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A compact monitoring system for patients affected by neurodegenerative diseases

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***Abstract* – In this paper we report about the development of a compact monitoring system for people affected by neurodegenerative diseases as Parkinson and Alzheimer. The electronic interface is based on a Linkit ONE development board, and it is equipped with an array of up to four ADXL345 accelerometers. By considering the main symptoms of Parkinson subjects, it is possible to monitor tremors/movements and accidental falls of people wearing the system and to send data to a supervisor by Wi-Fi, Bluetooth and GSM connections. Furthermore, the geo-tagging functions, developed by means of a GPS feature, already equipped in the board, allow the monitoring of the movements and the position of Alzheimer subjects, avoiding the lost for memory failures.**

I. INTRODUCTION

Recently the market of smart wearable systems for health monitoring is increased; this is due to the extensive efforts spent in both academia and industry in the research and development in the related technology and to the increasing of the demand of customers. This technological approach is bringing to commercial applications for wearable security devices for both outdoor and indoor scenarios. For instance, it is increasing the number of bracelet locators required by law enforcement agencies and health authorities [1], finding applications in Child protection, Law enforcement, Home arrest, Parole monitoring, Lone Worker Protection, Elderly Care and Alzheimer Care. The main required features in these devices are tamper detection, motion sensor, power saving and compression.

Neurodegenerative diseases, such as dementia, the Parkinsonism, the Koreas and motor neuron disease, affect the central nervous system characterized by a chronic process and the selective death of neuronal cells. The exact etiology behind this pathogenic process is not clear; however, the risk factors of both genetic and environmental origin seem to play a key role. The neuronal deterioration is due to an irreversible and inevitable loss of brain function that occurs, depending on the type of disease, with cognitive deficits, dementia, motor disturbances and behavioral disorders more or less serious. In such scenario, the employment of monitoring systems for early symptoms is mandatory, several approaches can be found in the literature[2]. Furthermore, by using wearable measuring systems it is possible to evaluate the tremor [3] and the freezing of gait (FOG) for Parkinson subjects [4], movement quality and posture [5]. In particular, it is possible to evaluate these alterations by means of measurement systems, equipped with accelerometers, able to record variations in acceleration on three axes XYZ, save the data and send them via wireless to a computer [6, 7]. Moreover, the efficacy of therapy procedures in Parkinson [8-10] and Alzheimer [11] subjects can be evaluated by means of wearable accelerometers. Often for some of these diseases, the motor alterations combine with memory impairment or dementia itself. In such cases, it would be useful to employ wearable systems able to conjugate, measurement data coming from accelerometers, with the ability to track users through GPS systems. In this way, it is possible to record both the movement anomalies or any falls, and the movements of patients even over long distances.

II. EXPERIMENTS

The system developed in this work uses a card Linkit ONE and an array of four 3-axis accelerometers ADXL345 (Analog Devices). The ADXL 345 is a small, thin, ultra low power, 3axis accelerometer with high resolution (13-bit) measurement at up to ±16 g. Digital output data is formatted as 16 bit two's complement and is accessible through either a SPI (3 or 4 wire) or I2C digital serial interface. The platform is equipped with a GPS positioning system, able to geo-reference data from the accelerometer and send them via Bluetooth, Wi-Fi and GSM protocols.

The core of the system is based on the MediaTek MT2502 (Aster) System-on-Chip (SOC); with a processor ARM7 EJ-S 260MHz and a memory of 4MB RAM and 16MB Flash. The platform is equipped with support for GSM, GPRS, Bluetooth 2.1 and 4.0, SD Cards, and MP3/AAC Audio, as well as Wi-Fi and GNSS.

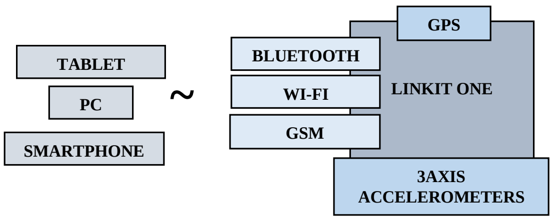


Fig. 1. Block Diagram of the monitoring system

Fig. 1 depicts a block diagram of the system: a crossplatform interface in Java allows you to make connections with the protocols available to the Linkit ONE, it is possible to select the most appropriate protocol based on the hardware device to be interfaced (Tablet PC, smartphone).
The system has the size of a cigarette packet, the design of the version with the array of four accelerometers and its realization are shown in Fig. 2 and Fig.3, respectively.

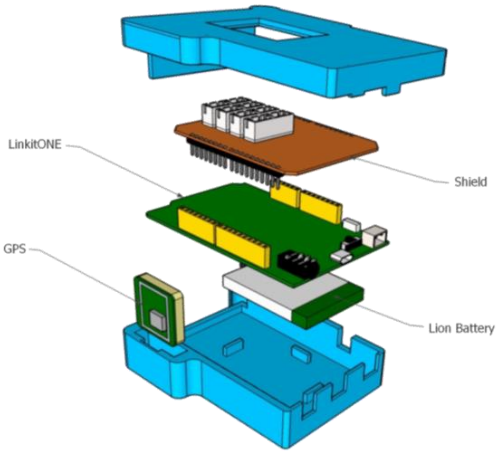


Fig. 2. 3D design of the enclosure.

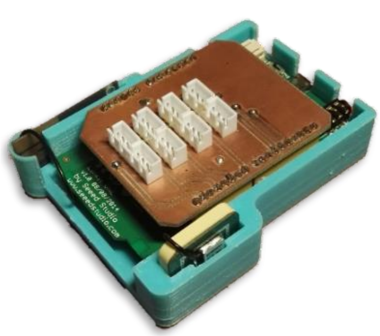


Fig. 3. 3D printed enclosure with the mounted board.

The enclosure is assembled in a 3D printed Polylactic acid (PLA) version especially designed for this application in our laboratory; it was printed with Renkforce RF1000 3D printer. The configuration with an array of four accelerometers is able to monitor movement quality, the sensors can be worn in several parts of the body, identifying the body zone with a specific device. A circuit board was designed to connect the accelerometer array to Linkit ONE board.

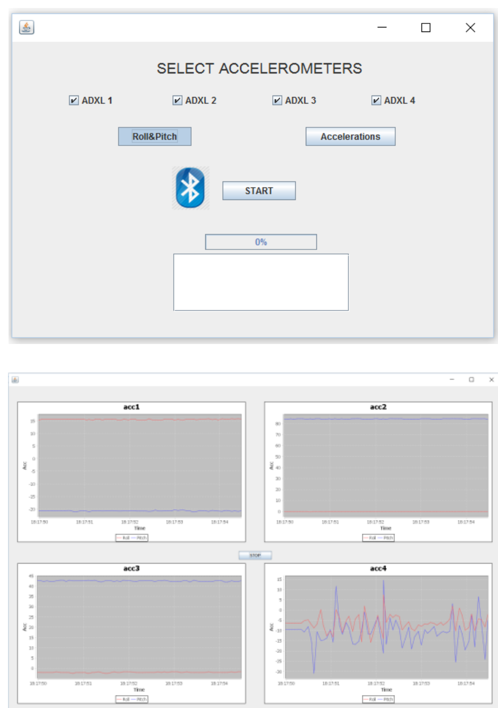


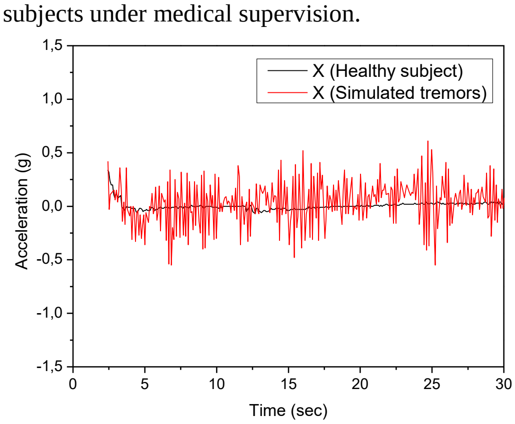
Fig. 4. The Graphical User Interface.

In Fig. 4 is reported the Graphical User Interface (GUI) for personal computer, developed in Java environment. Thanking to its multithread features, it is able to handle the data coming from the accelerometer array via Bluetooth low energy or via Wi-Fi protocols. It is possible to set the sampling time and the activation of each sensor to evaluate several parts of the body of the subject wearing the system. To monitor the subject in outdoor applications, as board provides the basic functions of a cell phone, the system can be activated by sending messages and data via GSM protocol. It is therefore equipped with long battery life (3.8 V 5100 mAh) and it is possible to send text messages to query the measuring system or to receive data concerning the patient's position on the territory and the quality of its movements, or send alarm messages or prerecorded calls to a central monitoring and control station for telemedicine.

This activation can be done without any operation from the subject wearing the system, then, external interrupts can be activated to detect accidental falls and to send alarms containing information about the position of the subject, the level of battery charge, and the sensor ID to a supervisor.

III. RESULTS

In this section are reported preliminary results about the validation of the measurement system. The frequency range is compatible with the frequency movement disorders due to neurological diseases [3]. The first procedure in order to evaluate the dominant frequency tremor was to ask healthy subject to hold with a hand the measurement system; then the action tremors (kinetic) of a Parkinson subject were simulated and recorded, this situation occurs when a voluntary contraction of a muscle follows a certain action—for example, holding a cup. The data coming from the accelerometer were recorded with the multithread Java interface. In Fig. 5 is reported the comparison between the two data set, showing how it is possible to evaluate both situations. This scenario can be considered when it is necessary to evaluate Parkinson subjects during the first phases of the disease. Further activities are in progress in our laboratories, in order to employ the array of four accelerometers, for the evaluation of the movement disorders in real Parkinson subjects under medical supervision.



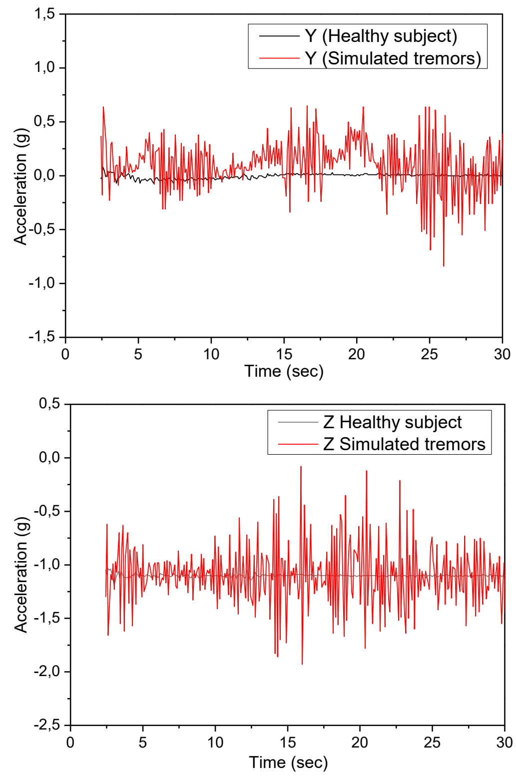


Fig. 5. Comparison between a healthy subject and a simulated one affected by tremors.

With the aim to perform a better evaluation of the measurement data, a digital low pass filter was employed. In order to choose the best solution for the specific application, both FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) filters have been implemented and compared. Transfer functions and design parameters are reported in Figs. 6 and 7 and Tabs. 1 and 2 respectively.

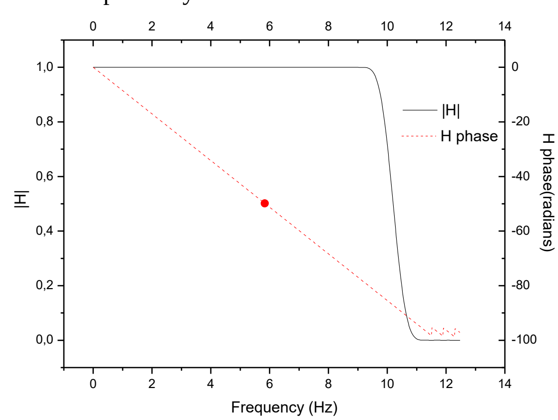


Fig. 6. Transfer function of FIR filter

Table 1. FIR filter (design parameters).

f_t	*10 Hz*
Δf	*2 Hz*
$A_s\|dB$	*60 dB*
$A_{cf}\|dB$	*3 dB*
Coefficients	*69*
Window	*Blackman*
f_s	*25 Hz*

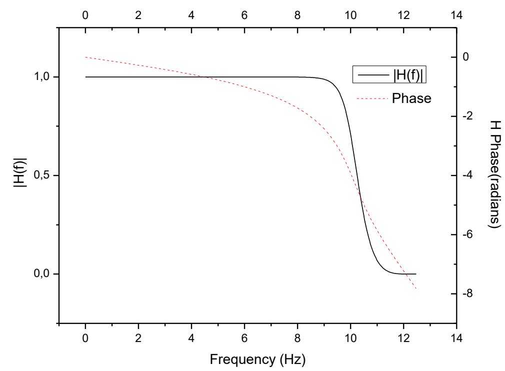


Fig. 7. Transfer function of IIR filter

Table 2. IIR filter (design parameters).

f_t	10 Hz
Δf	2Hz
$A_s\|dB$	*60 dB*
$A_{cf}\|dB$	*3 dB*
Filter	Butterworth
Order	5
f_s	*25 Hz*

FIR filters are implemented in a non-recursive way which guarantees for stability and linear phase response [12]. These features are important for biomedical applications considering that biomedical signals are primarily concerned with waveform features, e.g. the time at which different peaks occur. Nevertheless, after closely comparing IIR filters and FIR filters, we found that IIR filters perform better for this specific application. In fact, although the IIR filter phase response is non-linear, almost all of the non-linearities occurs within the stop-band (i.e. after 10Hz). Considering that spectra of our signals are concentrated at low frequencies (i.e. below 10Hz) the phase shifting introduced by IIR filters could be ignored in this specific application (as shown in Fig.8).

Moreover, IIR filters have low computational cost, this feature is important especially in the interfacing of array of sensors, where a large number of signals must be processed at the same time. However low computational resource devices (i.e. microcontrollers) are required for keeping costs down. The IIR filter achieves both of these goals while still providing high quality filtered signals.

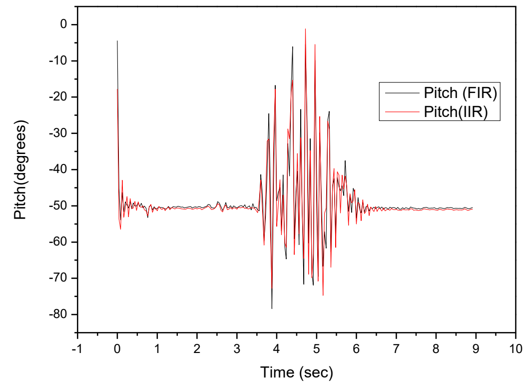


Fig. 8. Time comparison of FIR and IIR filtered Pitch.

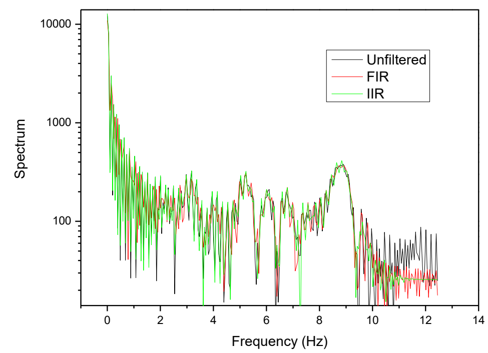


Fig. 9. Output spectrum comparison

Accordingly with literature [3], proper digital filters can be designed and integrated in the system to select specific movement contributions.

A second application scenario of the proposed system is outdoor monitoring of an Alzheimer subject wearing the box; in this context it is possible to activate the monitoring system by SMS without any further operation and to send back to the supervisor the requiring information including the geotagging data.

IV. CONCLUSIONS

A compact monitoring system for subjects affected by neurodegenerative diseases has been reported. The core of the measurement system is the Linkit ONE platform, based on the MediaTek MT2502 (Aster) System-on-Chip (SOC). It provides the basic functions of a mobile phone and it is possible to send the measuring system queries as SMS or to receive data regarding the patient's position and the quality of its movements, or send alarm messages or pre-recorded calls to a central monitoring and control station for telemedicine. The open source environment allows a high level of configurability; further activities are in progress to develop a Java interface working both on smartphones and on personal computers and to test the system with real patients under medical supervision.

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