REVIEW OF SEMG FEATURES FOR MUSCLE FATIGUE DETECTION AND FORCE ESTIMATION

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Abstract: *Nowadays, muscle signal (i.e. EMG) gets lots of attention in the application domain. There is lots application which uses SEMG (surface Electromyography) signal as a control signal to control the devices, such as robotic arm, assistive devices, myoelectric arm, etc. The SEMG providing an information about the magnitude of generating force and the functionality of the devices can be affected by the induced fatigue as it changes the behavior of SEMG signal. Detection of the presence of the muscle fatigue in addition level of fatigue help to improve the performance of the devices. This paper intended to review the features of the SEMG signal which help to detect the presence of the muscle fatigue and in addition algorithms to estimate the muscle force and muscle fatigue level from SEMG signal.*

Index Terms **– SEMG, muscle fatigue, muscle force, fatigue level detection, muscle force estimation.**

I. INTRODUCTION

Muscles have their own importance in our day to day life. Anything we do voluntary or involuntary related to the movement it's all because of contraction and relaxation of particular muscle or group of muscle. For example, the heart pumps the blood because of the cardiac muscles contraction and relaxation cycle. As another example, we are able to walk because of the groups of muscle activating and relaxing in a synchronous manner, [1].

The function of the muscle can be described as the force generating unit and as the force generated by the muscle increases so the electromyography (EMG) signals amplitude. But, muscle has a limit to generate the force, which can be improved by doing the exercises. The main factor which restricts the function of the muscle is the "MUSCLE FATIGUE". As muscle fatigue arise the force generated by the muscle decreases, extra efforts needed to maintain the force. Muscle Fatigue is nothing but the state of muscle which represent the muscle tiredness. Muscle functionality can also be affected by the weakening of muscle, [2].

Electromyography records the electrical activity of the muscle or group of the muscle by means of electrodes. EMG can be recorded invasively or non-invasively. Nowadays, the non-invasive way is more popular and its record the signal from the superficial muscles. But still for recording the activity of deep muscles invasive method is the only way, [3].

EMG signal will be conditioned by the means of signal conditioning technique and can be used to diagnose the muscle functionality and can be used for various applications like, to control the robotic arm and so on.

From now onwards the important features of SEMG (Surface EMG) to detect the presence of muscle fatigue and to estimate the muscle force. In addition, an algorithm to estimate the muscle force generated and algorithm for muscle fatigue level detection will be reviewed.

II. LITERATURE REVIEW

A. ROLE OF HIGH FREQUENCY (HF) BAND AND LOW FREQUENCY (LF) BAND IN MUSCLE FORCE ESTIMATION AND FATIGUE DETECTION

Yewguan SOO in their published paper titled as "Simultaneous measurement of force and muscle fatigue using frequency-band wavelet analysis" tested and validated the hypothesis, which states frequencies components above 60 Hz reflect the activity of FORCE generated by the muscle and below 45 Hz reflect the activity of FATIGUE arise in the muscle, for both static and dynamic contraction on Flexor Digitorum Superficialis muscle, [4].

To do so, first of all, they derived the MVC (Maximum Voluntary Contraction) of the subject by recording MVC value from three consequent trials with 5 minutes rest between two trials and then calculated averaged MVC for reference.

The second phase comprises of the recording SEMG signals first for static contraction and then after for dynamic contraction with force value 60% of MVC. In between 15 minutes break was provided. For static contraction experiment, the subject has to maintain the force till their muscle exhaust. For dynamic contraction phase, the subject has to contract and relax the muscle by squeezing and releasing the dynamometer, this complete a cycle which comprised of 10 seconds. Subject has to repeat mentioned pattern for dynamic recording several times without taking any break (refer Fig.1).

Now, the last step remains is signal processing, they used Continuous Wavelet Transformation method and sixth order Symlets (Sym6) as a mother wavelet. And divide the SEMG signals into two frequency bands coefficient, HF band (f > 60 Hz) and LF (f < 45 Hz) band, obviously using CWT. Then calculated the RMS value from those coefficients (refer Fig.2).

In results, they found that the graph of RMS value from the HF band show the strong correlation with the force curve from the dynamometer and the curve of the LF band showing the upward trends as fatigue arise, both in static contraction and dynamic contraction experiments (refer Fig.3 & Fig.4).

It can be concluded that it is possible to measure force and fatigue simultaneously from SEMG signal by processing separately HF band and LF band for Force and Fatigue, respectively, [4].

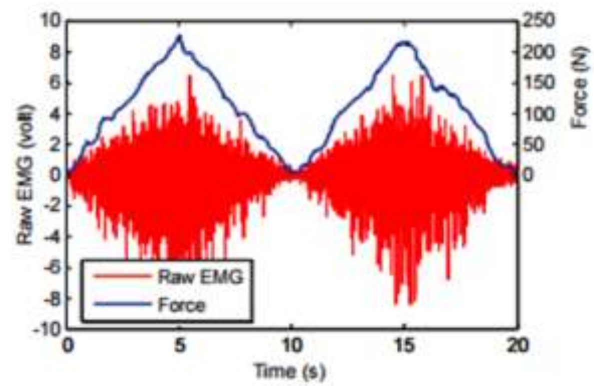

Figure 1: Signals recorded during Dynamic contraction experiment, [4].

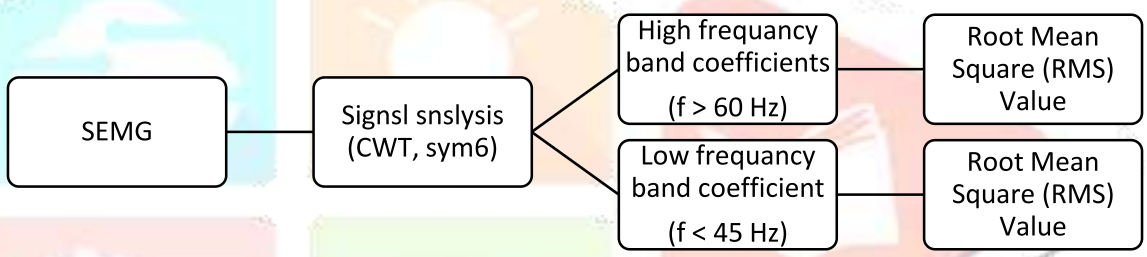

Figure 2: Block diagram illustrating steps followed in the experiment.

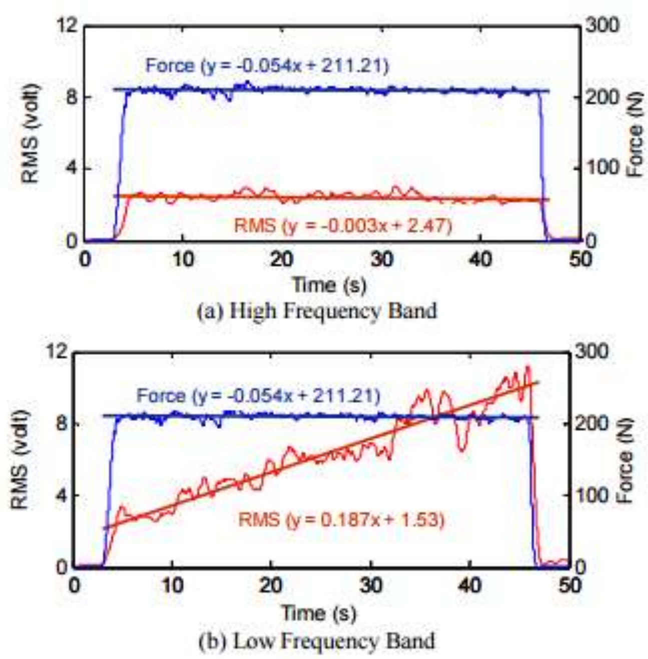

Figure 3: Static contraction (a) Force and RMS signal of HF band (b) Force and RMS signal of LF band, [4].

B. IMPORTANT FEATURES OF SEMG SIGNAL TO DETECT THE PRESENCE OF MUSCLE FATIGUE

Ming Dong investigated the correlation between Mean Frequency (MF), Median Frequency (MDF) and Root Mean Square (RMS) (of the frequency band 5 – 45 Hz) during muscle fatigue condition in their work named as "sEMG Feature Analysis on Forearm Muscle Fatigue During Isometric Contractions", [5].

The experiment was comprised of two steps, first of all, subjects mean MVC value was calculated from three MVC reading recorded by gripping the dynamometer with maximum force and 2 minutes break was provided between trials. As second steps, SEMG was recorded (Sampling Frequency (Fs) = 1000 Hz) from the Flexor carpi ulnaris of the right forearm while subject maintaining the force at 60% MVC by clutching grip sensor till muscle exhaust. Refer Fig.5 for a schematic of the measurement setup.

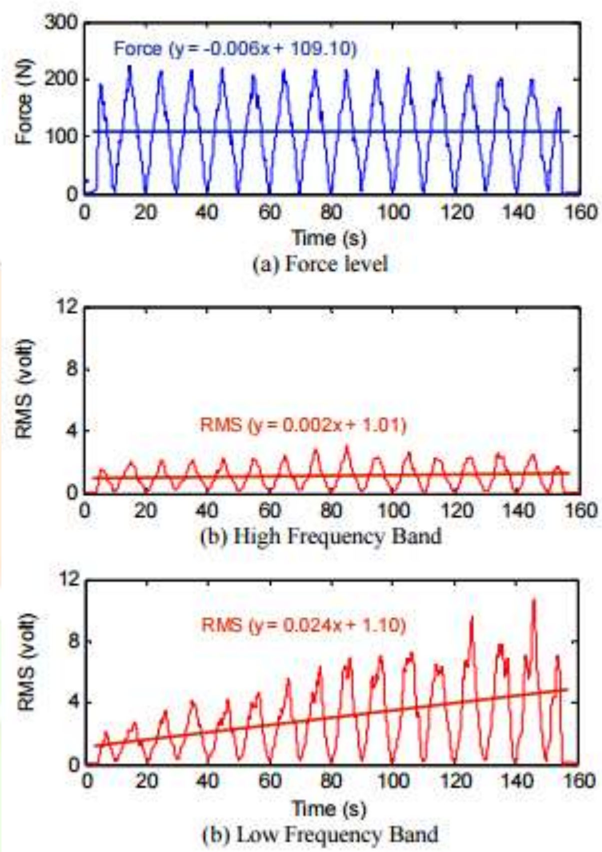

Figure 4: Dynamic contraction (a) Force signal (b) RMS signal of HF band (c) RMS signal of LF band, [4].

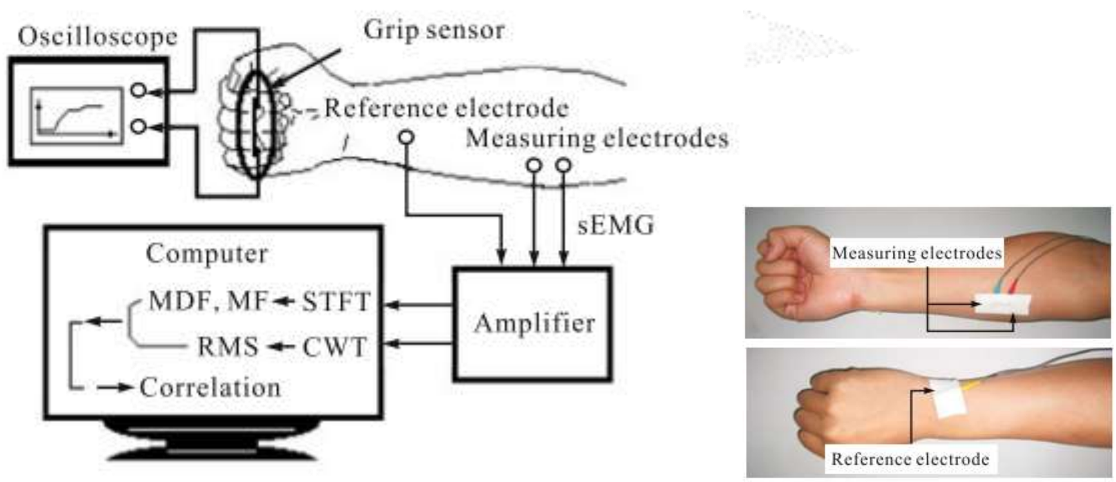

Figure 5: Schematic of an experimental setup, [5].

The data analysis was done in four steps. First of all, they have used STFT for spectrum analysis and plotted spectrogram of SEMG signal with window length equal to 1024 samples. Then MF and MDF curve plotted. In next step, they calculated RMS value of frequency band of 5 – 45 Hz using CWT (Sym6) analysis with 0.5 sec window length and smoothen the RMS data using

2nd order Low-pass filter with 25 Hz cutoff frequency. In the last step, they calculated the correlation coefficients between each pair of MF, MDF, and RMS.

The spectrogram shows that SEMG signal comprises of the frequency components between 25 – 150 Hz and as fatigue increase, the energy of the high-frequency component decreases and same was increases for low-frequency components (refer Fig.7). MF and MDF curves showed a downward trend with time, for better describing the trend they used a linear regression model on the curve (refer Fig.8). The smooth RMS plot showed an upward trend with time (Fig.9). All the three results quite resemble with the past studies. As for correlation coefficients of each pair of MF, MDF, and RMS for all participants shown in table 1. The mean correlation coefficients for each pair are larger than the 0.8, which evident the strong correlation between three parameters of SEMG signal on forearm muscle fatigue during isometric condition.

In the end, it is concluded that frequency spectrum shifting toward low frequency as fatigue arise and fatigue presence can be detected by extracting the MF, MDF, and RMS from recorded SEMG signal, as former two follow the downward trends and last one follow the upward trend, [5].

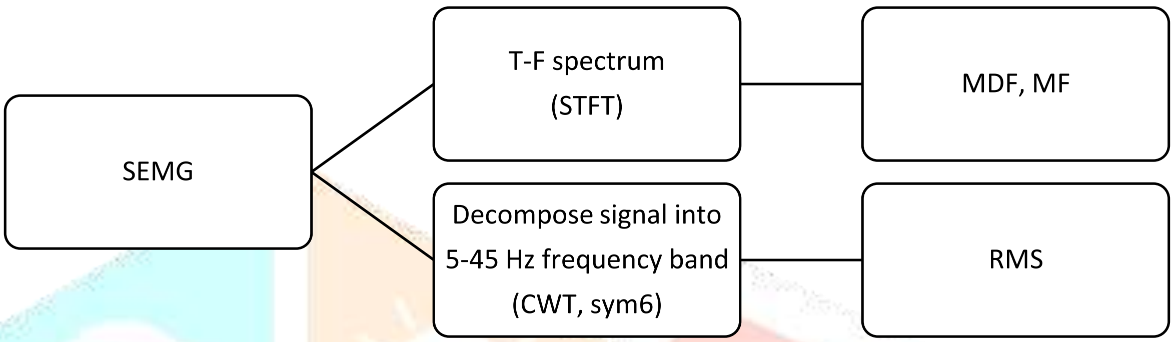

Figure 6: Block diagram of the data analysis.

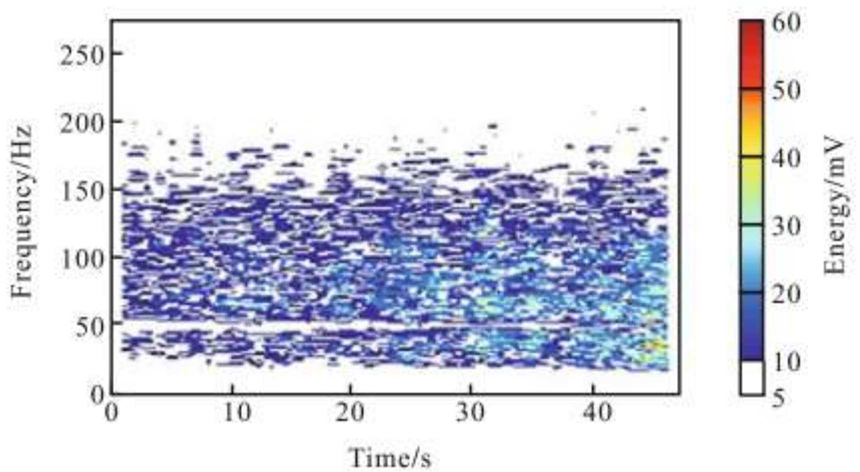

Figure 7: Spectrogram of SEMG during isometric contraction, [5].

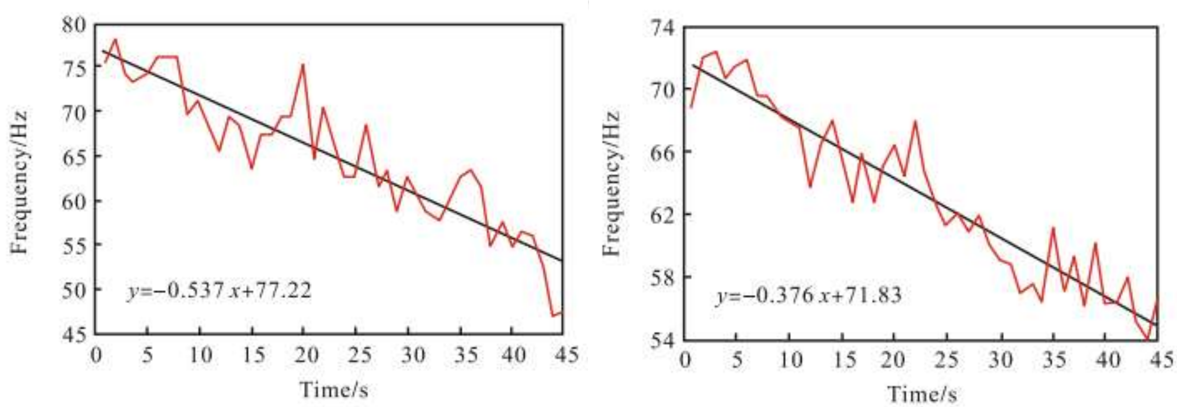

Figure 8: Changes in MDF (left) and MF (right) with time, [5].

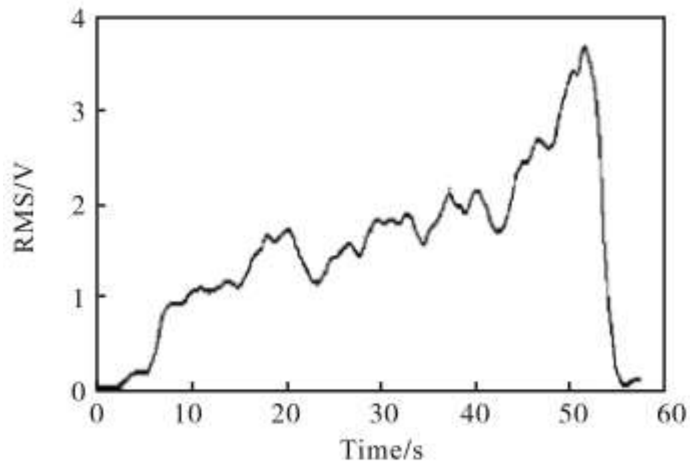

Figure 9: Changes in RMS value (5 – 45 Hz) with time, [5].

Table 1: Correlation coefficients between each pair from four subjects, [5].

Subject	RMS-MDF	RMS-MF	MDF-MF
1	−0.834	−0.867	0.912
2	−0.832	−0.847	0.962
3	−0.853	−0.859	0.978
4	−0.746	−0.726	0.945
Mean	−0.816 ± 0.047	−0.825 ± 0.066	0.949 ± 0.028

C. ESTIMATION OF MUSCLE FORCE AND MUSCLE FATIGUE LEVEL

Tomasz Marek Lubecki, in “Development of Intuitive Human-Machine Interface based on Electromyography for Assistive Robot (KAAD)” presented a work related to “knee active assistive device” which detect the user intention and provide assistance to the user in their action, in real time, using SEMG signal as a source of information. They had described the development of hardware, an algorithm for Force/Torque estimation and muscle fatigue level detection, [6]. Here, an algorithm for force estimation and muscle fatigue level detection will be reviewed.

The Force/Torque estimation algorithm, Fig.10, estimate the intended level of torque from SEMG signal and this data will be provided to the assistive device so device generates that much torque. To do so, SEMG signal was recorded with sampling frequency 2.5 KHz and processed with a bandpass filter (35 – 650 HZ). Then RMS value calculated and data normalized to the MVC value which ensure that algorithm work universally. The normalized signal pass to the SEMG to Force estimator to estimate the Torque/Force value. The estimators are different for different muscle. In their work, they had use third order polynomial estimator for biceps brachii, Eq.1.

$$Y = p1 * x + p2 * x2 + p3 * x3 + p4 \qquad (1)$$

Where, p1 = 5703, p2 = -1211, p3 = 93, p4 = -0.5

The estimator output signal filtered by a low-pass filter with 9 Hz cut-off frequency to smoothen the output. Now the final output represents the estimated force generated by the muscle. Which used to drive the actuator. The signal processing was done in less than 60 seconds which means this algorithm can drive the assistive device concurrently or faster than the muscle.

The Fatigue level detection algorithm has its own importance as it can help to improve the functionality of the device as well as to provide advance warning to ensure safety. Past studies have shown that MF is a promising parameter to identify the presence of the fatigue. Tomasz Marek Lubecki used MF and power to identify the fatigue level detection. Block diagram is shown in Fig.11 describe the algorithm they had used for the above-mentioned purpose. First of all signal processing done by using von Hann windowing function to minimize the spectral leakage, in addition, STFT applied and then signal band-passed. Now, the heart of the algorithm comes in the picture, MF and Power (P) derived from the acquired signal and both processed in their separate path. By using MF value the power for non-fatigue condition (i.e. P*) estimated using MF & P* relationship (Fig.12). Value of P* have characteristics to vary not only with power but also with fatigue. The ratio of P to P* was calculated, whose value rise with an increase in fatigue, and passed for the Fatigue Level Detection.

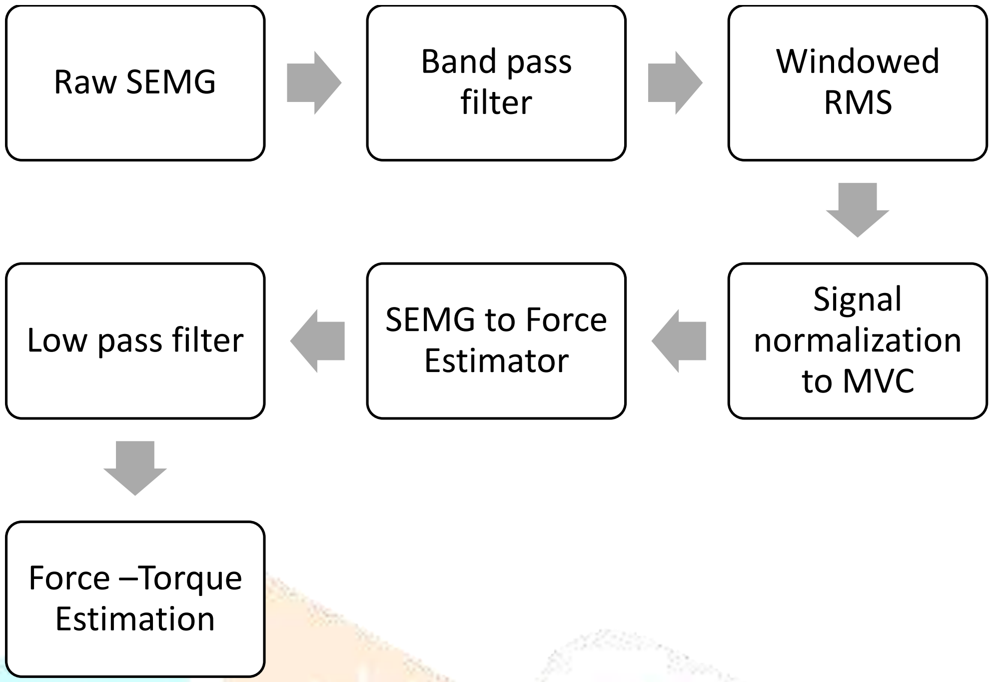

Figure 10: Block diagram illustrating steps followed for Force/Torque estimation, [6].

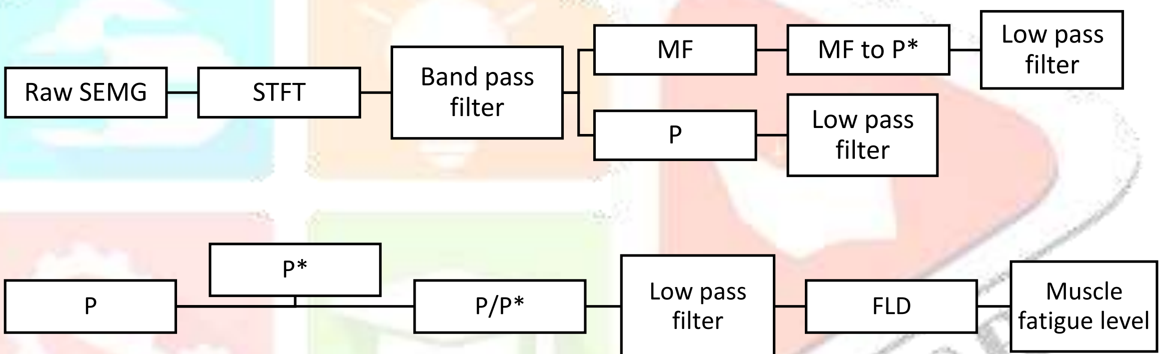

Figure 11: Block diagram illustrating algorithm for muscle fatigue level detection, [6].

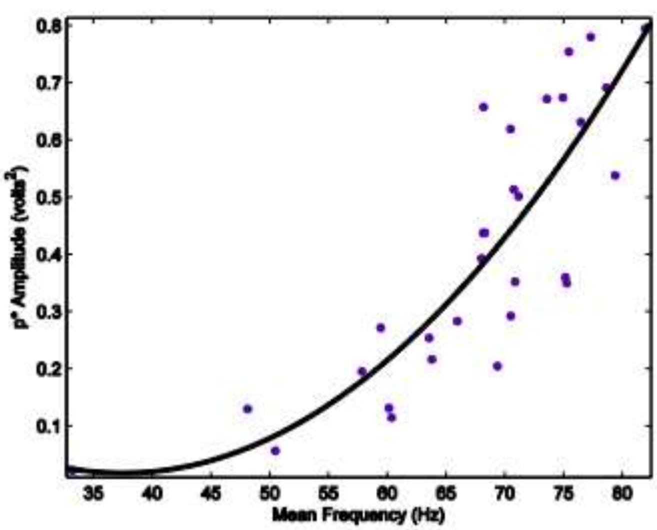

Figure 12: Mean Frequency to P* estimator, [6].

The Fatigue Level detection was following the rule mentioned in Eq.2 and Eq.3:

$$|v| = |v| + 1 \;\text{ if }\; s(n) \geq s_{tc\,|v|} + \varepsilon \qquad (2)$$

$$|v| = |v| - 1 \quad \text{if} \quad s(n) \leq s_{tc\,|v|} - \varepsilon \qquad (3)$$

Where, $|v|$ is discrete value of fatigue level,

$s(n)$ is continuous fatigue value for n^{th} input sample,

$s_{tc\,|v|}$ is a signal threshold value for given level of fatigue, and

ε is a hysteresis value.

The experiment was divided into two stage one for force measurement and second for fatigue level detection. For force measurement subject had to apply force on force gauge which measures the applied force and by using force estimation algorithm force value was derived from the SEMG signal and plotted as shown in Fig.13. Which show that algorithm curve closely follows the actual force curve of force gauge.

As part of testing fatigue level detection subject had to maintain the force at 92 N and fatigue level detection done. Results for these shown in Fig.14. The curve of P/P* was increasing with respect to time as fatigue was increasing and so the fatigue level.

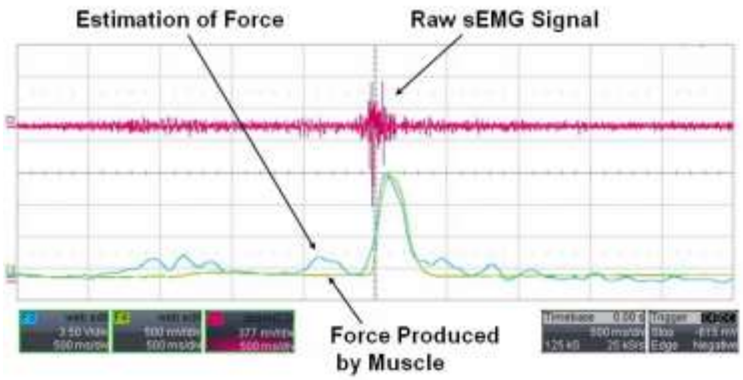

Figure 13: Force produced by muscle (force gauge reading), force estimation and the Raw SEMG signal, [6].

Referring to result in this work shown promising output, but as it was tested on less number of subject (as seems from the paper), a large number of experiments are needed to be conducted for further validation to ensure the reliability of the algorithms.

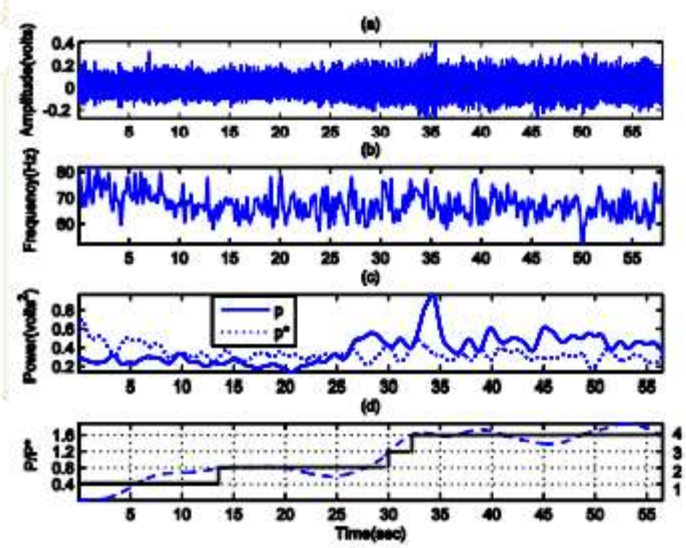

Figure 14: Fatigue detection results from the static contraction. (a) SEMG signal, (b) Mean Frequency, (c) P and P*, (d) P/P* and muscle fatigue level with range 1 to 4 where 1 means no fatigue and 4 is a significant level of fatigue, [6].

D. THE EFFECTIVENESS OF MUSCLE FATIGUE LEVEL DETECTION ALGORITHM IN ISOMETRIC AND DYNAMIC CONTRACTION

Fengjun Bai, in “Novel Time-Frequency Approach for Muscle Fatigue Detection Based on SEMG” developed a fatigue level detection algorithm and compared with using STFT & CWT as a feature extraction method for both isometric and dynamic contraction with minor changes in algorithm reviewed above (refer Fig.15), [7].

The relation between MF and P* was given by the second order polynomial estimator Eq.4 for both methods: STFT and CWT, [7].

$$Y = m1*x2 + m2*x + m3 \qquad (4)$$

Where,

For CWT, m1=2.1464, m2=-54.14, m3=215.8

For STFT, m1=0.0004, m2=-0.029, m3=0.531

Experimental protocol designed in two steps, first subjects had to perform three isometric trials at 20% MVC, at 40% MVC, and at 80% MVC till exhausted. Second step designed for dynamic contraction in which subject generate force up to 60% MVC from relaxing state and get back to relax state, same will be repeated till exhausted. One maximum force was exerted after each 60% MVC cycle. The force generated by the subject during elbow flexion (targeted muscle biceps brachii) measured by the force measuring strain gauge and displayed on a computer screen with target force, [7].

For both isometric and dynamic contraction, for both STFT and CWT methods, results showed a decrease in MF, increase in P and slowly decrease in P* values (Fig.16 and Fig.18). In Fig.17, fatigue presence curve and fatigue level shown. In results, STFT and CWT reached a Fatigue level 3 almost at same time, while CWT shows faster rise from level 1 to level 2.

For dynamic contraction, CWT method reaches 3rd fatigue level faster than STFT method. It was seen that at 58 sec fatigue level jump to a higher level for a while and then shift back to 3rd level, which is because of instability due to fast velocity dynamic muscle contractions, signal artifact noises, electrodes location and comparison ratio Q (refer Fig.19), [7].

This algorithm had shown its effectiveness for both isometric condition and dynamic contraction. More experiment still needs to be performed for a different muscle group and also for lower extremities for further validation.

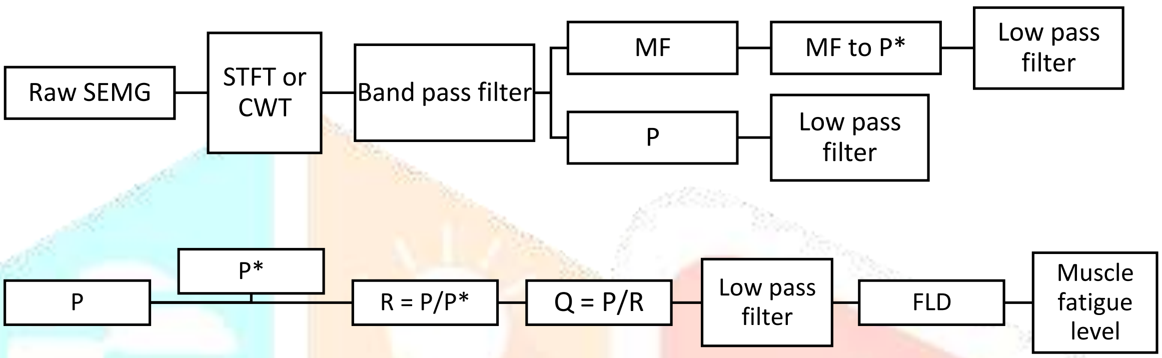

Figure 15: Block diagram of Muscle Fatigue Level Detection, [7].

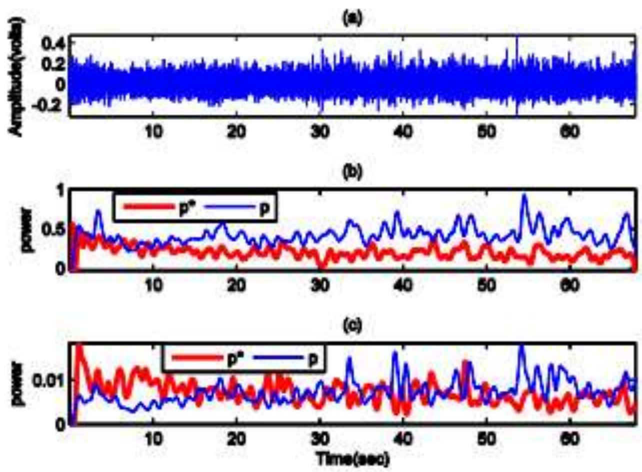

Figure 16: (a) SEMG signal of isometric contraction. (b) P and P* from STFT. (c) P and P* from CWT, [7].

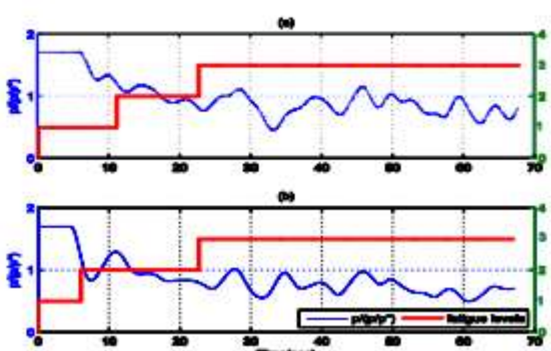

Figure 17: (a) P/(P/P*) and muscle fatigue level with force maintained at 80% MVC from STFT method. (b) P/(P/P*) and muscle fatigue level with force maintained at 80% MVC from CWT method, [7].

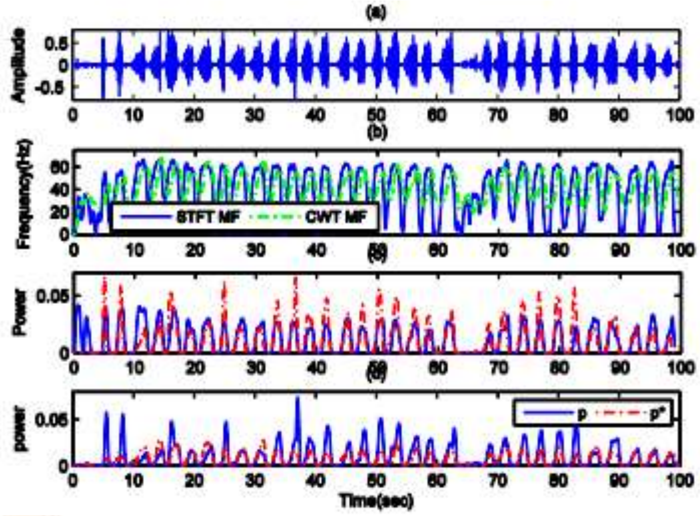

Figure 18: (a) SEMG signal. (b) MF from STFT and CWT. (c) P and P* from STFT. (d) P and P* from CWT, [7].

III. CONCLUSION

From above-discussed methodology and their results below listed point can be concluded:

I. Amplitude value (i.e. RMS value) of the High-Frequency component (f > 60 Hz) of SEMG signal showing a strong correlation with muscle force.
II. The amplitude value of Low-Frequency component (5 Hz < f < 45 Hz) of SEMG signal showing a strong correlation with muscle fatigue and it showing upward trends w.r.t. time as fatigue arises.
III. MF and MDF showing downward trends if traced w.r.t time in presence of muscle fatigue.
IV. Muscle power of the high-frequency components decreases and that's of the low-frequency components increases in fatigue condition.
V. The opposite happens in non-fatigue condition, i.e. muscle power of the high-frequency components increases and that's of the low-frequency components decreases.

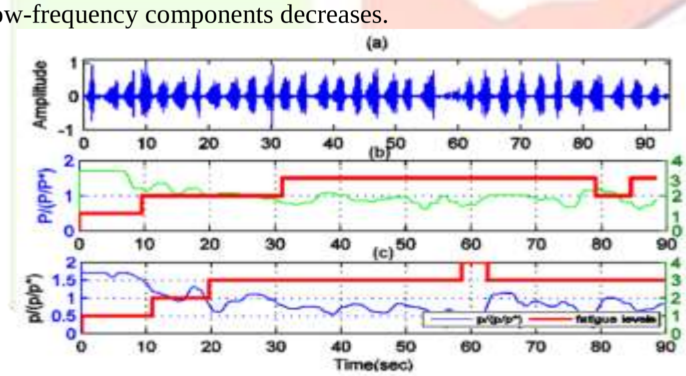

Figure 19: (a) SEMG signal. (b) P/(P/P*) and muscle fatigue level during dynamic contraction from STFT method. (b) P/(P/P*) and muscle fatigue level during dynamic contraction from CWT method, [7].

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