BISPECTRAL ANALYSIS OF SURFACE EMG

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Abstract: The objective of this ongoing study is to investigate whether or not Bispectral analysis (BS), a particular form of higher order spectra (HOS), may be utilized for analyzing the surface electromyographic signal (SEMG). The bicoherence index was used for characterizing the Gaussianity of the signal. Results indicate that SEMG signal distribution is highly non-Gaussian at low and high levels of force whereas the distribution has its maximum Gaussianity at the mid level of maximum voluntary contraction (MVC), i.e. at 50%. A measure of the linearity of the signal, based on deciding whether or not the estimated bicoherence is constant, follows the reverse pattern with the measure of Gaussianity. The power spectrum's (PS) median frequency, decreases from 105 to 93 Hz with increase of force, whereas the number of turns and the number of zero crosses increase with force. Further work is currently in progress in order to evaluate the usefulness of HOS in normal subjects and subjects suffering from neuromuscular disorders.

Index terms: Surface electromyography, Bispectral analysis, Power spectrum analysis.

I Introduction

Analysis of physiological signals using Power Spectrum (PS) techniques has been a well-accepted method for the last few decades. Due to the limitations though to: (i) detect and characterize existing non linearities in the SEMG signal, (ii) estimate the phase, and (iii) extract information due to deviations from normality [1], Higher Order Statistics (HOS), have been introduced in the 1960's and applied in the 1970's. Early attempts to use these in physiological signals have been reported and applied in electroencephalogram (EEG), with promising results. [2]. No attempts have been made, however, to utilize these in electromyography signals and, in particular, surface electromyography signals. (SEMG)

This study exploits the use of HOS in SEMG signal analysis in order to extract new parameters that could enhance the diagnostic character of SEMG.

II Materials and Methods

Data Capture. SEMG was recorded from the biceps brachii muscle of seventeen normal subjects (13 male and 4 female), aged between 25 and 55 years, using a four-bar EMG active probe, with an interelectrode distance of 10 mm and a bar width of 1 mm.

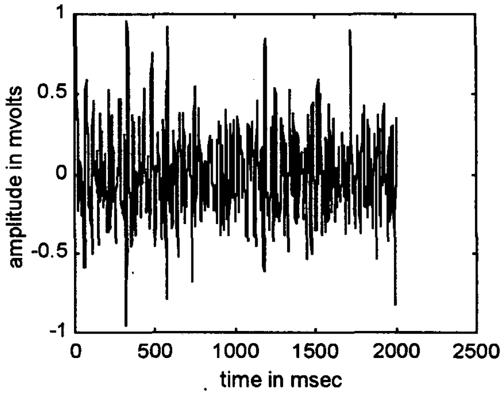

Figure 1: SEMG recorded for a subject at 50% MVC.

A bar configuration has been preferred, from the well-accepted circular configuration, since a bar type electrode intersects with more fibers than a circular type. By intersecting more fibers a greater amplitude will be recorded [3]. From the four bars of the electrode, the second was used as allocation index. In particular it was placed at a distance equal to 1/3 of the biceps length. This ensures that all four electrodes lay between the innervation zone of the motor unit and the tendon. The differential recordings were recorded simultaneously one from each pair of the electrode bars. Recordings were performed for 5 seconds at 10%, 30%, 50%, 70% and 100% of the maximum voluntary contraction (MVC). The sampling frequency was 1000 Hz and the signals were band pass filtered between 20 Hz and 500 Hz with. Furthermore, the skin temperature was noted, since it has been verified that the mean frequency or the mean power frequency of the EMG signal decreases with a reduction in muscle temperature [4]. A typical section of the recorder SEMG signal for a subject at 50% MVC is depicted in Fig. 1.

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Time domain analysis. The number of turns was defined as the number of slope reversals separated from the previous and the following turn by an amplitude difference greater than 50 μV. The number of zero crossings per second was defined as the number of sign reversals exceeding a threshold of 50 μV.

Power spectral analysis. The following measures were estimated from the power spectrum curve: median frequency, f_p, frequency at max power, f_{pmax}, max power, P_{max}, and total power, P_{total}. The signal was segmented at 512 points with 25% overlap.

Bispectral analysis. For a zero-mean, stationary process $\{X(k)\}$, the third-order cumulant (TOC) is defined as the expected value of the triple product

$$R(m,n)=E\{X(k)X(k+m)X(k+n)\}, \tag{1}$$

and the bispectrum is defined as the Fourier transform of the TOC sequence [5]:

$$B(\omega_1,\omega_2)=\sum_{m=-\infty}^{m=\infty}\sum_{n=-\infty}^{n=-\infty}R(m,n)e^{-j(\omega_1 m+\omega_2 n)}. \tag{2}$$

In addition, the sum of magnitudes of the estimated bispectrum is computed by

$$D=\sum_{(\omega_1,\omega_2)}|B(\omega_1,\omega_2)|. \tag{3}$$

To quantify the non-Gaussianity of a random process, the normalized bispectrum, or bicoherence is estimated as

$$B_n(\omega_1,\omega_2)=\frac{B(\omega_1,\omega_2)}{\sqrt{P(\omega_1)P(\omega_2)P(\omega_1+\omega_2)}}, \tag{4}$$

where $P(\cdot)$ is the power spectrum. The test of Gaussianity is based on the mean bicoherence power defined as

$$S_g=\sum|B_n(\omega_1,\omega_2)|, \tag{5}$$

with the summation performed over the non-redundant region.

The Gaussianity test (actually zero-skewness test) basically involves deciding whether or not the estimated bicoherence is zero. The linearity test involves deciding whether or not the estimated bicoherence is constant in the bifrequency domain, employing a measure of the difference (dR) between a theoretical and an estimated inter-quartile range R.

The BS analysis was performed with Hispec toolkit by MATLAB 5.3 (Mathworks Inc). The signal was segmented into overlapped records, for reducing the variance of the estimated BS, using a window of 512 points in length with a 25% overlap. The analysis for the Gaussianity test was accepted if the probability of false alarm, was less than 5%. The linearity analysis was accepted if the difference between the estimated statistic R was not more than a factor of two difference than the inter-quartile range of X^2_2 (λ) (the X^2 distributed random variable, with 2 degrees of freedom and non-centrality parameter, λ.

Seventeen percent of the recordings failed the Gaussianity criteria and fourteen percent failed the Linearity criteria as mentioned above. Analysis was performed using the Hispec toolkit by MATLAB.

III Results and Discussion

Figure 2 illustrates the PS and BS plots corresponding to the SEMG signal depicted in Fig. 1. Moreover, Table 1 tabulates the average parameters of all seventeen subjects from both pair of electrodes. Furthermore, in Fig. 3, the average degree of Gaussianity of all seventeen subjects is plotted against the various force levels used for both pairs of electrodes.

From the time domain analysis parameters, it is observed that the number of zero crossings and turns per second increases with force levels (FL). It should also be noted that there is no major difference between recordings of the two pairs.

From the frequency domain analysis parameters it is noted that the power spectrum median frequency decreases from 105/107 (1st electrode pair/2nd electrode pair), to 93/97 Hz with increase of FL, which again is in accordance with previous findings [6]-[8].

The total Power and max Power however increase with FL. These two parameters gave different results, which were more evident at higher levels of force. Similar findings were also reported by Li et al [9].Li studied the differences in total power recorded by the biceps brachii muscle at different force levels (20, 40 and 60% MVC), at distances 5 to 60 mm, between the end plate zone and the midpoint of the recording bipolar electrodes. Li et al reported that in the distal and proximal direction from the end plate zone, there is a great difference of the recorded power at 60%, less at 40%, and nearly no difference at 20% of MVC.

From the bifrequency domain analysis parameters it was found that the test for Gaussianity results are not similar among the two pairs of electrodes. The first pair (see Fig. 3) indicates that the signal becomes less Gaussian for the 10 to 30% transition, has a more Gaussian distribution at 50% and from there on becomes less and less Gaussian. The other pair though, presents a different profile. The Gaussianity increases from 10 to 50%, and with further increase of MVC the signal becomes less Gaussian. Similar findings were recorded for needle EMG [10]. However a measure of the signals linearity, based on deciding whether or not the estimated bicoherence is constant, follows the reverse pattern with that of Gaussianity.

Table 1: Average parameters analyzed for all 17 subjects for both pairs of electrodes. For each force level, the values of the 1st and 2nd recording electrode pairs are given, separated by backslash (/). (1st pair/2nd pair).

	Time domain		**Frequency domain**				**Bispectrum domain**	
% of MVC	**Zero Crossings/ Second**	**Turns/ Second**	**Median frequency fp_{median} (Hz)**	**Frequency at max Power (Hz)**	**Total power Pt (nV^2Hz)**	**Max Power Pmax (nV^2Hz)**	**Gaussianity Test S_g**	**Linearity test dR**
10	4/2	12/8	105/107	75/80	2/2	33/46	230/251	1.54/1.51
30	24/16	36/32	95/103	78/75	14/7	359/194	249/239	1.68/1.38
50	48/36	76/68	98/103	76/74	21/18	649/215	239/193	1.31/1.0
70	76/70	108/104	96/99	81/82	80/48	1860/1130	305/242	1.76/1.22
100	112/110	146/146	93/97	68/75	127/68	6740/4000	344/303	2.35/1.84

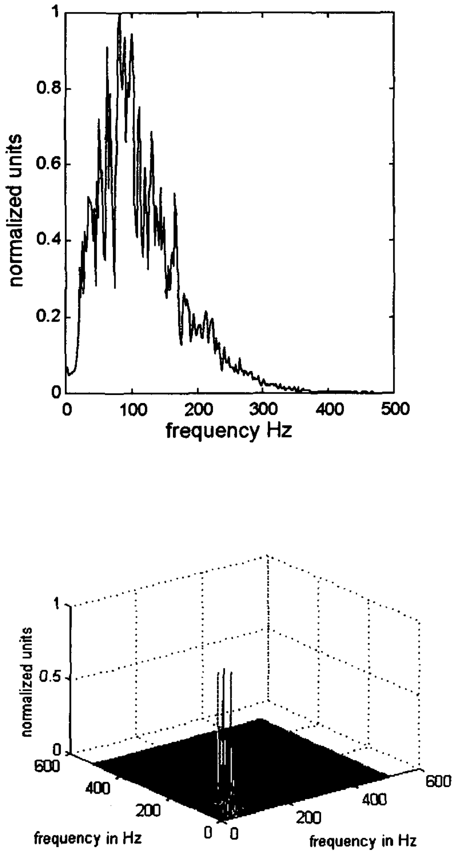

Figure 2: Power spectrum curve (top) and bispectrum curve (bottom) of the SEMG signal shown in Fig. 1.

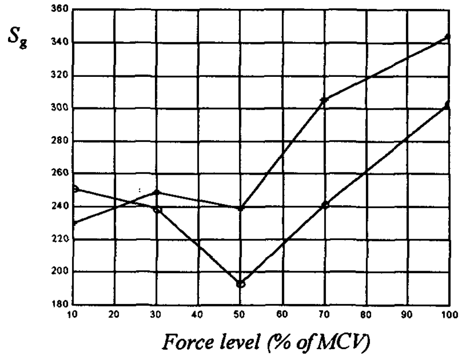

Figure 3. Change of Gaussianity, Sg with force level, for 1st (solid line) and 2nd (dashed line) recording pair.

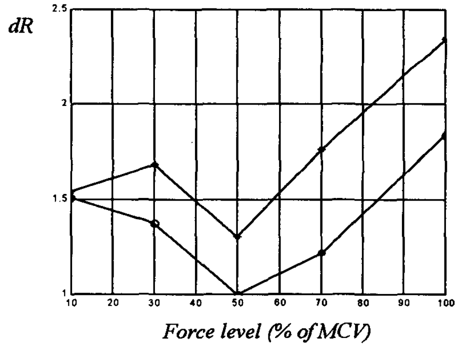

Figure 4. Change of Linearity, dR with force level, for 1st (solid line) and 2nd (dashed line) pair.

The average values for the linearity test are shown in Fig. 4. From this figure it is clear that the two pairs follow the same pattern, which is the reverse pattern of the first pair of the Gaussianity test as shown in Fig. 3. In this case, the signal seems to be less linear at 50% of MVC and more linear at 100% of MVC.

V Conclusions

The aim of this study was to investigate the usefulness of bispectral analysis in SEMG. Besides Bispectral analysis, time domain parameters and frequency domain parameters were examined. As expected, number of zero crossings and turns per second increased with FL.

From the frequency domain analysis, it was evident that the median frequency decreases with FL. Total Power and max power increase with FL, but they are also position dependent, as this was verified with the two electrode pairs used for recording. This was even more evident at higher levels of force.

Bispectrum analysis is also position dependent, since the first pair indicated that the signal become less Gaussian for the transition at low and high levels of force and has its maximum Gaussianity value at 50% of MVC. The other pair of electrodes which was positioned 20 mm away (mid point of two pairs), showed an increase of Gaussianity up to 50% of MVC and a decrease from there on. A measure of the Linearity showed an exact reverse pattern with that of Gaussianity.

More work is currently in progress to firstly to increase the data bank, with more recordings, for normals, as well as to develop a data bank with recording from subjects suffering with neuromuscular disorders.

VI Acknowledgements

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VII References

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