Instrumented Shirt to Evaluate Classical Human Movements

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***Abstract*—Among the smart domestic devices developed to provide healthy, elderly, sick or disabled people with a better life in their homes, there are the smart-walkers or the smart-shirt. The first ones permit the patient to move in their home or to do rehabilitation exercises, whereas the second ones monitor the patient's physical status. In this article, it is presented a smart-shirt able to monitor the biomedical parameters and managing some alarms for a robot-walker. In particular, it is evaluated the inertial system of the smart-shirt consisting of an accelerometer. Some typical human movements have been tested. The obtained results permit to know the movements and the positions of a patient using the antro-posterior and medio-lateral angles calculated by the acceleration signals. In the future, this instrumented shirt will be used to indicate to the robot-walker different potential problems, such as a fall or a wrong position.**

Keywords—smart-shirt; robot-walker; accelerometer; antro-posterior and medio-lateral angles; movement analysis.

I. Introduction

One of the most alarming problems in our society is the difficulty of dealing with the growing request of assistance to monitor the health status of elderly people or to guarantee the post-traumatic rehabilitative therapies. Until now, these activities have been made in the specialized structures and by relying on the help of medical staff. It is possible to imagine how many advantages there could be if the medical assistance was directly in our home: on the one hand, the decreasing of the health costs both for the patient and for the medical corps, of waiting time and of overcrowding in the medical structures, and, on the other hand, the increasing of the people independence and autonomy to improve their quality of life. Recently, new technological aids have been introduced to help the patients in their daily activities, as the smart walkers. The smart-walkers assist the walking offering the patient support and some other functionalities that stem from robotic. GUIDO [1], PAMM [2], MARC-SW [2], RT Walker [3] can assist the walk avoiding obstacles. Other Smart-Walkers [4-6] also assist the person for sit-to-stand. These are smart-walkers that assist the elderly from the sitting position. Furthermore, technology systems that monitor the physical status of a person, as the smart-shirts, exist. These devices are able to monitor the main biomedical parameters of a person as the electrocardiogram (ECG), the respiratory rate, the blood heat, the blood pressure and the movements or the positions of the patient. In the literature there are some examples about these smart-shirts. In [7] it is described a jacket that integrates some sensors for monitoring physiological parameters, but does not measure the acceleration and the position of the subject. In [8] the authors present the sensors integrated into the wearable device. The sensors measure physiological parameters and the chemical composition of body fluids with a particular interest for the sweat. In [9] it is shown a wireless system for real-time monitoring that measures the acceleration, ECG, and the body temperature of a patient. In a previous paper [10], an instrumented wearable belt for wireless health monitoring is shown. This belt measures some biomedical signals, such as ECG, respiratory, body accelerations and temperature, and transmits them to a remote unit by a RF module. The authors present preliminary results and, in particular, body accelerations without calculating the body angle. In [11], a smart vest integrating an inductive sensor is proposed for body position monitoring.

In this paper, an instrumented shirt is described; this smart-shirt monitors the ECG signal and the heart rate, the respiratory rate and the movements and the positions of a patient. This smart-shirt is designed to monitor the physic status of the patient and to generate some alarms for potential physical problems. In particular, the smart-shirt will be used like a redundant system for the robot walkers located in the robotic laboratory of ISIR Department of the UPMC of Paris because it lets monitor the complete physical status of the patient. In fact, during the rehabilitation, it is important to monitor the health status of the patient by some biomedical parameters like ECG signal, respiratory activity, body temperature, pressure and patient's movements. This article focuses on the analysis and evaluation of patient's movements systems using a single accelerometer. Exploiting the signals produced by the accelerometer it is possible to monitor the positions and the movements of the person measuring the antro-posterior and medio-lateral angles of the body. To validate the data obtained by the accelerometer it was used an optical measurement system. The preliminary comparison between the accelerometer data and the optical measurement system data for typical daily activities has been presented. In future works, alarm thresholds will be created using the results presented in this paper.

II. System Description

A. Electronic board description

The smart-shirt is composed by three main sensors: an accelerometer to monitor positions and movements, two

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electrodes to measure the cardiac activity, as ECG and heart rate, and a plethysmograph sensor to check the respiratory activity and to measure the respiratory rate. These sensors have been managed by an electronic board positioned on the smart-shirt with dimensions of 7 cm x 7 cm. In Fig. 1, the electronic board and the several circuit blocks that compose it are shown.

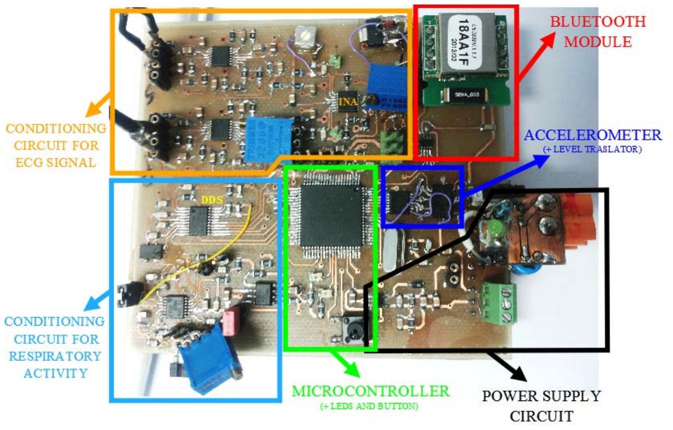

Fig. 1. Electronic board realized to mount on the smart-shirt.

In particular, the electronic board includes a low-power 10-bit microcontroller MC9S08AC128 by Freescale that works with a frequency clock of 4 MHz due to an external crystal. It manages the signals originated from the sensors and sends the stored data to an external unit. There are the conditioning electronic circuits for the signals generated by the sensors, electrodes for the ECG signal and plethysmograph sensor. Furthermore, a PARANI Bluetooth module has been mounted on the electronic board, which sends the data containing the sensor signal information to an external unit for further elaborations. Finally, the board includes the power supply circuit composed of two different circuits operating to 5.5 V and to 3.3 V. The first power supply has been obtained by the DC/DC converter TMR 3-1221 commercialized by Traco Power that, from input voltage of 12 VDC nominal, has created an output voltage of ±5 VDC, while the second supply has been generated by the LM3670 step-down DC/DC converter by Texas Instruments. The 12V voltage required has been derived from a lead battery Y0.8-12 by Yuasa with the capacity of 800 mAh, the dimensions of 62 mm x 25 mm x 96 mm (height x width x depth) and the weight of 340 g. In Fig. 2, the block diagram of the realized electronic board is shown.

In this paper, it is considered only the accelerometer as control signal for the patient activity.

B. *Movement and position measurements*

The used accelerometer is the low-power LIS3LV02DL commercialized by STMicroelectronics. It is a three axes digital output linear accelerometer composed by an inertial system and an IC interface to provide the measured acceleration signals from the sensing element to the external world through a SPI interface. This device is low-power and has operated with a supply voltage of 3.3 V and a supply current typical of 0.65 mA. The accelerometer configuration has been made by three control registers, which can set up the power-down mode, the data rate which acceleration samples are produced, the enables of the three axes measurement channels, the Full Scale (FS), the bits of the representation number, the SPI configuration and the setting of the internal digital filter. In our application, a measurement range FS of ±2g and an output data rate of 40 Hz are used. With this configuration the accelerometer resolution is 1.0 mg and the sensitivity is 1024 LSBs/g, about 1 mg.

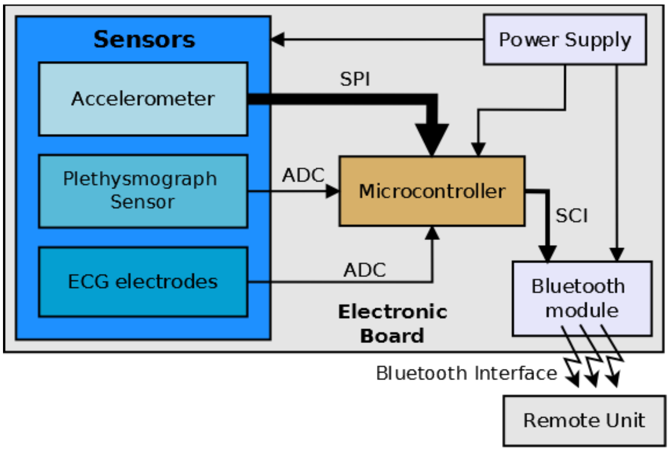

Fig. 2: The block diagram of the electronic board realized to manage the smart-shirt.

The accelerometer is able to measure the three accelerations on the x-y-z axes due to the internal inertial system. Each acceleration data is composed of 2 byte, high and low value. Therefore, the 6 bytes of the acceleration data packet are stored in a circular buffer of size 4 kB created in the internal RAM of the microcontroller. These data have been sent to the Bluetooth module using the SPI digital interface with a baud rate of 41.666 kHz. The acceleration data have been sent to a LabVIEW interface by the Bluetooth module by the SCI interface with a baud rate of 9600 bit/s. The LabVIEW program, after the configuration operation to connect the Bluetooth module on the board with the PC, has received the three acceleration data from the implemented board, calculates the angles and shows the trend of the accelerations and the angles according to the time on a graphical chart, as it is shown in Fig. 3. Furthermore, in the LabVIEW front panel there are the interactive tools, as the buttons to configure and to connect the Bluetooth module, and buttons to save the data into a text file.

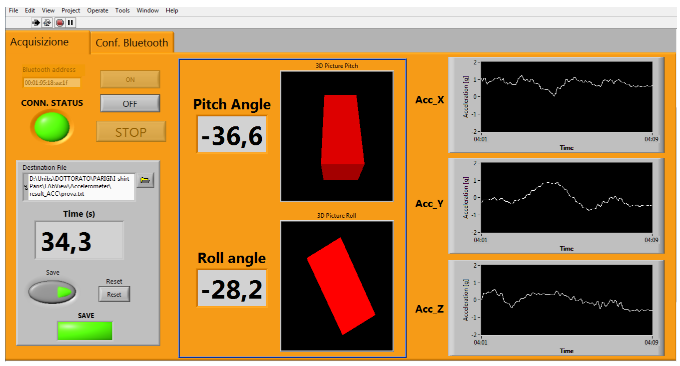

Fig. 3. Control Panel to the LabVIEW program that shows the x-y-z acceleration trends and the antro-posterior and medio-lateral angles calculated.

III. EXPERIMENTAL SETUP

The digital three axes accelerometer LIS3LV02DL can be used to tilt-sensing applications due to its capacity to measure static acceleration assuming that the gravity acceleration is the only acceleration value acted on the human body. Other accelerations, such as the dynamic contribution and the artifact due to the fabric movements, where the electronic board is fixed, have been filtered by a low-pass filter with a cut off frequency of 0.5 Hz, according to [12]. The Fig. 4 shows the coordinate system used in this application based on the accelerometer orientation:

- the accelerometer X-axis is aligned along the vertical human body and represents the vertical axis of the patient;
- the accelerometer Z-axis points forward with respect to the human body and represents the antro-posterior axis of the patient;
- the accelerometer Y-axis is aligned at right angles to both the x and z axes so that the three axes form a right handed coordinate system. This is the medio-lateral axis of the patient.

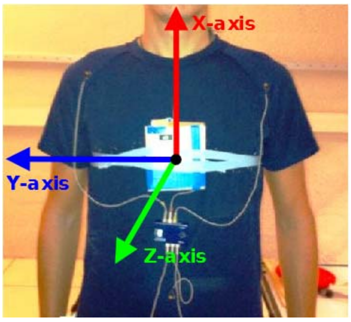

Fig. 4. Accelerometer axis orientations: X-axis is the vertical axis, Y-axis is the medio-lateral axis and the Z-axis is the antro-posterior axis.

Using a single three-axis accelerometer it can be possible to measure two rotation angles of a body in motion: the antro-posterior angle and the medio-lateral angle. The patient rotation of himself is not measurable because the rotation around the X-axis does not create an angular variation between the axis and the horizontal plane and so there are not acceleration changes. Hence, the useful information from the accelerometer is the acceleration by the patient movements and the ahead/back (antro-posterior angle) or left/right (medio-lateral angle) imbalances of the person that uses the smart-shirt. In this configuration, the antro-posterior angle is defined as the angle between the Z-axis axis and the horizontal plane. In the vertical rest position, as the figure 3, the angle assumes the value of 0 deg and it can go from -90 deg, when the patient falls back, to +90 deg when the patient falls ahead. The medio-lateral angle is defined as the angle between the Y-axis axis and the horizontal plane. As the antro-posterior angle, in vertical rest position the medio-lateral angle assumes the 0 deg value. The extreme value of the medio-lateral angle in this application is -90 deg when the patient is completely bending on the right side and +90 deg on the left side. The angles are calculated using the three acceleration values by the following equations (1) and (2), using the inertial measurement unit theory. The value a_x, a_y and a_z are the acceleration from the X-axis, Y-axis and Z-axis, respectively. In the same mode it is possible to calculate the angle created by the X-axis but it does not add further useful information.

$$antro\_posterior\ angle = \arctan \frac{a_z}{\sqrt{a_x^2 + a_y^2}} \quad (1)$$

$$medio\_lateral\ angle = \arctan \frac{a_y}{\sqrt{a_x^2 + a_z^2}} \quad (2)$$

IV. EXPERIMENTAL RESULTS

To evaluate the accelerometer data it has been used a 3D vision system commercialized by Codamotion and usable in the laboratories of the Institut des Systèmes Intelligent et de Robotique of the UPMC University in Paris. The Codamotion's 3D Motion Capture is able to measure, analyze and report on movement in a variety of different applications. It uses miniature infra-red active markers, each with their own unique identify, to track the positions on the subject. Signals from these active markers are beamed to three linear arrays inside a CODA camera unit which provides an immediate 3D measurement. So, it is possible to measure the positions and the human movements during some particular activities due to the 3D data provided with the active marker. In our application six active markers positioned like in Fig. 5 have been used.

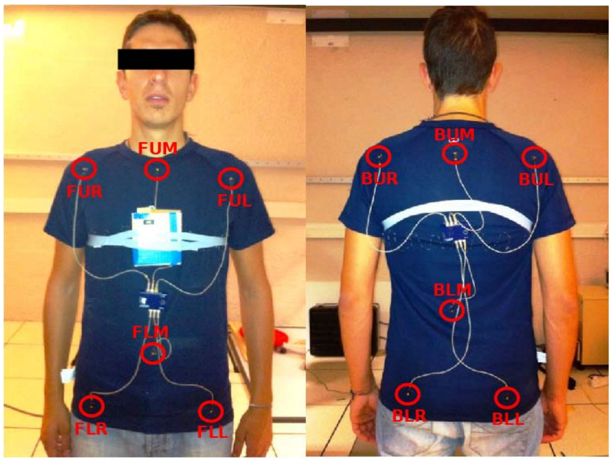

Fig. 5. Codamotion active marker positions on the human body, front and back sides (Marker legend: the first letter indicates F-front or B-back, the second letter indicates U-upper or L-low and last letter indicates R-right, L-left and M-medial).

To calculate the antro-posterior and medio-lateral angles using the 3D data produced of the Codamotion system, it is used the simple trigonometry rules. Six imaginary vertical lines have been traced on the body from a marker to another in front and in back side: FUR-FLR, FUM-FLM, FUL-FLL, BUR-BLR, BUM-BLM and BUL-BLL. Exploiting the marker coordinates it has been calculated the angular inclination of the imaginary axes with respect to the horizontal plane. In this way, it is possible to calculate the antro-posterior and medio-lateral angles using the Codamotion data in order to compare it with the accelerometer data. To validate the accelerometer data and the angles calculated from theirs, some physical exercises have been carried out to simulate the patient movements by a single person, for example walking, sitting, falling ahead and back, bending to catch something and oscillations left or right. For each activities have been acquired the accelerometer data, the accelerations and the angles calculated by the LabVIEW program in real time, and the Codamotion 3D position data at the same time. In particular, the Codamotion system worked at the frequency of 25 Hz, so the double with respect to the sample rate of the stored sequence of the accelerometer data on the text file. The activities have been repeated in a time interval of 60 s.

A. Walk

The Fig. 6 and the Fig. 7 show the trends of the antro-posterior angle (green line) and the medio-lateral angle (blue line) when the person is walking, respectively. Looking the trends, the single step is recognizable by the medio-lateral angle; in particular it is possible to recognize the right/left imbalances of the body in correspondence to the step with respect to the foot that the patient uses. The angle is positive when the person uses the right foot and it is negative when he uses the left foot. The red trends are the antro-posterior and medio-lateral angle values calculated using the Codamotion data, respectively. It is possible to view that the trends, in particular for the medio-lateral angle, are similar. This validates the data obtained with the accelerometer system.

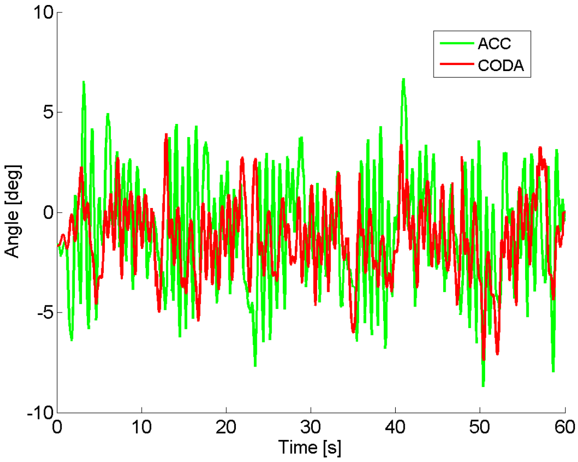

Fig. 6. The antro-posterior angle (green trend) compared with the angles (red trends) calculated with the Codamotion data when the patient walks.

B. Sit-down and stand-up

The Fig. 8 and the Fig. 9 show the sit-down and stand-up movements on/from a chair, antro-posterior and medio-lateral angles respectively. These movements are recognizable by looking the antro-posterior angle. The comparison with the antro-posterior angle calculated by Codamotion data is more positive. When the person sits-down or stands-up on /from the chair, he flexes his body forward and the antro-posterior angle increases versus positive value (about +45 deg). On the other hand, the medio-lateral angle does not add significant information about the movement. The differences of the angle trends, in the two different measurement systems, are due to the shirt slow movement respect the human body when the chest is moved forwards.

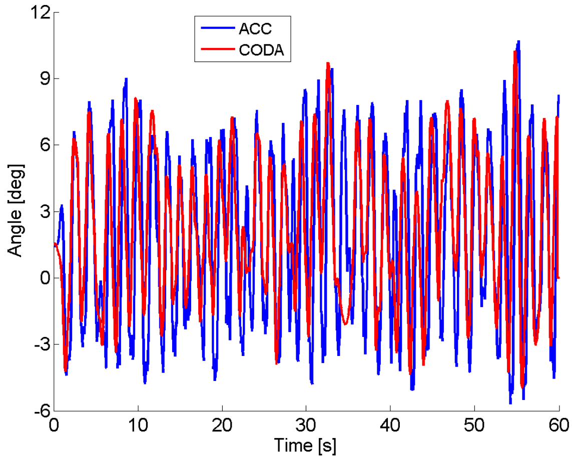

Fig. 7. The medio-lateral angle (blue trend) compared with the angles (red trends) calculated with the Codamotion data when the patient walks.

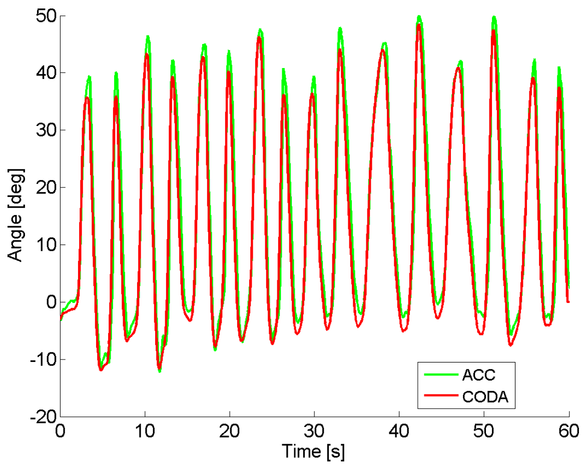

Fig. 8. The antro-posterior angle (green trend) compared with the angles (red trends) calculated with the Codamotion data when the patient sits-down and stunds-up on/from a chair.

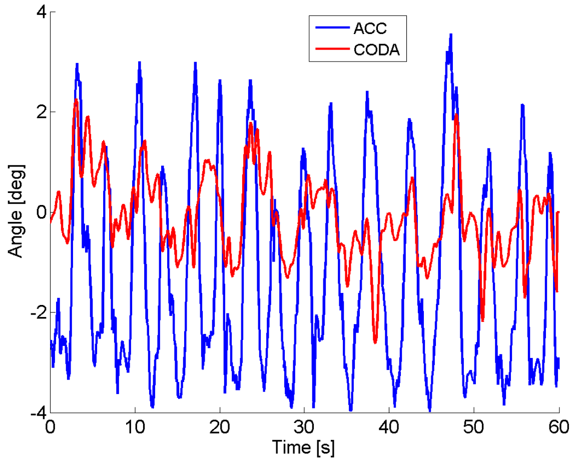

Fig. 9. The medio-lateral angle (blue trend) compared with the angles (red trends) calculated with the Codamotion data when the patient sits-down and stunds-up on/from a chair.

C. Fall-ahead

As the previously results the movements when a person fall ahead is recognizable by the antro-posterior angle because the person flexes his body in forward and arrives to the horizontal position in correspondence of the +90 deg, as it is shown in Fig. 10. The comparison with the Codamotion values is good for the antro-posterior angle, while the medio-lateral angle trends calculated with the accelerometer are very noisy and are not comparable (Fig 11). The angle spikes, calculated using the accelerometer, are due to the shirt movements close to the electronic board. As the sit-down/stand-up case, the chest movement goes ahead so that the board weight pulls the shirt, thus some unwanted acceleration contributions are generated.

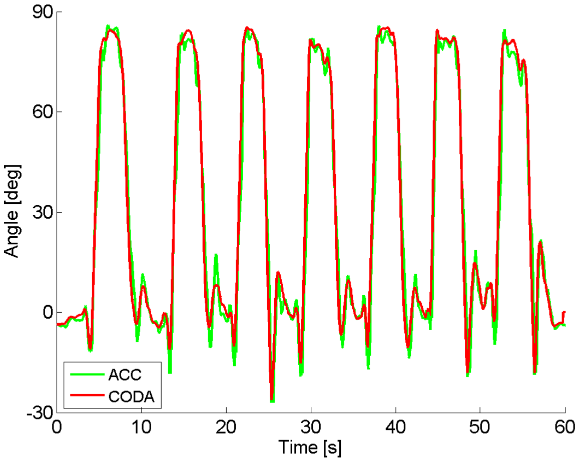

Fig. 10. The antro-posterior angle (green trend) compared with the angles (red trends) calculated with the Codamotion data when the patient falls forward starting from the vertical position.

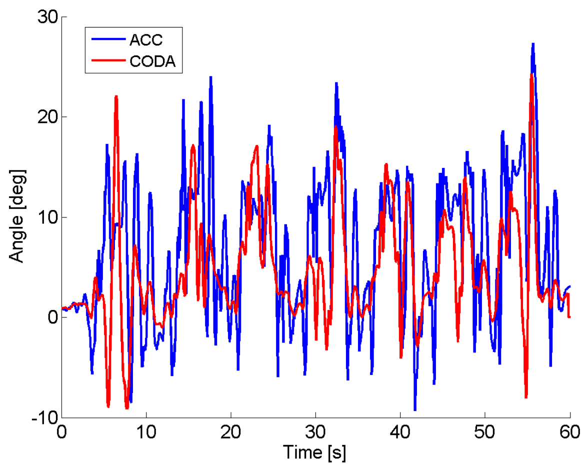

Fig. 11. The medio-lateral angle (blue trend) compare with the angles (red trends) calculated with the Codamotion data when the patient falls forward starting from the vertical position.

D. Fall back

In Fig. 12 and Fig. 13 it is shown the trends of the antro-posterior angle (left picture) and the medio-lateral angle (right picture) trends with respect to the trends, of the correspondence angles, calculated with the Codamotion data. Like the results obtained in the fall-ahead exercise, the fall back of the person is recognizable by the antro-posterior angle. In particular, his trends is inverse with respect to the previously results, in fact when a person falls back the antro-posterior angle goes to -90 deg. The medio-lateral angle is noisy but it is possible to view that the trends of the accelerometer and of the Codamotion are similar.

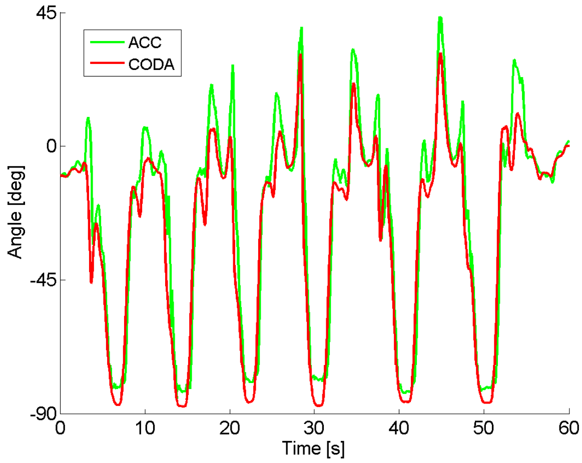

Fig. 12. The antro-posterior angle (green trend) compared with the angles (red trends) calculated with the Codamotion data when the patient falls back starting from the vertical position.

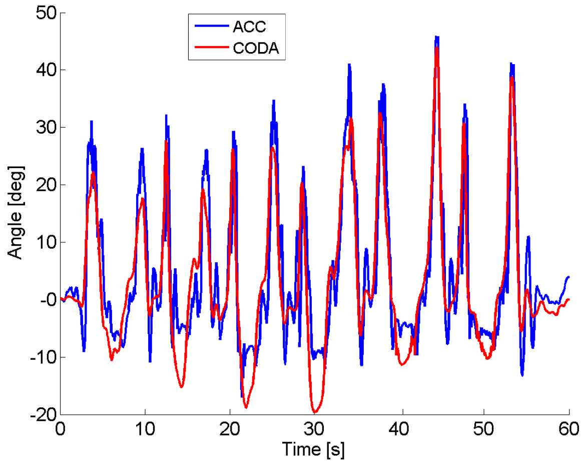

Fig. 13. The medio-lateral angle (blue trend) compared with the angles (red trends) calculated with the Codamotion data when the patient falls back starting from the vertical position.

E. Imbalance right/left

Obviously, the imbalance to right and left side of the body are visible due to the medio-lateral angle, as shown in Fig. 15. When the person is right imbalanced the medio-lateral angle is positive, on the contrary the angle is negative. Even the comparison to validate the data is very good. The antro-posterior angle does not provide useful information to recognize the imbalance, as shown in Fig. 14, but the comparison between the angle values calculated using the two measurement systems is good, excepting of some differences due to the non-static acceleration contributions.

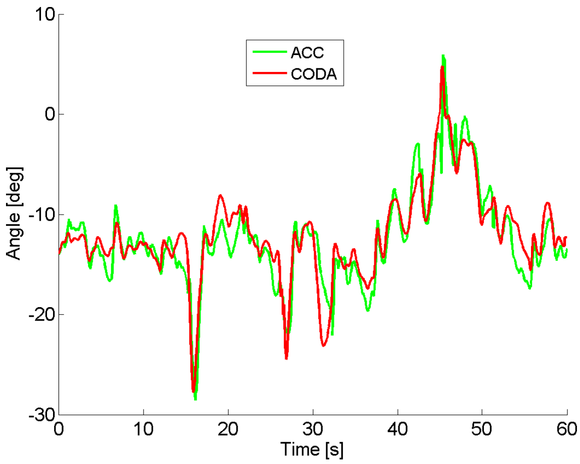

Fig. 14. The antro-posterior angle (green trend) compared with the angles (red trends) calculated with the Codamotion data when the patient oscillates on the right and left side.

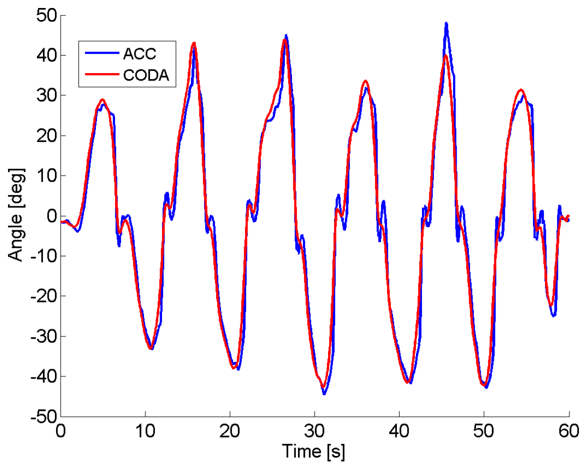

Fig. 15. The medio-lateral angle (blue trend) compare with the angles (red trends) calculated with the Codamotion data when the patient oscillates on the right and left side.

V. CONCLUSIONS

It has been developed an instrumented shirt to evaluate the ability to detect the main human movements and positions important for protocols with therapeutic rehabilitation machines, as robot-walkers. In particular, the antro-posterior and medio-lateral angles of a person have been calculated using the acceleration signals by a triaxial accelerometer. These angle data permit to derive movement and position information of a person and in the future the instrumented shirt will be used to generate specific alarms for the robot-walkers. The data have been compared with a system used for the movement analysis, the Codamotion's 3D Motion Capture. The preliminary analyses show that the trends of the antro-posterior and the medio-lateral angles measured by the accelerometer are comparable with the Codamotion's data. A deeper exam of the metrological analysis necessary to assess the measurement uncertainty of the measured data is in progress. Furthermore, the work will be focus on the identification of the limit values and the thresholds to setup each different specific alarm.

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