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Triaxial Accelerometry Wireless System for Characterization of Parkinsonian Tremor.

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***Abstract*— Parkinsonian Tremor (PT) is the most common symptom of Parkinson's disease. Its early detection plays an important role in the diagnosis of the disease as it is often mistaken for another type of tremor, called Essential Tremor (ET). Accelerometry analysis has proven to be a trustworthy method for determining the frequency, amplitude, and occurrence of tremor. In addition, the use of portable and wearable sensors has increased due to the rapid growth of Internet of Things (IoT) technology, allowing data to be collected, processed, stored, and transmitted. In this paper, a wearable system consisting of a digital 3-axis accelerometer ADXL345 and micro-controller unit ESP32 was implemented to transmit accelerometry (ACC) signals from each upper limb simultaneously to a Graphical User Interface (GUI), that was developed in Python as an MQTT client, allowing the user to visualize both real-time and offline signals as well as to add markers to indicate events during the acquisition. Furthermore, this GUI is capable of performing an offline analysis consisting of the computing of Power Spectral Density (PSD) using Welch's method and a Spectrogram to visualize a time-frequency distribution of the ACC signals.**

***Key Words*— Parkinson's Disease, Tremor Analysis, Diagnosis, Accelerometry, IoT, Wearables.**

I. INTRODUCTION

Parkinson's Disease (PD) is a progressive neurodegenerative disorder, being the most common after Alzheimer's Disease [1]. Parkinsonian Tremor (PT) is the characteristic motor symptom of PD, which is generally unilateral and usually oscillates in a frequency between 3-7 Hz. This tremor is described as a rapid back and forth movement of a body segment while the person is at rest, and phisyopathologically different from other PD symptoms; as a result, early detection is critical in patient management and care [2]. Since PT often exhibits similarities with another form of tremor, known as Essential Tremor (ET), there could be difficulties for a correct PD diagnosis [3]. Despite the fact that both tremors manifest symptoms of movement disorder, their characteristics are quite different. ET is a symmetric task-related tremor with a frequency range of 4-12 Hz that is rarely observed at rest and is not accompanied by any Parkinsonian signs or irregular posturing [4]. A differential diagnosis between PT and ET is important since treatment depends on the specific etiology of each type of tremor. Nonetheless, there is currently no efficient standard to identify or distinguish between these types of tremor. Nowadays, examination by an experienced physician remains the best diagnostic tool [5]. This diagnosis is based on a clinical evaluation, mainly on subject-dependent methods using the four parts standard assessment of the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS), and although these procedures are performed by an expert, it is a subjective tool as no measuring instrument is used. Furthermore, these measures lack validation against real tremor amplitude, making it inadequate for measuring minimal changes in tremor intensity [2]. One approach to distinguish between PT and ET is to quantify the amplitude and frequency of the tremor, which may be possible with Accelerometry (ACC) information of these tremors, from sensors capable of measuring both dynamic and static accelerations [6]. Rigas et al. [2] proposed a wireless system with a set of accelerometers placed on different patient's body segments, obtaining a quantification of tremor severity with 87% accuracy. Moreover, Machowska et al. [7] demonstrated, by using ACC registration, the disparity in tremor severity between hands, showing that asymmetry is a characteristic feature of PD. Nonetheless, the data acquisition of this study was carried out for the right and left hand separately. A system capable of measuring ACC signals from both hands simultaneously using a clinical protocol was developed by Gomez-Castro et al. [8], in which patients affected by PD showed activity in the limbs that were at rest, providing useful information on the use of simultaneous acquisition. However, some drawbacks such as the complication to perform the protocol maneuvers due to the use of wires to connect the sensors to the micro-controller, as well as saturation in the ACC signals while performing active movements were presented. In 2020, Soto-Domínguez et al. [9] developed an improved version of [8], solving ACC signals saturation problems, in addition to a customized user interface to manage the system. Nevertheless, this implemetation was also a wired system, providing the same protocol performing complications as in [8]. Based on the above, this work introduces a system implementation composed of two identical devices in a thimble-like case, that allow a wireless acquisition of triaxial accelerometry signals from both upper limbs simultaneously, in order to be an auxiliary tool in the diagnosis, evaluation and study of PD.

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II. METHODS

A. Hardware Design

The hardware stage was intended to retrieve ACC data from sensors and send them remotely to a computer. A thin, ultralow power, 3-axis accelerometer (ADXL345), with a digital output resolution up to ±16 g (1 g = 9.81 m/s^2) was used. A low power 32-bit WiFi micro-controller unit ESP-WROOM-32 (ESP32) was employed for data acquisition and wireless communication, and data transmission from the ADXL345 to ESP32 was implemented using Inter-Integrated Circuit (I^{2}C) protocol. A Printed Circuit Board (PCB) was designed with the required components including voltage regulator, capacitors, resistors, LED's and switches. Moreover, the PCB has the ability of In-system programming (ISP), thus, once soldered and assembled, the code was uploaded to the ESP32 using the open-source Arduino Software and a USB to TTL FTDI converter via ISP. The circuit was supplied by a 3.7V 500 mAh Lithium Polymer (LiPo) battery connected to a TP4056 charging module and to a LDO voltage regulator, providing a constant power supply of 3.3V. Both PCB and battery were placed within a thimble-like case, allowing to reduce signal distortion due to undesired movement of the sensors. The overall system integration dimension is 3.9 $\times$ 4.2 $\times$ 8.0 cm and weights 57 g.

B. Wireless Communication

Message Queue Telemetry Transport (MQTT) is an OASIS publish/subscribe standard messaging protocol for the Internet of Things (IoT) and very useful to connect remote devices [10]. Publishers and Subscribers (clients), and a Broker, that governs the communication between clients, are the main components in this protocol. The address to which the message is sent by the publisher client is known as a topic and is represented by a string with hierarchical structure, where each hierarchy is separated with a '/'. MQTT was chosen on this project because of its ability to work with remote connections between devices in a low-bandwidth environment, as well as its easy implementation and the offering of three levels of security to protect the information transmitted. On the system proposed, the PCBs were both publisher and subscriber clients as they were responsible for assigning the ACC data to the topics displayed in Table I, in order to publish it to the broker as a single JavaScript Object Notation (JSON) string, as well as for subscribing to a topic called *start* so that they received the transmission control messages as a single string of characters ("ON", "OFF").

Furthermore, a customized Python Graphic User Interface (GUI) was also used as both publisher and subscriber client. The MOSQUITTO open-source broker installed on a Raspberry Pi Zero W Board with a WiFi module included, was utilized due to its easy handling and implementation as there is no requirement of internet connectivity. Finally, although MQTT offers the ability to provide functionality anywhere in the world by directly connect to the web, it has the drawback of being reliant on that connection; this

TABLE I: Topics and respective JSON keys for both right and left arm sensors.

Thimble	Topic	JSON Keys
Right Arm	*right/acc/data*	"xright", "yright", "zright"
Left Arm	*left/acc/data*	"xleft", "yleft", "zleft"

could represent an issue or limitation in institutions such as universities or hospitals where, for security reasons, there is a restricted access to connectivity of devices to their network. Consequently, a Wireless Router Nyx 1200-AC was employed as a router/access point for the clients and broker in order to function as a stand-alone unit. Besides, static IP configuration has been used to automatic connection. The overall block diagram of the proposed triaxial accelerometry wireless system is depicted on Fig. 1.

C. Graphical User-Interface (GUI)

A GUI, which flowchart is shown on Fig. 2, was developed in Python, allowing to perform different tasks such as:

1) To enter patient's personal information: The user enters the information of the patient, such as name, age and a previously given id number as well as the time and date of the acquisition. Data are then saved as a text file.

2) Real-time acquisition and visualization of the signals: The user is able to choose visualize all six ACC signals simultaneously or individually. This GUI acts as an MQTT client that subscribes to the topics on Table I in order to receive the ACC data from the thimbles and be able to display them on a real-time plot. It then publishes on the previously mentioned topic *start* the indication to both begin and finish the data acquisition. Furthermore, the option of add markers while data acquisition is in progress was included.

3) To save the patient information and ACC signals as a text file: Once the acquisition of the signals is completed, they are stored in a text file along with the previously entered patient data.

4) Offline visualization and analysis of the signals: Within the processing stage, the user can select a signal to be visualized and analyzed offline. The signal was resampled at 90 Hz, due to variability of the sampling frequency (Fs)

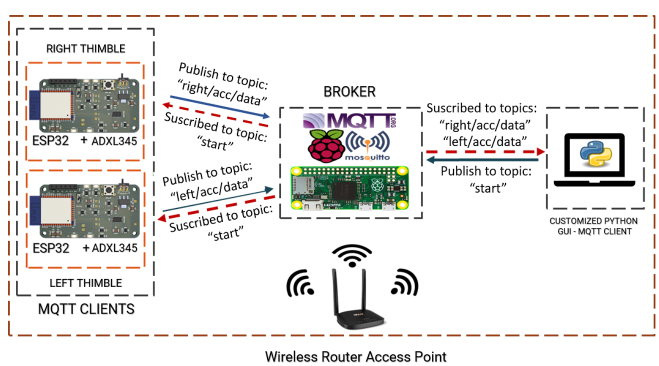


Figure 1: Block Diagram of the proposed Triaxial Accelerometry Wireless System.

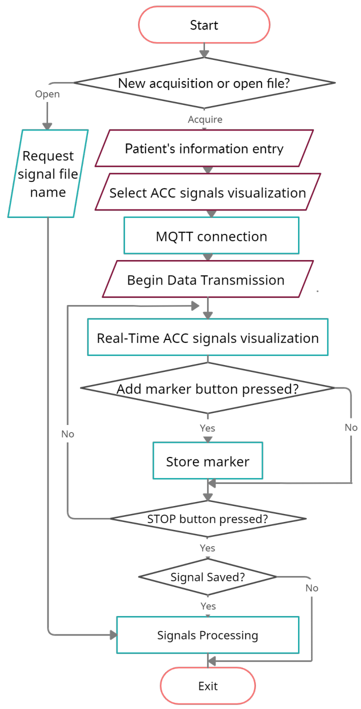


Figure 2: Flowchart of the GUI.

during acquisitions. The offline analysis includes the estimation of the Power Spectral Density (PSD) and the computing of the signal's Spectrogram. The PSD was done by implementing Welch's method which computes an approximation of the PSD by dividing the signal into overlapping segments [11]. This method computes a modified periodogram defined by (1):

$$PSD(f) = \frac{\Delta t}{N} \left| \sum_{n=0}^{N-1} x(n) e^{-j2\pi fn} \right|^2 \tag{1}$$

where $-1/2\Delta t < f \leq 1/2\Delta t$, x is the signal, Δt is the sampling period and N is the length of the signal. These periodograms are multiplied by a desired window and are subsequently averaged, generating a smoothed PSD. On the GUI, the user is able to select the window to use, the amount of segments in which the signal will be divided as well as the overlapping percentage between each of them. In addition, it is possible to decide between analyzing the entire signal or choosing a desired segment by entering its time interval. It was also included on the analysis section the signal's spectrogram (P_{SP}), i.e., a time-frequency representation of the squared magnitude of the Short-Time Fourier Transform (STFT) [12]. The spectrogam is defined by (2):

$$P_{SP}(t,\omega) = \left| \frac{1}{\sqrt{2\pi}} \int e^{-j\omega\tau} w(\tau - t) s(\tau) d\tau \right|^2 \tag{2}$$

where s is the signal, ω is the frequency, t is time and $w(t)$ is a window function centered at time t.

D. System Verification

The devices were placed on both right and left index fingers of the participant and, in order to test the developed system, maneuvers of a protocol from previous work [8] were used, allowing to detect movements outside those established, and thus, to evaluate the presence of tremor related to PD. The maneuvers used were:

1) Control (C): The volunteer remained seated with both hands placed over the thighs for one minute.
2) Extended Right Arm (ERA): The volunteer streched the right arm to form a 90º angle with the palm of the hand facing upwards for 30 s.
3) Right Arm Finger-Nose (RFN): The volunteer moved from REA position to touch the tip of the nose with the index finger alternately at a frequency of 1.5 Hz for 30 s.
4) Extended Left Arm (ELA): The volunteer performed with the left arm the same action as in stage two
5) Left Arm Finger-Nose (LFN): The volunteer performed with the left arm the same action as in stage three.
6) Recovering: The volunteer returned to C position for a one-minute recovery period.

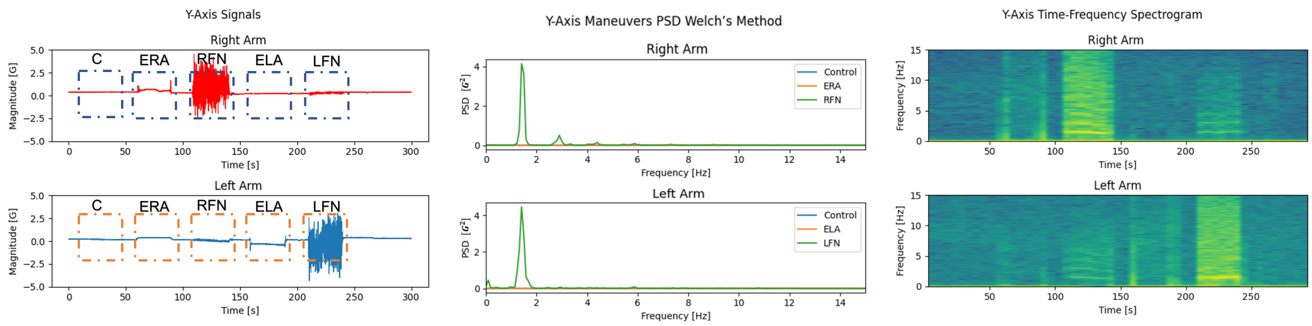
In addition, it is important to mention that between each stage of the protocol, there was a period of muscle relaxation of 20 s in C position. The experimental protocol had a total duration of five minutes and was applied to a total of five healthy volunteers (four men and a woman with ages between 22 and 58 years). All participants sign an informed consent according to Helsinki guidelines.

III. RESULTS

The purpose of this system was to be able to acquire, simultaneously and wirelessly, ACC signals from both upper limbs. Fig. 3a shows an example of the visualization results for the Y-axis signals belonging to both arms of one volunteer (male, 25 years old) who performed the protocol in order to test the proposed system. Here it is possible to observe the presence of changes in the ACC signals at different time intervals corresponding to active maneuvers on each arm. Furthermore, the PSD estimation, by Welch's method on the Y-Axis of both arms, is shown in Fig. 3b, belonging to C, ERA, RFN, ELA and LFN maneuvers, where it is possible to note a peak around 1.5 Hz, corresponding to the active frequency maneuvers RFN and LFN. Finally, Fig. 3c shows a spectrogram of both signals, which allows us to observe frequency information over time in each limb, where the zone with the highest energy corresponds to the values near to 1.5 Hz belonging to the time interval of RFN (110-140 s) on the right arm and LFN (210-240 s) on the left arm; this is consistent with the frequencies delivered by the PSD analyses on Fig. 3b.

IV. DISCUSSION

The proposed system is functional, portable and robust. In comparison with other systems [8], [9], its wireless



(a) (b) (c)

Figure 3: Visualization of Y-axis ACC signals of active maneuvers on both upper limbs (a), PSD estimation (b) and Spectrogram (c).

and wearable features allows volunteers to perform both active and passive maneuvers of an experimental protocol in an appropriate manner, providing continuous acquisition of signals without significant data loss. On the other hand, the proposed GUI delivered optimal results while being tested, making it possible to visualize the ACC signals in real time, remotely control the thimbles devices, and storing the data for further offline analysis.

In addition, it must be remarked that, in this work, five healthy volunteers performed the protocol, reason why no alterations were detected in the frequency ranges of PT and ET. Therefore, the analysis of the ACC signals provided in this work are only preliminary results of a system that aims to obtain information on the severity and frequency of PT by means of ACC data analysis, in order to characterize it, and thus, be able to aid in the early diagnosis of PD.

V. CONCLUSIONS

A system was developed and implemented on a PCB, resulting in a device that allows both wireless and simultaneous acquisition of six ACC signals through an established protocol. Also, the proposed GUI delivered optimal results while being tested, making it possible to visualize the ACC signals in real time, remotely control the thimbles devices, and storing the data for further offline analysis, in order to provide useful information to support an early diagnosis of this disease and tremor's severity. It is desired for further work to perform a complete 9-stages clinical protocol in a larger population that includes patients affected by PD and ET, and healthy volunteers matched in age with patients in order to have more evidence of the performance and robustness of the proposed system. In addition, other time-frequency representations could be used to characterize the PT. Finally, although this system focuses on obtaining ACC data in upper limbs, it is possible to extrapolate it to other parts of the body and be able to add more sensors by using the same communication and acquisition strategies.

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