



A Comparison of Butterworth Noise Filtration Frequency for Isotonic Muscle Fatigue Analysis

Nur Shidah Ahmad Sharawardi¹, Yun-Huoy Choo^{1(✉)}, Shin-Horng Chong²,
and Nur Ikhwan Mohamad³

¹ Computational Intelligent and Technologies (CIT) Lab, Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
nurshidah.sharawardi@gmail.com, huoy@utem.edu.my

² Motion Control Research Lab, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
horng@utem.edu.my

³ Faculty of Sport Science and Coaching, Sultan Idris Education University, Tanjong Malim, Perak, Malaysia
nur.ikhwan@fsskj.upsi.edu.my

Abstract. In sports training, fatigue prediction using surface electromyography analysis is manually monitored by human coach. Decisions rely very much on experience. Hence, the endurance training plan for an athlete needs to be individually designed by an experienced coach. The pre-designed training plan suits the athlete fitness state in general, but not in real time. Real-time muscle monitoring and feedback help in understanding every fitness states throughout the training to optimise muscle performance. This can be realized with muscle fatigue prediction using computational modelling. Due to the higher amount of motion artefact, research in isotonic muscle fatigue prediction is very much lesser than the isometric prediction. Thus, this paper investigates the Butterworth high-pass noise filter on isotonic muscle fatigue data. Three cut-off thresholds, i.e. 5 Hz, 10 Hz, and 20 Hz, were compared using the Fuzzy c-Mean Radial Basis Function Network model. Several features of time and frequency domains, i.e. the median frequency, mean frequency, mean absolute value, root mean squares, simple square integral, variance length, and waveform length were used as model predictors. The cut-off threshold at 10 Hz is the best frequency with the lowest average mean squared error of 0.0282 and best validation performance at epoch 972.

Keywords: Muscle fatigue · sEMG signal analysis
Butterworth cut-off threshold · Fuzzy c-Mean · Radial basis function network

1 Introduction

Surface electromyography (sEMG) signals shows the muscle activity based on behaviour of electrical signal produced by human body movement. Nowadays, computational modelling is widely used in assisting human decision making, such as in biomedical and clinical application due to the importance of sEMG study [1, 2]. The understanding of the characteristic of sEMG signal is usually recommended either improved the muscle

strength or the muscle endurance for sport application purposes. For example, sport training commonly use surface electromyography (sEMG) signals analysis that need a guide from human experts to prolong muscle endurance against fatigue.

A noise filter is designed to attenuate the specific ranges of frequencies while allowing other informative and meaningful data to pass. There are several types of the frequency spectrum of a signal filters such as low pass filter, high-pass filter, band pass filter and band stop filter. All of them need a specific cut-off frequency threshold during implementation. The movement artifact is the most critical noise in dynamic task and fundamentally important issue since noise filtration will directly affect the quality of data feeding into the learning model (e.g. RBF learning model). A recommended cut-off threshold is needed especially for modeling isotonic muscle task.

Typically, exercise training in sport is to increase the muscle strength against resistance. To complete muscle training includes three different types of muscle contraction, such as the concentric contractions, eccentric contractions, and the isometric contractions. All these contraction are needed each other to complete the isotonic muscle contraction workout and comprehensive training on all three types of muscular contractions is important for athlete in sport training.

Fatigue prediction studies are popular domain nowadays [3]. Moreover, many researches on muscle fatigue prediction are still concentrated on isometric training as compared to isotonic training. This is because isotonic training generates larger volume of motion artefact. Thus, it is giving a greater challenge of noise management on signal analysis [4]. The noise artefacts in isotonic muscle fatigue can be easily cleaned using the high-pass filter because the noise amplitude normally falls in the range between 0 Hz to 20 Hz. Butterworth filters has been widely used in sports science and human movement studies with varied filter range [5–8] and was commonly used to clean the undesired noises before prediction model building [9]. However, no literature has discussed and confirmed the best cut-off thresholds in isotonic muscle fatigue prediction, especially when different loads were imposed on a human subject.

Fatigue analysis using sEMG signals were usually carried out for isometric contraction task to identify the good predictor's performance set as well as for prediction muscle force and angle estimation [4, 5, 6]. For isotonic training, the onset of contractile fatigue was successfully predicted in [10] using Radius Basis Function Neural Network (RBFNN) model and Multilayer Perceptron (MLP) model. Research from [10] recommended the use of artificial neural network (ANN) model for muscle fatigue prediction. At the same time, many studies has proven empirically that models from ANN family such as RBF [10] and MLP [11] are good for isometric muscle fatigue prediction [9, 10] with mean squared error recorded between $1.76E-11$ to 0.5. However, the capability of ANN models in isotonic muscle fatigue prediction is but it does not perform comparatively well for isotonic fatigue analysis as it has achieved for isometric fatigue analysis [12] but is able to perform muscle fatigue analysis on isotonic training. Therefore, RBF is proposed in this study as a prediction model.

In other term, Fuzzy C-Mean (FCM) is one of the most popular fuzzy clustering techniques for different degree estimated problems. The successfully to determine the degree and used to choose the best description of faces in a reduced dimension [13]. Its strength over the famous k -Means algorithm due ability to yields the point's membership

value in each class [14]. The FCM clustering algorithm have been reported [15–19] to the best of knowledge but no similar study has been carried out in the isotonic muscle task using sEMG signal for sport application and it is still unclear which method can provide better clustering.

The RBFN algorithm is a popular muscle fatigue prediction technique due to its capability in improving the performance with respect to a priori of parameter [12, 20]. Hence, combining the FCM and the RBFN techniques is a possible promising approach to predict muscle fatigue based on group similarity estimator. However, the capability of FCM-RBFN in isotonic muscle fatigue prediction is yet to be confirming in the past literature.

2 The Experimentation

In this study, the FCM-RBFN technique is used to predict muscle fatigue when different loads were imposed on human subject. We investigated the influence of three Butterworth high-pass filter cut-off thresholds towards the fatigue prediction performance. The cut-off thresholds, i.e. at 5 Hz, 10 Hz and 20 Hz frequency ranges were tested in the experiments. The following sections explain details of the experimental paradigm design, data acquisition, and sEMG signals preprocessing phases.

2.1 Experiment Setup

The important phase in every experiment that includes capturing signal with sEMG is the skin preparation is needed to reduce the resistivity of the skin and the electrode must attach to the skin surface without any small barrier. The process of the cleaning hair, dirt, shaving, and the implementation of alcohol swab will decrease the noise that will embed in the signal [21].

The electrodes sensors are used to detect the electrical activities in muscle during movement. Therefore, the participants are asked to not making any additional movement to give less motion artifact. The dataset collected based on isotonic muscle contraction during the dumbbell lifting workout session. Muscle contractions from two muscle types were observed during the experiment, i.e. the flexor carpi radialis and biceps brachii from both right and left hand (see Fig. 1). The location of sEMG sensors on muscles are measured to ensure the position is fixed in each session. This is crucial to ensure data consistency. The armrest is able to ensure only the targeted arm muscles are used, not the other body muscles, especially lower body muscles. The amount of oxygen consumption was monitored throughout the whole workout session to avoid cardiovascular overload and this monitoring is not use as one of the prediction in the proposed model. In addition, video recording was used throughout the data acquisition sessions when the subjects were performing the workout to aid results validation especially in data exploration phase.



Fig. 1. The sEMG data collection setup for isotonic muscle contractions.

For non-sporting environment, upper limb frequently loaded for daily tasks [22]. In sporting environment upper limb muscle are highly important for sports such as swimming, combat sports and racquet sports. Due to these reasons upper limb muscle were selected for this experiment. sEMG data of upper limb provides the strength and conditioning coaches guidelines on which muscles were activated in each variations of exercises involved [23]. However, those sEMG data need to be meaningful. Thus, comparing cut-off filter threshold is essential, especially with significant changes in motor unit recruitment of biceps muscles after strength training interventions was hard to detect [24] due to several reasons such as a much slower rate of movement, typically less than 1 Hz [25] and smaller cross-sectional area (less motor-neuron) compared to lower limb muscles. Butterworth filters has also been widely used in sports science and human movement studies, with varied filters range [5–8]. Thus, further investigations needed to verify which range is the best.

In order to collect sEMG signal, a total of 27 undergraduate Sport Science students from Faculty of Sport Science and Coaching, Sultan Idris Education University were recruited to participate in the experiment based on voluntary basis. From the subject group, there were 9 healthy male subjects (age = 22–24 years; body weight = 50–75 kg; height = 152–180 cm) and 18 healthy female subjects (age = 22–24 years; body weight = 42–67 kg; height = 145–164 cm). All of the subjects are having normal body mass index. None of them has any history of neuromuscular disorder. The participants were required to lift a dumbbell in the position described [7] (see Fig. 1).

The dumbbell weight was predefined according to individual subject's one-repetition maximum (1RM) load. The measurement of 1RM is used to calculate the maximum load that a subject can lift in one maximal muscle contraction [26]. The subjects were asked to performed dumbbell lifting using the maximum load until fatigue in the trial experiment set. The Wathan formula [8], as shown in Eq. (1) below was used in the experiment.

$$1RM = 100w / (48.8 + 53.8 e^{-0.075R}) \quad (1)$$

Where w is the amount of weight used, and R is the number of repetition performed. To obtain the 1RM estimation, the subjects were tested with the maximum dumbbell weight load which he/she can afford to complete a full 10 repetitions. This is trial and

error estimation although the amount of weight used can be guided by past experience and also the best practice in sport science [16]. Hence, the more accurate the maximum weight used, the more realistic the 1RM measurement will estimate the true strength. Each subject repeated the experiment for 3 trials with 2 min’ rest in between trials (see Fig. 2).

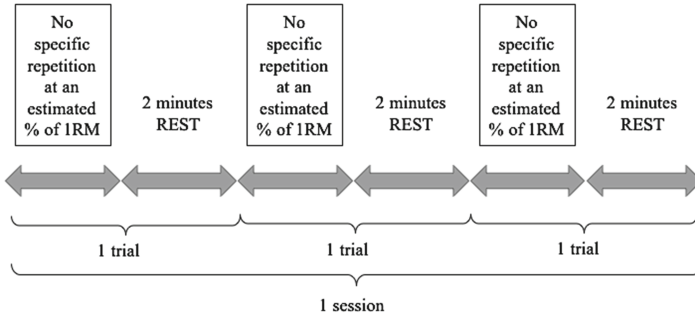


Fig. 2. The experimental paradigm for each individual workout session.

A total of 3 experiment sessions were conducted in three different days in orders of 1RM followed by 30%RM, and 50%RM. The orders of experiments for different percentage of RM measurement were designed as such to avoid performing the 1RM sEMG signal recording twice. Since the determination weight of 1RM for each subject needs to be performed in the initial trial, the sEMG signal for the particular trial will be used as one of the three trials in session 1RM to save time.

The experimental paradigm and design were approved by the Ethics Committee from the Centre for Research and Innovation Management, Universiti Teknikal Malaysia Melaka, as well as from the Medical Research and Ethics Committee, Ministry of Health Malaysia. The participants were informed of the experiment purposes and procedures. An informed consent was obtained from every subject prior to the experiment.

2.2 sEMG Signal Acquisition and Feature Extraction

After the experiment setup, sEMG signal can be acquired using acquisition device. The Delsys Trigno Wireless system was used as interfacing between EMG machine and the computer for sEMG signal acquisition. Four channels of electrode with 48 ms fixed group delay were applied on the surface of flexor carpi radialis and biceps brachii muscles. The sampling rate of 2000 samples per second was used [26].

The raw sEMG signal data were just an oscillation shown in amplitude across time. Thus, the raw data will normally less significance for classification and prediction task. Therefore, good feature extraction methods are able to produce a set of significant predictors to improve the fatigue classification result. Features extraction methods [26], such as the Median Frequency (MDF), Mean Frequency (MF), Mean Absolute Value (MAV), Root Mean Squares (RMS), Simple Square Integral (SSI), Variance Length (VL), and Waveform Length (WL) were used to extract meaningful data for fatigue

prediction. Later, the extracted features are normalized before prediction analysis. Therefore, the data will be in 12×7 array size such as in Table 1.

Table 1. The normalized data sample for 1 session.

TRIAL	MDF	MF	MAV	RMS	SSI	VAR	WL
1-LB	0.6567	0.8687	0.1377	0.0826	0.0054	0.0054	0.0114
1-LF	0.1109	0.1562	0.1377	0.0826	0.0054	0.0054	0.1305
1-RB	0.0894	0.1007	0.3257	0.2298	0.0385	0.0384	0.2305
1-RF	0.0887	0.0981	0.1452	0.0967	0.0073	0.0073	0.1026
2-LB	0.0966	0.1110	0.4256	0.2988	0.0421	0.0421	0.2054
2-LF	0.1101	0.1591	0.1600	0.0995	0.0050	0.0050	0.1017
2-RB	0.0898	0.0961	0.3276	0.2206	0.0233	0.0232	0.1477
2-RF	0.1743	0.2385	0.1582	0.0925	0.0043	0.0044	0.1338
3-RB	0.0990	0.1135	0.1654	0.1058	0.0087	0.0086	0.1305
3-LB	0.1691	0.2299	0.1373	0.08053	0.0052	0.0052	0.1714
3-RF	0.0883	0.1058	0.1338	0.0749	0.0045	0.0045	0.1007
3-RB	0.1653	0.2155	0.1375	0.0770	0.0047	0.0047	0.1621

3 Result and Discussion

Table 1 shows the normalized sEMG data sample of a single session used as the training data in the experiment. The trial indicates the signal data row of a subject for both biceps (B) and flexor (F) muscles on both left (L) and right (R) arms across 7 features vector. The overall training data were arranged according to the percentage from 1 RM, 30% and 50% of 1RM for session 1, 2 and 3 respectively. Table 2 shows the summary of average MSE comparison between FCM clustering techniques. RBFN technique was used for validating the clusters efficiency for classification.

Table 2. Prediction Performance of Butterworth High-Pass Filter With Cut-off Threshold at Different Frequency Ranges.

HZ	5 Hz		10 Hz		20 Hz	
	Epoch	MSE	Epoch	MSE	Epoch	MSE
1	972	0.0740	972	0.0301	196	0.0199
2	683	0.0199	377	0.0195	255	0.0199
3	637	0.0199	972	0.0311	255	0.0199
4	972	0.0740	385	0.0198	972	0.0380
5	972	0.0741	972	0.0301	972	0.0380
6	972	0.0740	972	0.0311	972	0.0380
7	972	0.0740	972	0.0301	972	0.0380
8	972	0.0220	972	0.0301	972	0.0380
9	972	0.0740	972	0.0301	972	0.0380
10	637	0.0199	972	0.0301	972	0.0380
MSE Average		0.0526		0.0282		0.0325

The results reveal that the best prediction results were produced by the data at 10 Hz frequency cut-off with the lowest average MSE value of 0.0283. The raw signal that has been filtered with 5 Hz frequency high-pass filter may have not enough to filter the noise out for sEMG isotonic training task. This has been proved with highest MSE value in FCM-RBFN (0.526). The 20 Hz frequency cut-off filter performed better in FCM-RBFN with 0.0326 MSE value than 5 Hz but had around 15% higher error rate as compared to the 10 Hz frequency cut-off. Hence, data exploration from experiments suggested that in terms of cut-off frequency for muscle fatigue prediction during isotonic contraction task using sEMG signal Butterworth high-pass filter with cut-off threshold at 10 Hz for FCM-RBFN with a lower average MSE than others and 10 Hz suitable to filter off the unwanted noise while maintaining the useful information for constructing learning model at the next phase.

In terms of epoch value, the higher of epoch value, the higher computational time it could take. The training process uses training data-set and must be executed epoch by epoch, in order to calculate the MSE of the network in each epoch for the dataset. The best network model then used by training data for training process with the minimum MSE is selected for the evaluation process. Therefore, to compare the reproducibility, each algorithm was executed 10 times for the same batch of data. The question of the computational time requirements of each method needs to be addressed. Epoch for all 10 times are lower than FCM-RBFN where most of the executing process is nearest to the maximum epoch = 1000 that assuming optimization reaches some local minima and continues to move around the minima. At such state the objective function and validation performance should both become stationary distributions and the optimal value should occur with uniform probability anywhere between when the epoch when the local optimum is reached and infinity.

The results in Table 2 below show that each human subject has different optimum epoch values and different mean squared errors. Therefore, muscle prediction is proven to be better based on group estimates from people with similar strength. FCM algorithm tends to cluster the training data into different group of subjects to facilitate the personalized prediction in RBFN.

The cut-off frequencies at 5 Hz and 20 Hz were trapped in the local minima MSE values and continues to move around the minima at loop 4 while the cut-off frequency at 10 Hz was trapped at the local minimum MSE value starting from loop 5 but was fluctuated at loop 8 and loop 10 (see Fig. 3). Among the three cut-off thresholds, the noise cut-off at 10 Hz has the most stable and lowest average MSE readings. The range of difference falls between 0.0116. The MSE fluctuation is the greatest when the 5 Hz cut-off threshold was used. The trend has showed that the noisy data influence has gradually softened when the cut-off threshold is set at 10 Hz and highest. However, it is not an advantage to increase the cut-off threshold just for the purpose of reducing the MSE values in any model building due to the overfitting issue. This is especially important during the data pre-processing stage. Hence, to preserve the original information at a satisfied model prediction is the best way to follows.

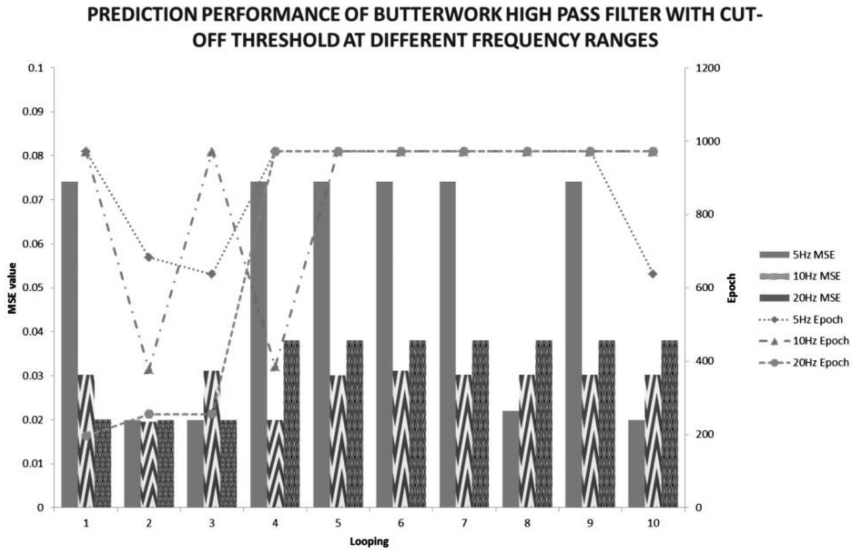


Fig. 3. The performance of Butterworth high-pass filter with cut-off threshold at different frequency ranges.

4 Conclusion

In this paper, we have investigated the performance of different cut-off frequency thresholds in Butterworth filter for isotonic muscle sEMG signal processing based on 2 biceps and 2 flexor arms' muscles. The research findings have recommended that the 10 Hz cut-off frequency threshold is the best setting in the proposed scenarios. The minimum average MSE value was recorded at 0.0282, with the maximum fluctuation range at 0.0116. Hence, the 10 Hz is also the most stable cut-off frequency compared with the 5 Hz and 20 Hz cut-off frequencies. In summary, the proposed model FCM-RBFN can be used for sport training analysis especially for isotonic muscle contractions. The approach of personalized prediction based on similar group estimate is proven to be possible in predicting variable load intensity isotonic task. One of the limitations of this study is the availability of participants and number of sessions involved, as rest in between sessions for muscle recovery need to be taken into considerations [27–29]. The future work should look into the prediction model architecture to enable real-time prediction in different loads used to prolong the endurance of an athlete and conduct more cut-off threshold at different frequency ranges.

Acknowledgment. The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and the Ministry of Higher Education, Malaysia for the financial supports given through the Research Acculturation Collaborative Effort (RACE) research grant, RACE/F3/TK12/FTMK/F00252 and UTeM Hi-Impact Short Term Grant, PJP/2016/FTMK/HI3/S01474. Appreciation is also credited to Faculty of Sport Science and Coaching, Sultan Idris Education University (UPSI) for voluntary contribution on experimental data collection.

References

1. Zeng, D., Youpan, H., He, Q., Haibin, W., Zou, H., Wu, W.: Study of intelligent bio-feedback therapy system based on transcutaneous electrical nerve stimulation and surface EMG signal, pp. 374–378 (2013)
2. Chowdhury, R.H., Reaz, M.B.I., Member, I.S., Ali, M.A.M., Member, I.: Determination of muscle fatigue in SEMG Signal using empirical mode decomposition. *IEEE Trans. Biomed. Eng.* 8–10 (2014)
3. Marri, K., Swaminathan, R.: Classification of muscle fatigue using surface electromyography signals and multifractals. In: 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015, pp. 669–674 (2016)
4. Kuriki, H.U., Azevedo, F.M., de, Takahashi, L.S.O., Mello, E.M., Filho, R. de F.N., Alves, N.: The relationship between electromyography and muscle force. In: *EMG Methods for Evaluating Muscle and Nerve Function*, pp. 31–54. InTech, Croatia (2012)
5. Amarantini, D., Bru, B.: Training-related changes in the EMG–moment relationship during isometric contractions: Further evidence of improved control of muscle activation in strength-trained men? *J. Electromyogr. Kinesiol.* **25**, 697–702 (2015)
6. Scott, D.J., Ditroilo, M., Marshall, P.A.: Complex training: the effect of exercise selection and training status on postactivation potentiation in rugby league players. *J. Strength Cond. Res.* **31**, 2694–2703 (2017)
7. Balshaw, T.G., Massey, G.J., Maden-Wilkinson, T.M., Morales-Artacho, A.J., McKeown, A., Appleby, C.L., Folland, J.P.: Changes in agonist neural drive, hypertrophy and pre-training strength all contribute to the individual strength gains after resistance training. *Eur. J. Appl. Physiol.* **117**, 631–640 (2017)
8. Schoenfeld, B.J., Contreras, B., Willardson, J.M., Fontana, F., Tiryaki-Sonmez, G.: Muscle activation during low-versus high-load resistance training in well-trained men. *Eur. J. Appl. Physiol.* **114**, 2491–2497 (2014)
9. Fratini, A., Cesarelli, M., Bifulco, P., Gatta, A. La, Romano, M., Pasquariello, G.: Acceleration driven adaptive filter to remove motion artifact from EMG recordings in Whole Body Vibration. In: 11th Mediterranean Conference on Medical and Biomedical Engineering and Computing 2007, pp. 990–993. Springer, Heidelberg (2007)
10. Mobasser, F., Hashtrudi-zaad, K.: Rowing stroke force estimation with EMG signals using artificial neural networks. In: *Proceedings of the 2005 IEEE Conference on Control Applications 2005, CCA 2005*, pp. 825–830 (2005)
11. Bravo, J., Hervás, R., Villarreal, V.: Ambient Intelligence for Health First International Conference, AmIHEALTH 2015 Puerto Varas, Chile, 1–4 December 2015, *Proceedings. Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 9456, pp. 3–14 (2015)
12. Sharawardi, N.S.A., Yun Huoy, C., Chong, S., Mohamad, N.I.: Isotonic muscle fatigue prediction for sport training using artificial neural network modelling. In: *Proceedings of 8th International Conference on Soft Computing and Pattern Recognition (SoCPaR 2016)*. Springer, India (2016)
13. Amin, M.A., Afzulpurkar, N. V., Dailey, matthew N., Esichaikul, V., Batanov, D.N.: Fuzzy C-mean determines the principle component pairs to estimate the degree of emotion from facial expressions, pp. 484–493. Springer, Heidelberg (2005)
14. Richard, C.D.: Cluster analysis and related issues. In: Chen, C., Pau, L., Wang, P. (eds.) *Handbook of Pattern Recognition and Computer Vision*, pp. 3–32. World Science Publishing Company, River Edge (1999)

15. Nguyen, V., Phung, D., Nguyen, X., Venkatesh, S., Bui, H.: Bayesian nonparametric multilevel clustering with contexts, vol. 32, pp. 1–12 (2014)
16. Charulatha, B., Rodrigues, P., Chitralakha, T.: A Comparative study of different distance metrics that can be used in fuzzy clustering algorithms. (2013). Ijettcs.Org
17. Van der Heijden, F., Duin, R.P.W., De Ridder, D., Tax, D.M.J.: Classification, Parameter Estimation and State Estimation: An Engineering Approach Using MATLAB (2005)
18. Bora, D.J., Gupta, A.K.: Effect of different distance measures on the performance of K-means algorithm: an experimental study in matlab. *Int. J. Comput. Sci. Inf. Technol.* **5**, 2501–2506 (2014)
19. Bezdek, J.C., Ehrlich, R., Full, W.: FCM: the fuzzy c-means clustering algorithm. *Comput. Geosci.* **10**, 191–203 (1984)
20. Tao, X., Cheng, B., Wang, B., Zhang, F., Li, G.: SEMG based recognition for lumbar muscle fatigue during prolonged driving, pp. 773–783. Springer, Heidelberg (2013)
21. Clarys, J.P., Scafoglieri, A., Tresignie, J.: Critical appraisal and hazards of surface electromyography data acquisition in sport and exercise (2010)
22. Fischer, S.L., Wells, R.P., Dickerson, C.R.: The effect of added degrees of freedom and handle type on upper limb muscle activity during simulated hand tool use. *Ergonomics* **52**, 25–35 (2009)
23. Engineering, S., Apr, S., Jun, A.: EMG in Straight Punching, pp. 849–856 (2014)
24. Watanabe, K., Kouzaki, M., Moritani, T.: Spatial EMG potential distribution of biceps brachii muscle during resistance training and detraining. *Eur. J. Appl. Physiol.* **115**, 2661–2670 (2015)
25. Yang, J., Hunt, A.: Real-time auditory feedback of arm movement and EMG in biceps curl training to enhance the quality. In: Proceedings of SoniHED—Conference on Sonification of Health and Environmental Data (2014)
26. SysML: EMG Analysis (2009)
27. Miranda, H., de Freitas Maia, M., Paz, G.A., de Souza, J.A.A.A., Simão, R., de Araújo Farias, D., Willardson, J.M.: Repetition performance and blood lactate responses adopting different recovery periods between training sessions in trained men. *J. Strength Cond. Res.* **1** (2017)
28. Stand, P.: Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* **41**, 687–708 (2009)
29. Robineau, J., Babault, N., Piscione, J., Lacombe, M., Bigard, A.X.: Specific training effects of concurrent aerobic and strength exercises depend on recovery duration. *J. Strength Cond. Res.* **30**, 672–683 (2016)