Selection of Spectrogram's Best Window Size in EMG Signal During Core Lifting Task

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***Abstract*—Electromyography (EMG) is one of the most commonly used tools to study human muscle condition. Past researchers have introduced various techniques from time distribution (TD), frequency distribution (FD) and time-frequency distribution (TFD) to extract information from this EMG signal. However, due to the complex characteristics of the EMG signal itself, TFD such as spectrogram has been widely used as it can provide both temporal and spectral information. However, since spectrogram has a fix window size, there exists a dilemma of resolution, where the too narrow window will result in a poor frequency resolution, and a too wide window will cause poor time resolution. Thus, this study aims to select the best window size to be used with spectrogram to monitor human muscle electrical activity during core lifting task. Four electrodes were placed over different types of muscles, which are the right and left biceps branchii (BB), and right and left erector spinae (ES). In this study, six window sizes (64, 128, 256, 512, 1024, and 2048) were used. The test has been done using two evaluating criteria, namely frequency resolution (F_r) and time resolution (T_r). The result shows that both window size of 512 and 1024 are acceptable, but the best window for this application is window size 512.**

***Index Terms*—Best Window Size; Electromyography; Instantaneous RMS Voltage; Lifting Task Spectrogram; Time-Frequency Representation.**

I. INTRODUCTION

EMG signal is a highly complex non-stationary signal used to measure electrical activity produced by skeletal muscle in the human body [1]. Research involving EMG are vastly growing as it can be used in various applications not limited to clinical, biomedical and human-computer interaction. Several advanced methods have been introduced to efficiently and effectively analyse the signal. One of the simplest methods is the fast Fourier transform (FFT). FFT is good in analysing stationary signals, but it does not provide any temporal information [2].

Since EMG is a non-stationary signal, to satisfy the stationary condition of FFT, the long-haul signal is separated into blocks of narrow fragments and take the Fourier transform of every segment [3]. This process is called the short-time Fourier transform (STFT). Another advanced technique is the spectrogram, which is the squared magnitude of the STFT. STFT and spectrogram provide time-frequency representation (TFR), thus resulted in higher accuracy. However, for both STFT and spectrogram, there is a compromise between time and frequency resolution [4]. The span of window controls the precision of the time and frequency, and this window is constant for all frequencies [5].

Currently, there are no proper guidelines for determining the window size, and the selection criteria vary for different applications. This paper presents a step-by-step selection process of spectrogram's best window size for core lifting task application, based on time-frequency resolution, time-frequency representation (TFR) and the plot of instantaneous RMS voltage ($V_{rms}(t)$).

II. EXPERIMENTAL PROCEDURES

A. Subjects

Five EMG recordings were inspected in this research. These EMG signals were recorded from five healthy control subjects of two male and three female (23.5 ± 1.5 years, 22.5 ± 3 body mass index). The subjects were recruited randomly by the use of advertisements and notices. A basic idea in enrolment of the volunteers was that the subjects did not have a previous history of musculoskeletal disorders. The Extremity Functional Index (UEFI) questionnaire and Oswestry Low Back Pain Disability questionnaire have been utilised in recognising the typical reference control subjects with a specific end goal to enlist them. The experimental procedures were approved by the Human Ethics Committee of Universiti Putra Malaysia, and information consent forms were signed by the subjects before the start of the experiment.

B. Lifting Protocol

Subjects were requested to perform a core lifting task which consists of six lifting phases in 1 cycle. The sequence of the6 lifting phases was shown in Figure 1. Before the lifting protocols, the subject is required to stand in front of the Valpar work centre as in Figure 2, and certain anthropometric measurements that specifically pertain to lifting were recorded (waist height, and above shoulder height (chin to nose level)). After one cycle, the weight will be added to the container. Weight progression flip chart (Figure 3(a)) in conjunction with the colour coded weights (Figure 3(b)) was used to progress the subject through the lifting task. The whole lifting task was performed at the SOCSO Rehabilitation Centre, Malaysia and follows the protocol set by the organisation to ensure the results are reliable.

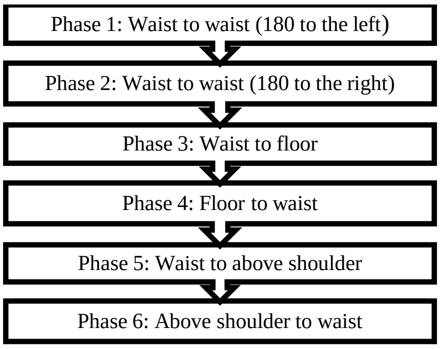
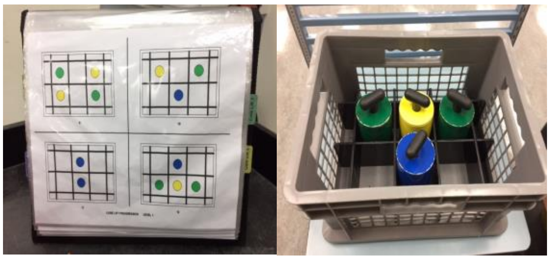


Figure 1: Core lifting task flow for one cycle

Figure 2: Valpar work centre



(a) (b)

Figure 3: (a) Weight progression flipchart (b) container with colour coded weights

III. sEMG Recording Procedure

sEMG signals were recorded using Consensys EMG Development Kits, which was design and fabricated by Shimmer Sensing (Dublin, Ireland). The signals were sampled at a sampling frequency of 1500 Hz. EMG signals from 4 muscles on the upper limb area (right and left BB) and the back area (right and left ES) were procured using Ag/AgCl electrodes from Kendal Meditrace 200. To ensure proper electrode attachment and to reduce noise, the entire area of the muscles were shaved and cleaned using BD Alcohol Swabs (70% Isopropyl Alcohol), before rubbing it with Signa gel to provide better conductivity.

The procedure for surface electrode placement follows the Non-Invasive Assessment of Muscle (SENIAM) guideline to get the maximum pickup zone of the EMG signals and to guarantee that the EMG signals are stable. Figure 2(a) shows the surface EMG electrodes attached at the biceps branchii name as input (A) and the reference electrode labelled as (B), while Figure 2(b) is the surface EMG electrodes attached at the erector spinae.

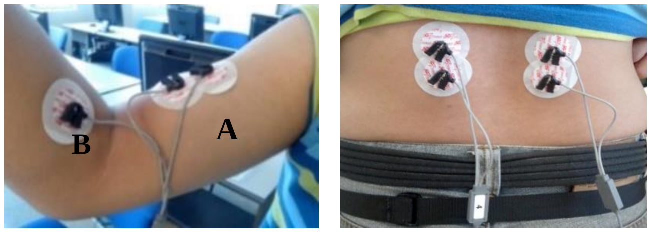


Figure 4: Electrode placement on (a) Biceps Branchii muscle (b) Erector Spinae muscle

The conventional pre-processing technique was utilised as an underlying stage to prepare the four channels of the EMG data before proceed with the spectrogram analysis. Since the power density function of the sEMG signals has negligible contributions outside the range 5-10 Hz to 400-450 Hz, a bandpass filter with the range of 5-500 Hz was used to include only the physiological frequency of a sEMG.This range is consistent with the high pass and low pass corner frequency recommended by[6], which is currently endorsed by the International Society of Electrophysiology and Kinesiology (ISEK).

IV. Spectrogram

TFR of the EMG signal was obtained using spectrogram, where spectrogram is defined as the squared magnitude of STFT and can be expressed as Equation (1).

$$S(t,f) = \left| \int_{-\infty}^{\infty} x(\tau) w(\tau - t) e^{-j2\pi f} \right|^2 dt \qquad (1)$$

Where $S(t,f)$ is the time-frequency representation, $x(\tau)$ is the input signal and w(t) is the observation window.

In this study, Hanning window was chosen since it has a low peak side slope compared to the rectangular and Hamming window, that would affect the narrow frequencies [7]. The window size was varied from 64, 128, 256, 512, 1024 and 2048 to find the best window with good time-frequency resolution. Frequency resolution (F_r) and time resolution (T_r) of the TFR were calculated using equation (2) and Equation (3).

$$F_r = \frac{F_s}{N_w} \qquad (2)$$

$$T_r = \frac{1}{F_r} \qquad (3)$$

where N_w is the window size and F_s is the sampling frequency.

From the TFR, the parameter used to represent the lifting flow is the instantaneous RMS voltage ($V_{rms}((t)$).

$$V_{rms}(t) = \sqrt{\int_0^{f_{max}} S(t,f)dt} \qquad (4)$$

here $S(t,f)$ is the time-fwrequency representation and f_{max} is the maximum frequency.

V. Result and Discussions

Since this study is focusing on finding the best spectrogram window size, only the TFR and $V_{rms}(t)$ plot for phase 5 was presented in detailed. Table I represents both TFR and $V_{rms}(t)$ for one subject and one muscle with different window size. Even though only the result for one subject and one muscle was presented for publication purposes, the other subjects still have similar trends of TFR, and $V_{rms}(t)$ plot as the window size is varied. This can be seen from the maximum $V_{rms}(t)$ mean plot and standard deviation error bars of 5 subjects for each window size, as in Figure 5.

Roughly by looking at the TFR plot in Table 1 for window size 64 and 128, it can be seen that the plot was stretched vertically with some of the signals were out of range. The red colour showed the location of the highest peak amplitude, which is situated at time range 2500 to 3000 ms. The $V_{rms}(t)$ plot showed the existence of multiple peaks that do not represent the lifting information. For window size 256, 512 and 1028, both TFR and $V_{rms}(t)$ plot provide reasonable results, while the highest window of 2048, the TFR was stretched horizontally and a part of the signal is out of range. The $V_{rms}(t)$ plot of window 2048 also does not represents the lifting flow as some of the information was missing.

The detailed summary of the analysis for each window size was presented in Table 2. For this application, frequency resolution and time resolution of the TFR must fulfil certain criteria, to be accepted as the best window size. Take note that the guidelines listed are different for different application and research needs. The two criteria that need to be fulfilled are listed as follows:

i. F_r must be smaller than the minimum frequency to be detected (f_{min} = 5 Hz)
ii. T_r must be smaller than 1s to detect each lifting phases correctly

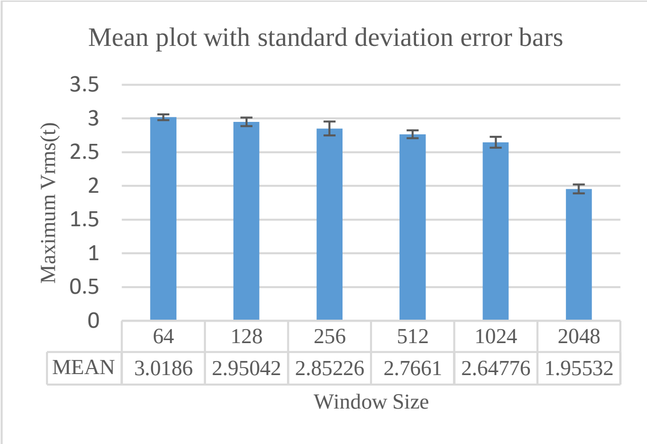
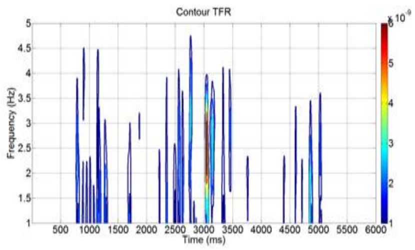
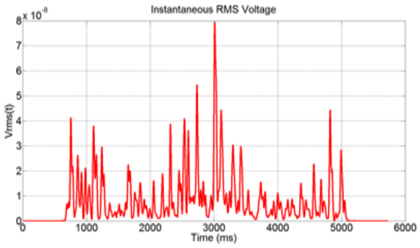
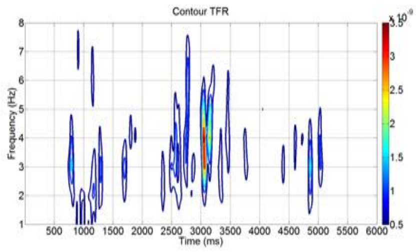
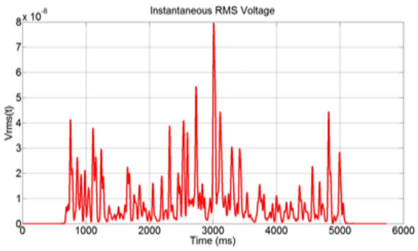
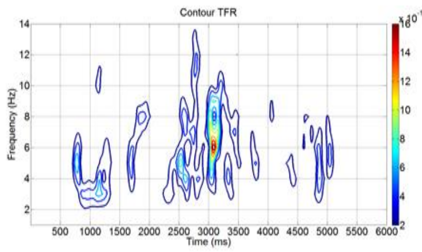
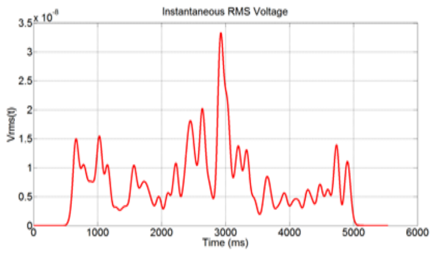
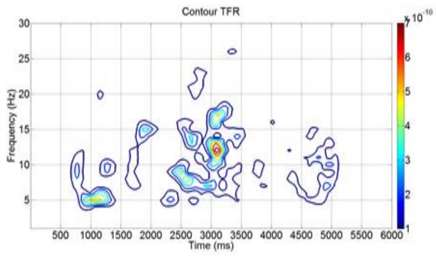


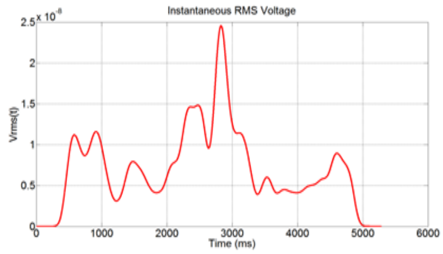
Figure 5: Maximum $V_{rms}(t)$ mean plot with standard deviation error bars of 5 subjects for each window size

Table 1
Time-Frequency Representation and Instantaneous RMS Voltage Plot for Different Window Size

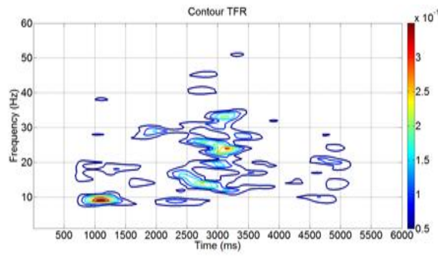
Window Size	Time-frequency Representation (TFR)	Instantaneous RMS Voltage
64		
128		
256		

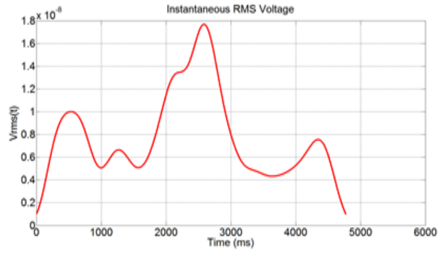
512



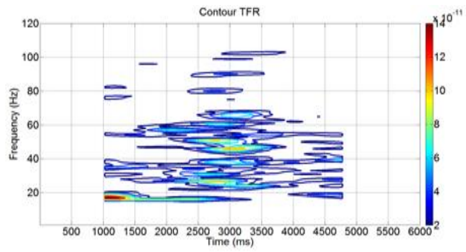


1024





2048



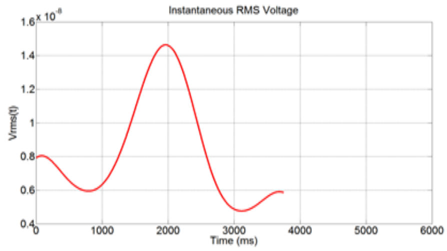


Table 2
Detailed Summary of the Best Window Size Analysis

Window Size	64	128	256	512	1024	2048
Sampling Frequency, F_s	1500 Hz	1500 Hz	1500 Hz	1500 Hz	1500 Hz	1500 Hz
Frequency Resolution, F_r Must be smaller than minimum frequency to be detected	28.44 Hz Unable to detect the minimum frequency	11.72 Hz Unable to detect the minimum frequency	5.86 Hz Unable to detect the minimum frequency	2.93 Hz Able to detect the minimum frequency	1.46 Hz Able to detect the minimum frequency	0.73 Hz Able to detect the minimum frequency
Time Resolution, T_r Must be smaller than 1s to detect each lifting phases correctly	0.0352 s Able to correctly detect each lifting phases	0.0852 s Able to correctly detect each lifting phases	0.1706 s Able to correctly detect each lifting phases	0.0352 s Able to correctly detect each lifting phases	0.0852 s Able to correctly detect each lifting phases	0.1706 s Able to correctly detect each lifting phases
Discussion	Good time resolution, bad frequency resolution Rejected	Good time resolution, bad frequency resolution Rejected	Good time resolution, bad frequency resolution Rejected	Good time resolution, good frequency resolution **Accepted**	Good time resolution, good frequency resolution **Accepted**	Bad time resolution, good frequency resolution Rejected

VI. Conclusion

Results presented in this paper showed that the experiment successfully provides a guideline to determine the acceptable window size to be used in the spectrogram analysis for core lifting task application. When dealing with time-frequency distribution such as spectrogram, a good time resolution and good frequency resolution is very crucial to ensure that the analysis is reliable and accurate. From the results, a window size of 512 and 1024 are considered acceptable as it fulfils the criteria of a good frequency resolution (F_r must be smaller than the minimum frequency to be detected) and good time resolution (T_r must be smaller than 1s to detect each lifting phases correctly). This criterion, however, varies from one application to another depending on the research needs. Since this study used a bandpass filter with the lower cut off frequency was set to 5 Hz, a good Fr must be able to detect this frequency. The second criterion was set based on the time taken to complete each lifting phase. In this study, each lifting phase was done in 4 s with a time interval of 1 s. To ensure there is no information loss between each interval, T_r must be smaller than 1 s. Although there is no direct measure to determine the best window size between window 512 and 1024, by comparing the TFR and $V_{rms}(t)$ of both windows, 512 is considered the best for this application since the location of the peak frequency based on the TFR is proportional to the peak in the $V_{rms}(t)$ plot.

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