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Review on Feature Extraction and Classification of Neuromuscular Disorders

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ABSTRACT

Electromyography is an efficient tool for the diagnosis of neuromuscular diseases. There are wide variety of neuromuscular diseases that affects the muscles and nervous system, in which the most important are Amyotrophic Lateral Sclerosis (ALS) and Myopathy. These diseases change the shape and characteristic of motor unit action potentials (MUAPs). By analyzing the EMG signals and MUAPs neuromuscular diseases can be diagnosed. This paper gives a brief review of various techniques used in the analysis of EMG signals for the diagnosis of neuromuscular diseases. Various features that are extracted from the signals in time domain, frequency domain and time-frequency domain and different classification techniques and their performance are also studied in this paper.

KEYWORDS: *Amyotrophic lateral sclerosis (ALS), Electromyography (EMG), feature extraction, K-nearest neighborhood (KNN) classifier, Myopathy.*

I. INTRODUCTION

Neuromuscular disease is a disorder that affects the peripheral nervous system, which includes muscles, neuromuscular junction and the motor-nerve cells in the spinal cord. Nerve cells or neurons help to control the muscle movement by receiving and transmitting information through electrical signals. When there neurons become die or they lack important components, then the communication between the nervous system and muscles breaks down, which then results in muscle weakness or wastage of muscle. There are different varieties of disorders with varying degrees of complexity. However, many of these disorders exhibits almost same symptoms at their early stages and are very difficult to diagnose the disorder. Electromyography is the most popular method for the diagnosis of neuromuscular disorders. This technique is widely used in evaluating and recording electrical activity produced by the muscles and is performed using an instrument called electromyograph which produces a record called electromyogram. EMG signals can be obtained from the muscles in two different methods which are needle electromyography and surface electromyography. The signals obtained in this test are examined by an expert by visual and audio feedback. At the early stage of disease the changes in EMG signal of diseased person is very difficult to understand from normal signal. This leads to the development of

automatic classification systems that assist the diagnosis. The classification is done by extracting some relevant features from the EMG signals. These are many researches which are interested to diagnosis neuromuscular disorders. In most of these researches the first step is preprocessing of data for feature extraction. Then a set of features are extracted and a suitable classifier is applied to separate the signals into different classes (i.e normal, ALS and Myopathy).

II. Neuromuscular Disorders

A wide range of diseases that affects the functioning of nervous system, muscles and associated parts are known as neuromuscular disorders. They can be caused due to various reasons. Major two neuromuscular disorders are Amyotrophic Lateral Sclerosis (ALS) and Myopathy.

Amyotrophic Lateral Sclerosis

A type of motor neuron disease, Amyotrophic Lateral Sclerosis, affects the brain and spinal cord. ALS causes damages to both upper and lower motor neurons. It gradually leads to the death of motor neurons. The name of this disease is originated from a Greek word "amyotrophia", which means "no muscle nourishment". "Lateral" means the damaged area of spinal cord and "sclerosis" refers to hardening of the muscle tissue. A famous baseball player Lou Gehrig (Figure.1 (a)) had affected with this disease. Thus ALS is also known as Lou Gehrig's disease. Usually a person with ALS lives about two to five years after affecting with this disease. But the famous physicist and cosmologist Stephan Hawking (Figure. 1(b)) lived for almost five decades after affecting with this disease.

(a) (b)

Figure 1.(a) Lou Gehrig (b) Stephan Hawking

ALS causes gradual degeneration and death of motor neurons. Motor neurons are special type of neurons which are extended from brain to the spinal cord and to the muscles. Motor neurons that are present in the brain are called upper motor neuron and in the spinal cord are called lower motor neurons. In ALS, both the upper motor neurons and lower motor neurons are affected and stop the communication to the muscles. Thus the muscles gradually weaken and waste away as in Figure 2.

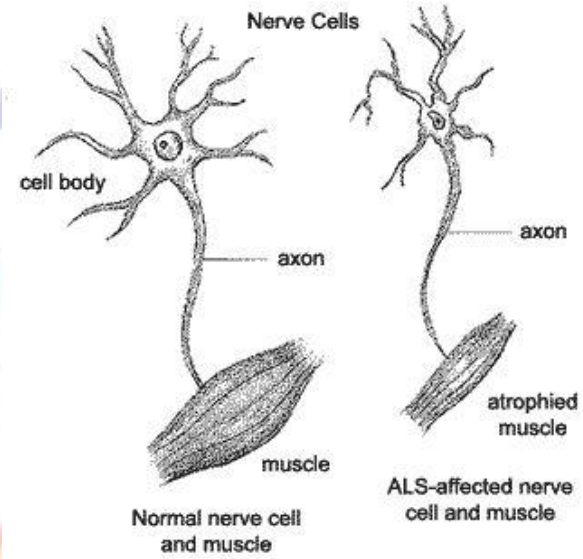

Figure.2. Normal and ALS affected nerve cells

Early symptoms of ALS are muscle twitches in the leg, arm, shoulder and tongue, stiffness in the muscle, muscle weakness, muscle cramps, slurred speech, difficulty in chewing and swallowing etc. But the people with ALS retain their memory or their mind stays fully awake. Diagnosis of ALS is done by the physical examination of the patient about the history of the symptoms by a physician followed by a series of tests. Electromyography, nerve conduction study and magnetic resonance imaging (MRI) can help to diagnose ALS. Currently no cure is available for ALS disease.

Myopathy

Myopathy refers to disease of muscles. When a person's muscle is affected, the muscles work less effectively than they should. This occurs when the muscle development is not proper or when they lack important components. A human muscle is made up of proteins and other structural components. When the muscle lacks any of the components, this may leads to myopathy. There are a wide variety of myopathies and each has different causes and tests.

The main symptom of myopathy is muscle weakness. Other symptoms include lack of energy, fatigue, stiffness, cramps, and muscle pains. For persons with myopathy for several years may cause

atrophying of muscles, that is thinning and wasting away of muscles. It may leads to abnormal shape of muscles. Diagnosis of myopathy can be done by physical evaluation including examination of reflexes, balance, muscle strength and sensations. Electromyography, some blood tests, thyroid tests, muscle biopsy etc. have been in use to diagnose myopathy.

III. METHODOLOGY

Basic steps for classification of neuromuscular disorders are shown in Figure 3.

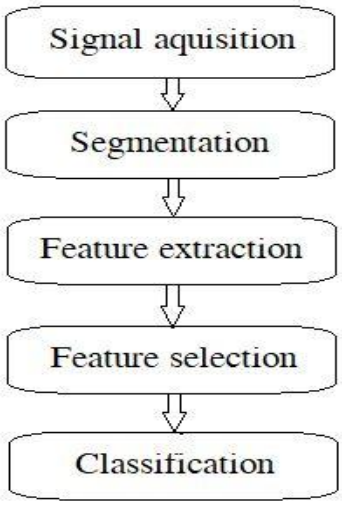

Figure.3. Steps for EMG signal processing

EMG Signal Acquisition

For the diagnosis of neuromuscular disease, the patient is examined by an expert physician and the medical and family history of the patient is noted. By checking the patient's reflexes and muscle strength the physician will order other tests like blood tests, magnetic resonance imaging (MRI), electromyography, Lumbar puncture, nerve conduction studies, muscle biopsy and genetic testing.

Electromyography is the study of electrical activity produced by the muscles. The functional unit of muscle is motor unit which contains a motor neuron and associated muscle fibres. These motor units produce electrical potential and summation of electrical potentials of individual muscles fibres connected by same motor neuron is known as motor unit action potential. Neuromuscular disease changes the shape and characteristics of MUAP. Therefore EMG signal analysis is an efficient method for the diagnosis of the disease. Electromyography is mainly two kinds: surface EMG and intramuscular EMG. Needle EMG is one of the simplest approach in intramuscular EMG.

EMG signal for neuromuscular disease detection was acquired from biceps branchiimuscle using concentric needle electrodes. The band pass filtered signal at 5 Hz to 10 KHz is then sampled at 20 KHz for 5s with 12 bit resolution. This measurements where done in Neurology Department of University of Gaziantep [8]. Also the is carried out with publically available clinical EMG database which is made public satisfying Institutional Review Board (IRB) practices of EMGlab and local IRB. It consists of 10 normal (6M, 4F) aged 21-37 years, 8 ALS (4M, 4F) aged 35-67 years and 7 Myopathy (5M, 2F) aged 19-63 years [14]. Each recording has 262134 samples on 11.184 sec at 23438 samples/sec sampling rate.

Segmentation

The significant portion of an EMG signal is selected based on the basis of root mean square (RMS) value of various frames. The RMS value of each frame can be obtained as

$$RMS = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} x^2(n)} \quad (1)$$

Where, N is the number of samples.

The RMS values corresponding to the ALS patients has more variations in the initial and final frames but it shows a stable range of values in the middle frames. On the other hand, the RMS values corresponding to normal and myopathy data exhibit steady RMS value. Thus the middle steady regions, from each dataset 25 frames (from 31st frame to 55th frame) are selected

Feature Extraction

Feature extraction has an important role in achieving a good classification performance. From the extracted features, feature or feature set that provides best classification performance is selected. Feature extraction is performed in three main domains: time domain, frequency domain and time-frequency domain. Feature extraction can be done in direct or MUAP based method. Direct method is frame-by-frame analysis of EMG signal while MUAP method means features are obtained from extracted MUAP only.

1) *Time domain method:* Some important time domain features of MUAP waveform are listed below.

a) Amplitude: Difference between maximum negative and positive peak gives the amplitude.

b) Duration: It is the time interval between the beginning and ending of MUAP waveform .

c) Area: It is the region between MUAP waveform and the base line over the entire time duration.

d) Phase: Section between two baselinecrossing having an absolute value of 0.02mv.

e)Turns: It is the number of positive and negative peaks.

In MUAP method, the time domain features such as amplitude, duration and phases extracted from MUAPs are very useful for the differentiation of normal and diseased patients with duration being important parameter [4]. As muscle forces increases the number of MUAPs also increased, which make difficult for an expert to distinguish individual MUAP. Therefore, EMG signals decomposition and MUAP classification gives important information for the evaluation of neuromuscular disorders [3]. Since a large number of MUAPs are present in single EMG signal, feature dimension may increase. Also the number of MUAPs extracted from each signal is also different. So the dominant MUAP is selected to reduce the dimension. Dominant MUAP is selected on the basis of energy content present in each MUAPs. This is due to the fact that energy of MUAP is different in different class. For example MUAPs of ALS patients are high in amplitude and longer duration while for myopathy they are shorter in duration with low amplitude compared to normal signals. In [12], several time domain features are extracted from MUAP such as rise time, spike duration and phases etc. Morphological features of MUAPs are used along with variety of classifiers. A set of morphological features (duration, spike duration, amplitude, area, spike area, number of phases and turns) are utilized as features [7],[13].

Time domain feature can also be extracted from direct EMG based rather than MUAP based. In direct EMG method features are extracted from the entire signal rather than from MUAPs. Time domain features for direct method are:

a) Root mean square (RMS): Root mean square value is defined as the square root of the mean of the squares of the values. It is used to quantify the electric signals. It is given by (1).

b) Standard deviation (SD): Standard deviation gives the amount of deviation of a signal from its mean value around the origin.

$$SD = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}(x_n - \mu)^2} \quad (2)$$

Where, μ is the mean value.

c) Zero Crossing (ZC): It is defined as the number of times the amplitude value of a signal crosses the zero y-axis. In order to remove the voltage fluctuations, a particular value is set as threshold. ZC is given by,

$$ZC = \sum_{n-1}^{N-1}[sgn(x_n - x_{n+1}) \cap |x_n - x_{n+1}| \geq threshold] \quad (3)$$

Where,

$$sgn(x) = \begin{Bmatrix} 1, & if\ x \geq threshold \\ 0, & otherwise \end{Bmatrix}$$

A threshold of 0.01mV is applied.

d) Waveform Length (WL): It is defined as the overall waveform length over a given time period. It represents the complexity of the particular signal. WL is given by,

$$WL = \sum_{n=1}^{N}|x_{n+1} - x_n| \quad (4)$$

e) Willison Amplitude (WA): It is described as the number of times that the difference between adjacent EMG signal amplitude exceeds a threshold. It is given by,

$$WAMP = \sum_{n=1}^{N} f(|x_n - x_{n+1}|) \quad (5)$$

Where,

$$f(x) = \begin{Bmatrix} 1, if\ x \geq threshold \\ 0, \ otherwise \end{Bmatrix}$$

*f) Skewness:*Skewness gives the measure of asymmetry of the signal.

$$Skew = \frac{\frac{1}{N}\sum_{n=1}^{N}(x_n - \mu)^2}{\sigma^3} \quad (6)$$

Where, μ is the mean value.

g) Kurtosis: It is the measure of peak value of the probability distribution of the signal.

$$Kurt = \frac{\frac{1}{N}\sum_{n=1}^{N}(x_n - \mu)^3}{\sigma^3} \quad (7)$$

Where, μ is the mean and σ is the deviation standard

In this method EMG signal is divided into time slots and then features such as root mean square (RMS), waveform length, slope sign changes, zero crossing and autoregressive coefficients are extracted [18].

2) Frequency domain method: On the other hand, frequency domain features of MUAPs provide some information for the evaluation of neuromuscular diseases. Frequency domain features are extracted from power spectral density (PSD). Periodogram is used to estimate PSD. The main features are mean frequency, median frequency peak frequency, bandwidth and quality factor. Some frequency domain features are:

a) Mean frequency (MNF): Mean frequency is the average frequency of signal which is calculated as the sum of product of the power spectrum and frequency divided by the total intensity of spectrogram.

$$MNF = \frac{\sum_{j=1}^{M} f_j p_j}{\sum_{j=1}^{M} p_j} \quad (8)$$

b) Median frequency (MDF): Median frequency is the mid frequency at which the power spectrum is divided into two parts with same amplitude. It is given by,

$$\sum_{j=1}^{MDF} p_j = \sum_{j=MDF}^{M} p_j = \frac{1}{2}\sum_{j=1}^{M} p_j \quad (9)$$

The MUAP power is similar to the MUAP duration [3] or duration of spike [2]. The more useful parameter for the classification of EMG signal is median frequency (MD). Studies proved that median frequency deviates from its normal value in the case of neuromuscular disease condition [1]. Median frequency of MUAP is the frequency content of the MUAP which is similar to the duration of MUAP. Spectral analysis of EMG signals haves been in use for the study to infer changes in motor unit recruitment [5]. In some literature five features are extracted from bispectrum of EMG signals.

3) Time-frequency domain method: Time-frequency analysis represents the signals in both time and frequency domains. Wavelet transform is a multi-resolution time-frequency analysis and widely used for feature extraction. Wavelet transform decomposes the signal into different frequency bands or a set of basis functions called wavelets. Frequency content of each MUAP is characterized using wavelet transforms [4].

Discrete Wavelet Transform (DWT) is used to extract frequency resolution components in the signal by decomposing the signal into both time and frequency domain. DWT divides the signal into approximation and detail coefficients. It uses scaling functions and wavelets functions which are associated to low pass and high pass filters. Each stage of this method output is down sampled by 2. The output of high pass filter provides detail coefficients and that of low pass filter provide approximate coefficients. The approximate coefficients are further decomposed and the process is repeated. Approximation and detail coefficients are reconstructed using Daubechies4 (db4) wavelet filter as given in [9][10]. In [11],[15] DWT features are extracted on a frame by frame basis and instead of using all the coefficients, higher values of DWT are used which reduces feature dimension. A. B. M. S. U. Doulahet. Al [14] proposed two methods for feature extraction: direct and MUAP based. In direct method, DWT coefficients are extracted in a frame by frame manner and DWT coefficients with higher value along with maximum value are proposed to be utilized as features, same as in [11]. In MUAP based method, first all the MUAPs from EMG signal is extracted and dominant MUAP is selected. Then some statistical properties of DWT coefficients of selected MUAP is utilised for feature extraction. ShravantiKalwaet. al [16] performed wavelet decomposition on dominant MUAP and maximum and standard deviation of coefficient are computed foe classification. The dimension of DWT features of dominant MUAP is reduced using mean of absolute values of coefficients, average power of coefficients, standard deviation of coefficients in each sub band [17].

Classification

The best suitable feature set extracted from the signals is then given to the classifier as input in order to map different signals to corresponding classes or groups. The role of classifier is to differentiate normal, ALS and myopathy signals. So far the ability of different classifiers with different measures is studied. There are several types of classifiers have been in use such as Artificial Neural Network (ANN), k-Nearest Neighbour (k-NN) and Support Vector Machine (SVM).

1) Neural Networks (NN): A Neural Network is suitable for the classification of non-linear data. The set of algorithms that are designed to recognize patterns are called neural networks. Neural network helps to cluster and classify patterns by interpreting sensory data through machine perception. In [6], Subasi developed Feed-forward Error Back-propagation Networks (FEBANN) and Wavelet Neural Networks (WNN) for detecting EMG signals. In WNN, node activation function in

hidden layer used is discrete wavelet function. Autoregressive spectrum of EMG is given to the input layer of FBANN and output represents normal, myopathy or neurogenic disorder. C.D. Katsis employed a two-stage method for MUAP classification which are Radial Basis Function Artificial Neural Network and decision trees [7]. This method requires minimal use of parameters. In [8], Subasi developed adaptive neuro-fuzzy inference system for classifying signals of patients with neurogenic and myopathic disorders.

2) k-Nearest Neighbour (k-NN): Another important classifier is k-Nearest Neighbour (k-NN), which is a simple classifier. A distance function is computed between test set and k-neighbouring points from normal and diseased training set.Euclidean distance function is computed between test set and k-neighboring points from normal and diseased training set. The Euclidean distance between the two points aand bis given by,

$$d(a,b) = \sqrt{\sum_{i=1}^{n}(a_i - b_i)^2} \qquad (10)$$

Then the test point is classified based on the labels of k-nearest pattern is used. A suitable value of k for obtaining best classification accuracy should be selected. An example of k-NN classifier is shown in Figure4.

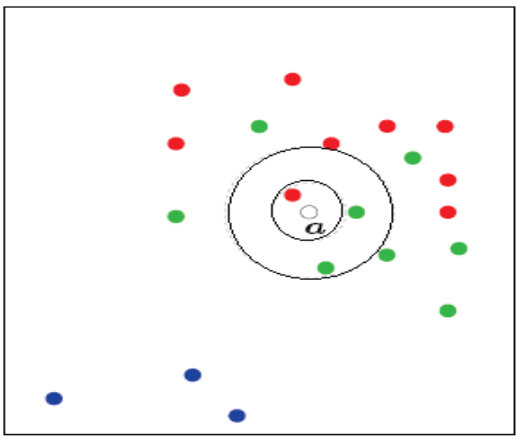

Figure 4.. Working of k-NN classifier

Red, green and blue are the points in training set and 'a' is the test point. Here the nearest neighbour of "a" is red, therefore "a" is classified as red.

k-NN method is proposed in [11] to classify normal, ALS and myopathy signals. Doulah et al. [14] extracted the dominant MUAPs and classified using k-NN classifier for both small and large dataset separately. Here using large dataset, classification accuracy of 98.80% is obtained using wavelet domain features, which is more than previous methods. Performance of different Daubechies wavelets for k-NN classification is compared in [16]. Db7 gives more accuracy compared to db4, db5 and db6. A distance weighted k-nearest neighbourhood (DWKNN) classification is performed in [17].

3) Support Vector Machine (SVM): The binary classifier SVM is a type of machine learning method and is used for pattern recognition. SVM uses a hyper plane in multidimensional space to separate different classes of data. There can be more than one hyper plane and one hyper plane is selected by maximizing the margin. SVM can be of two kinds:linear and non-linear. In the linear classifier model, the training examples plotted in space. These data points can be separated by a gap. A straight hyperplanecan be used to divide 2 classes. The primary focus while drawing the hyperplane is on maximizing the distance from hyperplane to the nearest data point of either class. The drawn hyperplane called as a maximum-margin hyperplane. But in some cases, linear SVM cannot be possible. For this Vapnik suggested creating Non-Linear Classifiers by applying the kernel trick to maximum-margin hyperplanes. In Non-Linear SVM Classification, data points plotted in a higher dimensional space.To solve three classesproblem multiclass classifications which include One-Against-All (OAA) and One-Against-One (OAO) are used. SVM classifier is used to classify normal, ALS and myopathy using maximum value and standard deviation of approximation and detail coefficients as features. A Particle swarm optimization (PSO) algorithm which is a population based algorithm is used by Subasi [10]. PSO-SVM can improve the classification accuracy upto 99.60% from 97.90% obtained from SVM only.

Table 1 shows different classifiers used in neuromuscular disease classification. It is clear that k-NN classifier provides

Table 1. Classification accuracy of various classifiers in the reviewed literature

Author	Paper	Feature Extraction	Classifier	Accuracy
Subasi A. et. al.	Classification of EMG signals using wavelet neural network	AR modeling	FEBANN WNN	88% 90%
Katsis, Christos D. et. al.	A two-stage method for MUAP classification based on EMG decomposition	Time domain	RBFANN and decision tree	89%
Subasi A.	Medical decision support system for diagnosis of neuromuscular disorders using DWT and fuzzy support vector machines	DWT	LDA RBFN MLP C4.5 DT SVM FSVM	79% 84% 90% 85% 92% 94%
Subasi A.	Classification of EMG signals using PSO optimized SVM for diagnosis of neuromuscular disorders	DWT	RBFN k-NN SVM PSO-SVM	94% 95% 97% 98%
Fattah S. A. et. al.	Identification of motor neuron disease using wavelet domain features extracted from EMG signal	Time Frequency DWT	k-NN	72% 70% 100%
A.B.M.S.Doulah et. al.	Wavelet domain feature extraction scheme based on dominant motor unit action potential of EMG signal for neuromuscular disease classification	DWT	k-NN	98.80%
Kalwa, S. et. al.	Neuromuscular disease classification based on discrete wavelet transform of dominant motor unit action potential of EMG signal	Wavelet decomposition	k-NN	67%
KhanM. et. al.	A Multi-Classifier Approach of EMG Signal Classification for Diagnosis of Neuromuscular Disorders	Time & DWT	Multi-classifier, DWKNN	97% 95%

IV. Conclusion

EMG signal is very important in the diagnosis of neuromuscular disorders. Various techniques for EMG signal recording, segmentation, different feature extraction methods, and classification techniques were discussed in this paper. Different frequency domain, time domain and time-frequency domain parameters derived from the signals and are used for classifying the EMG signals as normal, ALS and myopathy. Feature extraction can be done in direct method and MUAP method. Various features that are obtained from the two methods are discussed in this paper. Also

various classifiers and their accuracy are also discussed. Selection of classifier is very important in differentiating neuromuscular disorders. For neuromuscular disorders k-NN classifier provides best classification accuracy when feature extraction is performed on MUAPs of the signals.

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