Fall Risk Evaluation by Electromyography Solutions

Gabriele Rescio, Alessandro Leone, Andrea Caroppo and Pietro Siciliano

Abstract Falls are very dangerous events among elderly people. Several automatic fall detectors have been developed to reduce the time of the medical intervention, but they cannot avoid the injures due to the fall. The purpose of this study has been to identify a computational framework for the real-time and automatic detection of the fall risk, allowing the fast adoption of properly intervention strategies, to reduce injuries and traumas due to falls. A wearable, wireless and minimally invasive surface Electromyography (EMG)-based system has been used to measure four lower-limb muscles activities. Eleven young healthy subjects have simulated several fall events (through a movable platform) and normal Activities of Daily Living (ADLs) and their patterns have been analyzed. Highly discriminative features extracted within the EMG signals for the pre impact fall evaluation have been explored and a threshold-based approach has been adopted, assuring the real-time functioning. The threshold level for each feature has been set to distinguish an instability condition from normal activities. The proposed system seems able to recognize all falls with an average lead-time of 840 ms before the impact, in simulated and controlled fall conditions.

Keywords Wearable · Wireless surface electromyography probes · Healthcare · Risk of fall

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1 Introduction

The injuries due to a fall remain one of the main cause of accident and wellness issues among older people, resulting in the loss of their independence [1]. Several automatic, miniaturized, wireless and wearable fall detectors have been developed [2, 3]. Even if this kind of technology is more invasive regarding to the vision or acoustic sensors, it presents some important advantages, such as: the re-design of the environments is not required, outdoor operation and the privacy are preserved. The fall detectors appear very important for minimizing the time of medical intervention, however it is desirable the development of a system able to detect falls before the impact on the floor, which working together with an impact reduction systems, prevents some injuries. Several solutions have been proposed in the prevention of falls and high-quality reviews have been presented [4]. They use inertial sensors and above all threshold based techniques for the classification of the events. Their performance suggest that specificity and sensitivity values are high, but the lead-time before the impact is low (less than 400 ms). For this reason a new EMG-based system to detect the risk of fall in a faster mode has been investigated. To reduce the invasiveness, only four EMG sensors, placed through the gelled electrodes, have been considered and used for the measuring of the lower limb muscles activities. The main purpose of the work, deals with the development of a low-power, wireless, real time, automatic and effective fall risk detection EMG based framework. The lead-time before the impact has been evaluated by simulating imbalance condition and fall events through a moveable platform activated by a pneumatic piston. The obtained results show that the system, in simulated and controlled conditions, is able to detect the falls about 840 ms before the impact on the floor.

2 Materials and Methods

2.1 Hardware Architecture

The EMG data are acquired using the BTS FREEEMG1000 device produced by BTS Bioengineering [5]. It is made up of four wireless, wearable surface EMG probes and an USB receiver (Fig. 1a); their main characteristics are summarized in the Tables 1 and 2. The sensors have been worn through the common pre-gelled Ag/AgCl electrodes by using clips, allowing a fast, simple and resistant to the user's movements mounting. Each probe integrates two low noise active electrodes for the sensing and the RF transmitter to send the data according to the Zigbee protocol. The system allows the transmission in a range of more than 20 m in free space and up to 10 m in presence of a 50 cm thick wall. The data can be sent during a period of about 8 h in streaming mode, through the rechargeable lithium-ion integrated batteries. The logical framework for EMG signals acquisition and

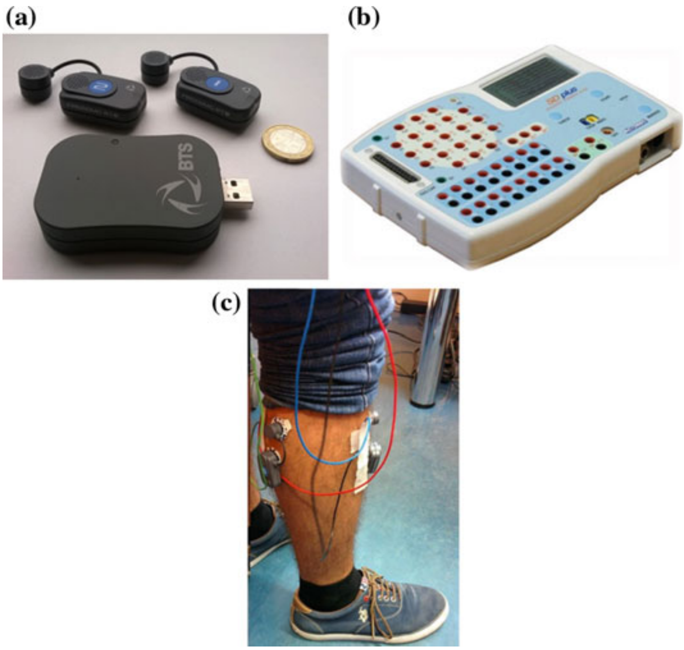

Fig. 1 BTS bioengineering Freeemg 1000 wireless surface EMG probes and USB receiver System (**a**); EEG-EMG MICROMED wired system (**b**); EMG wireless signals validation mounting setup (**c**)

Table 1 Main features of USB receiver

USB receiver	Technical features
EMG channels	Up to 20 probes
Dimensions	82 × 44 × 22.5 mm
Weight	80 g

elaboration is hosted on a Windows PC, composed by a CPU i5@2.20 GHz and 8 GB memory DDR3 RAM. During the first step of the work, the BTS EMG validation signal has been provided through the comparison with the data coming from the certified wired biomedical system EEG-EMG MICROMED (Fig. 1b). In particular five young actors simulated several lower limb muscles contractions, wearing the wired and wireless electrodes on the gastrocnemius and tibialis muscles as shown in Fig. 1c. Based on the results obtained, the signals of BTS and MICROMED systems have shown a high degree of similarity (maximum cross-correlation measured has been more than 0.9 for all simulations).

Table 2 Main features of EMG probe

Wireless probes	Technical features
Resolution	16 bit
Data transmission	Wireless IEEE 802.15.4
Battery	Rechargeable lithium-ion
Autonomy	8 h battery life in streaming mode
Acquisition range	Up to 20 m in free space
Memory	On board solid-state
Certification	Class "IIa"
Weight	10 g
Dimensions	41.5 × 24.8 × 14 mm (mother electrode) 16 × 12 mm (satellite electrode)

2.2 *Software Architecture*

To develop and to test the fall risk assessment algorithm a large dataset has been created, conducting a study on 11 young healthy actors with different age (29.5 ± 8.2 years), weight (65.4 ± 11.1 kg), height (1.77 ± 0.2 m) and sex (8 males and 3 females), who have simulated Activities of Daily Living (ADLs) and falls through the movable platform. The research has been focused on the electromyography patterns evaluation of the two lower limbs (tibialis anterior and gastrocnemius lateralis muscles).

The main computational steps of the software architecture have been validated as first on the Mathworks Matlab. They are (a) pre-processing, (b) calibration, (c) feature extraction, (d) classification. During the pre-processing phase, the raw data, coming from each EMG channel, have been band-pass filtered using a 12th order FIR filter, with cut frequencies between 20 and 450 Hz, to reduce the artefacts and to avoid signal aliasing. In Fig. 2 it is reported an example of the EMG signal artifacts, simulated through an external perturbation by tapping the probes, in quiescent condition (a) before and (b) after the filtering.

Then, to compare the EMG-tension relationship the signals have been processed by generating their full wave rectification and their linear envelope, using a 10th order low-pass Butterworth filter, with cut-off frequency of 10 Hz. The calibration procedure has been accomplished after device mounting by recovering the initial condition and the maximum EMG signal amplitude values for muscles of interest. For the feature extraction, the parameters that have shown higher degree of discrimination for the imbalance condition and lower computational cost are: Root Mean Square (RMS), Waveform length (WL), Co-contraction Index (CCI), Zero Crossing (ZC), Integrated EMG (IEMG) and Willison Amplitude (WAMP) [6]. In the end, for the classification of the fall risk event, a single threshold approach has been adopted. This method has been chosen to guarantee a real time operation to detriment of generalization ability.

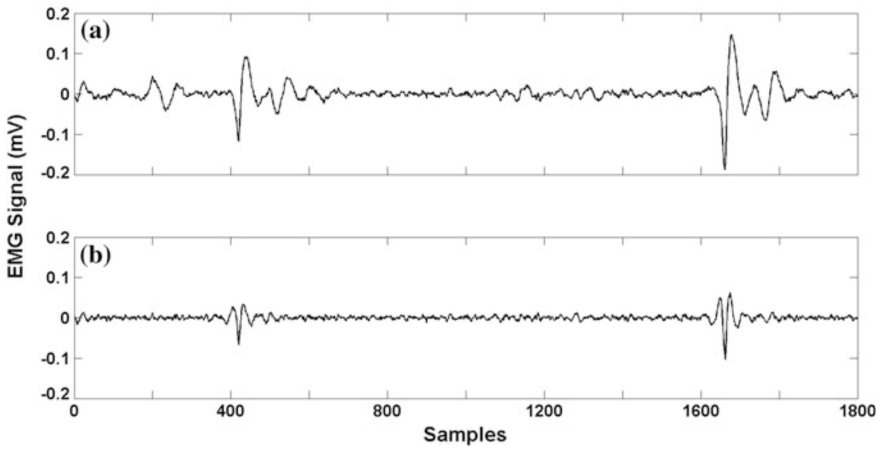

Fig. 2 Example of EMG signals with artifacts in quiescent condition **a** before and **b** after the filtering

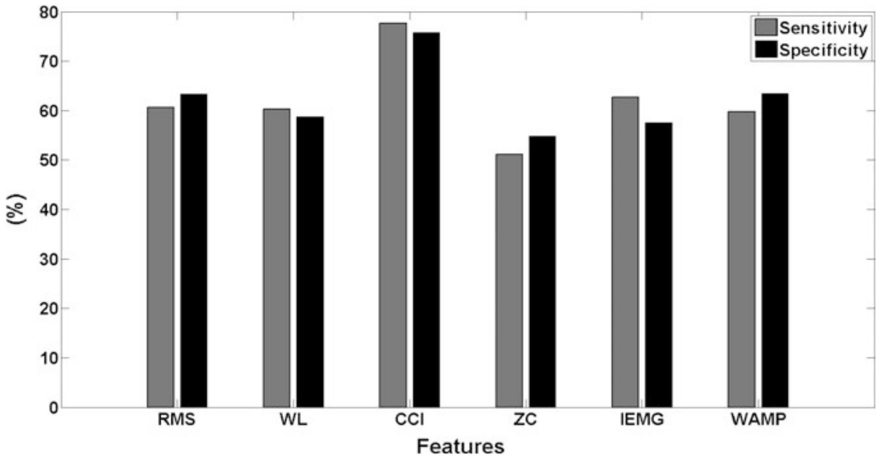

Fig. 3 Sensitivity and Specificity values for the features extracted

3 Results

The performance of the algorithm has been evaluated considering the aforementioned features for more than 250 ADLs and fall events, simulated during the acquisition campaign. In particular, one half of the dataset has been used to calculate the threshold values of features to detect the instability events, while the remaining part has been considered to test the performance in terms of sensitivity and specificity [7]. In Fig. 3 the performance obtained for each feature have been reported. The best results have been achieved with Co-Contraction indices

(77.6% for sensitivity and 75.8% for specificity). To reduce the computational cost, for the feature extraction, only the CCI have been selected.

These results have been obtained considering 1 kHz frequency sampling for the EMG signals. To reduce the computational cost, a performance evaluation on the system according to the down sampling EMG has been conducted. In particular the signals coming from each sensor has been digitally down sampled at 500, 250 and 125 Hz and Co-Contraction Indices have been calculated. Based on the experimental results, the performance remains quite the same from 250 Hz up to 1 kHz sampling frequency; instead significant changes have been measured for 125 Hz. Consequently for the real time application, developed through Microsoft C#, the frequency of 250 Hz has been chosen. For the analysis of the lead-time before the impact and the related gastrocnemius/tibialis muscles behavior, a movable platform to simulate involuntary falls has been considered, according to the work proposed in [8]. It is driven by a pneumatic system that can cause slow and fast involuntary falls. The mat, where the subjects fell, has been sensorized in order to detect the instant of the impact: in this way it has been possible to evaluate the period of time from the onset of the perturbation up to the user impact on the mat. The average of this period was about 1.4 s and the average lead-time before the impact on the mat has been measured in about 840 ms, considering all fall events recognized. From the results obtained, the solution developed appears a good starting point to realize a fast and efficient system for the fall risk assessment. With respect to the inertial fall detection system, the solution proposed could act before the start of falling phase defined in [9], through the monitoring of the electrical activity produced by muscles after an imbalance condition. The performance in terms of sensitivity and specificity could be improved increasing the area of legs monitored (through a larger number of probes). Furthermore, a relevant open issue present in literature regards the wearability of the Ag/AgCl electrodes. In fact they may cause skin irritation and allergies, moreover their signal quality may degrade due to the drying of the gel over time [10, 11]. To address these problems new biocompatible, textile and more comfortable wearable electrodes [10, 11] could be adopted to increase the user acceptability.

4 Conclusion

This work presents a preliminary study on a real-time and minimally invasive pre-fall detection surface Electromyography-based system. Significant performance in terms of lead-time before the impact on the floor has been measured, in simulated conditions, by using only four EMG probes. Future works will be focused to improve the performance and the user acceptability of the system increasing the number of probes and using more biocompatible and comfortable electrodes.

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