Seizure Prediction and Detection

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Feb. 9, 2011
Outline

• Seizure prediction using spectral power features and SVM-classification (Freiburg database)
• Implantable seizure predictor – low-cost/power (2-4 electrodes, battery life > 1 year)
• Seizure detection on large scale data – preliminary results (100+ electrodes)
Overview of Epilepsy

- Epilepsy: 2nd most common neurological disorder
- Affects approximately 1% of US population, nearly 3 million
  - 1/3 spontaneously recover
  - 1/3 successfully treated with antiepileptic medications
  - 1/3 have intractable seizures
    - 40% successfully treated with surgery
    - 20% continue to have epilepsy after surgery
    - 40% inoperable

- $15.5 billion in direct and indirect costs per year in US
  (Epilepsy foundation, 2005)
- Implantable device provides warnings, and therapy
Seizure Prediction based on EEG

• Prediction: classification of *preictal* (prior to a seizure) from *interictal* (between seizures)

• Detection: classification of *ictal* from *non-ictal*
Seizure Prediction Using SVMs

- Mainly consists of **feature extraction** and **SVM-classification**
- Features: **spectral power in 9 bands** from 20-sec-long window
  - $\delta$ (0.5-4Hz), $\theta$ (4-7Hz), $\alpha$ (8-13Hz), $\beta$ (13-30Hz), $\gamma$ (30-50Hz, 50-75Hz, 75-100Hz, 100~Hz), and Total
  - **Bipolar** (space-differential) and/or **time-differential** preprocessing
- **SVM-classification** with RBF kernel
  - **Cost-sensitive SVMs** for highly unbalanced datasets
- **Freiburg EEG database**
  - [https://epilepsy.uni-freiburg.de/freiburg-seizure-prediction-project/eeg-database](https://epilepsy.uni-freiburg.de/freiburg-seizure-prediction-project/eeg-database)
  - 18 of 21 patients selected who have $\geq$ 3seizure recordings
(A) Raw
(B) Bipolar
(C) Time-diff
(D) Bipolar & Time-diff
Kalman filter for post-processing

• Reduce # of FP while maintaining the sensitivity
• The change rate of two continuous windows should undergo smooth transition $\rightarrow$ 2$^{\text{nd}}$ order Kalman filter
# Results

- Bipolar improves sensitivity; time-diff improves FP rate
- Submitted to Epilepsia in Aug 2010 (under review)

<table>
<thead>
<tr>
<th>PSD</th>
<th>Sens (%)</th>
<th>FP/hr</th>
<th>FP%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>93.8</td>
<td>0.29</td>
<td>13.7</td>
</tr>
<tr>
<td>Bipolar</td>
<td>97.5</td>
<td>0.27</td>
<td>13.0</td>
</tr>
<tr>
<td>Time-diff</td>
<td>92.5</td>
<td>0.20</td>
<td>9.49</td>
</tr>
<tr>
<td>Bipolar/time-diff</td>
<td>93.8</td>
<td>0.23</td>
<td>10.7</td>
</tr>
</tbody>
</table>

# patients = 18, # seizures = 80  
Total interictal hours = 437
## Results’ Comparison with Others in Same Freiburg Database

<table>
<thead>
<tr>
<th>Group</th>
<th># Pat</th>
<th># Sz</th>
<th>Interictal hours</th>
<th>Prediction horizon (min)</th>
<th>Sens (%)</th>
<th>FP/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winterhalder, et al., 2003</td>
<td>21</td>
<td>88</td>
<td>509</td>
<td>30</td>
<td>42</td>
<td>0.15</td>
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<tr>
<td>Aschenbrenner, et al., 2003</td>
<td>21</td>
<td>88</td>
<td>509</td>
<td>50</td>
<td>34</td>
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</tr>
<tr>
<td>Maiwald, et al., 2004</td>
<td>21</td>
<td>88</td>
<td>509</td>
<td>32</td>
<td>30</td>
<td>0.15</td>
</tr>
<tr>
<td>Schelter, et al., 2006</td>
<td>4</td>
<td>20</td>
<td>96</td>
<td>40</td>
<td>70</td>
<td>0.15</td>
</tr>
<tr>
<td>Park, et al Submitted 2010</td>
<td>18</td>
<td>80</td>
<td>437</td>
<td>30</td>
<td>97.5 (B)</td>
<td>0.27 (B)</td>
</tr>
<tr>
<td>(Epilepsia, under review)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>92.5 (T)</td>
<td>0.20 (T)</td>
</tr>
</tbody>
</table>
Towards an Implantable Seizure Predictor!

• Features limited to 4-5
• Target power consumption: 50 microwatt
• **Reduce computational complexity**: Feature consolidation, Feature Selection by maximizing divergence
Feature Reduction

• **Feature Consolidation**: Test 1D Henze-Penrose divergence (HPD) of two adjacent power spectrum band features and combine them if 1D HPD of combined bands is greater than or equal to each one of them.

• HPD is based on Minimum Spanning Tree (MST)

• **Feature Selection**: Iteratively obtain 4 features that produce maximum 4D HPD
Preliminary Results

- Feature consolidation and feature selection used
- Mean(8-tap) and median (9-tap) filter used for postprocessing

<table>
<thead>
<tr>
<th>Patient</th>
<th>Predicted</th>
<th>Missed</th>
<th>FP/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0.343</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0.133</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0.058</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0.666</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0.444</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>0</td>
<td>0.133</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0</td>
<td>0.541</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>1</td>
<td>0.614</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>0</td>
<td>0.354</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>1</td>
<td>0.812</td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>1</td>
<td>0.406</td>
</tr>
<tr>
<td>17</td>
<td>4</td>
<td>1</td>
<td>0.433</td>
</tr>
<tr>
<td>18</td>
<td>3</td>
<td>1</td>
<td>0.760</td>
</tr>
</tbody>
</table>

- Sensitivity: 85.5%
- Avg. FPR: 0.44/Hour
- Full Features: 97.5%
- Full Features: 0.27/Hour
Detection of Epileptic Seizures

- Seizure (onset) detection using linear features of EEG
- Easy to reach high sensitivity but challenging to reduce FP rate

(A) Ictal

(B) Interictal
Seizure Detection by Cross-Channel Covariance

- Seizure detector with a few features & simple classifiers
- Preliminary result using cross-channel covariance of pre-whitened signals
Conclusion

• Established seizure predictor based on SVM-classification and Kalman filter: **97.5% sensitivity** and **0.27 FP rate** were achieved with bipolar spectral power features

• Implantable seizure prediction device: consolidate and select features using HPD (ongoing)

• Build **seizure detector with least number of electrodes, features and fusion of simple classifiers** (ongoing)

• Extend our approaches into Mayo database
Acknowledgements

• IEM grant
• MSI
• Medtronic (Technical discussions)
• Collaborators:
  Dr. Vladimir Cherkassky (ECE, U of M)
  Dr. Tom Henry (U of M Medical School)
  Dr. Greg Worrell (Mayo Clinic, Mayo database access)