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TOWARDS THE INVESTIGATION OF KINEMATIC PARAMETERS FROM AN INTEGRATED MEASUREMENT UNIT FOR THE CLASSIFICATION OF THE RISING FROM THE CHAIR

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Abstract—— **In this paper we introduce a new method to evaluate the ability to rise from a chair by means of the sit-to-stand locomotion task. It is based on the analysis of the vertical acceleration peaks and the timing as assessed by an our designed device. Preliminary results indicate the feasibility of discriminating the rising from a chair fixed to different heights and the discrimination by pathological and non pathological parkinsonian subjects.**

I. INTRODUCTION

One of the most used tasks in the ability/disability evaluation is the sit-to-stand task; the ability to rise from a chair by means of this task is basic for the life quality; furthermore the sit-to-stand task is largely considered as one of the more mechanically demanding functional task of the daily activities [1] [2] and essential for gait [3]. One of the main problem which rises when studying the ability/disability is the lack of quantitative methods to be added to the simplicity of the used clinical tests [4] [5-6]. Optoelectronic equipments or similar ultrasound equipments are not adequate for their costs and encumbrance; furthermore they need an elevate markers' number which constrain the investigated movement itself and suffer of shadowing effect. Kinematic sensors could be a valid aid to the functional study, they in fact could add the necessary quantitative measurement to the qualitative observation. The motion analysis performed by means of kinematic sensors is based essentially on the use of accelerometer sensors which directly furnish motion acceleration. ACcelerometers (ACs) are small and light enough that can be easily connected to a body segment without hindering the execution of the motor tasks. ACs can be combined together into a single accelerometric assembly which can be positioned in a single device or used as a single motion sensor affixed in different body positions to provide an integrated, practical method for long-term, ambulatory, monitoring of human movement [18-21]; especially in the past few years advances in miniature devices and a growing interest for non-invasive patient monitoring have promoted a huge development of the use of these sensors as it is well documented by Mathie et al. in their recent review [7], where they showed that ACs can be successfully used for the human continuous monitoring , for the gait analysis, sit-to-stand and stand-to-sit analysis , postural sway, fall risk.

Recently we showed that pure accelerometric systems such as the Morry s one [10] and Padgaonkar one [11] architecture were critical if used for the trajectory reconstruction [12], this was essentially due by the errors in eliminating the gravity acceleration component. We also have showed that architectures with accelerometers and rate gyroscopes assured better performances than pure ACs systems for short locomotor tasks [13,17,22-23] thanks to the use of the rate-gyroscopes which are insensitive to g.

Up to now very little work has been reported using kinematic sensors for assessment of the sit-stand-sit movement. Mathie et al. found using a portable device based on kinematic sensors that the sit-to-stand can be automatically divided into phases [8], Aminian et al. proposed a methodology of the study of this locomotory task based on a portable device and identifying the succeeding of two different postures, the sitting one and the standing one [9]. Our aim was to investigate this specific task with our device with classification objectives; we designed then a specific protocol and performed a dedicated cinematic analysis.

II. MATERIALS AND METHODS

A. Algorithms

The transducer [22-23] consists of three mono-axial accelerometers (3031-Euro Sensors, US) and three rate gyrosopes (Gyrostar ENC-03J-Murata, Japan), assembled together and relatively oriented according to an orthogonal reference system. The actual body segment angular velocity vector (wx, wy, wz) is obtained by multiplying the relevant calibration matrix by the gyrostar tern output vector.

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$$R^{-1} * \frac{dR}{dt} = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix} \quad (1)$$

The real instantaneous linear acceleration vector is obtained by equation (2).

$$\begin{bmatrix} ax \\ ay \\ az \end{bmatrix} = [R] \begin{bmatrix} ax' \\ ay' \\ az' \end{bmatrix} - g \quad (2)$$

where ax' ay' and az' are the acceleration vectors in the reference system solid with the device.
All the algorithms, drift zeroing comprised were developed by Matalb R12 (The Mathworks, USA)

B. The used Device

The device is composed of two separate units: a sensor unit and a powering, connecting unit. The circuitry of the sensor unit essentially consists on 6 signal conditioning chains (3 for the triaxial accelerometer, 3 for the gyrostars) a microcontroller that features a 12 b A/D converter and an 8 bit D/A converter. For this specific application, the conditioning chains comprise six amplifiers (G=10) and six 2nd order filters with a Chebichev Low Pass Filter response with a cut-off frequency optimizable by means of a bench test to 12.1 HZ.

A dedicate equipment (Testing Equipment))was developed in order to calibrate the equipment and for the bench test based on the DMC-1410 controller and a step-by-step motor with encoder (Galil, USA)[15].

C. Calibration

The calibration of the accelerometer tern was carried out during the static phase. The sensor unit was subjected to different g vectors by positioning each of its six faces on a horizontal plane; the output signals were averaged over a 6-second time interval. The dynamic calibration performed with the Testing Equipment was completely different for the ranges and the steps to the one defined in [13] being optimised for this specific application. A plate on which the device is affixed was rotated by means of the Testing equipment and to impose known rotational time laws with the necessary accuracy. Angular velocities ranging from 5 to 90 °/s (steps of 1 °/s) in both directions were imposed for each of the three orthogonal axes. In both cases the calibration matrixes were computed by the least squares method. $[C_A]$ was the matrix for the accelerometers channels, $[C_{RG}]$ was the matrix for the rate-gyroscopes channel. Each one of these matrix was obtained solving the following equation

$$[C]=[L][S]^T([S][S]^T)^{-1} \quad (3)$$

where [L] is the matrix of the imposed quantities and [S] is the matrix of the assessed quantities.

III. INVESTIGATION PROTOCOL AND RESULTS

Figure 1 shows the main phases of a sit-to-stand investigation, as determined by the reconstructed vertical component of acceleration. For each trial, the value and temporal position (M_i, m_i) of the main important points corresponding to the phases of the sit-to-stand were registered. For the determining of the timing of these acts, we used the algorithms developed in [14] and also used in [13]. For the determining of the timing of these acts, we used the algorithms developed in [15]; this algorithms basically fix two thresholds for each subject ; the first by means of quite acquisitions during the sitting and the second by means of quite acquisitions during the standing.

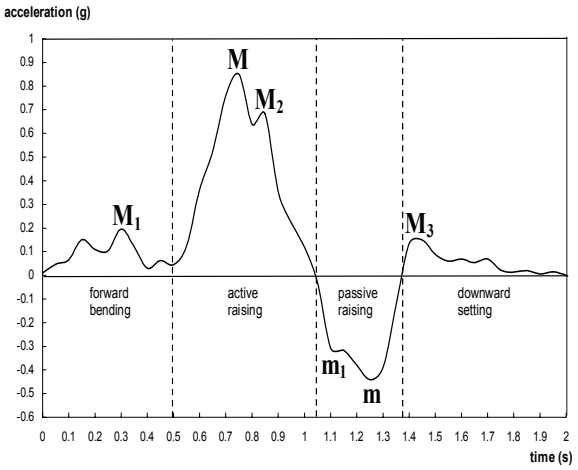

Fig. 1 The phases of the sit-to-stand

We used an investigation approach based on the determination of the distribution of the timing and acceleration amplitudes of the sit-to-stand. In particular we determined the value of the position of the absolute maximum and minimum in the waveform in figure 1 (M,m). Figure 2 shows the acceleration and angular velocity processing scheme.
The sit-to-stand of 5 healthy subjects was recorded, with a sample period of 50 ms, during 4 second trials in three different conditions:

A) High of the chair fixed to the 90 % of the high from the feet to the knee (Trial 90T)

B) High of the chair fixed to the 100 % of the high from the feet to the knee (Trial 100T)

C) High of the chair fixed to the 110 % of the high from the feet to the knee (Trial 110T)

Three trials were performed for each condition; the order of the trials was randomised.
The same protocol above described was performed on 3 parkinsonian subjects (at first stage of pathology)

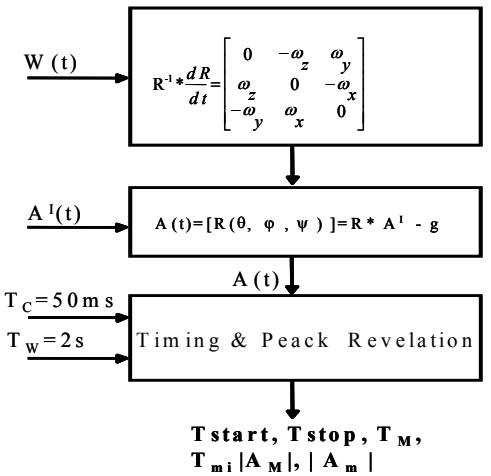

Fig. 2 Signal processing: The peak acceleration revelation and the timing revelation

In Figure 3 we report, for the three different chair heights, the minimum and maximum acceleration peak absolute mean values (in g), assessed over all the 15 trials (three for each subject); in Figure 4, instead, we report the minimum and maximum acceleration time mean values (in seconds). Figure 5 and 6 reports the same results for pathological subjects. As we can observe in Figure 3 and 4, both time and peak mean values are adequate to discriminate between the three different chair heights. Figures 5 and 6 report that the same results for the pathological subjects showing that the distributions are completely different.

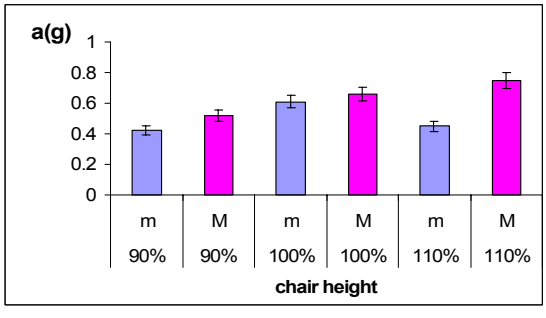

Fig. 3. Maximum and minimum acceleration peak (healthy subjects): mean value and standard deviation

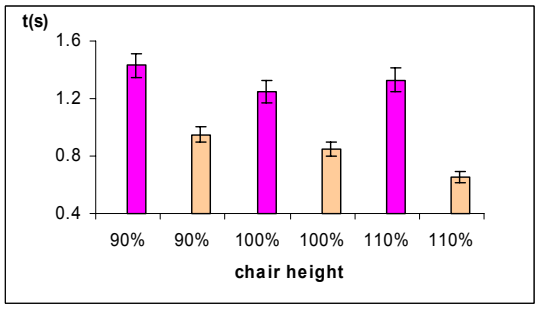

Fig. 4 Maximum and minimum acceleration peak time (healthy subjects): mean value and standard deviation

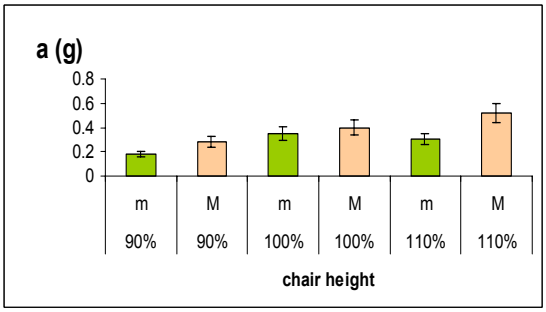

Fig. 5 Maximum and minimum acceleration peak (pathological): mean value and standard deviation

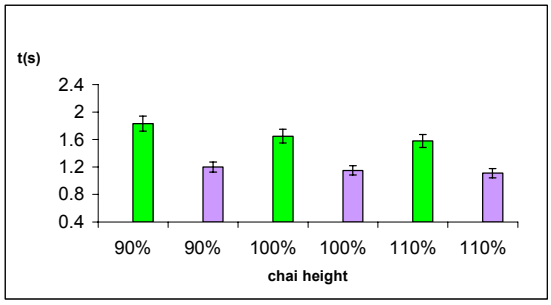

Fig. 6 Maximum and minimum acceleration peak time (pathological): mean value and standard deviation

IV. Discussion and Conclusions

By means of this paper we concentrated on a simple, largely used task (the sit-to-stand one) and we used a wearable device and a simple postprocessing procedure in order to characterize the kinematic properties of the sit-to-stand act in different situations of the real life corresponding to different chair heights. We added then an our response to the limitation of the quantitative measures used in the ability/disability evaluation often based only on simple tasks which are not conjugated with a feasibility and/or simplicity of the parameters assessment.

Results showed the feasibility of the use of the developed procedure for determining the principal characteristics of the sit-to-stand locomotory task. Preliminary results also prove the feasibility of the use of the mean acceleration peak and mean timing values for discriminating between the three different chair heights for the non pathological subjects;

furthermore, the used method also demonstrates the preliminary feasibility of discriminating the space of the investigation into pathological and non pathological subspaces.

Another main aspect emerged from the analysis of the potentialities of this system seems to be a promising starting point in the development of a classification procedure to be used in the discrimination of many locomotory acts – sit-to-stand and standing the stair included – as well as to build up a powerful diagnostic tool for the identification of kinematic pathologies in their first stage. The next step will be the widening of the set of parameters involved in the investigation, through the inclusion of other important phases of the specific act (besides mi, Mi), as well as by taking into account different chair heights. Obviously, a boost to the power of the investigations can be given deriving the above mentioned parameters from frequency domain, instead of time domain. Nevertheless, the most interesting and promising improvement relies in the exploiting of an automatic classification methodology based on adaptive systems, such as Neural Networks [16]. Both supervised and unsupervised learning algorithms are well suited for this application. In future works, they will be investigated and applied to locomotory act classification. Neural classifiers can be exploited to process huge amounts of data, to develop knowledge bases for the identification of particular pathologies – such as Parkinson disease – in their early stage.printing.

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