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Upper Limbs Triaxial Accelerometry Signal Acquisition System for Parkinson's Disease Tremor Study

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Abstract

In this work, we proposed the design of a triaxial accelerometry signal acquisition system for the study and characterization of Parkinson's disease tremor in upper limbs, using components and technologies commonly available in academic environments. The system consists of hardware and software stages, which were implemented by using commercial integrated circuits, the Arduino IDE and the Processing programming language. This allowed to decrease the cost compared to currently available options in the market and to properly personalize the functionality of the system (hardware and software) in order to fulfill the needs in terms of the acquisition of accelerometry signals to assess tremor in Parkinson's disease. The system was tested in academic and research projects and the obtained data was compared qualitatively to the one obtained previously with a commercial system. The designed system is capable of measuring triaxial accelerometry signals from both upper limbs simultaneously, each sample contains data from six axes in the form of a comma separated string in order to be appended to a text file by the developed desktop application, and is sent to a personal computer via Bluetooth for further analysis.

Keywords: Parkinson's disease, Triaxial accelerometry, Tremor characterization.

1. Introduction

Tremor is a rhythmical, involuntary oscillatory movement of a body part. Movement disorders manifesting in tremor influence the quality of life for millions of people. Two prevalent types of movement disorder are Parkinson's Disease (PD) and Essential Tremor (ET) but the misdiagnosis rate for ET and PD has been reported to be higher than 25% [1, 2].
PD is a neurological disease caused by progressive loss of the dopaminergic neurons located in the compact part of the substantia nigra, causing reduction of dopamine levels and, consequently, damage to the motor system. This disease is characterized by the presence of cardinal signs, such as bradykinesia, resting tremor, stiffness and postural instability. As the disease progresses, there is an increase in motor dysfunctions, which makes it necessary to evaluate and monitor these changes [1, 2]. By contrast the predominant symptom of ET is a kinetic tremor of the arms, which may be the result of an abnormality in cerebellar outflow pathways [3]. Besides, ET is inversely related to age and patients with severe ET also have a postural tremor.

Although ET and PD both manifest movement disorder tremor symptoms, their tremor characteristics are notably different. PD presents tremor that is observable during resting status, with a frequency range between 3 and 7 Hz. Additionally, resting tremor may decrease in severity or even disappear when the subject conducts voluntary movement. On the other hand, ET commonly displays kinetic tremor instead of resting tremor with a frequency range between 4 and 12 Hz [1, 2, 4].

The differential diagnosis of these tremors is important since the treatment depends on the specific etiology of each tremor type [5]. Therefore, one approach to distinguish PD and ET is to quantify the amplitude and frequency of tremor, this can be done with accelerometers, which measure dynamic and

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static accelerations. These measurements are generally done for both resting and action tremors separately [6, 7].

Recently the relationship between asymmetry of tremor intensity and asymmetry of frequency has been studied, showing the relevance of the signal acquisition in both sides [8]. However, the measurements have been carried out separately on the right and left hands. Therefore, our research group have proposed a system to acquire accelerometry signals from both hands simultaneously, obtaining promising results, allowing the differentiation of tremor types using short clinical protocols [4]. However, the used acquisition systems were relatively expensive and presented significant drawbacks, such as accelerometry signals saturation while performing some of the required active maneuvers. Based on this, in this work we present a developed new acquisition system, consisting on hardware and software stages, capable to personalize the required acquisition specifications, such as accelerometers output range, and to save the data for an off-line analysis of tremor accelerometry signals.

2. Methodology

2.1 Electrical Circuits and Components

The hardware stage was meant to obtain data from accelerometers and send it via Bluetooth to a computer. Thus, the next functional components were required: two triaxial accelerometer sensors (one for each upper limb), a Bluetooth communication module, a microcontroller and a DC power supply. The developed circuit should be compact and allow subjects to properly move the upper limbs and to perform active and passive maneuvers.

Accelerometry Sensors. The ADXL345 integrated circuit (IC) was chosen due to its availability in our region and the specifications listed on its datasheet [9]. The IC allows for output range and resolution selection, up to ±16g. A range of ±4g was configured and used during this work. The sensors were tested and calibrated based on the instructions provided by the fabricant, using an Arduino UNO board for testing. Constant acceleration due to gravity is used for calibration as a reference value [10].

Bluetooth Module. The HM-10 module was chosen due to its low power consumption, its capacity to connect with most operating systems and to be coupled with AVR microcontrollers [11].

Microcontroller. The Arduino UNO board was used in the early stages of development, obtaining optimal results. Thus, we decided to use the same microcontroller this board uses, ATMEGA328P. The microcontroller was programmed and extra components added such as instructed by Arduino, using the Arduino UNO board as a sketch uploader [11]. The obtained measurements were sent to the microcontroller serial port as a queue of strings containing the sensed value of each axis, separated by commas, for a total of 6 measurements per line. The data was sent with a sample frequency of 25Hz.

Power Supply. The power supply choice was based on previous work [4]. Lithium polymer (LiPo) batteries were chosen for the DC supply. A 300mAh capacity was chosen in order to allow long lasting acquisitions (more than 2 hours of continuous use) and to avoid the greater dimensions related to greater capacity batteries. The TP4056 module was added in order to allow USB charging. A single pole single throw (SPST) switch was included between the battery and the charge module in order to easily turn the circuit on/off.

All the listed components were tested independently and coupled after obtaining the desired functionality. A single layer printed circuit board (PCB) was designed in order to completely couple all components. The CircuitMaker (Altium Limited) software was used for the design and considering having all the components in a PCB as compact as possible the board final dimensions were 5.5cm width and 3cm height.

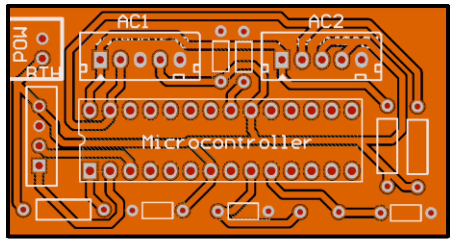

Fig. 1. Designed PCB for the proposed acquisition system

2.2 Sensor Coupling and Casing

The two systems used in the past by our research group were implemented using the BITalino ® board (Fig. 2.A) and the sensors were placed and held in place using different methods, such as adhesive tape and Velcro attached to a glove and the back of the circuit. These methods were ineffective for a long-term usage of the device (Fig. 2.B and 2.C).

In order to solve these issues, the developed circuit had to be included in a case in order to protect it from mechanical stress and prevent electrical hazard during its usage therefore 3D printed cases were designed. The SolidWorks CAD software (SolidWorks Corp., Waltham, MA, USA) was used for this purpose. One case was designed to contain all the components on the designed PCB while allowing users to easily connect both sensors to the circuit, turn the circuit on/off using the SPST switch and to connect the USB cable for charging the battery (Fig. 2.D).

The other cases were designed to enclose and protect the ADXL345 modules (Fig. 2.E). The cases were designed using smart rings as an inspiration. The users would be able to attach the modules in their finger using a Velcro adjustable strap (Fig. 2.F). This would allow to implement a better attachment method and reduce signal distortion due to undesired movement of the sensors.

Finally, the cases were fabricated using the Fused Filament Deposition (FFD) printing technique, which is a rapid and low-cost 3D printing approach, and the printing material used for this work was Acrylonitrile Butadiene Styrene (ABS).

Even though the resulting circuit and cases present greater dimensions than its predecessors, the ability to place the circuit in different places other than the back of the hand, allows for improved mobility and comfort for tests subjects. The cased circuit can be contained inside a small pouch and placed where it best suits the subject.

2.3 Software Development

This stage was developed in order to allow users to have a wireless connection between a computer and the proposed circuit via Bluetooth communication, visualize the obtained data, save it and export it as a text file. The designed program was meant to be deployed as a desktop application for devices with Windows operating system (OS).

The Processing language and IDE (The Processing Foundation) were used due to previous experience using this technology. The IDE includes the required functionality for importing and using several libraries, including the ability to access the OS paths and file management system, serial communication and graphic user interface (GUI) development. The Processing Serial official library includes all the methods needed for connecting the HM-10 Bluetooth module to the computer [12]. After receiving the data, each axis was plotted individually, in order to allow the researcher to evaluate the current maneuver execution in real time.

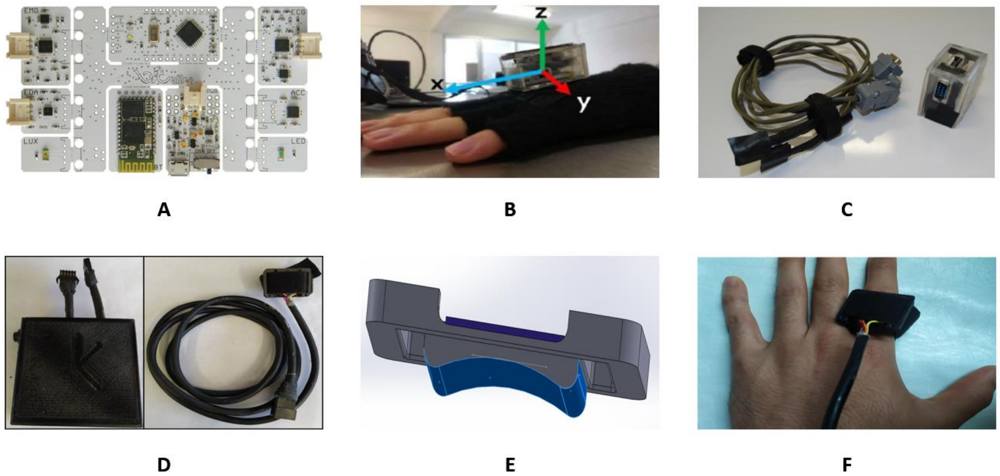

Fig. 2. (A) BITalino ® acquisition board used in the design of the first and second systems (B) First proposed system. (C) Second proposed system. (D) Current proposed system. (E) Designed case for the ADXL345 sensors (F) Representation of wearing the ADXL345 sensor case as a ring.

After testing the data visualization, the text file export phase was developed. It is possible to access the OS directories using different classes included in this language. This allows to create an empty file in a path specified by the user and then fill the file with the strings queue sent by the circuit. Each string is printed in a new line, and each line contains 6 measurements (one for each accelerometry signal).

Then, an optional accelerometry signal processing phase was developed. This stage uses the text file generated during the signal acquisition stage as input. Given the string structure (comma separated values), each axis signal can be easily obtained by using the string split method present in Processing as well as in several other languages. The Processing language is based on the Java programming language, thus, several modules and packages of this language can be imported and used. A Fast Fourier Transform (FFT) implementation was imported and used in order to obtain the power spectral density (PSD) of the accelerometry signal, the resulting PSD is plotted next to the original time domain signal [13]. Simplicity was preferred over efficiency as the signals processing was not performed in real time.

Finally, an additional signal processing phase was developed with the idea to provide a diagnosis suggestion based on calculated variables using the PSD results from the acquired signals. The proposed variables include the maximum peak frequency and the area under the curve (calculated with the trapezoidal rule), and both variables are calculated in a frequency range between 0 and 10 Hz. Content due to gravity is not significant during dynamic measurements. The calculated values are printed on the screen alongside a binary diagnosis statement ("Patient might present Parkinson's disease" / "Patient might not preset Parkinson's disease"). It is important to mention that the needed threshold values for each diagnosis statement still have to be calculated and evaluated, this task is proposed as future work. All the described functions performed by the proposed software are shown in Fig. 3.

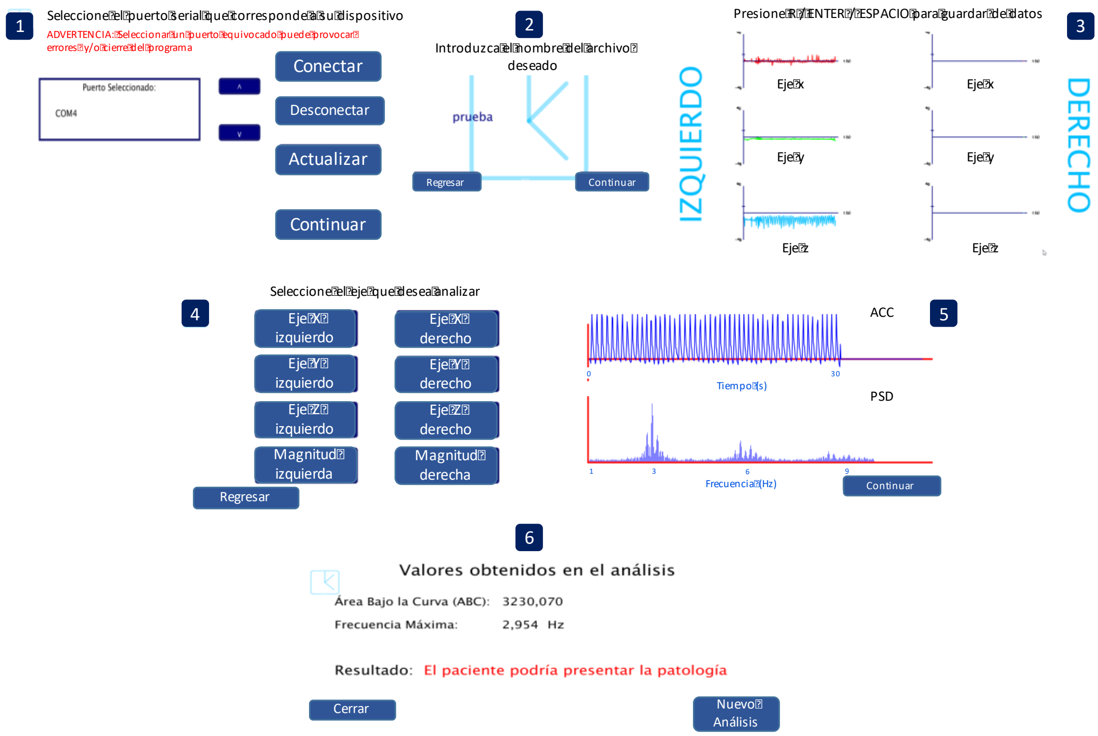

Fig. 3 Developed software application phases: 1) Port Connection Phase, 2) File Naming Phase, 3) Plotting and Acquisition Phase, 4) Axis Selection Screen, 5) FFT Calculation and Plotting Phase, 6) Results and Statement Phase.

2.4 Testing

In order to test the developed system, maneuvers from previous work were used [4]. The maneuvers consist of resting phases followed by controlled unilateral arm movements with a fixed frequency. During the rest phases the subject remains seated with both hands placed over the thighs. During the movement phases, the maneuver is performed with one arm while the other remains at rest. The chosen test maneuver is called Extended Arm (EA) and consists of repeated short extension and flexion of the arm, with the hand facing downward and the ring finger pointing at an imaginary point placed at the subject's nose height. The maneuver was executed with a frequency of 3Hz with a duration of thirty seconds. This maneuver was preceded and followed by rest phases each with a duration of 20 seconds. It is important to mention that EA maneuver was selected in this work considering that it has proved to be particularly useful for the analysis of PD tremor because it enhances the parkinsonian tremor due to a slight stress caused by an specific active movement performed at a rapid pace [4, 14].

After a first test, the text files delivered by our system were imported in the Arduino IDE, plotted and compared to those generated by the second system used in the past and already available for study. The BITalino board and the OpenSignals software were used in the past and they were used as our comparison reference in this work

3. Results and Discussion

The resulting proposed circuit was functional, robust and compact, and the casing allowed the subjects to properly perform the required passive and active maneuvers. However, more testing needs to be performed in order to have more evidence of the robustness of the system.

The developed application (software) delivered optimal results while being tested. Communication with the device was uninterrupted thus, no data lost was presented. The application was tested in three medium performance laptops (minimum requirements: 8gb RAM, Intel Core i5 8th gen) obtaining similar results.

For a comparison purpose, it is important to mention that the BITalino accelerometer has a fixed output range of ±3g and a bandwidth of 0–50 Hz [15]. In the past, this output range appeared to be insufficient for correctly portraying some of the required clinical active maneuvers. The amplitude and frequency of movement allegedly produced measurements not included in the BITalino accelerometry sensor output range, which gave rise to the accelerometry signal saturation, both at the upper and lower limits of the sensor output range, making the system unable to detect small variations in the proximity of these limits, an example of this behavior is presented in Fig. 4.A. In addition, the previously used BITalino system allows for simultaneous acquisition of a maximum of 6 different signals, which is enough for the acquisition of triaxial accelerometry signals of both upper limbs. However, if more variables are needed to be monitored one of the axes would have to be dismissed in order to couple another sensor, such as a gyroscope or an ECG, limiting the use of the systems based on the BITalino board for other applications.

The developed system and the ability to modify its output range allowed to improve the acquisition results. The main comparison parameters were signal saturation avoidance and PSD content congruence with the proposed execution frequency from the test maneuvers. Signal saturation was prevented, and proper data could be gathered from the generated files (Fig. 4.B). It is important to mention that both graphics of Fig. 4 were not simultaneous acquired during an EA maneuver, therefore they are presented just for visual comparison purposes. In addition, given that the signals are sent in a single comma separated string, more sensors could be added with no difficulty. This would allow to monitor more variables during the maneuvers in order to get more useful information.

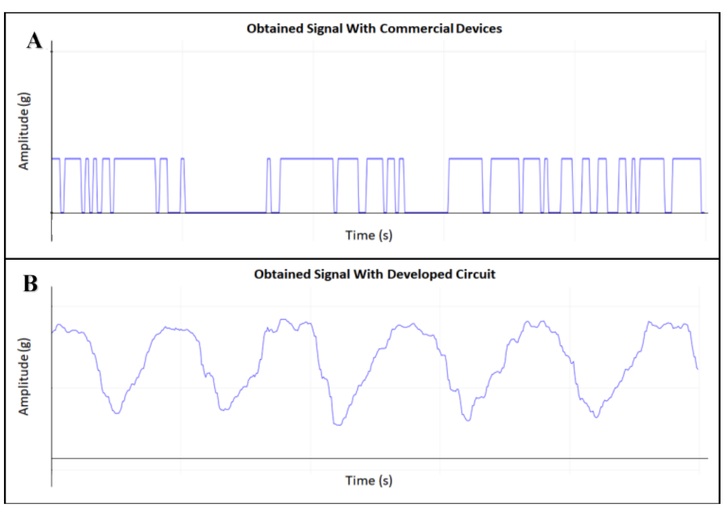

Fig. 4. (A) Time domain plot of data delivered by BITalino accelerometer. Saturation and transient changes in amplitude were a common issue during some maneuvers. (B) Time domain plot of data delivered by the developed circuit. Listed issues are solved by changing the output range of the ADXL345 sensors.

In order to show the performance of the off-line processing stage, an example of the z-axis signal acquired during the EA maneuver is presented in Fig. 5 with its corresponding PSD. In this case, the calculated PSD presented global maximum values in the vicinity of the maneuver frequency (3 Hz). The off-line analysis allows the user to focus on an individual axis or to estimate the PSD of the triaxial magnitude for each arm. It is important to mention that the plotting capabilities of the system need to be improved in order to have a more accurate information on the vertical axis of the graphs.

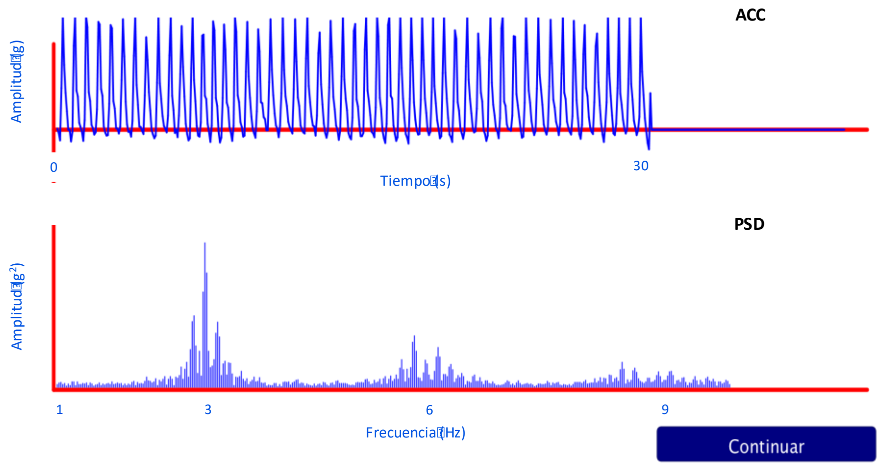

Fig. 5. Signal Processing screen as observed in developed application (Top). Original z-axis signal obtained by performing the EA test maneuver. (Bottom) PSD calculated by our application. The observed maximum peak matches the proposed execution frequency around 3Hz.

4. Conclusions

The developed circuit fulfills the required specifications of our research group for the assessment of PD tremor, being portable, robust and capable to have a wireless communication with a computer. The circuit was subjectively declared more aesthetically pleasant and easier to use than its predecessors. Also, downfalls from previous work were solved, particularly the ability to modify output ranges of the accelerometry sensors, avoiding the saturation of the accelerometry signals. In addition, the designed cases make possible to use the sensors in different parts of the body, only by changing an adjustable strap.

The developed desktop application allows the user to acquire and observe simultaneously six accelerometry signals in real time, and to save all the data for an off-line analysis. Furthermore, the proposed application could also be used with other Arduino based devices, enhancing its portability and allowing its usage in a broad variety of projects where other physiological variables might be acquired.

Even though price was not a crucial parameter during the design of the system, it is important to mention that the total cost of implementation was around \$50 USD in contrast to an approximate expense of \$190 USD by using the BITalino commercial board and sensors.

Future work includes further evaluation in clinical environments with the acquisition of a data base considering control subjects and patients with PD and ET. In addition, performing additional studies in PD patients could encourage the design of new indicators that could be used to improve the diagnosis suggestion statements and assist in the differentiation of different tremor types. Finally, replacing all the used components with surface mounted components would minimize the device size to obtain a truly wearable device.

Besides improving the former systems performance and decreasing the total production cost, this system could be used for other applications involving the usage of Arduino based boards or microcontrollers for sensor data acquisition in academic and research environments.

Conflict of Interest

Authors declare no conflict of interest.

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