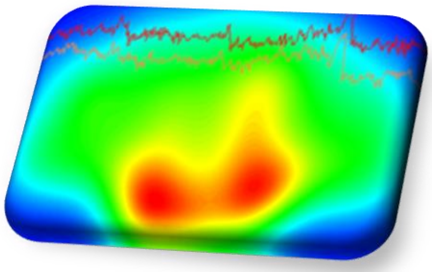

EEG-Based Vigilance Analysis

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ACM Honored Class
Department of Comp. Sci.
Shanghai Jiao Tong University

Jun 20, 2007

Outline

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

Outline – Introduction

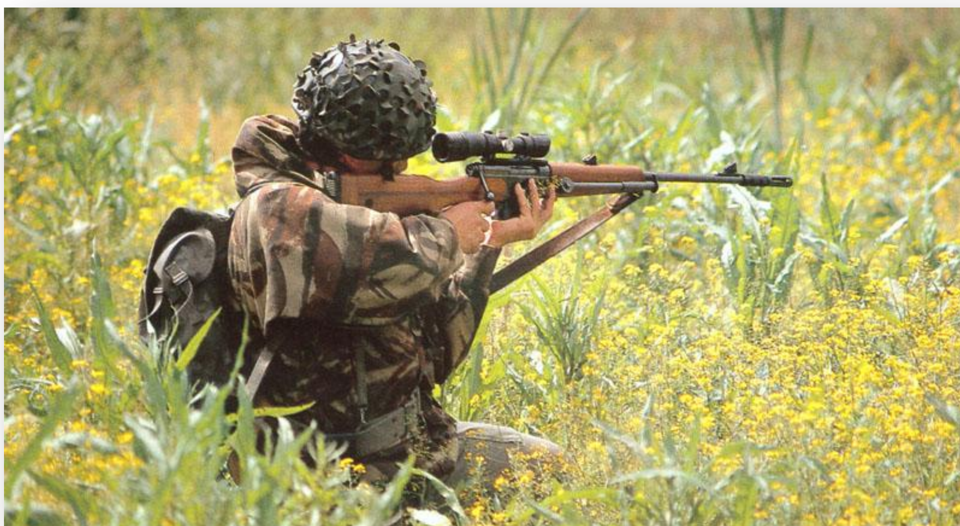
- What are EEG signals
- What is vigilance
- The purpose of the research
- What methods are adopted

What are EEG Signals

EEG is the abbreviation of Eletroencephalography (脑电图).

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

Methods Adopted

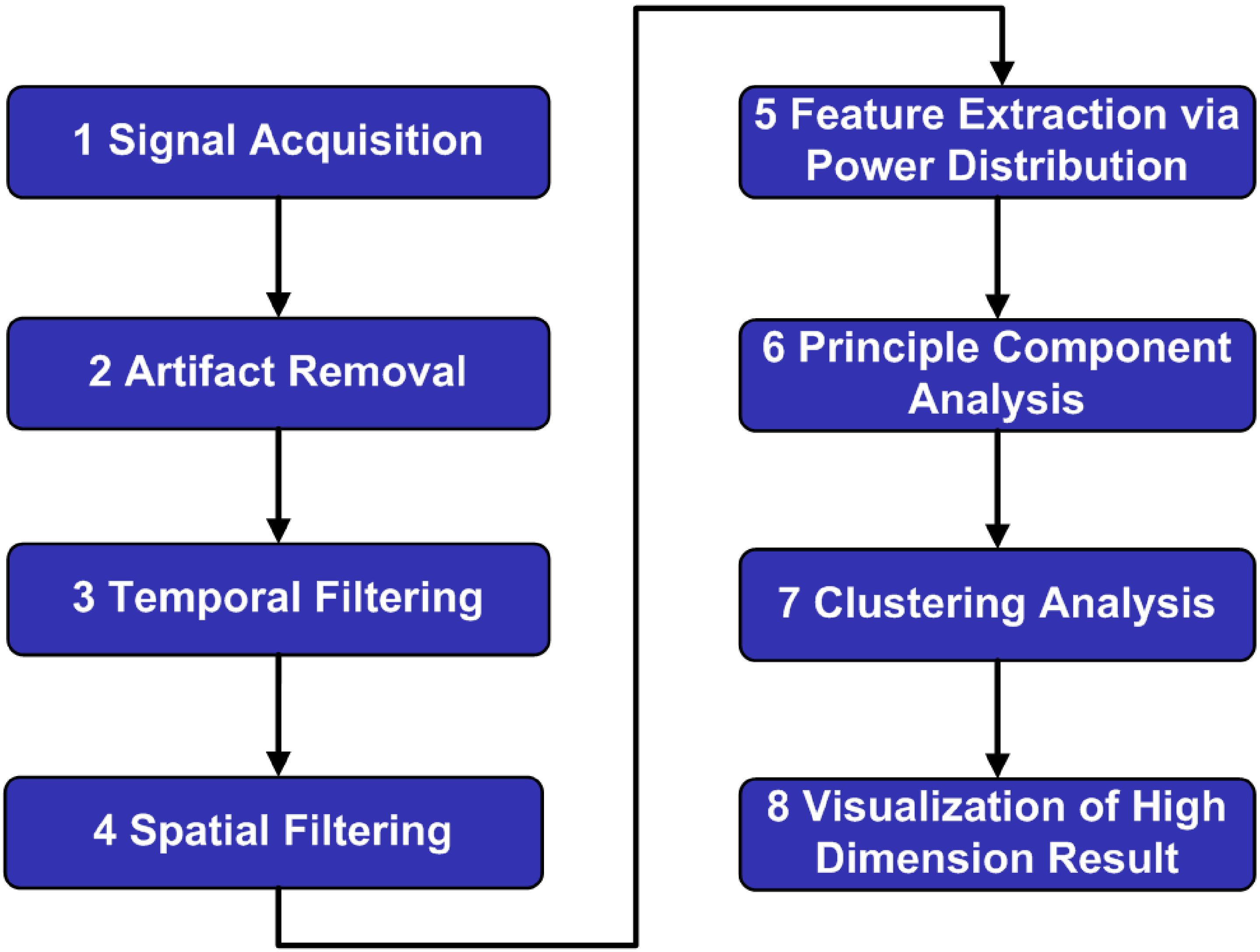
We adopt an intra-discipline methodology combining

- Signal Processing
- Statistical Learning
- Data Mining
- Visualization

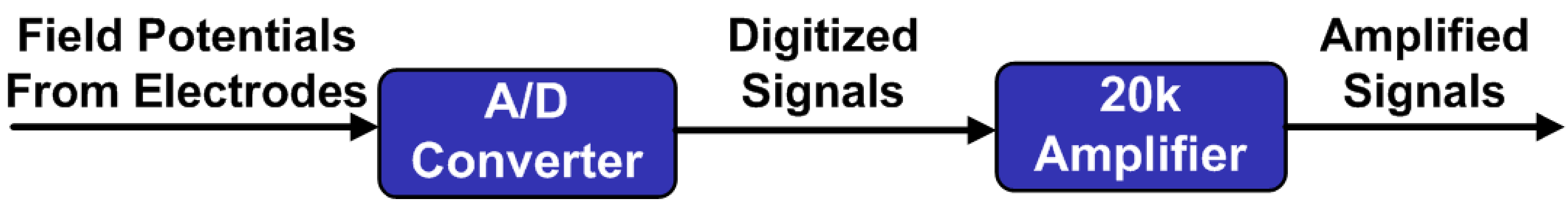
Outline - Methodology

- **Overview of the framework**
- **Step-by-step introduction**

Overview of Our Analysis Framework



Signal Acquisition



Artifact Removal

Signal Acquisition | **Artifact Removal** | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | Clustering Analysis | Vis. of High Dim. Result

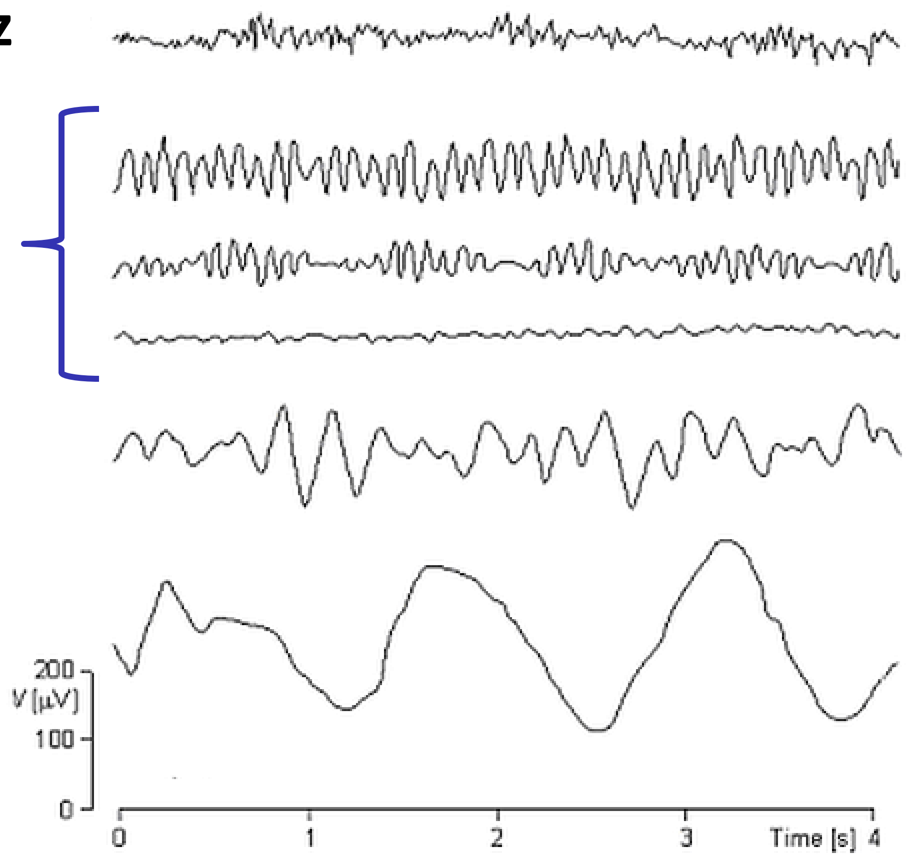
Artifact (Noise) includes

- **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**

Temporal Filtering

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 α and β rhythm) will gradually decrease, meanwhile EEG energy around 4Hz (between δ and θ 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.

Spatial Filtering

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.**

Spatial Filtering – Common Spatial Pattern

We use the *Common Spatial Pattern* (CSP) technique to achieve Spatial Filtering. In math, it simultaneously diagonalizes two covariance matrices.

CSP Analyzing Phase

Any EEG Trail

Multiplied by CSP Projection Matrix *W*

Filtered Result

$$Z=W*E$$

66-Channel EEG Matrix *E* (66*L)

2-Channel EEG Matrix *Z* (2*L)

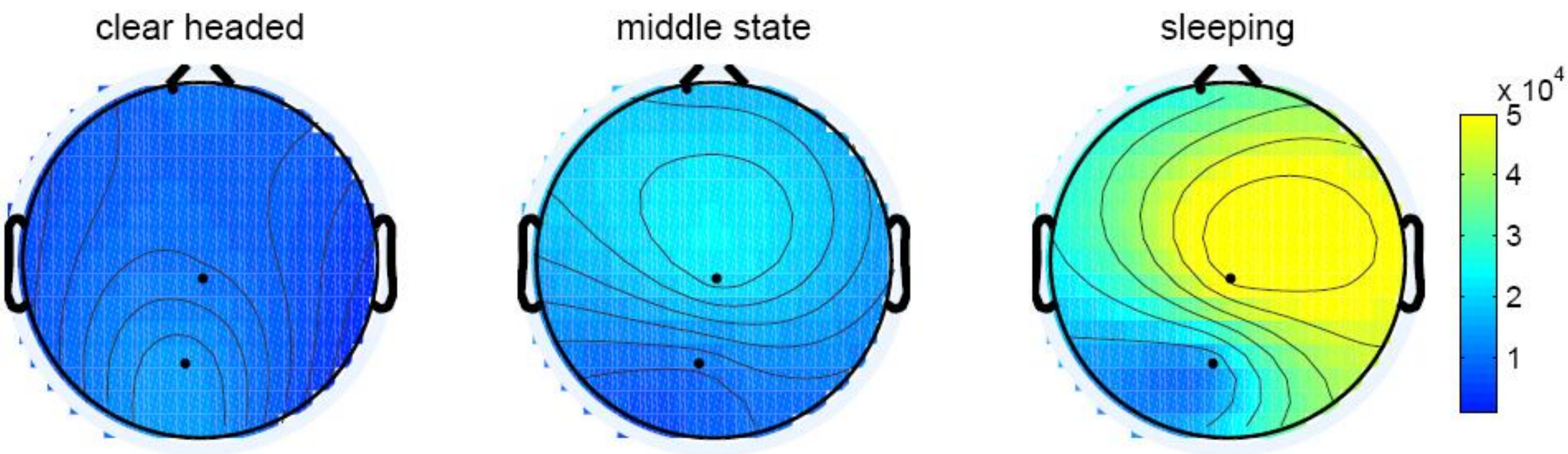
Spatial Filtering

After *Spatial Filtering*:

- **The number of channels is significantly reduced.**
- **Information *not* related to the vigilance is filtered.**

Feature Extraction

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

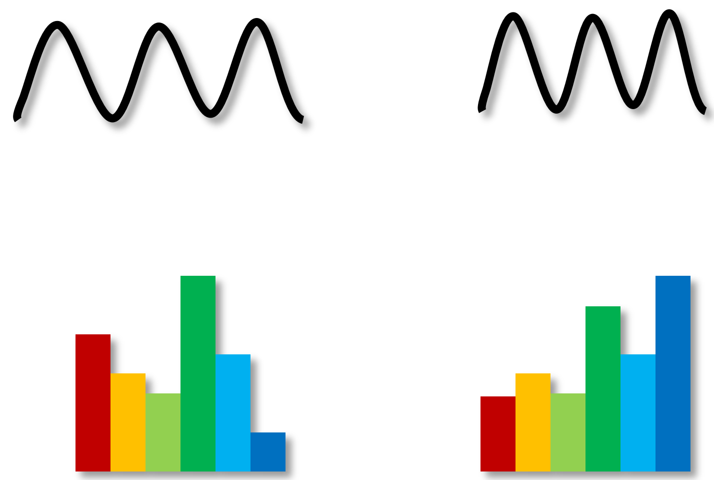
2-Channel discrete signal trial
in temporal domain
(Processed by CSP)

Short Time Fourier Transform (STFT)

2-Channel discrete signal trail
in frequency domain

Calculating Power Distribution

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



$$(x_1, x_2, x_3, \dots, x_n)$$

Principle Component Analysis

PCA (Principle Component Analysis) is a statistical technique to reduce the dimension of feature vectors. It is based on *Eigenvectors* of the covariance matrix.

$$(x_1, x_2, x_3, \dots, x_{128})$$

$$\downarrow$$

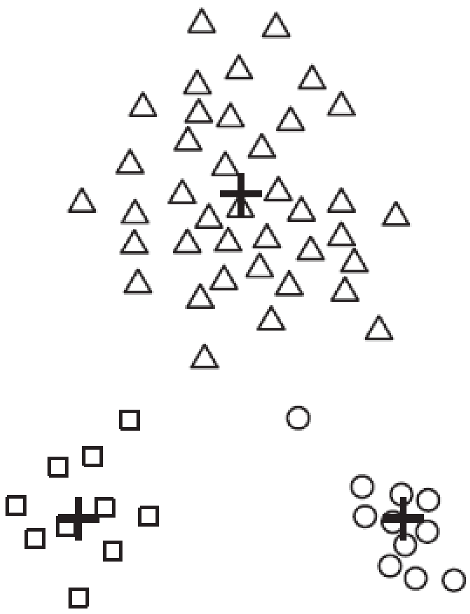
Principle Component Analysis

$$\downarrow$$

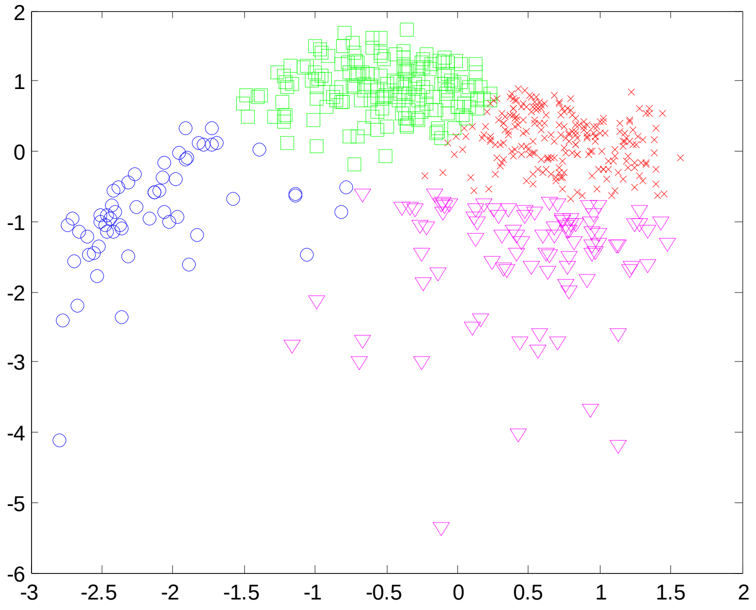
$$(\alpha, \beta, \gamma)$$

Clustering Analysis

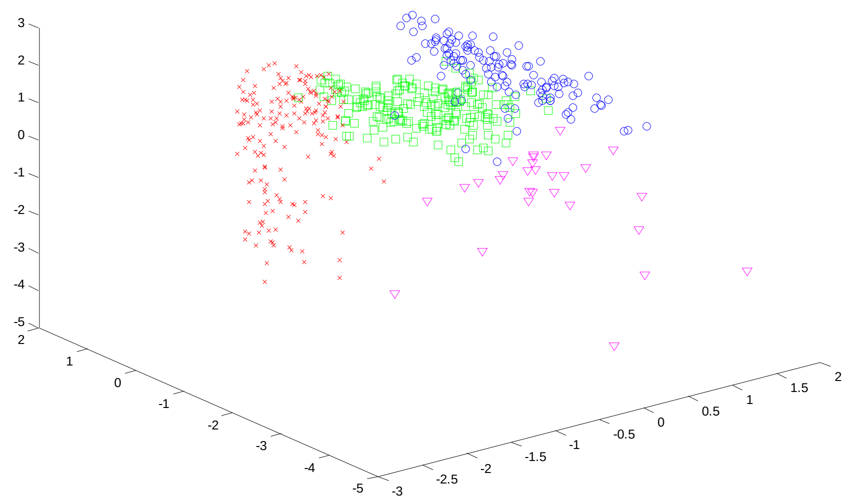
We use clustering algorithms to discover different vigilant states and their corresponding time automatically.



Visualization of High Dimension Clustering Result



Clustering Result of 2-Dim Feature Vectors

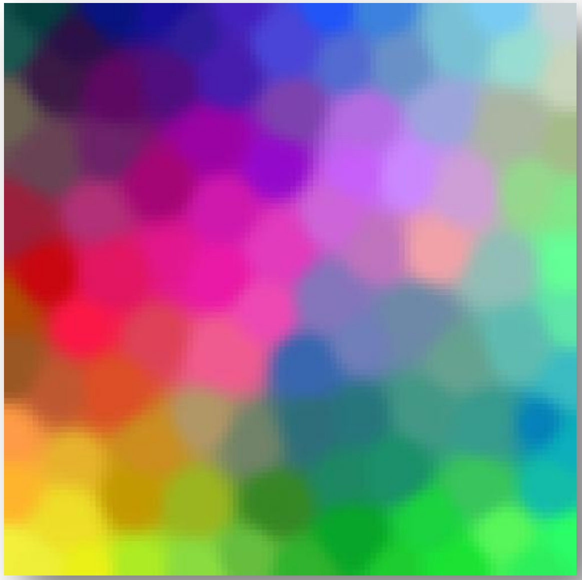


Clustering Result of 3-Dim Feature Vectors

How to visualize clustering result of n-Dim Feature vectors (n>3) ???

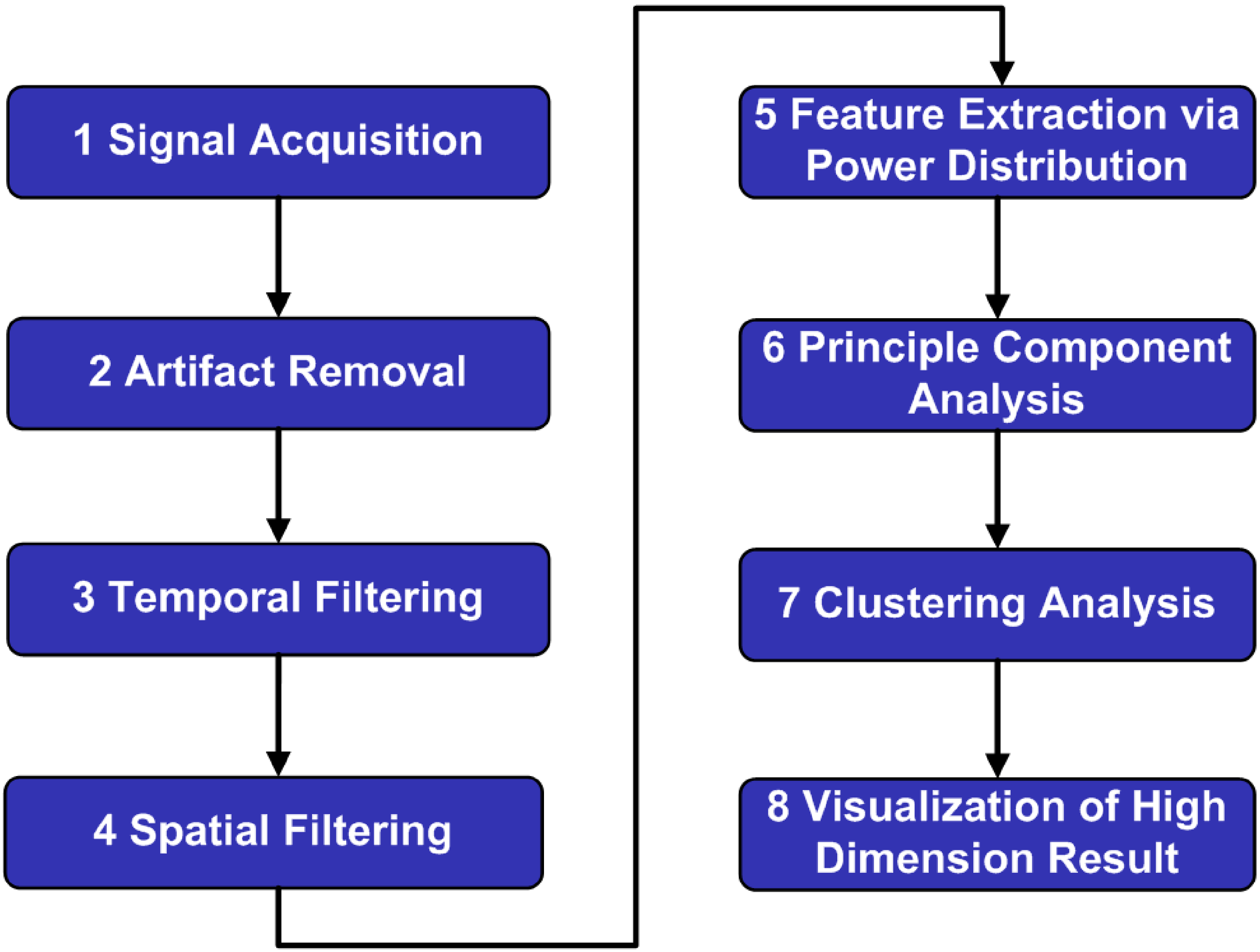
Self Organization Maps

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.

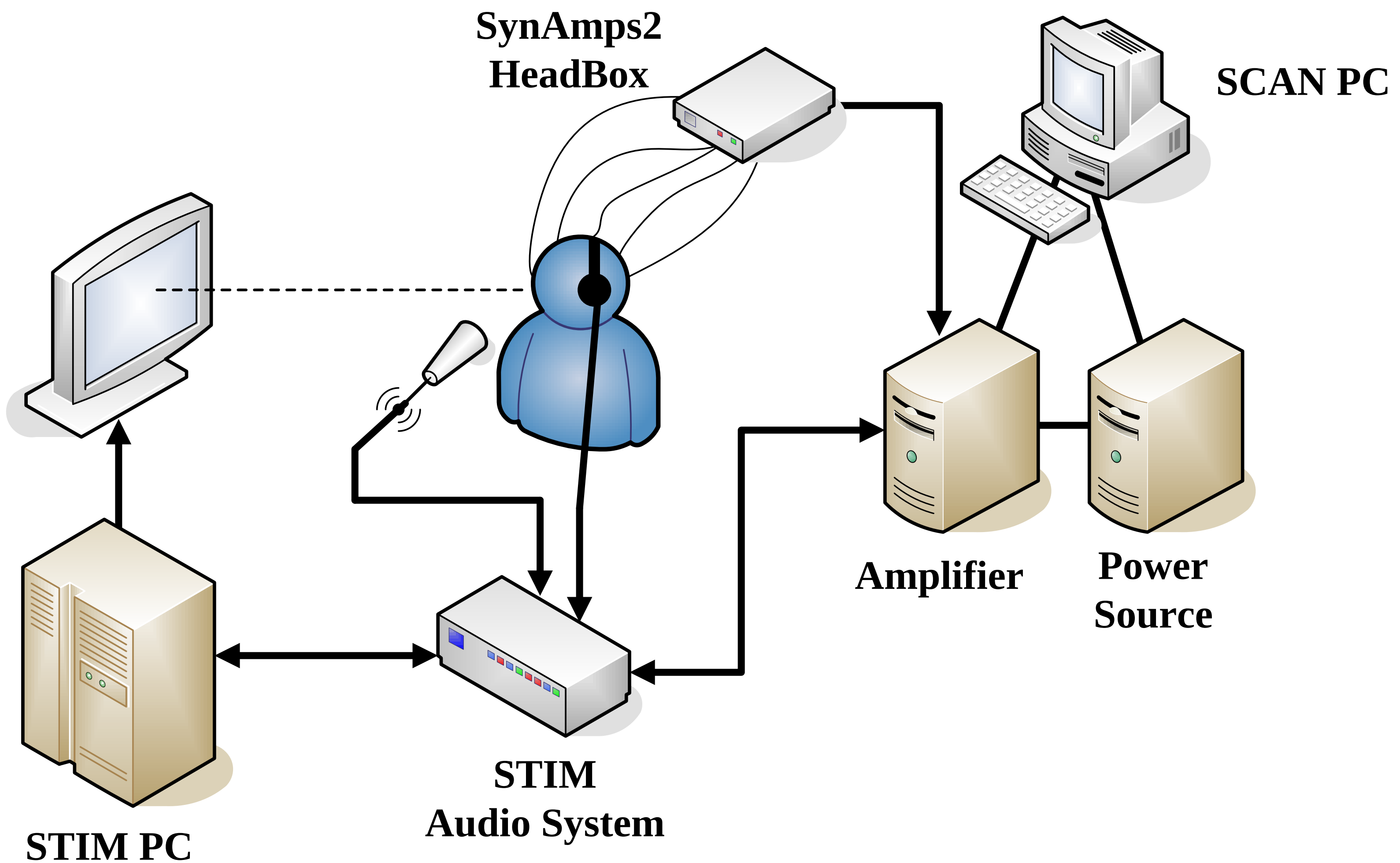
Review of Our Analysis Framework



Outline – Experiments

- **Environment**
- **Step-by-step introduction**
- **Results**

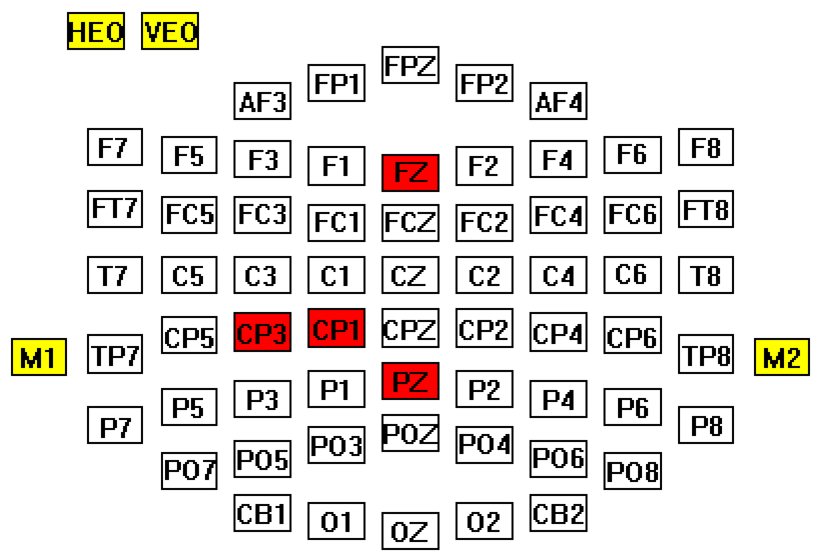
Experimental Environment



NeuroScan System 3.0 @ BCMI

Signal Acquisition

Electrode Distribution Diagram



Damaged Electrodes

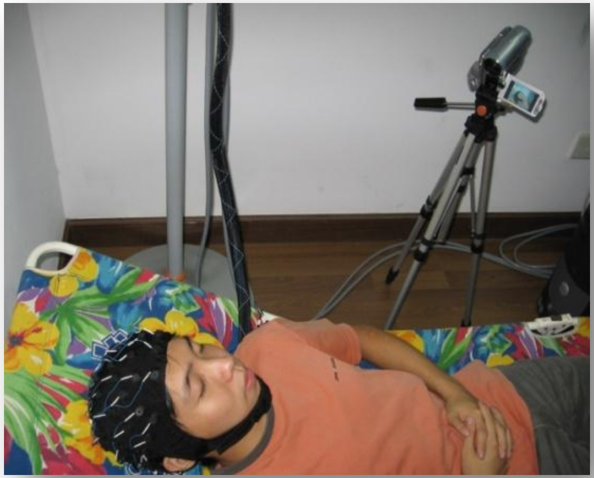
Omitted Electrodes

66-8=58 Channels are used

Signal Acquisition

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | Clustering Analysis | Vis. of High Dim. Result

- **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

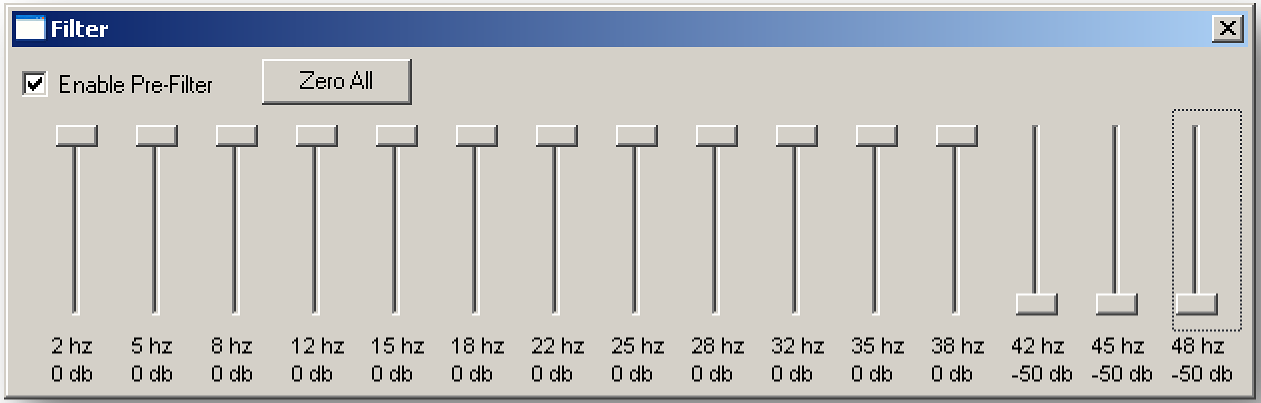
Signal Acquisition | **Artifact Removal** | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | Clustering Analysis | Vis. of High Dim. Result

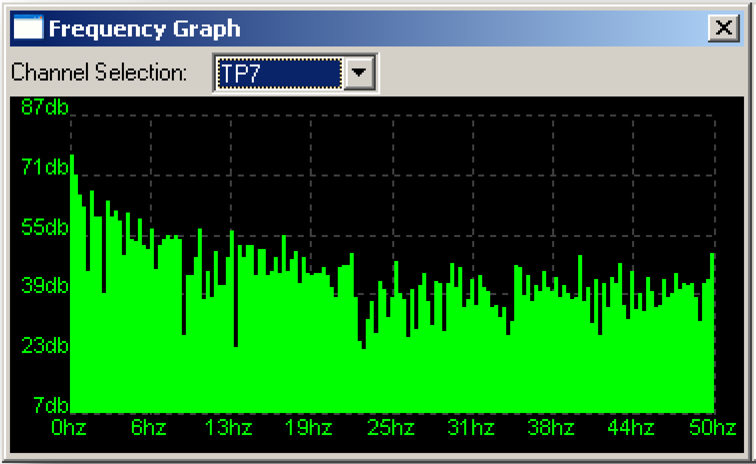
Artifact Removal is done manually. 42 sects are discarded.

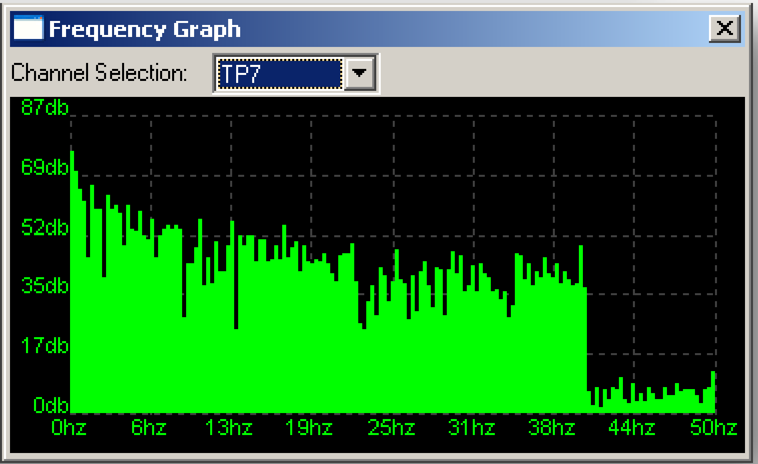
00:00-02:25	11:13-11:16	13:43-13:45	16:29-16:32	20:30-20:32	22:18-22:22
23:00-24:00	25:12-25:16	26:54-27:04	27:46-27:53	31:17-31:22	32:28-32:44
34:06-34:24	35:54-36:16	37:03-37:11	37:26-37:53	38:04-38:26	38:54-39:00
39:34-39:44	40:37-40:46	41:37-41:44	42:57-43:12	43:34-43:44	44:01-44:11
44:49-45:13	44:23-45:30	46:00-46:10	46:38-46:48	47:38-47:49	48:18-48:25
49:37-49:44	50:22-50:30	50:39-51:00	51:32-51:50	52:18-52:32	52:41-52:53
53:00-53:10	58:25-58:40	1:00:43-1:00:53	1:02:35-1:02:57	1:03:21-1:03:54	1:05:14-end

Temporal Filtering

We use a 40Hz low pass filter.







Spatial Filtering

The subject's response to the sound stimulation

Time	Blinked
18:22	Yes
26:54	No
35:26	No
52:18	Yes

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 trails between 25:00 and 35:00
Each Trial: 400 points (4sec), no overlapping
CSP Output: 12*58 Projection Matrix

Feature Extraction and PCA

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | **Feature Extraction** | **PCA** | Clustering Analysis | Vis. of High Dim. Result

Window Size of STFT:	**1024 Points**
Overlapping:	**512 Points**
Num. of Valid Windows:	**552**
Num. of Feature Vectors:	**552**
Energy Levels:	**64**
Num. of Channels:	**12 (Processed by CSP)**
Dim. of Feature Vectors:	**12*64=768**
Reduced Dim. of Feature Vectors:	**2 to 30 (Processed By PCA)**

Clustering Analysis

Clustering Algorithms:

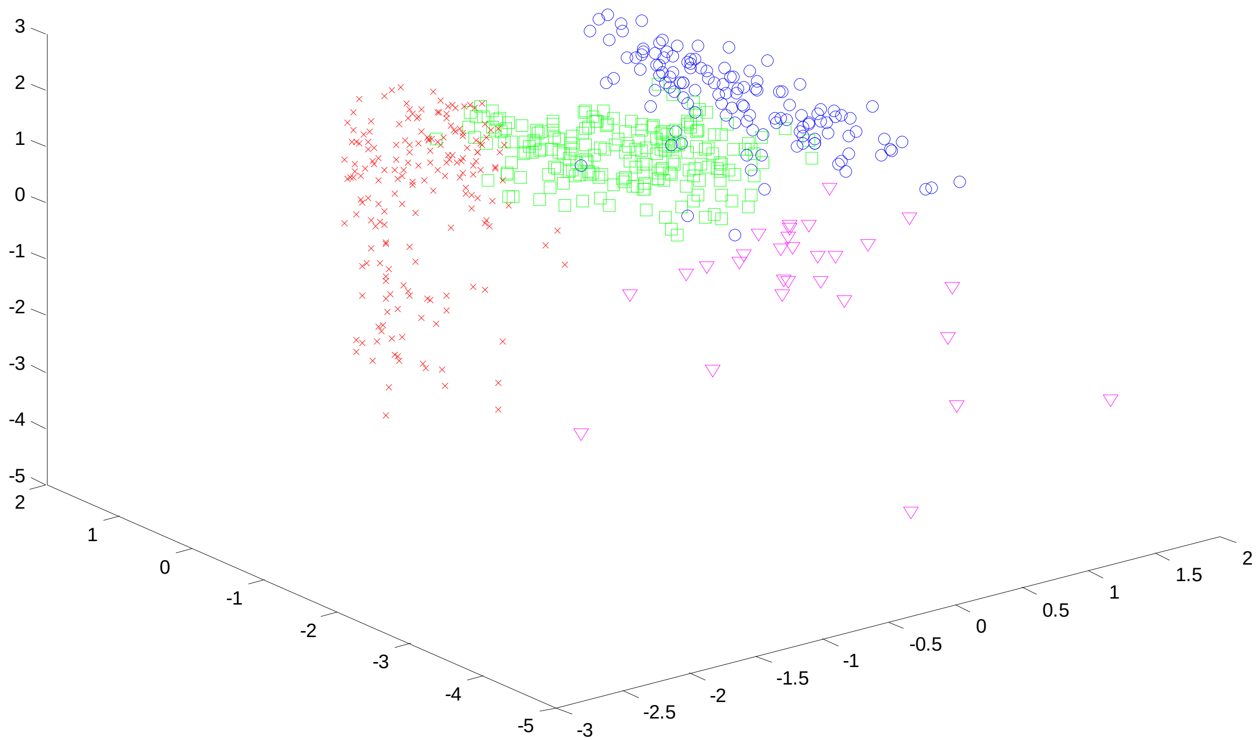
- Standard K-Means Algorithm
- Bisecting K-Means Algorithm
- Density Based DBSCAN Algorithm
- Fuzzy Clustering Algorithm (FCM)

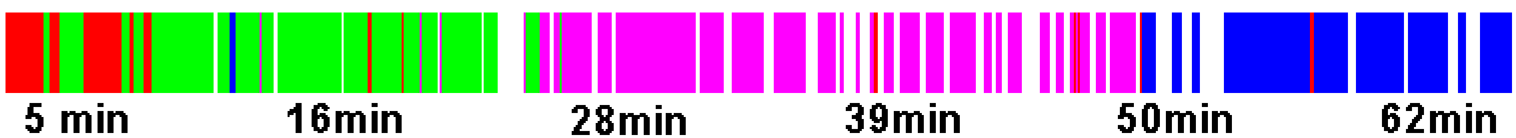
High-Dim Visualization Technique:

- Self Organization Maps (SOM)

Results

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | **Clustering Analysis** | **Vis. of High Dim. Result**

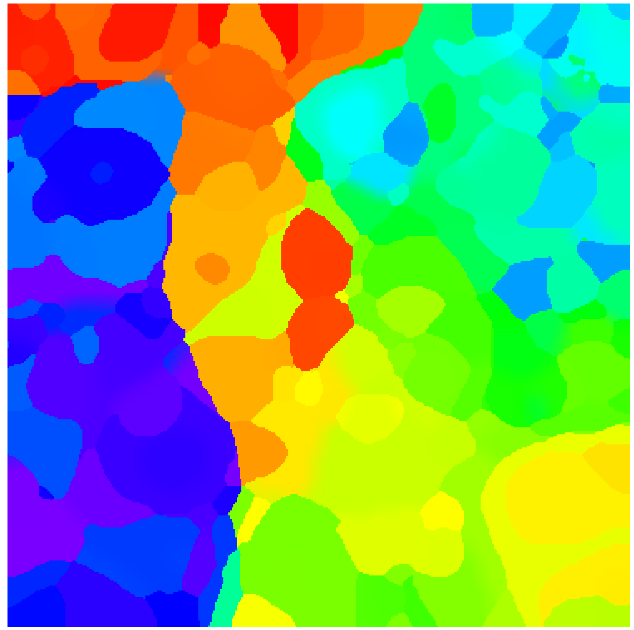


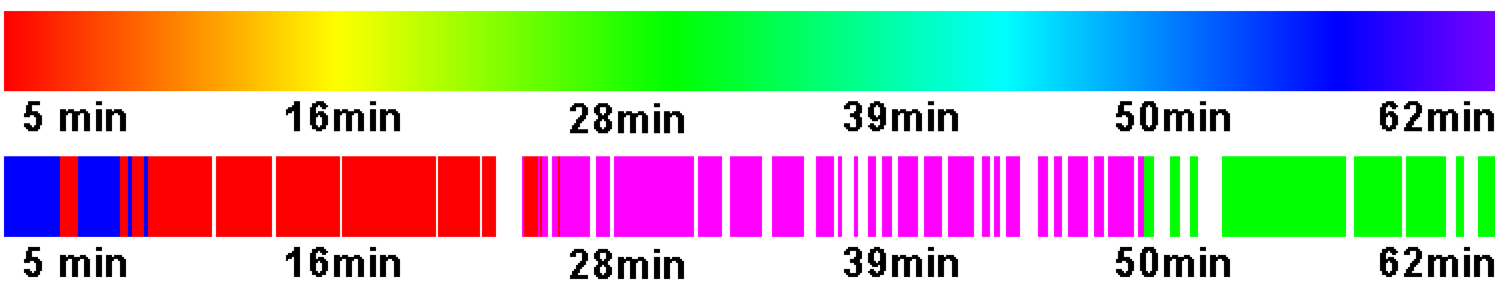


Standard K-Means, 3 Dims, 4 Clusters

Results

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | **Clustering Analysis** | **Vis. of High Dim. Result**





Standard K-Means, 8 Dims, 4 Clusters

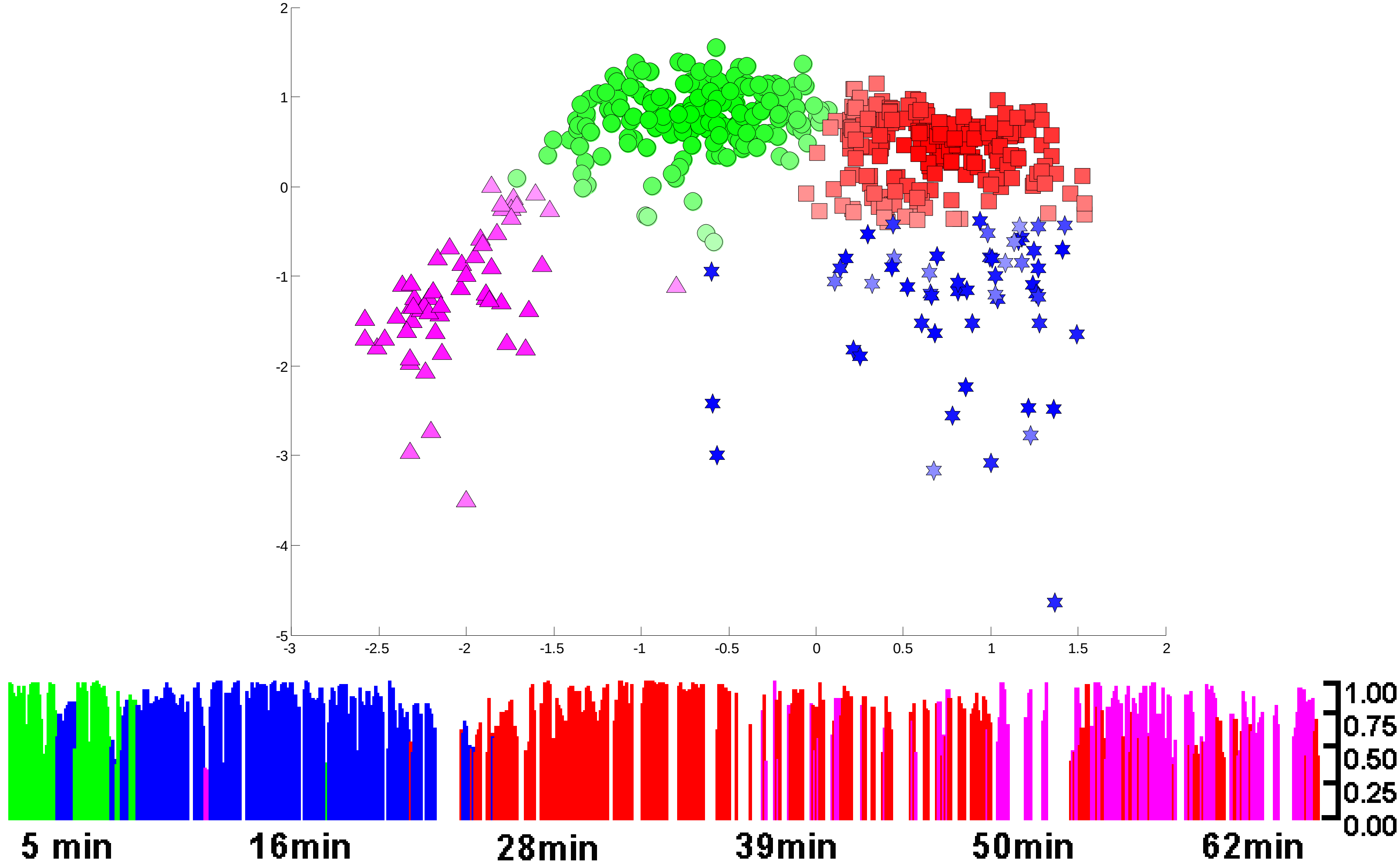
Results

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | **Clustering Analysis** | **Vis. of High Dim. Result**

Bisecting K-Means, 20 Dims, 2 Clusters

Results

Signal Acquisition | Artifact Removal | Temporal Filtering | Spatial Filtering | Feature Extraction | PCA | **Clustering Analysis** | **Vis. of High Dim. Result**



Fuzzy C-Means, 2 Dims, 4 Clusters

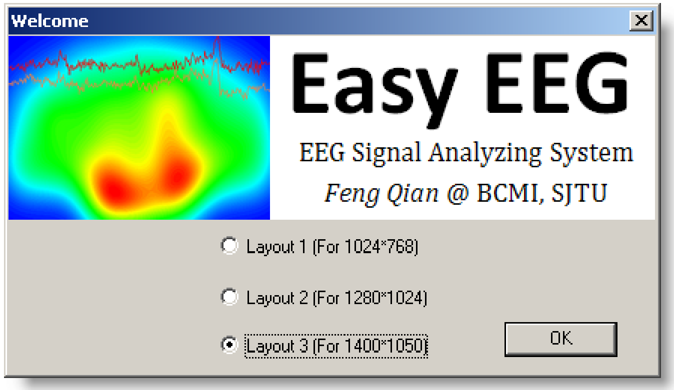
Outline – Engineering Project

- Overview
- Introduction of Components
- Optimizations

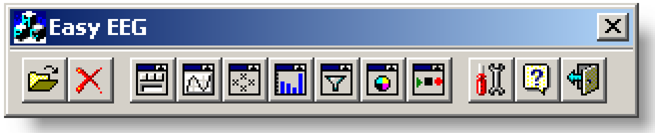
Engineering Project – Easy EEG

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

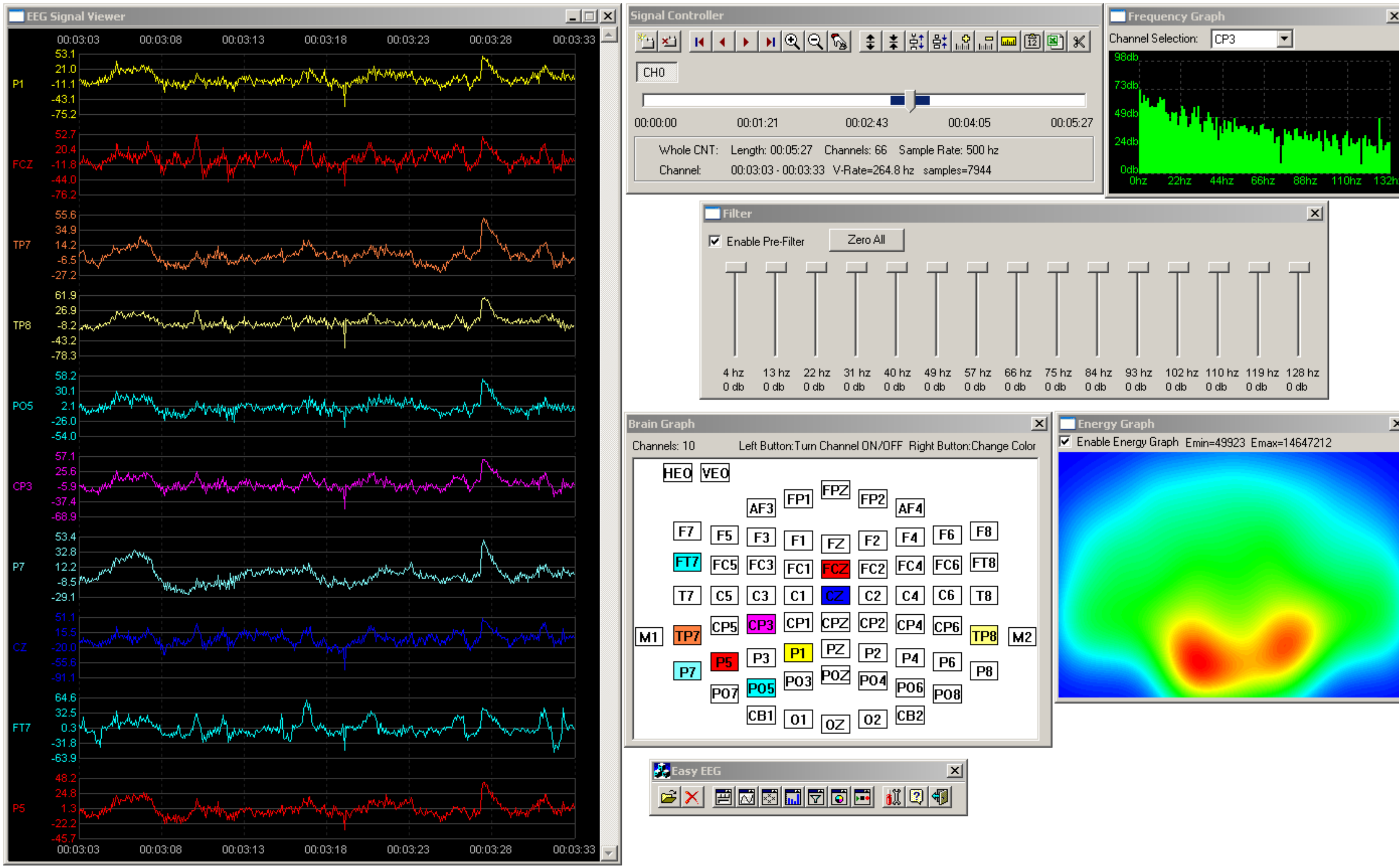


Logo



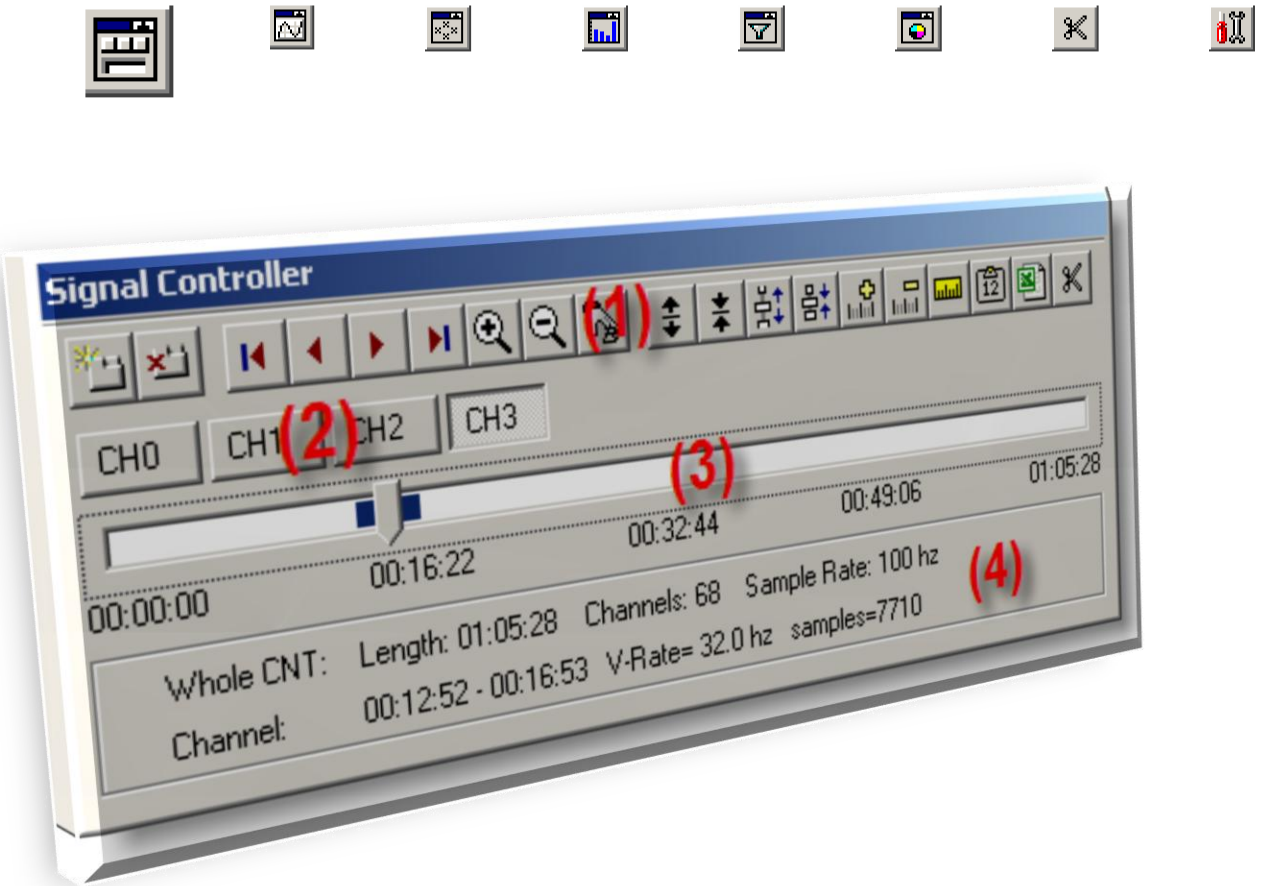
Main Toolbar

Engineering Project – EasyEEG



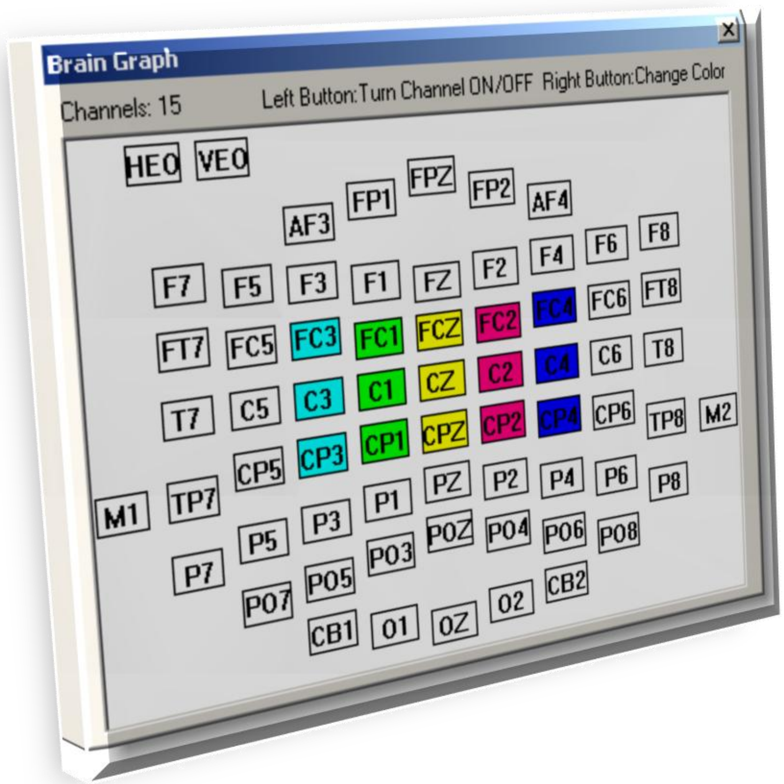
Integrated Environment

Signal Controller

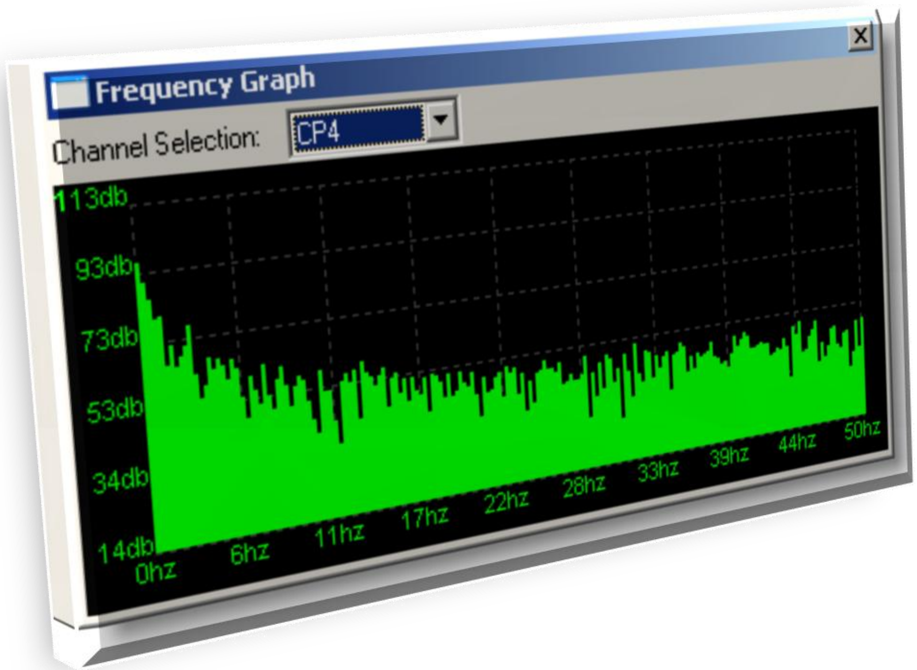


Temporal Domain Viewer

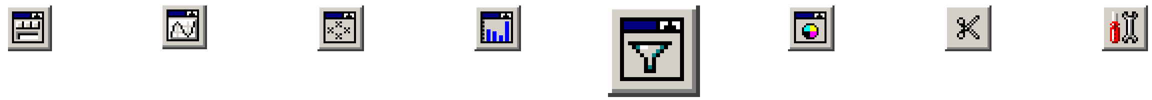
Channel Selector

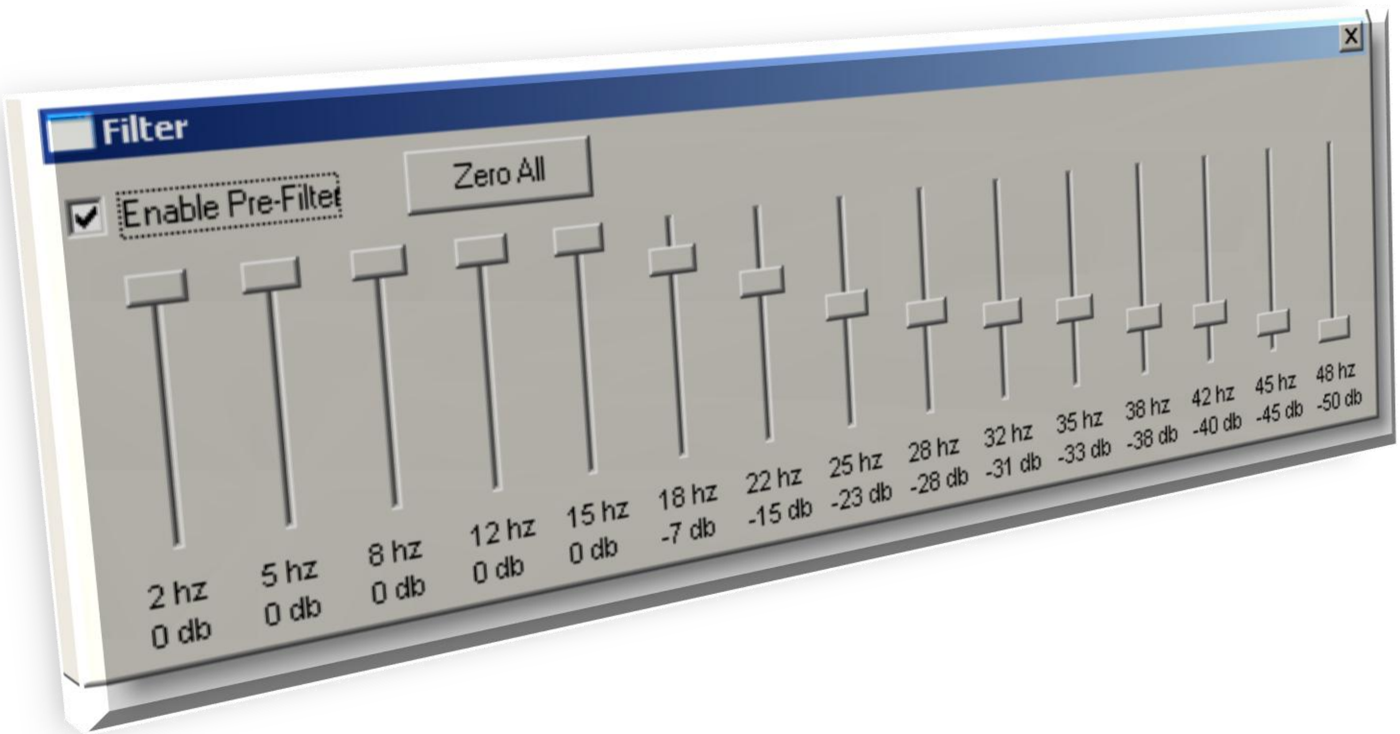


Frequency Domain Viewer

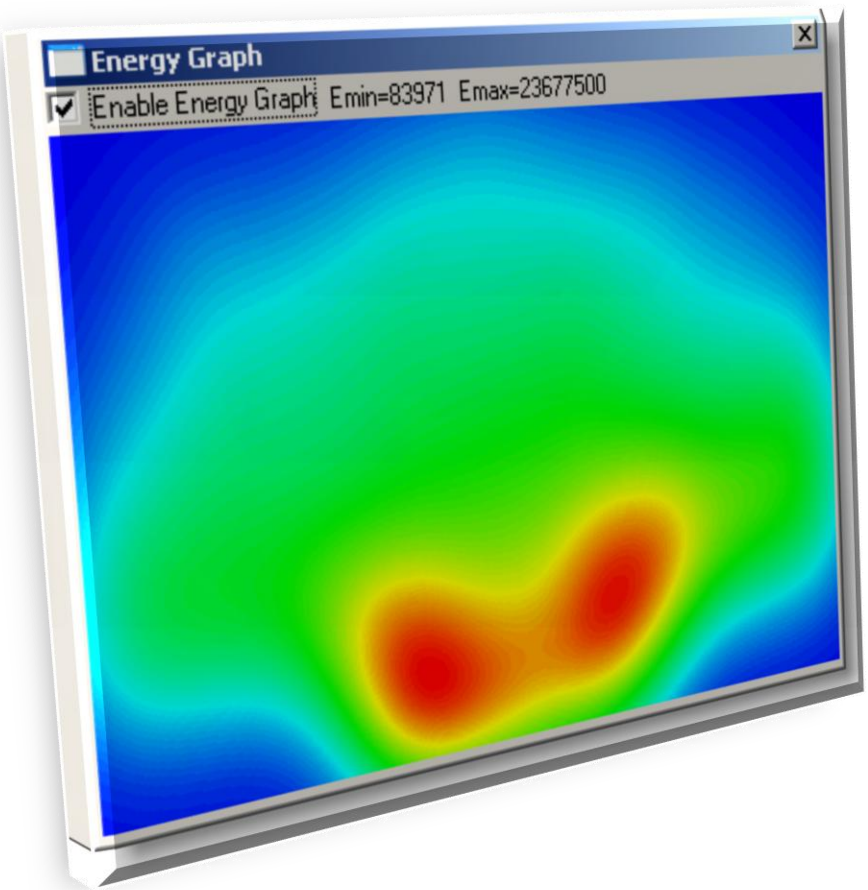


Filter

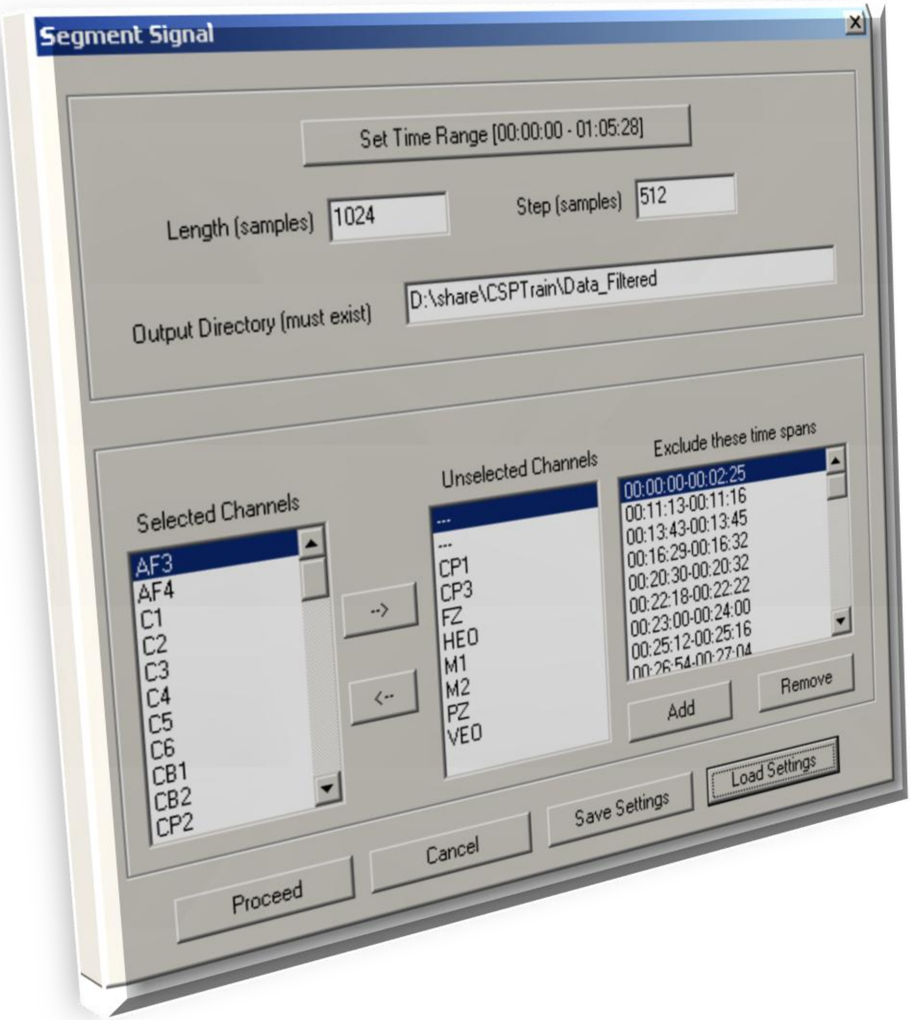



Filter
Enable Pre-Filte
Zero All
2 hz 0 db
5 hz 0 db
8 hz 0 db
12 hz 0 db
15 hz 0 db
18 hz -7 db
22 hz -15 db
25 hz -23 db
28 hz -28 db
32 hz -31 db
35 hz -33 db
38 hz -38 db
42 hz -40 db
45 hz -45 db
48 hz -50 db

Power Distribution Viewer



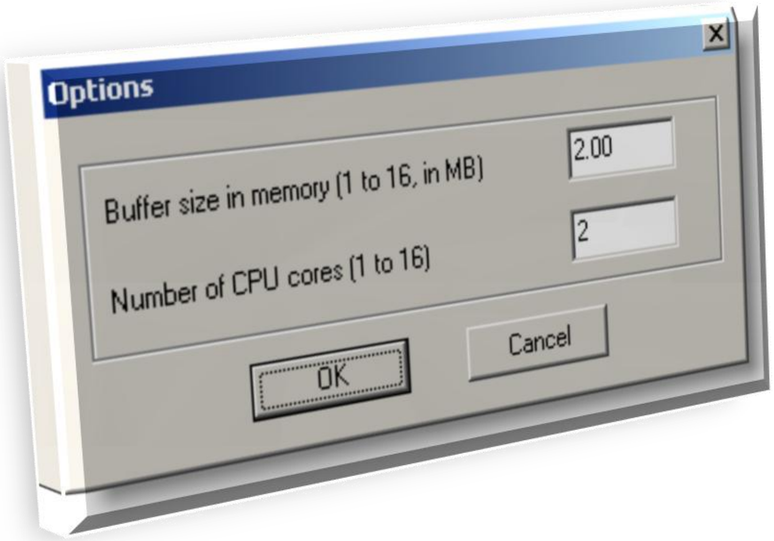
Signal Cutter



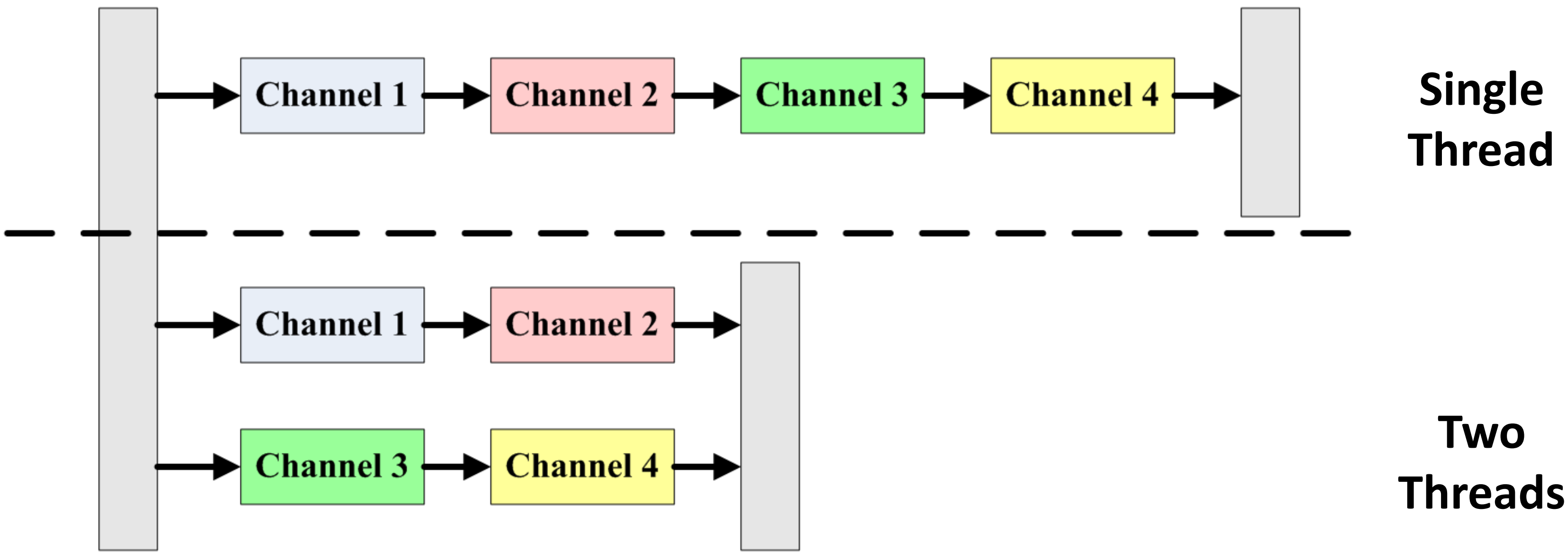
Optimizations

Optimizations:

- **Reading EEG Data in Various Sampling Rate**
  Enable the system to respond the user in real-time.
- **Multi-core Optimization**

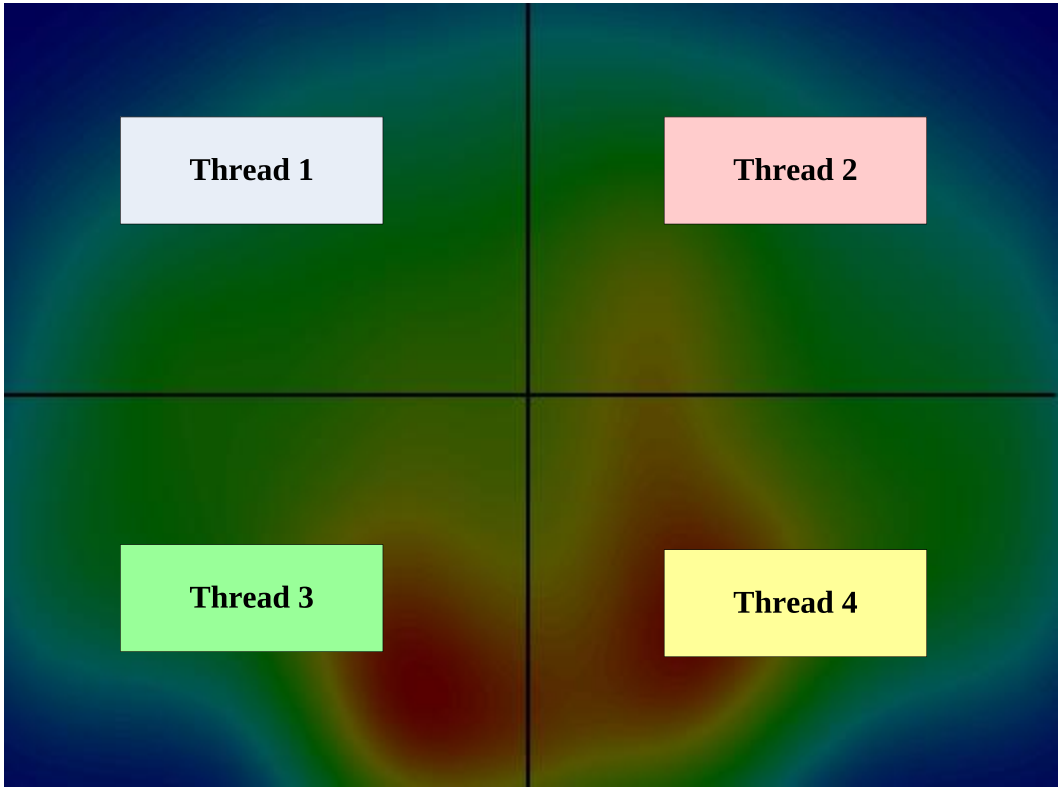


Multithreading Opt. for Multi-Core Processors



Multi-Threading Optimization in Signal Filter for a Dual-Core Processor

Multithreading Opt. for Multi-Core Processors



Multi-Threading Optimization in Power Distribution Viewer for a Quad-Core Processor

Multithreading Opt. for Multi-Core Processors

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

- I would like to express my gratitude to professors at BCMI (*Prof. Lu, Baoliang* and *Prof. Zhang, Liqing*), my advisor (Prof. *Luo, Yuan*) my technical instructor (Ph.D. candidate *Mr. Shi, Lichen*), my classmates (*Mr. Sun, Han* and *Mr. Liang, Weiming*) and all my friends at *SJTU*.
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