# COMPARATIVE ANALYSIS FOR CANCELLATION OF BASELINE-FLUCTUATION IN EMG SIGNAL

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**Abstract -** Electromyography (EMG) is an electrodiagnostic technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an Electromyograph, to produce a record called an Electromyogram. An EMG signal is a record of the stress/pressure in muscles which is measured by analysing the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. These signals can be analyzed to detect medical abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement. EMG is a very sensitive and needs high actuations for proper diagnostic results but generally this is degraded by noise. There are various sources of noise which hinder the proper recording of EMG but the fluctuations in the baseline is the most alarming issue which is required to be cancelled appropriately for accurate diagnosis.The present work focus on the various quantitative techniques and their comparative study for elimination of noise present in EMG signal. Presenting these techniques through simulated EMG signal results gives their advantages and disadvantages in terms of both visual inspection and merit figures.For the removal of BLF we use three methods namely: Statistical Method, Moving Averaging Method and Digital Filter Design Method. For recording the EMG signals we have used concentric needle electrode.The only purpose of this work is to reduce BLF noise in EMG signal and present a comparison between the outputs obtained by using the listed three sequential techniques.

***Key Words***: Electromyography, EMG signal, Baseline fluctuation, Bioelectric potential, Segmentation, MUAP.

## 1.INTRODUCTION

Electromyography (EMG) is the study of the electrical activity of muscles and forms a valuable aid in the diagnosis of neuromuscular disorders [1]. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells[2] when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement.

There are a number of neuromuscular disorders in human and animals that affects various parts of the body like brain, spinal cord, nerves and muscles. EMG examination studies the electrical activity of muscles and forms a valuable neurophysiological test for the assessment of neuromuscular disorders.

The motor unit action potential (MUAP) expresses the electrical activity of the muscle fibers of a motor unit (MU) recorded from a needle electrode. The shape of MUAP waveforms and the degree of similarity in consecutive firings contain valuable information about the nature and state of a muscle. It helps to distinguish normal from pathological conditions and to measure the degree of abnormality [1]. MUAP analysis is thus a routine procedure in clinical electromyography (EMG). In the usual clinical procedure, different MUAP discharges (similar waveforms that supposedly correspond to different firings of the same MU) are extracted from the continuous electromyographic record. Conventional electromyographs present a manual or automatic selection of several discharges from a MU, which are then aligned and averaged [2-4], to form the MUAP waveform (typically a 50ms analysis window in which the MUAP main peak occupies the central position). After that, qualitative (visual-based) and/or quantitative (parameter-based) analyses are carried out. The quality of the EMG signal may be degraded by baseline oscillations, disturbing the processes of MUAP extraction, classification and analysis. An adequate cancellation of the BLF would enhance signal quality and accordingly make the processes described above easier and more reliable, easier and more reliable.

In ideal condition, a noise free signal which does not have any fluctuations, noises and any other artifacts then the baseline of these signals will match the electrical zero of the equipment. But these noise free signals do not exists in the real world and a low frequency fluctuation is usually can be observed.

There are various artifacts of different nature which leads to the baseline wander such as: movement of the recording needle relative to the muscle, variation of skin potential induced by the needle, and/or electrical drifts in the acquisition equipment [2-4]. However, the main source of BLF is the activity of distant MUs, which do not generate recognizable and well defined MUAPs, and appear as a mild baseline wander.

The EMG signals without the noise and baseline fluctuation are required for various applications like clinical, biomedical and human machine interaction etc. But a noise free signal does not exist in the real environment. So a proper cancellation of BLF is required, which would enhance the signal quality and accordingly make the process easier and reliable and then it could be further used in various tasks.

In this paper we present different methods that automatically eliminate the BLF in a continuous EMG signal. In this paper, three techniques are devised for removal of baseline fluctuation.

## 2.MATERIAL USED

We analyzed recording of EMG signal from the muscles in a healthy subjects at low force level, using concentric needle electrode. The signal was analogue band pass filtered at 3 Hz to 10 KHz and sampled at 20 KHz. The EMG signal was then low pass filtered at 8 KHz and down sampled by a factor of two at 10 KHz. Recording equipment comprised an electromyography and disposable concentric needle electrodes. The electromyography amplifies the input signals according to a manually selected gain. An EMG signal with baseline fluctuation and low frequency noise is shown in Figure 1.

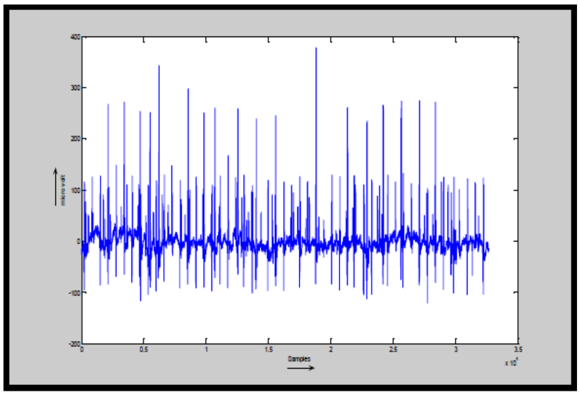

**Fig 1**: Raw EMG Signal

## 3.METHODS

A decent elimination of baseline fluctuation would helps to increase the quality of EMG signal and enables us to work more efficiently. There are three methods used for the removal of baseline fluctuation of are listed below.

- Statistical approach
- Moving average approach
- Digital filter design approach

### 3.1 Statistical Approach

It is a very simple technique which can easily remove the low frequency oscillations presents in the baseline of EMG signal and thus it may increase the quality of EMG signal. This technique is generally based on the threshold values and segementation process, which can be calculated easily with the help of a simple algorithm or matlab programming. This method is developed in some sequential steps, which are listed below.

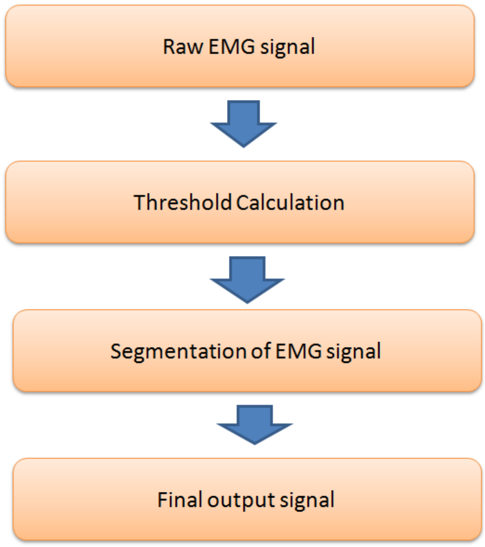


**Fig 2**: Flow chart of Statistical Approach

- **Threshold calculation**

To constitue the BLF, MUAP free segments or the baseline segment (BLS) must be acclaimed from MUAP segments of the EMG signal. The threshold plays a consequential role to do this job or it can be concluded that the threshold calculation is the most significant part in the removal of BLF of EMG signal in the statistical technique. It is used in the estimation of level of EMG activity, segmentation and classification of whole EMG signal. The value of threshold is calculated on the base of mean absolute value of each samples present in the EMG signal X (t).

A simple algorithm used for the calculation of threshold T is given below:
If maximum X (t)>30* mean (abs X (t))
Then
Threshold = 5 * mean (abs X (t))
Else
Threshold =maximum X (t)/5

The value o threshold can be changed as per the requirement. So therefore the values of threshold are different for different values of EMG signals.

- **Segmentation of EMG**

Segmentation process with the help of discreet wavelet transform (DWT). It convert the EMG in possible segments (active segments) and low frequency segments (baseline segment). The DWT decompose the EMG signal into active segment and baseline segment by using a defined algorithm, which is given in the Matlab toolbox.

- **Final output signal**

In this section, only the active segments are will remains same. Only the baseline segments are corrected. The oscillations or disturbance present in the baseline segment of EMG signal are removed by subtracting the value of threshold T1 from the absolute value of the each samples present in the BLS of the first window of the size of 30 samples and then taken the next window and subtract the value of respective threshold T1 from the absolute value of each samples of this window. Now this error free signal can be used for various applications.

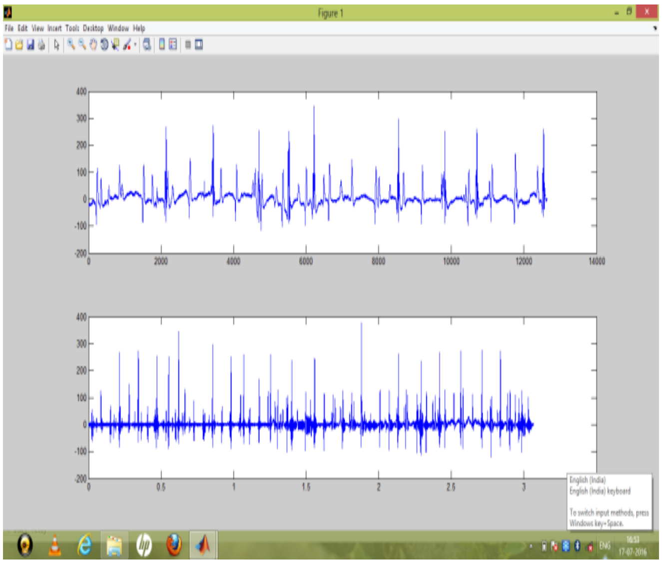

**Fig 3**: Raw EMG signal and output signal without baseline fluctuation

### 3.2 Moving average method

Moving average method is one of the simplest methods to do this work, because the algorithm used in this method is easier and smaller than other methods. In this method, one of the moving average techniques can be used such as, simple Moving average and Weighted moving average and Savitzky method. In the present work, simple moving average is used to filtering out the baseline oscillations. A direct function for smoothing a data of specified length is given in MATLAB, which can smooth the data easily. Moving average method devised for removal of baseline fluctuation present in the EMG signal is discussed below in four sequential steps:

- **Select the data/signal**: The digital signal which contains some specific data or samples which we want to smooth is loaded and then specifications such as name and quantitative and qualitative informations are loaded.
- **Select the smoothing methods**: One of the smoothing methods such as moving average method, locally weighted method and Savitzky method can be used to perform the smoothing.
- **Select the span**: In this section, We have to select the number of data points of the full length raw signal which is known as span (window). Smoothing process will always produce a new data set. For Moving average and Savitzky method, the span must be odd. For all weighted method, if the span is less than one, it is interpreted as the percentage of the total number of data points. By default the value of the span in Moving average method is five.
- **Select the degree**: In this section, the degree of polynomial is selected. But this is used ony for the Savitzky method. The degree must be smaller than span.

The EMG signal with BLF and smoothed response of this signal (EMG signal without BLF) is given in Figure 4.

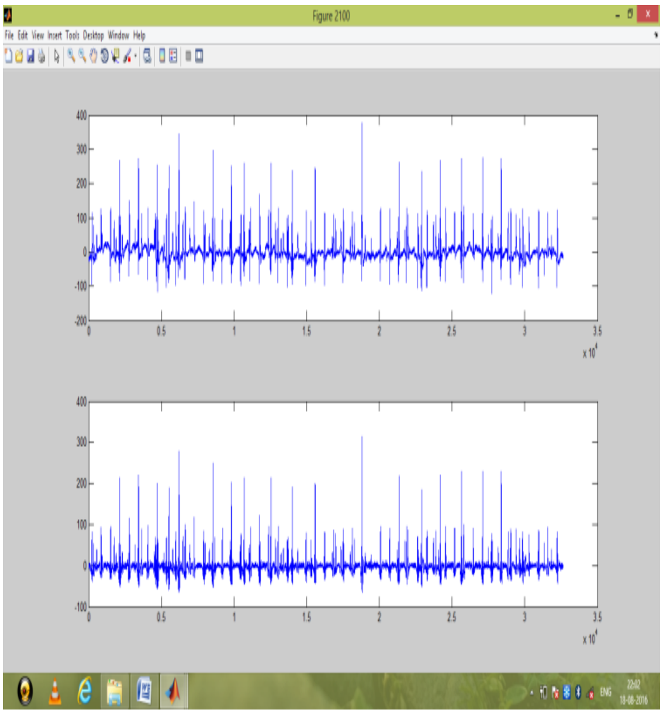

**Fig 4**: The EMG signal with BLF and smoothed response of this signal (EMG signal without BLF)

### 3.3 Filter designing approach

The method devised for filtering out the BLF in EMG signal is comprised of various sequential steps.

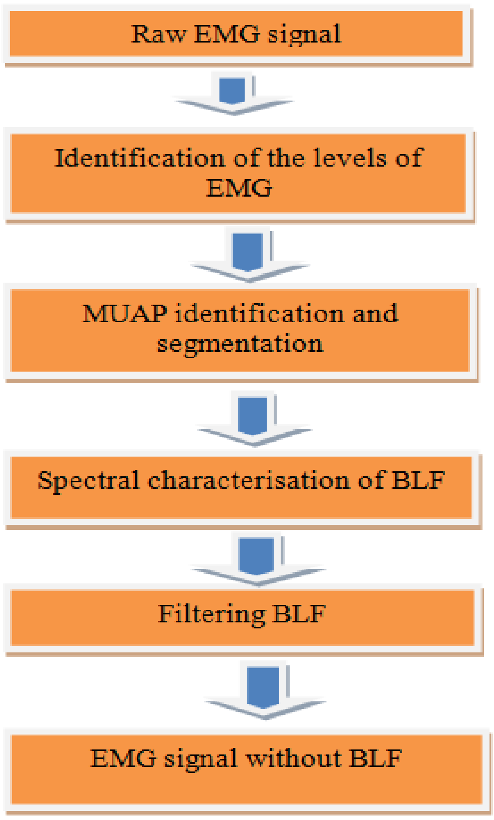


**Fig 5**: Block diagram of filter designing for BLF removal

- **Identification of level of EMG**

Te basic function present in the identification of the level of EMG signal is the number of distinct MUAPs present in it. This is directly proportional to the degree of contraction, stress and pressures present in the EMG signal.
If the contractions of the muscle increases then the level of EMG activity will also increases, this means more number of motor units will be employed, which makes MUAP free segment less frequent.
To peculiarize the BLF, MUAP-free segments or BLS must be acclaimed from MUAP segments. EMG activity, which we quantify in terms of density of peaks in the signal, can be used to help in the isolation of MUAP-free segments

So for that we use the temporal peak density (TPD) as a quantitative measure of this level. To estimate the TPD, the amplitude range of the EMG signal (from minimum to maximum) is divided into 20 intervals (bins) of equal width. From these, the amplitude histogram is created by counting the number of signal samples in each bin. Amplitude threshold (Th1) is established as the maximum absolute value from the two ends of the most frequent histogram bin, which is usually the central one (Fig. 6).

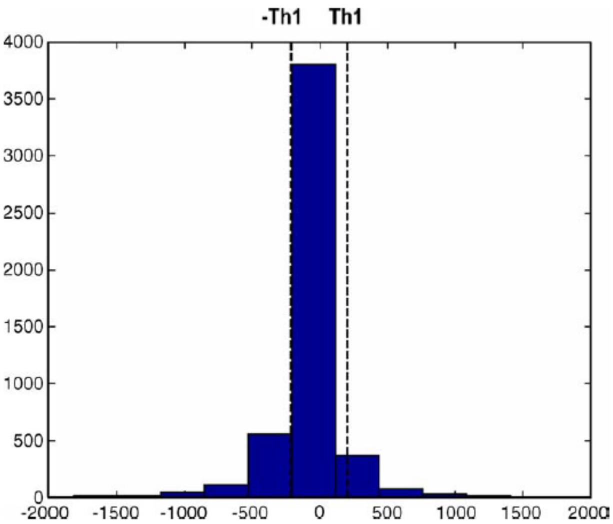


**Fig 6**: Twenty bin amplitude histogram

The TPD is then achieved as the number of signal extrema (minima and maxima) with amplitude higher than this threshold, divided by the signal length (given in ms). Calculation of Th1 is based on the idea that most of the samples of the signal corresponding to EMG peaks have higher amplitude than non-peak samples (related to the BL). Th1 is EMG activity TPD calculated such that it disunits these two sets of samples with only a small number of errors.

Note also that Th1 is a dynamic threshold that adapts itself to the characteristics of the EMG signal and the degree of BLF present in it.

**Table 1:** Classification of levels of EMG

| | |
|---|---|
| Low | 0–4.165 |
| Low-medium or medium | 4.165–6.117 |
| Medium-high | 6.117–8.01 |
| High | 8.01–13.20 |
| High-non-processable | >13.20 |

To valuate the cogency of TPD as an estimate of the EMG activity level, an expert electromyographist carried out a qualitative classification of our signals based on visual inspection. He divided the range of activity levels into seven categories: low, low-medium, medium, medium-high, high, high-nonprocessable, non-processable. In most of the signals under study a direct relationship between these categories and the calculated TPD could be appreciated. This relationship is given in Table 1.

We evaluated histograms with different number of bins and found that the best acceding between TPD and expert visual assessment was concluded with 20 bins.

- **MUAP identification and segmentation**

Segmentation is the process to cut the EMG signal into the AS and BLS. The process of segmentation is same, which has been discussed in the last section. In the segmentation process first of all the threshold T is considered, which has been calculated in the last step depending on the maximum and mean value of whole EMG signal. In the present work segmentation is performed into two stages. In first stage AS are obtained and in second stage BLS are obtained. In the first stage segmentation algorithm calculates the threshold, peaks over the calculated threshold are considered as candidate MUAPs. Now a window of constant width of 120 points is applied centered at the identified peak. If a greater peak is found in the window, the window is centered at the greater peak otherwise the 120 points are saved as a candidate MUAP waveform. In second stage to perform the BLS of EMG signal, second threshold, named T1 is also calculated. In this step a windows of constant width of 30 points is taken and calculates T1, then selects the next window of 30 samples and calculate the value of T1 again. Thus the whole length of the EMG signal is divided into the window of 30 samples and threshold is calculated each time. The value of threshold is change for every next window. The threshold T1 is also calculated on the basis of mean absolute value of whole samples present in a window of 30 samples. Now the BLS is performed by the comparison of this threshold T1 with first threshold T, which has been calculated in last section. If threshold T1 is greater than the threshold T then the samples are again considered as the candidate of MUAPs waveform or we can say that these are the active, otherwise the segment is baseline segment. The value of second threshold T1 is calculated as:

*T1=mean [abs(X (w))]*

Where w is the size of window, the size of window can be changed on the basis of the requirement of accuracy.

- **Spectral characterisation of BLF**

Firstly a continuous baseline reconstruction from the discontinuous BLF is needed to attain a spectral characterisation of BLF. Three steps are carried out in the spectral characterisation phase: averaging of BLS (step a), cubic spline interpolation (step b) and AR spectral estimation (step c).

**(a) Averaging of BLS**: BLS still contains some smooth and low amplitude potentials along with high frequency noises from distinct origins. To reduce the influence of these artifacts in BL reconstruction, consecutive samples of these segments are averaged.

**(b) Interpolation**: The previously averaged points are interpolated by means of cubic splines, which closely chase the BL through (along) its fluctuations (Fig. 5.7). The cubic splines technique interpolates signal points by means of concatenated cubic polynomies such that the obtained interpolation curve and its time derivative are both continuous throughout the whole time span, and the signal points to be interpolated are exactly on the curve. We analysed alternative interpolation techniques, such as polynomial interpolation of various orders and mean squares interpolation, but they turned out to be faulty: since the interpolated curve is not forced to contain the average BL samples of the previous stage, it often fails to make room conscientiously the actual BL variability or BLF. However, certain problems may arise when cubic splines are used to interpolate the BL in EMG signals with high activity. The continuity constraints imposed by the method result in extra curvature of the interpolated curve. This can be a significant problem when the available BL samples are scattered, as in the case considered in the example, but even so, the frequency content of the interpolated curves still close to that of the actual BL, and thus can be used in subsequent stages to estimate and remove the spectral components of the present BLF.

**(c) AR spectral estimation**: AR spectral estimation [9] is done to obtain a smooth and high resolution power spectral density (PSD). Akaike's criterion is used for model order selection, and Burg'smethod is then recruited for AR estimation [9]. Fig. 5.8 shows the spectrum of an EMG signal (a), and the spectrum of the BLF estimated by means of cubic splines interpolation (b). The AR model spectrum of the estimated BLF (c) is also plotted. As expected, the PSD corresponds to a low frequency signal. The 3 dB cut-off frequency of this PSD is then obtained.

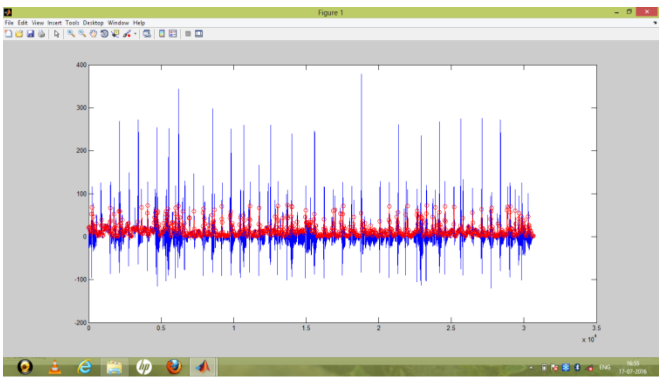

**Fig 7**: Interpolation points

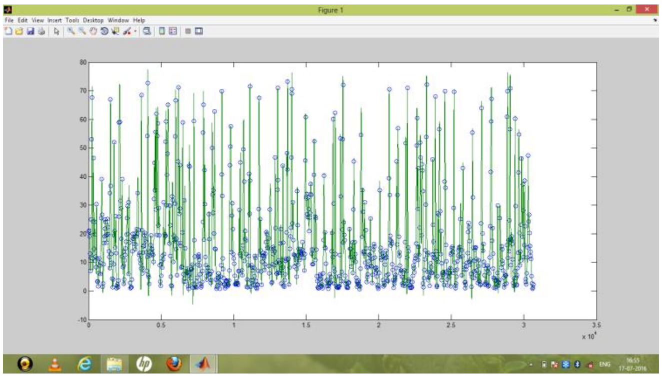

**Fig. 8**: Interpolated BLS

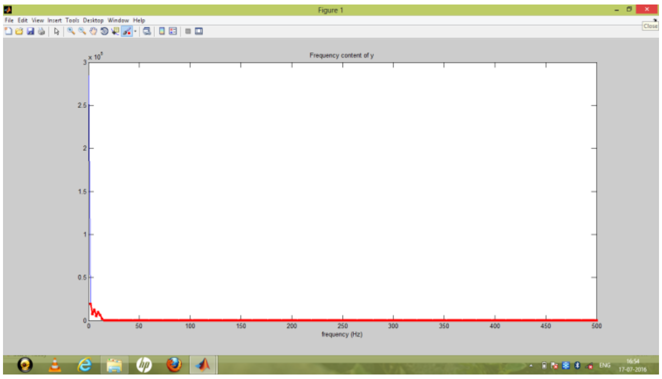

**Fig 9**: PSD of BLS

- **Filtering BLF**

At last, a high pass Butterworth filter of 3 db cut off frequency and the above achieved stop band of 15 Hz is designed. Here IIR Butterworth filter is used for this specific task because it has a consistent linear phase characteristic and maximally flat magnitude response. Most commonly used method named; bilinear transformation can be followed for designing the IIR Butterworth filter. To eliminate the BLF, the EMG signal is filtered out by the above designed high pass filter. The designed filter of the above specification cut the signal up to the frequency range of 15 Hz and passes the signal of the frequency above the 15 Hz. In this way low frequency BLF are filtered out from the EMG signal and the active segment of high frequency pass through the filter thus it will remain same throughout the whole filtering process. Almost linear phase characteristic of the Butterworth filter guarantees the preservation of MUAP shape as far as possible. As mentioned before, the BLF filtering method using FFT spectral estimation followed by high pass Butterworth filter is found to be the best approach for baseline fluctuation filtering. An EMG signal with and without baseline fluctuation is shown in Figure 5.10.

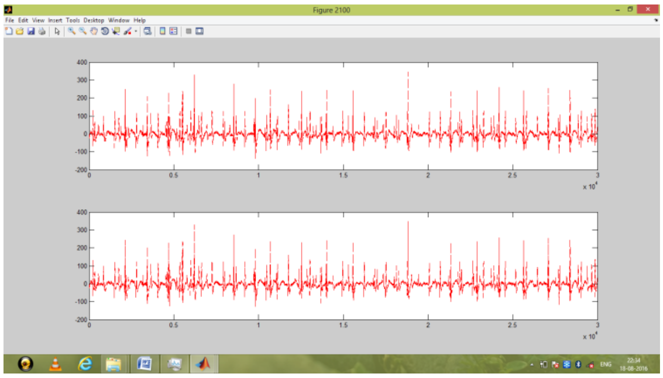

**Fig 10**: Filtered output by using both butterworth filter and chebyshev filer respectively

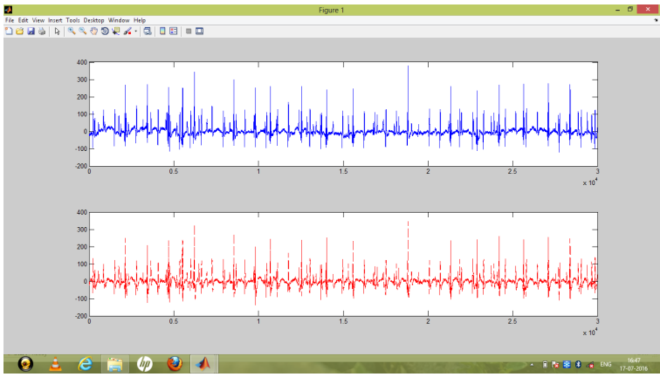

**Fig 11**: Raw EMG signal and filtered EMG signal using Butterworth filter

## 4.QUANTITATIVE EVALUATION AND RESULTS

For the effective comparison between the methods used for the removal of the a quantitative evaluation is needed. BLF raises or lowers the mean level of a potential or of a portion of a potential, so the degree of waveform variation in the discharges in a MUAP train is increased artifactually by the BLF. We devised two merit figures ($F$ and $N$) for measuring the degree of BLF. They were calculated as follows:

(1) All the single potentials (waveforms in the EMG record corresponding to non-overlapped MUAPs) are manually selected and classified, by eye, on the basis of waveshape into several classes corresponding to different MUAP trains.

(2) For each MUAP train, the corresponding discharges are time aligned so that correlation between them is maximized. Let $Yk = \{yk(1), yk(2), \ldots, yk(nk)\}$ be the discharge number $k$ of the set of $m$ discharges of a certain MUAP train, where $yk(t)$ is the $t$ sample of $Yk$. Discharges in $Yk$ are normalized dividing their samples values by the maximum absolute value in the whole set.

The two proposed merit figures are defined as below.

$F=S.D_k.\{meant(Y_1)........mean(Y_m)\}$

First the temporal mean of every discharge is calculated; then the standard deviation of all these means is computed.

$N=mean_t[S.D.\{Y_1(t)..........Y_m(t)\}]$

The standard deviation across different discharges is calculated for every sample time; the resulting set of values is then averaged. Because of the above-mentioned normalization, F and N values will be in the range 0-1. F measures the variability of the mean of the different discharges pertaining to the same MU along the EMG signal. Ideally, if BLF were not present, and if all discharges from the same MU were equal, F would be zero. When there is BLF, some discharges appear higher than others and the value of F increases accordingly.

On the other hand, N measures the variability of amplitude values of amplitude values of a MUAP waveform throughout a MUAP train. N will be zero if no BLF is present and the discharges do not differ from each other. However, if the BL fluctuates, the amplitude of MUAP samples will vary from one discharge to another and N will increase according to this variation.

Thus the degree of BLF cancellation provided by a given method on a certain EMG signal can be measured indirectly by looking at the decrement in the signal's F and N values. BLF removal methods can be compared by direct computation of F and N parameters in the processed signal. For lower the F and N values, the lower the remaining BLF, and better the performance of method. The values of F and N are calculated here for all these three techniques.

Following tables shows the values of F and N corresponding to three BLF removal methods.

**Table 2:**Values of F and N of Raw EMG signal

| MUs | Values of F of Raw EMG signal | Value of N for Raw EMG signal |
|---|---|---|
| MU1 | 0.0254 | 0.028 |
| MU2 | 0.0338 | 0.0206 |
| MU3 | 0.0387 | 0.1770 |

**Table 3:**Values of F and N of filtered EMG signal using statistical method

| MUs | Values of F of filtered EMG signal | Values of N of filtered EMG signal |
|---|---|---|
| MU1 | 0.0195 | 0.0124 |
| MU2 | 0.0085 | 0.0202 |
| MU3 | 0.0091 | 0.1770 |

**Table 4:** Values of F and N of filtered EMG signal using moving average method

| MUs | Values of F of filtered EMG signal | Values of N of filtered EMG signal |
|---|---|---|
| MU1 | 0.0195 | 0.1637 |
| MU2 | 0.015 | 0.1539 |
| MU3 | 0.017 | 0.1648 |

**Table 5:** Values of F and N of filtered EMG signal using digital filter method

| MUs | Values of F of filtered EMG signal | Values of N of filtered EMG signal |
|---|---|---|
| MU1 | 0.023 | 0.0203 |
| MU2 | 0.0231 | 0.2003 |
| MU3 | 0.0321 | 0.1711 |

From the above tables, it can be easily shown that the reduction in the values of F and N is large in case of statistical approach as shown in Table 6.1. So, based on the value of F and N, it can be concluded that the statistical technique used for removal quantity of BLF provide the better performance in comparison of Moving average and digital filter design.

On the other hand, in case of Moving average the values of F and N are reduced significantly in comparison of digital filter design approach. The value of F and N will be zero if no BLF is present and discharge do not differ will each other. However, if the BL fluctuates, the amplitude of MUAP samples will vary from one discharge to another and F, N will increase according to this variation. Both effects can be appreciated in Figure 8 for each technique, which shows a set of discharges of the same MU before and after removal of BLF.

## 5.CONCLUSION

The present work focus on the various quantitative techniques and their comparative study for elimination of noise present in EMG signal. Presenting these techniques through simulated EMG signal results gives their advantages and disadvantages in terms of both visual inspection and merit figures.

For the removal of BLF we use three methods namely: Statistical Method, Moving Averaging Method and Digital Filter Design Method. For recording the EMG signals we have used concentric needle electrode.

The only purpose of this work is to reduce BLF noise in EMG signal and present a comparison between the outputs obtained by using the listed three sequential techniques.

The selection of one of the method from the above three methods for BLF removal can be based on the requirement of the work. Although, all these methods are promising for enhance EMG signal quality, So that the process of MUAP extraction and analysis would be easier and reliable.

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