Motor-Imagery EEG Signals Classification using SVM, MLP and LDA Classifiers

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Abstract: Electroencephalogram (EEG) signals based brain-computer interfacing (BCI) is the current technology trends in the field of rehabilitation robotic. This study compared the performance of support vector machine (SVM), linear discriminant analysis (LDA) and multi-layer perceptron (MLP) classifier with the combination of eight different features as a feature vector. EEG data were acquired from 20 healthy human subjects with predefined protocols. After the EEG signals acquisition, it was pre-processed followed by feature extraction and classification by using SVM MLP and LDA classifiers. The results exhibited that the SVM method was the best approach with 98.8% classification accuracy followed by MLP classifier. Finally, the SVM classifier and Arduino Mega controller was employed for offline controlling of the gripper of the robotic arm prototype. The finding of this study may be useful for online controlling as well as multi-degree of freedom with multi-class EEG dataset.

Keywords: Motor-Imagery, EEG signal, SVM, MLP, LDA, PCA.

1. Introduction

Neural activities of the brain are shown in the form of EEG signals which are captured with the help of multiple-electrode EEG machines either over the cortex under the skull (inside the brain) or over the scalp[1]. The representation of EEG signal is done in the time domain whereas, few EEG measuring devices are available which can perform some signal processing steps to obtain frequency analysis along with imaging tools to visualize EEG topographies [2], [3].

Generally, EEG signals are considered as the projection of neural activities that usually gets attenuated by dura mater, leptomeninges, scalp, cerebrospinal fluid, and the galea[4]. It is difficult to understand and locate the rhythms of the brain [5]. So, the advanced technology and processing tools[6] must have the ability to isolate the desired waveforms from the EEG signals and then analyze it[7]. EEG system comprises delicate electrodes, filters, needle-type registers and set of the differential amplifier[8]. The EEG signals can be graphically represented on the paper. It was observed that the signal must be in digital form for analysis and it requires the sampling, quantization, and encoding of the signal [9], [10]. The computerized system permits simulations, variable settings, sampling frequency, and some advanced processing equipment [11], [12], [6].

So, the EEG signals are converted from analogue into the digital form by using analogue-to-digital converters (ADC)[13], [14]. EEG signal has a bandwidth of approximately 100 Hz. Hence, the minimum sampling frequency of 200 samples/sec is required for sampling the EEG signals[15]. EEG signals undergo the process of quantization to preserve diagnostic information[16]. Each signal sample is represented by up to 16 bits for accurate recording[17]. This provides the required memory volume for epileptic seizure monitoring records and storing the signals massively[18]. Generally, the memory size for storing the EEG signal is much smaller than that used for storing the radiological images [19][20], [21].

This work computes the performance of the total eight features to classify the EEG signals for discriminating left hand and right-hand movements by using SVM, MLP, and LDA classifiers. The whole work is divided into four parts, the first one is the introduction part, and Second part presents the materials and methods while the third part describes the results and discussion. Finally, the conclusion of work is presented in section 4.

2. MATERIALS AND METHODS

1.1. EEG data acquisition

EEG data were acquired from 20 healthy subjects at Bio-Medical Laboratory of NITTTR Chandigarh, India[22], [23]. After the raw EEG signal acquisition, EEG data was passed through a 4th order band-pass Butterworth filter (8Hz to the 30Hz range) for noise elimination[24]. Further, a notch filter of cut off frequency 50 Hz was employed for power line interference. Ocular artifacts were rejected by spatial filtering based on ICA algorithm[25]. After these steps, suitable features are extracted with the help of the CSP method followed by dimension reduction by PCA[26]. Finally, the classification is done and accuracy is used for performance comparison [27]. Fig. 1 shows the complete experimental setup for EEG data recording from a healthy human subject.
2.2 EEG feature extraction

Total eight features were extracted namely as AAR parameter, Barlow parameter, Hjorth parameter, Temporal and Spatial Complexity (TSC), Running Fractal Dimension (RFD), minimum energy, band power, and variance. Variance is calculated with the window length 500 millisecond (ms) with 492 ms overlapping and the band power is calculated for alpha and beta region whereas signal to noise ratio is computed by using minimum energy approach. EEG data sequence complexity is measured by TSC. Higuchi’s algorithm is used for RFD calculation [28]. Hjorth parameter, Barlow parameter, AAR parameter are calculated [29]. Fig. 2 shows the four channels EEG signals recorded in temporal form from a healthy human subject. Table 1 shows the features utilized for EEG signal classification for discriminating the left and right-hand movements to control the robotic arm prototype.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>features</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Activity (A²)</td>
<td>$A^2 = \frac{1}{T} \int_{t_1}^{t_2} x(t)^2 dt$</td>
</tr>
</tbody>
</table>
| 2      | Mobility            | $D^2 = \frac{1}{T} \int_{t_1}^{t_2} \left( \frac{dx(t)}{dt} \right)^2 dt$  
$\text{Mobility} = \frac{D^2}{\text{Activity}}$ |
Complexity

\[
\text{Complexity} = \frac{1}{T} \int_{t=1}^{T} \left( \frac{d^2 x(t)}{dt} \right)^2 dt
\]

Mean Amplitude (MA)

\[
MA = \frac{1}{T} \int_{t=1}^{T} |x(t)| dt
\]

Mean Frequency (MF)

\[
MF = \frac{E \left[ \frac{d x(t)}{dt} \right]^2}{E \left[ x(t) \right]^2}
\]

Spectral Purity Index (SPI)

\[
SPI = \frac{E \left[ \frac{d^2 x(t)}{dt^2} \right]^2}{E \left[ \frac{d x(t)}{dt} \right]^2 E \left[ x(t) \right]}
\]

6th orders AAR parameter

\[
x_k - a_{1,k} x_{k-1} - \cdots - a_{p,k} x_{k-p} = \epsilon_k
\]

Variance

\[
\text{Variance} = \sum_{i=1}^{N} \frac{(x_i - \bar{x})^2}{N - 1}
\]

2.3 Classifiers

After extracting the features, a feature vector was formed to classify the EEG data whose dimension was reduced by PCA approach. In this study, SVM, MLP and LDA classifiers were compared to each other[30], [31], [32]. Threefold cross-validation technique was applied for achieving the classification accuracy[33]. In threefold cross-validation technique, the whole dataset was divided into three equal parts in which two parts were used for training the classifier whereas one part of data was utilized for testing purpose and no part of data was used for validation the classifiers[34], [35]. Fig. 3 shows the block diagram representation of the complete workflow.

![Fig 3. Complete block diagram of EEG signal classification model](image)

3. RESULTS

In this study, the performance of the total of three classifiers namely SVM, MLP and LDA were compared with a total of eight features. Threefold cross-validation method was employed for computing the classification accuracy of all classifiers. Accuracy for 768 number of sample was taken to decide the final results for comparison purpose. Finally, the best classifier was chosen for controlling the two movements of the robotic arm (gripper open and close operations). Fig 4 shows the complete structure of MI-based movement controlling of robotic arm prototype.

![Fig 4 Controlling of Assistive Devices Using MI-based EEG Signals](image)
The classification accuracy of the LDA method was presented in Table 2 in which the error for class1 and class2 was 0% and 9.4% thereby indicating the good discrimination capability of approach. Initially when the number of samples for classification was 128 then the total error was 50% thereby indicating 50% classification accuracy. Finally, it achieved a 91.6% overall accuracy.

<table>
<thead>
<tr>
<th>No of Sample</th>
<th>Error class1 (%)</th>
<th>Error class2 (%)</th>
<th>Total error (%)</th>
<th>Overall Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>0.0</td>
<td>50.0</td>
<td>50</td>
<td>50.0</td>
</tr>
<tr>
<td>256</td>
<td>22.5</td>
<td>21.9</td>
<td>44.4</td>
<td>55.6</td>
</tr>
<tr>
<td>384</td>
<td>20.0</td>
<td>16.9</td>
<td>36.9</td>
<td>63.1</td>
</tr>
<tr>
<td>512</td>
<td>21.3</td>
<td>20.6</td>
<td>41.9</td>
<td>59.1</td>
</tr>
<tr>
<td>640</td>
<td>13.8</td>
<td>14.4</td>
<td>28.1</td>
<td>71.9</td>
</tr>
<tr>
<td>768</td>
<td>0.0</td>
<td>9.4</td>
<td>9.4</td>
<td>91.6</td>
</tr>
</tbody>
</table>

Table 2. Performance of LDA classifier for EEG signals classification.

The classification results of the SVM classifier was presented in Table 3. The table shows the 98.8% classification accuracy. When EEG data samples were 128, accuracy was 50%. But when the number of samples increased gradually then it achieved the higher classification accuracy and at last 98.8% accuracy was achieved by SVM classifier. The performance of SVM classifier was found best as compared to other classifiers used in this work.

<table>
<thead>
<tr>
<th>No of Sample</th>
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<th>Error class2 (%)</th>
<th>Total error (%)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>0.0</td>
<td>50.0</td>
<td>50</td>
<td>50.0</td>
</tr>
<tr>
<td>256</td>
<td>1.5</td>
<td>46.9</td>
<td>48.4</td>
<td>51.6</td>
</tr>
<tr>
<td>384</td>
<td>0.0</td>
<td>50.0</td>
<td>50</td>
<td>50.0</td>
</tr>
<tr>
<td>512</td>
<td>0.0</td>
<td>50.0</td>
<td>50</td>
<td>50.0</td>
</tr>
<tr>
<td>640</td>
<td>0.0</td>
<td>28.1</td>
<td>28.1</td>
<td>71.9</td>
</tr>
<tr>
<td>768</td>
<td>0.0</td>
<td>1.2</td>
<td>1.2</td>
<td>98.8</td>
</tr>
</tbody>
</table>

Table 3. Performance of SVM classifier for EEG signals classification.

The classification performance of the MLP method was shown in Table 4. If the number of EEG data samples were 128 then accuracy was 50%. With 640 number of samples, accuracy increased up to 75% and finally, with 768 number of samples MLP classifier achieved 95% classification accuracy. MLP classifier was found second-best classifier with the eight feature combination in the form of feature vector whereas LDA was found the least performer. It is clear from the above discussion that SVM classifier was best with the given feature vector and utilized for controlling the robotic arm prototype.

<table>
<thead>
<tr>
<th>No of Sample</th>
<th>Total error (%)</th>
<th>Overall Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>256</td>
<td>56.9</td>
<td>43.1</td>
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<tr>
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<td>512</td>
<td>41.3</td>
<td>59.7</td>
</tr>
<tr>
<td>640</td>
<td>25.0</td>
<td>75.0</td>
</tr>
<tr>
<td>768</td>
<td>5.0</td>
<td>95.0</td>
</tr>
</tbody>
</table>

Table 4. Performance of MLP classifier for EEG signals classification.

4. CONCLUSION

This work compared the performance of three classifiers namely SVM MLP and LDA with eight different features combination in the form of the feature vector. In this context, 20 healthy human EEG dataset was acquired and pre-processed before the features extraction process. Finally, all feature were combined in the form
of a feature vector and applied to all classifiers for comparison purpose. The results showed that SVM classifier was found best among all classifier with the given feature vector. Therefore SVM classifier was utilized for actuating the robotic arm prototype. Results also showed the successful controlling for gripper open and close operation with SVM classifier and Arduino Mega controller. In near future, the multimodal data-based technique can be used for simultaneous recognition of hand, leg and finger movement with modular control facilities in which EEG signals will be fused with EMG and EOG signals depending upon the user’s requirement for developing the assistive technology.

References


