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FILTERING CORNER FREQUENCY USING UNDECIMATED WAVELET TRANSFORM FOR SURFACE EMG

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Abstract

Surface electromyography is a non-invasive electrical potential from human muscle. The signals are easily disturbed by many interference and noise. Lower frequency range of surface electromyography needs to be eliminated due to motion artefacts, instability and unpredictable fluctuation. There is no standard range of corner frequency and it highly depends on the dynamic movement during surface EMG signal collection. Adding high pass filter active or digital may require more cost or computation; yet, sometimes is unable to remove all corner frequency noises. This paper presents a new method in filtering the remaining corner frequency after conventional filter is employed, using Undecimated Wavelet Transform (UWT). Results show that the decomposing surface EMG signals, which are at 1400 Hz frequency sampling of surface EMG signal and at six levels decomposition, are suitable for setting the highest corner frequency within the range of 0-20Hz. Hard threshold de-noising technique and method of UWT reconstruction enable the easy removal of 20Hz corner frequency noise of surface EMG employing the stated parameter.

Keywords: Corner frequency, De-noising, Surface electromyography, Undecimated wavelet transform.

1. Introduction

Surface electromyography (EMG) is an electrical activity of human skeletal musculature acquired from the skin [1, 2]. It can be detected at the occurence of contraction burst during muscle activation and exists within the frequency bandwidth between 20-2000 Hz with an amplitude between 1-10mV [3].

During signals acquisition, noise may emanate and contaminate EMG signals from various sources. Those sources include power line interference signal at the frequency of 50Hz and its harmonics, interference signals generated by tissue/electrode interface and frequency distortion [1, 4].Surface EMG may also be interfered by baseline wander, motion artefacts, interference at electrode-skin interface, instability, unpredictable fluctuation and firing rates, which is commonly known as corner frequency noise [5].

Corner frequency noises in surface EMG have been commonly discussed in previous researches but there is no standard range for the noises. Few recommendations were proposed in removing corner frequency particularly for reporting any related investigations regarding surface EMG data [6]. Merletti & Torino, 1999 recommended neglecting surface EMG signals outside 5-10Hz and adopting a high pass filter at 5Hz as the requirement. On the other hand, Hermie J.Hermens; Bart Freriks, Roberto Merletti; Dick Stegeman; Joleen Blok, 1999 proposed a high pass filter between 10- 20hz; while, Basmajian & De Luca, 1985 recommended 20 Hz as the corner frequency. The difference of corner frequency range depends on the application and movement during surface EMG [6] collection. As more vigorous the movement turns out, the higher corner frequency noises are involved. Selecting corner frequency below 20Hz is not recommended as surface EMG energy is weak below the frequency range; whereas, strong energy corresponds to firing rates or motor units [7]. However, it is recommended to increase corner frequency above 20 Hz to eliminate the artefact effects in particular for surface EMG collected from sports activities [7].

Corner frequency noises are normally removed with active or passive high pass filter (HPF) circuit or digital HPF [3, 8, 9]. Active or passive HPF circuit employs higher order filter circuits to ensure that corner frequency noises are completely removed. Higher order filter circuit usually costly since it involves more electronics components. The employment of HPF digital filter is another solution of corner frequency noises. A good digital filter involves high order for good frequency response, but it requires more computation and creates delay during processing [10]. Since the range of corner frequency noise highly depends on the dynamic movement during surface EMG acquisition process, a fix HPF cut off range may leave partial of corner frequency noise outside the range. Therefore, extended processing is essential to remove the remaining noises.

In processing surface EMG signals, other than eliminating corner frequency noises, other noises also need to be removed such as baseline noises. The baseline noises can be mitigated with wavelet de-noising technique [11-13]. Hence, this paper proposes new technique of removing the remaining corner frequency noises after HPF using wavelet de-noising technique. By employing this technique, both corner and baseline noises can be removed concurrently. Thus, making signal processing is more efficient, less complex and less time consuming.

2. Methodology

2.1. Data collection

First, surface EMG signals were collected on biceps femoris (BF) from twenty participants (24.45± 3.9 years, 22.25± 4 body mass index). The signals were gathered using surface EMG acquisition system which has signals to noise ratio (SNR) up to 25 db [8]. The signals then were acquired utilizing NI-DAQ 6008 with sampling rate at 1000Hz. HPF cut-off at 10Hz was employed to remove baseline wandering noise during surface EMG measurement. Without the HPF during signals acquisition, it was very difficult to recognize surface EMG signals. At this stage, a higher cut-off range was not employed to avoid the elimination of essential signals. Therefore, the actual corner frequency noise range was re-evaluated after data acquired.

Ag/Ag Cl electrodes from Kendal Meditrace 200 were used to acquire the signals. The electrodes were placed according to SENIAM standard. To collect surface EMG signal from BF, initially the participants were needed to place one of their legs one foot (1ft) away from Point C, which was at Point D. Then, the participants were asked to stand and move that particular leg further from Point D to Point E as shown in Fig. 1. Whilst, BF contracted when the hip was extended; the knee flexed [14]. As the body moved 30˚ forward, the knee flexed until the leg was lifted about 15cm to Point E. This distance was selected as it provides the maximum activation of BF during movement [15]. Henceforth, the participants were requested to move their legs from Point D to Point E for three (3) times with ten (10) seconds interval for each position. It is essential to note that the experiment protocol was approved by the institution’s ethical committee.

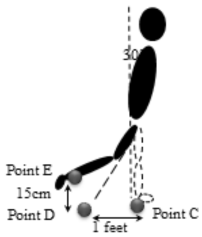

Fig. 1. Knee movement to activate biceps femoris muscle.

2.2. Signals processing

The raw surface EMG signals collected were transformed using Fast Fourier Transform (FFT) to evaluate the range of corner frequency noises. Figure 2 indicates that the corner frequency noises of the collected surface EMG signals were within 0-20 Hz range. It signifies that digital HPF cut off at 10Hz employed during signals acquisition was inadequate to remove the corner frequency noises.

In the experiment, the remaining corner frequency noises were eliminated through wavelet de-noising. The de-noising process involved three main components; decomposition, thresholding and reconstruction. Decomposition process in Undecimated Wavelet Transform (UWT) enables users to access signals at different level of frequency bands with similar resolution sizes. UWT or also known as stationary wavelet transform was purposely designed for de-noising application and introduced to overcome DWT limitation including the unability to be time-invariant transformed and has a drawback [16].

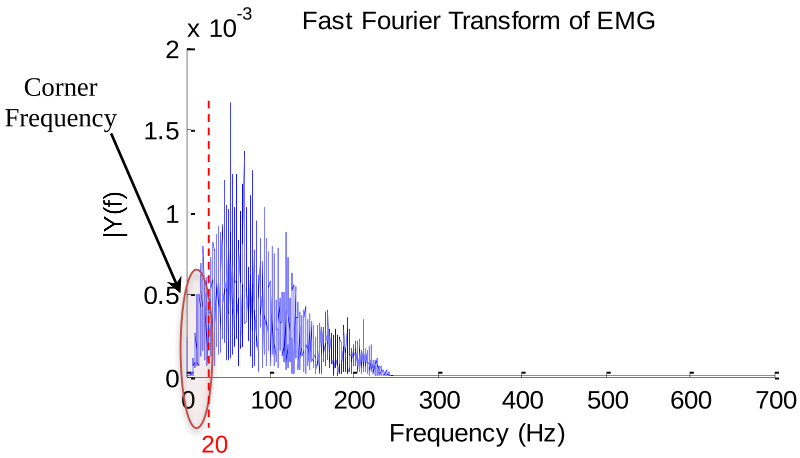

Fig. 2. Frequency spectrum of collected surface EMG signals.

In the first process, the decomposition through UWT enabled the users to access signals at different level of frequency bands with similar resolution sizes. The manipulation of the lowest frequency band range can be performed by determining its sampling frequency and level of decomposition. During the process, signals frequency was cut into halve through high and low pass filters for every level of the decomposition. Theoretically, to set the lowest band for approximation and detail coefficient around 0-20Hz, the frequency sampling of surface EMG signals is required to be set at 1400Hz. Surface EMG would decompose into six levels, which enable the setting of the lowest frequency band approximation, a_6 at 0-10.94Hz, and detail coefficient, d_n at 10.94-21.88Hz as shown in Fig. 3.

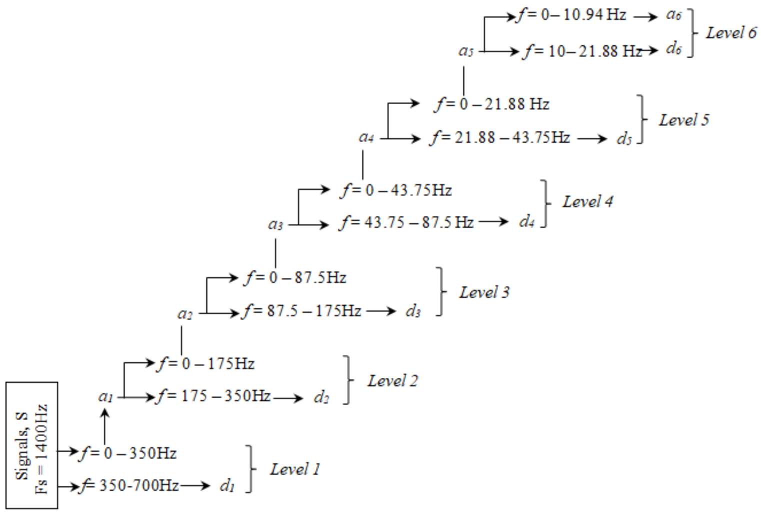

Fig. 3. Setting the lowest decomposition level between 0-20 Hz corner frequency range.

Wavelet de-noising process occurred in the thresholding stage. At this stage, the technique tends to remove/supress samples below threshold value and preserve samples above the threshold value. Moreover, the maximum threshold value was employed to eliminate detail coefficient of level 6th decomposition, d_6. De-noising process only involves detail coefficient, d_6; whereas, the lowest approximation details, a_6 of the decomposition commonly need more computation to be removed. However, by taking advantage on the reconstruction process in UWT, which employs average basis inverse approach, the lowest approximation may be able to be removed or mitigated as in formula (1) [17].

$$a_j[n] = \frac{1}{2}(a_{j+1}[n] + d_{j+1}[n]) \tag{1}$$

where, a = approximation details, d = detail coefficient, n = number of samples and j=level of decomposition.

Figure 4(a) displays the decomposition of collected surface EMG signals into six levels of decomposition using UWT followed by Fig. 4(b), which illustrates the frequency spectrum of detail coefficient. Before the decomposition, the signals interpolate to frequency sampling, F_s 1400 Hz as the frequency band at each level of the detail coefficient are structured as in Fig. 3. Figure 4(a) indicates that surface EMG signals were easily identified at D_4 to D_6 levels of the decompositions. Figure 4(a) also points out that the collected signals were not disturbed by 50 Hz powerline noise. Meanwhile, Fig. 5 reveals that the highest amplitude identified in D_6 was about 0.05V, with the frequency range within 10-23 Hz. However, the signals are advised to be eliminated since it was a trivial energy and actually belonged to discharge and fluctuation known as the corner frequency noises.

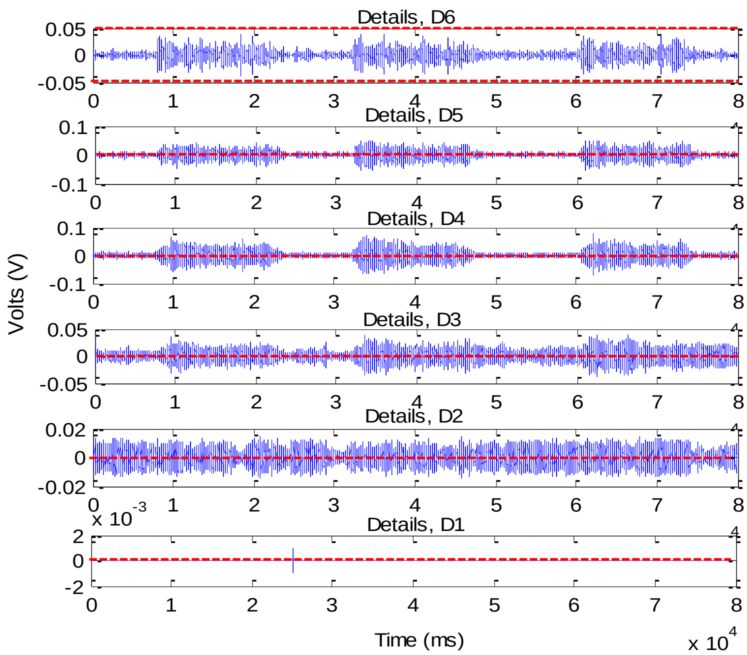

Fig. 4(a). Detailed coefficient, d_n of surface EMG signals at six levels decomposition.

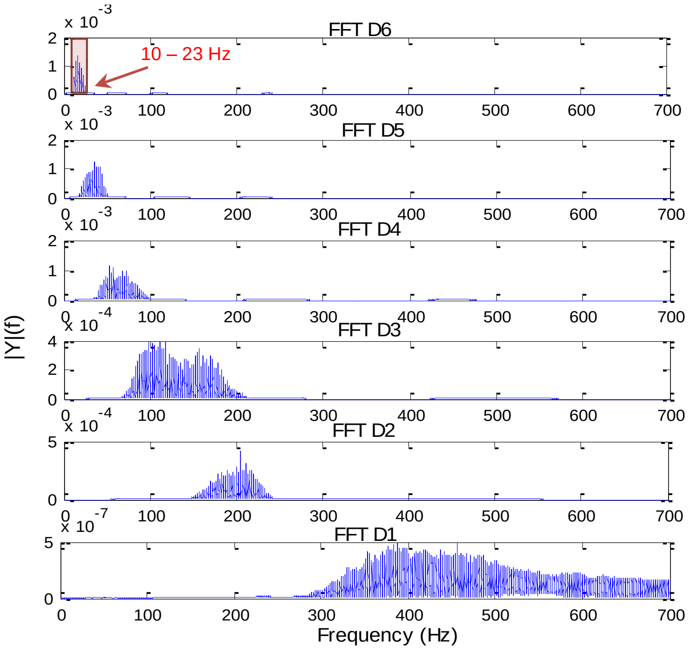

Fig. 4(b). Frequency spectrum of the detail coefficient.

To eliminate the noise, threshold values (red lines in Fig. 4(a)) were set at every level of d_n. Since this paper purposely intends to eliminate corner frequency noises, threshold value for d_6 was set >0.05V (the highest value of d_6) to eliminate signals within this frequency band; whereas, the other levels were set at 0.

Figure 5 shows the approximation details at level 6 of decomposition, a_6 and its frequency spectrum. Although, HPF cut-off at 10Hz was employed during data acquisition, Fig. 5 exhibits the presence of small energy below 10 Hz frequency range in the surface EMG signals. However, the energy did not signify any significant information of surface EMG signals and was simply considered as noises.

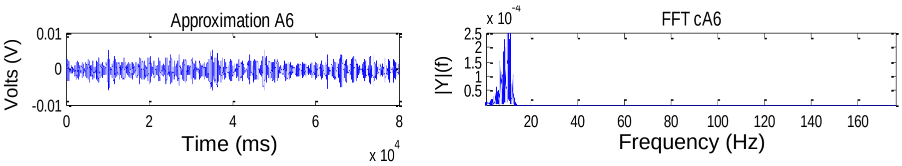

Fig. 5. Approximation coefficient at level 6,a_6
of surface EMG signals and its frequency spectrum

The advantage of de-noising process using UWT is that by eliminating the highest level of detail coefficient, it mitigates the signals at the highest level of the approximation during the reconstruction process. In this case, setting the highest threshold at d_6 mitigated the energy in a_6 frequency band, which was below 10 Hz. As comparison, similar methods were repeated using DWT to demonstrate the ability of both wavelet transforms in eliminating corner frequency noises.

3. Results and Discussion

Results in Fig. 6(b) and Table 1 demonstrate that corner frequency was successfully removed through de-noising process using UWT. The ability to remove the lowest level frequency band of decomposition, which was below 23Hz frequency range, was due to its reconstruction property. Furthermore, Fig. 7 reveals the enlarged image of frequency spectrum at corner frequency range based on UWT and DWT. The reconstruction approach used is based on the average basis inverse, where it averages both approximation and coefficient details of each level. As a result, it produces an energy of the lowest approximation value that is insignificant and can be neglected (see Fig. 6(b)). Compared to DWT reconstruction method (see Fig. 7), the reconstruction started from the upsampling of approximation details which disables the lowest frequency band so that the removal would be easier; while, retaining the energy.

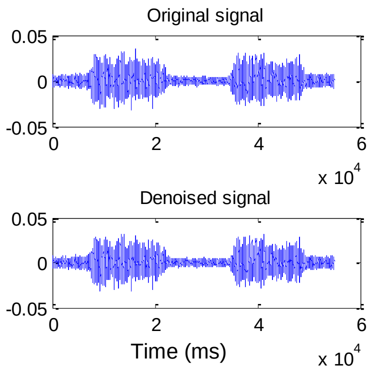

Fig.6. (a) Original and de-noised signals using UWT.

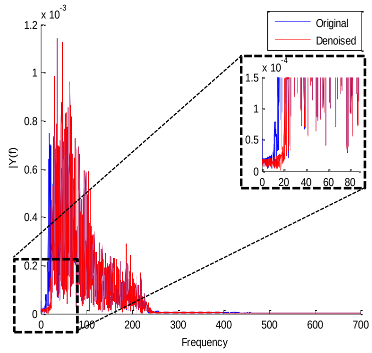

Fig.6. (b) Frequency spectrum of original and de-noised using UWT.

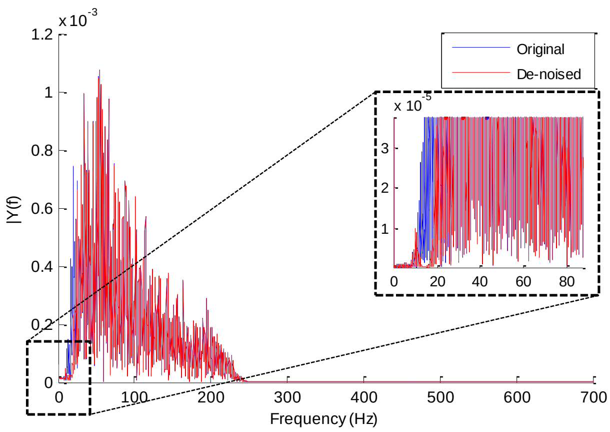

Fig. 7. Energy at corner frequency range after de-noised using DWT.

Table 1. Results comparison of original and de-noised.

	Lowest Frequency (Hz)	SNR (dB)	Baseline Value (V)
Original Signal	0	6.44 ± 3.49	0.0042 ± 0.00015
De-noised Signal using UWT	20 ± 2.55	6.25 ± 3.50	0.0042±0.0001
De-noised Signal using DWT	0	6.30 ± 3.50	0.0042 0.00013

Results in Table 1 indicates the lowest frequency identified after de-noising using UWT is 0Hz. This demonstrates that the proposed method has successfully removed corner frequency noises using UWT. Table 1 also proves that similar method adopted using DWT was unable to remove corner frequency noises completely especially below 10Hz as supported in Fig. 7. Results tabulated in Table 1 further show that removing corner frequency noises through UWT and DWT was unable to increase SNR value. It is also important to note that in calculating SNR of surface EMG, it was denoted as a ratio between the contraction signals to the baseline. The lower value of SNR after de-noising was due to the corner frequency noises which fluctuated and were unstable signals occurred in high amplitude compared to the essential surface EMG signals. Eliminating the noises causes the de-noised signals to have slightly lower amplitude and leads to lower SNR.

At this stage, eliminating corner frequency noises may not show any significant effects on the quality of surface EMG signals. The quality of the signals can be further enhanced by removing baseline value as demonstrated in [18]. In addition, the process presented in this paper was assisted by HPF cut-off at 10 Hz during signals acquisition stage. However, eliminating corner frequency noises is still required as expected by certain high impact journals in reporting any surface EMG related investigations. The existence of corner frequency noises may demonstrate misleading interpretations.

4. Conclusions

Results of the investigation as shown in the paper indicate that there are alternative methods in eliminating the remaining of corner frequency noises. This paper has demonstrated that the selection of wavelet transform is significant in ensuring the expected noises to be completely removed. The methodology employed in this paper can be integrated with other wavelet processing in eliminating different sources of noises such as baseline noises or powerline interference (if any). The integration with other methods in wavelet de-noising may reduce cost and time consumption as well as algorithm complexity in the future.

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Nomenclature

a_n	Approximation coefficient
d_n	Detail coefficient
F_s	Frequency sampling

Abbreviation

DWT	Discrete Wavelet Transform
EMG	Electromyography
FFT	Fast Fourier Transform
HPF	High Pass Filter
SNR	Signal to Noise Ratio
UWT	Undecimated Wavelet Transform

References

1. Nagel, J.H. (2000). *Biopotential amplifiers.* In *The biomedical engineering handbook: Second Edition*. Bronzino, J.D. (ed.). CRC Press.
2. Medved, V.; and Cifrek, M. (2011). Kinesiological electromyography. *Biomechanics in Applications*, 349-366.
3. Thakor, N.V (1999). *Biopotentials and electrophysiology measurement*. In *Measurements, Instrumentations and Sensors Handbook*, CRC Press.
4. Neuman, M.R. (2000). *Biopotential electrodes*. In *The biomedical engineering handbook: Second Edition*. Bronzino, J.D. (ed.). CRC Press.
5 Basmajian, J.V.; and De Luca, C.J. (1985). *Muscles alive - Their functions revealed by electromyography.* (5th ed.) Williams & Wilkins.
6. De Luca, G. (2003). *Fundamental concepts in EMG signal acquisition.* Boston: Delsys Inc.
7. De Luca, C.J.; Gilmore, L.D.; Kuznetsov, M.; and Roy, S.H. (2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *Journal of Biomechanics*, 43(8), 1573-1579
8. Jamaluddin, F.N.; Ahmad, S.A.; Mohd Noor, S.B.; and Wan Hassan, W.Z. (2014). Flexible Bio-signals channels acquisition system for ECG and EMG application. *2014 IEEE Student Conference on Research amd Development (SCOReD)*, 1-4.
9. Marson, R.A. (2012). Relationships between surface electromyography and strength during isometric ramp contractions. *Computational Intelligence in Elecromyography Analysis - A Perspective on Current Applications and Future Challenges*, 53-65.
10. Fauzani, N.J.; Ahmad, S.A.; Mohd Noor, S.B.; Wan Hassan, W.Z.; Kamal, M.; Aminnudin, A.; and Bakti, Z.A.K. (2013). Two electrodes system: Performance on ECG , FECG and EMG detection. *2013 IEEE Student Conference on Research amd Development (SCOReD)*, 16-17.
11. Bartolomeo, L.; Zecca, M.; Sessa, S.; and Takanashi, A. (2012). Wavelet thresholding technique for sEMG denoising by baseline estimation. *International Journal of Computer Aided Engineering and Technology*, 4(6), 517-534.

12. Jamaluddin, F.N.; Ahmad, S.A.; Mohd Noor, S.B.; Wan Hassan, W.Z.; and Yaacob, A. (2016). Estimation of wavelet threshold value for surface EMG baseline removal. *2016 IEEE-EMBS Conference on Biomedical Engineering and Sciences* (*IECBES*), 6-9.
13. Phinyomark, A.; Limsakul, C.; and Phukpattaranont, P. (2011). Application of wavelet analysis in EMG feature extraction for pattern classification, *Measurement Science Review*, 11(2), 45-52.
14. Stegeman, D.; and Hermens, H. (2007). Standards for surface electromyography: The European project surface EMG for non-invasive assessment of muscles (SENIAM), in SENIAM reports, 108-112.
15. Gazendam, M.G.J.; and Hof, A.L. (2007). Averaged EMG profiles in jogging and running at different speeds. *Gait Posture*, 25(4), 604-614.
16. Misiti, M.; and Poggi, J. (2014). Wavelet Toolbox ™ User ' s Guide R 2014 b, MATLAB Inc.
17. Nason, G.P.; and Silverman, B.W. (1995) *The stationary wavelet transform and some statistical applications*. In: Antoniadis A., Oppenheim G. (eds.) *Wavelets and statistics. Lecture Notes in Statistics*, Vol 103. Springer, New York, NY.
18. Jamaluddin, F.N.; Ahmad, S.A.; Mohd Noor, S.B.; Wan Hassan, W.Z.; Yaacob, A.; and Adam, Y. (2015). Performance of DWT and SWT in muscle fatigue detection. *2015 IEEE Student Symposium in Biomedical Engineering & Sciences (ISSBESS)*, 54-57.