Classification of Ocular Signals using Electrooculography to Control External Devices

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Problem Statement

To control the cursor on a computer screen with the movement of eyeballs using Electrooculogram (EOG) headset.

Introduction

- Motive is to assist people with physical disabilities to control external devices.
- EOG recordings are simple and cheaper than most other techniques like image processing, and can be recorded with minimal discomfort.
- EOG readings are more accurate for classification than image processing techniques.

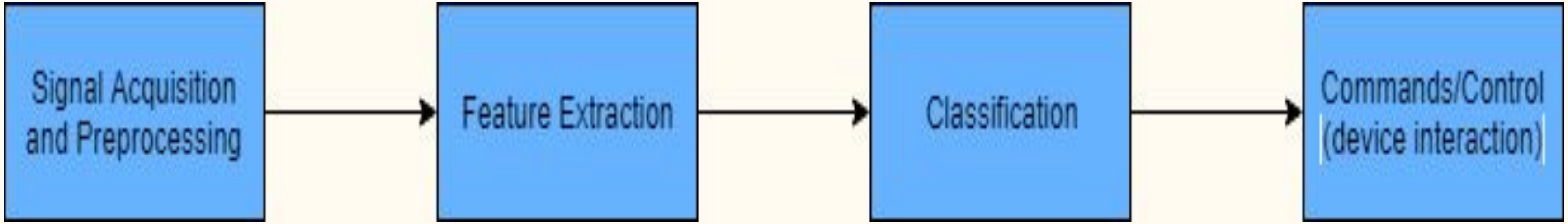
Literature Survey

- Deap - A Database for Emotion Analysis using Physiological Signals [1] .
- Participant-dependent and Participant-independent Classification of Emotions using EEG Signals [2].
- Brain-Computer Interface (BCI) Trajectory Prediction [3].
- Detecting eye movement direction from stimulated Electro-oculogram by intelligent algorithms [4].

Existing Work

- In the paper written by Soumya Sen et al. (2012)[5] explains how they moved the cursor in a particular direction (same as that in which the eye rotates) till an eye blink is encountered, using Emotiv Epoc Neuroheadset with 14 electrodes

Model Design



Hardware And Software

- OpenBCI Cyton Biosensing Board, a 8-channel neural interface, 32-bit processor to sample EOG signals.
- OpenBCI dongle to aid communication between Board and Computer.
- OpenBCI GUI as an interface for communication between the board, and visualization of signals being recorded.

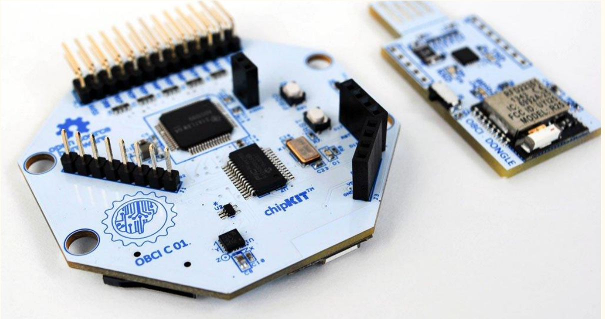
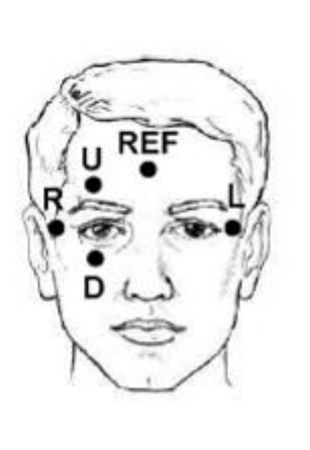


Fig 1: Cyton Board and Dongle
Source: [6]

Recording the data

- Ocular data was obtained from a single subject on three different days.
- Five Gold cup electrodes (wet electrodes) were placed at the 5 prominent positions near the eye, connected to Cyton Board.
- Four different patterns- Right, Down, Left, and Up, each with 3 different increasing speeds, each repeated for 3 times at 3 different positions were shown.
- The subject was asked to move eyes in the direction of the cursor following the patterns.



Source: [7]

Recording the data...

Fig 1: PyGame scenario

Fig 2: Respondent with electrodes

Recording the data...

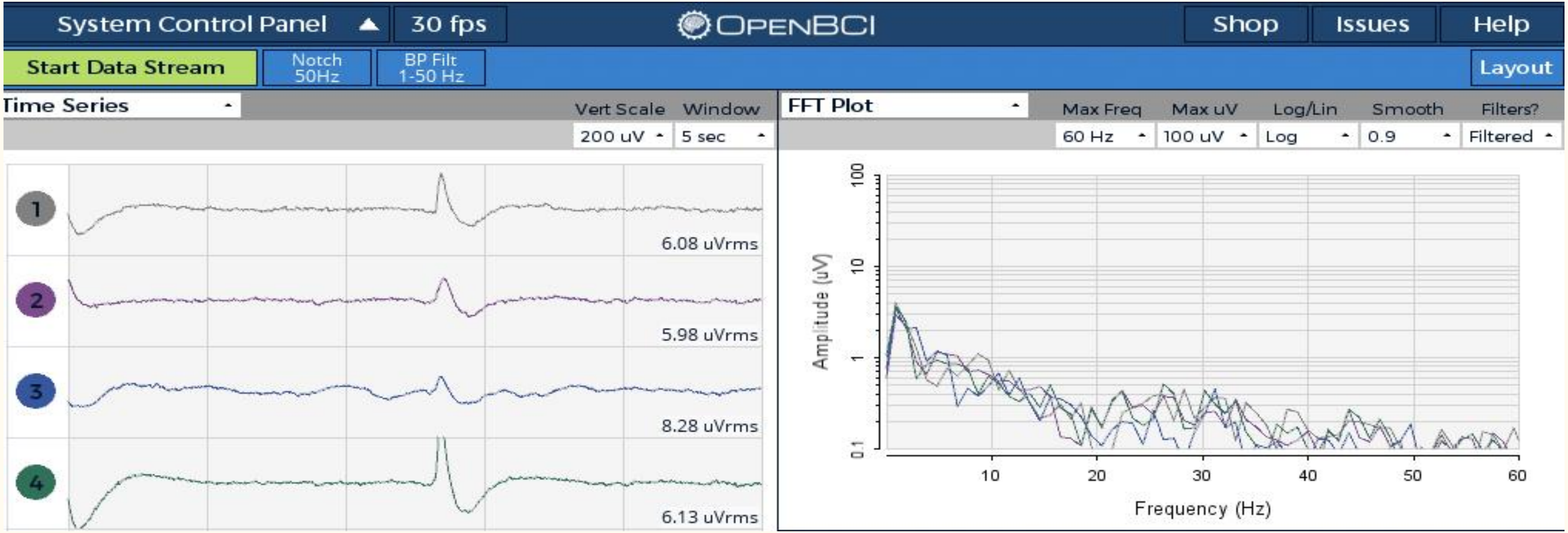


Fig 2: Time series plot in OpenBCI

Fig 3: FFT plot in OpenBCI

Recording the data...

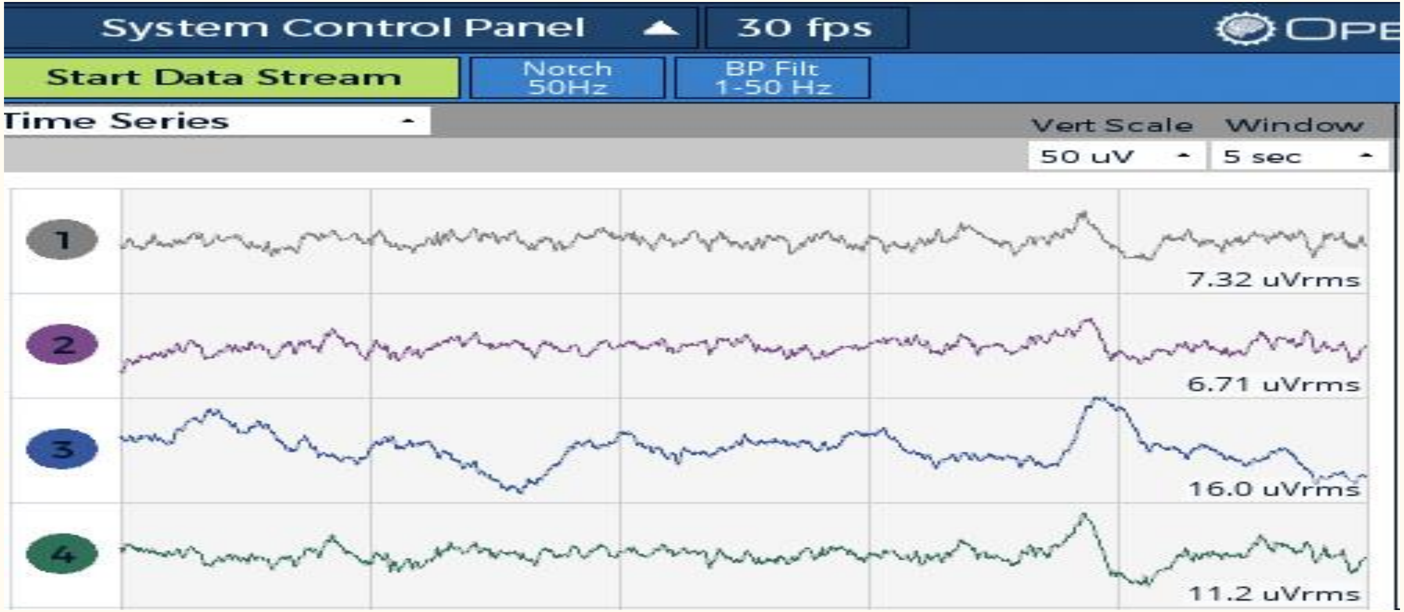


Fig 4: Time Series Plot with 4x zoom

Recording the data...

- The signals were obtained at 256 Hz sampling rate with a band pass filter (1-50Hz) and a 50 Hz notch filter.
- Each trail of a pattern and it’s speed were stored separately.
- So Dataset now contains
  1. 108 records - 27 each for 4 patterns.
  2. 324 records put in total for 3 days’ recordings.
  3. Each record contains 4 channels’ readings, separated as columns.
- All stored as text files.

Preprocessing

- The first 5 seconds of the every signal data was inconsistent, so it was removed.
- Since the eye movements are concentrated in the frequency range of 0.5-30 Hz, a butterworth filter of 5th order was used.
- The Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the passband.
- Higher the order, higher is the flat band (less ripple) , but is also more compute intensive.

Preprocessing...

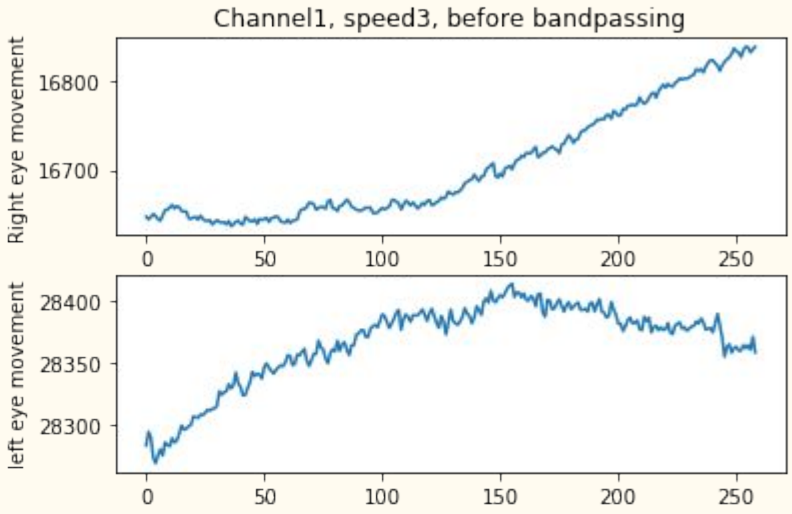


Fig 5: Without linear detrending
(Voltage in microvolts (y) vs sample (x)

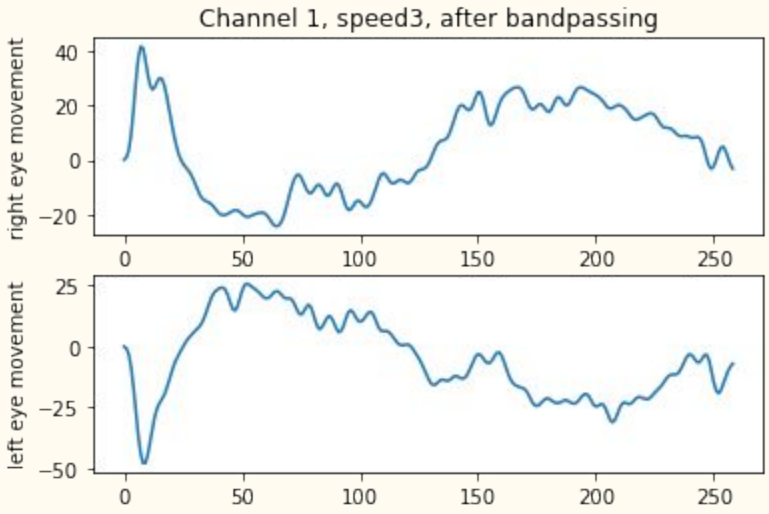


Fig 6: With linear detrending
Voltage in microvolts (y) vs sample (x)

Feature Extraction

- Features that are specific only to a particular class need to be extracted in order to differentiate between various classes of eye movements.
- Various feature extraction methods were tried, and evaluated in terms of the classification accuracies.
- The feature extraction methods tried out are-
  1. Discrete Wavelet Transform (DWT)
  2. Hjorth Parameters
  3. Power Spectral Density (PSD) using Welch method

Feature Extraction - Hjorth Parameters

- Hjorth Parameters are indicators of statistical properties in the time domain.
- Two parameters, Mobility and complexity of the signal were the 2 features Extracted for each channel
- The Mobility parameter represents the mean frequency
- The Complexity parameter represents the change in frequency
- So a total of 8 features from 4 channels were extracted for each trial

Mobility	$\sqrt{\dfrac{\mathrm{var}(y'(t))}{\mathrm{var}(y(t))}}$
Complexity	$\dfrac{\mathrm{mobility}(y'(t))}{\mathrm{mobility}(y(t))}$

var-> variance, y(t)-> signal

Feature Extraction - PSD using Welch

- Features extracted using PSD are statistical features obtained using Welch method
- Welch method is used for estimating the power of a signal at different frequencies. The method consists of dividing the time series data into (possibly overlapping) segments, computing a modified periodogram of each segment, and then averaging the PSD estimates
- The statistical features which were extracted includes Mean, Variance and Maximum frequency of the PSD coefficients
- So a total of 12 features were extracted from 4 channels for trial

Feature Extraction- DWT

- The fundamental idea of wavelet transforms is that the transformation should allow only changes in time extension, but not shape.
- A discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled.
- Daubechies (db) mother wavelet of order 4 was used to obtain the detail coefficients from level 5.
- Mean, variance and power was calculated from these coefficients.
- So, a total of 12 features were extracted from 4 channels for each trial.

Feature Extraction - DWT

$$PW_i = \frac{1}{K}\sum_{m=1}^{K}(p_i(m)^2)$$

Power

$$Std_i = \sqrt{\frac{\sum_m (p_i(m) - \mu)}{m-1}}$$

Standard Deviation

$$\mu = \frac{1}{K}\sum_{m=1}^{K} p_i(m)$$

Mean

Classification

- Classification is the step to distinguish the different directions of the eyeball movement from the EOG signal.
- Features extracted from each feature extraction method against their label was fed to different classifiers.
- Overall, K-Nearest Neighbors (KNN) , Support Vector Classifier (SVC), Random Forest Classifier, and Multilayer Perceptron (MLP) gave good results.
- The features obtained were split into training and testing data using Stratified K-Fold with 5 fold.

Classification...

- Each individual feature was centred to mean and scaled to unit variance across samples.
- KNN with k-neighbors=4 was chosen.
- SVC with penalty parameter of the error term C=1 and kernel='rbf' was chosen.
- MLP with one hidden layer containing 100 neurons, activation='relu', alpha=0.0001, and maximum iterations=200 was chosen.
- Random Forest with number of trees=10 was chosen.

Results

Classifier	Welch (statistical features)	Hjorth	DWT (statistical features)	Welch
KNN	95.07	79.74	91.6	88.36
SVC	83.92	78.20	87	83
MLP	86.86	85.10	91.42	91.69
Random Forest	95.03	90.01	91.3	91.23

Conclusion and Future Work

- KNN classifier for Welch PSD Features gave the best results.
- The same combination will be used for real time data acquisition, and cursor control.
- Scope for future work :

  1. Make the cursor movement dynamic.
  2. Control other external devices like wheelchair, toy car etc.
  3. Generalize the model across all participants; make the model person independent.
  4. Build a sophisticated wearable headset.

References

[1]. S. Koelstra et al., "DEAP: A Database for Emotion Analysis ;Using Physiological Signals," in IEEE Transactions on Affective Computing, vol. 3, no. 1, pp. 18-31, Jan.-March 2012

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[3]. Brain-Computer Interface (BCI) Trajectory Prediction

[4]. A. Banerjee, A. Konar, D. N. Tibarewala and R. Janarthanan, "Detecting eye movement direction from stimulated Electro-oculogram by intelligent algorithms," Computing Communication & Networking Technologies (ICCCNT), 2012 Third International Conference on, Coimbatore, 2012, pp. 1-6

[5]. S. Sen Gupta, S. Soman, P. Govind Raj, R. Prakash, S. Sailaja and R. Borgohain, "Detecting eye movements in EEG for controlling devices," 2012 IEEE International Conference on Computational Intelligence and Cybernetics (CyberneticsCom), Bali, 2012, pp. 69-73.

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[6]. Cyton Biosensing Board (8-channels)

[7]. A. López, F. J. Ferrero, M. Valledor, J. C. Campo and O. Postolache, "A study on electrode placement in EOG systems for medical applications," 2016 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Benevento, 2016, pp. 1-5.

Thank You