Biomedical Signal Processing and Computation

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Biomedical signals are generated by biomedical systems measuring biomedical variables. These variables can be influenced by environmental/external variable(s). The sensor, acting as a measuring device, transforms the biomedical signal into an action potential.
Properties of Biomedical Systems and Signals

Biomedical systems are:
- dynamic
- nonlinear
- stochastic
- non-stationary (time varying)
- spatially distributed
- most have multiple signaling pathways
- some of them are oscillatory

Consequently, biomedical signals are:
- of limited bandwidth with noise that is colored
- complex (attractors, chaos, fractals)
- noisy
- non-stationary
- high dimensional
- redundant (spatial correlations)
- some of them are periodic
Example 1

Neuronal action potentials

(data from monkey brain)

Temporal resolution: <1ms
Spatial resolution: ~20 μm
Example 2

Electroencephalogram (EEG)

Temporal resolution: ~10 ms
Spatial resolution: ~2 cm

(data from human brain)
Research in this area is highly cross-disciplinary!
Investigator and the Lab

Investigator: Zoran Nenadic
- DSc in Systems Science and Mathematics, Washington University, St. Louis, MO
- Postdoctoral Training, California Institute of Technology, Pasadena CA

Graduate students (PhD):
- Christine E. King (BME)
- Chang Won Lee (BME)
- Po T. Wang (BME)
- Victor Quintanar-Zilinskas (MCSB)

Collaborators (UCI):
- An H. Do, MD (Neurology)
- Xiangmin Xu, PhD (Anatomy & Neurobiology)
- A. Lee Swidlehurst, PhD (EECS)
- David J. Reinkensmeyer, PhD (MAE)
- Steven C. Cramer, MD (Neurology)
Long-term research question: How does the brain process information?

Short-term research problem(s):
• If we measure brain activity, what inferences can we make about the underlying cognitive processes?
• Can we develop analytical and computational tools to efficiently analyze measurements without making unnecessary or unsupported assumptions? Can this lead to the development of new theories?
• Can we translate this into something useful?

Major project: Brain-computer interface (BCI)
Background:

“We will be engaged in the development of principles and techniques by which information from the nervous system can be used to control external devices such as prosthetic devices, communications equipment, teleoperators [· · ·] and ultimately perhaps even computers.”

Karl Frank, Founder of the Laboratory of Neural Control at the National Institute of Neurological Disorders and Stroke, [1].

BCI Featured on “60 Minutes”
P300 Speller

P300 is a brain wave that is generated when a person sees a "rare" event. It is visible roughly 300 milliseconds after seeing the event.
2nd Generation P300 Speller

- Practical error-free typing rates as high as 12.75 characters/min.
- Error-free information transfer rates >3 bit/sec.
- These are 3 times higher than the performance of similar systems in the field.

P.T. Wang, C.E. King, A.H. Do and Z. Nenadic, Pushing the communication speed limit of a noninvasive BCI speller. (submitted)
Non-oddball

Oddball
BCI as a Prosthetic Technology for Spinal Cord Injured (SCI)

Subject with paraplegia (T8, ASIA B), 11 years post-injury uses BCI to control the linear ambulation of a virtual reality avatar.

Summary of Experiment:

- Subject instructed by visual cues
- Upon the cue, the subject clenches the right fist
- EEG measured by the EEG cap
- EEG data analyzed by BCI computer
- BCI computer drives the orthosis mounted on the left hand
- Hand movements measured by custom-made goniometers [2]

<table>
<thead>
<tr>
<th>Lag (sec) (n=5)</th>
<th>$\rho$</th>
<th>Omission</th>
<th>False Alarm</th>
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<tr>
<td>2.24 (0.20)</td>
<td>0.78 (0.06)</td>
<td>0.40 (0.89)</td>
<td>1.8 (1.10)</td>
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</table>

BCI-FES System for Neurorehabilitation after Stroke

How does it work?

<table>
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<th>Subject</th>
<th>Lag (sec)</th>
<th>$\rho$</th>
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<th>False Alarm</th>
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<td>5</td>
<td>2.9</td>
<td>0.77</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>
Will it work on stroke subjects?

Subject with Foot Drop due to Stroke Operates BCI-FES System
Future Work:

• BCI-driven wheelchair
• BCI-driven functional electrical stimulation device for restoring ambulation in subjects with paraplegia due to SCI
• Invasive BCI control of upper extremity prosthesis
BCI Control of Upper Extremity Prosthesis

- 6 DOF robotic arm
- Electrocorticogram (ECOG) grid
- x-ray of ECOG grid
More videos can be found at:

http://cbmspc.eng.uci.edu/
http://www.youtube.com/user/UCIBCI

Funding sources: