EEG-Based Vigilance Analysis

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Outline – Introduction

1. Introduction
   - What are EEG signals
   - What is vigilance
   - The purpose of the research
   - What methods are adopted

2. Methodology

3. Experiments

4. Engineering Project
What are EEG Signals

EEG is the abbreviation of Eletroencephalography (脑电图).

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What is Vigilance

Vigilance (警觉度), or sustained attention, refers to the ability of observers to maintain their focus of attention and to remain alert to stimulus for prolonged periods of time.

High Vigilance

Low Vigilance
The Purpose of Vigilance Analysis

During our daily lives, for many human machine interaction systems, the operators should retain vigilant above a constant level to keep working safely. We need an effective method to measure the current vigilance level of the operator.

An EEG Based Assistant Driving System Developed by DaimlerChrysler Company
We adopt an intra-discipline methodology combining
- Signal Processing
- Statistical Learning
- Data Mining
- Visualization
Outline - Methodology

1. Introduction
2. Methodology
3. Experiments
4. Engineering Project

- Overview of the framework
- Step-by-step introduction
Overview of Our Analysis Framework

1. Signal Acquisition
2. Artifact Removal
3. Temporal Filtering
4. Spatial Filtering
5. Feature Extraction via Power Distribution
6. Principle Component Analysis
7. Clustering Analysis
8. Visualization of High Dimension Result
Signal Acquisition

Field Potentials From Electrodes → A/D Converter → Digitized Signals → 20k Amplifier → Amplified Signals
Artifact (Noise) includes

- Electromyography (EMG) Signals (肌肉电信号)
- Electrooculography (EOG) Signals (眼球电信号)
- Electrocardiography (ECG) Signals (心电信号)
- 50Hz Alternating Current Interference
Frequency Band of EEG is less than 30Hz.

- **Beta Rhythm**: 13 to 25 Hz
- **Alpha Rhythm**: 8 to 13 Hz
- **Theta Rhythm**: 4 to 8 Hz
- **Delta Rhythm**: 0.5 to 4 Hz
Temporal Filtering

From awake to sleep, EEG energy around 13Hz (between $\alpha$ and $\beta$ rhythm) will gradually decrease, meanwhile EEG energy around 4Hz (between $\delta$ and $\theta$ rhythm) will gradually increase.

Frequency Band of Sleeping-Related EEG is less than 20 Hz. According to Nyquist Sampling Theory, a Low-Pass Filter of 40Hz could be used.
We use a 66-channel (66-electrode) sampling device. Each channel (electrode) is located at a unique position on the scalp. After Spatial Filtering:

- The number of channels is significantly reduced.
- Information *not* related to the vigilance is filtered.
We use the *Common Spatial Pattern* (CSP) technique to achieve Spatial Filtering. In math, it simultaneously diagonalizes two covariance matrices.
CSP Analyzing Phase

66-Channel EEG Matrix $E$ (66*L) Multiplied by CSP Projection Matrix $W$

$Z = W^*E$

2-Channel EEG Matrix $Z$ (2*L)
After *Spatial Filtering*:
- The number of channels is significantly reduced.
- Information *not* related to the vigilance is filtered.
Experiments show that the *Energy* has close relationship with vigilance. Then we base the feature extraction on *Energy*.

The energy distribution around 3Hz in three vigilant states of the scalp
Feature Extraction

2-Channel discrete signal trial in temporal domain (Processed by CSP)

Short Time Fourier Transform (STFT)

2-Channel discrete signal trial in frequency domain

Calculating Power Distribution

A feature vector (2*k dimensions, k is the number of energy levels)

\((x_1, x_2, x_3, \ldots, x_n)\)
PCA (Principle Component Analysis) is a statistical technique to reduce the dimension of feature vectors. It is based on *Eigenvectors* of the covariance matrix.

\[(x_1, x_2, x_3, \ldots, x_{128})\]

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**Principle Component Analysis**

\[(\alpha, \beta, \gamma)\]
We use clustering algorithms to discover different vigilant states and their corresponding time automatically.
Clustering Result of 2-Dim Feature Vectors

Clustering Result of 3-Dim Feature Vectors

How to visualize clustering result of n-Dim Feature vectors (n>3) ???
Self Organization Maps (SOM) is adopted to visualize high-dimensional vectors on a 2D plane.

Visualize 3D Colors on a 2D Plane. Similar colors are automatically grouped together.
Review of Our Analysis Framework

1. Signal Acquisition
2. Artifact Removal
3. Temporal Filtering
4. Spatial Filtering
5. Feature Extraction via Power Distribution
6. Principle Component Analysis
7. Clustering Analysis
8. Visualization of High Dimension Result
Outline – Experiments

1. Introduction
2. Methodology
3. Experiments
   - Environment
   - Step-by-step introduction
   - Results
4. Engineering Project
Experimental Environment

- STIM PC
- SCAN PC
- SynAmps2
- HeadBox
- Amplifier
- Power Source
- NeuroScan System 3.0 @ BCMI

Undergraduate Thesis Defense  
EEG-Based Vigilance Analysis
Signal Acquisition

Electrode Distribution Diagram

Damaged Electrodes

Omitted Electrodes

66-8=58 Channels are used
Signal Acquisition

- Subject: A 25-year old healthy man
- Total Signal Length: 1 hr 5 min 28 sec
- Channels (Electrodes): 58
- Sampling Rate: 1000Hz (Down Sampling to 100Hz)
- Sound Stimulation Time: 18:22, 26:54, 35:26, 52:18
Artifact Removal is done manually. 42 sects are discarded.

<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
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<tbody>
<tr>
<td>00:00-02:25</td>
<td>11:13-11:16</td>
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<tr>
<td>23:00-24:00</td>
<td>13:43-13:45</td>
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<tr>
<td>34:06-34:24</td>
<td>16:29-16:32</td>
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<td>39:34-39:44</td>
<td>20:30-20:32</td>
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<td>53:00-53:10</td>
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<td>00:00-02:25</td>
<td>20:30-20:32</td>
</tr>
<tr>
<td>23:00-24:00</td>
<td>22:18-22:22</td>
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</table>
We use a 40Hz low pass filter.
Spatial Filtering

The subject’s response to the sound stimulation

<table>
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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>18:22</td>
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</tr>
<tr>
<td>26:54</td>
<td>No</td>
</tr>
<tr>
<td>35:26</td>
<td>No</td>
</tr>
<tr>
<td>52:18</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Estimated clear-headed time: 00:00 to 15:00
Estimated sleeping time: 25:00 to 35:00
CSP Training Set 1: 141 trials between 00:00 and 15:00
CSP Training Set 2: 141 trials between 25:00 and 35:00
Each Trial: 400 points (4sec), no overlapping
CSP Output: 12*58 Projection Matrix
### Feature Extraction and PCA

<table>
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<th>Window Size of STFT:</th>
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<tr>
<td>Num. of Valid Windows:</td>
<td>552</td>
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<tr>
<td>Num. of Feature Vectors:</td>
<td>552</td>
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<tr>
<td>Energy Levels:</td>
<td>64</td>
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<tr>
<td>Num. of Channels:</td>
<td>12 (Processed by CSP)</td>
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<tr>
<td>Dim. of Feature Vectors:</td>
<td>12*64=768</td>
</tr>
<tr>
<td>Reduced Dim. of Feature Vectors:</td>
<td>2 to 30 (Processed By PCA)</td>
</tr>
</tbody>
</table>
Clustering Analysis

Clustering Algorithms:
- Standard K-Means Algorithm
- Bisecting K-Means Algorithm
- Density Based DBSCAN Algorithm
- Fuzzy Clustering Algorithm (FCM)

High-Dim Visualization Technique:
- Self Organization Maps (SOM)
Results

Standard K-Means, 3 Dims, 4 Clusters
Results

Standard K-Means, 8 Dims, 4 Clusters
Results

Bisecting K-Means, 20 Dims, 2 Clusters
Results

Fuzzy C-Means, 2 Dims, 4 Clusters
Outline – Engineering Project

1. Introduction
2. Methodology
3. Experiments
4. Engineering Project
   - Overview
   - Introduction of Components
   - Optimizations
Project Name: Easy EEG
Platform: 32/64 bit Windows
Language: C++
Size: About 10,000 lines
Components:
- Signal Controller
- Temporal Domain Viewer
- Frequency Domain Viewer
- Channel Selector
- Filter
- Power Distribution Viewer
- Signal Cutter
- Optimizations
Integrated Environment
Temporal Domain Viewer

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Channel Selector
Frequency Domain Viewer
Filter

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EEG-Based Vigilance Analysis
Power Distribution Viewer

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EEG-Based Vigilance Analysis
Signal Cutter

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EEG-Based Vigilance Analysis
Optimizations:

- Reading EEG Data in Various Sampling Rate
  Enable the system to respond the user in real-time.
- Multi-core Optimization
Multithreading Opt. for Multi-Core Processors

Multi-Threading Optimization in Signal Filter for a Dual-Core Processor
Multi-Threading Optimization in Power Distribution Viewer for a Quad-Core Processor
We tested the multithreading program on a Intel T7200 Dual Core 2 Laptop Computer with 1.50GB of RAM. After the optimization (using two threads), it runs approximately 1.5 times faster.
Conclusion

Summary of my work:

- Successfully use a synthesized framework to do vigilance analysis based on EEG Signals.
- Independently established an integrated EEG analyzing system.
Acknowledgements

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