A Novel Approach to Motor Imagery Classification via Mini Epoch Ensembling

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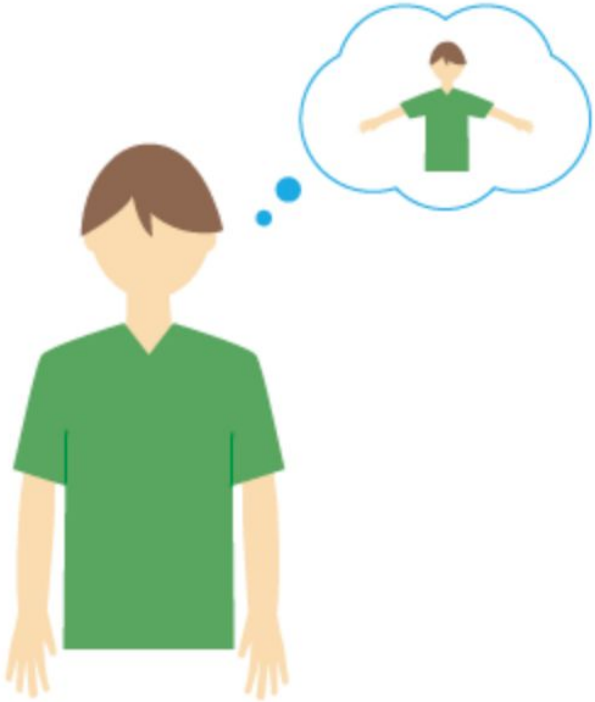
Motor Imagery

"A cognitive process in which a subject imagines [performing] a movement without actually performing [it] and without even tensing the muscles [1]."



Applications to Brain-Computer Interfaces (BCI)

Improvements in rehabilitation in post-stroke paresis patients [2]

- Incorporating neurofeedback through the electroencephalogram (EEG)-based BCI in motor imagery has been shown to improve functional recovery of limbs

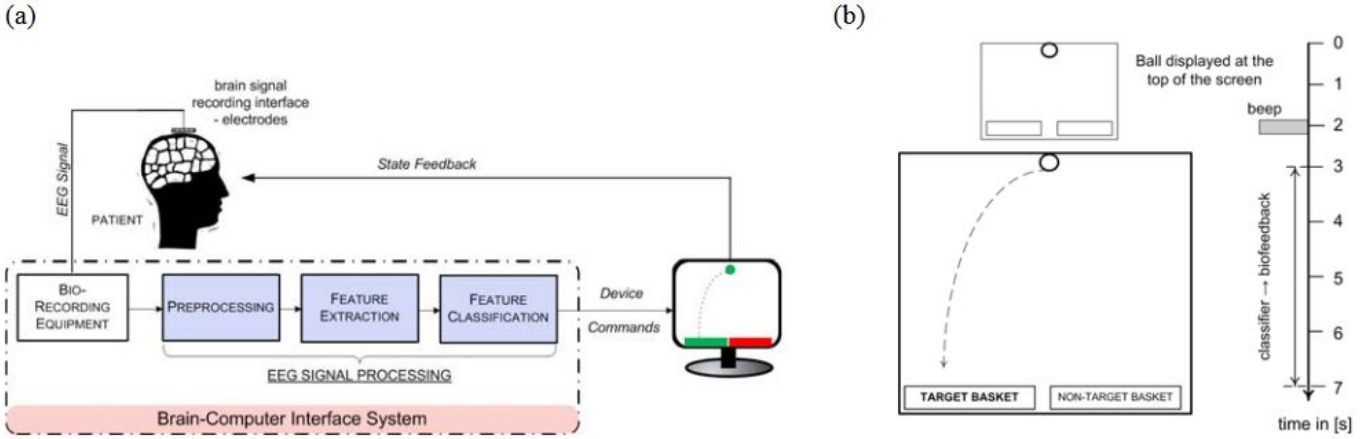


Figure 1 An illustration of a Brain-Computer Interface: **(a)** Main components of a BCI. **(b)** Timings of a ball-basket game paradigm.

Dataset: Berlin BCI Competition IV Dataset 2a [3]

Subjects underwent sessions in which subjects were cued to imagine the movement of various motor imagery tasks. Such motor imagery tasks include:

- Left hand
- Right hand
- Tongue
- Foot

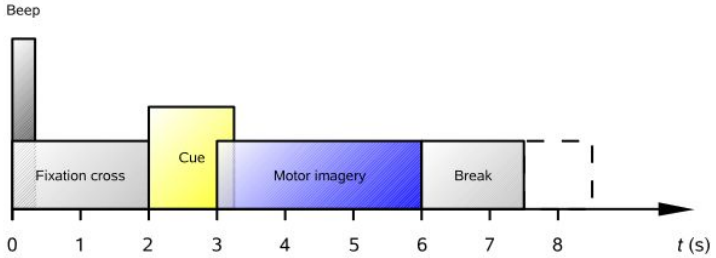


Figure 2: Timing scheme of the paradigm.

In total: 288 trials with 22 EEG channels + 3 (electrooculography) EOG channels

Methods: State-of-the-art [4]

A. Echtioui, W. Zouch, M. Ghorbel, C. Mhiri and H. Hamam, "Fusion Convolutional Neural Network for Multi-Class Motor Imagery of EEG Signals Classification," 2021 International Wireless Communications and Mobile Computing (IWCMC), Harbin City, China, 2021, pp. 1642-1647, doi: 10.1109/IWCMC51323.2021.9498885.

- A fusion of CNN layers and a LSTM layer for final classification
- Final accuracy of 61.68%

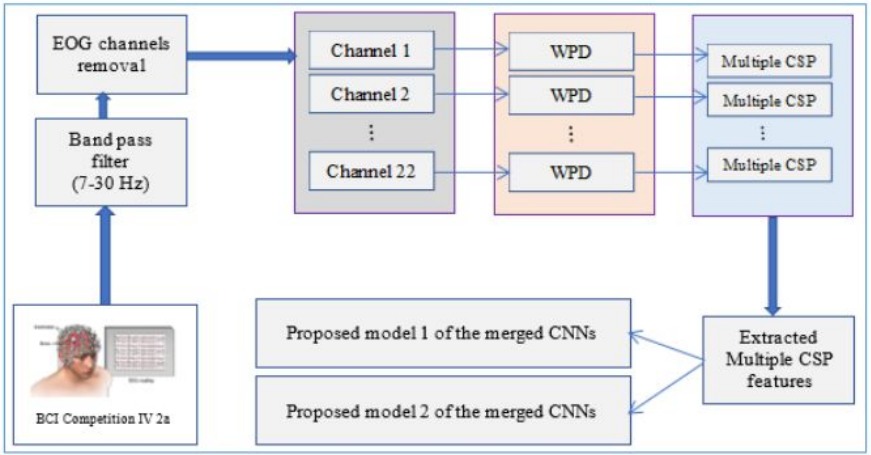


Fig. 2. Block diagram of our proposed methods.

Methods: Preprocessing

We copied A. Echtioui et. al's signal processing pipeline

1. Bandpass filter of 7-30 Hz
2. Remove all electrooculography (EOG) channels
3. Epoch time signal from 1-4 seconds
4. Wavelet Packet Decomposition
5. Common Spatial Patterns
   - Huge reduction of feature dimension

Methods: Key Related Work [5]

Luo J, Gao X, Zhu X, Wang B, Lu N, Wang J. "Motor imagery EEG classification based on ensemble support vector learning", Comput Methods Programs Biomed. 2020 Sep;193:105464. doi: 10.1016/j.cmpb.2020.105464. Epub 2020 Mar 27. PMID: 32283387.

- Same dataset
- Ensemble learning algorithm based on support vector machine classifier
- Final accuracy of 0.6 (kappa value)

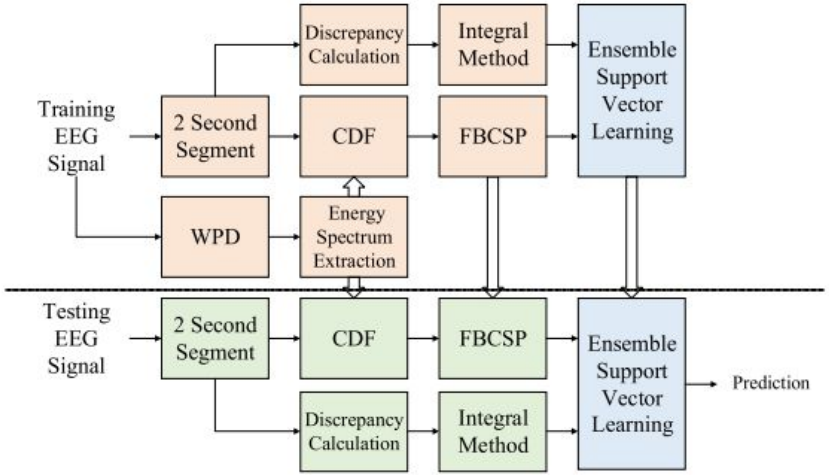


Fig. 1. Block diagram of the proposed ESVL method.

Methods: Mini-epoch Ensemble-based

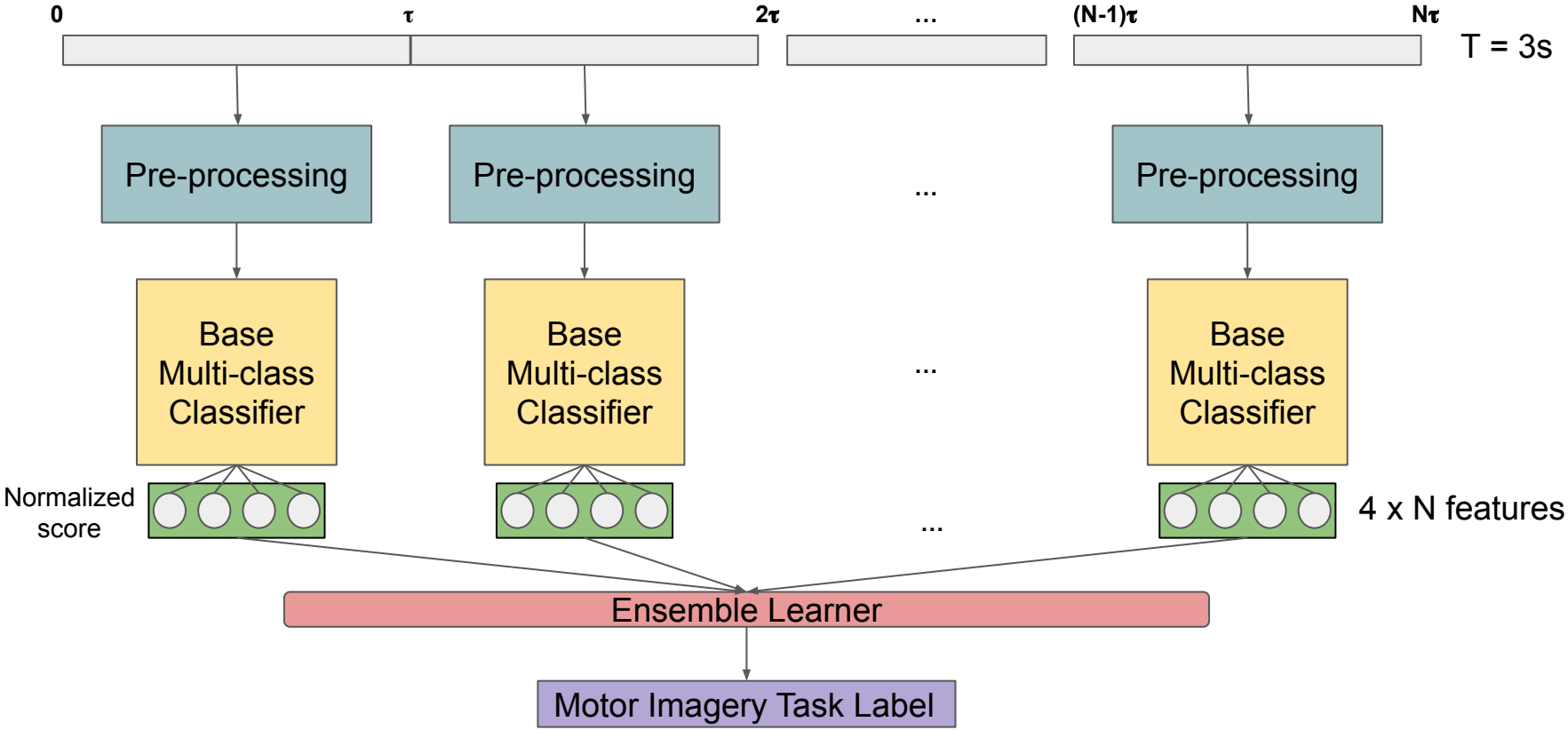
Problem:

- Loss of potentially time-variant information after signal processing
  - Motor imagery is rooted in neurobiology: not immediately apparent how signal processing might cover up time variance

Motivation:

- Individually consider small time intervals (mini-epochs)
- Make classifier “ensembles” for each mini-epoch

Methods: Mini-epoch Ensemble-based



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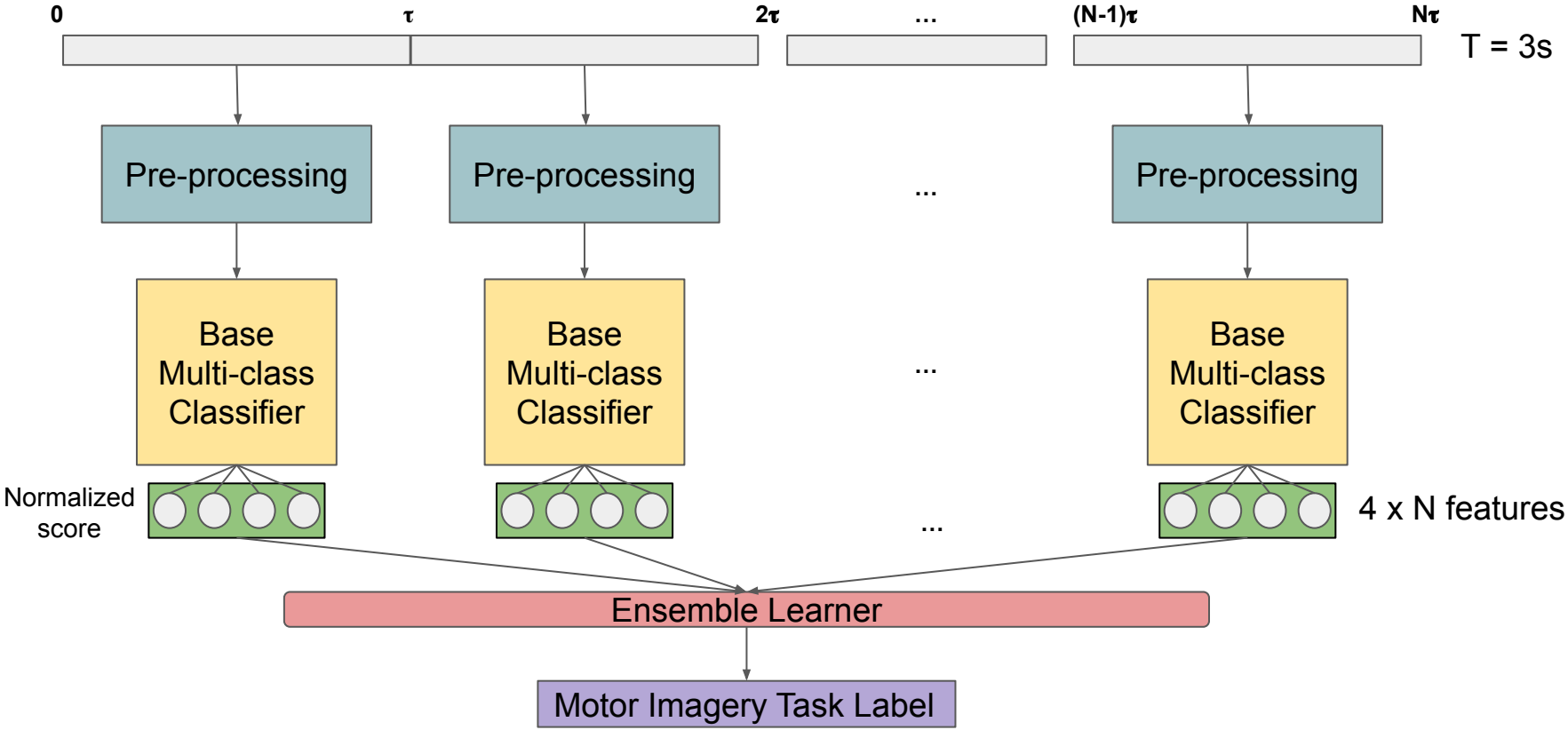

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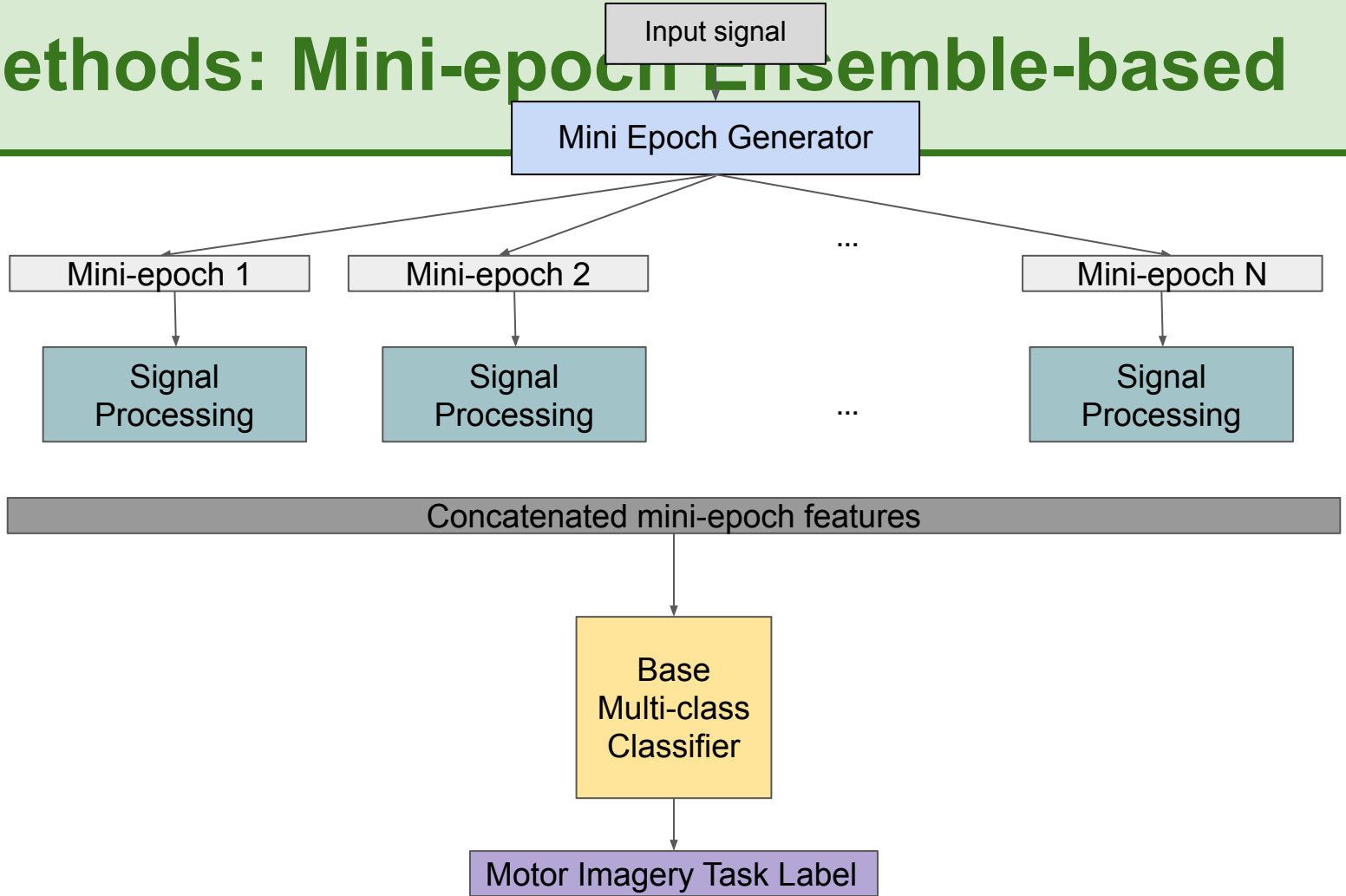
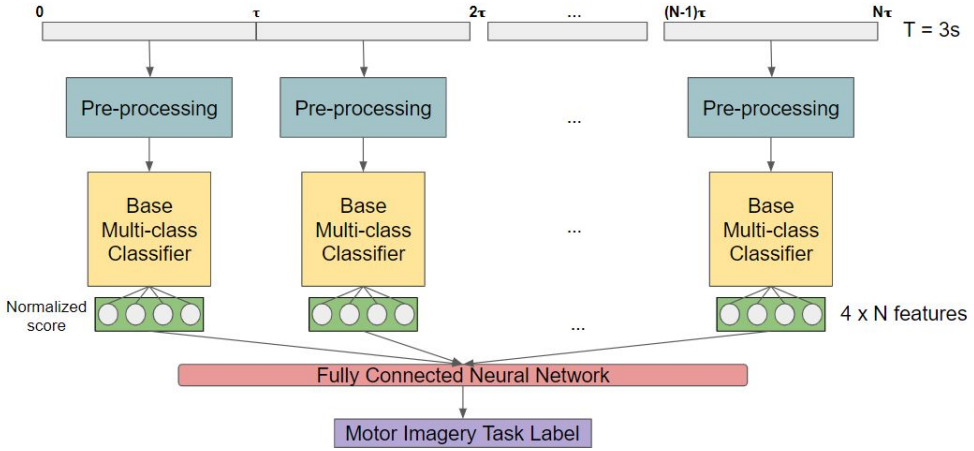


Methods: Mini-epoch Ensemble-based

- N mini-epochs
- Individual pre-processing and base multi-class classifiers
  - NN, XGboost ,etc.
- Class probability from the “ensemble”
- Emphasizes the mini epoch with more discernible labels

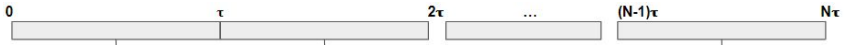


Hypothesis

Can our mini-epoch ensemble-based method beat state of the art?

High-level Functions:

- Mini epoch window



- Sliding mini epoch window

Metrics we want to evaluate on:

- Performance - How accurate is our model?

Tentative Results - Coding Pipeline

Pytorch implementation of mini epoch window ensemble based method.

- Each base multi-class learner is also a shallow multi-layer perceptron
- Allows end-to-end training of the whole network using gradient descent

Tentative Results - Training and Test Accuracy

Base learner	1 Layer		2 Layers		3 Layers		4 Layers	
L2 Reg	1e-3	1e-5	1e-3	1e-5	1e-3	1e-5	1e-3	1e-5
Train Accuracy	65.1%	69.9%	71.2%	98.1%	94.5%	100.0%	97.2%	100.0%
Test Accuracy	55.1%	51.3%	50.7%	48.2%	43.9%	44.5%	33.5%	42.8%

Future Plans

Mini Epoch ensemble method is not performing as well as state-of-the-art

Considerations for improvement:

- Parameter-tuning: optimize the number of weights at each layer
- Test Sliding Epoch Window Functionality
- MLP $\longrightarrow$ Convolutional neural network implementation from [4]
- Stratified cross-validation for accurate evaluations

References

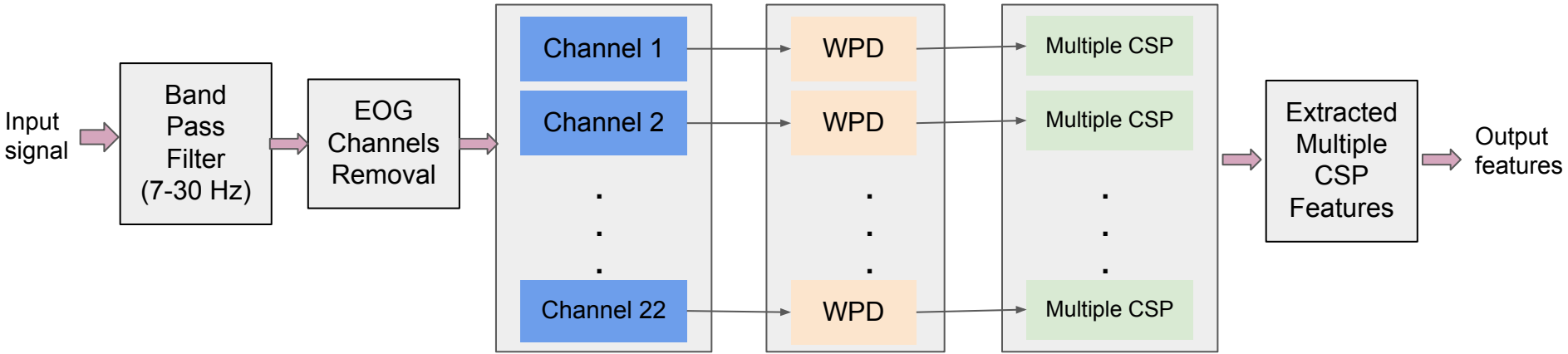
[1] Mulder T. Motor imagery and action observation: cognitive tools for rehabilitation. J Neural Transm (Vienna). 2007;114(10):1265-78. doi: 10.1007/s00702-007-0763-z. Epub 2007 Jun 20. PMID: 17579805; PMCID: PMC2797860.

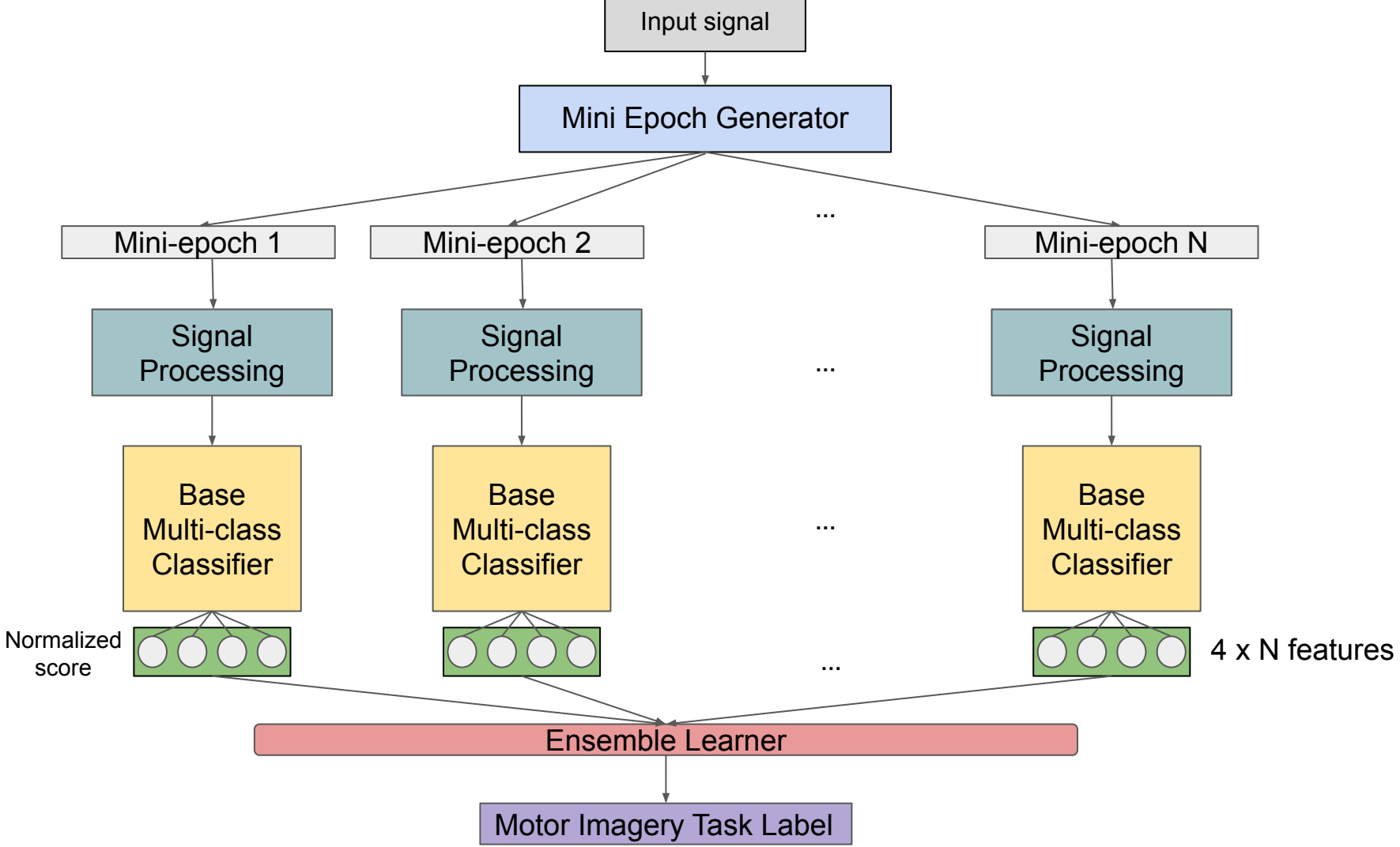
[2] Prasad G, Herman P, Coyle D, McDonough S, Crosbie J. Applying a brain-computer interface to support motor imagery practice in people with stroke for upper limb recovery: a feasibility study. J Neuroeng Rehabil. 2010 Dec 14;7:60. doi: 10.1186/1743-0003-7-60. PMID: 21156054; PMCID: PMC3017056.

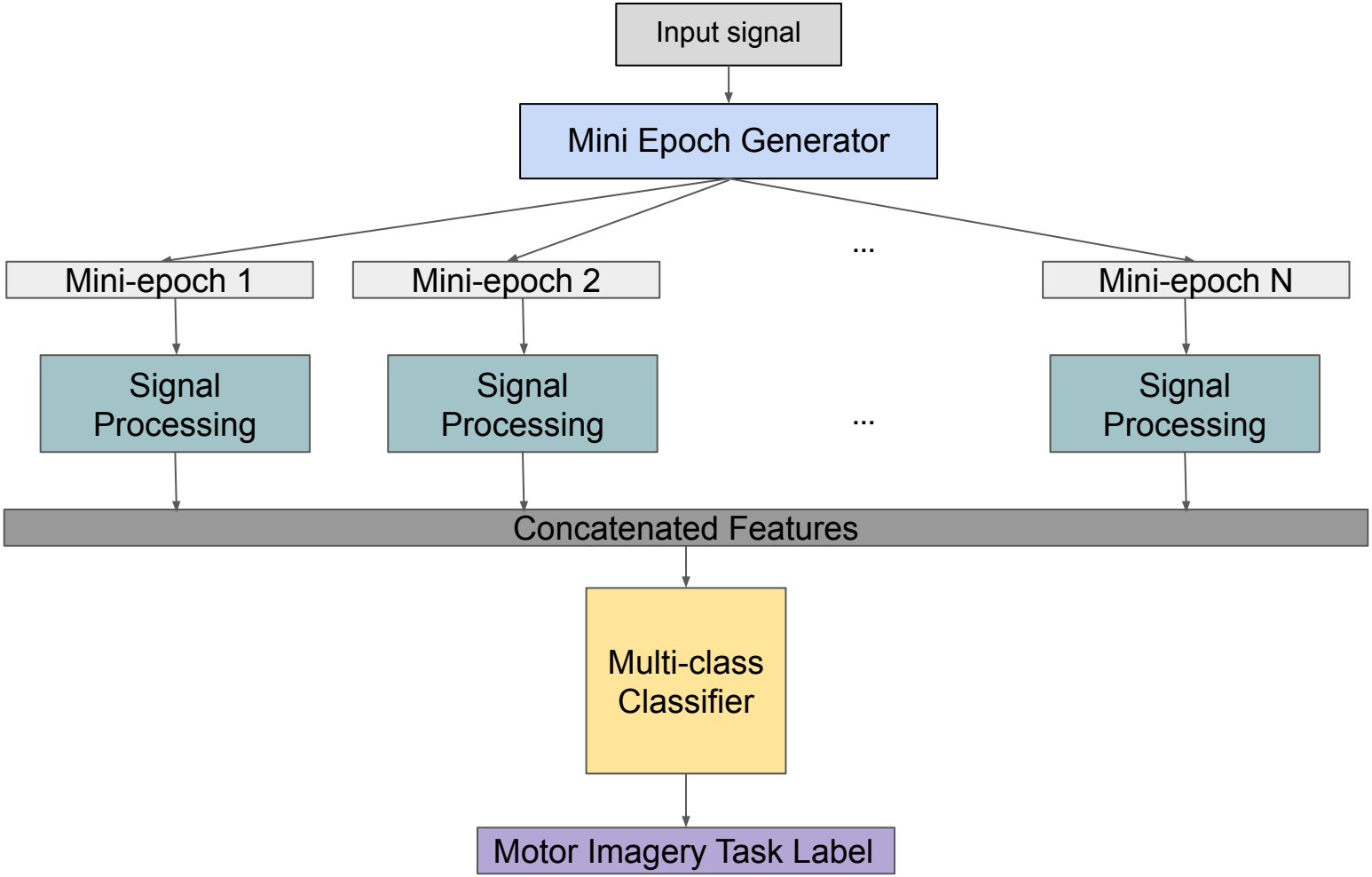
[3] Benjamin Blankertz, Guido Dornhege, Matthias Krauledat, Klaus-Robert Müller, and Gabriel Curio. The non-invasive Berlin Brain-Computer Interface: Fast acquisition of effective performance in untrained subjects. NeuroImage, 37(2):539-550, 2007.

[4] A. Echtioui, W. Zouch, M. Ghorbel, C. Mhiri and H. Hamam, "Fusion Convolutional Neural Network for Multi-Class Motor Imagery of EEG Signals Classification," 2021 International Wireless Communications and Mobile Computing (IWCMC), Harbin City, China, 2021, pp. 1642-1647, doi: 10.1109/IWCMC51323.2021.9498885.

[5] Luo J, Gao X, Zhu X, Wang B, Lu N, Wang J. “Motor imagery EEG classification based on ensemble support vector learning”, Comput Methods Programs Biomed. 2020 Sep;193:105464. doi: 10.1016/j.cmpb.2020.105464. Epub 2020 Mar 27. PMID: 32283387.


Input signal
Band Pass Filter (7-30 Hz)
EOG Channels Removal
Channel 1
Channel 2
Channel 22
WPD
WPD
WPD
Multiple CSP
Multiple CSP
Multiple CSP
Extracted Multiple CSP Features
Output features


Input signal
Mini Epoch Generator
Mini-epoch 1
Mini-epoch 2
...
Mini-epoch N
Signal Processing
Signal Processing
...
Signal Processing
Base Multi-class Classifier
Base Multi-class Classifier
...
Base Multi-class Classifier
Normalized score
...
4 x N features
Ensemble Learner
Motor Imagery Task Label


Input signal
Mini Epoch Generator
Mini-epoch 1
Mini-epoch 2
...
Mini-epoch N
Signal Processing
Signal Processing
...
Signal Processing
Concatenated Features
Multi-class Classifier
Motor Imagery Task Label