Artificial Intelligence Research Group

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A Comparative Study of Features and Classifiers in Single-channel EEG-based Motor Imagery BCI

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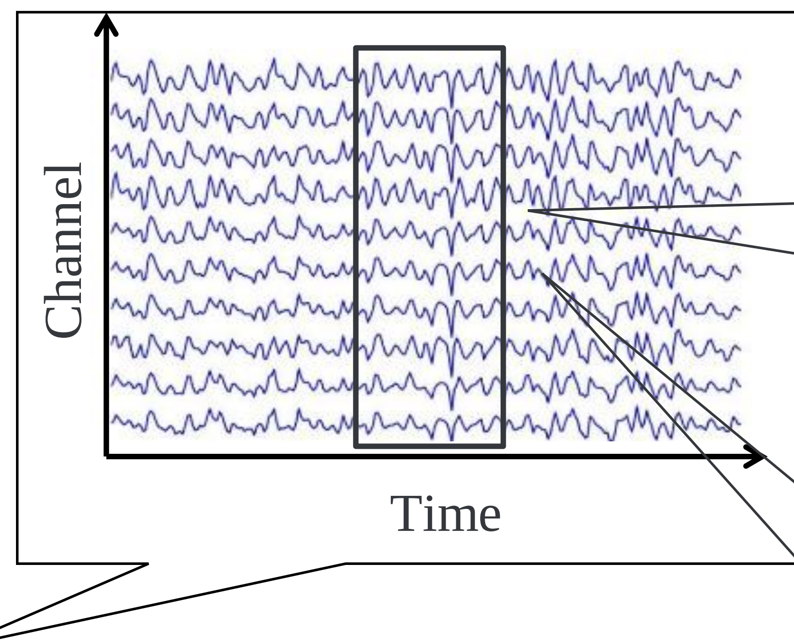
Motor Imagery Brain—Computer Interfaces

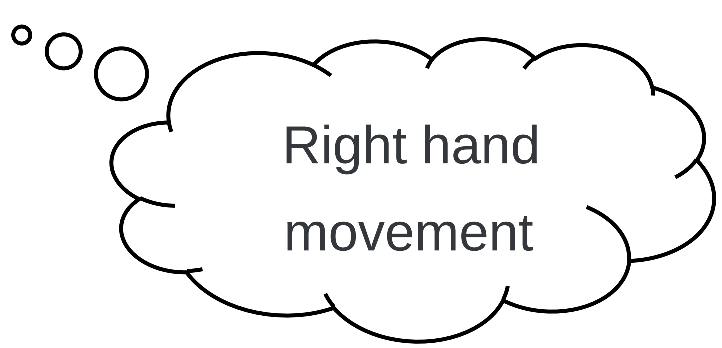
- Use rhythmic EEG features by motor imagery

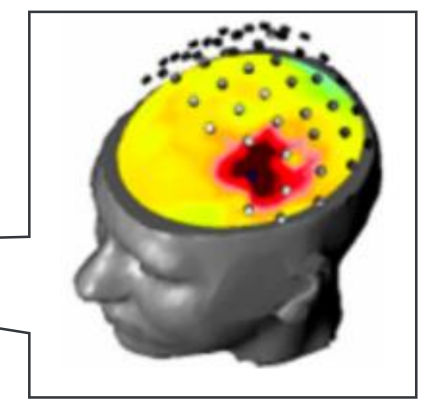
  μ and β rhythms in motor areas are discriminative features

- Integrate spatial filter to emphasize the features

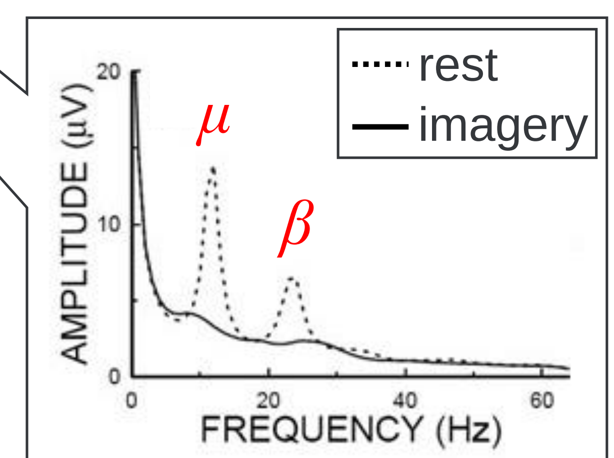
  But, … the filter needs multichannel information







Topographical map



Spectra over left sensorimotor cortex [1]

[1] http://web.media.mit.edu/~cvx/sht.htm, accessed 13-Nov.-2018.

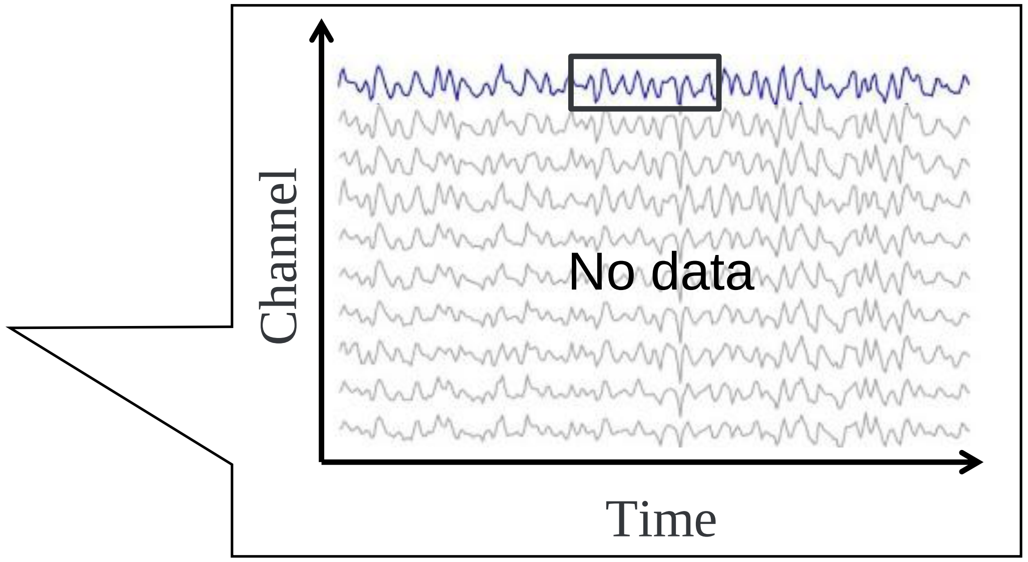
Single(/Few)-channel measurement devices

◆ Recently developed

- Portable
- Cheap
- Limited channel

  (Ultimately single)

MindWave [2]



→ **We can not use spatial filter for feature extraction**

◆ Only allow specialized feature extraction technique to emphasize rhythmic features

→ **Comparative study by using the same dataset is required**

[2] http://store.neurosky.com/, accessed 1-Nov.-2018.

Motivation

Investigating how to build the best single-channel motor imagery BCI

- Research objective

  To find the best combination of **channel**, **feature**, and **classifier**

- Materials

  EEG dataset: BCI competition IV dataset 2a [3]

- Analysis

  - Epoch segmentation
  - Artifact rejection
  - Feature extraction : 3 types (PS, SCCSP, GLCM)
  - Classifiers : 6 types (LDA, k-NN, GMM, RF, MLP, SVM)
  - Evaluation : 2-class classification with 10-fold CV

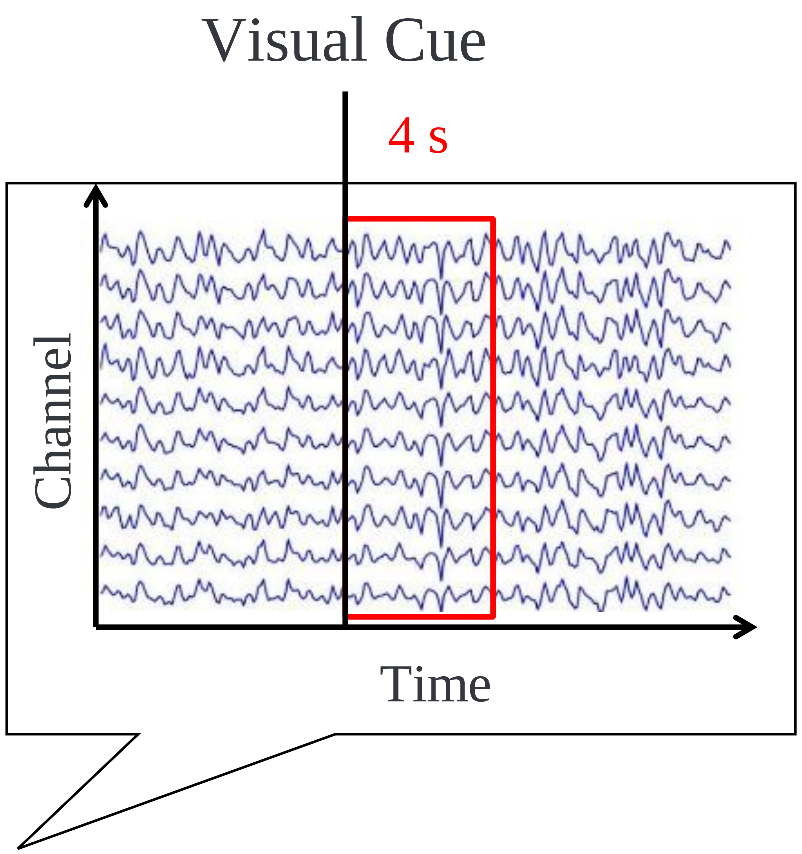
[3] M. Tangermann, et al., “Review of the BCI competition IV,” Frontiers in Neuroscience, vol. 6, 2012.

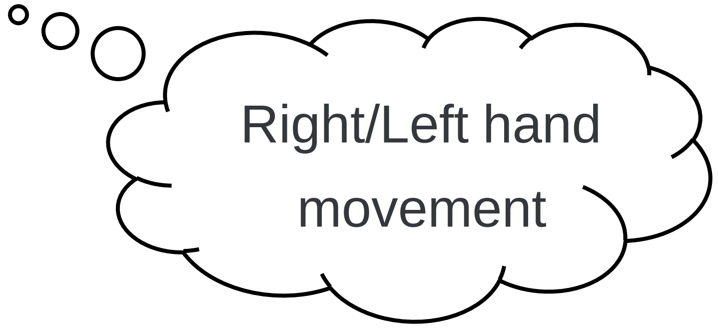
Materials (1/2)

◆ Open-access EEG dataset

BCI competition IV dataset 2a[3]

- # of channels: 22
- # of subjects: 9
- Task: Image a movement
- # of classes: 2 (left or right hand)
- Duration: 4 s
- # of trials: 288
- Sampling rate: 250 Hz
- Bandpass filter: 4 and 40 Hz (Fourth-order Butterworth filter)



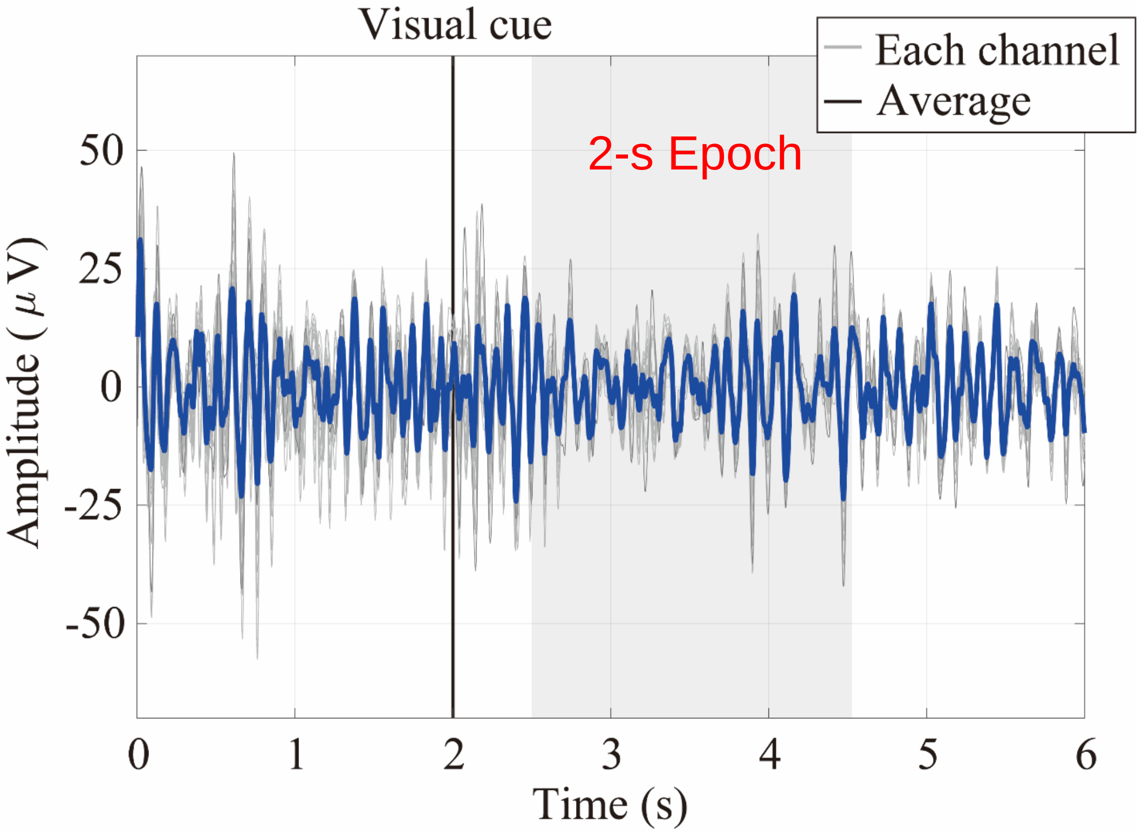


[3] M. Tangermann, et al., “Review of the BCI competition IV,” Frontiers in Neuroscience, vol. 6, 2012.

Materials (2/2)

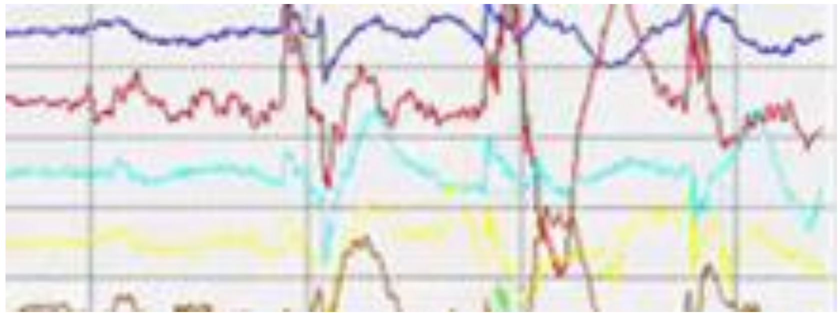
- **Epoch segmentation**
  - 0.5-2.5 s after the cue[4]

    → 288 2-s epochs



- **Artifact rejection**
  - Some epochs were contaminated artifacts (e.g. muscular and ocular)
  - The labels are given by the BCI competition (maybe visual inspection)

    → 221 to 279 epochs were used for classification



Artifactual epoch

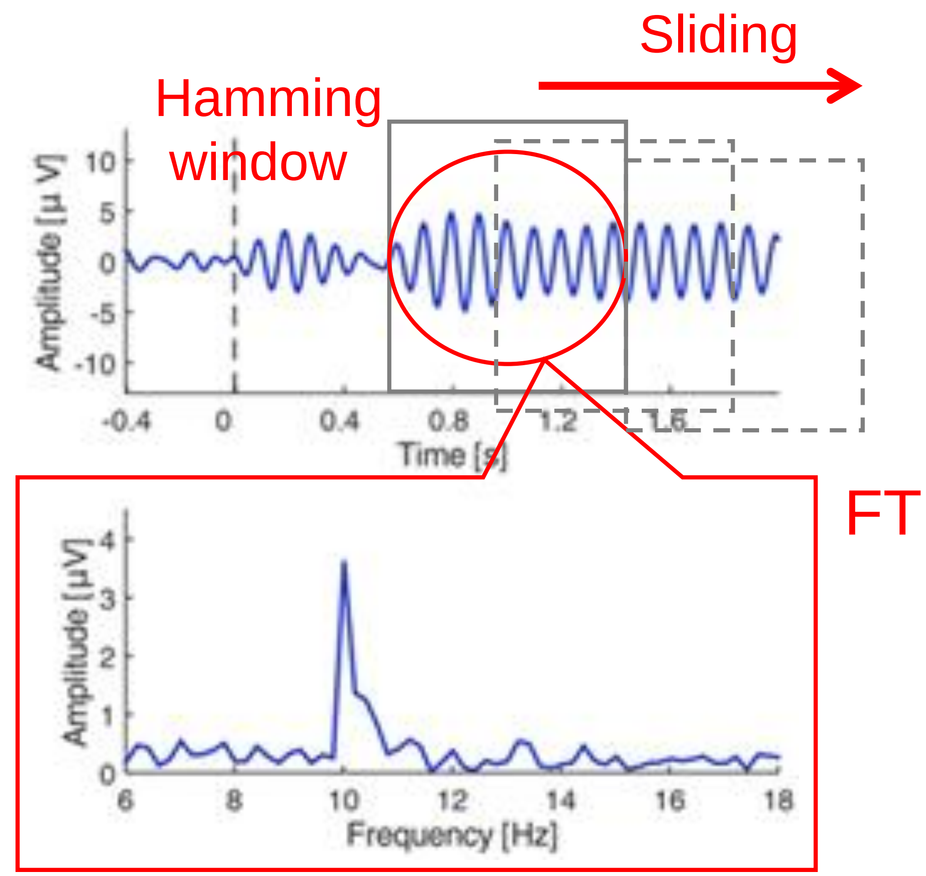
[4] K. K. Ang et al., "Filter bank common spatial pattern algorithm on BCI competition IV datasets 2a and 2b," *Front Neurosci.*, vol. 6, 2012.

Feature Extraction (1/2)

◆ Power spectra (PS)

Fourier transform

- 100 sample points (and 28 zeros)
- 50% overlap Hamming window
- Log-scaled variance ranged 4 - 40 Hz



◆ Single-channel common spatial pattern (SCCSP)[5]

Calculates filter $\boldsymbol{W}$ which maximize the variance of two-class frequency bins

- Similar to classical CSP (frequency bins as channels)
  → Common 'spectral' pattern…?
- Log-scaled variance

\# of frequency bins

$$\boldsymbol{X}_t \in \mathbb{R}^{d \times N}$$

$$\Sigma_t = \boldsymbol{X}_t \boldsymbol{X}_t^{\mathrm{T}} \in \mathbb{R}^{d \times d}$$

$$\boldsymbol{w}_c = \max_{\boldsymbol{w}} \boldsymbol{w}^t \Sigma^{(c)} \boldsymbol{w}$$

$$\text{s.t. } \boldsymbol{w}^t \left(\Sigma^{(c)} + \Sigma^{(c')}\right) \boldsymbol{w} = 1$$

[5] S. Ge et al., "Classification of four-class motor imagery employing single-channel electroencephalography," *PloS ONE*, vol. 9, no. 6, e98019, 2014.

Feature Extraction (2/2)

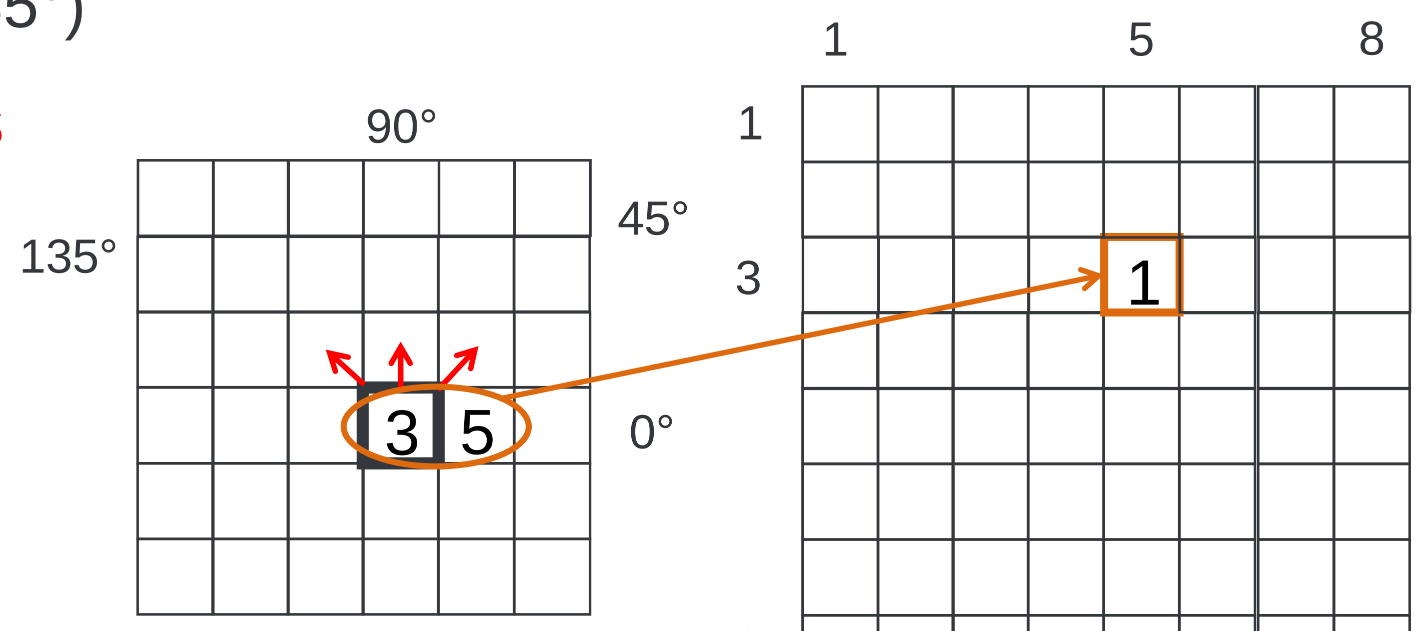
◆ Gray-level co-occurrence matrix (GLCM) [6]

- Concatenates PS to be a spectrogram
- Translates spectrogram into 8-level values
- Sums co-occurrence counts from the 8-level values

  4 directions (0, 45, 90, and 135°)

- Used for 4 text descriptors

  1. Contrast
  2. Correlation
  3. Energy
  4. Homogeneity



8-level valued PS

GLCM

→ To capture

co-occurrence power fluctuation (by event-related (de)synchronization)

[6] J. Camacho et al., "Real-time single channel EEG motor imagery based brain computer interface," *World Automation Congress* pp.*1-6,* 2016.

Classification

◆ Six classifiers:

1. Linear discriminant analysis (LDA)
2. k-nearest neighbor (k-NN)
3. Gaussian mixture model (GMM)
4. Random forest (RF)
5. Multi-layer perceptron (MLP)
6. Support vector machine (SVM)

◆ Assessments

- Independent validation for each subject and channel
- 10-fold cross validation (10 times to avoid selection bias)

The best combination of **channel**, **feature**, and **classifier**

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Results and Discussion (1/2)

◆ Classification accuracy

Subject	Feature	Classifier: LDA	k-NN	GMM	RF	MLP	SVM
⋮							
S3	**PS**	70.6±0.8 (C3)	67.9±0.8 (C3)	60.7±0.7 (C3)	69.2±0.8 (C3)	**71.4±0.7 (C3)**	70.8±0.7 (C3)
	SCCSP	67.0±0.7 (C3)	64.4±0.8 (C3)	62.1±0.9 (C6)	65.6±0.9 (C3)	71.1±0.8 (C3)	66.6±0.6 (C3)
	GLCM	64.4±0.7 (C4)	64.3±1.2 (C3)	60.5±0.5 (C3)	63.5±0.8 (C3)	64.0±0.7 (C3)	65.9±0.7 (CP4)
⋮							
S9	PS	85.0±0.5 (C3)	82.2±1.4 (C4)	80.6±0.8 (C4)	83.0±0.7 (C4)	85.4±0.7 (C4)	85.0±0.7 (C4)
	SCCSP	83.8±0.5 (C3)	84.2±0.5 (C4)	**86.6±0.6 (C4)**	85.0±0.6 (C4)	86.2±0.5 (C4)	**86.6±0.4 (C4)**
	GLCM	68.0±0.8 (CP3)	72.3±1.0 (CP4)	69.1±0.9 (CP4)	71.6±0.9 (C4)	71.7±0.9 (CP4)	73.7±0.8 (C4)
Mean	**PS**	61.8±0.5	62.3±0.4	60.0±0.4	61.8±0.4	63.1±0.4	**63.5±0.4**
	SCCSP	61.8±0.4	62.2±0.4	61.6±0.4	61.2±0.42	**63.5±0.4**	63.3±0.4
	GLCM	61.4±0.4	60.7±0.3	58.5±0.3	58.7±0.3	60.3±0.4	61.4±0.3

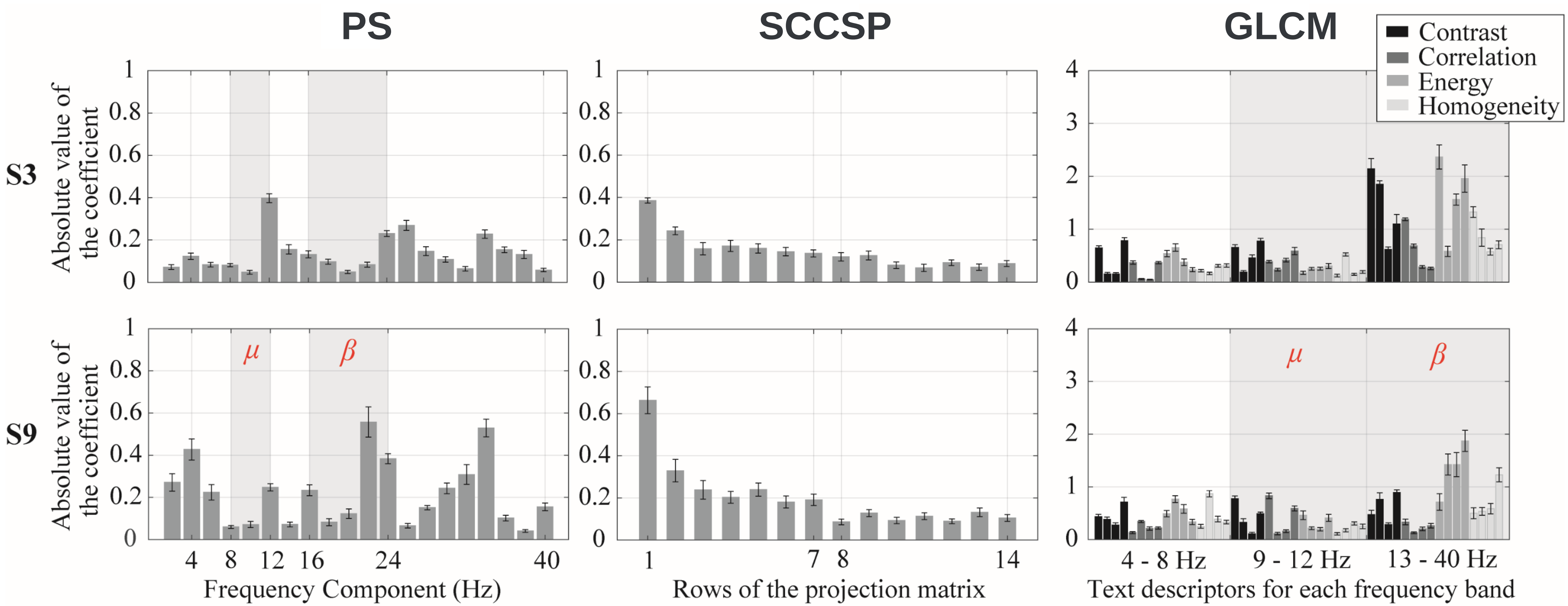
- **PS** and **SCCSP** showed superior performance than GLCM ($p<0.001$)
- **MLP** with SCCSP / **SVM** with PS effectively classified EEG data

→ Average: 63.5 ± 0.4%

Best : 86.6 ± 0.4% (**C3** or **C4** position)

Results and Discussion (2/2)

◆ Absolute values of the coefficients in LDA



μ and β rhythms would have large coefficients …?

→ The relationship between features and classifiers should be further investigated.

Conclusions

Investigating how to build the best single-channel motor imagery BCI

◆ Results

- PS and SCCSP showed superior performance than GLCM ($p<0.001$)
- MLP with SCCSP / SVM with PS effectively classified EEG data

Average: 63.5 ± 0.4%

Best : 86.6 ± 0.4% (C3 or C4 position)

◆ Limitation

Original dataset used multichannel environment

(Not used single(/few)-channel measurement device)

Appendices