REMOVAL OF BASELINE FLUCTUATION FROM EMG RECORDINGS

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1. Abstract:

Appropriate cancellation of the baseline fluctuation (BLF) is an important issue when recording EMG signals as it may degrade signal quality and distort qualitative and quantitative analysis. We present statistical and filter-design approach for cancellation of the BLF based on several signal processing techniques used sequentially. The methodology is to estimate the spectral contents of the BLF, and then to use this estimation to design a high pass Butterworth filter by using Bilinear Transformation that cancel the BLF present in the signal. Two merit figures are devised for measuring the degree of BLF present in an EMG record. These figures are used to compare both methods which naively consider the baseline without any fluctuation i.e. constant potential shift. Applications of the techniques on real and simulated EMG signals show the superior performance of our approach in terms of both visual inspection and the merit figures.

Keywords- Needle EMG, Baseline removal, MUAP

2. Introduction-:

EMG findings are used to detect and describe different disease processes affecting the motor unit, the smallest functional unit of the muscle. With voluntary muscle contraction, the action potential reflecting the electrical activity of a single anatomical motor unit is recorded. It is the compound motor unit action potential (MUAP) of those muscle fibers within the recording range of the needle electrode. The electrical signals produced by the muscles and nerves are analyzed to assess the state of neuromuscular functions in subjects with suspected neuromuscular disorders. The repetitive activation of several individual motor units results in superposed pulse train and constitutes the electromyogram signal. The potentials from individual motor units are characterized by unpredictable shapes depending upon the motor unit structure, electrode shapes and sizes, electrode placement, intervening tissues, and the state of neuromusculature. The analysis of the EMG is based on its constitute i.e. motor unit action potential (MUAPs). It consists of a group of muscle fibers, which are innervated from the same motor nerve. The shape of MUAP reflects the pathological and functional states of the motor unit. With increasing muscle force, the EMG signal shows an increase in the number of activated MUAPs recruited at increasing firing rate, making it difficult for the neurophysiologist to distinguish individual MUAP waveforms. The clinical examinations are carried out with the EMG signal recorded at low contraction level of the muscle; usually such individual motor unit action potentials are distinguishable. This single motor unit activity is the summation of electrical activity of each muscle fiber within a motor unit. However, the MUAP waveform from different motor units may be similar in amplitude and shape when the muscle fibers of two motor units have a similar spatial arrangement in detectable vicinity of electrode. The information extracted from the EMG is of great importance and is used for the diagnosis and treatment of the various neuromuscular disorders and to study the neuromuscular control mechanism and muscle fatigue. But the quality of EMG signal may be reduced by baseline oscillations and low frequency noise, disturbing the process of MUAP extraction, analysis and classification. Thus there is a necessity of efficient and effective techniques which can separate individual MUAPs from the complex fluctuation without loss of the diagnostic information. An adequate cancellation of baseline fluctuation can enhance the quality of EMG signal. In ideal conditions without any fluctuation, noise and artifacts, the baseline would match the electrical zero of the equipment. This noise free signal does not exist in real environment, but the oscillation present in the signal can be reduced with the help of various techniques.

3. Material:

Analysis of the recording of EMG signals from the muscles in 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. The 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 Figure1.

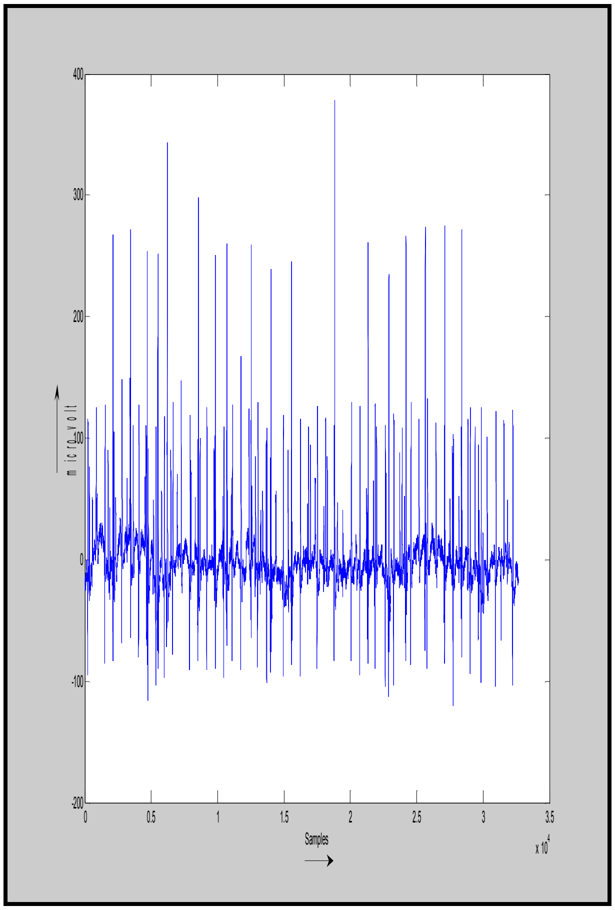

Figure1. Raw EMG Signal

4. Methods:

There are two techniques are used for removal of baseline fluctuation, which is listed below.

4.1. Statistical technique based on threshold

Statistical technique based on threshold method comprises several sequential phases:

(a) Calculation of threshold
(b) Segmentation of EMG signal
(c) Removal of baseline fluctuation

4.2 Digital Filter designing for removal of BLF

Digital Filter designing for removal of BLF method comprises several sequential phases:

(a) Calculation of threshold
(b) Segmentation of EMG signal
(c) Interpolation of baseline points
(d) Analysis of Power spectrum density
(e) Filter designing & filtering of raw EMG signal

4.1. Statistical technique based on threshold:

4.1(a) Calculation of threshold-

The calculation of threshold is used to find out the activity level of the EMG signal, classification and segmentation of whole EMG signal x(t). An algorithm used for the calculation of threshold T is given as

If maximum x (t)>30* mean (abs x (t))
Then
Threshold = 5 * mean (abs x (t))
Else
Threshold =maximum x (t)/5

4.1(b) Segmentation of EMG signal-

The process to cut the EMG signal into segment of possible MUAPs segment (active segment) and low activity areas or baseline segment (MUAPs free segment) is known as segmentation. Segmentation of EMG signal can be performed with the help of discrete wavelet transform (DWT) [4]. Another approach of segmentation is performed into two stages. In first stage AS are obtained and in second stage BLS are obtained. In the first step segmentation algorithm calculates the threshold; peaks over the calculated threshold are considered as candidate MUAPs. 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 obtain the BLS of EMG signal, second threshold, named T1 is 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. The BLS is performed by the comparison of threshold T1 with first threshold T. If threshold T1 is greater than the threshold T then the samples is again considered as the candidate of MUAPs waveform i.e. 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.

4.1(c) Removal of baseline fluctuation

From the segmentation of whole EMG signal the AS and BLS distinguished from the EMG signal. The removal of BLF present in the BLS of the EMG signal can be performed. The AS of the EMG signal will remain same, only the correction is required in the BLS of the signal. 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 take the next window and subtract the value of respective threshold T1 from the absolute value of each samples of this window. This sequential procedure is applied to the whole windows of BLS of the EMG signal. After applying all the above procedure, a new BLS is obtained, which is free from the BLF. Figure 2(a) and 2(b) show the BL with Fluctuation and without fluctuation. The EMG signal without BLF can be further used for required applications. In this way an adequate cancellation of BLF can be obtained, that can enhance the signal quality and accordingly make the process of extraction and analysis of EMG signal easier and reliable.

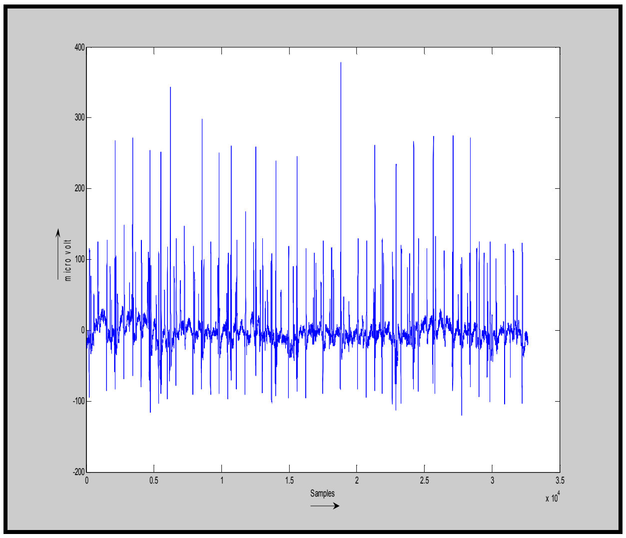

Figure 2(a). EMG signal with BLF

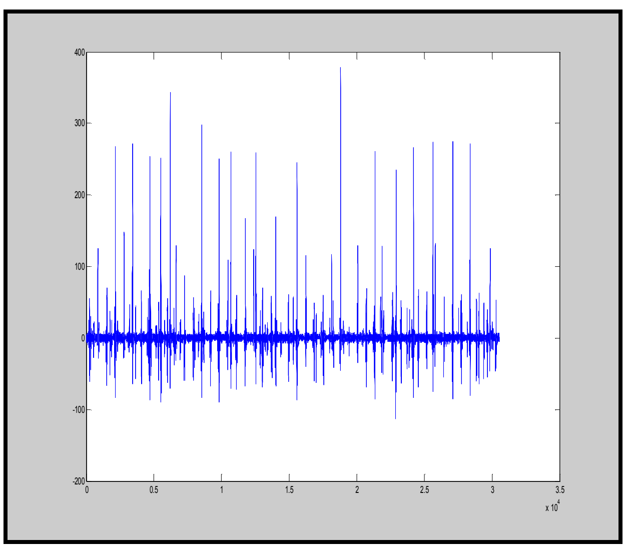

Figure 2(b). EMG signal without BLF

4.2 Digital Filter designing for removal of BLF:

4.2(a) The Calculation of threshold and 4.2(b) the Segmentation of EMG signal are same as discussed in section 4.1(a) and 4.1(b) respectively.

4.2(c) Interpolation of baseline points-

Interpolation is the process of estimation of values between the data points. The previously averaged points are interpolated by means of cubic splines, which closely follows the BL through (along) its fluctuations (Fig 3a). The cubic splines technique interpolates signal points by means of concatenated cubic polynomials 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 (Fig 3b).

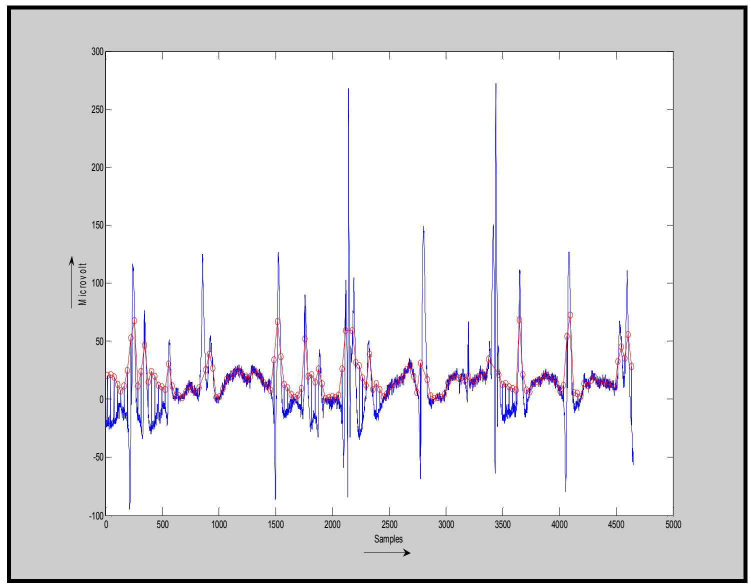

Figure 3(a). Interpolation points

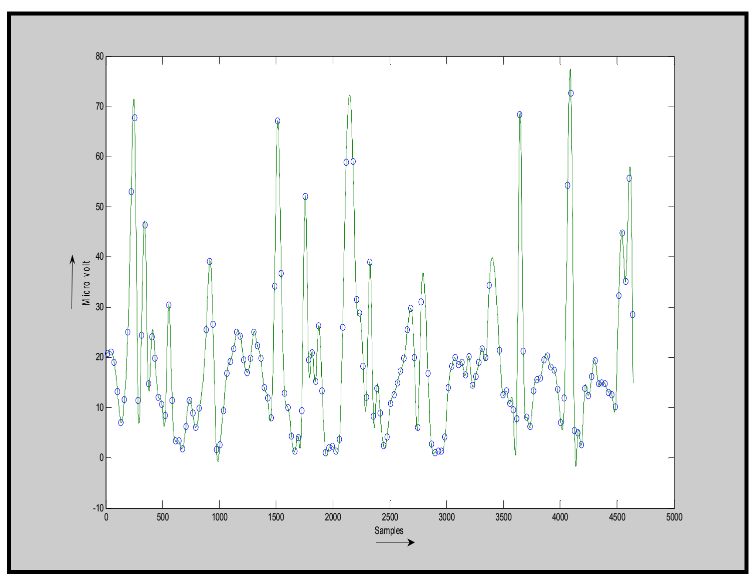

Figure 3(b). Interpolated BLS

4.2(d) Analysis of power spectrum density-

The power spectrum density of the interpolated baseline segments will be obtained to find out the frequency range of the baseline, so that the filter would be designed for the specified cut off frequency. There are various methods to estimate the frequency spectrum of baseline segment. AR spectral estimation can also be used on the interpolated signal to obtain a smooth and high resolution power spectral density but in this paper Fast Fourier transform is used to obtain the Power spectrum density of interpolated baseline segment.

PSD Estimation using FFT:

For a wide-sense stationary (WSS) process X (n), the power spectral density, $S_{xx}(f)$, is the Fourier transform of the autocorrelation function r_{xx} (k) (Wiener-Khintchine) [3]. The power spectral density, $S_{xx}(f)$, is a real and nonnegative function and the signal variance is

$$\sigma^2 = r_{xx}(0) = \int s_{xx}(f)df \qquad (1)$$

A. Periodgram:

Given a finite sequence x[n], of length N, the autocorrelation function can be estimated by

$$r_{xx}(k) = \frac{1}{N}\sum_{n=0}^{N-k-1} x(n)x^*[n+k] \qquad (2)$$

This is asymptotically unbiased, consistent with low variance.

Taking the Fourier transform of both sides and making some mathematical manipulation. We get the period-gram estimate of power density spectrum.

$$s_{xx}^{PER}(F) = \frac{1}{N}X(f)X^*(f) = \frac{1}{N}|X(f)| \qquad (3)$$

The properties of periodgram estimator are

- Asymptotically unbiased

$$\varepsilon[s_{xx}\ (f)] = w_B(f) * s_{xx}(f) \qquad (4)$$

Where $w_B(f)$ is the Fourier transform of Bartlett (Triangular) Window

- Not consistent

$$\text{Va}[s_{xx}^{PER}(f) \approx s^2{}_{xx}(ff)] \qquad (5)$$

B. The Bartlett and Welch Estimates:

In order to reduce the periodgram variance, Bartlett proposed the following method.

- Divide the original spectrum into K non overlapping segments.
- Take the period-gram estimate of each segment.
- Average the K Periodgram do get $s_{xx}^{BAR}(f)$

The result is a reduction of frequency resolution by a factor K and a reduction of variance by approximately K.

C. The Blackman-Tukey Estimate:

The Blackman-Tukey method used a windowed version of auto correlation function thus minimizing the unreliable estimate at large lags, k;

- Estimate the autocorrelation function.
- Window $r_{xx}[k]$ with lag window
- Calculate the Fourier transform.

In this PSD analysis, the cut off frequency of the BLS is 15 Hz. Figure 3(c) shows the power spectrum density of baseline segment.

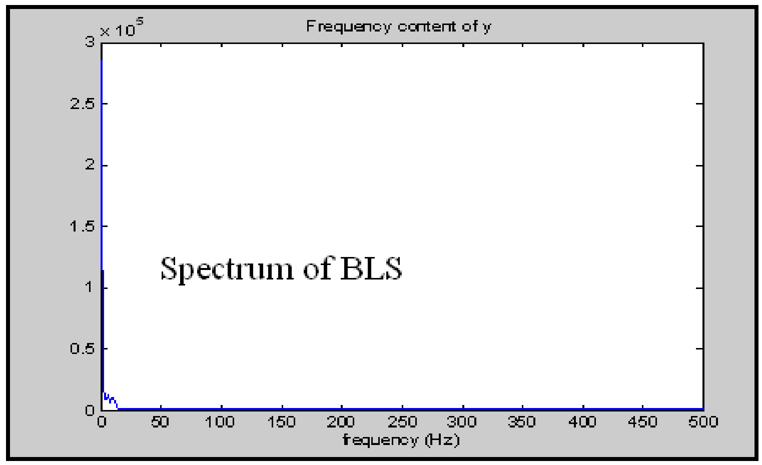

Figure 3(c). PSD of BLS

4.2(e) Filter designing & filtering of EMG signal

A high pass Butterworth filter of 3 db cut off frequency with stop band of 15 Hz is designed. Most commonly used method named; bilinear transformation can be followed for designing the IIR Butterworth filter..

The **Butterworth filter** is one type of digital filter. It is designed to have a frequency response which is as flat as mathematically possible in the pass band. The frequency response of Butterworth filter is given in Figure 3(d). Another name for them is 'maximally flat magnitude' filters.

Let H (z) =B (z)/A (z) denote the transfer function of a digital filter. The degree on B (z) will be denoted by L+M, where L is the number of zeroes at z =-1and M is the number of remaining zeroes.

Assume $L \le N$ and *M=0,* then the rational function $F(x) = \frac{P(x)}{Q(x)}$ is given by

$$F(x) = \frac{(1-x)^L}{\left((1-x)^L \pm cx^N\right)} \qquad (6)$$

The classical Butterworth filter is obtained when $N=L$. Note that

$$\left|H\left(e^{j\pi/2}\right)\right|^2 = F(1/2) = \frac{1}{(1+c.2^{L-N})} \qquad (7)$$

It is clear that, c should be chosen so that this value lies between 0 and 1. Therefore, c must be greater than zero. To choose c to achieve a specified half-magnitude frequency is straight forward. The equation $\left|H(e^{j\omega_0})\right|$ =1/2becomes $F(x_0) = 1/4$ where $x_0 = (1-\cos\omega_0)$.

Solving this equation for c, one obtain c=3 $(1-x_0)^L / x_0{}^N$

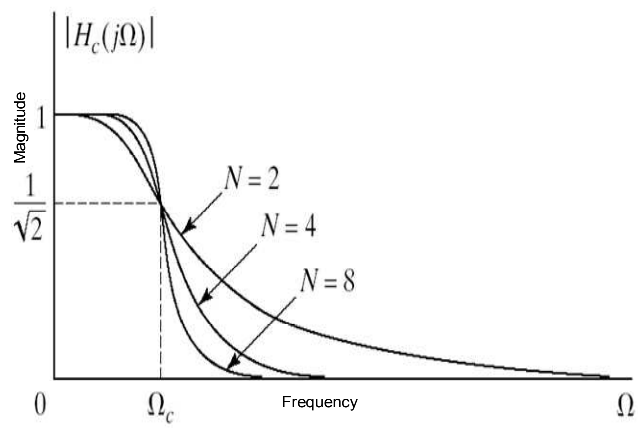

Fig. 3(d) Frequency response of Butterworth filter

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 (fig 3e).

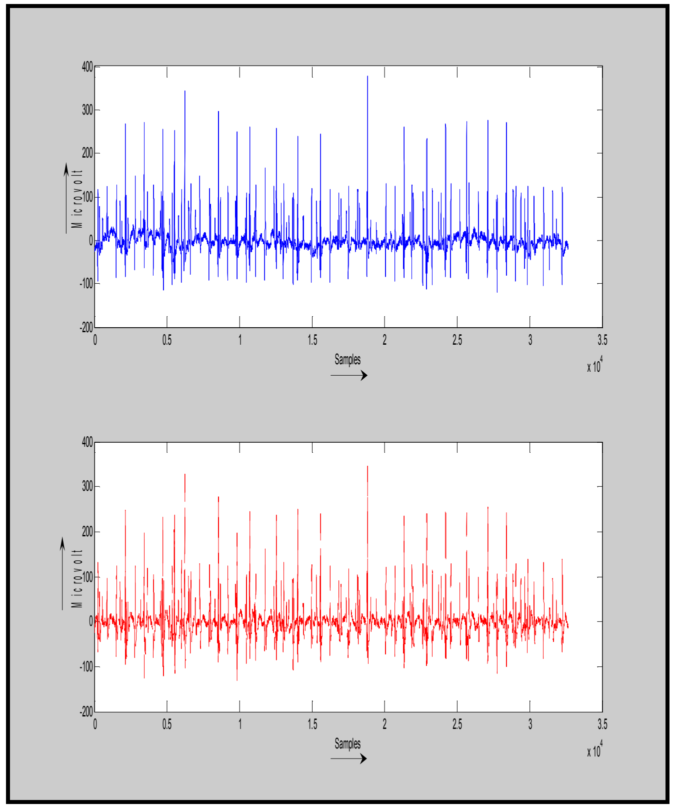

Figure 3(e). Original EMG signal and filtered BLF

5. Results and Discussion:

- **Quantitative Analysis**

Quantitative explanation is required to compare the baseline removal methods. Baseline raises or lowers the mean level of a potential or of a portion of a potential, so the degree of waveform variation in the discharge in a MUAP train is increased by BLF.

Two quantities (F and N) are devised to measure the degree of BLF. They are calculated as follows.

1. All the single potential are manually selected and classified, by eye, on the basis of wave shape 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 $Y_k = \{y_k(1), y_k(2)............y_k(n_k)\}$ be the discharge number k of the set of m discharges of a certain MUAP train, where $y_k(t)$ is the t sample of Y_k. Discharge in Y_k are normalized dividing their samples values by the maximum absolute value in the whole set.

The two proposed quantities are defined below.

$$F = S.D_k(mean_t(Y1)..................mean(Y_m))$$
(8)

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

$$N = mean_t(s.d_k(y_1(t)................y_m(t)))$$
(9)

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 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.

Table 1.1 shows the values of F and N corresponding to two BLF removal methods.

Table 1.1(a): Values of F and N of Raw EMG signal

MUs	Value of F for Raw EMG signal	Value of N for Raw EMG signal
MU1	0.0257	0.207
MU2	0.0337	0.205
MU3	0.0388	0.1768

Table 1.1(b): Values of F and N without BLF, using Digital filter

MUs	Value of F for filtered EMG signal	Value of N for filtered EMG signal
MU1	0.0203	0.203
MU2	0.0230	0.2002
MU3	0.0320	0.1711

Table 1.1(c): Value of F and N without BLF, using Statistical technique.

MUs	Value of F for filtered EMG signal	Value of N for filtered EMG signal
MU1	0.0195	0.122
MU2	0.0083	0.0204
MU3	0.0089	0.1640

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 performance of all these two method can also be classified on the basis of two parameters names: BL removal quantity and change in the originality of signal. In the sense of changes in the originality of signal, digital filter designing approach is efficient and reliable than statistical method, on the basis of the quantity of the removal of BLF, the statistical approach is descent one as compare to digital filter method.

6. Conclusion :

- Two methods have been proposed to remove the BLF in EMG records. It makes use of several signal processing techniques in a sequential fashion: Threshold calculation, EMG signal segmentation into BLS and AS segments, averaging and cubic spline interpolation of the BLS, AR frequency characterization of the interpolation curve, and final IIR filtering.
- Two merit figures have been devised to measure the degree of BLF present in an EMG signal. Tests with real and simulated signals indicate the validity of these merit figures and demonstrate that they are sensitive to variations in BLF amplitude, and less sensitive to the BLF frequency distribution.
- In the sense of changes in the originality of signal, the digital filter designing approach is efficient and reliable and on the basis of the quantity of the removal of BLF, the statistical technique is descent.

7. References:

[1] Adriano de Oliveira Andrade, Slowamir J. Nasuto Peter Kyberd. "The GTM classifier and its application to the classification of motor unit action potentials"

[2] Carlo J. De Luca," Surface Electromyography: Detection and Recording".

[3] C. Campos, A. Malanda, L. Gila, V. Segura, I. Lasanta, J. Artieda, Quantification of jiggle in real electromyography signals, Muscle Nerve, (2000), pp 1022–1034.

[4] C.R. Meyer, H.N. Keiser, Electrocardiogram baseline noise estimation and removal using cubic spline and State-space computation techniques, in computers and biomedical research, Academic Press New York, (1997), pp 459-470.

[5] Christodoulos I. Christodoulou, Constantinos S. Pattichis. "A New Technique for the Classification and Decomposition of EMG Signals" Christodoulou, C.I.; Pattichis, C.S.; Neural Networks, 1995. Proceeding, IEEE International Conference 1996.

[6] C.s. Pattichis, A. Elia, C.N. Schizas, "Classification performance of motor unit action potential features" , 1994 IEEE, pp 1338- 1339.

[7] Craven, P. and Grace Wahba, (1979), Smoothing Noisy Data with Spline Functions: Estimating the Correct Degree of Smoothing by the Method of Generalized Cross-Validation", pp 377-403.

[8] C.S. Burrus, J.H. McClellan, A.V. Oppenheim, T.W. Parks, R.W. Schafer & H.W. Schussler. Computer-Based Exercises for Signal Processing Using MATLAB. Prentice-Hall, 1994.

[9] D.C. Preston, B.E. Shapiro, Electromyography and Neuromuscular Disorders, Butterworth-Heinemann, Boston, 1998.

[10] E. Stalberg, S. Andreassen, B. Falk, H. Lang, A. Rosenfalk, W. Trojaborg, Quantitative analysis of individual motor units potentials: a proposition for standardized terminology and criteria for measurement, J. Clin. Neurophysiol. (1986), pp 313–348.

[11] E. Stalberg, M.Sonno, assessment of variability in the shape of MUAP, the "jiggle", at consecutive discharges.

[12] Emmanuel C. Ifeachor & Barrie W. Jervis "Digital signal processing a Practical Approach" second edition (Publisher: Pearson Education Asia).

[13] I.Rodriguez-Carreno, A. Malanda Trigueros proposed an approach for the segmentation of EMG signal, (2006).

[14] J. V. Basmajian and C.J.Deluca, "Muscles Alive, Their Functions Revealed by Electromyography", Williams & Wilkins, Baltimore, fifth edition, (1985)

[15] Jhnjun Fang, Bhagwan T. Shahan, Francis "Estimation of single motor unit discharges" pattern based on fractional process on patient, (1995),pp 1327-132