Performance Analysis of the Windowing Technique on Elbow Joint Angle Estimation Using Electromyography Signal

Triwiyanto1,3,*, O Wahyunggoro1, H A Nugroho1, Herianto2

1 Department of Electrical Engineering & Information Technology, Universitas Gadjah Mada, Jl. Grafika No. 2, Yogyakarta, Indonesia; 2 Department of Mechanical & Industrial Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Yogyakarta, Indonesia; 3 Department of Electromedical Engineering, POLTEKKES KEMENKES, Surabaya, Ministry of Health, Jl. Pucang Jajar Timur No.10, Surabaya, Indonesia
*Triwiyanto123@gmail.com

Abstract. In the digital signal processing, the windowing technique is essential in the feature extraction process because it influences the performance of the proposed models. The objective of this study is to evaluate the performance of the windowing technique in the elbow joint angle estimation based on electromyography (EMG) signal. In the elbow joint angle estimation, the results showed that the window length and percentage of overlap in windowing technique affected the performance of the estimation for all time-domain features. In the adjacent windowing technique, a window length of 100 milliseconds has the highest performance in estimation. In the overlap windowing technique, the percentage of overlap is 10%. It is the highest performance of the estimation. Features ZC, SSC, WAMP, and MYOP have better RMSE than the others. In the window length of 100 milliseconds, the mean and standard deviation of RMSE for the features ZC, SSC, WAMP, and MYOP are 14.41°±3.86°, 15.20°±4.59°, 14.50°±3.33° and 13.56°±3.53°, respectively.

1. Introduction
High performance in the elbow joint angle estimation using electromyography (EMG) is important in the devices that is based on EMG control [1]. EMG signal is bioelectric which is generated from muscle when the muscle performs a contraction. EMG signal can provide any information which relates to the kinematic parameters such as angle, force, and torque of the joint of human limbs. A digital signal processing (DSP) is required to obtain those parameters. Feature extraction is an important part of the DSP to obtain the characteristics of the information and to reduce the number of EMG samples. Choosing a correct windowing technique is important in the feature extraction process in order to obtain high performance in estimating the parameters. Furthermore, the failure in choosing the type and length of window will influence the performance of the estimation. Some efforts have been proposed to find the best type and window length in order to improve the performance.

Smith investigated numbers of windows length which ranged between 50 and 550 milliseconds for machine classifier to discriminate 7 motions. The results show that the optimal windows length covers from 150 to 250 milliseconds [2]. In the development of the force prediction, it was found that the length of the window determined the Pearson’s correlation coefficient of the prediction [3]. St. Amant stated that window length is also influenced the signal to noise ratio (SNR) in determining the amplitude of the EMG signal [4]. The findings were that the SNR increased along with the window length. Some studies reported that the longer of the window length, the more increase the accuracy is.
2. Material and Methods

2.1. Data Collection

In order to perform the purpose of this study, four male subjects were involved. The EMG signal was collected only from bicep muscle using disposable electrode (Ag/AgCl, size: 57 x 48 mm, Ambu, Bluesensor R, Malaysia) while the elbow performed a flexion and extension motion. A metronome program was run to guide the elbow in performing the flexion-extension motion. In this work, the period of motion was set at 2 seconds. A linear potentiometer was installed in the exoskeleton frame in order to measure the real elbow joint angle. The measured angle was used as a gold standard in the evaluation. This experiment protocol had been approved by the Ethics Committee of Health Polytechnic of Surabaya, Ministry of Health.

2.2. Data Processing

In order to estimate the elbow joint angle, the DSP of the EMG signal was performed. The DSP consisted of rectifying, normalizing, windowing, feature extraction, and a lowpass filtering (Figure 1). The EMG signal is extracted using twelve of time-domain features. Those time domain features were the root mean square (RMS), integrated EMG (IEMG), variance (VAR), mean absolute value (MAV), logarithmic (LOG), waveform length (WL), average amplitude change (AAC), difference absolute standard deviation value (DASDV), zero crossing (ZC), sign slope change (SSC), Wilson amplitude (WAMP), and myopulse percentage rate (MYOP) [9]. Finally, the results of the estimation are
evaluated using root mean square error (RMSE). The data processing of the elbow joint angle estimation is shown in Figure 1.

2.2.1. Windowing Technique. Windowing technique is an important part in the data processing which is used to find the optimum length of window for feature extraction process. Windowing technique is classified into adjacent and overlap windowing [7][10]. In the adjacent windowing, the signal is segmented into some windows with the end of the previous window is connected to the following window (Figure 2(a)). In the overlap windowing, some part of the previous and next window is overlapped (Figure 2(b)). In this study, various window lengths used to evaluate the performance of the windowing technique are 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 milliseconds. In the overlap windowing technique, the percentages of overlap are 10, 20, 30, 40, 50, 60, 70, 80, and 90%.

![Figure 2. Windowing technique to extract the EMG signal. (a) Adjacent and (b) overlap windowing.](image)

2.2.2. Time Domain Features. The feature extraction process is used to reduce the dimension and to obtain the characteristics of the EMG signal. The EMG signal was extracted using twelve of time-domain features. Those time domain features were the root mean square (RMS), integrate EMG (IEMG), variance (VAR), mean absolute value (MAV), logarithmic (LOG), waveform length (WL), average amplitude change (AAC), difference absolute standard deviation value (DASDV), zero crossing (ZC), sign slope change (SSC), Wilson amplitude (WAMP), and myo-pulse percentage rate (MYOP) [9]. Windowing techniques in feature extraction process used are adjacent and overlap window (Figure 2).

2.2.3. Normalize the Features. Each of 12 of the time domain features has a different unit. So that the unit of the features needs to be normalized. The equation (1) was used to normalize the features.

\[
EMG_N = \frac{EMG_F - EMG_{F(MIN)}}{EMG_{F(MAX)} - EMG_{F(MIN)}}
\]

When \(EMG_N\) is the normalized features, \(EMG_F\) is the EMG features, \(EMG_{F(MIN)}\) is the minimum value of the features, and \(EMG_{F(MAX)}\) the maximum value of the features. In this study, normalization was used to obtain the same range value for all the features which ranged between 0 and 1 [9].

2.2.4. IIR Butterworth low pass filter. The digital filter was applied to reduce the noise in the EMG features. The IIR filter, as well as the Kalman filter, have been used a lot in previous studies to decrease the noise [9][11]. Infinite impulse response (IIR) was selected because the number of the tap is minimal. In this study, the IIR was designed as a Butterworth low pass filter. The filter coefficients were calculated using MATLAB program. The basic equation of the IIR filter is shown in equation (2) as follows:
\[ y[n] = b_0 x[n] + b_1 x[n-1] + \ldots + b_M x[n-M] \\
- a_1 y[n-1] - a_2 y[n-2] - \ldots - a_N y[n-N] \]

(2)

2.3. Data Analysis

The effect of window length and percentage of overlap to the performance of the elbow joint angle estimation was evaluated by calculating the root mean square error (RMSE). The variance of performance was represented in the box plot diagram so that some parameters can be read simultaneously such as minimum, Q1, median (Q2), mean, Q3, and maximum value.

3. Result and Discussion

In the evaluation, the performance was calculated using RMSE which was based on the estimated angle and the measured angle (as the gold standard). Figure 3 and Figure 4 show that the window length and percentage of overlap in windowing technique affected the performance of the elbow joint angle estimation for all time-domain features. In the adjacent windowing technique, a window length of 100 milliseconds has the highest performance in estimation. In the overlap windowing technique, the percentage overlap is 10% and it is the highest performance of the estimation. Features ZC, SSC, WAMP and MYOP have the best RMSE. In the window length of 100 milliseconds, the mean and standard deviation of RMSE for features ZC, SSC, WAMP and MYOP are 14.41°±3.86°, 15.20°±4.59°, 14.50°±3.33° and 13.56°±3.53°, respectively.

Figure 3. The effect of window length on the RMSE values in the adjacent windowing technique.
In the adjacent windowing technique, the mean RMSE for all features increased after window length of 100 milliseconds (Figure 3). The box plot diagrams (Figure 3) of RMSE show that the RMSE of MYOP feature has the lowest RMSE in the window length of 100 milliseconds (mean±SD.: 13.56°±3.53°). The effect of the windows length on the performance of the estimation was also observed in the overlap windowing technique. The RMSE values were increased with length of window and the increase of the RMSE are close to quadratic function (Figure 4).

Figure 4. The effect of overlap percentage in RMSE values in the overlap windowing technique.

The impact of the window length to the performance was also showed by some previous studies [3], [5]–[7]. However, generally, this finding is contrary to the previous study which stated that the longer window length, the better the accuracy is. In this study, the performance increased for window length of 50 to 100 milliseconds, however, the performance will decrease after the window length more than 100 milliseconds. The reason is that in the classifier based on machine learning, has more input or longer window of the learning machine. It will eventually close to the real input objects.

The limitation of this study is the experiment that was performed in the continuous motion and in the non-fatigue condition. The evaluation should also be examined when the motion was conducted in the random motion due to the complexities of the EMG signal which will increase in the random motion. Muscle fatigue was an essential problem in the study which used the EMG signal [12][13]. Therefore, it should be considered in the next research when evaluating the effect of window length on the
performance of the estimation. In the next research, the period of motion should be considered whether it is affected the estimation or not.

4. Conclusion.
This study evaluates the performance of the elbow joint angle estimation based on the windowing technique. Two windowing techniques, the adjacent and overlap window were applied in this experiment to find the best window length and the percentage of overlap which resulted to the best performance to estimate the elbow joint angle. The performance was indicated by the RMSE. The results of the study suggested that window length of 100 milliseconds and percentage of overlap 10% are effective in the feature extraction process for elbow joint angle estimation using EMG signal. Feature ZC, SSC, WAMP, and MYOP have higher performance than the other features. The performance of the estimation (RMSE) is affected by the length of the windows.

5. References
[1] M Asghari Oskoei and H Hu2007 Myoelectric control systems-A surveyBiomed Signal Process Controlvol 2 no 4 pp 275–294.
[2] L H Smith, L J Hargrove, B a Lock, and T a Kuiken2011 Determining the optimal window length for pattern recognition-based myoelectric control: Balancing the competing effects of classification error and controller delayIEEE Trans. Neural Syst. Rehabil. Eng, vol 19 no 2, pp 186–192.
[3] E N Kamavuako, D Farina, K Yoshida, and W Jensen 2009 Relationship between grasping force and features of single-channel intramuscular EMG signalsJ. Neurosci. Methods. Vol 185 no 1 pp 143–150.
[4] Y St-Amant D Rancourt and E a Clancy1998 Influence of smoothing window length on electromyogram amplitude estimatesIEEE Trans. Biomed. Eng. vol. 45 no 6 pp 795–800.
[5] K Englehart, B Hudgins, and P a Parker2001 A wavelet-based continuous classification scheme for multifunction myoelectric controlIEEE Trans. Biomed. Eng. vol 48 no 3 pp. 302–311.
[6] E Scheme and K Englehart2011 Electromyogram pattern recognition for control of powered upper-limb prostheses: State of the art and challenges for clinical use J. Rehabil. Res. Dev. vol. 48 no 6 p 643.
[7] M a Oskoei and H Hu2008 Support Vector Machine-Based Classification Scheme for Myoelectric Control Applied to Upper LimbIEEE Trans. Biomed. Eng. vol 55 no 8 pp 1956–1965.
[8] JU Chu I Moon and M S Mun,2006A real-time EMG pattern recognition system based on linear-nonlinear feature projection for a multifunction myoelectric handIEEE Trans. Biomed. Eng. vol 53 no 11 pp 2232–2239.
[9] Triiwianto O Wahyunggoro H A Nugroho and Herianto 2017 An investigation into time domain features of surface electromyography to estimate the elbow joint angleAdv. Electr. Electron. En, vol 15 no 3 pp 448–458.
[10] M Hakonen H Piitulainen and AVisala2015 Current state of digital signal processing in myoelectric interfaces and related applicationsBiomed. Signal Process Control vol 18 pp 334–359.
[11] T Triiwianto O Wahyunggoro H A Nugroho and H Herianto2017 Evaluating the performance of Kalman filter on elbow joint angle prediction based on electromyographyInt. J. Precis. Eng. Manuf. vol 18 no 12 pp 1739–1748.
[12] T Triiwianto O Wahyunggoro H A Nugroho and H Herianto 2018 Muscle fatigue compensation of the electromyography signal for elbow joint angle estimation using adaptive featureComput. Electr. Eng. vol 71 no 7 pp 284–293.
[13] T Triiwianto O Wahyunggoro H A Nugroho and H Herianto 2017 Continuous wavelet transform analysis of surface electromyography for muscle fatigue assessment on the elbow joint motion Adv. Electr. Electron. Eng. vol 15 no 3 pp 424–434.