Emotional State Classification in Machine Learning for EEG Signals

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***Abstract*-- Emotional health is very important to build our life. Emotional health is equally as important as our physical health. Dealing with our emotions is a difficult task because we can't see them. To analysis emotional state is also the interested field of the researcher. We can test the brain wave to analysis the emotion using electro-encephalography (EEG) signals. There are many kinds of emotions. We propose to classify the human brain wave for happy, disgust, surprise, anger, sad and fear. To classify six types of human emotion needs data annotation, feature extraction, feature selection and classification methods by analyzing electroencephalography (EEG) signals. We propose time frequency domain analysis to EEG signals and the result is filtered by finite impulse response (FIR). The pure signal is label with logistic regression machine learning algorithm to classify the feature of the signals. We propose the good method for FIR and combine with logistic regression to show the high accuracy of the signal classification.**

Keywords — electro-encephalography (EEG), data annotation, feature extraction, feature selection, time frequency domain analysis, finite impulse response, Logistic regression, machine learning.

I. Introduction

Emotion is a strong feeling deriving from outside of our body which one's circumstances, mood, or relationships with others [2]. Human Emotions are effected to response the significant internal and external events. Most of the actions are influences by the emotion of our feeling. Emotions are happened in our daily lives and play a main role in how we feel inside our body and how we behave individually and socially to the environment. There are many psychologists try to identify the different types of emotions. Basically, emotions can be identified happiness, sadness, disgust, fear, surprise, and anger [2].

Human's emotion is come out from the brain and deep affect to the soul because of the high thinking of the brain and feeling of the soul. All emotions are come out from the brain's limbic system. That is placed near brain stem and about the size of a walnut [6]. The limbic system controls emotion and other brain functions related to our instincts and memories.

There are so many kinds of methods to take the signals from the brain. To understand some of the processes of the brain like working memory, translating languages and sensory perception emotion to the dynamics in the brain can compute by studying the electricity of the brain electromagnetic waves. We can measure that waves using EEG electroencephalography that directly connect with scalp on the head. EEG measures ionic current voltage which are come out from within the neurons of the brain [5]. EEG records the electrical activity of the brain's spontaneous over a definite of time and then record the wave signals of multiple electrodes placed on the scalp.

There are four steps to classify emotions state from the EEG signals: data annotation, feature extraction, feature selection, and classification. Data annotation can be labeled the type of emotions and the state of calm. Feature Extraction which includes principle components analysis. It has *n* dimensional features $x1$, $x2$, xn to map it to a lower dimensional space which is m dimensional and to get the features $z1$, $z2$, zm. This is the new features where *m* is less than *n*. Taking the original features and mapping it to a lower dimensional space and each feature is obtained as a function of the feature set. It is a projection of a higher dimensional features space to a lower dimensional feature space. The smaller dimensional feature set can help to be better classification or faster classification. The Database for Emotion Analysis using Physiological Signals (DEAP) is used to show the performance of the proposed method. In this paper, time-frequency domain analysis technique is used for signal processing to process the signals. The result wavelet is filtered by using finite impulse response (FIR) to filter the accurate part of the signals. The result data is labeled to classified with logistic regression algorithm of the supervise machine learning approach. The accuracy of the propose method is higher comparing with the training data of predefine dataset.

II. Related Work

One of the research papers propose the system of emotion recognition from EEG signals to classify human emotions using two discrete wavelet transform (DWT) based feature extraction. At that propose system used the three types of statistical features: Root Mean Square (RMS), energy and Recording Energy Efficiency (REE). EEG signals is used to classify four kinds of emotions (surprise, happy, disgust and fear). To distinguish emotion Fuzzy C-Mean (FCM) unsupervised clustering method is used. The wavelet transform based feature extraction 'db4' is used to show the results confirm to the possibility [13].

Another research paper proposes analysis of EEG signals for medical diagnosis of various diseases like epilepsy, dementia, brain disorders like stress etc. The propose system applications include seizure analysis. That is the modeling of neuron potentials with the mathematical operations using EEG signal. This system makes the windowing, filtering and then finally reconstruction on the EEG signals to create the application [14].

III. EEG SIGNALS RECORDING AND RHYTHMS

EEG detects the brain wave of the human and provides an image of electrical waves of varying frequency, amplitude and shape. It can be used to measure brain activity and emotional states. The typical electrical activity that occurs in association with an event is sometimes referred to as the event-related potential [1].

The recorded brainwaves are shown at a computer passing through the amplifiers to process the data. A computer can be recorded the amplified signals which resemble wavy lines. The rhythmic of EEG is considered to extract the useful and correct information from the EEG diagnosis. The amplitude of the EEG waveforms is typically between 10_v to 200_v and frequency range of 1Hz to 100Hz. EEG signal can be classified into the following five kinds of rhythms according the frequency bands [7]. The part of the different brain waves of the rhythms are shown in Fig. 1.

i. Alpha (α) wave – it is a regular wave. It is present the condition of healthy adult while they are comfortable and eyes closed. In this condition the frequency range of 8Hz to 23Hz and normal voltage range of about 20v to 200v. The waveform is mostly pragmatic from the posterior region of the head.

ii. Beta (β) wave: the frequency range of 16Hz to 32Hz and voltage range is 5v to 10v. The waves appear from the central nervous system when feel awareness and alertness. The waves can collect from the frontal and parietal region via the scalp.

iii. Theta (θ) wave: the frequency range of 0Hz to 4Hz and voltage range is 10v to 55v. The waves appear when exciting stress and idling. The wave is recorded from the parietal and temporal part of the scalp. This kind of wave is linked for the activities like focusing, awareness, psychological effort and stimulation processing.

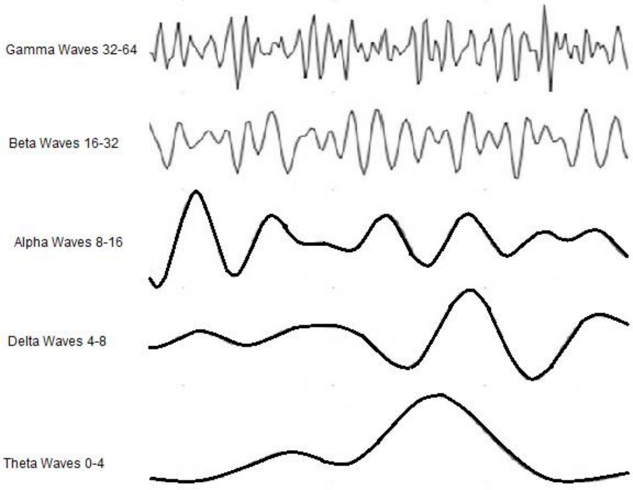

Fig. 1. Different rhythms of EEG signals [8]

iv. Delta (δ) wave: the frequency wave is 4Hz to 8Hz and voltage ranges from 20v to 200v. The wave occurs during deep snooze, with the serious of organic brain diseases and newborn. The waveform is recorded from the frontal head of adults and posterior head of children.

v. Gamma (γ) wave: the frequency wave range is 32Hz to 64Hz. This is recorded by the case of cross model sensory processing, perceptible impression, during short-term memory to distinguish matter [8].

iv. EEG pure wavelet: the wavelet is labeled by using logistic regression machine learning algorithm.

IV. PROPOSED METHODOLOGY

The recorded EEG signals are clarified to extract the emotional stages. The role of EEG signal processing is feature annotation, feature extraction and classification. For feature annotation we propose the following stages to get the high accuracy for the analysis of next step.

i. EEG recording: EEG signals are acquired

ii. EEG pre-processing: EEG signals are cut by using time frequency domain analysis

iii. EEG wavelet: the wavelet is filtered with finite impulses response (FIR) to improve the noise-signal rate. The system flow diagram of our propose system is shown in Fig. 2.

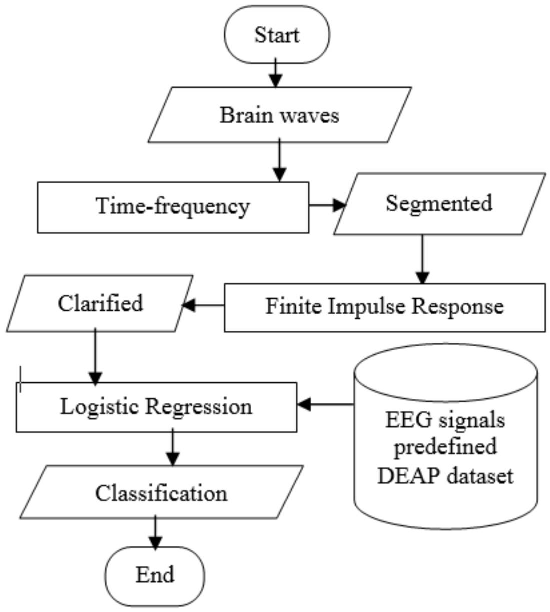

Fig. 2. System flow diagram for Feature Annotation of EEG signals

A. *Time frequency domain analysis of the EEG Signals*

In the signal processing, time-frequency analysis is the main techniques for manipulating the various signals in time [4]. The signals from EEG are non-stationary. To extract the signals to get correct information, EEG considered as stationary signals for very short durations of the intervals. The segmentation of EEG signals is useful for classified the emotional stage. The segmented EEG signals are stationary signals with the time frequency statistics. There are three segments to divide - posterior, occipital and postictal segment which give beneficial to get various rhythm of frequencies [9].

B. *Five main steps for the time-frequency analysis*

Step 1: to determine actually what is even being shown on the plot generally the most feature of the data to show in time frequency plots is power. This is the intensity or the strength of the frequency band specific activity over time.

It's important to make sure what feature of the data is being shown in the plots.

Step 2: to inspect the ranges and the limits of the plot on the x and y axes. Most of the time the x-axis shows time and y-axis shows frequency. What is the color limit or the grayscale intensity? This is related to what is being shown the color refers to power but that's important to determine whether it's absolute power or power relative to a baseline and so on. A lot of the main time frequency dynamics are contained with one frequency window.

Step3: to look at the results and to see if the results are distributed in time frequency space or if they are more localized to interpreting the results. Time frequency base analysis deliver a very large and high dimensional space. It's actually quite common something like a five dimensions hyper cube of results.

Step4: to link the result to experiment design assuming that there is some kind of task. What is happening at time zero is it a stimulus that came on the screen or an auditory stimulus or a button press or some kind of response are there multiple tasks events? How are these represented or shown in the time frequency plot? It involved cognitive control and response conflict.

Step5: to try and understand these statistical procedures that is shown in the plot. Link the results to the experiment design. There is no statistical threshold in which case the analyses should be considered qualitative rather than quantitative. If statistics were performed at every time frequency pixel our multiple comparisons issues addressed are the analyses more geared towards data exploration or are they more hypothesis driven. This will change how you interpret the results [10].

The time and frequency representation of the EEG signals are shown in Fig. 3. Time frequency base analyses used to make inferences about is neural oscillations brain oscillations. The time frequency base analysis to represent and analyze the signal not in the time domain but in the frequency domain. The signal has 1-3 peaks within 1 second that is 3 Hz in a unit frequency.

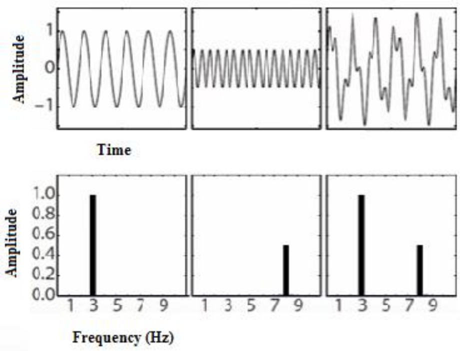

Fig. 3. Time and frequency with amplitude [11]

C. *Wavelet transform*

There are many different ways for the valid time–frequency distribution function, among them we propose wavelet transform. Hilbert transform which was developed by Hilbert mathematician. Hilbert transform is an alternative method for extracting the amplitude or the magnitude and phase information from EEG data which we extract time frequency information. Take a raw EEG time series performed convolution with a complex wavelet. The result of convolution is a time series of complex dot products from which we can extract the projection onto the real axis. That is the band pass filtered part of the signal. The distance and magnitude of the dot product get from the origin to the dot product. That is squared to get the power time series and the angle of this vector with respect to the real axis. That is our phase angle time series and we can basically extract the same information using the Hilbert transform [11]. Start with a real sine wave:

$$A * \cos(2\pi ft)$$

A = real value data, f = frequency, t = time

The real value data is conceptualized with cosine on to the real part of the signal. It's not possible to estimate what the phase angle is or what the power is. Therefore, complex sine wave is used:

$$A * \exp(i * [\cos(2\pi ft)])$$

i = quarter cycle

We need complex sine wave on a signal. The phase-quadrature component can be obtained by a 90° (quarter-cycle) shift on the complex plane.

$$A * e^{i(2\pi ft)} = A * \cos(2\pi ft) + \underbrace{i * A * \sin(2\pi ft)}_{\text{phase-quadrature component}}$$

D. *Finite impulses response (FIR) band-pass Filtering*

We propose narrow band pass filter that wavelet always have a Gaussian shape in the frequency with a peak in the shape at the frequency. In theory we can create this filter to have whatever shape we want. We can have multiple frequency peaks in the filter.

Fig. 4 is shown by defining ideal filter that has six points. The first point is DC that's zero frequency. The last point is the Nyquist frequency and the other four points these are the things that we have control over. Points three and four are edges of the data. Points two and five are the transition or define the transition zones from these frequency edges. The best filter would be a perfect edge. Need to filter to get the best reflect the characteristics of the actual data.

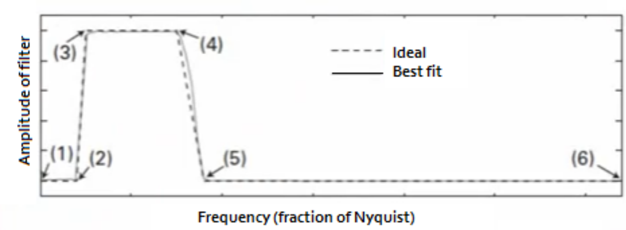

Fig. 4. Constructing an FIR filter

EEG data can apply Hilbert transform after bandpass filtering will give analytic signal from which can extract the projection onto the real axis which is a bandpass filtered signal the distance from the origin of the complex base. That points and square will get power and angle of this vector relative to the positive real axis and get the phase angle time series. Apply the Hilbert transform to broadband data is technically a valid it's accurate but it provides results that are extremely difficult to interpret because they're basically just dominated at every time point by whatever frequency happens to have the largest power in a signal. EEG data are very dynamic and they have broadband characteristics. So, apply the Hilbert transform after already applying some kind of narrowband filter. Parameterization of filters bent these types of plateau shaped bandpass filters have several parameters. One of them is the width of the frequency response in the frequency domain. This provides the same time frequency trade-off with wavelet convolution [10].

E. Logistic Regression classification algorithm of Machine Learning

Logistic regression is the technique for classification problem by estimating the values of parameters coefficients. At the end of the training of the machine learning model, we got the function that best described the relationship between the input and the output values. The prediction of the output is transformed using a nonlinear function called the sigmoid function as well as the logit function developed by a statistician to describe probability of the result. Each object in the image is assigned a probability between 0 and 1. Logistic regression technique can be used for traditional statistics machine learning [12].

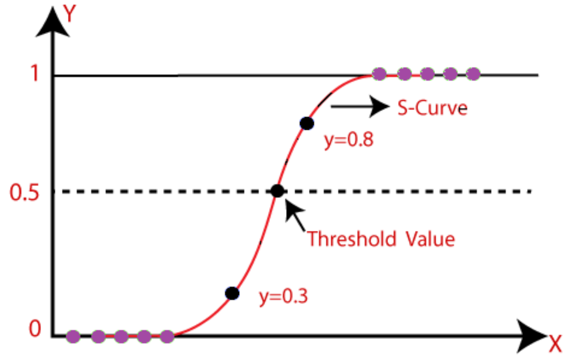

Fig. 5. Curve of logistic regression

In Fig. 5. logistic regressions ability is used to classify and to provide probabilities, with new samples using continuous and discrete measurements. It used maximum likelihood. Pick a probability scaled by frequency of observing the signal and use that to calculate the likelihood. Lastly, multiply all of those likelihoods together that's the likelihood of the data given this line. Then shift the line and calculate a new likelihood. Finally, the curve with the maximum likelihood is selected.

We propose multiclass classification with logistic regression algorithm to various kings of signals with different patterns. To build a machine learning model that can predict the base patterns of signals. The first we need to plot a scatter plot which like Fig 5. We can draw a curve line to predict better. Sigmoid [3] or logit function:

$$\text{Sigmoid}(z) = \frac{1}{1+e^{-z}} \qquad e = \text{Euler's number} \sim 2.71828$$

In this equation 1 is divided by slightly greater than 1 and the outcome will be less than 1 the range between 0-1 shape function. Regression line to sigmoid function:

$$y = \frac{1}{1+e^{-(m*x+b)}}$$

We just test to if a variable effect to the prediction is different from 0. If not, the variable cannot help the prediction.

In binary logistic regression for a particular event happening is probability of an event happening by probability of an event not happening:

$$y = \frac{p}{1-p} \qquad \text{y is between 0,1} \qquad p \text{ is the probability of event}$$

At the multiclass logistic regression y = 0, 1…n. Binary classification is needed to run multiple time for each class. Softmax function is used to interpret the probabilities. That take input that is a vector of K real numbers and normalizes it to be a probability distribution. It consists of K probabilities that is proportion to the exponent of the input numbers. Some vector components are negative or greater than one. The formula of Softmax function is :

$$\sigma(z_i) = \frac{e^{z(i)}}{\sum_{j=1}^{K} e^{z(j)}} \qquad for\ i=1,.,.,.,K\ and\ z = z_1,.,.,.,z_K \qquad \text{K is real number}$$

The standard exponential function is applied for each element z_i of the input vector z that is divided by the sum of all these exponentials to normalize. This is ensure that the total of the components of the result vector $\sigma(z)$ is 1 [15]. Logistic regression is used with SQL on library and CSV file to plot the different time frequency signals. We use train-taste split method [19] to split the data set to training set and testing set. This method is fit actually doing 60% of the dataset for training model to make predictions. The score shows the accuracy of the model. We can predict a probability of data sample being in one class versus the other used for classification. Logistic regression can work with continuous data.

In this proposed method used DEAP dataset (Database for Emotion Analysis using EEG Physiological Signals) [18] to show the consistency. It consists of two parts:

i. The rated results of the people who watch the video based on arousal, valence and dominance.
ii. The rating of the participant, physiological recordings and frontal face video of an experiment.

The participants watched the music videos and discrete 9-point scale for valence and arousal are rated. The strongest volunteer ratings and a small variation is selected to maximize the strength of elicited emotions. For each video *x* normalized arousal and valence score are calculated by mean rate divided by standard deviation (μ_x/σ_x) [22].

V. Result

The five different rhythms from the EEG signals is detected by segmenting the frequency. The signal becomes 5 chunk signals. DEAP datasets [18] contains all together 40 channels recorded including with 32 channels for EEG. The Fig. 6 show the five different kinds of incoming EEG frequency and the prediction of emotions result. These graph shows different valence (on X–axis) and arousal (on Y–axis) levels.

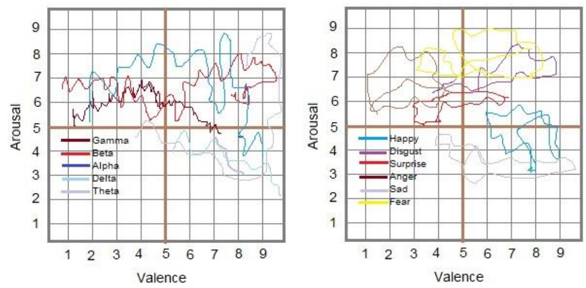

Fig. 6. The classification of emotion result from the EEG frequency

The principal component analysis (PCA)/ support vector machine (SVM) are commonly used in pattern recognition.

It is an effective methodology for multi-sensor system [20]. The Robust Fuzzy PCA (RF-PCA) is used to reduce the sensitivity of noise with robust estimation technique [21].

Table 1 show the performance of the emotional state classification. TP is the number of True classification class 1 (high valance). FP is the number of False Positive classification class 1 (low valance) [16]. Precision is the level of accuracy between information and predictions. The harmonic mean of TP and Precision is called F-Measure [17].

TABLE 1. PERFORMANCE OF EMOTIONAL STATE CLASSIFICATION

Methods	TP Rate	FP Rate	Precision	F-Measure	Class	Accuracy (%)
SVM+PCA	1.000	1.000	0.554	0.713	high	55.46
	0.000	0.000	0.75	0.005	low	
	0.554	**0.554**	**0.64**	**0.005**	**Avg**	
RF+PCA	0.782	0.746	0.566	0.657	high	54.69
	0.254	0.218	0.485	0.334	low	
	0.547	**0.510**	**0.530**	**0.513**	**Avg**	
SVM	0.988	0.977	0.557	0.712	high	55.77
	0.023	0.012	0.609	0.045	low	
	0.558	**0.546**	**0.580**	**0.415**	**Avg**	
RF	0.779	0.745	0.565	0.655	high	54.54
	0.255	0.221	0.482	0.334	low	
	0.545	**0.511**	**0.528**	**0.512**	**Avg**	
	0.817	0.624	0.640	0.718	high	**65.98**
Prepose Method	0.376	0.183	0.601	0.462	low	
	0.630	**0.437**	**0.624**	**0.610**	**Avg**	

Our propose method classified into high class using is 1365 data, SVM+PCA is 1489, RF+PCA is 1165 data, SVM is 1471, RF is 1160. Our propose method using low class data is 428, SVM+PCA is 3, RF+PCA is 305, SVM only is 28, RF only is 306. The comparison of experimental results for emotional classification with 6 conditions at ratio 5:3, is shows our experimental method has the best performance in parameter TP rate=0.6. The result of our method accuracy is 65.98.

VI. CONCLUSION

To know the state of human emotions is important to treat the patients. This research is intended to achieve higher classification accuracy using machine learning algorithm. All of the input EEG signals are analyzed based on period of time and frequency of the temporal and spatial characteristics. Our study will show that it achieves higher classification accuracy by comparing the classification methods. We will use stories, video and pictures to provoke emotional response in subjects, who then used a computer to record physical changes. This research will demonstrate that the consistency of the result by classifying the EEG signals obtained from all channel.

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