A Wearable Pervasive Platform for the Intelligent Monitoring of Muscular Fatigue

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Abstract— **There are currently approximately 45 million people in Europe who report a long standing health problem or disability; according to the World Health Organization data the total number of persons chronically ill are 860 million at a worldwide level. Within a person centric health management framework, the modern healthcare systems must move away from the 'health care' to 'health management' in order to shift from 'how to treat patients' to 'how to keep people healthy'. Assistive and health monitoring technologies can help to automatically identify and address major deficits. In this work we describe a wearable pervasive platform able to monitor the muscular fatigue during his/her daily life. Our system monitors the performance of a subject through the evaluation of sEMG signals using a wearable device aimed to immediately recognize the onset of muscular fatigue.**

Keywords-wearable sensors, sEMG, muscle fatigue monitoring

I. INTRODUCTION

There are currently approximately 45 million people in Europe who report a long standing health problem or disability; according to the World Health Organization data the total number of persons chronically ill are 860 million at a worldwide level. Within a person centric health management framework, the modern healthcare systems must move away from the 'health care' to 'health management' in order to shift from 'how to treat patients' to 'how to keep people healthy'. Assistive and health monitoring technologies can help to automatically identify and address major deficits. During his/her daily life, the performance of a subject can be continuously evaluated by using wearable systems to recognize immediately the onset of possible problems, such a muscular fatigue, related to reduced performances.

In physiology, fatigue is usually defined as the loss of voluntary force-producing capacity. Physiological fatigue is not necessarily accompanied by self-perceived fatigue, nor viceversa. The loss of force-producing capacity can both (and simultaneously) have a peripheral and a central origin. Median and mean spectral frequencies are commonly used as indicators of muscle fatigue. Analyzing the sEMG spectra during isometric contractions, it is possible to monitor the personal muscular fatigue. By using wearable devices, this process is non-invasive and non-painful to the subject.

In this paper, implementing a strategy and a protocol, based on gold standard methods, we report a method for the intelligent monitoring of the personal muscular fatigue. The wearable wireless platform, the stream of information, the data processing techniques and the method is managed by a common smartphone allowing the muscular fatigue to be assessed everywhere.

II. THE PROBLEM: MUSCULAR FATIGUE

Kinesiological sEMG, behavioural and physiological data can be used to monitor and coach physical exercise for rehabilitation purposes. Especially for elderly people, ageing is associated with progressive loss in function across multiple systems, including sensation, cognition, memory but also motor control, bone and muscle strength. In particular muscular strength decline due to qualitative changes of muscle fibres, such as selective atrophy, and neuronal changes, such as lower activation of the agonist muscle and higher coactivation of the antagonist muscles, reduce the capacity to carry out basic daily life activities and put people at risk of falls and dependence.

Compromised bone strength and falling, alone, or more frequently in combination, are the two independent and immediate risk factors for elderly people's fractures, one of the most important causes of long-standing pain, functional impairment, disability, and death in this population.

III. THE SYSTEM ARCHITECTURE

Our architecture is designed to monitor, support and manage the muscular fatigue, especially for the elderly in the framework of the OASIS EU Project. OASIS is the acronym of a Large Scale Integrated Project co-financed by the European Commission (7th Framework Programme, ICT and Ageing – Grant Agreement No: 215754). The full project name is: Open architecture for Accessible Services Integration and Standardization. It started on January 1, 2008 and has a length of four years. The OASIS Consortium is composed of 33 Partners from 11 countries. Large Industries, SMEs, Universities, Research Centers, Non-

Profit Organizations, Public Organizations and Healthcare Centers are all represented.

OASIS introduces an innovative, Ontology-driven, Open Reference Architecture and Platform, which will enable and facilitate interoperability, seamless connectivity and sharing of content between different services and ontologies in all application domains relevant to applications for the elderly and beyond.

We developed an unobtrusive monitoring wireless platform integrating surface electromyography (sEMG) transducers and pre-processing electronics by programming the SHIMMER platform and communication protocols (figure 1).

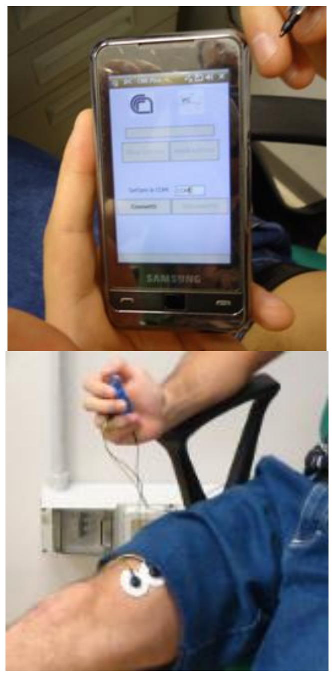

Figure 1. The wearable platform.

sEMG technology allows information regarding the overall muscle function and condition to be ecologically collected from the surface of the skin. We integrate the sEMG input, historical data of the user's activity profile and the user's health profile in order to infer a personal muscular model of her/his fatigue monitoring the mean spectral frequencies in the sEMG signals during isometric contractions and assess the activity risk and provide a feedback to the user. The slope of the mean spectral frequencies over time during a dedicated exercise is a interpreted as the fatigue index. The personal "activity risk assessment" (Figure 2) is defined by the ratio between the actual fatigue index and the reference fatigue index of the specific user while doing the same type of activity. Three "risk ranges" are defined: No risk /green region), medium-moderate risk (yellow region), medium-high risk (red region).

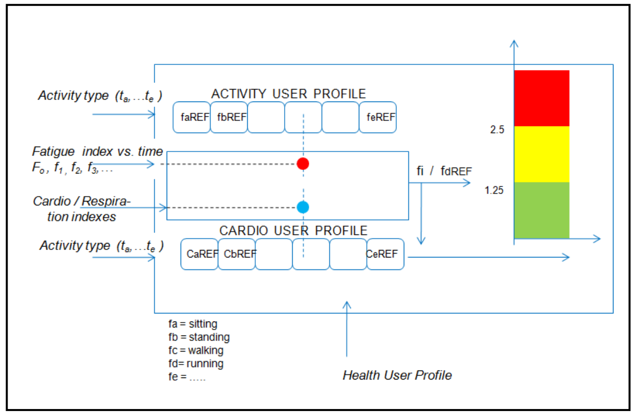

Figure 2. Risk assessment algorithm.

IV. INTELLIGENT WEARABLE HEALTH SENSING

Presently, egocentric sensing systems consisting of biomimetic wearable suits (BWSs) for the unobtrusive biomonitoring of body-kinematics and physiological and behavioural signals are continuously improving. BWSs integrate smart sensors together with on-body signal conditioning and pre-elaboration, as well as the management of the energy consumption and wireless communication systems. Integrated wearable systems are able to transduce heart rate and electrocardiographic signals (ECG), as well as electromiographic signals (EMG), electrodermal response (EDR), respiratory values and arterial oxygen saturation. Acquired information is correlated to obtain blood pressure, body temperature, hearth rate variability (HRV), end tidal CO2 and thoracic impedance pneumographic values. A most recent breakthrough in the development of wearable systems has involved the recently developed textile substrates for the distributed on-body biochemical measurements and monitoring of body fluids. Intelligent reading strategies of unobtrusive piezoresistive networks and physiological modelling allow human upper limb kinematic variables to be inferred. This property was exploited in the realization of many sensorized garments, such as gloves, leotards, seat covers capable of reconstructing and monitoring body shape, posture and gesture to record and classify non verbal communication and body language.

The general aim of the kinesiological sEMG is the analysis of the function and coordination of muscles in different movements and postures in healthy subjects as well as in the disabled, in sedentary as well as in athletes, under laboratory conditions as well as in the field. One of the fundamental tool to measure movement is the EMG of the muscles producing the movement. Since EMG is a direct measure of alfa motor neuron activity, it provides information about the central nervous system command that generates the movement, and in case of hierarchical models of intentions of the mirror neuron system. Numerous muscle are involved in every limb movement and consequently it is necessary to record from at least two muscles with antagonistic actions. EMG can be also used as measure of force, even though relationship between EMG amplitude and force is only approximate and not linear. The timing information from the EMG signal, instead, is much more accurate. EMG data can be measured with surface (sEMG), needle or wire electrodes. sEMG technology allows information regarding the overall muscle function and condition to be collected from the surface of the skin. This process is non-invasive and non-painful to the subject. The sEMG signal detected on the skin surface includes information from a greater proportion of the muscle of interest than conventional clinical EMG, acquired using needle electrodes. sEMG is widely used to evaluate muscle activity and can determine which muscles are active, their degree of activity, and how active; it can also used to estimate muscle force. Furthermore, they are easy to use and provide objective inter-intra-subjects comparable data, suitable for statistical analysis. sEMG based studies have provided relevant contributions to the understanding of human movement, neuromuscular adjustments and adaptations occurring while - or following - exercise and training and, in a wider sense, to the clarification of some aspects of neural control of movement.

Figure 3. Experimental Protocol.

V. METHOD

We analysed 58 subjects ranging from 65 to 75 years old. In the phase of the test, the subject's upper body was secured to the seat with the hip and knee joint angles at 90° from full extension like showed in figure 3. During task each subject was instructed to maintain a maximal voluntary contraction for approximately 20 s and rest position for approximately 5 s for a full cycle of about 6 minutes. Data were segmented extracting only the knee extensions intervals in order to assess the sEMG signal during isometric contractions.

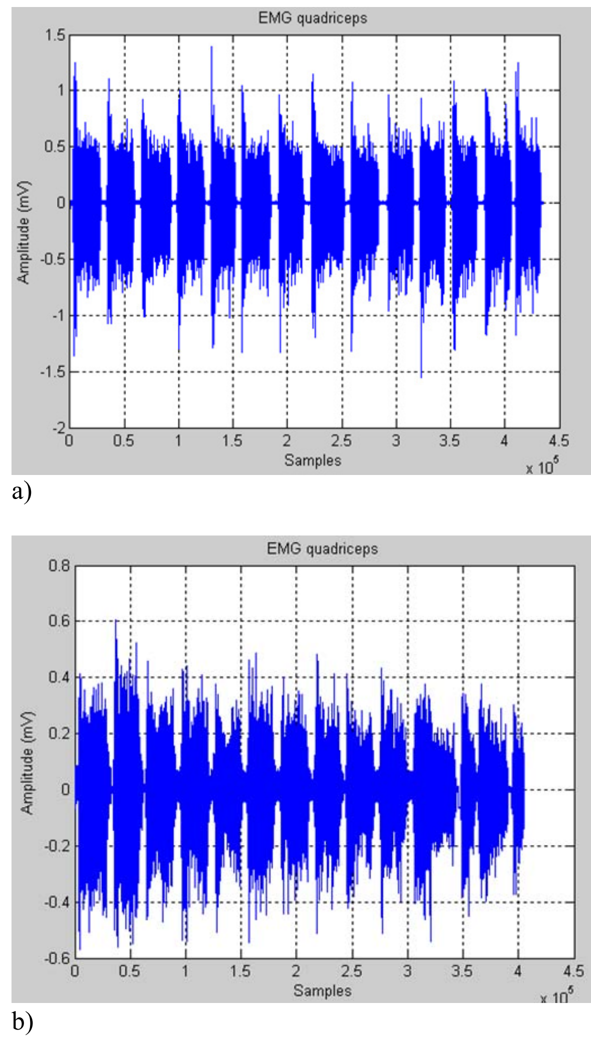

Figure 4. sEMG in case of a) absence of fatigue and b) presence of fatigue.

We evaluated the power spectral density through the short-time Fourier transformation extracting the mean frequencies. In case of fatigue, it is possible to observe a decrease of the mean frequencies over time. In Figure 4 and 5 the results obtained in case of fatigue and in case of absence of fatigue of quadriceps are shown.

VI. CONCLUSIONS

A pervasive activity management and rehabilitation support system was realized. The system consists of a wirelessly connected wearable platform for the acquisition of sEMG signals. Our aim is gain a continuous evaluation of the user, to monitor and coach the rehabilitation exercises, as well as to enable an early detection of excessive fatigue and activity abnormalities minimising the risk and maximizing the benefits for the user.

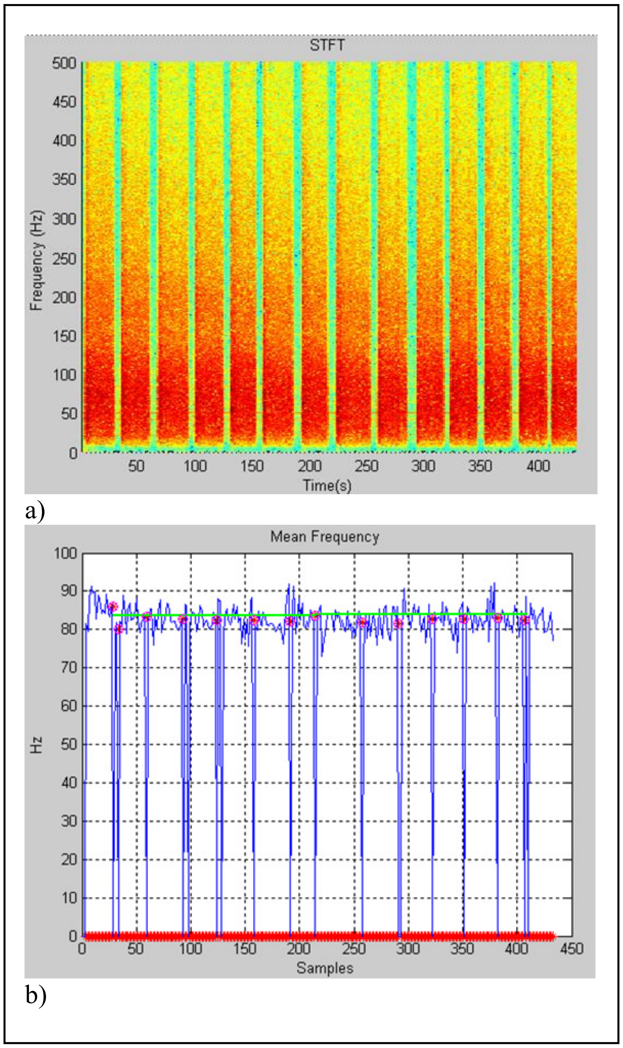

Figure 5. Analysis in case of absence of fatigue

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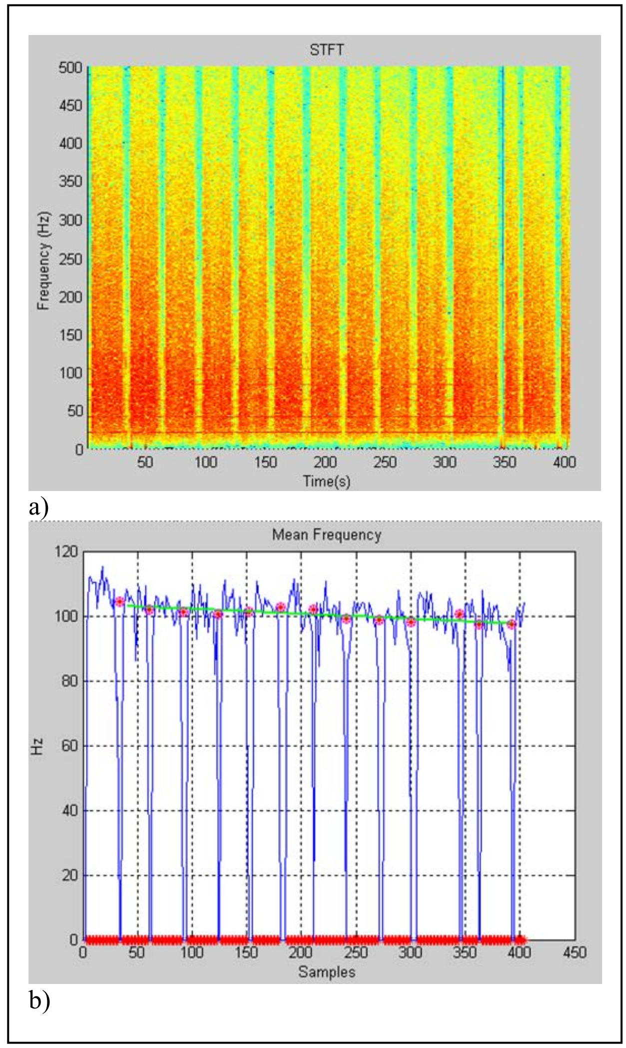

Figure 6. Analysis in case of presence of fatigue.

REFERENCES

[1] G. Pioggia, G.Tartarisco, G. Ricci, G. Siciliano, and S. Bonfiglio, "A Pervasive Activity Management and Rehabilitation Support System for the Elderly", Proc. IEEE Pervasive Computing and Communication, 2010.

[2] G. Pioggia, M. Ferro, F. Di Francesco, A. Ahluwalia, and D. De Rossi, "Assessment of Bioinspired Models for Pattern Recognition in Biomimetic Systems", Bioinspiration and Biomimetics, 3(1), 016004, 2008.

[3] M. González-Izal, A. Malanda, I. Navarro-Amézqueta, E.M. Gorostiaga, F. Mallor, J. Ibañez, and M. Izquierdo, "EMG spectral indices and muscle power fatigue during dynamic contractions", Journal of Electromyography and Kinesiology, 2009

[4] A. Merlo, D. Farina, and R. Merletti, "A Fast and Reliable Technique for Muscle Activity Detection From Surface EMG Signals", IEEE Transactions on Biomedical Engineering, 50(3), 2003.