temporal sample to one of n = 18 equally spaced phase bins.

In order to determine if we have “trough-max” or “peak-max” coupling, for each of the 11 electrodes, calculate the ratio of the PAC from the trough (-π/2 to π/2) and from the peak (-2 π to -3 π/2 PLUS 3 π/2 to 2 π).

Average the peak / trough ratio for all frontal electrodes, and for all parietal electrodes.

Output the 2 averages every 30 seconds to OSC.

1. **Frontoparietal weighted phase lag index**

We are interested in how the midline frontoparietal wPLI and lateral frontoparietal wPLI change with consciousness (midline functional connectivity is more connected to internal/self awareness, while lateral functional connectivity is more connected to awareness of the external environment).

Using a 10-second window of EEG from these electrodes:

Midline:

* For the EGI system, use the EEG data from 6 electrodes around Fz (electrodes 4, 10, 11, 16, 18, 19) and 5 electrodes around Pz (electrodes 61, 62, 67, 72, 77, 78).
* For the DSI-24 system, use the EEG data from 3 frontal electrodes (F3, Fz, F4) and 3 parietal electrodes (P3, Pz, P4).

Lateral:

* For the EGI system use EEG data from electrodes: lateral frontal (27, 33, 34, 116, 122, 123) and lateral parietal (51, 58, 59, 96, 97, 101)
* For the DSI-24 system, use the EEG data from lateral frontal (F7, F8) and lateral parietal (P7, P8).

For each window, calculate the wPLI for all combinations of frontal to parietal electrodes for the midline, and all frontal to parietal electrodes for lateral.

We will need to test the next part to see if it is feasible in real-time, but ideally: shuffle the data ~10 times to develop an approximate surrogate wPLI. Find the average surrogate wPLI, subtract it from the calculated wPLI.

Average surrogate-corrected frontoparietal PLI values for all midline electrodes, and lateral electrodes. Output these two values to OSC every 10 seconds.

1. **Frontoparietal directed phase lag index**

Same instructions as 4, but using dPLI instead of PLI. Same output to OSC every 10 seconds.

1. **Hub locations**

This feature will only be possible to calculate with the EGI amplifier (e.g. 128 channels). Again, we will need to see if this is feasible in real-time. For a window of 10 seconds of EEG data:

* Calculate the wPLI values of all combinations of electrodes, corrected with 10 iterations of surrogate wPLI.
* Choose the top 10% of wPLI values (this value will also need to be adjustable).
* Calculate the degree of each electrode.
* Find the electrode with the highest degree.

Every 30 seconds, output the average location (check with Florian how he wants this – MNI coordinates?) of the highest degree node to OSC.

1. **Permutation Entropy**

This is the one feature that hasn’t yet been implemented in EEGapp. I am writing to my collaborators at the University of Michigan for the MATLAB code and will pass it along as soon as I hear back.

Background

Permutation entropy (PE) measures the local dynamical changes of EEG – we want to see this in frontal and posterior channels. PE quantifies the regularity structure of a time series, based on a comparison of the order of neighboring signal values, which is conceptually simple, computationally efficient and artifact resistant (Bandt and Pompe, 2002), and has been successfully applied to the separation of wakefulness from unconsciousness (Olofsen et al 2008, Li et al 2008, Jordan et al. 2013, Ranft et al. 2016).

The calculation of PE requires two parameters: embedding dimension (d\_E) and time delay (). In line with previous studies, we will use d\_E=5 and =4 in order to provide a sufficient deployment of the trajectories within the state space of the EEG beta activity during wakefulness and anesthesia (Jordan et al. 2013, Ranft et al. 2016).

Implementation

Using a 10-second window of EEG, for frontal (Fp1, Fp2, F3, F4 and Fz) and posterior (P3, P4, Pz, O1, O2 and Oz) for both EGI and DSI-24 headset, calculate PE for each channel. Average over all frontal channels and all parietal channels. Output these values to OSC every 10 seconds.