

Muscle activity characterization by laser Doppler Myography

Lorenzo Scalise, Sara Casaccia, Paolo Marchionni, Ilaria Ercoli, Enrico Primo Tomasini

Dipartimento di Ingegneria Industriale e Scienze Matematiche (DIISM)
Università Politecnica delle Marche, 60131, Ancona, ITALY

E-mail: l.scalise@univpm.it

Abstract. Electromyography (EMG) is the gold-standard technique used for the evaluation of muscle activity. This technique is used in biomechanics, sport medicine, neurology and rehabilitation therapy and it provides the electrical activity produced by skeletal muscles. Among the parameters measured with EMG, two very important quantities are: signal amplitude and duration of muscle contraction, muscle fatigue and maximum muscle power. Recently, a new measurement procedure, named Laser Doppler Myography (LDMi), for the non contact assessment of muscle activity has been proposed to measure the vibro-mechanical behaviour of the muscle.

The aim of this study is to present the LDMi technique and to evaluate its capacity to measure some characteristic features proper of the muscle. In this paper LDMi is compared with standard superficial EMG (sEMG) requiring the application of sensors on the skin of each patient. sEMG and LDMi signals have been simultaneously acquired and processed to test correlations. Three parameters has been analyzed to compare these techniques: Muscle activation timing, signal amplitude and muscle fatigue. LDMi appears to be a reliable and promising measurement technique allowing the measurements without contact with the patient skin.

1. Introduction

Electromyography (EMG) is the most common biomedical instrumentation used for the evaluation of muscles activity [1]. EMG uses needle electrodes (invasive measurement of EMG) or adhesive skin electrodes which are placed in contact with skin (non-invasive measurement of EMG) to measure the myoelectric activity. In this work, we use the latter method to measure the EMG signal that is commonly known as surface electromyography (sEMG) [1,2]. sEMG is not always easy to be performed because it requires the patient collaboration and the possibility to apply the electrodes to the skin; it is therefore required an accurate skin preparation (removing eventual hair, skin detersion, etc.) and particular attention to the placement of the electrodes and cable positioning.

The aim of this study is demonstrate that it is possible to evaluate some parameters related to the muscle activity without contact by means of a novel optical measurement method (Laser Doppler myography, LDMi [3]). This is possible because the muscle contraction is characterized by two component: the electrical component measured by sEMG and the mechanical component measured by Laser Doppler myography. So, the Laser Doppler vibrometer measures the muscle vibrations [3,4] during an isometric muscle contraction. In recent years, the Laser Doppler vibrometer has been widely used for biomedical applications and it has already been demonstrated to be a valid instrument for the assessment of the vibrational behaviour of the human skin[3-7].



2. Materials and methods

The study is focused on the detection of the muscle contraction from different muscles: flexor carpi ulnaris and tibialis anterior. The test involved the simultaneous acquisition of the sEMG signal and the LDMi signal during an isometric contraction of the muscle. In order to record the sEMG signal it is necessary to apply two Ag-AgCl electrodes on the skin in correspondence to the right and left flexor carpi ulnaris/tibialis anterior while a reference electrode is fixed on the wrist for the flexor carpi ulnaris and on the ankle for the tibialis anterior (bipolar configuration, fig.1). Before electrodes application, the skin must be shaved and cleaned and cables were fixed in order to limit the noise. During the test on the forearm carpi ulnaris, the subject was asked to seat on a chair with the elbow flexed at the right angle and the dorsal side of the forearm in a horizontal downwards position and for the muscle contraction he must contract the hand holding an object. While for the test on the tibialis anterior the subject was seated with the leg stretched and he brought the tip of the foot upward without extension of the great toe. The LDMi signal is measured with a single point system (PDV100; calibration accuracy ± 0.05 mm/s, bandwidth 0.05 Hz- 22 kHz, spot dimension < 1 mm, working wavelength He-Ne 632.8 nm). The velocity of vibration of the measurement point was measured. The laser beam was pointed perpendicular to the skin surface at a distance of about 30 cm and the laser spot was pointed between the skin electrodes. sEMG and LDMi signals are acquired by a 12 bit acquisition board (ML865 PowerLab 4/25T). The surface EMG signal is filtered by a band-pass filter (10-200 Hz) and by a Notch filter to eliminate 50 Hz noise. Both the acquired signals are sampled at 1kHz, synchronously. The experimental setup is reported in fig.1.

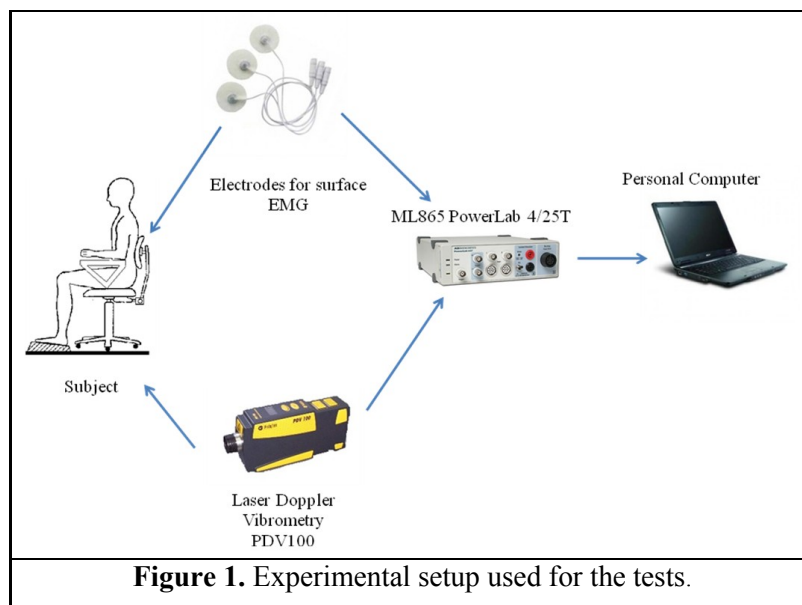


Figure 1. Experimental setup used for the tests.

Tests have been performed on 20 subjects (10 females and 10 males), of mean weight $65 \pm (10)$ kg, height $170 \pm (10)$ cm, and $24 \pm (5)$ years. All subjects have been measured on flexor carpi ulnaris and tibialis anterior (left and right). They were trained with the experimental protocols before the test. To investigate that the LDMi method is valid to determine the muscle contraction, we have calculated the RMS (root mean square) of the signals which can be considered as an index of the signal sensitivity and an index of muscle fatigue [8].

3. Results

3.1 Timing of muscle activity

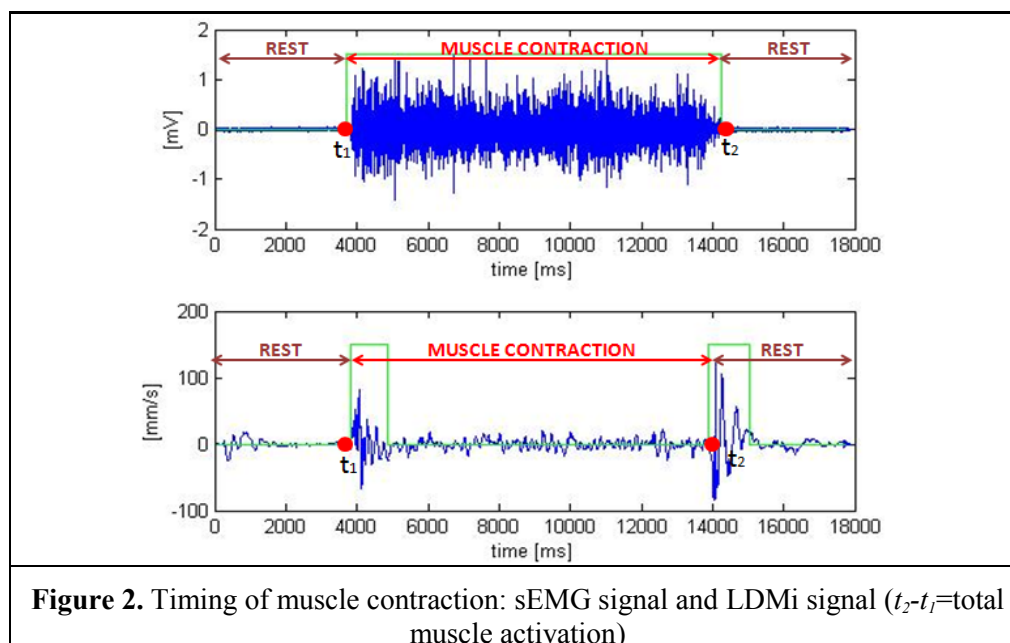
The detection of the muscle activation has been performed using a threshold algorithm. This method allows to evaluate activation events analyzing the RMS of the signals. This algorithm is applied to

both the acquired signals (sEMG and LDMi) to evaluate the differences of timing of the signal activations measured by the sEMG and the LDMi (tab.1). The threshold to discriminate the muscle contraction was based on the rest condition. A muscle activation is detected when the RMS of the signal reaches values higher then the threshold for a at least 100 samples. Each test was characterized by 3s of rest, 10s of muscle activation and of 3s of rest after the contraction and each subject was asked to repeat the test 4 times.

Table 1. Mean and standard deviation of the duration of the muscle contraction, activation and deactivation time for sEMG and LDMi

	Deviation between sEMG and LDMi values		
	t_2-t_1	t_1	t_2
Right flexor carpi ulnaris (mean$\pm$SD)	0.12 $\pm$ 0.09	0.01 $\pm$ 0.05	0.13 $\pm$ 0.09
Left flexor carpi ulnaris (mean$\pm$SD)	0.23 $\pm$ 0.44	-0.008 $\pm$ 0.04	0.22 $\pm$ 0.06
Right tibialis anterior (mean$\pm$SD)	0.18 $\pm$ 0.13	-0.07 $\pm$ 0.04	0.12 $\pm$ 0.11
Left tibialis anterior (mean$\pm$SD)	0.15 $\pm$ 0.12	-0.05 $\pm$ 0.03	0.10 $\pm$ 0.09

The activation on the sEMG signal is characterized by a clear increase of the RMS signal amplitude respect to the amplitude of the RMS of the noise. The deactivation phase is clearly visible by the decreasing of the RMS signal amplitude. For the LDMi signal, the activation starts with the first group of peaks and it finishes before the last group of peaks. An example of the events detection (activation/deactivation) is shown in fig.2 for both the signals (sEMG and LDVi):

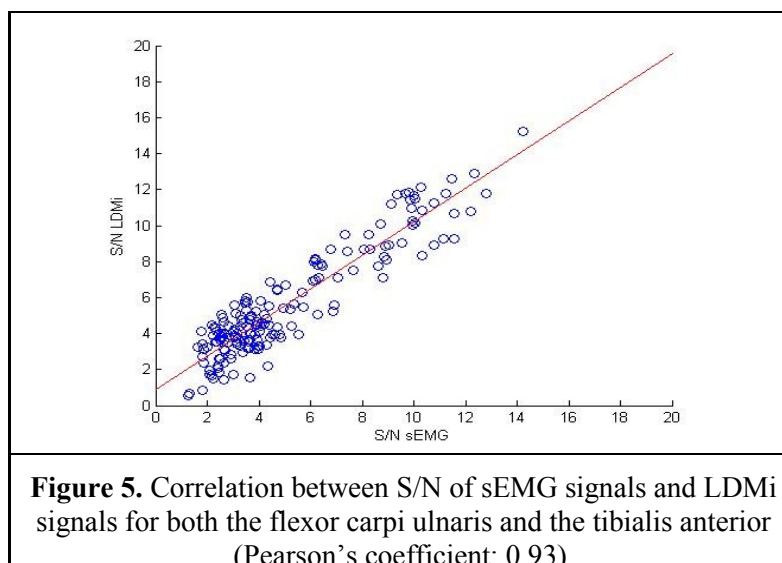
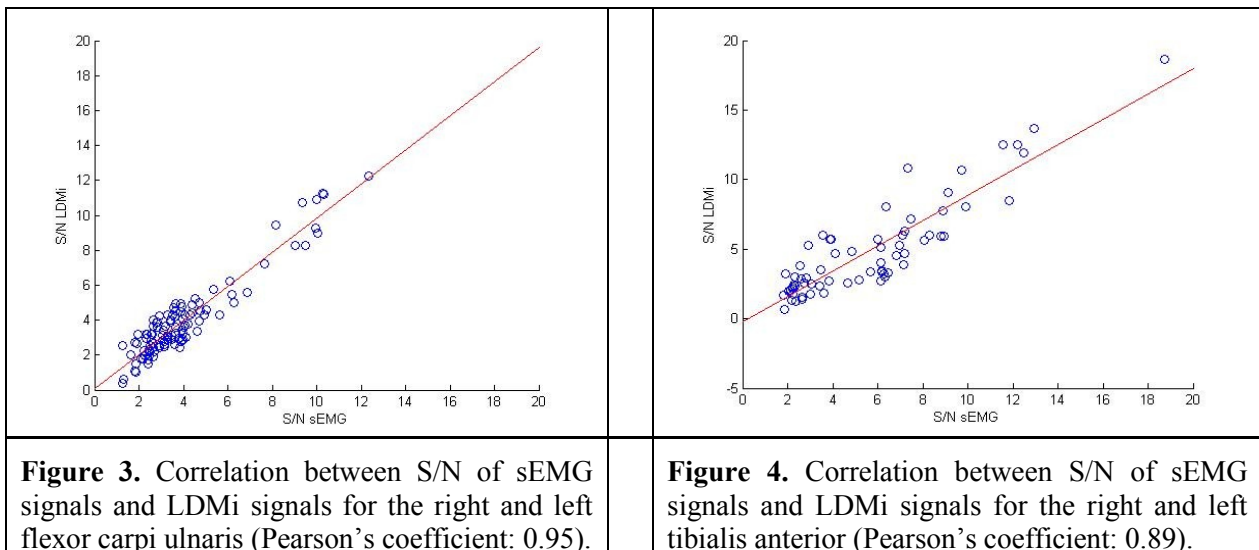


3.2 Signal amplitude

The signal amplitude was evaluated by the calculation of the RMS value of the acquired signal during the activation and rest phases on sEMG signal and LDMi signal (fig.2). The ratio of the RMS values of each of two signals (sEMG and LDMi) during activation (t_2-t_1) and rest (t_1) was then calculated. This ratio is called Signal to Noise Ratio (S/N). With this parameter is possible to evaluate the sensitivity of the signal on the noise.

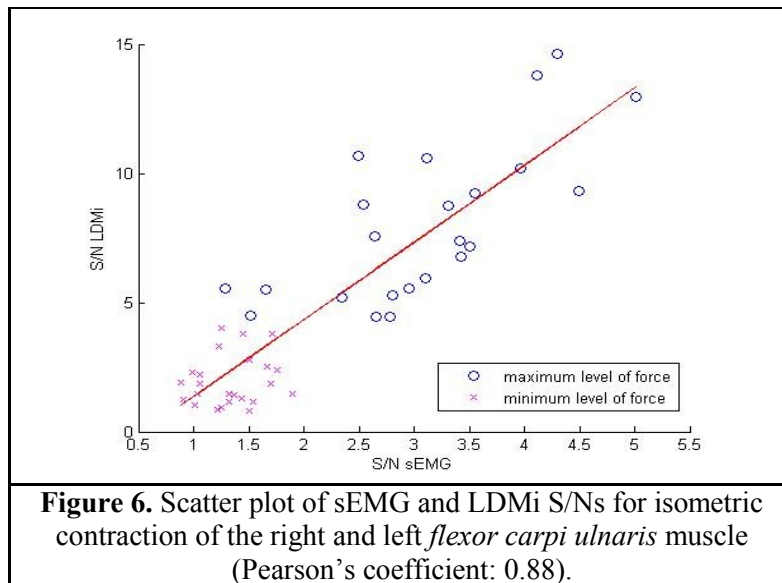
$$S / N = \frac{\sqrt{\frac{1}{t_2 - t_1} \sum_{i=t_1}^{t_2} musclecontraction_i^2}}{\sqrt{\frac{1}{t_1} \sum_{j=0}^{t_1} rest_j^2}} \quad (\text{eq. 1})$$

LDMi signal was filtered in order to remove noise; a wavelet filter was applied using a Sym4 mother for the case of the flexor carpi ulnaris acquisition, while the Sym2 was used for the case of the tibialis anterior. Correlation between S/N of the sEMG signals and S/N LDMi signals - calculated using eq. 1 – are reported in fig.3, fig.4 and fig.5.



3.3 Relationship between sEMG and LDMi signals

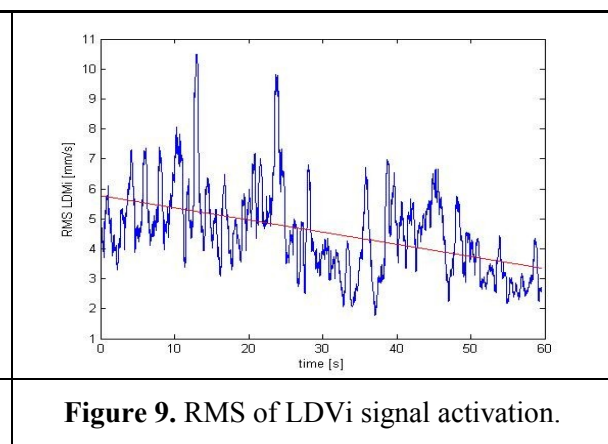
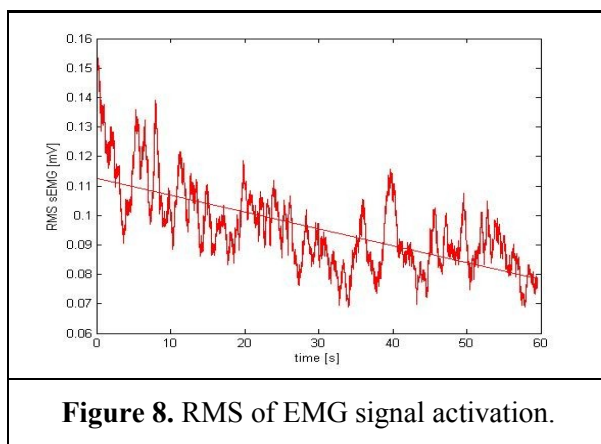
A second test was carried out aiming to analyze the correlation between surface EMG and LDMi amplitudes. The subject contracted the flexor carpi ulnaris muscle with two different force levels (minimum and maximum). For this test the subjects were 3 and each subject repeated the test 4 times for the maximum level of force and 4 times for the minimum level of force. The parameter that was calculated is S/N (according eq.1) and the LDMi signal was filtered with a Wavelet (sym4).



In correspondence to a force increase, it's possible to observe an increase of the S/N sEMG signal amplitude as well as of the LDMi signal which allows to cluster the data in terms of force level.

3.4 Muscle fatigue

The RMS value of the time signals and the slope of the interpolating line are known parameters for the evaluation of the muscle fatigue. The RMS value, according eq.1, is calculated during the muscle contraction for sEMG and LDMi signals. For this test, acquisitions stands for 60s. In fig. 8 and 9, an example of time series of the RMS of the acquired signals are reported; it is possible to observe a negative slope on both the interpolating lines testifying the effect of the muscle fatigue.



4. Discussion

The aim of this research is to present a non-contact measurement procedure for the determination of the muscle characteristics related to the muscle contraction. Comparative tests with sEMG and the proposed method have been carried out on a population of 20 subjects on the flexor carpi ulnaris and tibialis anterior (left and right) muscles. The RMS value of the acquired signals and the Signal to Noise ratio (S/N) have been calculated and results show that the detection timing is sufficiently accurate (maximum standard deviation: 440 ms). A good correlation between the S/N of sEMG signals and the S/N of LDMi signals is also reported (mean Pearson coefficient: 0.93). This result is also shown for the test at minimum and maximum level of force. Finally, it was also possible to evaluate the muscle fatigue.

Such results highlight the possibility to measure such parameters, related to the muscle activity, using the proposed method without contact, obtaining results which are in accord with the ones measured with the gold standard (sEMG).

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