Closing the Loop: Towards Smart Integrated Medical Systems & Assistive Technologies

Aydin Farajidavar, PhD

Integrated Medical Systems (IMS) Laboratory
School of Engineering and Computing Sciences
New York Institute of Technology

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Outline

- Integrated Solution for Pain Management
  - Recording from Spinal Cord
  - Recording from Thalamus
  - Recording from Somatosensory

- Integrated Solution for Relieving Gastroparesis
  - Gastric Electrical Activity

- Integrated Assistive Technology for Speech Impairment
  - Tongue Tracking System

- Integrated Solution for Medication Adherence
  - Smart Connected AT/WD

- Conclusion
Basic Neuroscience

Extracellular single-unit recording

http://en.wikibooks.org/wiki/Human_Physiology/The_Nervous_System
Background on EEG/ECoG

- Delta (up to 4 Hz) - Sleeping
- Theta (4 - <8 Hz) - Drowsy
- Alpha (8 - <13 Hz) - Relaxed
- Beta (13 - <30 Hz) - Alert
- Gamma (30 - 100 Hz) - Complicated Sensory Proc.
Brain Machine Interface (BMI)

- A brain–machine interface (BMI) is a direct communication between the nervous system and an external device.
- BMIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.
Neurostimulation: Deep Brain Stimulation

DBS mechanism

http://www.youtube.com/watch?v=izKL1mVXF7c&feature=related
Problems of Current Neurostimulators

- Tuning (trial and error)
- Feedback from nervous system
- The battery life
Develop an integrated system, to acquire information about the state of nervous system, and **stimulate** the brain when necessary in order to normalize the state.
Treating Neural Disorders: Neurostimulation

- Chronic Pain
- Gastroparesis
- GERD
- Epilepsy
- Depression
- Parkinson's
- Dystonia
- Incontinence
- Sexual Dysfunction
- Respiratory Support
- Obesity
- TBI
- Alzheimer's
- Huntington's

Chronic Pain

- **Statistics**
  - 40 million medical visits annually
  - $100 billion costs annually

- **Little has been done**
  - Treating with drugs (depression and addiction)
  - Quantifying pain
Pain Pathways (Spinothalamic)

- Somatosensory cortex (ECoG)
- Thalamus (VPL/VPM) (Single-unit)
- Dorsal horn spinal cord (Single-unit)

Kandel et al. 2000
Extracellular Recording from SC Stimulating PAG

- Head stage
  - Transmitter
  - Amplifiers
  - Microcontroller

- Receiver

- USB-6008
- Receiver station
- 1401 Plus
- Transmitter station

- Labview & Spike 2

- Brush Pressure Pinch
  - 2 Sec.

- PW: 100 μsec.
- 100 Hz

- 1 Volt
- 100 Hz

- Receiver RX2
- Microcontroller BS1-1C
- Transmitting antenna
- Receiving antenna
Real-time Experiments

- Brush: Rate of APs
- Pressure: Inhibition
- Time delay

Stimulation triggered

- Time (s)
- Rate of APs (Spikes/500 ms.)
- Recorded APs (relative voltage)
Real-time Experiments

Brush
Pressure
Pinch

Initiation of the pressure stim.
Inhibition

2.6 s.

Rate of APs (Spikes/500 ms)
Stimulating pulses (V.)
Recorded APs (relative voltage)

Time (s)
Importance of Statistical Results

It is rather interesting phenomenon. Every time I press this lever, that post-graduate student breathes a sigh of relief.

http://www.cyc-net.org/humour/070801laugh.html
Performance of the System

**Mean number of stimulation triggered ± SEM**

<table>
<thead>
<tr>
<th></th>
<th>brush</th>
<th>pressure</th>
<th>pinch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1.85 ± 0.23</td>
<td>3.62 ± 0.16</td>
</tr>
</tbody>
</table>

System found pinch stimulus twice as painful as pressure (n=29).

**Mean time delay in ± SEM**

<table>
<thead>
<tr>
<th></th>
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<th>pressure</th>
<th>pinch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>--</td>
<td>4.46 ± 0.49 (s)</td>
<td>0.91 ± 0.16 (s)</td>
</tr>
</tbody>
</table>

System detected pinch stimulus five times faster than pressure (n=29).
Statistical Results

The mean rate of Action potentials (APs)/sec. ± SEM (standard error of mean), n=29 (number of recorded neurons)
Pain Pathways (Spinothalamatic)

- Somatosensory cortex (ECoG)
- Thalamus (VPL/VPM) (Single-unit)
- Dorsal horn spinal cord (Single-unit)

Kandel et al. 2000
The mean rate of Action potentials (APs)/s. ± SEM (standard error of mean), n=40 (number of recorded neurons)
Problems and Issues with Single-Unit APs

- Long-term recording of single-unit action potential has not been demonstrated in clinical practice.
- Adds extra surgical procedures to the implantation of DBS.
Pain Pathways (Spinothalamic)

- Thalamus (VPL/VPM) (Single-unit)
- Somatosensory cortex (ECoG)
- Dorsal horn spinal cord (Single-unit)

Kandel et al. 2000
Hardware Characteristics to Acquire EEG/ECoG

(1) Size and weight
(2) Wireless transmission
(3) Multichannel recording
(4) Energy consumption
(5) Cost efficient
Multichannel Wireless System to Acquire EEG/ECoG

(a) Back-end

(b) (c)

Labview

Radio

μC

Radio

ADC

Amplifier & Filter

AIN0

AIN1

... AIN6

ECoG

(c)
Comparing Wired and Wireless Systems

(a) Relative gain (dB) vs. Frequency (Hz)

(b) Relative magnitude (µV) vs. Time (s)

(c) Relative power vs. Frequency (Hz)

(d) Relative power vs. Frequency (Hz)
Video of a Rat with the ECoG Front-end
Experimental Procedures

1. Thermal stimulation
2. Chemical stimulation
3. Mechanical stimulation

Motor Cortex

Somatosensory

Ling et al. 2004
Implantation Methodology

(a) M1
S1HL
Supporting screw
Cerebellum

(b)

(c)

(c)
In 87.5% of the withdrawal incidents a peak was detected in the time-domain signal.
Power Spectrum in Various Frequency Bands for Thermal Stimulation to Right Paw

**M1L**

- **Baseline**
- **Heating**
- **Withdrawal**

**S1L**

- **Baseline**
- **Heating**
- **Withdrawal**

**M1R**

- **Baseline**
- **Heating**
- **Withdrawal**

**S1R**

- **Baseline**
- **Heating**
- **Withdrawal**
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- Obesity
- TBI

Gastroparesis

- Vagus nerve is damaged / Gastric emptying delayed
- Stomach does not move

Symptoms
- Nausea
- Vomiting
- High / low blood glucose levels

Statistics
- 40-50% of diabetic population suffers from Gastroparesis
- 25 million people in the US suffering from Diabetes in 2010
Integrated Solution for Relieving Gastroparesis
Acquiring Gastric Electrical Activity (GEA)
In-vivo Experiment for Recording GEA

Cable electrodes

Recording system
Results for GEA

Wired

Wireless

Wired

Wireless
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Visual Biofeedback for Speech Impairment

Velocity time
\( Vx(t) = 3 \quad \text{Goal} = 5 \)
\( Vy(t) = 1 \quad \text{Goal} = 3 \)
\( Vz(t) = 2 \quad \text{Goal} = 3 \)

Acceleration time
\( Ax(t) = 5 \quad \text{Goal} = 6 \)
\( Ay(t) = 4 \quad \text{Goal} = 3 \)
\( Az(t) = 2 \quad \text{Goal} = 4 \)

KP factors

Tongue tip

Target region

Oral space in 2D

Tongue trajectory

Rewarding signal (KR factor)

SLP: Owens; Patient #: 3
Tongue Tracking Systems (TTS)
Mathematical Model for A Magnetic Dipole

\[ B(s, a, m) = \frac{\mu_0}{4\pi} \frac{3[m \cdot (s - a)](s - a) - \|s - a\|^2 m}{\|s - a\|^5}, \]
Tongue Tracking Systems (TTS)
Human Subject Experimental Results

Recorded by our TTS System

Recorded by Carstens (Katz et al.)
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Conclusion

Integrated Closed-loop systems are the game-changers of future wearable / implantable medical systems and assistive technologies since they can improve the quality of human life more efficiently, help patients live independently, and significantly reduce clinical costs.
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