35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Analysis of Subtle Movements Related to Neurodegenerative Diseases Using Wearable Inertial Sensors: A Study in Healthy Subjects

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Abstract— **Evaluation of movement disorders is a useful tool for the diagnostic and monitoring of diseases related with damage of the motor control systems, such as Parkinson´s disease. The evaluation of well characterized movement disorders has been proposed using different techniques each one with their advantages and limitations. This document propose the use a system based on inertial sensors and wireless technology for the measurement and evaluation of three of the most common movement disorders related with Parkinson´s disease. Measurement of Anticipatory Postural Adjustments (APAs), Postural Sway and hand´s tremor were carried out using inertial sensors modules (IMU). Results obtained from measurements in elderly and young subjects are presented, as well as the set up and parameters suggested for quantitative analysis.**

Keywords: Hands tremor, APAs, sway, inertial sensors

I. Introduction

Movement disorders are a common symptom among diseases affecting the nervous system. The characteristics of the movement disorder depend of the localization of the lesion in the nervous system [1]. Parkinson´s disease is the second most common degenerative disease of the nervous system affecting, only in the United States, more than 500,000 people and 50,000 new cases are reported every year [2]. Parkinson´s disease occurs when the nerve cells of an area in the brain known as *substantia nigra* die or become impaired. These cells produce dopamine, a chemical messenger responsible for transmitting signals from the substantia nigra to the corpus striatum, acting like a "relay station" producing smooth and purposeful movements. The lack of dopamine results in four motor symptoms: bradykinesia (slowness of movement), Rigidity (Stiffness of movement), Tremor (involuntary shaking of the hands, feet, arms, legs, jaw, or tongue usually more prominent at rest) and postural instability (tendency to fall) [3]. These motor disorders appear, and slowly progress over a period of 10 to 20 years[4], and are usually ignored until they affect severely the quality of life (QOL) of the patients. Several researchers have reported different techniques to correlate the measurement of these motor disorders and the progress of the disease or to evaluate the effect of pharmacodynamic studies [5]–[8] with good results. These movement disorders measurements have been carried out using different tools such as force platforms, [9] inertial sensors[7], [10] etc. Inertial sensors have shown good characteristics for movement evaluation [11] and especially useful for Parkinson´s movement disorders. In this document we present a system based on inertial sensors for the evaluation of three tasks related to movement disorders usually present in Parkinson´s patients: tremor, postural instability and bradykinesia. More specifically, we measured and evaluated hand´s tremor, postural sway and anticipatory postural adjustments using inertial sensors in order to detect changes between elderly and young people, expecting to find some relationship between these different movement disorders and finally, using these results to obtain a more accurate monitoring of motor disorders not only in Parkinson´s disease but other neurodegenerative diseases.

*Research supported by the Mexican Department of Public Education, Program for Improvement of higher Education Teachers (SEP-PROMEP).

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II. Materials and methods

A. Equipment:

An inertial module unit (IMU) collecting acceleration and angular velocity in three axes for each type of signal was developed. This IMU consisted of a 3D accelerometer (MMA7260Q; Freescale Semiconductor, Inc., Austin, TX, USA) and a 3D angular velocity sensor composed of two ENC-03RC sensors (Murata Manufacturing Co., Ltd., Tokyo, Japan) and one X3500 sensor (Epson, Tokyo, Japan) mounted orthogonally. The module has also three connectors for external sensors connection and synchronization purposes. The signals from all sensors including the battery voltage sensors are converted to digital and packed using a 12-bit ADC embedded into a digital signal controller (DSC) dsPIC30F3012 (Microchip Technology, Inc., Chandler, AZ, USA) running at 5 MIPS to sampling the signals at 100 Hz. The data is transferred via Bluetooth using a ZEAL-S01 module (ADC Technology, Inc., Tokyo, Japan), and received in a portable computer running a ad-hoc program created with

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Visual Basic 2005 (Microsoft, Redmond, WA, USA). The program included an algorithm for detecting data losses, which ensures the reliability of data transmission. Characteristics of the IMU are given in table 1.

B. Subjects:

27 healthy subjects, including 16 elderly (age, 69.3 ± 3.6 years; weight, 62.1 ± 8.49 kg and height, 164.68 ± 9.0 cm) subjects recruited from people living in the community and 11 young (age, 23.6 ± 2.2 years; weight, 61.6 ± 8.92 kg and height, 169.8 ± 7.4 cm) subjects recruited mainly from Chiba University students.

TABLE I. MAIN CHARACTERISTICS OF THE IMU

Total weight (Including battery)	93 g.
Size [mm]	58 x 30 x 55
Average battery duration	8.5 hours
Acceleration range	± 1.5 g *
Acceleration sensitivity	800 mV/g
Frequency response	0 to 28 Hz
Angular velocity sensitivity	16.8 mV/deg/s
Angular velocity range	± 80 deg/s *
Response frequency	0.01 to 28 Hz

* Range are adjustable by software, the ranges showed are the minimums available.

All participants were asked to avoid drinking coffee or alcoholic drinks at least 12 h before the test. All participants reported sleeping between 6 and 8 h every day and exercised at least once weekly; only two were smokers. None of the subjects had taken drugs for pain or flu at least 12 hours prior to the test. Before the test, the subjects were informed of the purposes and conditions of the test and were asked to sign a consent form developed by the ethics committee of Chiba University in Japan were this measurements were carried out.

C. Test procedures

1) Tremor measurement

Two IMU´s were attached on each hand, on the wrist using an adjustable belt. For each hand another extra accelerometer was attached on the middle finger and connected to the extra inputs of the IMU, as show in Fig. 1.

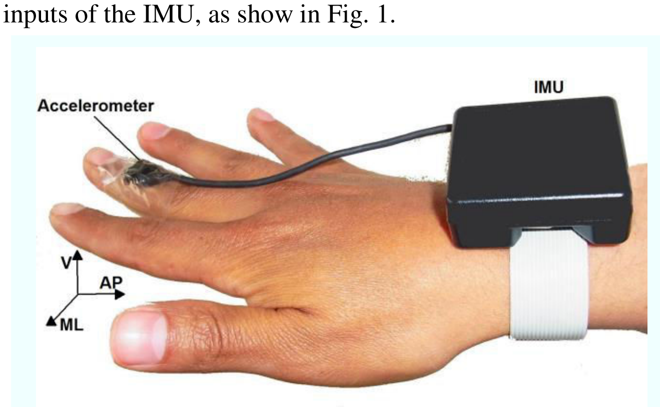

Figure 1. Attachment of the accelerometers on the hands.

The subjects were sitting straight, forearms resting on the armrest of a chair, as shown in Fig. 2a. Subjects were asked to perform two positions: one measurement was taken with the wrists and hands resting on the armrest and, the other measurement was taken while the hands and wrist were unsupported. Each measurement lasted approximately one minute.

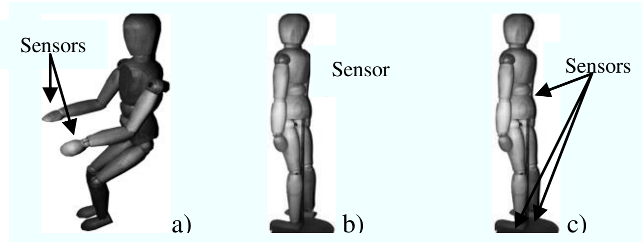

Figure 2. Position of the subjects for each measurement and attachment of the sensors. a) Hands´ tremor measurement, b) Sway measurement, c) Anticipatory postural adjustments

Between each measurement there were rests of one minute during which the subjects were allowed to move freely their arms and hands. A full measurement (two positions) was repeated four times for each subject.

2) Sway measurement

The IMU was attached on the low back near the L3 vertebrae using an adjustable belt. The sway was measured under two conditions. First, the subject was standing upright, barefoot on the firm floor with feet no more than shoulder width apart, with arms at the sides and staring at a mark on the wall, 3 m in front of the subject. The subjects maintained this position as still as possible for around 40 seconds. The second condition was exactly as the first condition but closing the eyes. After each measurement the subjects were allowed to sit down and rest for approximately one minute. This procedure was repeated four times for each subject. Position of the subjects and position of the IMU is depicted in Fig. 2b. This procedure using inertial sensors was already proved in [12]

3) Anticipatory Postural Adjustment (APAs) measurement

The IMU was attached near the L3 vertebrae, position chosen due to the proximity to the center of mass (CoM) of the human body. Two force sensors FSR 406 (Interlink Electronics, Camarillo, Ca, USA) were attached to the heel of each leg, around the area of the calcaneus bone. The FSR sensors were connected to the IMU in order to get synchronized data. This procedure for APAs detection was already proved and reported in [13]. Subjects were asked to stand on the floor, barefoot, with their arms at their sides and looking at a mark on the wall 3 m in front of the subject. The feet position for each subject was controlled by asking to the subjects to put their feet on the marks drawn on a sheet of paper firmly attached to the floor. The separation between the feet was 2cm and their longitudinal axis parallel to the anteroposterior (AP) plane. At the beginning of the measurement, the subjects were focused on the mark on the wall and trying to stand as still as possible. Subjects were asked to start walking normally on hearing a command from the experimenter. This command was chosen randomly without previous announcement. These movements were performed five times starting the walk using the right leg and five times starting the walk using the left leg. We were interested only on the first step so, after 3 steps the subjects were asked to go back to the starting point.

All the measurements were taken consecutively for each subject.

III. Results

Signals from all the measurements were analyzed offline using MATLAB® (MathWorks, Natick, MA). Signal processing for sway and APAs data was already reported in [12] and [13].

1) Tremor analysis

Raw data from tremor was high pass filtered to minimize earth gravity influence and high frequency noise. The frequency for resting tremor is between 4 and 6 Hz and for

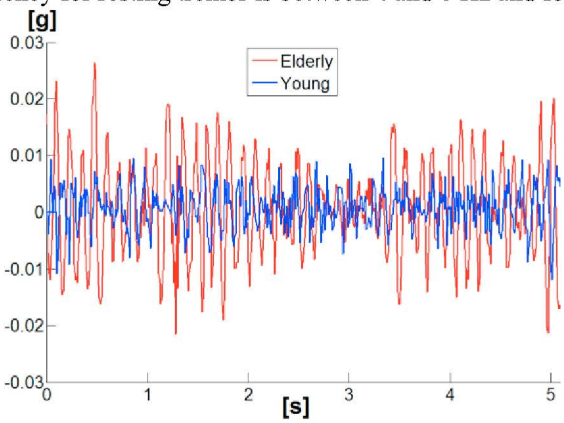

Figure 3. Signals of vertical acceleration from the left hand of elderly and young subjects

postural tremor is between 5 and 12 Hz [14]. Because this study was performed in healthy subjects a frequency range of 0.5 to 15 Hz was chosen. Fig. 3 shows the amplitude of acceleration of the left hand for postural position in elderly and young subjects. As expected, elderly subject present higher amplitude compared with the young subject, also is possible to see a higher frequency in the signals from the young subject. This is due to a better fine control of the younger subject which implies higher frequencies to maintain the postural position.

It was also calculated the average peak frequency for all the subjects. The results are shown in Fig. 4. Average peak frequency was calculated for each axis, mediolateral (ML), anteroposterior (AP), vertical (V) and the resultant of the three axes (RD) which was calculated using the Euclidean norm. In this case, the postural tremor is below 10 Hz for almost all the subjects which is logic because they are healthy subjects, however it is interesting to note that the proposed system is capable to detect changes between healthy subjects attributable to age differences, However these apparent differences between elderly and young subjects were not significant using a t-test.

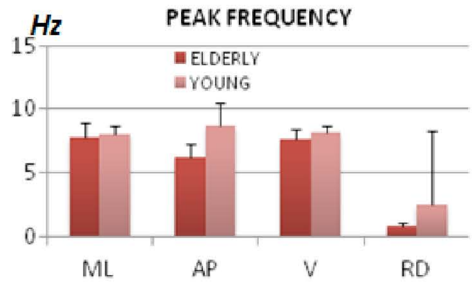

Figure 4. Maximum average frequency in elderly and young subjects (Vertical axis is for frequency in Hz)

The power spectrum for the 50% of the total frequency content was also calculated and it is shown in Fig. 5. For this case it is also possible to observe an apparent difference between elderly and young subjects but it was not significant. Other characteristics can be obtained from the signals such as maximum peak of the signal (amplitude), or total power spectrum.

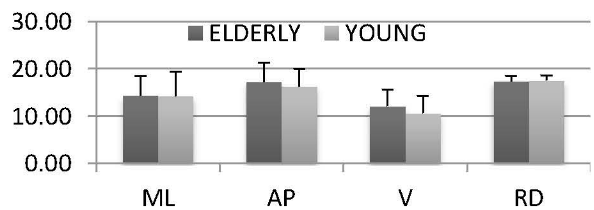

Figure 5. Power spectrum of the first half of the total frequency content for all the acceleration signals of elderly and young subjects.

2) Sway results

For this movement, the method for signal conditioning and analysis as well as parameters suggested proposed in [12] was used. The gravity acceleration was eliminated by subtracting the mean acceleration; a high-pass filter at 0.3 Hz was used to eliminate slow movements no related to sway and a Savitzky-Golay smoothing filter was used to minimize the high frequency noise of the signal. To compare the signals, the average acceleration resultant (AAR) in the anteroposterior plane parameter was selected because this was one of the parameters which permits to differentiate between elderly and young subjects according to [12]. Results are shown in Fig. 6.

The results obtained show that elderly people has a greater sway acceleration compared with young subjects $P < 0.01$.

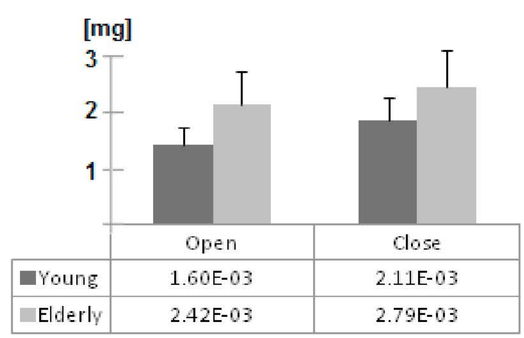

Figure 6. Comparison of average acceleration resultant in elderly and young subjects. $P < 0.01$ (t-test).

3) Anticipatory postural adjustment results

Signal was processed and analyzed as reported in [13]. Fig. 7 presents an example of the signals measured using the system proposed. Fig. 8 shows a comparison of the magnitude between elderly and young subjects using angular velocity signals. Similar results were obtained using acceleration signals. It is visible a difference between both groups.

IV. Conclusion

We developed a wearable system for evaluation of three of the most common movement disorders in Parkinson´s disease. At this stage, the system was tested using only healthy subjects. No significant difference was detected for hand´s tremor, however, it was possible to detect apparent changes which are expected to be significant different compared between healthy and neurodegenerative disease patients. The future work is to compare Parkinson´s disease patients with similar age healthy group in order to evaluate if it is possible to detect changes due to Parkinson´s disease using the methods here proposed.

Acknowledgments

The authors would like to thank to the Department of Public Education, Program for Improvement of higher Education Teachers (SEP-PROMEP) for the economic support for the development of this research. Also we thank to professor Masaki Sekine for provide us with the first IMUs for this project.

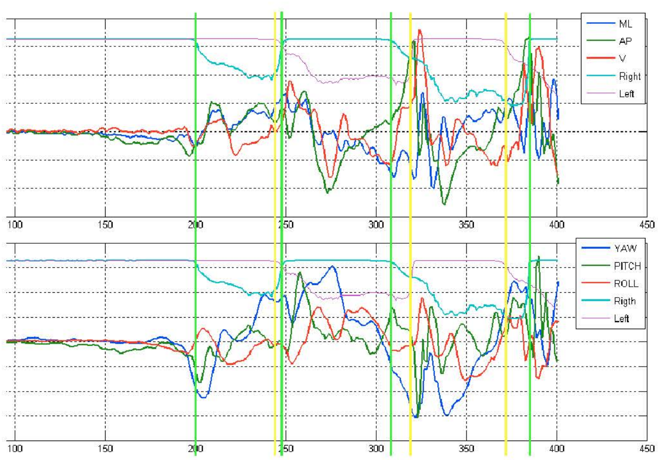

Figure 7. Signals from accelerometers (above) and angular velocity sensors (below) for the APAs measurement. Each division on the vertical axis represents 0.1 g for acceleration and deg/s for gyroscopes. Horizontal axis are the number of samples, 100 samples take one second of time. Purple and aqua color lines are from the FSR sensors. APAs begins since the signals starts to change (aproximately in the sample 150 and last until the step is given).

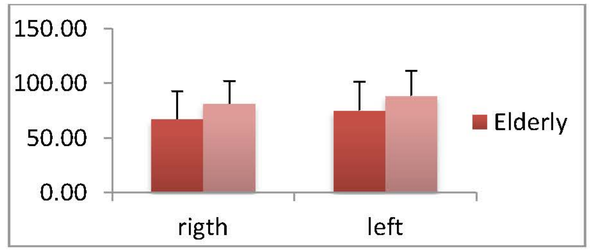

Figure 8. Anticipatory postural adjustments comparison between elderly and young subjetcs using angular velocity signals. Vertial axis represents deg/s.

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