Advanced Signal Processing I

Digital Filters
Time Frequency Approaches
Ocular Artifacts

Announcements

- Research Proposals due next Monday (May 2) no later than 2 pm via email to instructor
- Word format (DOCX or DOC) preferred
- Use the stipulated format (check website for details)
- Look at the relevant “guidelines” paper(s) (link on website)
- Take home final distributed next week, due May 9 at noon (hardcopy in my mailbox).
- 3x5s x 2

Digital Vs. Analog Filtering

- Analog filters can introduce phase shift or lag
- Certain frequency components "lagging" behind the others
- This is the effect of a capacitor literally slowing a signal
- Some frequencies are slowed more than others
- Problem: some ERP components could be distorted
- Hence, digital filtering is a preferred alternative.
  - No phase shift
  - Is widely used in last several decades
  - If digitized signal has minimal filtering, nearly infinite possibilities exist for digital filtering later
The Details!

- **Handout on Digital Filtering**

### Filter Details

A. Linear digital filters may be conceived of as vectors of weights that are to be multiplied by the digitally sampled values from a waveform. The filters given below are both 11 point digital filters with a half-amplitude frequency cutoff of approximately 17.5 Hz for data sampled at 200 Hz.

<table>
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<th>LOW PASS COEFFICIENT</th>
<th>LAG</th>
<th>HIGH PASS COEFFICIENT</th>
<th>LAG</th>
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<tr>
<td>0.0166</td>
<td>-5</td>
<td>-0.0166</td>
<td>-5</td>
</tr>
</tbody>
</table>

### More Details

- **Digital filters have characteristics that are sampling-rate dependent.**
- **These same filters would have a different cutoff frequency for data sampled at different sampling rates.**
- **Once you know the characteristics of a digital filter at a given frequency, it is a simple matter to convert the filter to another sampling rate as follows:**
  - \(17.5/200 = x/1000\); \(x = 87.5\) @ 1000 Hz Sampling rate
  - \(17.5/200 = x/20\); \(x = 1.75\) @ 20 Hz Sampling rate

### Muy Simple Filter

\[ \begin{bmatrix} 0.25 & 0.5 & 0.25 \end{bmatrix} \]

To apply: Iterate through data segments the size of the filter

\[ \text{filtered point} = \text{filtered point} \times \text{filtered point} \]
Some filters and their Transfer Functions

Cook & Miller, 1992

Figure 1. The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

Pragmatic concerns

- Sample extra data points; many if you want sharp roll-off
- The filter cannot filter the first \((n-1)/2\) points for filter length \(n\)
- Try out your filter via FFT analysis or via derivation of the transfer function before you apply it routinely
Use in Single Trial Analysis

- With stringent digital filtering, you may be able to discern peaks on an individual trial basis.

Digital Filtering and More!

A bit more on phase and such
COURTESY OF MIKE COHEN

2. How do brain regions "talk" to each other?

Synchronized oscillations is an intuitive concept, but how to measure it quantitatively?

The time interval for one degree of phase is inversely proportional to the frequency.

- You know…. the frequency of a signal $f$ is expressed in Hz.

- The time $t$ (in seconds) corresponding to:
  - one degree of phase is: $t_{\text{deg}} = 1 / (360 f)$
  - one radian of phase is approximately: $t_{\text{rad}} = 1 / (6.28 f)$

Adapted from http://whatis.techtarget.com/

See empirical work and reviews by: Rubino, Lisman, Singer, Engel, etc.
2. Inter-site phase coherence.

Electrodes: Fp1 & C4

Electrodes: Fp1 & Fp2

2. Inter-site phase coherence?

"Polar plot" of phase angle differences.

2. Circular variance.

Draw a line through the "average" of vectors.

2. Circular variance.

The length (magnitude) of that vector varies from 0 to 1, and is the phase coherence.

Phase coherence: 0.11

Phase coherence: 0.94

2. Circular variance.

The equation for phase coherence is simple:

\[ \text{Phase coherence} = \left| \text{mean}(\exp(i \times \text{angle differences})) \right| \]
2. Inter-site phase synchrony with one "seed" site.

2. Inter-trial phase synchrony within one electrode.

Many trials from the same electrode:

2. Inter-trial phase coherence

Calculate phase coherence across trials at each time point

Phase coherence, 154 ms: 0.11

2. Inter-trial phase coherence

3 different electrodes
Thanks Mike!
NOW BACK TO JOHN’S SLIDES

Power, Phase, ERPs

The Importance of Phase!

Time-Frequency Approaches to Error Monitoring

Classic ERPs Vs Phase Resetting
Ocular Artifacts

- The problem
  - Eye movements and blinks create a potential that is propagated in volume conducted fashion
  - Manifests in recorded EEG
- Why?
  - Eye not spherical; more rounded in back
  - Potential is therefore positive in front with respect to rear of eye
  - Movements = Moving dipole
  - Blinks = Sliding variable resistor
Ocular Artifacts

- Eye-blinks are **systematic** noise with respect to the ERP signal
- Occur at predictable latencies (Stim-Resp-Blink)
- Are meaningful variables in and of themselves:
  - John Stern: Information processing and blink latency
  - Peter Lang: Blink Amplitude and affectively modulated startle response

Signal averaging will not remove this "noise" (noise wrt signal of interest)
Average waveform $a(t)$ is mixture of timelocked signal $s(t)$ and randomly distributed error (noise)

\[
a(t) = s(t) + \frac{1}{n} \sum_{i=1}^{n} e(t)
\]

- If non-ERP signals are random with respect to stimulus onset, then the latter term will approach zero with sufficient trials ($n$)
- If not, the latter term will not sum to zero, but will include time-locked noise
- Noise will therefore average IN, not average OUT

Ocular Artifacts

- Eye-blinks tend to occur at the cessation of processing.
  - Recall that the P300 is also a good index of cessation of processing.
  - As a result, eye-blink artifact tends to appear as a late P300ish component

What to Do?!

- Reject trials during which eye-blink occurred.
- Problems:
  - Trials which elicit blinks may not be equivalent to those which do not.
  - Large data loss, may be unable to get usable average
  - Telling subjects not to blink creates dual task
- Eye-blink correction (Gratton, Coles, & Donchin, 1983)
  - Assumes that the effect of an eye-movement or blink on the recorded EEG can be inferred from activity recorded near the source of the artifact (top and bottom of eye, e.g.)
  - Model ocular potentials as a source, and remove from scalp sites (more later)
The Details

- Must determine extent to which EOG signal propagates to various scalp loci.
- Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels.
- Event related activity in both channels may spuriously inflate estimate of propagation.
- Based upon correlation and relative amplitudes of EEG & EOG, a scaling factor is computed. The scaling factor is then applied on a trial by trial basis as follows:

  Corrected EEG = Raw EEG - K*(Raw EOG)

- Corrected EEG epochs then averaged together to get blink-corrected ERP.

Validity of Ocular Correction

- Can produce valid results, but important to examine data to ascertain how well procedure worked.
  - Creates blink-locked averages.
  - Should reduce event-related contributions to correction estimate.
  - Produces highly similar results.

Other Methods (in brief)

- Most other methods also depend upon subtraction of a proportion of the EOG signal or some transformation of the EOG signal.
- Frequency-domain methods recognize that not all frequencies in the EOG channel propagate equally to scalp sites.
- Source localization methods attempt to derive a source that represents the equivalent of the origin of the eye potentials, and then compute the extent to which these sources would project onto scalp.
  - BESA
  - ICA
Demonstration of Ocular Correction