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On The Relationship between Features Extracted from EMG and Force for Constant and Dynamic Protocols*

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Abstract— **The main objective of this study was to characterize the relationship between electromyography and force based on the results obtained from a developed analysis tool. The developed tool presents interesting features for the study of this relationship. Among them, it can be highlighted the possibility of simultaneous analysis of various features in the time domain (obtained from electromyographic signals), and the generation of graphics that allow the visualization of the relation between the selected features and the force signal. The tool also allows a feature evaluation based on different models (e.g., linear, quadratic and exponential) allowing a better understanding of the EMG-force relationship. In order to evaluate the developed tool and study the EMG-force correlation, electromyographic signals (EMG) and force measurements were collected from 15 subjects while executing eight different experimental protocols. The obtained results showed that statistical features (e.g., kurtosis and skewness) are less sensitive to dynamic force protocols; and also that features related to the amplitude of the signal are more appropriate to represent the relationship between EMG and force during the execution of constant force protocols. These results, besides having several practical applications, can be used as part of EMG signals simulators, developed for different applications, such as the evaluation of automatic systems used in the decomposition of EMG signals.**

Keywords – **Electromyography, EMG-Force Relationship, First Dorsal Interosseous**

I. INTRODUCTION

In an attempt to represent any real system in a satisfactory manner, it is necessary to have a model that represents with fidelity the studied system and its relationship with variables of interest.

The modeling of any type of signal allows for the generation of different scenarios from which it is possible to guide decision-making processes, to undertake the analysis and evaluation of systems and to propose solutions for improving the performance of systems.

Simulation of eletromyographic (EMG) signals is, such as other subjects, greatly improved by the evolution of its simulation models. The more we are able to describe an EMG signal in relation to factors underlying the muscle contraction mechanism, the more it is known about the signal behavior and, consequently, misbehavior (malfunctioning) [1].

In the present work, the relationship between the EMG signal and the muscle force has been chosen as a focus mainly due to the importance of this factor in the investigation of muscle dysfunction, fatigue and other diseases that can be assessed by means of the analysis of EMG activity.

The EMG-force relationship has been studied by various authors [2-6], and most of them consider linear the relation between EMG and muscle force. However, there is a lack of studies that assess different types of features extracted from EMG activity and the correlation of these features with force.

In this context, the objective of this paper is to investigate a feature-based relationship between electromyography and force, with the use of a developed analysis tool. This relationship, besides having several practical applications, can be used as part of EMG signals simulators, developed for different applications, such as the evaluation of automatic systems used in the decomposition of EMG signals [7-10].

II. METHODS

In total 15 subjects were involved in the study. The EMG activity was collected from the *First Dorsal Interosseous* (FDI) muscle, which is a small muscle responsible for the adduction movement of the index finger. A parallel bar Ag/AgCl electrode (1cm x 1mm with inter-electrode distance of 1cm) was employed as an active sensor.

A computer program was developed in C# to control data collection. The idea was to synchronize both the force gauge, used for the actual force measurement, and the EMG acquisition while conducting eight distinct experimental protocols.

These protocols were developed to guide the subject in varying, or maintaining, his muscle force, while measuring the related EMG force. Five out of the eight protocols were based on muscle contraction with constant force at different levels; whereas three protocols were based on muscle contraction with varying force. During the execution of Protocol 1 the subject was asked to maintain the force, F, constant (equivalent to 100 g – 200 g) for 30 s. A similar procedure was adopted in Protocols 2, 3, 4 and 5, however with different force levels such as depicted in Figure 1. Protocols 6, 7 and 8 were time-varying force protocols,

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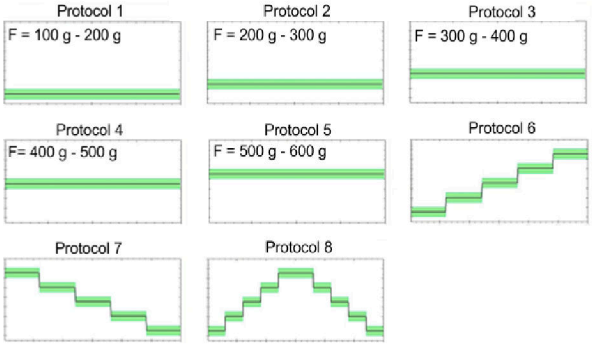
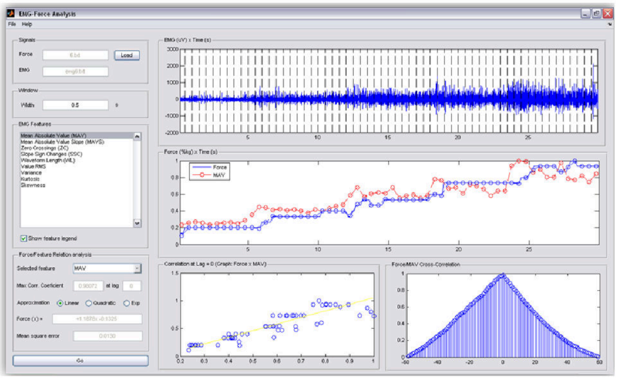


Figure 1.Experimental protocols employed in the study. Protocols from 1 to 5 are time invariant, whereas Protocols from 6 to 8 are time-variant. F is the required force in grams. Refer to the text for more information on the meaning of the protocols.



Force 6.txt

EMG emg6.txt

Width 0.5 s

Mean Absolute Value (MAV)
Mean Absolute Value Slope (MAVS)
Zero Crossings (ZC)
Slope Sign Changes (SSC)
Waveform Length (WL)
Value RMS
Variance
Kurtosis
Skewness

☑ Show feature legend

Selected feature MAV

Max Corr. Coeficient 0.98072 at lag 0

Approximation ● Linear ○ Quadratic ○ Exp

Force (x) = +1.1678x -0.1325

Mean square error 0.0130

Figure 2. Customized graphical user interface of the software developed in Matlab for the analysis of the EMG-force relationship.

where the force level varied every 5 seconds. The force levels varied in accordance to those defined in Protocols 1, 2, 3, 4 and 5.

In order to analyze the data a custom-made program was developed in Matlab. The tool was able to load the recorded EMG (see Figure 2 - top) and actual force signals (see Figure 2 – middle) and show them on the graphical user interface. In addition, the tool was responsible for windowing the EMG signal (non-overlapping windows of 500 ms each) and extracting features from each window.

The following set of features proposed in [11, 12] for prosthetic control is available in the tool and was investigated in this study: Mean Absolute Value (MAV); Mean Absolute Value Slope (MAVS); Zero Crossings (ZC); Slope Sign Changes (SSC); Waveform Length (WL); Variance (VAR); Kurtosis (KUR) and Skewness (SKEW).

The feature MAV captures changes in the amplitude of the signal, whereas the feature MAVS describes the variation of the steepness of this amplitude. The ZC and the SSC provide measures of frequency, and the WL provides information on the complexity of the waveform in each segment. VAR, KUR and SKEW are statistical moments.

The implemented tool allows the user to perform a visual comparison of the actual force with the estimated force based on EMG features. In Figure 2 the red waveform is the estimated force which is compared to the blue waveform which is the estimated force based on a specific feature. The correlation between these waveforms can also be studied by different types of models (i.e., linear, quadratic and exponential) which are available in the program.

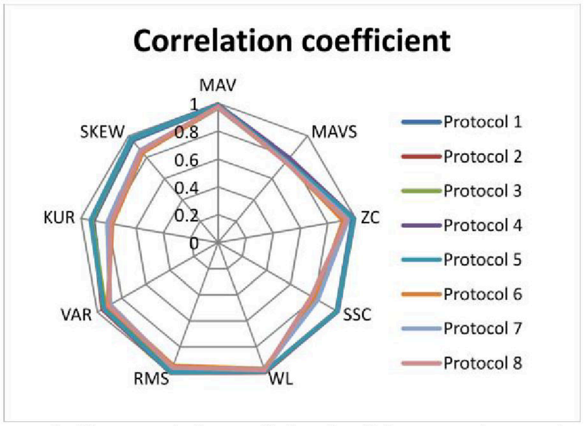


Figure. 3. Mean correlation coefficient for all features and protocols.

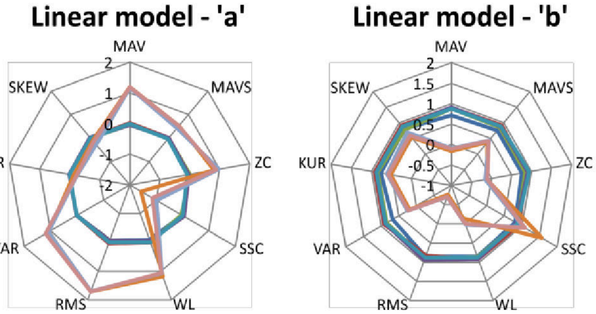


Figure. 4. Mean of the linear model parameters ‘a’ (left) and ‘b’ (right) for all features and protocols.

The following models and parameters were investigated in the study:

1. The correlation coefficient;
2. The linear model (parameters a and b, as in $y = ax+b$);
3. The quadratic model (parameters a, b and c, as in $y = ax^2+bx+c$);
4. The exponential model (parameters a and b, as in $y = be^{ax}$);

The mean value of each parameter of the models above was estimated for all subjects and for each type of experimental protocol.

III. RESULTS

The results are presented in Figures 3-6. Figure 3 shows the labels adopted for each type of protocol in all figures.

Figure 3 shows the results concerning the mean correlation coefficient estimate for each feature and for all protocols. The mean correlation coefficient for protocols 1, 2, 3, 4 and 5 (constant force) was 0.9499 with standard deviation of 0.0047. The mean correlation coefficient for protocols 6, 7

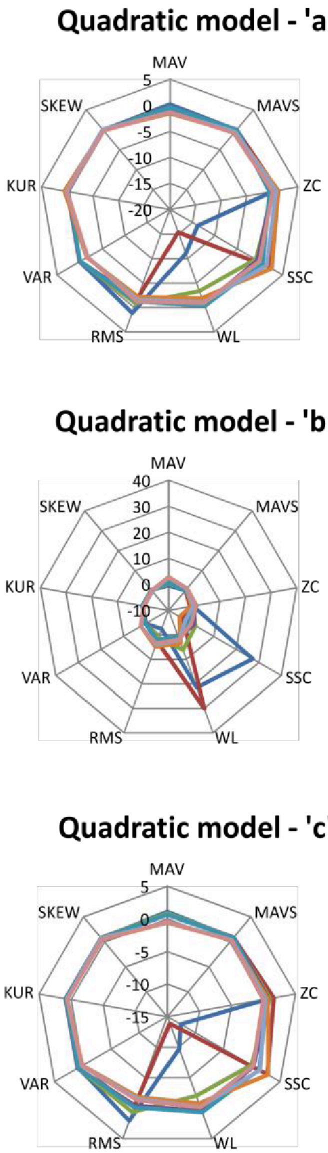


Figure. 5. Mean of the quadratic model parameters ‘a’ (top) and ‘b’ (middle) and ‘c’ (bottom), for all features and protocols.

and 8 (dynamic force) was of 0.8815 with standard deviation of 0.0059.

For all protocols, it was the feature MAVS the one which showed the lowest correlation with force (mean of 0.7684 for constant force and mean of 0.7570 for dynamic force). The RMS was the feature which showed the highest correlation (0.9930) with force in the case of constant force, whereas for the case of dynamic force it was the feature MAV the one which showed the highest correlation with force (0.9718).

Figure 4 shows the results concerning the parameters ‘a’ and ‘b’ of the linear model. The mean value of ‘a’, ‘b’ and the mean squared error, for the constant force protocol, was respectively -0.0137, 0.8616 and 0.0194. These values were 0.5389, 0.2253 and 0.0370 for the dynamic force protocol.

Figure 5 shows the results concerning parameters ‘a’, ‘b’ and ‘c’ of the quadratic model. The mean value of ‘a’, ‘b’, ‘c’ and the mean squared error, for the constant force protocol, was respectively -1.1146, -0.2567, -0.1201 and 0.0052. These values were -0.5113, 1.0166, 0.1184 and 0.0327 for the dynamic force protocol.

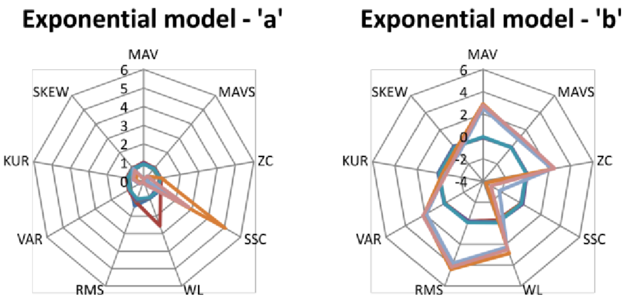


Figure. 6. Mean of the exponential model parameters ‘a’ (top) and ‘b’ (bottom) for all features and protocols.

Figure 6 shows the results concerning parameters ‘a’ and ‘b’ for the exponential model. The mean value of ‘a’, ‘b’ and the mean squared error, for the constant force protocol, was respectively 0.9626, -0.0434 and 0.0109. These values were 0.6714, 1.2151 and 0.3102 for the dynamic force protocol.

IV. DISCUSSION

The analysis of the correlation coefficient (see Figure 3) suggest that the features MAV, RMS and WL are the ones which yielded the highest correlations between force and EMG for both steady (i.e., constant force) and dynamic (i.e., varying force) protocols. Since these features capture changes in the EMG amplitude and the studied correlation is a linear measure, it can be suggested that there is a strong linear correlation between force and the features MAV, RMS and WL.

The study of the parameters of the linear model given in Figure 4 indicates that such a model is more suitable for representing the constant force protocol than the dynamic protocol. This is because the model parameters ‘a’ and ‘b’ are respectively close to 0 and 1, for the constant force case and for all features. The statistical features KUR and SKEW were more invariant to the type of protocol, although they are not the ones which yielded the highest correlation values as shown in Figure 3.

From the presented results it is possible to conclude that all models could be used to discriminate the two groups of protocols used in the study: the protocols with a constant force value (protocols 1, 2, 3, 4, 5) and the ones with a variable force (protocols 6, 7, 8). This can be seen by analyzing the model parameters shown in Figures of 4 to 6.

Considering that the main difference between the two investigated protocols is related to the increase of motor unit recruitment and its firing rate, we can make the hypothesis that this factor strongly influences most of features except for KUR and SKEW.

Although the exponential model yielded a small mean square error for the constant force protocol, it yielded a large error for the dynamic protocol which makes it not suitable for representing the relationship between EMG and force. In our study both the linear and quadratic models showed to be adequate for modeling this relationship, being the quadratic model the one which yielded the smallest fitting error for both types of protocols.

V. CONCLUSION

The work presented here had as its primary goal to analyze the relationship between the EMG signal and the muscle force. This objective was achieved with the presentation of a quantified relationship between the force in the *First Dorsal Interosseous* muscle and the representative features of the EMG signal.

The developed tools for signal analysis were designed in the most general way possible, and they can then be used in other researches on the area of electromyography or signal analysis.

The main conclusions of the study are: statistical features, such as kurtosis and skewness are less sensitive to dynamic force protocols; features related to amplitude such as MAV, RMS and WL are more appropriate to linearly represent the relationship between EMG and force; both linear and quadratic models are suitable for modeling this relationship, being the quadratic model less sensitive to varying force protocols.

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