

Determining Best Window Size for an Improved Gabor Transform in EMG Signal Analysis

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Abstract

Electromyography EMG is a standout amongst the most regularly utilized tools to study human muscle condition. But due to the intricate attributes of the EMG itself, time-frequency distributions such as Gabor transform and spectrogram are more preferred than the simpler time distribution and frequency distribution. These techniques have been broadly utilized as it can provide both time and frequency information. However, both techniques have a fix window size for all frequency values, thus there exist a problem of determination of the window size, where excessively limit window and too wide window, will result in poor frequency resolution and time resolution, respectively. Along these lines, the point of this study is to choose the best window size so as to be utilized with Gabor transform to screen human muscle activity during core-lifting task. Four electrodes were placed on the right and left biceps brachii, and left and right erector spinae. In this study, the results of five acceptable window sizes (300, 400, 430, 450 and 520) were shown, despite the fact that other window sizes were also tested. Three criteria have been considered during the determination of the best window size, which are good time resolution, good frequency resolution, and high accuracy. Results demonstrate that window size of 450 is the best compared to others. As an additional analysis, the result is compared to a spectrogram and it can be seen that Gabor transform is better, as it has the flexibility in choosing the window size, thus affects the resolution and accuracy.

Keywords: *Electromyography, Time-frequency distribution, Gabor transform, Best window size, Lifting task*

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1. Introduction

Electromyography (EMG) signal is a highly complex non-stationary signal used to measure electrical activity created by skeletal muscle in the human body [1]. Research involving EMG are inconceivably developing as it can be utilized as a part of different applications not restricted to clinical, biomedical and human-computer interaction. A few propelled techniques have been acquainted to efficiently and successfully analyze the signal [2].

Among researchers, it is well known that the Fourier transform (FT) is the simplest among the other transformation method [3]. It is also a perfect technique for analyzing periodic functions, and to represent them as a superposition of pure frequencies [4]. This, however, makes sense for stationary signals only [5], whereas EMG is a non-stationary signal. Thus, the idea of time-frequency representations (TFR) of signals came up [6]. One of the simplest methods is the short-time Fourier transform (STFT), since for many purposes the STFT of a signal is easier to handle because it depends in a linear way on the analyzed signal [7]. This technique has become a common tool in signal analysis. Other than this, the concept of the TFR also motivates other researchers to come up with a more advanced techniques such as spectrogram and Gabor transform. These two techniques are preferred than the traditional Fourier techniques, whenever time dependence of the analyzed signal is of an indistinguishable significance from its frequency dependence [6]. However, there exist strict limits to the maximal

time-frequency resolution of these both techniques, since there is a compromise between time and frequency resolution [8]. Both of these techniques require the choice of a window function and window size, which are used to localize analyzed signal in a decent way [9]. This includes the control of precision of the time and frequency resolution [10]. The window chosen however is constant for all frequencies.

In previous research, the author already came up with a proper guideline in determining the window size of spectrogram for core lifting task application, while this paper presents the selection process in determining Gabor transform's best window size for the same application. The same selection criteria are applied which based on time-frequency resolution, time-frequency representation (TFR) and the plot of instantaneous RMS voltage ($V_{rms}(t)$). The performances of the chosen window size for both techniques are then compared.

2. Experimental Procedures

2.1. Subjects

Eleven EMG recordings were inspected in this research. These EMG signals were recorded from eleven healthy control subjects aged 22-25 years. Table 1 summarized the subjects' demographic details. The subjects were selected arbitrarily by the utilization of ads and notices. A fundamental idea in enrolment of the volunteers was that the subjects did not have a past history of musculoskeletal disorders. The Extremity Functional Index (UEFI) survey and Oswestry Low Back Pain Disability survey have been used in perceiving the typical reference control subjects with a particular end goal to enlist them. The experimental procedures were affirmed by the Human Ethics Committee of Universiti Putra Malaysia, and all the subjects are required to signed informed consent forms before the start of the experiment.

Table 1. Subject's Demographic Details

Demographic details	
Age (years) (Mean \pm SD)	23.5 \pm 1.5
Body mass index (Mean \pm SD)	22.5 \pm 3
Sex, male/female	6/5

2.2. Lifting Protocol

Subjects were asked to perform a core-lifting task, which comprises of six lifting phases in 1 cycle. The succession of the 6 lifting phases was shown in Figure 1. Preceding the lifting protocols, the subject is required to remain in front of the Valpar work centre as in Figure 2 and certain anthropometric data that particularly relate to lifting were recorded (midsection height, and above shoulder height (jaw to nose level)). After one cycle, weights will be added to the container. Weight progression flip diagram as shown in Figure 3(a) in conjunction with the colour-coded weights as shown in Figure 3(b) was utilized to advance the subject through the lifting task. The entire lifting task was performed at the Social Security Organization (SOCSCO) rehabilitation centre, Malaysia and takes after the convention set by the association to guarantee the outcomes are solid.

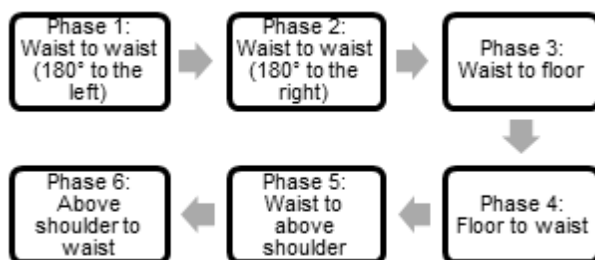


Figure 1. Core-lifting task flow for 1 cycle



Figure 2. Valpar work centre



Figure 3. (a) Weight progression flipchart and (b) container with colour-coded weights

3. sEMG Recording Procedure

sEMG signals were recorded by utilizing 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 biceps brachii) and the back area (right and left erector spinae) were obtained utilizing Ag/AgCl electrodes from Kendal Meditrace 200. To guarantee legitimate electrode attachment and to lessen noise, the whole area of the muscles were shaved and cleaned utilizing BD Alcohol Swabs (70% Isorophyl Alcohol), before rubbing it with Signa gel to give better conductivity.

The strategy for surface electrode placement follows the Non-Invasive Assessment of Muscle (SENIAM) rule to get the most extreme pickup zone of the EMG signals and to ensure that the EMG signals are stable. Figure 2(a) shows the surface EMG electrodes attached at the biceps brachii named as input (A) and the reference electrode named as (B), while Figure 2(b) is the surface EMG electrodes appended at the erector spinae.

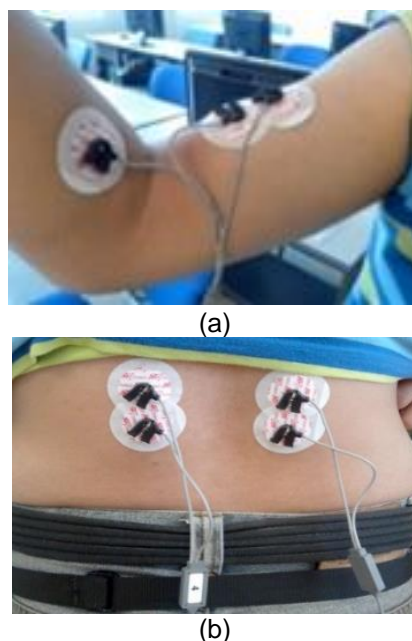


Figure 4. Electrode placement on (a) biceps brachii and (b) erector spinae muscles

The ordinary pre-processing method was used as a hidden stage to prepare the 4 channels of the EMG information before continuing with the Gabor transform analysis. Since the

power density capacity of the sEMG signals has irrelevant contributions outside the range 5-10 Hz to 400-450 Hz, bandpass filter with the range of 5-500 Hz was utilized to incorporate just the physiological frequency of a sEMG. This range is consistent with the high pass and low pass corner frequency prescribed by [11], which is currently supported by the International Society of Electrophysiology and Kinesiology (ISEK).

4. EMG Signal Analysis

4.1. Spectrogram

Spectrogram is defined as the squared magnitude of STFT and can be expressed as equation 1.

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

where $S(t, f)$ is the time-frequency representation, $x(\tau)$ is the input signal and $w(t)$ is the observation window. In the previous research by the author herself, Hanning window was chosen for the spectrogram, since it has a low peak side slope compared to the rectangular and Hamming window, that would affect the narrow frequencies [12]. The window size was changed from 64, 128, 256, 512, 1024 and 2048 so as to locate the best window with good time-frequency resolution. Window size of 512 and 1024 were found to be suitable for the application, but window size 512 was found to be the best between those two.

4.2. Gabor transform

Gabor transform is an expanding of the signal into a set of functions that are concentrated in both time and frequency representation and then utilize the coefficients as the descriptors of the EMG signal's property. Gabor transform is defined as equation 2.

$$C(n, k) = \int_{-\infty}^{\infty} x(\tau) h^*(n, k) d\tau \quad (2)$$

where $C(n, k)$ is the time-frequency representation, $x(\tau)$ is the raw EMG signal and $h(n, k)$ is the set of elementary function, which defined as;

$$h(n, k) = w(\tau - nT\omega) e^{-j2\pi k f_0 \tau} \quad (3)$$

where $w(\tau)$, $T\omega$ and f_0 are the observation window, time sampling, and frequency sampling, respectively. Both time and frequency sampling must satisfy the Heisenberg uncertainty relationship as follows;

$$T_w f_0 \geq \frac{1}{4\pi} \quad (4)$$

In this study, Hanning window was chosen, same as the spectrogram. Since the best window size for spectrogram is 512 as previously reported, the window size for the Gabor transform was varied around this value. This is to save time as the determination of window size was done on a trial and error basis. The window size was varied from 300 to 520 in order 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 5 and equation 6.

$$F_r = \frac{F_s}{N_w} \quad (5)$$

$$T_r = \frac{1}{F_r} \quad (6)$$

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 ($V_{rms}(t)$).

$$V_{rms}(t) = \sqrt{\int_0^{f_{max}} S(t, f) dt} \quad (7)$$

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

4.3. Best Window Size Selection

For this application, frequency resolution and time resolution of the TFR must satisfy certain criteria, keeping in mind the end goal to be acknowledged as the best window size. Observe that the guidelines listed are distinctive for various applications and research needs. The two criteria that should be satisfied are listed as follows:

- F_r must be equal or smaller than the minimum frequency to be distinguished ($f_{min} = 5$ Hz)
- T_r must be smaller than 1 s in order to effectively distinguish each lifting phases

5. Results and Discussions

Since this research is concentrating on finding the best window size for Gabor transform, only the TFR and instantaneous RMS voltage plot for stage 5 were displayed. Figure 5 shows the TFR and $V_{rms}(t)$ plot for spectrogram using window size 512 which is found to be the best window size for this application, based on previous research done by the author. Roughly looking at Figure 5(a), it can be seen that the spectrogram able to produce a good time resolution and frequency resolution of the TFR and the red colour in the TFR showed the location of the highest peak amplitude

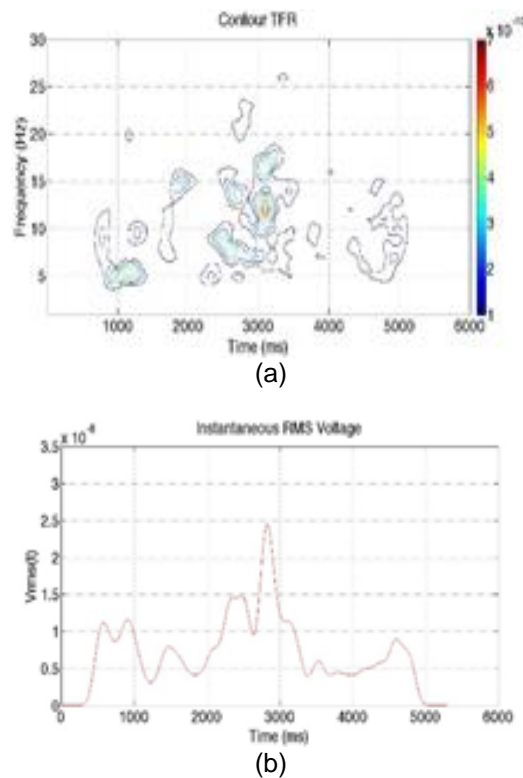


Figure 5. (a) TFR of spectrogram and (b) $V_{rms}(t)$ plot for window size 512

The following five figures as shown in Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 represent the TFR and $V_{rms}(t)$ plot of Gabor transform for window size 300, 400, 430, 450 and 520, respectively. The selection of these window sizes are based on the selected best window size (512) explained in previous research. The window sizes were varied by trial and error method near this value and the resolution for both time and frequency were monitored for

any improvement or decrement on the Gabor transform performance. This paper only presents the result of five window sizes for further analysis.

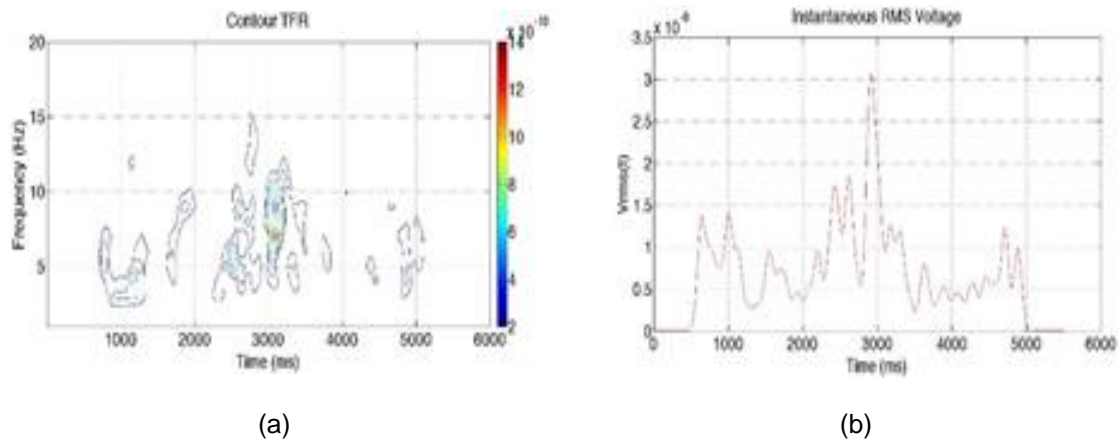


Figure 6. (a) TFR of Gabor transform and (b) $V_{rms}(t)$ plot for window size 300

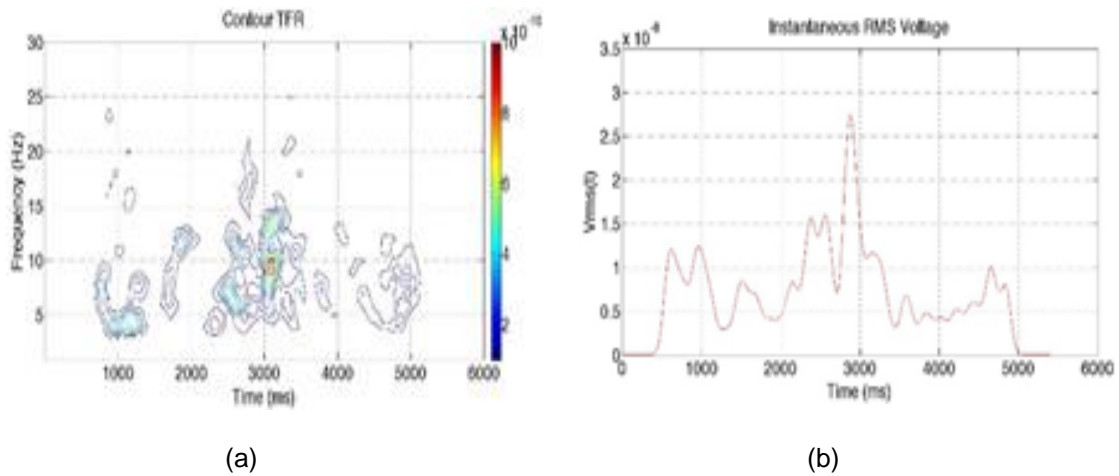


Figure 7. (a) TFR of Gabor transform and (b) $V_{rms}(t)$ plot for window size 400

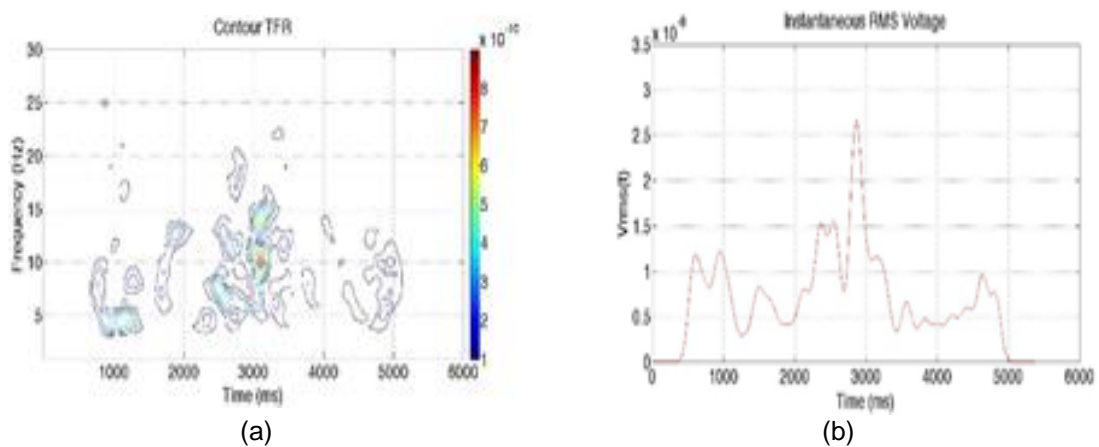


Figure 8. (a) TFR of Gabor transform and (b) $V_{rms}(t)$ plot for window size 430

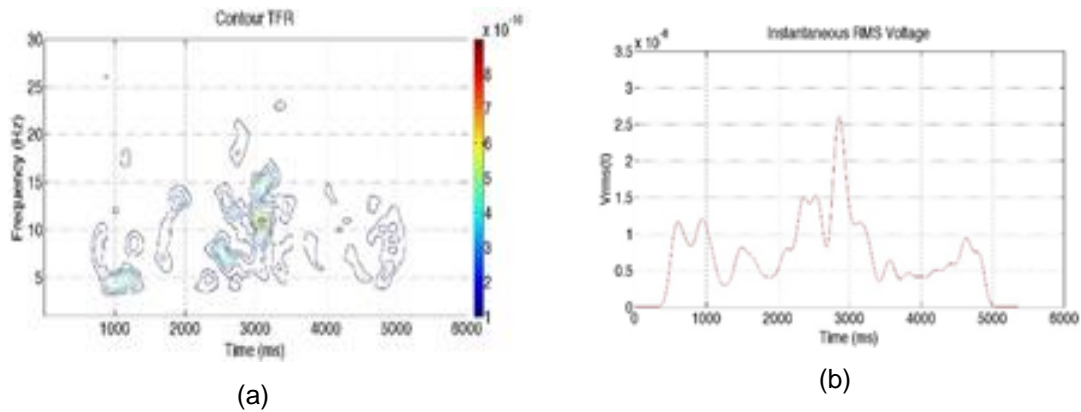


Figure 9. (a) TFR of Gabor transform and (b) $V_{rms}(t)$ plot for window size 450

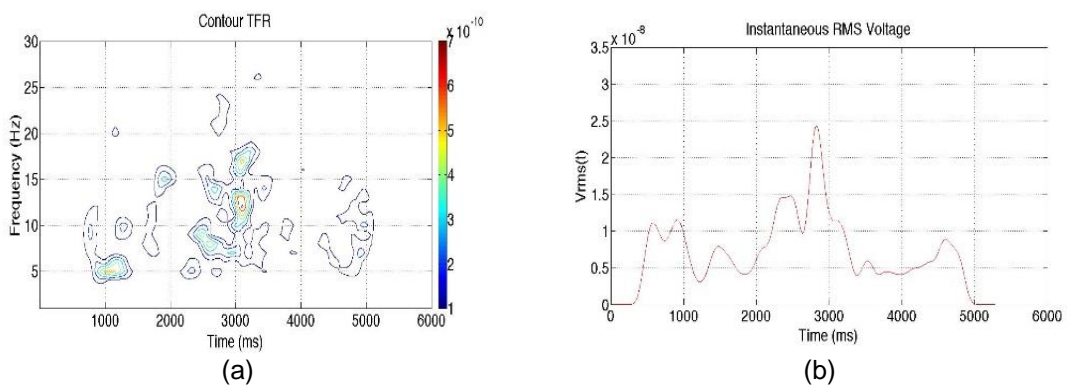


Figure 10. (a) TFR of Gabor transform and (b) $V_{rms}(t)$ plot for window size 520

All five window sizes presented in this paper have acceptable time and frequency resolution based on the criteria listed before. Table 2 summarizes the frequency resolution and time resolution for all window sizes tested. Since a bandpass filter with a range of 5-500 Hz was used in the pre-processing stage, thus the minimum frequency, f_{min} to be detected is 5 Hz. It can be seen that all window sizes in Table 2 able to detect the minimum frequency exist in the signal since all of them have frequency resolution that is either equal or smaller than f_{min} . Similar to the time resolution, T_r criteria, all window sizes must have T_r less than 1 s to effectively distinguish each lifting cycle. All window sizes listed in Table 2 satisfy this criterion.

Table 2. Comparison of Time Resolution and Frequency Resolution for Each Window Size

Window Size	Sampling Frequency, F_s	Frequency Resolution, F_r	Time Resolution, T_r
300	1500 Hz	5 Hz	0.2 s
400	1500 Hz	3.75 Hz	0.2667 s
430	1500 Hz	3.49 Hz	0.2865 s
450	1500 Hz	3.33 Hz	0.3003 s
520	1500 Hz	2.85 Hz	0.3509 s

As to distinguish which window size is the best, the TFR peak time and $V_{rms}(t)$ peak time were measured and the absolute error was calculated. By referring to Table 3, as the window size increased, the absolute error is also increased. Thus, after thorough study and comparing, and considering not just the time resolution and frequency resolution, but also the absolute error exist between the TFR peak time and $V_{rms}(t)$ peak time, the window size of 450 was considered as the Gabor transform best window size for this application.

Table 3. Comparison of Absolute Error for Each Window Size

Window Size	TFR Peak Time (ms)	$V_{rms}(t)$ Peak Time (ms)	Absolute Error (ms)
300	3.090	2.913	0.177
400	3.094	2.882	0.212
430	3.098	2.866	0.232
450	3.091	2.858	0.233
520	3.097	2.827	0.270

Table 4 summarizes the results of Gabor transform and spectrogram using their best window size resulted from the analysis. Not just by having a slightly better time resolution compared to the spectrogram, Gabor transform also has a lower absolute error, which is the main criteria to look at when having results that have acceptable time and frequency resolution.

Table 4. Performance Comparison between Gabor Transform and Spectrogram

	Gabor Transform	Spectrogram
Frequency Resolution, F_r (Hz)	3.33	2.93
Time Resolution, T_r (ms)	0.3003	0.3413
TFR Peak Time (ms)	3.091	3.090
Instantaneous RMS Voltage Peak Time (ms)	2.858	2.833
Absolute Error (ms)	0.233	0.257

Despite the fact that only the result for one subject and one muscle was presented, alternate subjects still have comparable patterns of TFR and $V_{rms}(t)$ plot as the window size is changed. This can be seen from the absolute error mean plot and standard deviation error bars of eleven subjects for every window size, as in Figure 11.

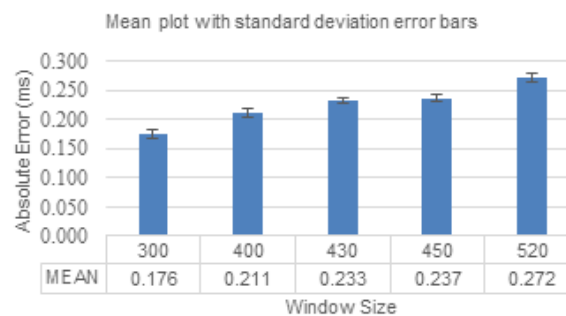


Figure 11. Absolute error mean plot with standard deviation error bars of eleven subjects for each window size

6. Conclusions

Results presented demonstrated that the study effectively introduces guidelines to decide acceptable Gabor transform window size to be used in the analysis of core-lifting task. The main problem occurs when dealing with time-frequency distribution such as Gabor transform and spectrogram, is the problem of resolution, as this can affect the reliability and accuracy of the analysis. This issue, however, can be solved by choosing a suitable window size.

Despite the two main criteria of a good frequency resolution (F_r must be equal or smaller than the minimum frequency to be detected) and good time resolution (T_r must be smaller than 1 s to correctly identify each lifting phases) as presented in the author's previous research, another criteria that is important to determine the best window size especially when dealing with multiple window size that have good time and frequency resolution, is the absolute error. By considering these three criteria, the window size of 450 was found to be the best for this application. However, this value is not fixed as different researchers may have different opinions and different applications may have a different level of importance of the three criteria.

When the performance of Gabor transform and spectrogram were compared, it can be seen that Gabor transform provides a marginally better time resolution and lower absolute error, with a more flexibility in choosing the window size to suits various research applications.

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