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EEG Tensor Discriminant Analysis for Brain Computer Interface

Liqing Zhang

MOE-Microsoft Key Lab for Intelligent Computing and Intelligent Systems,
Shanghai Jiao Tong University

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Brain Computer Interface

Outline

一 Background

二 Problem Formulation

三 EEG Feature Extraction

四 BCI Platform and Apps

五 Perspectives

电子信息与电气工程学院
School of Electronic, Information and Electrical Engineering

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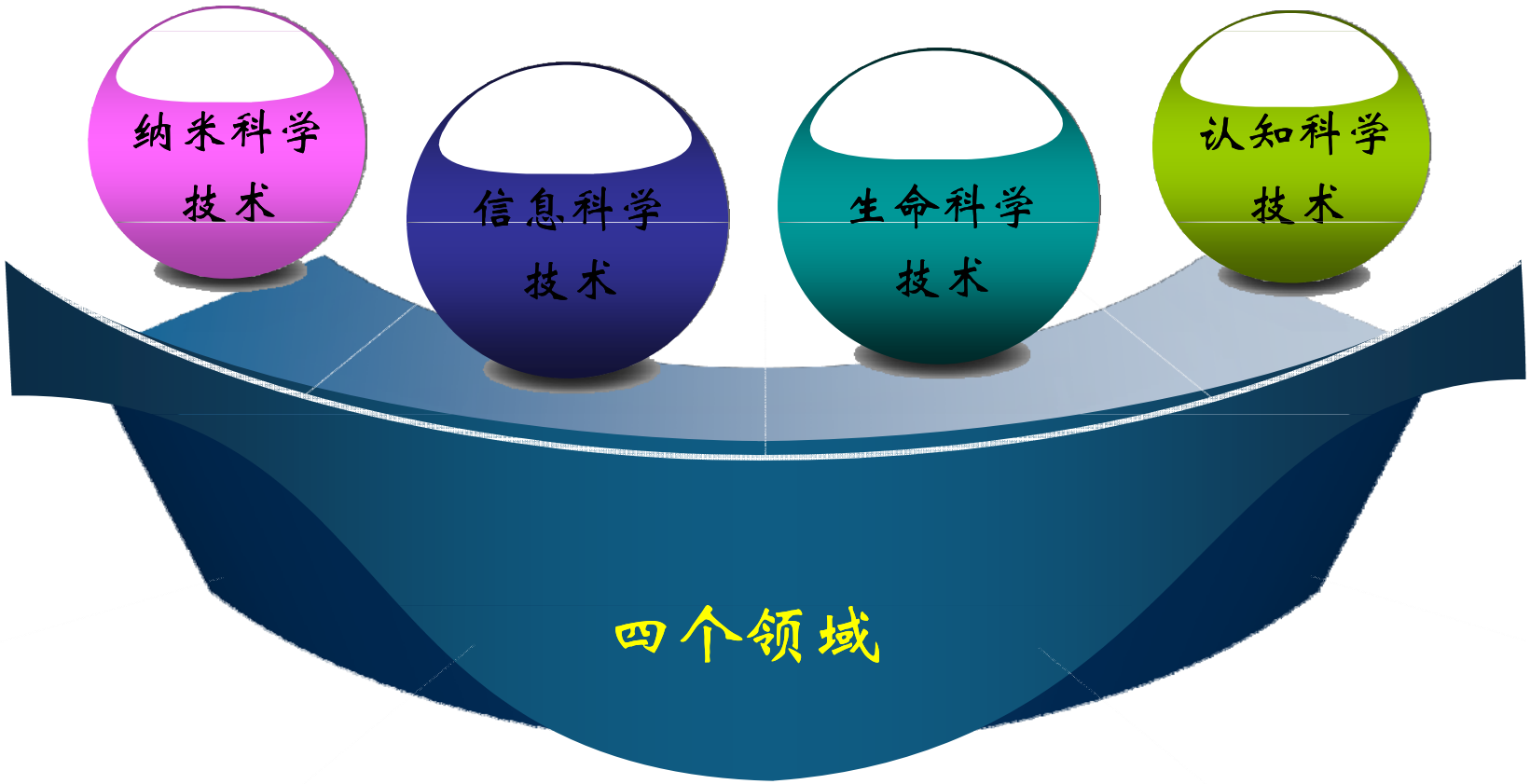
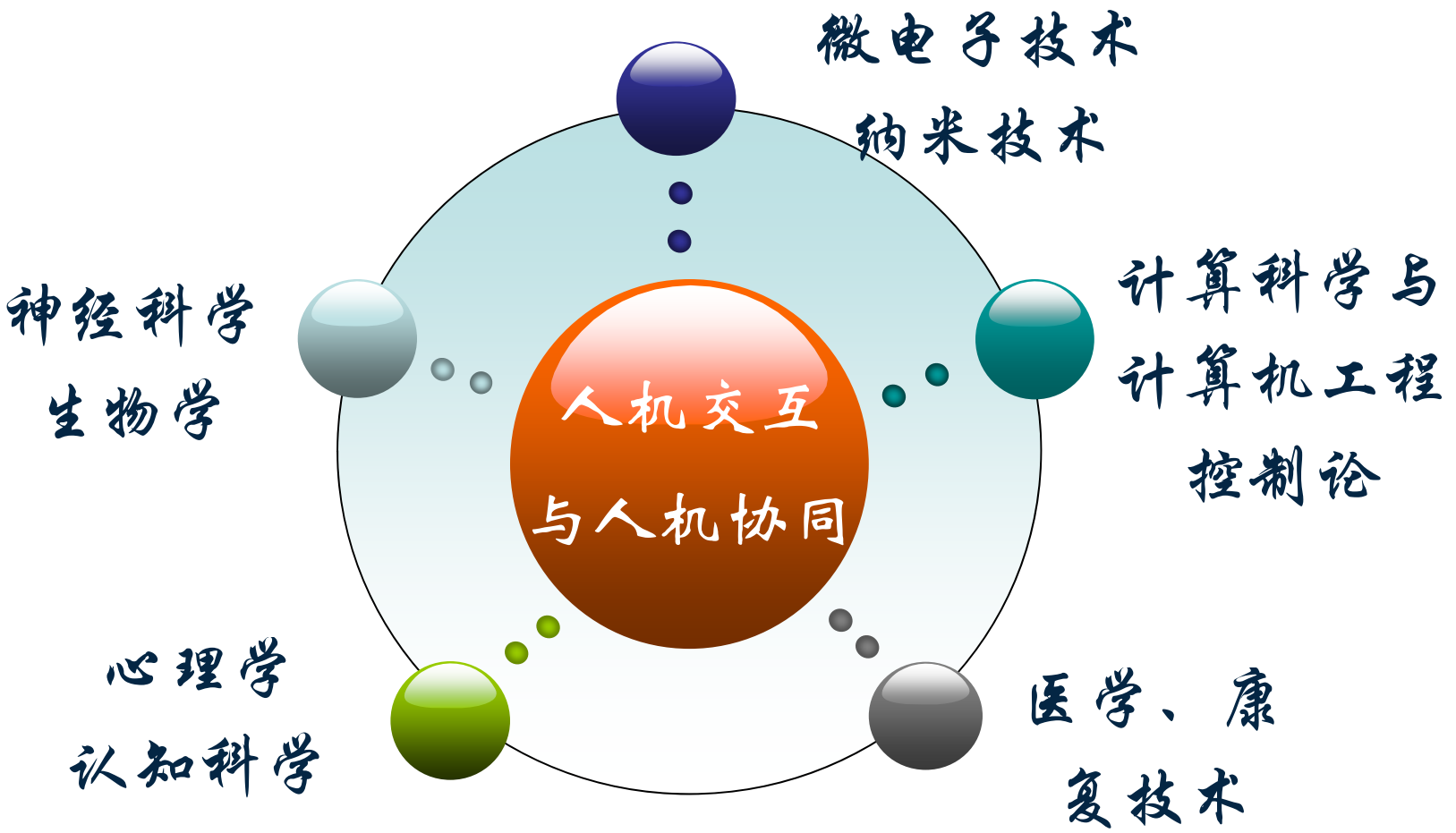
Research Interests

- Natural/Intelligent Human Computer Interaction (HCI)
  - Brain-like Computing (Structure & Principle)
  - Visual Neural Representation and Coding
  - Multimodal (Visual/auditory) Interaction
  - Machine Selective Attention
  - Brain-Computer Interface
  - Wearable Computing (E-Health)
- To build a human-machine integrated System

为提升人类能力的融合技术



BCI – 典型汇聚技术


微电子技术
纳米技术
计算科学与
计算机工程
控制论
医学、康
复技术
心理学
认知科学
神经科学
生物学
人机交互
与人机协同

BCI应用：家电/电话BCI控制

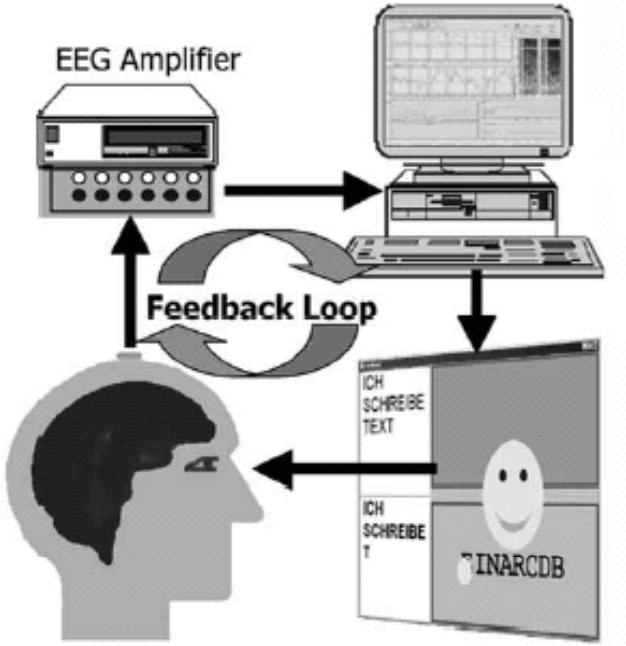
Tsinghua Group *Gao et al., 1999, 2002, 2003*

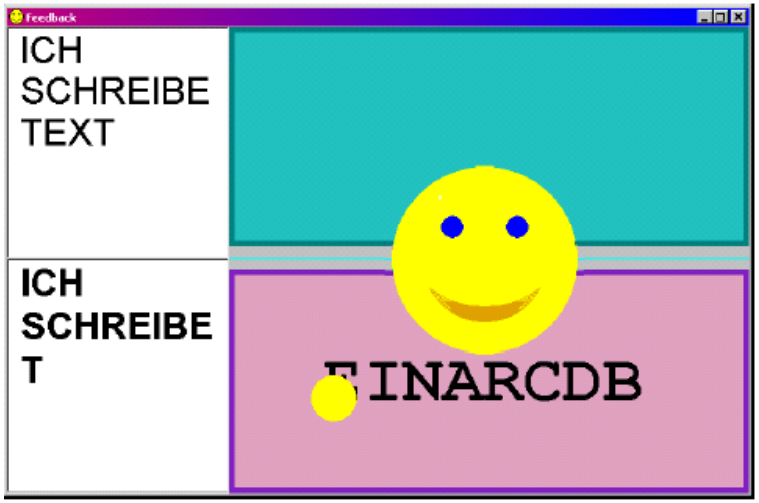
家电控制

BCI电话

BCI应用：字符输入

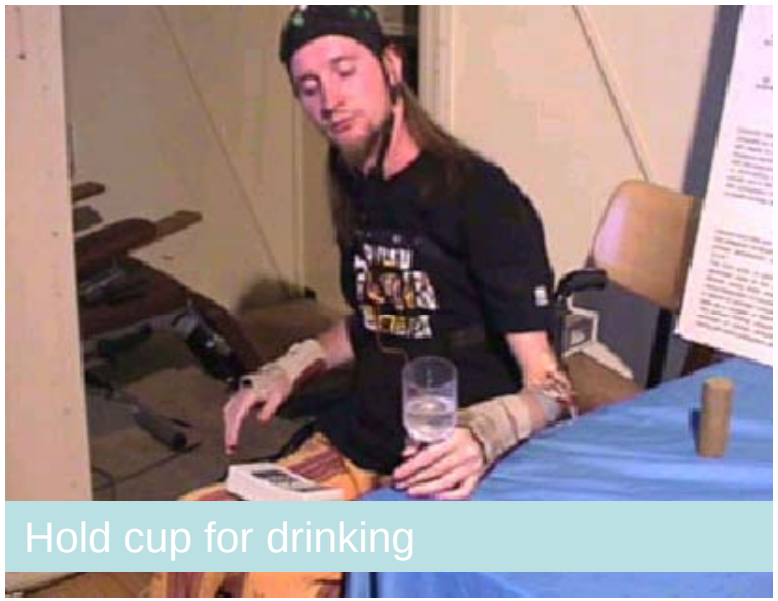
Tübingen Group *Birbaumer et al., 2000, Hinterberger et al., 2004*



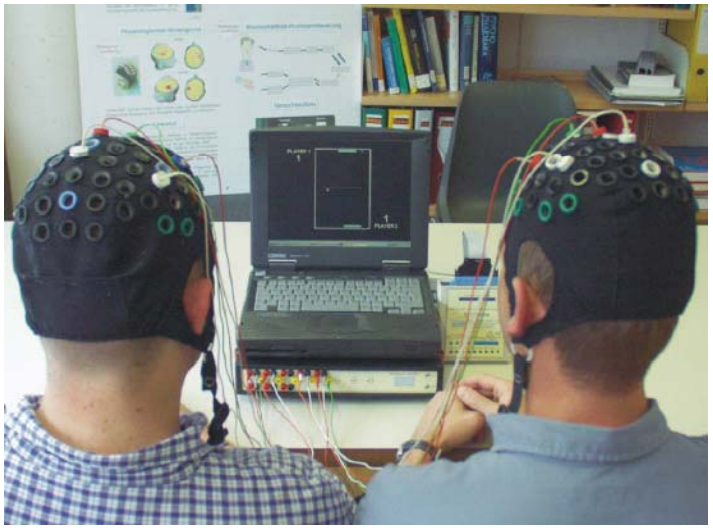


BCI应用： 残疾人自助

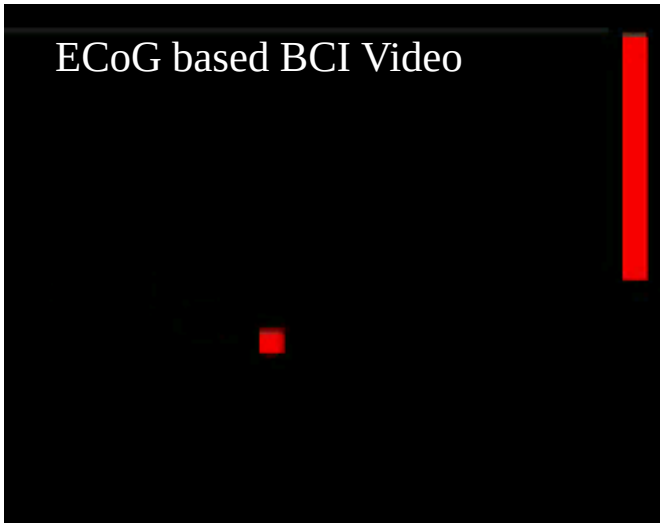
Graz Group *Pfurtscheller et al., 1993, 2000, 2003*



BCI应用： BCI 游戏



Pfurtscheller et al., 2003



Leuthardt et al.,2004

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BCI应用：轮椅车BCI控制

Shanghai Jiao Tong University, 2009

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BCI应用

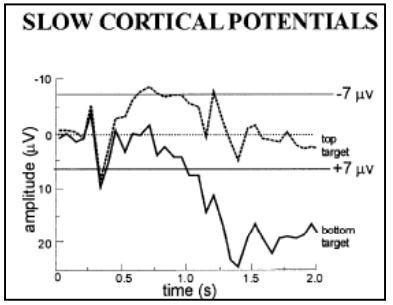
- 生物医学工程领域
  - ✓ 肢残人的康复训练、控制假肢、 BCI残疾人轮椅
  - ✓ 健康监护系统、疾病判别
- 认知、心理学研究
  - ✓ 情感、警觉度等精神状态估计预测
- 军事领域：“心思认知”系统与“意识头盔”
- 人工智能领域：理解人类大脑智能信息处理机理和认知过程
- 娱乐领域：脑操纵游戏

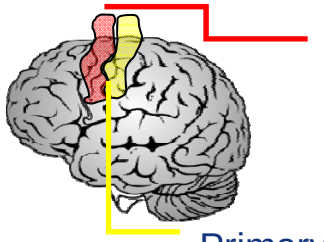
脑机交互神经机理

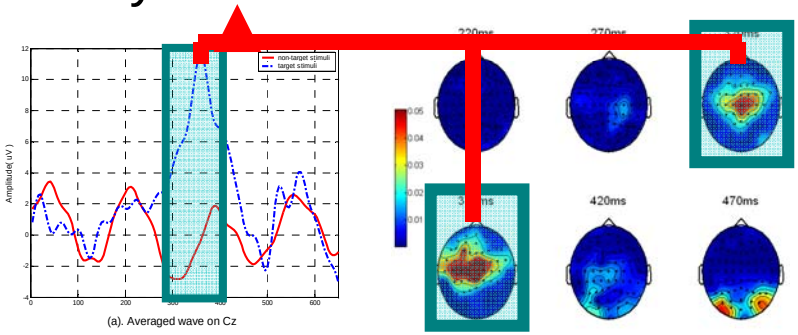
特性	诱发电位			自发电位		
	VEP	SSVEP	P300	SCP	ERD/ERS	TRSD/TRSS
需外部刺激信号	√	√	√	×	×	×
需主动意识参与	×	×	√	√	√	√
属单次反应	√	×	√	×	√	×
属多次反应	×	√	×	√	×	√
锁时性	√	×	√	×	√	×
锁相性	√	√	√	×	×	×
同步性	√	×	√	×	√	×
异步性	×	√	×	√	×	√
需用户长期训练	×	×	×	√	×	×

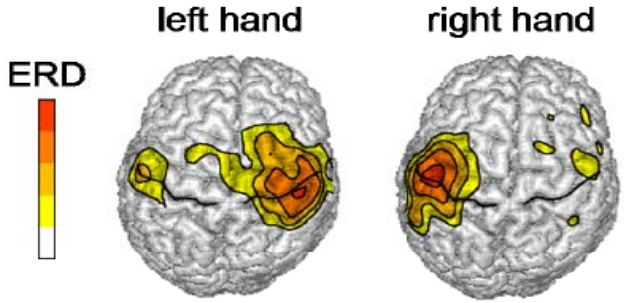
Neurophysiological Fundamentals

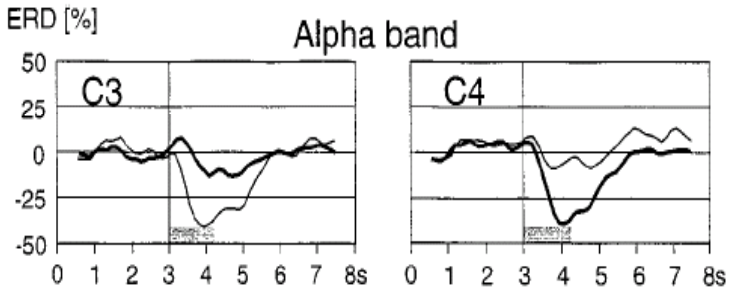
- Slow Cortical Potential（SCP）
- Steady state visual evoked potential (SSVEP)
- P300
- The event-related desynchronization and synchronization (*ERD/ERS*)



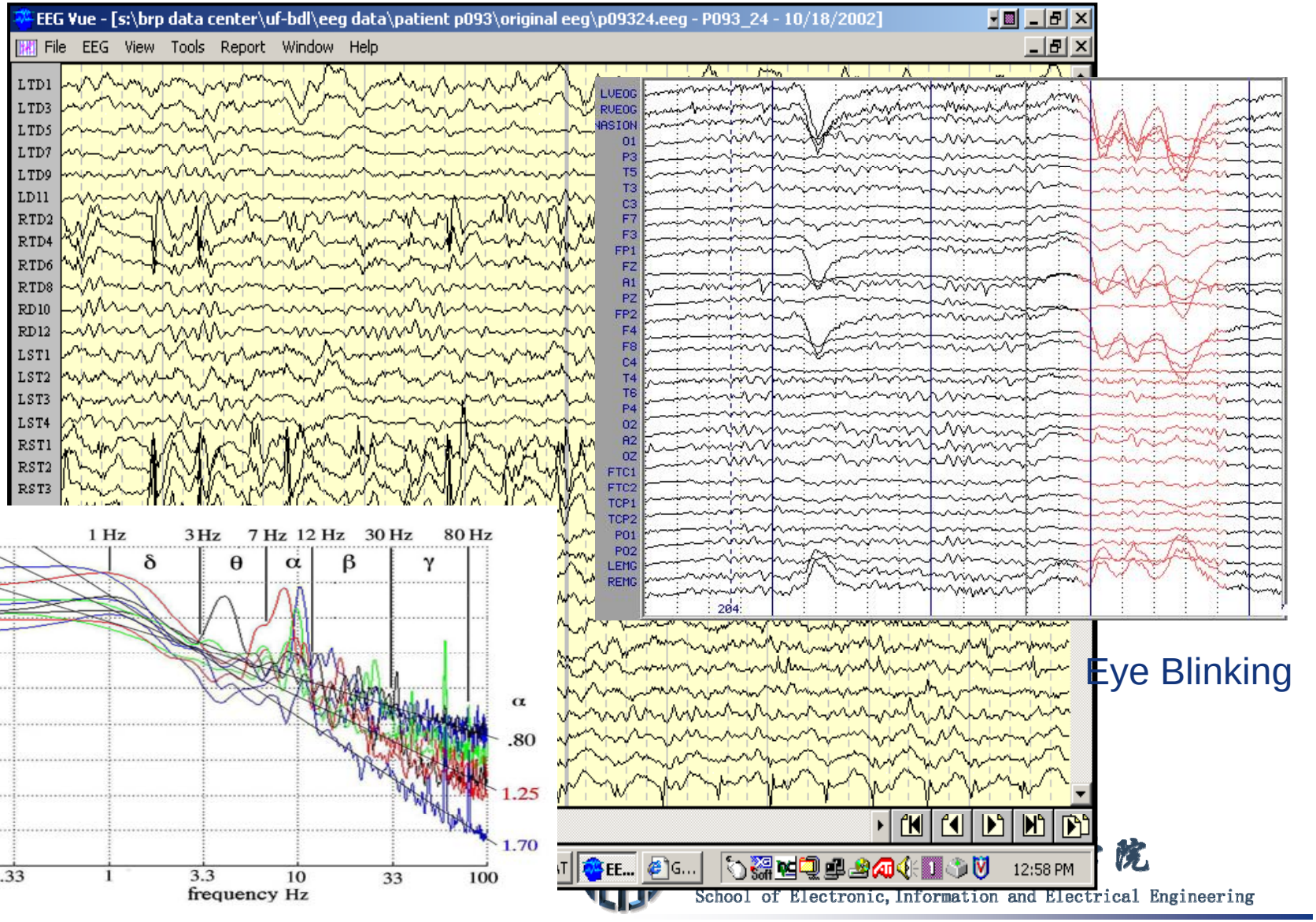








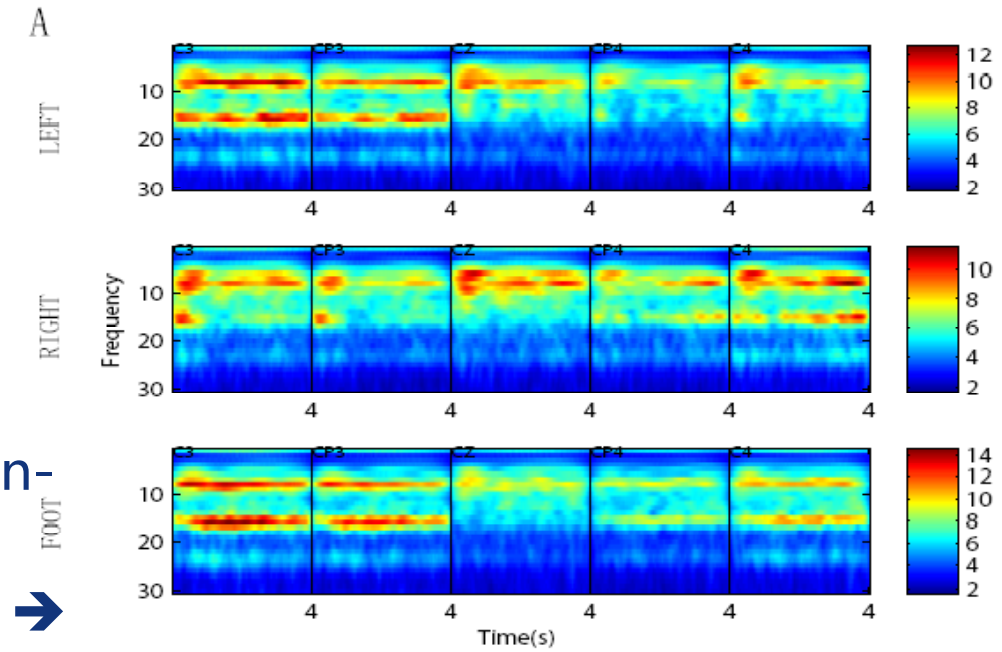
EEG Data



Eye Blinking

Task-Related Sustained ERD/TRSD

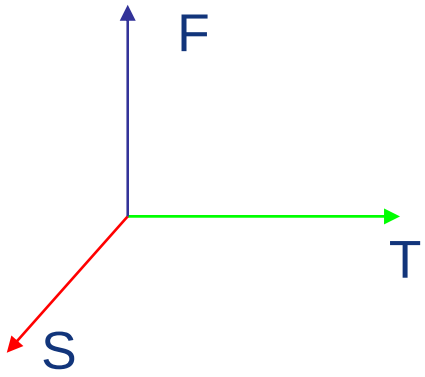
- Repeat Imagery Task
- Sustain ERD for certain period
- ERD->TRSD
- Advantage
  - Non-phase lock; Non-time lock
  - Binary control value → real control value
  - New dimension for control



Chinese Science Bulletin 2009

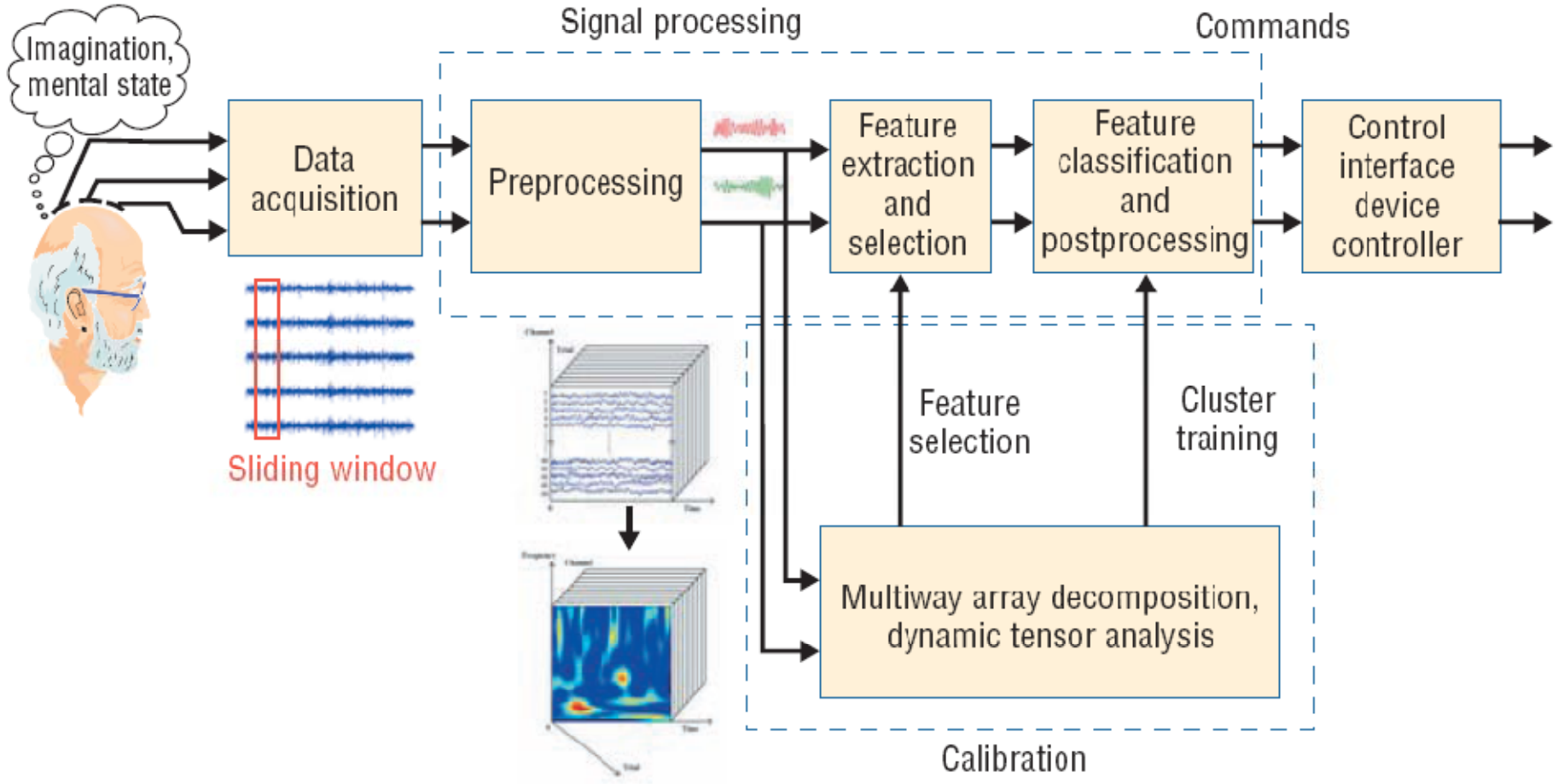
Methods for Feature & Classificatior

- Preprocessing
  - Temporal filtering; channel selection
  - Denoising and Enhancement（BSS, cICA)
- Feature Extraction
  - Common Spatial-frequency Pattern（ CSFP）
  - Incremental CSP（ICSP）
  - Common Tensor Decomposition Analysis（CTDA）
- Pattern Classification
  - Support Vector Machine（SVM）
  - Discriminant Analysis （LDA / FDA）



Extraction method	Time	Freq.	Space	Examples
Time-Frequency Representation	✓	✓	✓	STFT, wavelet
Cell firing rate	✓	✓	✓	-
Power Spectral Density	✗	✓	✓	Welch
Pattern matching	✓	✗	✓	Correlation
Raw signal	✓	✗	✓	Amplitude
Model parameters	✓	✗	✓	AR,AAR, Kalman
Other transforms	✓	✗	✓	ICA, PCA

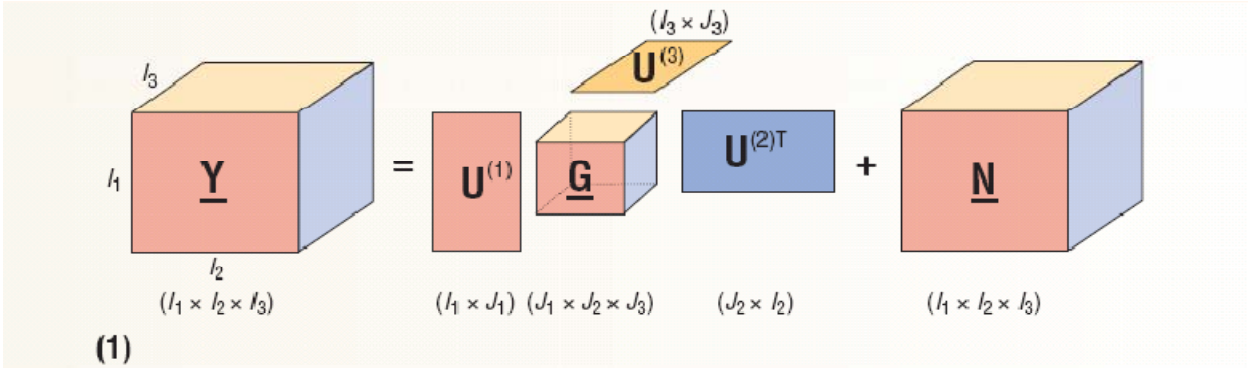
Feature Extraction Based TF



Tensor Decomposition

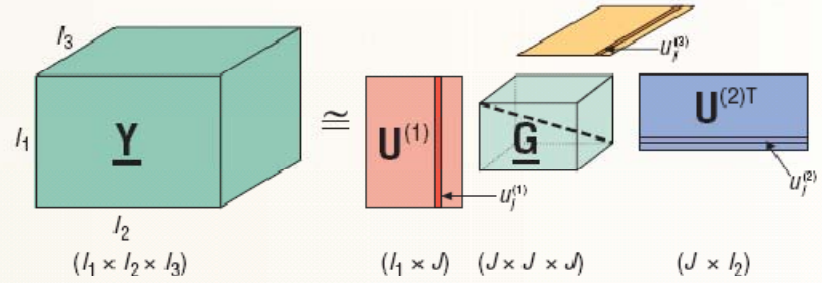
$$\underline{\mathbf{Y}} = \underline{\mathbf{G}} \times_1 \mathbf{U}^{(1)} \times_2 \mathbf{U}^{(2)} \ldots \times_N \mathbf{U}^{(N)} + \underline{\mathbf{N}}$$

Tucker

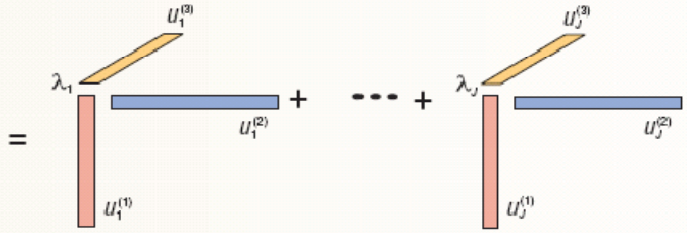


(1)

PARAFCA



(2)



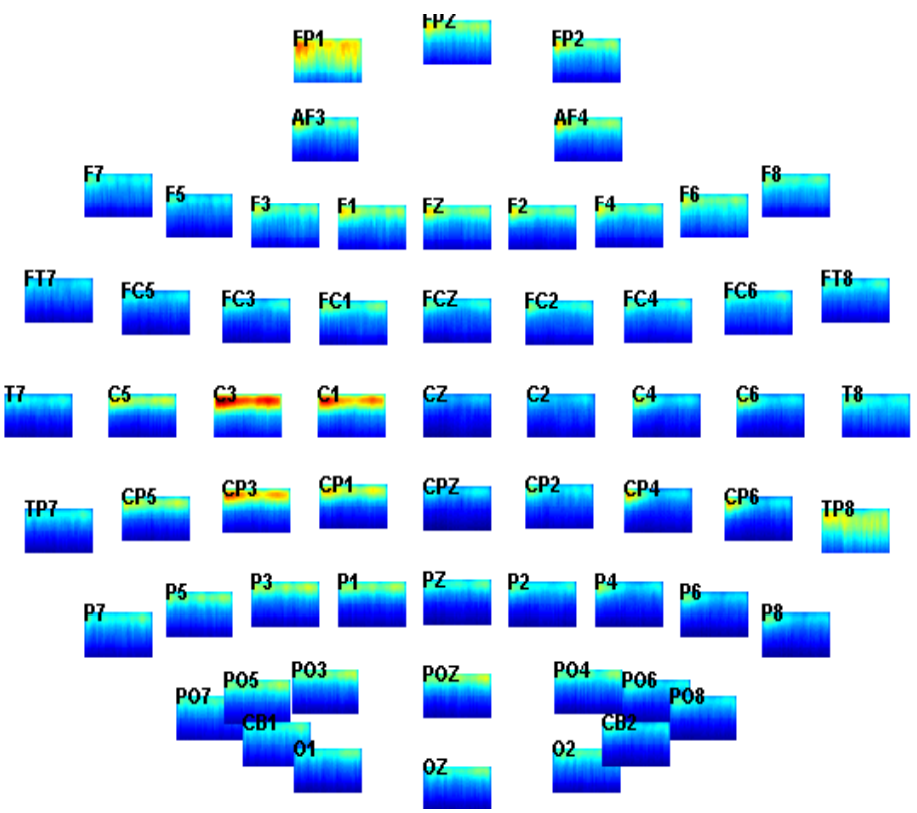
$$\underline{\mathbf{Y}} \cong \sum_{j=1}^{J} \lambda_j \mathbf{u}_j^{(1)} \circ \mathbf{u}_j^{(2)} \circ \ldots \circ \mathbf{u}_j^{(N)} = \underline{\Lambda} \times_1 \mathbf{U}^{(1)} \times_2 \mathbf{U}^{(2)} \ldots \times_N \mathbf{U}^{(N)}$$

IEEE Computer 2009

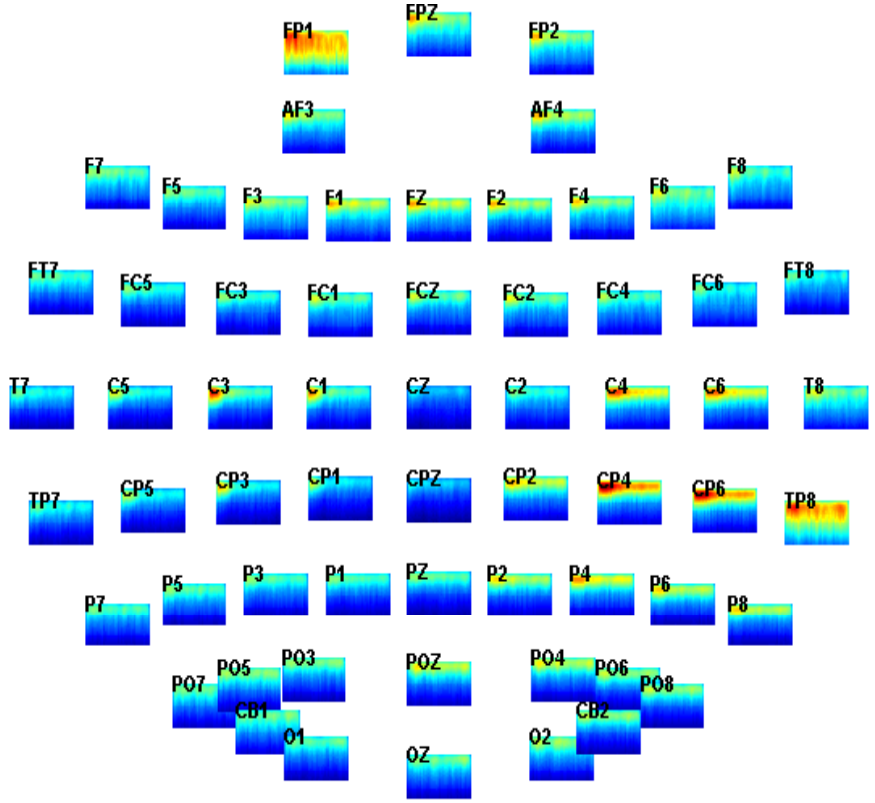
Tensor Representation

- Averaged Tensor

Left hand imagery



Right hand imagery



$$X^{channel \times frequency \times time \times class}$$

Common Spatial Frequency Pattern

- CWT Transform (Morlet Wavelet)

$$W^{c,k}(a,t)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}x^{c,k}(\tau)\psi(\frac{\tau-t}{a})d\tau,$$

$$\mathbf{p}_k^{c,f}=\left\|\hat{W}^{c,k}(f,t)\right\|^2,$$

- Temporal-Frequency Vectors

$$\mathbf{U}_k^c=\left(\mathbf{p}_k^{c,f_1}\mathbf{p}_k^{c,f_2}\cdots\mathbf{p}_k^{c,f_m}\right)^T \text{ and } \mathbf{V}_k^f=\left(\mathbf{p}_k^{c_1,f}\mathbf{p}_k^{c_2,f}\cdots\mathbf{p}_k^{c_n,f}\right)^T,$$

- Vectorizing

$$\mathbf{Y}_k=\begin{pmatrix}\mathbf{U}_k^{c_1}\\ \mathbf{U}_k^{c_2}\\ \vdots\\ \mathbf{U}_k^{c_n}\end{pmatrix} \quad or \quad \mathbf{Y}_k=\begin{pmatrix}\mathbf{V}_k^{f_1}\\ \mathbf{V}_k^{f_2}\\ \vdots\\ \mathbf{V}_k^{f_m}\end{pmatrix},$$

Common Spatial Frequency Pattern (CSFP)

- Objective Function (Multi-task)

$$\underset{\mathbf{w}}{\operatorname{argmax}} \frac{\mathbf{w}^T \mathbf{S}_I \mathbf{w}}{\mathbf{w}^T \mathbf{S}_T \mathbf{w}}. \qquad \mathbf{S}_I = \boldsymbol{\Gamma}^{(i)}|_{i=1}^{M}, \quad \mathbf{S}_T = \frac{1}{M}\sum_{i=1}^{M} \boldsymbol{\Gamma}^{(i)}$$

- Sub-Component

$$\mathbf{S}_I \leftarrow \mathbf{S}_I(\mathbf{I} - \frac{\mathbf{w}^T \mathbf{w} \mathbf{S}_T}{\mathbf{w}^T \mathbf{S}_T \mathbf{w}})$$

- Projection

$$\mathbf{Z}_k^p = \sum_{f=f_1}^{f_m} \sum_{c=c_1}^{c_n} \mathbf{w}_p^{c,f} \mathbf{Y}_k^{c,f},$$

- Feature Vector

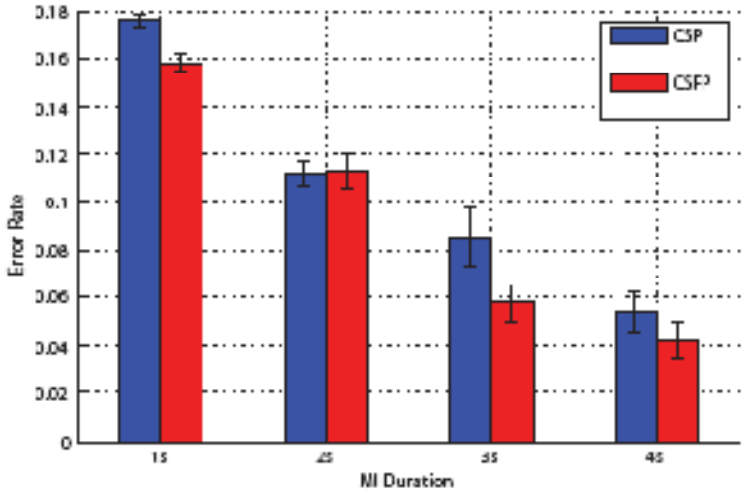
$$\mathbf{f}_k = \log\left(\frac{\operatorname{diag}(\mathbf{Z}_k \mathbf{Z}_k^T)}{\operatorname{tr}(\mathbf{Z}_k \mathbf{Z}_k^T)}\right)$$

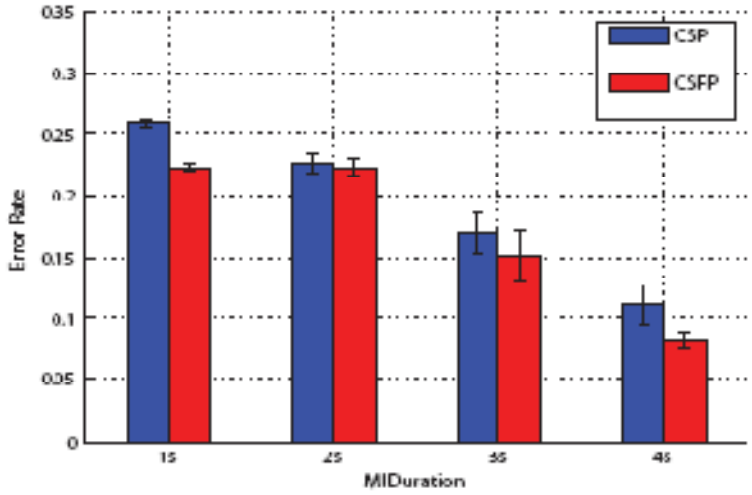
Classification Results:10 cv

Two Classes

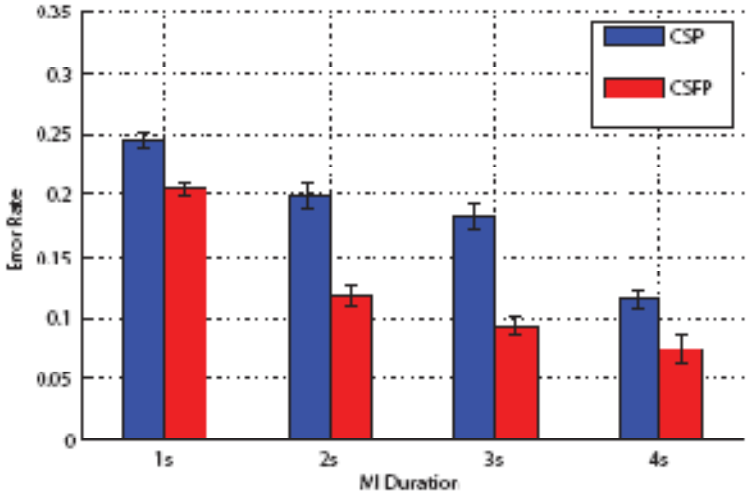
Three Classes

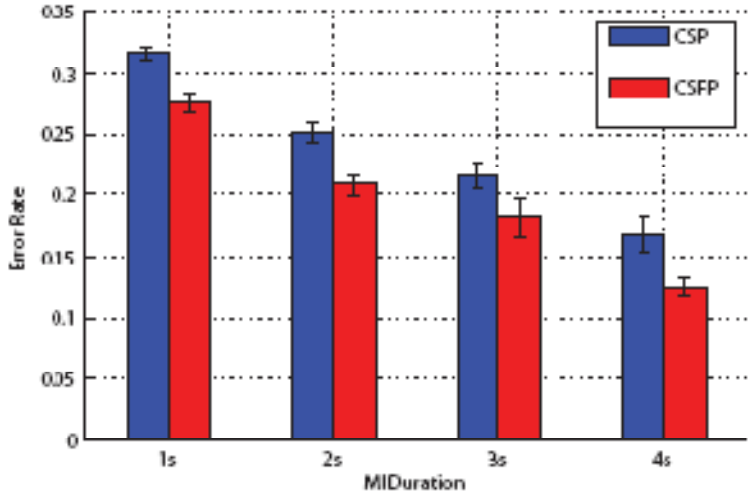
Subject 1





Subject 2





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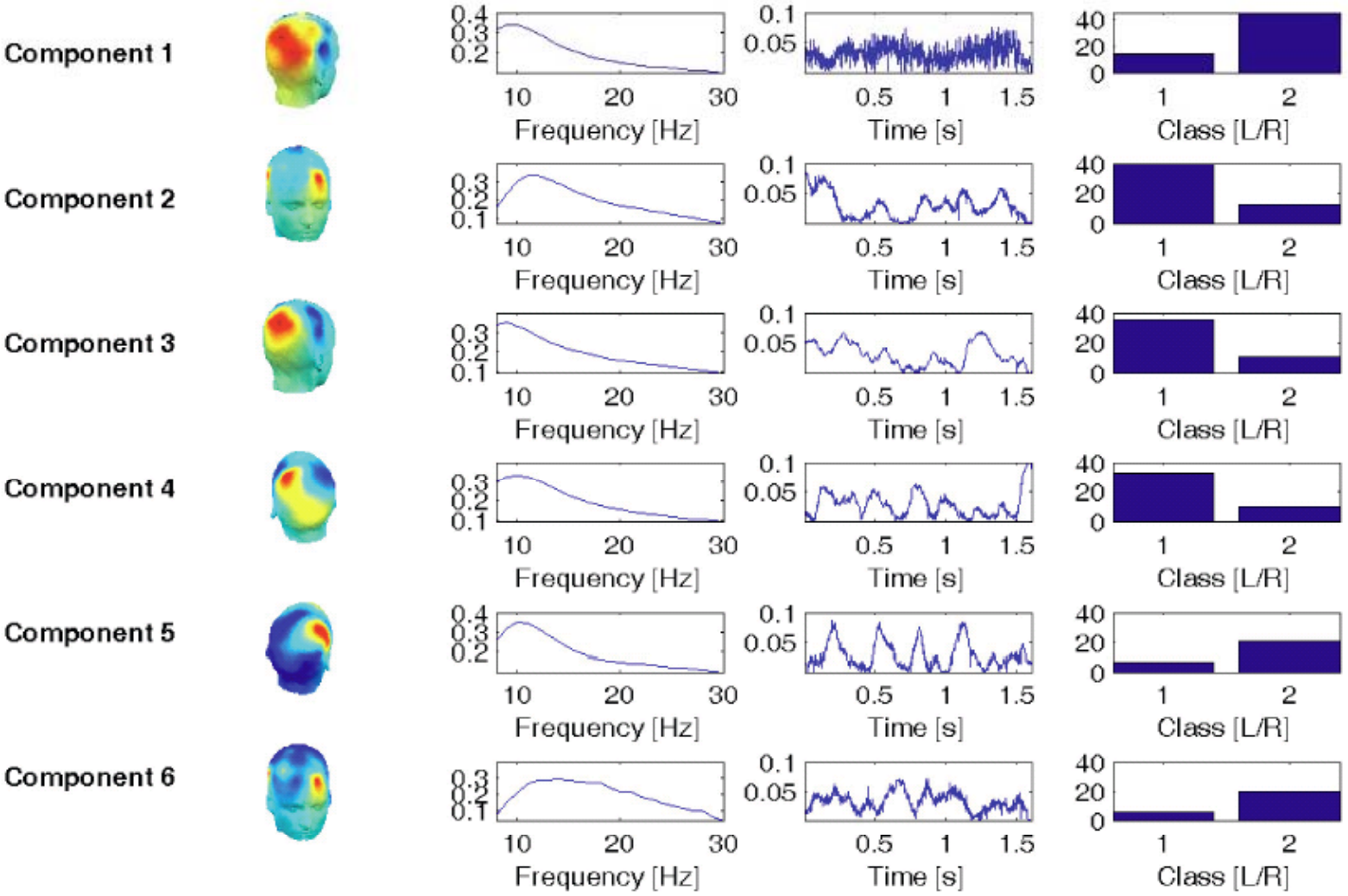
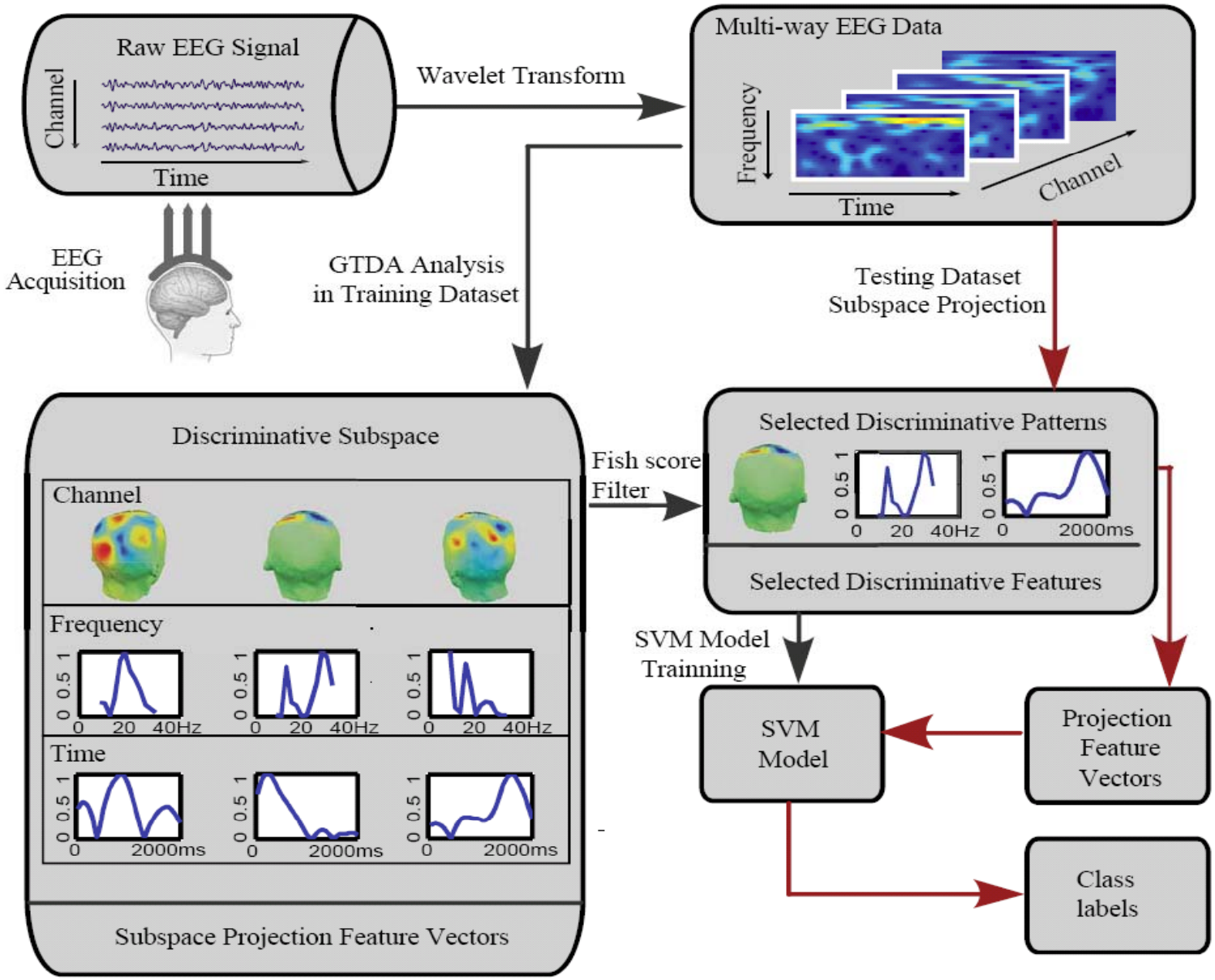
Decomposed Components



Tensor Feature Extraction



Discriminative model

- Logistic Regression Model

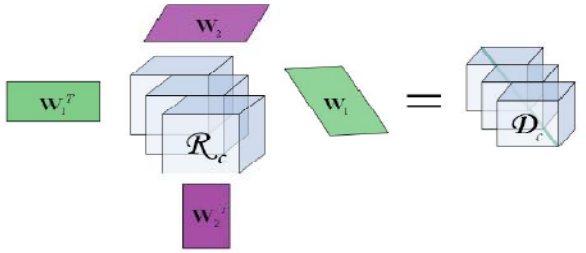
$$\log \frac{P(y=+1|\mathscr{X})}{P(y=-1|\mathscr{X})} = f(\mathscr{X},\theta) = \mathscr{X}\prod_{d=1}^{m} \times_d w_d + b,$$

$$\min_{w_d|_{d=1}^{m} \in R^{D_d}, b\in R} \sum_{n=1}^{N} \log(1+e^{-y_n f(\mathscr{X}_n,\theta)}) + \sum_{d=1}^{m} \lambda_d^1 \|w_d\|^2 + \lambda_d^2 |w_d| - \lambda_d^3 (w_d^T K_d w_d),$$

Common Tensor - CTDA

- Tensor Covariance

$$\mathcal{R} = \frac{1}{n}\sum_{i=1}^{n}[[\mathcal{X}_i \circ \mathcal{X}_i; (M)(M)]]$$



- Objective Function

$$\sum_{c=1}^{C}\mathcal{R}_c \times_1 \mathbf{W}_1^T \times_2 \mathbf{W}_2^T = \mathcal{I}$$

$$\mathcal{R}^{(c)} \times_1 \mathbf{W}_1^{(c)T} \ldots \times_{M-1} \mathbf{W}_{M-1}^{(c)T} \times_M \mathbf{W}_{M-1}^{(c)} \cdots \times_{2(M-1)} \mathbf{W}_1^{(c)} = \mathcal{D}^{(c)}$$

$$\left(\sum_{c=1}^{C}\mathcal{R}^{(c)}\right) \times_1 \mathbf{W}_1^{(c)T} \ldots \times_{M-1} \mathbf{W}_{M-1}^{(c)T} \times_M \mathbf{W}_{M-1}^{(c)} \cdots \times_{2(M-1)} \mathbf{W}_1^{(c)} = \mathcal{I},$$

- Feature Projection

$$\mathrm{f} = \log\left\{\frac{\mathrm{diag}\left[\mathrm{mat}_M^T\left(\mathcal{X}\prod_{l=1}^{M-1}\times_l \mathbf{W}_l^T\right)\mathrm{mat}_M\left(\mathcal{X}\prod_{l=1}^{M-1}\times_l \mathbf{W}_l^T\right)\right]}{\mathrm{tr}\left[\mathrm{mat}_M^T\left(\mathcal{X}\prod_{l=1}^{M-1}\times_l \mathbf{W}_l^T\right)\mathrm{mat}_M\left(\mathcal{X}\prod_{l=1}^{M-1}\times_l \mathbf{W}_l^T\right)\right]}\right\}$$

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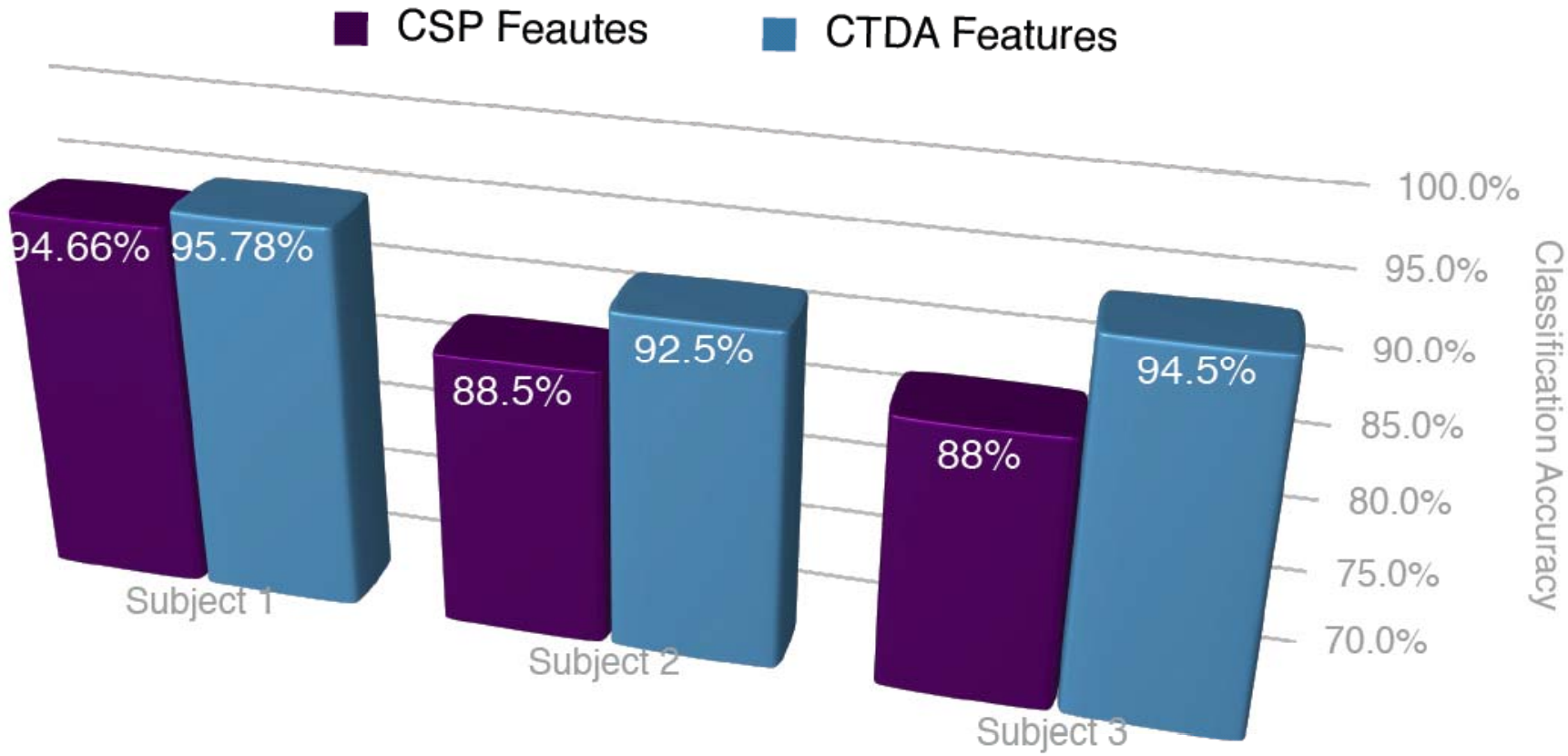
Comparisons: CSP & CTDA



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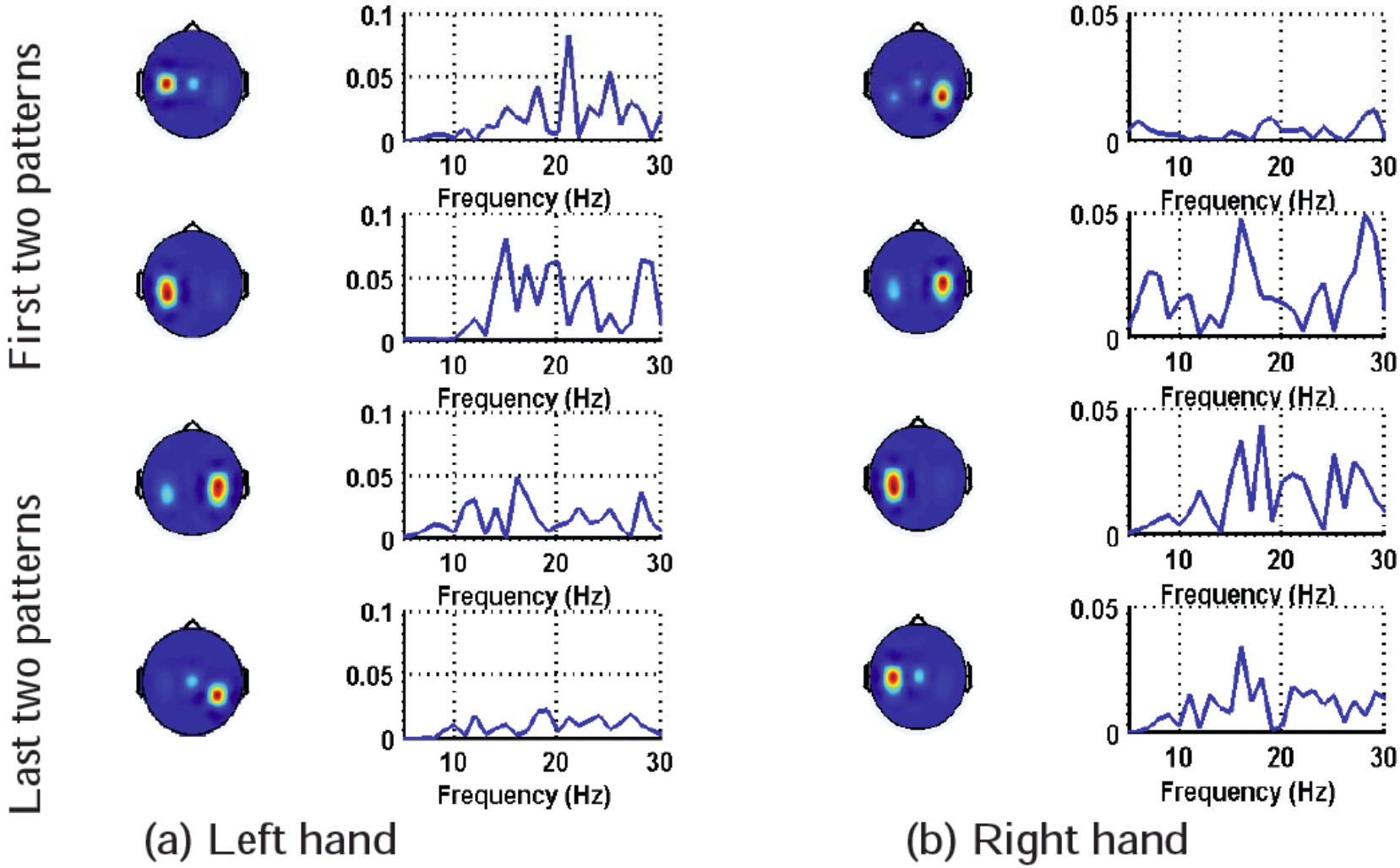
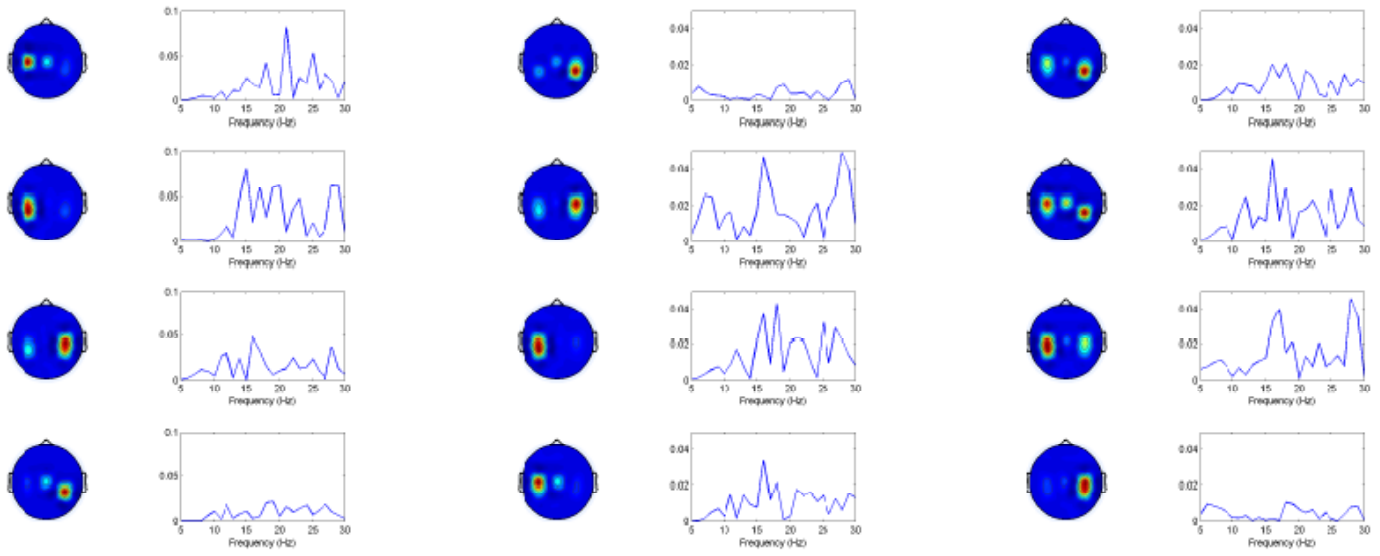
CTDA



Pattern recognition Letter 2009

Experiment Results



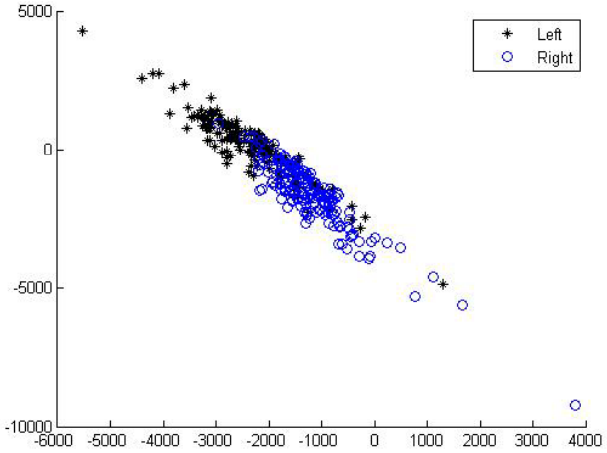
(a) Left (b) Right (c) Foot

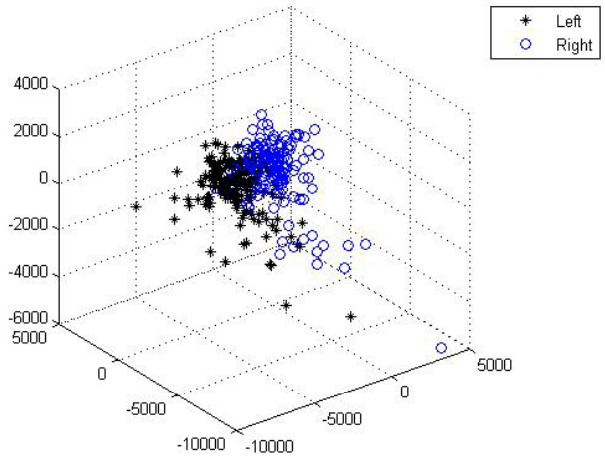
Projection

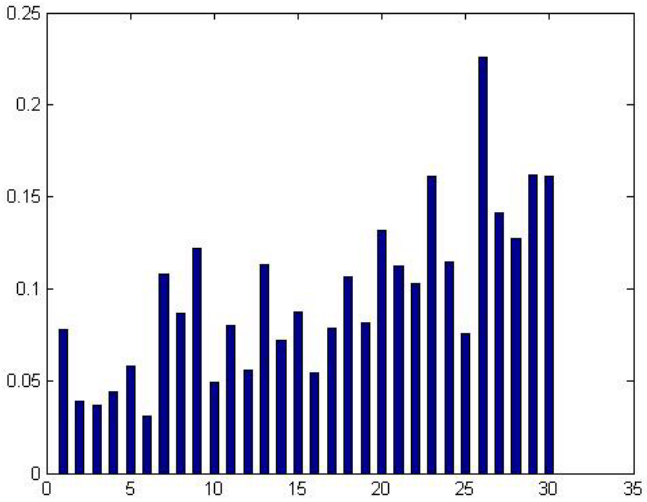
Subjects	2 classes		3 classes	
	CSP	CTDA	CSP	CTDA
S1	94.66±0.84	95.78±0.75	88.95±1.60	91.80±0.57
S2	88.50±0.70	92.50±1.18	83.11±1.39	87.56±0.75
S3	88.00±1.00	94.50±0.67	84.93±0.95	88.33±0.35

Classification Performance

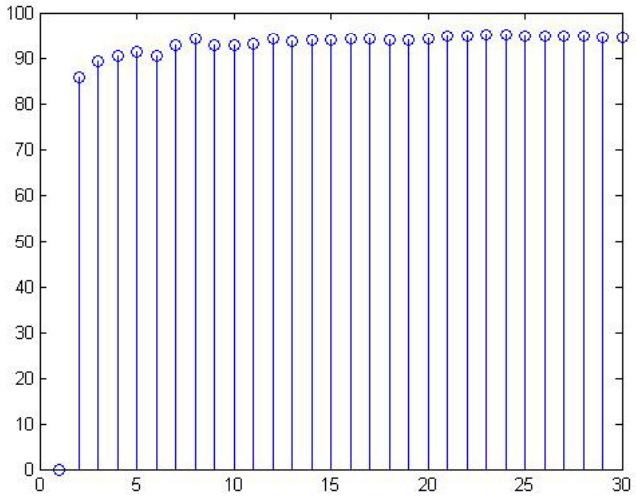
Classification







MI between Feature and Class



Accuracy – Number of features

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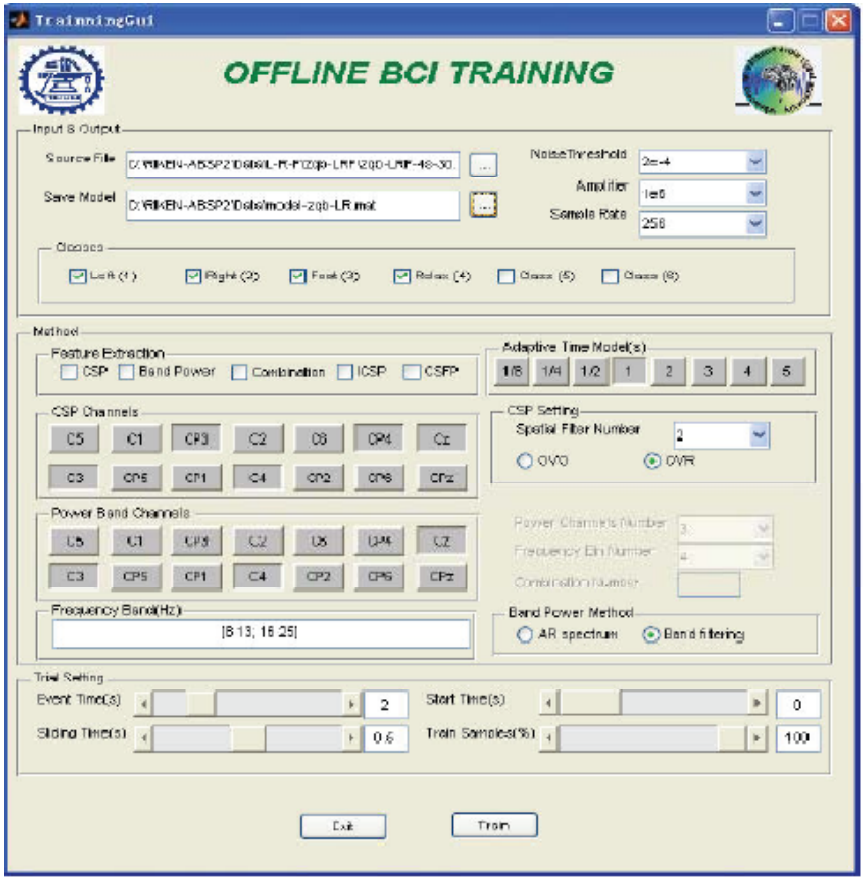
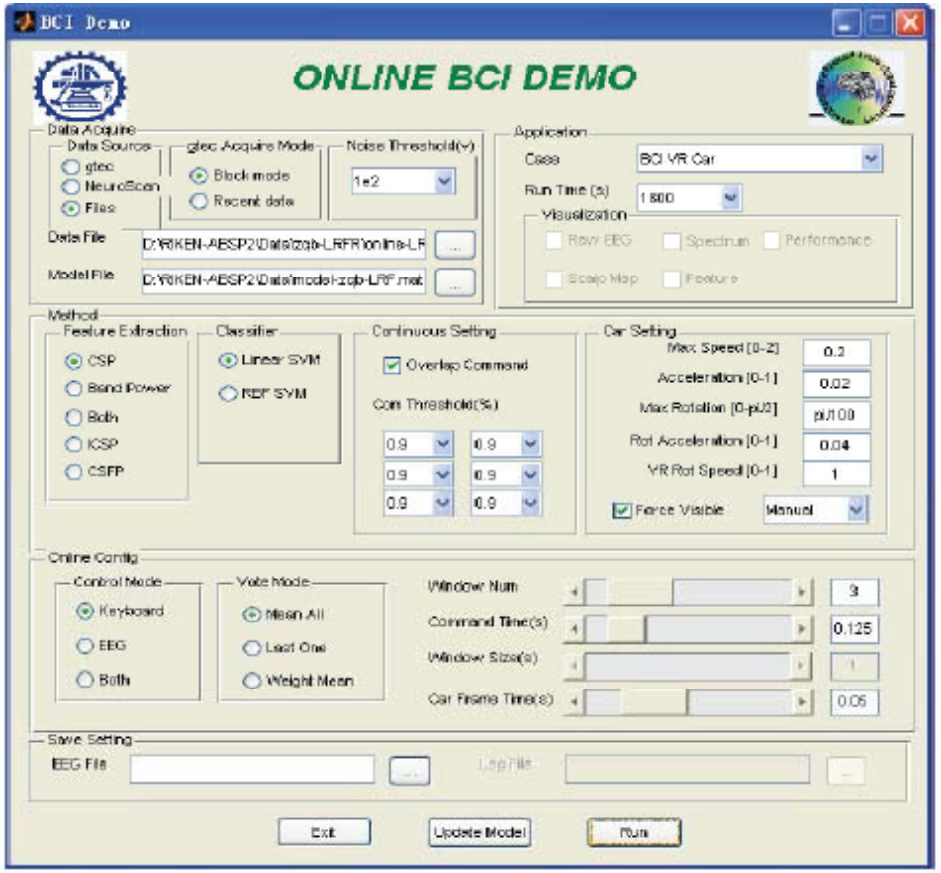
BCI Development Platform





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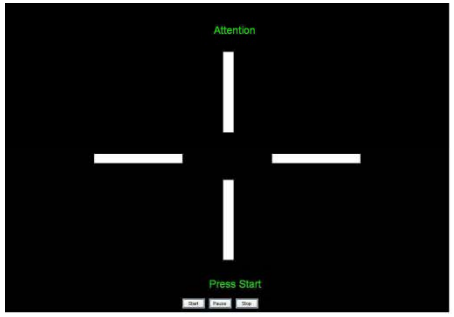
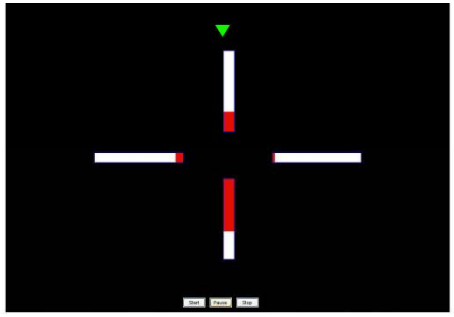
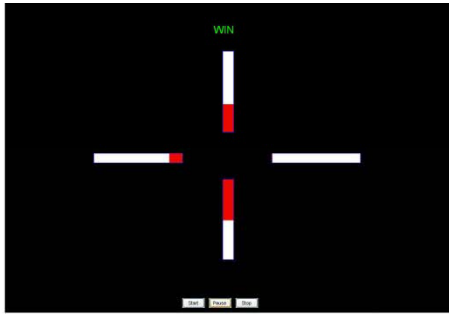
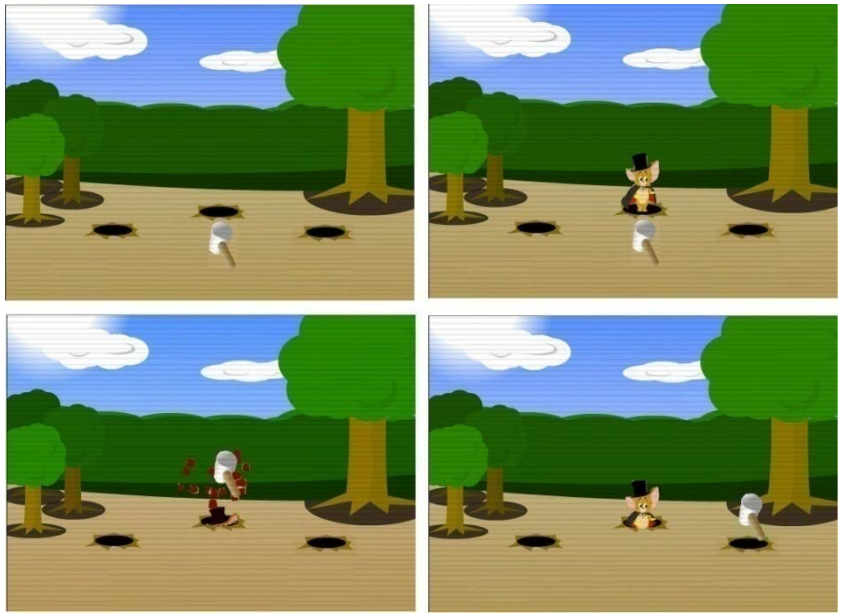
BCI Game









Classification accuracy

受试者	离线分析			在线分析		
	1s	2s	3s	1s	2s	3s
S1	0.78	0.9	0.95	0.62	0.75	0.9
S2	0.88	0.98	1	0.65	0.8	0.93

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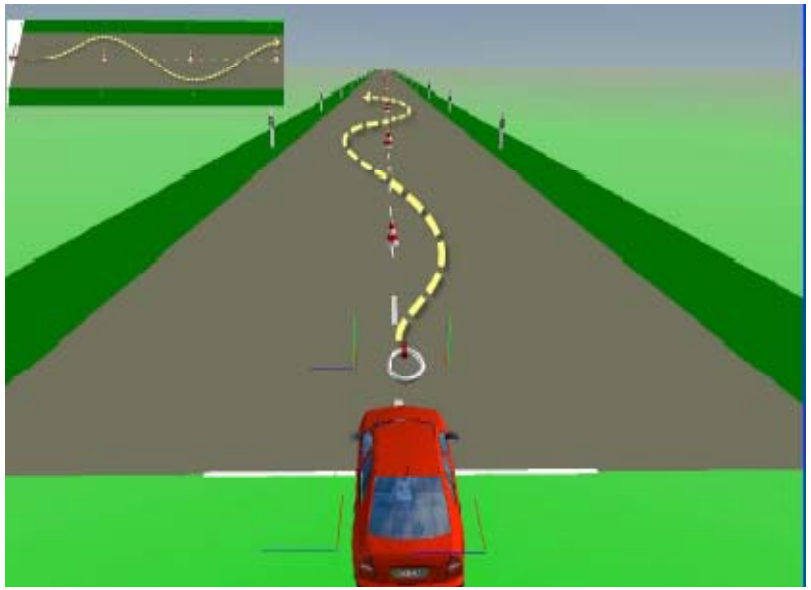
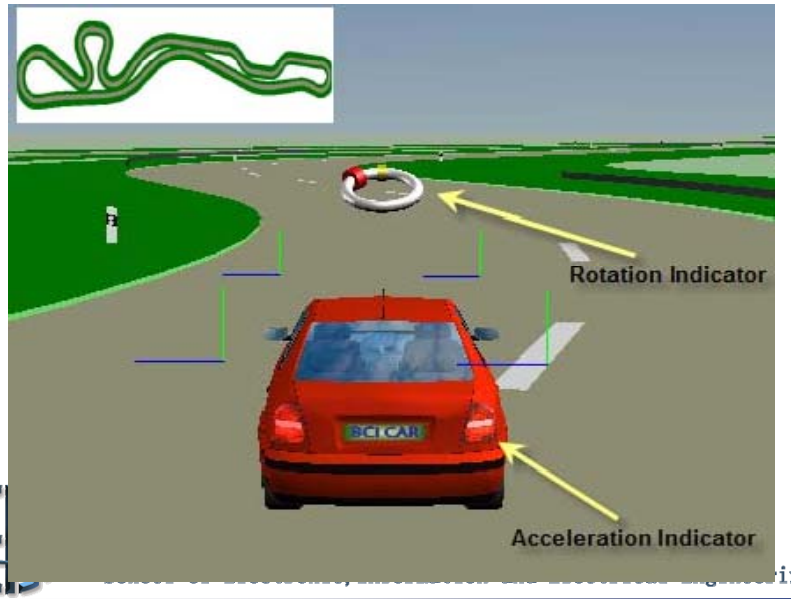
BCI Car Driving System

- Noninvasive, spontaneous and asynchronous
- Two scenarios to test the BCI performance
- Control directions and speed

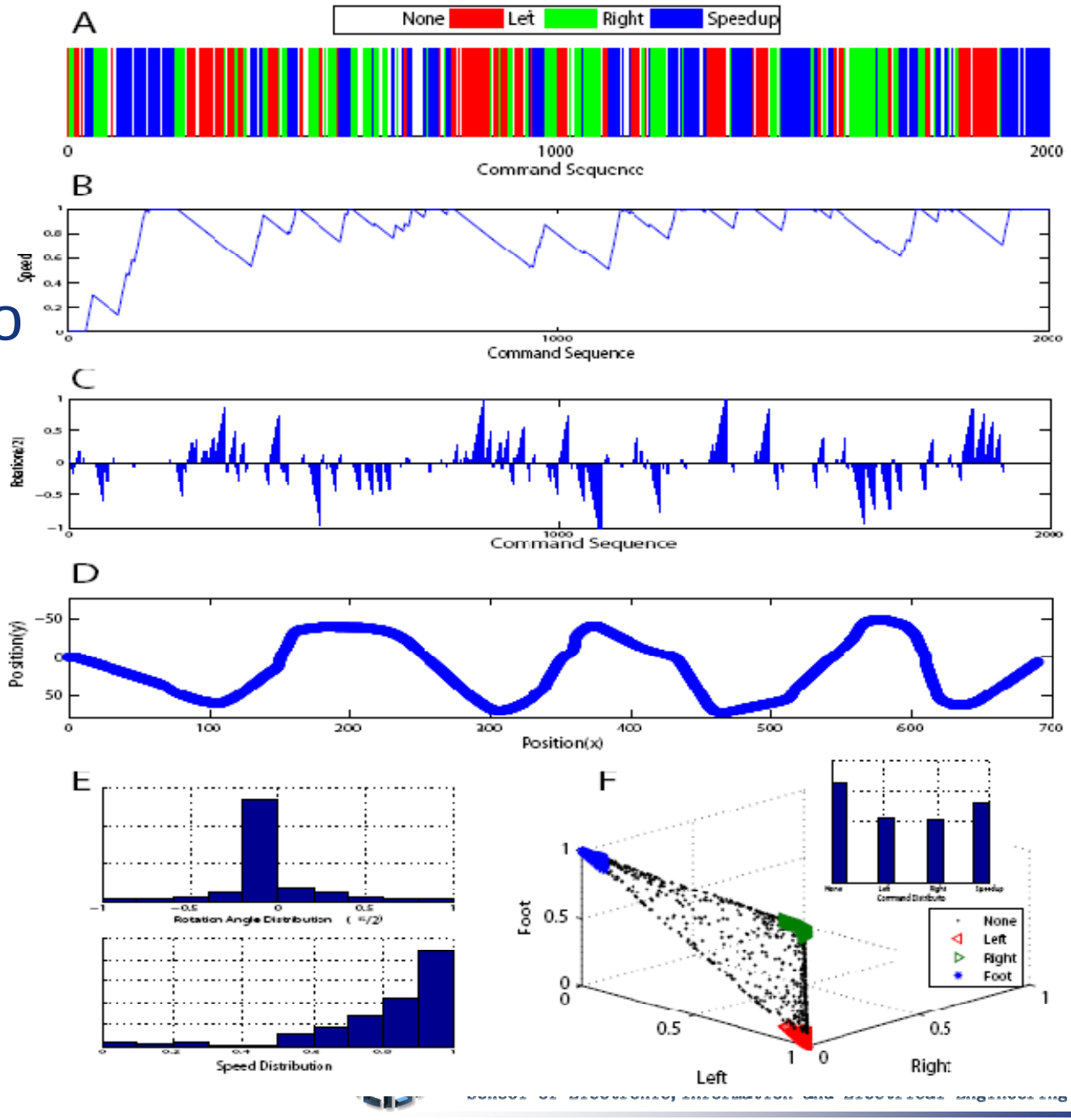
scenario I



scenario II



- On-line implementation
- No-task state
- Real value control parameter
- Error toralence



BCI Wheelchair

BCI Remote Car Control

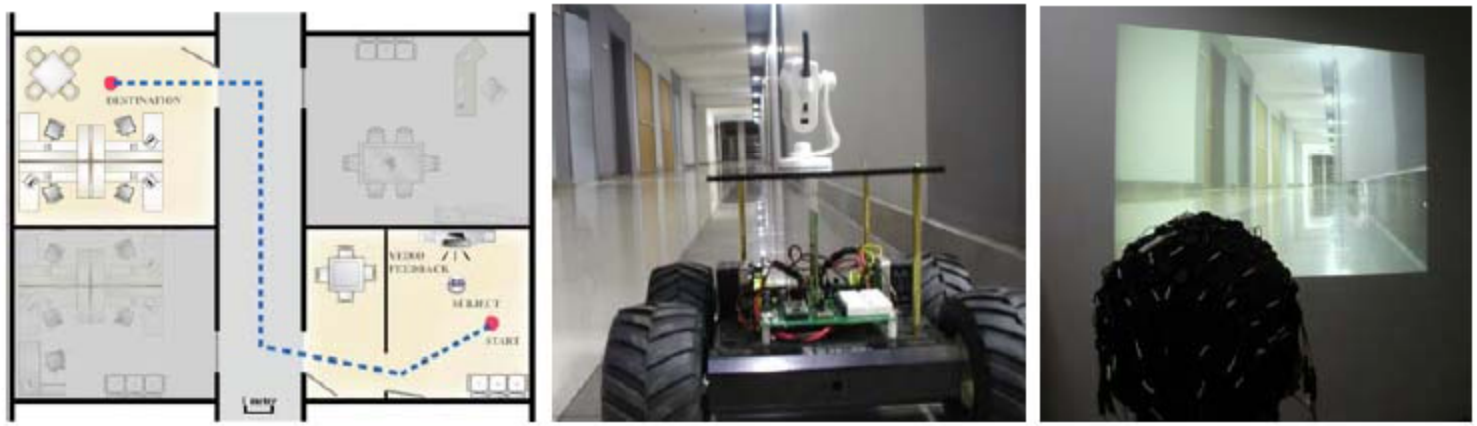
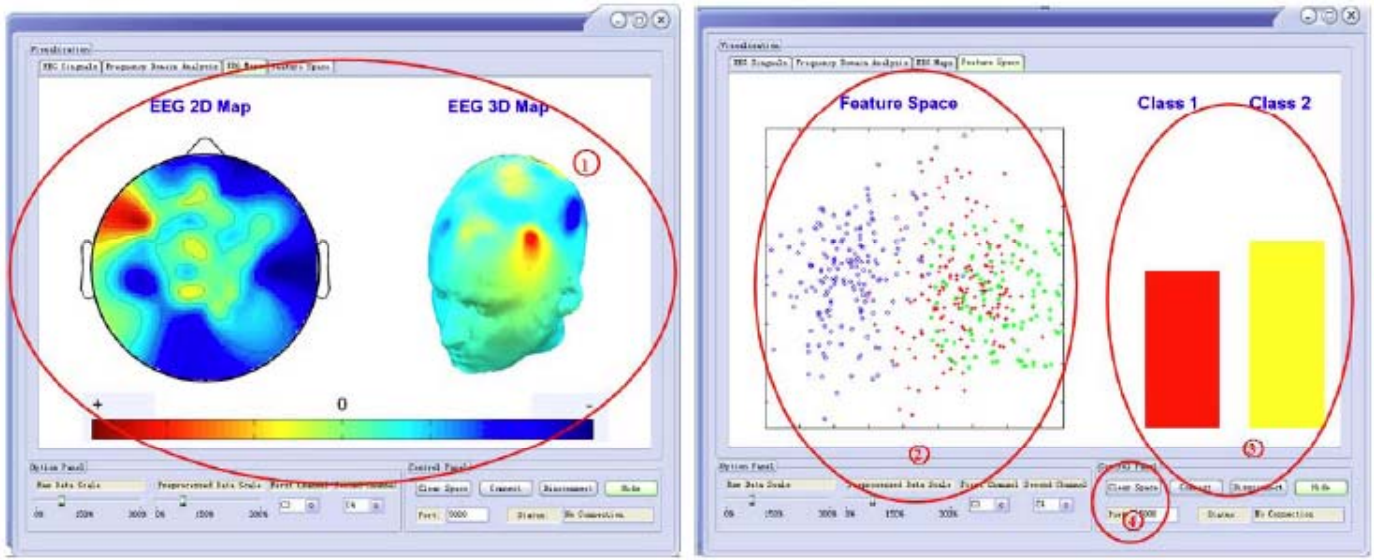
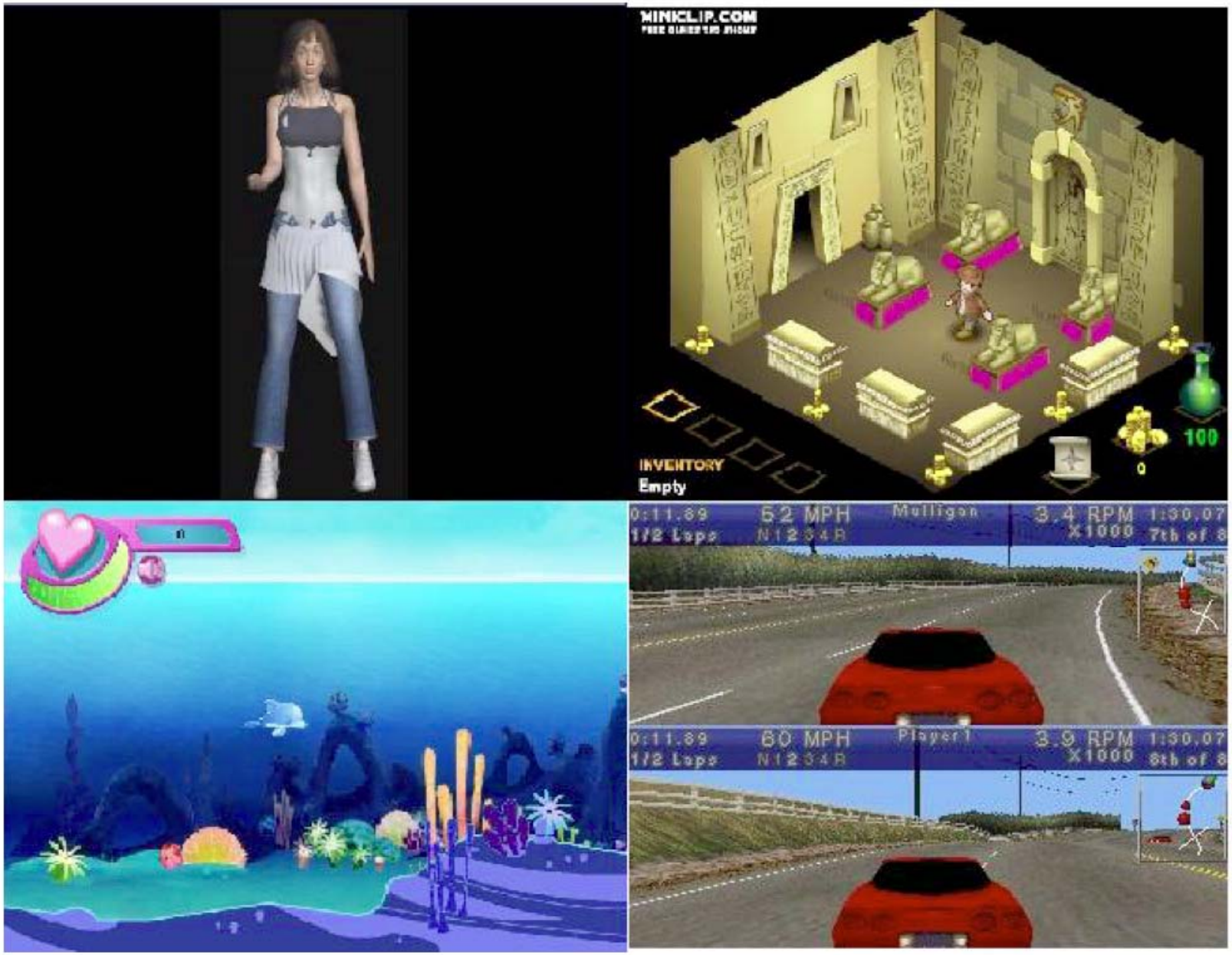
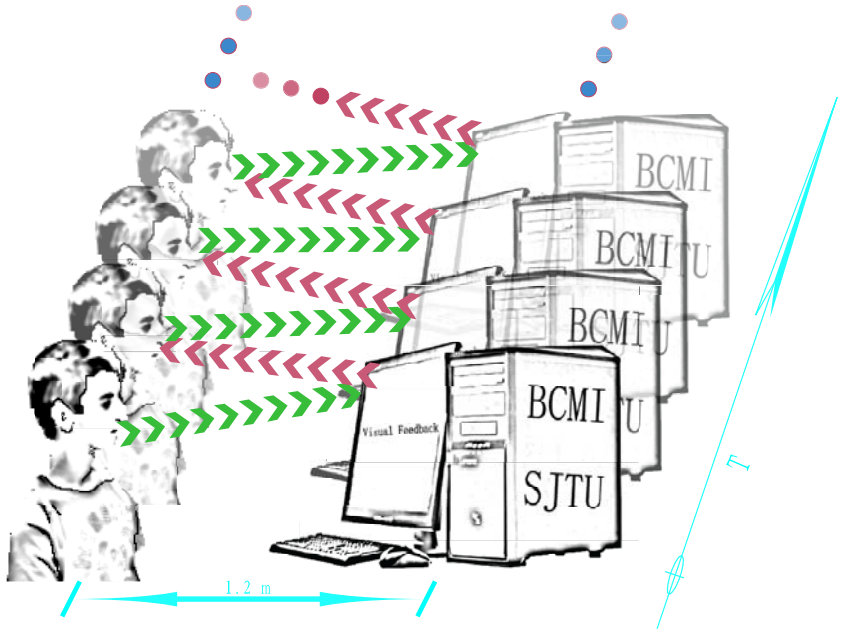


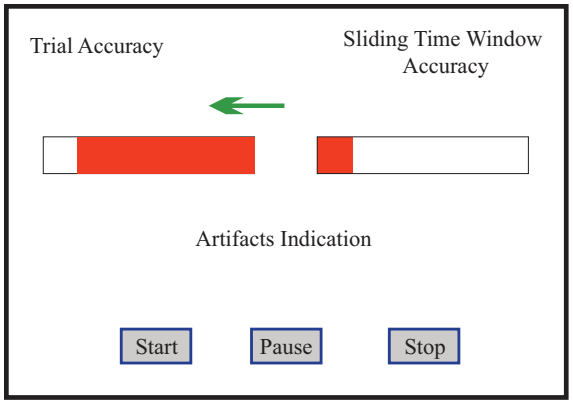
图 4-2　在线远程机械车驾驶




MINICLIP.COM
INVENTORY
Empty
100
0:11.89
52 MPH
Mulligan
3.4 RPM
1:30.07
1/2 Laps
X1000
7th of 8
0:11.89
60 MPH
Player 1
3.9 RPM
1:30.07
1/2 Laps
X1000
8th of 8

Bilateral Training Framework

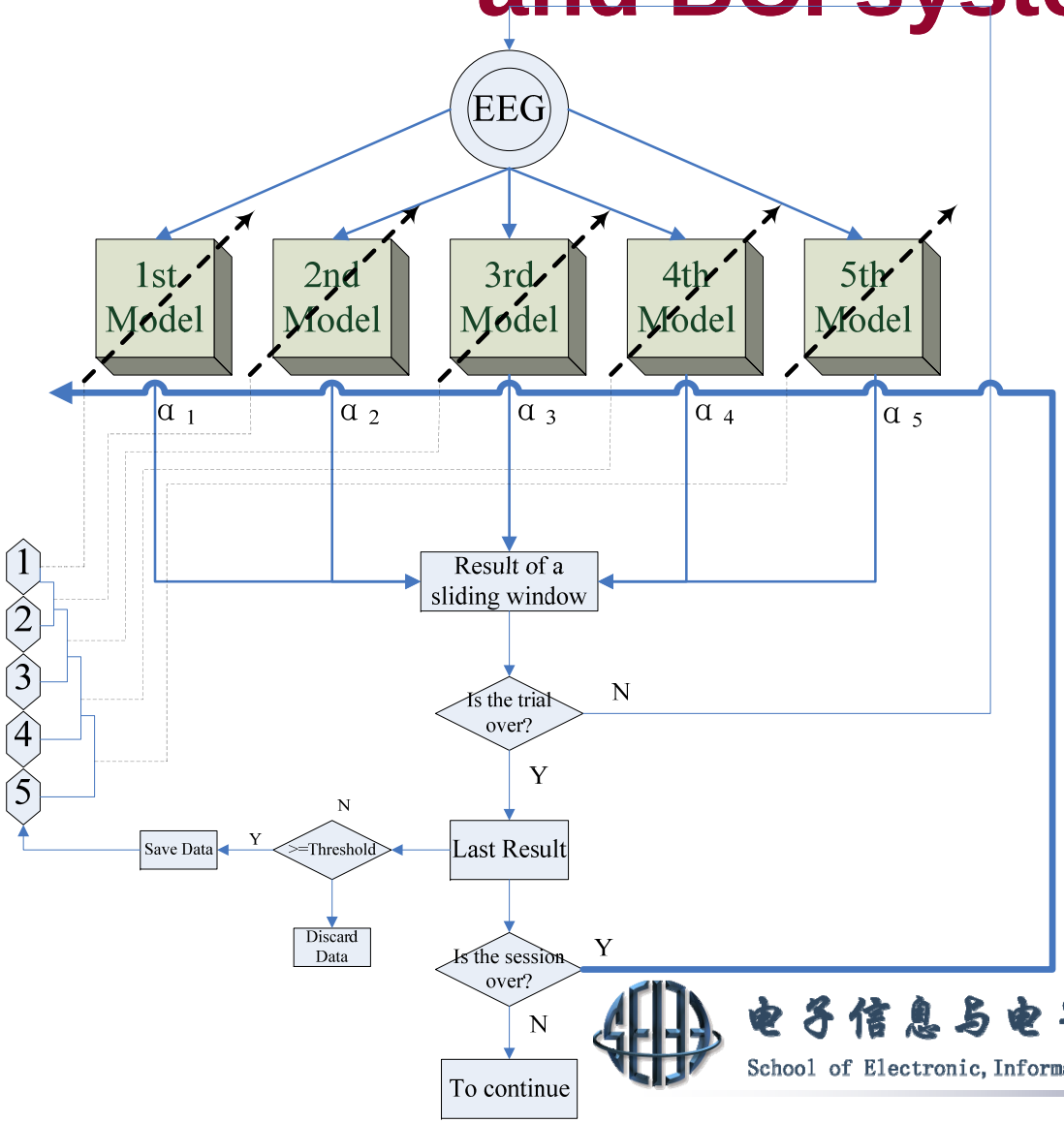




- Sketch map of bilateral training process. Green arrow represents BCI system training. Red arrow represents humans training. Dots mean to continually repeat training over the whole experiment time.

J Neurosci Meth, 2010

Interaction between humans and BCI system



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Latest Demos

- RIKEN – BCI Control of Wheelchairs(CCTV)
- RIKEN - BCI Control of Wheelchairs(NHK)
- Driving A Car in VR
- BCI Wheelchair (SJTU / RIKEN /)
- BCI Car Racing System
- BCI Remote Car Control

Related Publications

- Junhua Li and Liqing Zhang, Bilateral Adaptation and Neurofeedback for Brain Computer Interface system, **Journal of Neuroscience Methods** 193: 373–379, (2010)
- Jie Li, Liqing Zhang, Dacheng Tao, Han Sun and Qibin Zhao, A Prior Neurophysiologic Knowledge Free Tensor-based Scheme for Single Trial EEG Classification, ***IEEE Transactions on Neural Systems and Rehabilitation Engineering***, 17(2):107-115,2009
- Jie Li, and Liqing Zhang, Phase Interval Value Analysis for motor imagery task in BCI, ***Pattern Recognition Letter***, 2009
- Jie Li and Liqing Zhang, Phase Interval Value Analysis for the Motor, Imagery Task in BCI, ***Journal of Circuits, Systems, and Computers,*** Vol.18(8), pp1441-1452, (December 2009)
- A. Cichocki,, A. Phan, S. Choi, H. Lee, Q. Zhao, L. Zhang, and Y. Li, Noninvasive Brain-Computer Interface: Current Trends and Challenges in Signal Processing - Multiway Array Decompositions, ***IEEE Computer***, Vol. 41(10), pp.34-42, October, 2008
- *Qibin Zhao, Liqing Zhang, Andrzej Cichocki*, Multilinear Generalization of Common Spatial Pattern, The 34th IEEE International Conference on Acoustics, Speech and Signal Processing ***(ICASSP2009),*** Taipei, April 19-24, 2009
- Qibin Zhao, Liqing Zhang and Andrzej Cichocki, EEG-based asynchronous BCI control of a car in 3D virtual reality environments, ***Chinese Science Bulletin***, Vol.54 No. 1, pp.78-87, 2009
- Qibin Zhao, Liqing Zhang, Andrzej Cichocki and Jie Li, Incremental Common Spatial Pattern Algorithm for BCI, ***IJCNN2008,*** pp2657-2660, Hongkong, 2008
- Oibin Zhao, Liqing Zhang and Jie Li, Multi-Task BCI for Online Game Control, in Mahr & Sheng (eds), ***Autonomous Systems – Self-Organization, Management and Control***, *Springer*, pp.29-38, October, 2008
- L. Zhang, A. Cichocki and S. Amari, Multichannel Channel Blind Deconvolution of Non-minimum Phase Systems Using Filter Decomposition, ***IEEE Transactions on Signal Processing***, Vol. 52,

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Brain-like Computing
&
Machine Intelligence

Thanks for Your Attention

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