Abstract—In the context of physical medicine and rehabilitation, gait analysis is the "gold standard" for an effective assessment of any problems in the locomotor patterns. Surface electromyography is one of the exams within the protocol of the gait analysis, allowing an assessment of functional limitations in the walking. Considering the Physical Medicine and Rehabilitation Unit of the University of Catanzaro, physicians are limited to a visual analysis of the electromyographic signals coming from the muscles of the lower limbs, to extract useful information for diagnosis and monitoring of treatment. The objective of this work is to provide to specialists a simple and flexible system that allows the extraction of quantitative synthetic parameters in time and frequency domain from EMG signals; in particular we propose a novel EMG data acquisition and processing system, referred as EMG-Miner, that allows the automated acquisition and analysis of EMG signals along the different stages of the rehabilitation process (follow-up) of a patient.

Keywords — Dynamic EMG; Signal Processing; Rehabilitation

I. INTRODUCTION

Electromyography (EMG) is a technique widely used for diagnostic analysis and therapeutic treatment of myopathies and neuropathies, providing information about the functionality of the peripheral nerves and the skeletal muscles [1]. There are two types of electromyography: needle electromyography and surface electromyography. The first one is a very invasive technique and requires the use of needle electrodes that are inserted into the muscle under examination by the physician, recording its activities. Surface electromyography (sEMG) delivers a safe, easy and noninvasive method for the objective quantification of the energy of the muscle. The genesis of the myoelectric signal does not refer to the electrically stimulated contraction but to the system of voluntary contraction. The motor units are activated at different frequencies and their contributions to the signal of the skin are added asynchronously, generating a random signal. This signal has amplitude that depends on the intensity of the contraction and ranges from 50μV to 5mV. It presents significant harmonics between 2 Hz and approximately 500Hz [2].

A clinical use of sEMG (referred as dynamic EMG) involves dynamic recording motor output during intentional movements. Dynamic EMG is employed within the framework of clinical gait analysis, and it offers information related to gait disturbance [3]. Particularly, quantitative gait analysis, including kinematic, joint motions measurements and dynamic electromyography recording, quantifies functional limitation along within impairment and disability and allows an objective evaluation of the effectiveness of various rehabilitation treatments aimed at improving gait disability [4].

As a part of a gait analysis protocol, the sEMG is being more and more frequently applied. Gait laboratories have considerably increased and are currently present in the most relevant rehabilitation and medical centers. The development of proper tools to facilitate data analysis and quantitative description of locomotor patterns will possibly contribute to a more effective study and comprehension of locomotor coordination strategies and gait-related postural control mechanism [5].

In this paper we propose the design and implementation of an innovative automatic EMG data acquisition and processing system, referred as EMG-Miner. The goals of the proposed system are: (i) to automatize the acquisition and analysis of EMG signals, such that derived features can be shown in real time to the doctors during the rehabilitation process; (ii) to give to the doctors objective measurements of the rehabilitation activities, that can be stored and compared along several phases of the rehabilitation process (follow-up).

Starting from the use of a certified electromyograph whose software includes only the EMG signal acquisition and saving of the track, we have improved the system using a data acquisition board and creating the management software of the board, supplemented by a series of signal processing functions, that compute the most significant and useful time
and frequency features for dynamic EMG signals. These features can be computed in real time that is in the same acquisition time of the signal or later, starting from the saved EMG signals.

The remainder of the paper is organized as follows: section II illustrates a summary of time domain and frequency domain analysis of dynamic EMG signals; section III describes the architecture and functionalities of EMG-Miner; in section IV obtained experimental results are discussed; finally section V concludes the paper.

II. BACKGROUND ON TIME AND FREQUENCY ANALYSIS OF DYNAMIC EMG

In the clinical practice, specialists to obtain information about the status of the muscles visually inspect the EMG signal. The limit of this approach is the subjectivity [6]. To overcome this problem, a quantitative analysis based on objective procedures in time, frequency or joint time-frequency domain, is needed [7]. Many studies have been discussed the parameters to be considered for a quantitative analysis of EMG signals obtained under dynamic conditions, especially regarding the gait analysis in physiological and pathological patients [5].

A necessary step in dynamic EMG processing is the rectification of the signal. This pre-processing procedure allows the calculation of amplitude parameters such as average, maximum, minimum peak and area under the curve [8]. The analysis in the time domain consists in the calculation of three estimators of signal amplitude: (i) Average Rectified Value (ARV), defined as the average value straightened or Mean Absolute Value (MAV), the average amplitude in the linear case [9]; (ii) Maximum peak [9]; (iii) Root mean square (RMS), which calculates the square root of the average power of the raw EMG signal in a specific time period [10].

De Luca’s [11] research group considers both the ARV and RMS as suitable analysis methods, while other authors prefer the RMS [12] since it can be used to obtain a moving average. The latter approach is used to process raw EMG signals from dynamic contractions since it identifies the rapid changes in muscle activity during these contractions using short duration sampling windows [13]. Several studies consider the RMS indicator of fatigue of the muscle fibers, [14-15], as it was noted an increase in the RMS amplitude in the presence of a muscle fatigue.

Also EMG signals may be analyzed in the frequency domain [3] using the power spectral density (PSD) to describe how the power of a signal is distributed between its frequency components. The spectrum of the power of a recording sEMG, obtained from the Fourier transform of the signal, showing that most of the signal power is located between 10 and 250 Hz and that the frequency with the maximum amplitude is reached at about 80 Hz [7]. For example, muscle fatigue is represented by significant changes of the power spectrum [16]; in particular after the onset of fatigue, the PSD increases in low frequency components and decreases in high frequency components. Two of the most common frequency-dependent features in EMG analysis are the mean frequency (MNF) and median frequency (MDF). The first one is the average frequency of the power spectrum, which is calculated as the sum of product of the EMG power spectrum and the frequency divided by the total sum of the power spectrum [17]; the following shows the definition of MNF:

\[
MNF = \frac{\sum_{j=1}^{M} f_j P_j}{\sum_{j=1}^{M} P_j}
\]

where \(f_j\) is the frequency value of EMG power spectrum at the frequency bin \(j\), \(P_j\) is the EMG power spectrum at the frequency bin \(j\), and \(M\) is the length of frequency bin. MDF is defined as the frequency which divides the power spectrum in two parts with equal areas. The following shows the definition of MDF:

\[
MDF = \sum_{j=1}^{M} \frac{P_j}{2} = \sum_{j=MDF}^{M} P_j
\]

Hagberg [18] said that if there is an increase in the EMG signal amplitude and the MDF decreases, this is an indication of fatigue. With increasing fatigue, decreased values of the mean and median frequency are related to a decreased conduction velocity of the action potential of the motor units [19-21].

III. SYSTEM ARCHITECTURE

The proposed system (Fig. 1) has been designed in LabVIEW environment [22] and implemented integrating an innovative electromyograph (ZeroWire EMG, Aurion) [23] and a data acquisition board (DAQPAD-6015 USB, National Instruments) [24].

Since the software of the electromyograph has a limited number of signal processing operations, we have sought to realize a new system of EMG data acquisition (however based on the ZeroWire EMG) with a major number and a custom typology of signal processing operations. Once we have chosen to use the Labview graphical programming environment, it was necessary to select a data acquisition board to pass the EMG data to the PC. The choice has fallen on the NI DAQPAD-6015 USB.

ZeroWire is an innovative completely wireless EMG system. The innovative WiFi acquisition technique firstly ensures the isolation of the patient, which is not in close contact with the electrical circuit. Moreover, the absence of wires on the patient favors the analysis in situations where there is a need for maximum freedom of movement. The signal is acquired up to a distance of 10-20 m. The system uses standard electrodes (Ag/AgCl), each equipped with a miniaturized unit for processing and transmission of the signal. There are 8 acquisition channels and 2 footswitches for the gait analysis [23]. Each footswitch includes four electrodes.
placed respectively in proximity of the heel, the hallux, the upper metatarsal and in an intermediate position between hallux and upper metatarsal of each foot.

The National Instruments DAQPad-6015 multifunction data acquisition (DAQ) device provides plug-and-play connectivity through USB to the acquisition, generation and data logging in a wide range of portable and desktop applications. DAQPad devices with screw terminals or BNC connectors give direct connectivity so that it is possible to easily connect sensors and signals without additional costs. All devices feature 16-bit accuracy at up to 200 kS/s. NI DAQPad-6015 includes NI-DAQmx measurement services software with which it is possible to quickly configure and start the measurements with the DAQ device. NI-DAQmx provides a perfect interface to LabVIEW.

The connection between the devices has been achieved, by providing ad hoc cable, which allowed the transmission of the analog EMG signal from the electromyograph to the data acquisition board. In particular, we used a C10015 cable with one end welded to a male DB25 connector to be inserted into the female DB25 connector of the ZeroWire EMG and the other end directly connected to the screw terminals of the data acquisition board. Finally we connected the data acquisition board to the PC via the USB bus.

### A. EMG-Miner Functions

We designed and implemented the proposed system in the LabVIEW environment for the control of data acquisition board and the custom processing of the acquired signals. It was created a very simple and intuitive user interface that offers the possibility to choose how to perform signal processing and analysis. Therefore the operator can choose whether or not to insert each block of signal processing, thus customizing the operation. The software application is divided into three main operations, which are executable in an exclusive manner: (i) calibration for the calculation of maximum voluntary contraction (MVC) of the muscles associated with each channel, (ii) acquisition and on-line processing, and (iii) post-processing analysis. In the acquisition phase the following operations are present:

- Display of the raw signals;
- Filtering (notch filter, low pass and high pass filter);
- Rectification;
- EMG signal maximum and minimum evaluation;
- Calculation of the root mean square (RMS);
- Power spectrum;
- Mean frequency (MNF) and median frequency (MDF) evaluation;
- Normalization of the signal relative to the MVC;
- Saving of EMG signals and all processing results with patient information.

These operations may be selected or not by the operator before and during the acquisition through a series of buttons located in the user interface. For many of the previous signal processing tasks, EMG-Miner offers to the user the possibility to set some control parameters e.g. filters cutoff frequency, temporal window for RMS, etc.

If the operator wants to analyze the EMG signals after the acquisition, he/she can upload the signals previously saved. Moreover, in this case the different tasks of signal processing may be included or not.

### IV. EXPERIMENTAL RESULTS

EMG-Miner was used to acquire and process the EMG signals acquired from patients with different pathologies, in order to derive a set of parameters in the time and frequency domains that can assist the medical staff.

#### A. Patients data and acquisition protocol

The signal recording for system experimentation was carried out at the “Mater Domini” University Hospital of
Catanzaro, under the supervision of the medical staff of the Physical Medicine and Rehabilitation Unit. 8 patients and 3 normal subjects were involved in this experimentation (see Table I). All patients were informed and gave their consent.

Superficial electrodes are placed on the muscles of the lower limbs of interest (right rectus femoris, left rectus femoris, right biceps femoris, left biceps femoris, right tibialis anterior, left tibialis anterior, right gastrocnemius and left gastrocnemius) for each patient group.

Patients walk in a room, at a self-determined speed. The duration of the acquisitions varies from patient to patient based on the walking ability. 8 channels are selected for the muscles of the leg and 2 footswitches to evaluate gait. The sampling frequency is 2 KHz, resulting in a sampling time of 0.5 ms.

<table>
<thead>
<tr>
<th>Patient code</th>
<th>Diagnosis</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>01T</td>
<td>Tibialis deficit</td>
<td>F</td>
</tr>
<tr>
<td>02T</td>
<td>Tibialis deficit</td>
<td>F</td>
</tr>
<tr>
<td>01H</td>
<td>Hemiparesis</td>
<td>F</td>
</tr>
<tr>
<td>02H</td>
<td>Hemiparesis</td>
<td>M</td>
</tr>
<tr>
<td>03H</td>
<td>Hemiparesis</td>
<td>F</td>
</tr>
<tr>
<td>01M</td>
<td>Multiple sclerosis</td>
<td>M</td>
</tr>
<tr>
<td>02M</td>
<td>Multiple sclerosis</td>
<td>F</td>
</tr>
<tr>
<td>03M</td>
<td>Multiple sclerosis</td>
<td>F</td>
</tr>
<tr>
<td>01C</td>
<td>Control</td>
<td>M</td>
</tr>
<tr>
<td>02C</td>
<td>Control</td>
<td>M</td>
</tr>
<tr>
<td>03C</td>
<td>Control</td>
<td>M</td>
</tr>
</tbody>
</table>

**B. Results and Discussion**

Fig. 2 shows the EMG signals, appropriately filtered through a high pass filter with cutoff frequency of 2 Hz, of the rectus femoris and the biceps femoris of the left leg of one normal person who is walking. It is possible to see how the two muscles (agonist and antagonist) are activated one at a time in an exclusive manner.

Fig. 3 displays the EMG signal of the left tibialis anterior muscle for a patient with deficit of the tibialis anterior muscle. It is possible to see how the muscle is always active without ever going into the resting phase.

Fig. 3: EMG signal of left tibialis anterior muscle of a patient with tibialis deficit

Of the same patient are illustrated the power spectra in the first (Fig. 4a) and last (Fig. 4b) phase of walking exercise. As you can see, the second spectrum is shifted slightly to the left and the last frequencies are lower. This is an index of muscle fatigue.

Fig. 4: Power spectra of the EMG signal acquired from the left tibialis anterior muscle of a patient with tibialis deficit at beginning (a) and at the end (b) of a walking exercise.

In the following, we reported the main initial significant results obtained, with our system, from the acquisition and analysis of EMG signals relative to patients affected by tibialis deficit, multiple sclerosis and hemiparesis.

Fig. 5 refers to the mean RMS and MNF values of EMG signals acquired from three patients affected by multiple sclerosis. Multiple sclerosis (MS) is a demyelinating disease of the central nervous system and causes damage to the axons. This framework can lead to impaired motor function, increased fatigue and weakness in the muscles. Different studies [25-26] show that the muscle fatigue can be considered as a symptom of multiple sclerosis. Patients suffering from this type of disease are unable of generating the force required to perform a strenuous exercise due to a decrease in the work of muscles. Decreasing the muscle work, there is an increase in the average frequency (MNF) in patients with MS. The experimental data confirmed this: in fact, the EMG signals of MS patients analyzed in this study, have in almost all the muscles higher values of MNF than the other patients group (Fig. 5b). Moreover, the mean RMS values (Fig. 5a) are higher in the left muscles than the right ones.

The EMG signals coming from patients affected by hemiparesis of the right side are characterized by higher mean RMS values in the left area than the right one (Fig. 6a). This is a symptom of fatigue of the part not affected by paresis, which must compensate, during the walking, the weaker body area [27]. In fact, the hemiparesis is a disease that leads to a drop or partial disappearance of muscle strength and voluntary
motility of a side or part of the body. The indices of MNF are lower in the left muscles than the right ones, which could be indicative of muscles fatigue (Fig. 6b).

Fig. 7 reports the results relative to the analysis of EMG signals of patients affected by tibialis deficit. The deficit of the tibialis anterior muscle is a disease that consists of an intense and sharp localized pain in the front of the leg, with enlargement of the interested tibialis anterior muscle. Subjects are unable to have a normal gait. In fact, Fig. 7a shows that the right tibialis anterior muscle has a higher mean RMS value than all the right muscles; similarly the left tibialis anterior muscle has a higher mean RMS value than all the left ones. In addition, the right tibialis anterior muscle fatigues more than the left one, as the RMS values are higher. As regards the values of the MNF tibialis anterior (Fig. 7b), we found that...
there was only in one of the two subjects a decrease in MNF value relative to the right tibialis anterior than the left because of fatigue.

V. CONCLUSIONS

In this work, a novel integrated automatic system for EMG acquisition and processing in the clinical rehabilitation context has been presented. The main contributions of the work are the implementation of the DAQPAD-6015 board management software and the EMG-Miner software that offers a set of signal processing functions, made available through a GUI on the doctor PC. The system has been experimented and partially validated in a real clinical context.

A main advantage of the proposed system is the possibility for the doctors to see and store, in addition to the time domain EMG graphs, also the previously described features and diagrams in the time and frequency domain. Moreover, the possibility to store those measures values enables the easy performing of clinical studies and an easy follow up of each single patient.

As future work, exploiting the features of LabVIEW for remote control, we plan to extend EMG-Miner so that the acquisition and processing phases can be conducted remotely using e.g. a mobile device through the TCP/IP protocol. In this way, EMG-Miner will offer its services for telemedicine applications, enabling the remote transmission of medical information from the patient to the Hospital and vice versa, without physical displacements.

ACKNOWLEDGMENT

This work has been partially funded by the PON DICET-INMOTO-ORCHESTRA (PON04a2_D) project, funded by the Italian Ministry of Research and Education (MIUR).

REFERENCES