A novel Body Sensor Network for Parkinson's disease patients rehabilitation assessment

M.Caldara, D.Comotti, M.Galizzi, P.Locatelli, V.Re
Department of Engineering
University of Bergamo
Dalmine (BG), Italy

D. Alimonti[1], M.Poloni[1], M.C. Rizzetti[2]
[1]Department of Neurosciences - Neurology Unit
Papa Giovanni XXIII Hospital
Bergamo, Italy
[2]San Isidoro Hospital - PD Rehabilitation Unit
Trescore Balneario (BG), Italy

***Abstract*— A miniaturized wireless Attitude and Heading Reference System has been developed with the primary purpose to achieve a body sensor network for motor performance quantitative analysis of Parkinson's disease patients during rehabilitation sessions. The paper describes the performance of the single node, the peculiarities of the developed wearable network and the custom software developed specifically for the Extended Timed-Up-and-Go test. An experimental protocol on Parkinson's Disease patients is currently ongoing. This paper reports the preliminary results, involving 13 patients (mean age 64.6±9) with a moderate disease level and 4 controls (mean age 64.3±4). The data taken during rehabilitation exercise have been analyzed and outcomes are discussed.**

Keywords—Parkinson's Disease; Rehabilitation; Gait analysis; Wireless sensors; Inertial module; AHRS

I. INTRODUCTION

The availability of miniaturized, low-cost and high accuracy MEMS sensors drives the development of Attitude and Heading Reference Systems (AHRS), achievable with the combination of sensors with a microcontroller able to determine the 3D orientation. By providing a wireless interface, such devices are particularly attractive as body motion tracking systems. Rehabilitation field can particularly profit of wireless body motion tracking, for achieving low-cost, but accurate analysis of body motor functionalities [1]. Such technologies are also attractive for mobile health applications, by allowing a patient to perform rehabilitation exercises at home and providing a feedback about the performance at the same time [2]. This paper focuses on Parkinson's disease (PD) patients rehabilitation; PD is one of the most diffused neurodegenerative human diseases, peculiar of adult age. It's a chronic and progressive disease having an incidence which increases with age; considering individuals of 65 years or older the annual incidence in the US is of 160 per 100,000 persons, while the prevalence is about 1% of the population over 65 years [3]. PD is classically defined on peculiar motor deterioration signs as Muscular Rigidity, Tremors at rest, Bradykinesia, Hypokinesia/Akinesia and Postural Instability. The drugs therapies act on the dopaminergic nigrostriatal system and they are used to control the motor disabilities related to the disease. There is a general consensus about improvements of physical exercise in both performance and quality-of-life in patients with PD. Moreover Intensive multidisciplinary rehabilitation (physical exercise, occupational therapy, treadmill with visual and auditory cues) emerges as key in the treatment of PD [4]. In this paper we present the development of a system for PD patients rehabilitation assessment; the solution, composed by a BSN with a wireless interface and a software, is dedicated to clinicians as a quantitative tool for patient motor performances evaluation, but potentially is the basis of a patient-oriented system for home rehabilitation.

II. HARDWARE DESCRIPTION

A. Single Node

The developed BSN is based on a miniaturized, multi-sensor AHRS node named "neMEMSi". NeMEMSi is the evolution of the system presented at BSN 2013 [5]; the 3D orientation is achieved by reading data from a 9DoF MEMS sensor (LSM9DS0 from STM), and implementing data fusion and algorithms in a low-power 32bits microcontroller. The 3D orientation, expressed in terms of quaternions, is finally directed with a serial protocol to a miniaturized Bluetooth radio (BT33 from Amped'Up RF). Figure 1 shows a block diagram of neMEMSi, while Table 1 summarizes the performance of the platform [6].

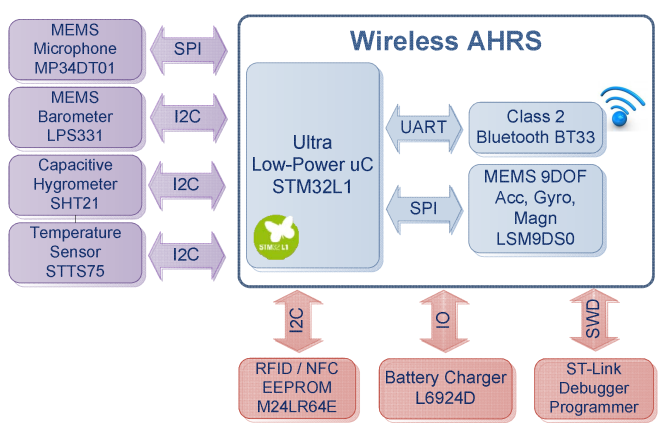

Fig.1 neMEMSi block diagram; the part enclosed in the solid rectangle represents the wireless AHRS. Additional sensors and functions are present on each module.

978-1-4799-4959-5/14 $31.00 © 2014 IEEE
DOI 10.1109/BSN.2014.28

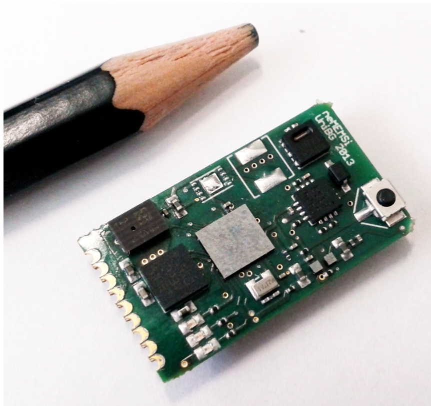

Fig.2 neMEMSi assembled PCB; a single node includes additionally a battery and a plastic enclosure with mounting straps.

TABLE I. MAIN FEATURES OF NEMEMSI

Parameter	**Value**
PCB dimension	25x14mm^2
Battery	90mAh, Li-poly, dimensions 25x11x3mm^3
Radio	Bluetooth V3.0, Class 1.5
User selectable 3D orientation ODR	25, 50, 100, 150 Hz
Power Consumption	29mA (@3.8V) streaming at 50Hz
3D dynamic orientation accuracy	0.55 deg average on Roll, Pitch, Yaw
3D static orientation resolution	0.057 deg average on Roll, Pitch, Yaw

III. SOFTWARE AND SYSTEM ARCHITECTURE

The PD patients rehabilitation software has been developed following the requirements given by the medical staff; it is a tool based on elaboration of the data coming from the BSN composed by five neMEMSi modules. The program is mainly composed by three layers: a data acquisition layer, a compensation layer, necessary to refer all the measurements to a unique patient reference system and finally an analysis and visualisation layer (see Fig. 3). The operation is semi-automated and the results are shown immediately after the execution of the test.

A. Body Sensor Network for PD patients studies

Five neMEMSi modules have been enclosed in plastic boxes, providing a 90mAh Li-poly rechargeable battery and a mini-USB connector for module recharge. A set of stretchable straps has been used to obtain a wearable kit for body motion tracking. The platforms have been mounted on-body in the positions described in Table 2; the decision on the body limb to be monitored is dictated by the parameters to be analyzed. The chosen number of platforms is the minimum needed to study patient posture, asymmetries and tremors.

B. Acquisition software

In order to acquire data from one or more neMEMSi, a software based on the C# programming language has been developed. This software allows to establish the connections and retrieve data from the devices at the desired output data rate (ODR). The Bluetooth communication between neMEMSi and PC makes use of SPP (Serial Port Profile). The software provides the following features (as depicted in Fig. 4):

- To associate a given serial port to a body limb, to initialize the Bluetooth link and to run a 4 seconds acquisition test (ODR 50 Hz) for checking the correct operation of each platform;
- Start simultaneous transmission from the devices with a user selectable ODR and save acquired data on text files;
- Save the calibration parameters of magnetometer of each device for off-line analysis;
- Shutdown each platform remotely for battery lifetime extension.

TABLE II. BODY SENSOR NETWORK

	Body Position	**Measurable Parameter**
	Spine	Posture, Gait direction, Turning, Excersise duration, intermediate times
	Left Forearm	Oscillation, Tremors, Asymmetries
	Right Forearm	
	Left Lower Leg	Gait quality, Freezing gait, Bradikinesia
	Right Lower Leg	

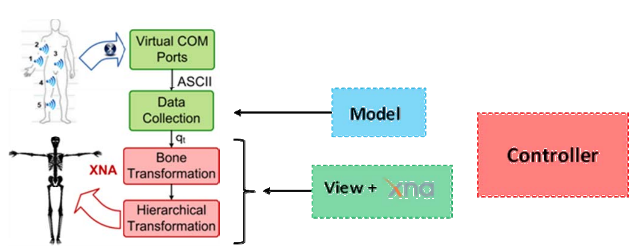

Fig.3 Rehabilitation software structure.

Fig.4 Data acquisition software interface.

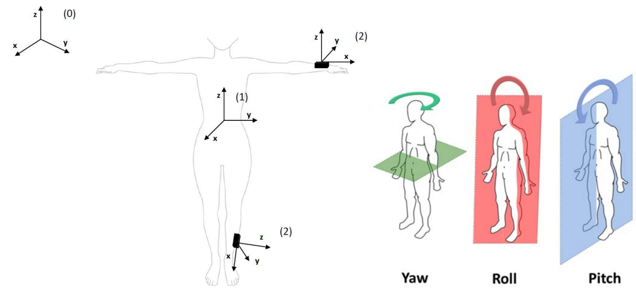

Fig.5 BSN reference systems and body rotations nomenclature.

C. Alignment

The mounting position of each neMEMSi directly affects the acquired data and consequently the body orientation estimation. An alignment method has been studied in order to determine the orientation of each node with respect to a common reference system independently of the device mounting position [5]. The orientation of each neMEMSi is computed depending on the data measured on board sensors and is represented by means of quaternions. In this paper, the following convention has been adopted:

$$q_{b,c}^{a} \tag{1}$$

which represent the rotation from b to c with respect to the reference system a. Each node of the network can be referred to one of the following systems (Fig. 5):

- the main reference system (0), corresponding to the earth reference system and represented by the identity quaternion (1 0 0 0);
- the reference system of the subject wearing the devices (1), which can be achieved from the main reference system by applying a yaw offset:

$$q_{0,1}^{0} = \left(q_{1w}\, 0\, 0\, q_{1z}\right) \tag{2}$$

- the reference system of each device (2), which depends on the specific positioning conditions (mounting), and achieved from the main reference system by the specific rotation $q_{0,2}^{0}$;
- the reference system of each device during the experiment (3), identified by the quaternion $q_{0,3}^{0}$ estimated on board.

In order to represent all the rotations with respect to the reference system of the subject, the quaternion $q_{2,3}^{1}$ is needed, which is given by:

$$q_{2,3}^{1} = q_{1,2}^{1} \otimes q_{2,3}^{2} \otimes q_{1,2}^{1\,*} \tag{3}$$

where $q_{1,2}^{1}$ is the rotation between the earth reference system and the module mounting position while $q_{2,3}^{2}$ is the module orientation during the exercise with respect to its initial position. This latter quaternion is based on the orientation estimated by each AHRS.

This calibration method allows to establish the orientation of each node of the network with respect to the reference system of the subject; in particular each rotation around x, y and z axis of the body reference system are addressed as Roll, Pitch and Yaw.

D. Analysis and visualization software

The clinical criteria of Parkinson's disease diagnosis focus mainly on deteriorations in patient's movements, such as muscular rigidity, asymmetry of the arms swings, incorrect posture, tremors: preliminary studies confirmed the ability to recognize the pattern of some of this parkinsonism's, through the analysis of the data obtained from the sensor network. In order to provide the medical personnel with an easy-to-use instrument, a software that automates as much as possible the process of data elaboration and analysis has been developed. Moreover an intuitive visual feedback is provided to the user.

The software support the loading of the exercise data, that have been saved previously on text files with the acquisition software. After selecting the north quaternion and the start index of the exercise, an automated procedure perform the quaternions alignment and converts data into Euler angles. The results are plotted on a graph; furthermore, a 3D model reproduces the movements performed by the patient during the exercise by means of the libraries of the XNA framework: this function offers a visual feedback to the specialized personnel, increasing the comprehension of the acquired data.

Preliminary measures confirmed the presence of univocal patterns observable during an acquisition session, such as the swing motion of the arms. One of the aims of the developed software is to execute an automated analysis of the data taken from a routine exercise asked of patients, during which at present only the duration is evaluated manually, in order to provide general information about the exercise to the user. For this reason, a version of the Todd-Andrews algorithm [7] for the peaks detection has been implemented. By applying the algorithm to the pitch (rotation angle around y axis) of both the arms and the back, the software determines respectively the mean swing amplitude for each arm and the duration of the exercise: these parameters can be used to assess the patient motor performance during the rehabilitation period or for monitoring pharmacological therapy effects.

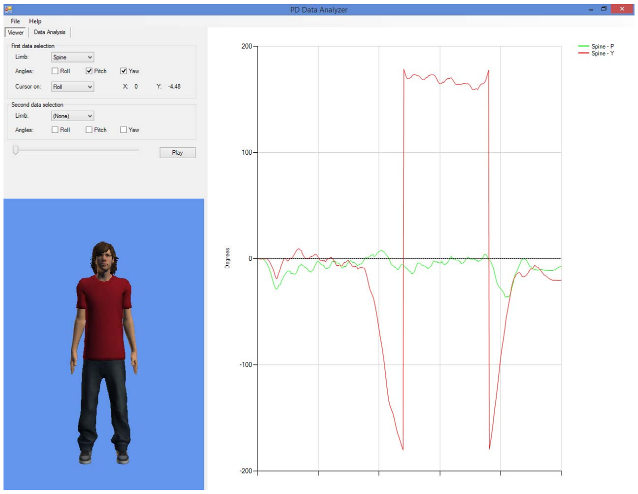

Fig.6 Rehabilitation software interface; in the upper left part the user can select which body limb and angle to visualize. When playing the data a plot cursor indicated the synchronism between the data and the 3D human model.

IV. Experimental Protocol

Up to present 13 PD patients (mean age 64.6±9) and 4 controls (mean age 64.3±4) have been measured. The PD patients have a moderate disease severity (average H&Y index 2±0.7, average UPDRS III 15.2±6.6) and they were measured during their ON-state (under effect of pharmacological therapy). The system has been worn during the Extended Timed-Up-and-Go test, a routinely gait exercise, which is daily performed during hospitalization in a medical rehabilitation center.

A. Extended Timed-Up-and-Go test

The Timed- Up and Go test is used to study mobility, stability, gait performance and fall risk for elderly. It's considered a reference exercise in rehabilitation field for a variety of diseases, as Alzheimer's disease or Parkinson's disease. It consists of three steps:

- Patient sit, with the spine lean on the seatback;
- At the operator start the patient stands up, walks for three meters, turns and walk back to the chair;
- The patient sits down.

The material needed for the exercise is minimal, consisting in a chair, a marker for the turning and a chronometer. The patient is instructed before performing the test and is allowed to do one trial with no score. The Extended TUG (ETUG) test, with respect to the standard TUG, consists of:

- The distance to be covered is 10m (see Fig. 7);
- The curve trajectory is bigger with respect to TUG;
- Intermediate times are taken, in order to evaluate single actions like standing/sitting, walk time, turning time.

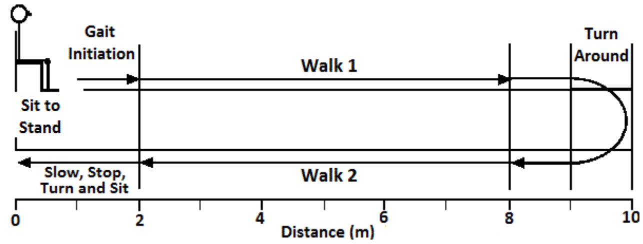

Fig.7 Schematic drawing of an ETUG exercise.

B. Results

The body motion patterns during ETUG test has been first analyzed for control cases, in order to set-up the algorithms for data analysis. Figure 8 depicts lower legs and forearms pitch during an ETUG test, while Fig. 9-10 depict the same limbs for two PD patients. From the arms/legs data the following parameters can be extracted:

- Legs and arms swing during gait is typically out-of-phase, with 60deg and 50deg amplitude respectively;
- With the ETUG distance fixed, it is possible to evaluate the average step length and the number of steps;
- Arms asymmetries and tremors are clearly detectable; tremor frequency (4-6Hz) is higher than arm oscillation frequency;
- All the Pitch measurements shown in Fig. 8-10 are subject to baseline wondering, given by a gait direction change; it is thus necessary to use an algorithm insensitive to it in evaluating oscillations/asymmetries [7].

The ETUG test time duration detected by the rehabilitation software has been compared with the manual measurements provided by the medical assistants, obtaining generally a good correlation (Fig. 11). The automated detected time in most of the cases underestimates the ETUG test time by about 1s, due to the time delay between the nurse vocal start command and the effective patient standing movement. This issue can be overcome by pressing the start acquisition and giving the vocal command simultaneously. The BSN can thus automatically measure the cognitive delay between the auditory stimulus and the effective body motion. Moreover in Fig. 11 a false detection of the algorithm is emphasized by an arrow; in this case the patient didn't stop to move once sit down. The risk of incorrect detected time can be minimized by stopping the acquisition right after patient's sitting phase. Finally it can be noticed that control subjects performed the ETUG test between 10 and 15 s, while the PD patients results are heterogeneous, reaching values as high as 50 s.

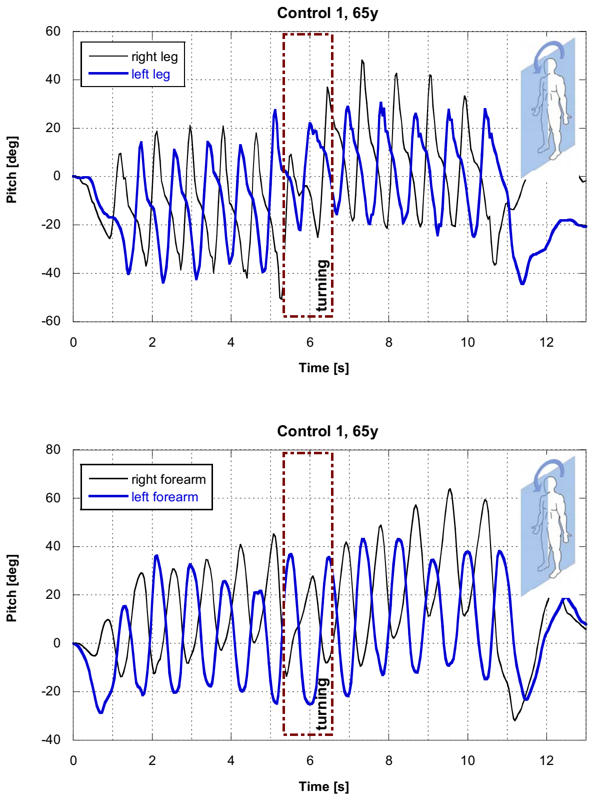

Fig.8 ETUG test Legs (top) and forearms (bottom) pitch with a control subject.

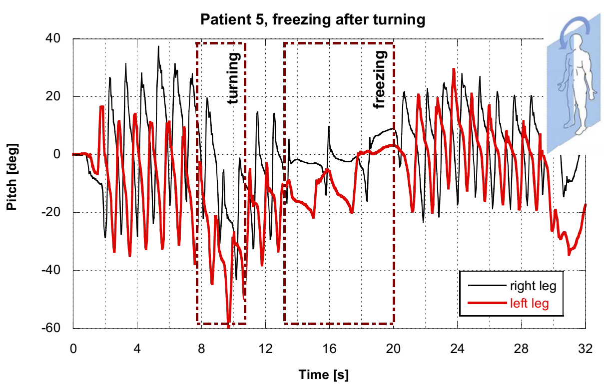

Fig.9 Legs pitch of a patient during an ETUG test; during the return phase a freezing event is clearly visible. After recovery a reduced step amplitude and an increase in step number is also detected.

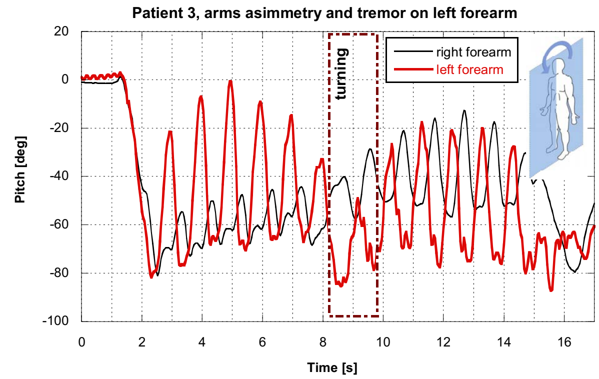

Fig.10 Forearms pitch of a patient during an ETUG test; an average asymmetry of 30deg and a superimposed tremor on left forearm are visible.

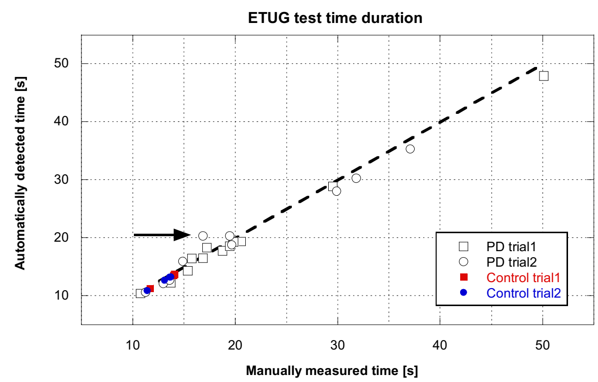

Fig.11 Automatically detected ETUG test time duration with respect to the manually detected times; the dotted line represents the ideal correspondence. An arrow emphasize an overestimation of the automated method.

V. CONCLUSIONS

The paper presents a BSN based on five wireless AHRS used to assess different PD patients motor features during the ETUG test. The preliminary results on the ongoing clinical study shows that the system is able to monitor, during the exercise, a considerable amount of parameters as asymmetries during gait, posture, tremors and total and intermediate times of the exercise execution. The custom developed software provides, in addition to the Euler angles plots of each body limb, a human 3D model, which is the basis of a future development aimed to provide a visual feedback to patients for home-based rehabilitation.

REFERENCES

[1] Abdelkrim Hadjidj, Marion Soui, Abdelmadjid Bouabdallah, Yacine Challal, Henry Owen, “Wireless sensor networks for rehabilitation applications: Challenges and opportunities”, Journal of Network and Computer Applications, Volume 36, Issue 1, January 2013, Pages 1-15, ISSN 1084-8045, http://dx.doi.org/10.1016/j.jnca.2012.10.002.

[2] Paraskevopoulos, I.; Tsekleves, E., "Use of gaming sensors and customised exergames for parkinson's disease rehabilitation: A proposed

virtual reality framework," Games and Virtual Worlds for Serious Applications (VS-GAMES), 2013 5th International Conference on , vol., no., pp.1,5, 11-13 Sept. 2013, doi: 10.1109/VS-GAMES.2013.6624247.

[3] Hirtz D1, Thurman DJ, Gwinn-Hardy K, Mohamed M, Chaudhuri AR, Zalutsky R., “How common are the "common" neurologic disorders?”, Neurology. 2007 Jan 30;68(5):326-37.

[4] Frazzitta G, Balbi P, Maestri R, Bertotti G, Boveri N, Pezzoli G, “The beneficial role of intensive exercise on Parkinson disease progression”, Am J Phys Med Rehabil. 2013 Jun; 92(6):523-32, doi: 10.1097/PHM.0b013e31828cd254.

[5] D.Comotti, M.Ermidoro, M.Galizzi, A.Vitali, "Development of a wireless low-power multi-sensor network for motion tracking applications", Body Sensor Networks (BSN), 2013 IEEE International Conference on, pp.1,6, 6-9 May 2013, doi: 10.1109/BSN.2013.6575466.

[6] D.Comotti, M.Galizzi, A.Vitali, “neMEMSi: one step forward in wireless attitude and heading reference systems”, 1st International Symposium of Inertial Sensors and Systems (ISISS), 2014 IEEE, 25-26 February 2014, in press.

[7] Bryan S. Todd, David C. Andrews, “The Identification of Peaks in Physiological Signals”, Computers and Biomedical Research, Volume 32, Issue 4, August 1999, Pages 322-335, ISSN 0010-4809, http://dx.doi.org/10.1006/cbmr.1999.1518.