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Souha Baklouti, Tayssir Rezgui, Safa Mefteh, Anis Sahbani, Asma Chaouch, et al.. Investigation of the performance of force-myography as a possible substitute for surface electromyography in quantitative assessment of muscle contraction. *Computer Methods in Biomechanics and Biomedical Engineering*, 2021, ABSTRACTS 46ème Congrès Société Biomécanique, 24, pp.S80 - S82. 10.1080/10255842.2021.1978758 . hal-03701253

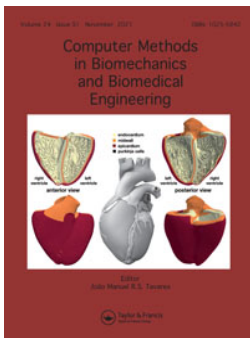
HAL Id: hal-03701253

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Submitted on 21 Jun 2022

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Computer Methods in Biomechanics and Biomedical Engineering

ISSN: (Print) (Online) Journal homepage: <https://www.tandfonline.com/loi/gcmb20>

ABSTRACTS 46^{ème} Congrès Société Biomécanique

To cite this article: (2021) ABSTRACTS 46^{ème} Congrès Société Biomécanique, Computer Methods in Biomechanics and Biomedical Engineering, 24:sup1, S1-S325, DOI: [10.1080/10255842.2021.1978758](https://doi.org/10.1080/10255842.2021.1978758)

To link to this article: <https://doi.org/10.1080/10255842.2021.1978758>



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Published online: 26 Nov 2021.



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Investigation of the performance of force-myography as a possible substitute for surface electromyography in quantitative assessment of muscle contraction

S. Baklouti^a, T. Rezgui^b, S. Mefteh^c, A. Sahbani^c, A. Chaouch^d and S. Bennour^a

^aThe Mechanical Laboratory of Sousse (LMS), National School of Engineers of Sousse, University of Sousse, Sousse, Tunisia;

^bApplied Mechanics and Systems Research Laboratory (LASMAP), Polytechnic School of Tunisia, University of Carthage, Carthage, Tunisia; ^cENOVA Robotics, Novation City, Tunisia; ^dNetworked Objects Control and Communication Systems Laboratory (NOCCS), National School of Engineers of Sousse, University of Sousse, Sousse, Tunisia

1. Introduction

Information about the muscle's activation pattern can be used to diagnose patients with musculoskeletal disorders. Surface electromyography (sEMG) is the main non-invasive technology used to study the contraction of muscles. However, sEMG recordings are sensitive to several factors such as electrode properties and placement, skin properties and preparation, external electromagnetic interference, and other sources of noise (Gerdle et al. 1999). This limitation makes the sEMG technique hard to implement in long-lasting real work situations. In recent years, another non-invasive technique, called Force-Myography (FMG), has gained recognition and acceptance. This technique is mainly used in physical activities prediction and monitoring applications (Xiao and Menon 2019). Surprisingly, there has been few works done to investigate its performance in quantitative assessment of muscle health. The aim of this paper is to investigate FMG performance in quantitative assessment of muscle health as a potential substitute of sEMG.

2. Methods

2.1. Materials and data collection

For this study, a sensor system has been designed for simultaneous acquisition of FMG and sEMG signals at the same measurement point. To record FMG and sEMG signals, we used Interlink-402 FSR and the commercial MyowareTM sensors, respectively. Since FSR sensor becomes unreliable in a direct contact with the skin, as described by Esposito et al. (2018), a mechanical coupler was mounted on

the FSR active area. To improve the sensor's sensitivity and reduce its drift, additional conditioning was needed. Even though Interlink Electronics suggests using a simple voltage divider circuit (2021), Xiao and Menon stated that this configuration dramatically degrades the sensor's sensitivity and complicates its drift (2019). That is why, we regulated the input voltage into a constant voltage of 3.3V. In addition, we used a Current-to-Voltage converter, as recommended by Interlink Electronics (2021), for response linearization. Our recordings were collected from healthy Biceps Brachii muscle of 5 volunteers (1 Male, 4 Females, 23 ± 2 years old) according to SENIAM (2021) recommendations. Maximum voluntary contractions (MVC) and submaximal voluntary contractions (SUB) were recorded for each subject. Through all tests, volunteers were asked to sit with the back supported. Before the experiment, subjects were instructed on how to perform MVCs and allowed to practice. Then, three MVC trials were recorded for 9 seconds on the verbal command of the investigator. For SUB recordings, volunteers were asked to perform, at a comfortable rate, 6 repetitions of elbow flexion-extension.

2.2. Data processing

Recorded signals during SUB tests were normalized by MVC to allow comparisons and then divided into segments for next feature extraction step. For the normalization, we used the two stage EMG onset detection method (Drapała et al. 2012). This method is the first to yield a computational estimation of EMG onset. We applied the first stage to obtain rough estimations of beginning and end points. But, for the second stage, we determined exact estimates by applying Komi and Cavanagh's single-threshold method (1979).

2.3. Data analysis and feature extraction

Recent studies showed that features extracted from sEMG data are more significant in quantitative assessment applications with reduced noise (Farago et al. 2019). As suggested by Phinyomark et al., features used for signal classification could be reduced into 4 types: (i) the energy and complexity information represented by mean absolute value (MAV) and modified mean absolute value type 1 (MAV1) and type 2 (MAV2). Waveform length (WL), (ii) the frequency information by Willison amplitude (WAMP), (iii) the prediction model represented by Auto-regressive coefficients (AR1, AR2, and AR3) and (iv) time-dependence resumed in the mean absolute

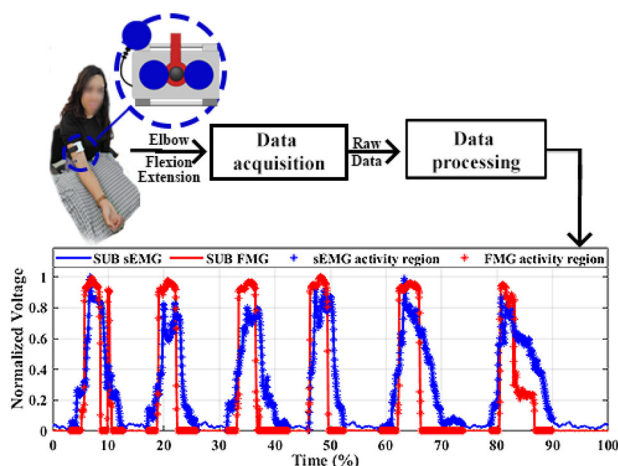


Figure 1. Processed and segmented SUB FMG and sEMG signals of a subject performing six elbow flexion-extension movements.

value slope (MAVS). For better signal classification, authors suggested also to add mean frequency (MNF) and power spectrum ratio (PSR) to the feature input vector (2012). All calculations were performed with MATLAB software package.

3. Results and discussion

Figure 1 shows a sample of processed, and normalized SUB signals recorded from Biceps Brachii of a subject and their activity segments. The dotted lines mark activity segments.

From these segments, features were extracted, and regression analysis algorithm was applied to fit lines through their scatter plots. After that, correlations between features and their regression lines were computed for each subject. Figure 2 sums up the mean values and standard deviations (SD) of these correlations. All features included in this study show a strong mean correlation ($r > 0.7$) indicating that the features extracted from FMG have a strong linear relationship with features extracted from sEMG.

MAV, MAV1, AR3, MNF, and PSR are the most consistent since they have the highest correlations and lowest SD. However, MAV2, WL, WAMP, AR1, AR2, and MAVS indicate a strong linear relationship between FMG and sEMG features but with higher SD. In reality, 1 out of our 5 volunteers reported weak correlations ($r < 0.5$) between these features and their regression lines. We believe this is related to an insufficient contact between sEMG electrodes and skin (Gerdlé et al. 1999).

4. Conclusions

Our study shows that FMG can be used as a substitute for sEMG technique in muscle contraction

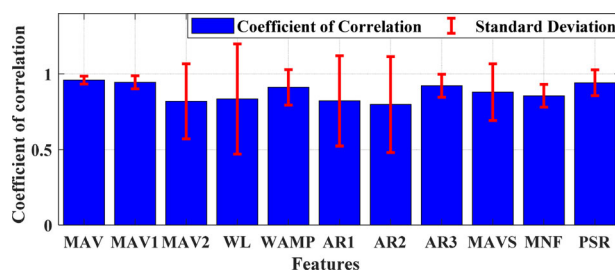


Figure 2. Mean values and SD of correlations between features scatter plots and their regression lines.

assessment. Compared with sEMG features recommended for signal classification, FMG features showed a strong linearity relationship. This relationship enables obtaining signal classification input features vector from FMG data. Further understanding of the relationship between sEMG and FMG features will be important to exploit this technique in many clinical and engineering applications, improve the wearability of muscle health assessment devices and reduce their requirements.

Acknowledgements

This project is carried out under the MOBIDOC scheme, funded by The Ministry of Higher Education and Scientific Research through the PromEssE project and managed by the ANPR.

Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Surface electromyography; force-myography; quantitative assessment

 baklouti.souha@eniso.u-sousse.tn