Journal of Physics: Conference Series **450** (2013) 012055 doi:10.1088/1742-6596/450/1/012055

Wearable sensor network for health monitoring: the case of Parkinson disease

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Abstract. The aim of this paper is to show how wearable sensors can be useful in health solutions, improving the continuous monitoring and management of patients. This paper is focused on the available solution for motion analysis, providing a description of human motion features which can be measured through the use of wearable sensors. Moreover, this paper presents an example of wearable solution used for the objective assessment of Parkinson's disease symptoms. Results indicate that wearable sensors are useful for the objective evaluation of motor fluctuation and clinicians can benefit from these tools in order to adjust and personalise the treatment.

1. Introduction

The importance of bio-medical engineering and wearable solutions for healthcare is growing during the last decades thanks to the improvement and the availability of many devices and technological solutions, as well as their cost reduction. As a consequence, the interest in applying and combining those technologies to the monitoring and treatment of several kinds of diseases has increased.

This paper addresses the problem of continuous monitoring of patients using a wearable sensors network to improve the following and management of them, with a particular attention to those affected by Parkinson's disease (PD).

1.1. Parkinson disease

Parkinson's Disease (PD) is a neurodegenerative disorder of the central nervous system that affects motor skills and speech [1]. The primary biochemical abnormality in PD is a deficiency of dopamine due to degeneration of neurons in the substantia nigra pars compact [2]. The characteristic motor features of the disease include bradykinesia (i.e. slowness of movement), tremor, rigidity (i.e. resistance to externally imposed movements), flexed posture, postural instability and freezing of gait. Furthermore, PD is usually characterised by the loss of normal prosody of the speech [3].

According to the World Health Organisation (WHO]) there are more than six million people worldwide affected by PD. The syndrome typically appears around the age of 60. It affects Europeans and North Americans more often than Asians or Africans and it is more common in men than in women. PD affects about 2% of the population over the age of 65 years, figure that is expected to double by 2020. For those reasons, PD poses a significant public health burden, which is likely to increase in the coming years [4].

Technology in general and specifically wearable sensors' solutions might be an affordable alternative for PD's patients' treatment and management [5]. The development and integration of specific sensors for the remote health status monitoring, are been able to provide reliable data for the qualitative and quantitative assessment of people suffering from neurodegenerative diseases [6]. This new scenario is expecting to provide in the future a remarkable improvement in patients' management as well as a substantial cutting-off of the economic burden generated by the disease. New technologies allow monitoring the evolution of the disease through the employment of a wide range of wearable and user-friendly micro-sensors. Moreover, the last advances in data processing and data mining algorithms is bound to provide more accurate information about the diverse aspects of PD evolution [7].

1.2. Sensors for motion analysis

Over the past decades various technologies, methodologies and systems have been proposed for the monitoring and the assessment of the Parkinson's disease. A significant number of studies investigated the characteristic parameters of the different symptoms of PD. Others focused on the evaluation and quantification of the patients' motor status by the use of computerized motion tests (e.g. handwriting, inserting pegs, and games). The main goal of these studies was the objective assessment of PD parameters through the motion analysis, using ICT technologies. Sensors play an important role in this steps, considering that the technology associated to them must be able to assure reliable data without interfere with the actions performed by the patients during the motion analysis test.

Table 1 describes some features of the human motion, as well as the characteristics which can be measured through the use of wearable sensors, with a specific focus on PD motion analysis.

Table 1. Parkinson's disease – wearable sensors for human motion related measurements.

Features	Characteristics	Sensor
Gait	Speed of Locomotion Variability of the gait Rigidity of legs	Accelerometer
Posture	Trunk inclination	Gyroscope
Leg movement	Speed Motion sensor Motion sensor Motion sensor Length of Step Step Frequency Stride	Accelerometer
Hand Movement	Speed Angle Amplitude	Accelerometer + Gyroscope
Tremor	Amplitude Frequency Duration Asymmetry	Accelerometer
Fall	Fall Detection	Accelerometer
Freezing of Gait	Leg movement analysis	Accelerometer
Levodopa induced Dyskinesia	Duration Angle amplitud Intensity	Accelerometer + Gyroscope Inertial sensors
Bradykinesia	Speed Duration Frequency	Accelerometer + Gyroscope
Aphasia	Pitch	Microphone

The accuracy of measurements of the parameters above described depends on several technical features that are often in conflict with other needs such as usability, wearability, technical feasibility and the social acceptance of the devices used by the subjects. In Table 2 a description of these desirable properties along with their conflicts is presented.

Table 2. Wearable sensors desirable properties & conflicts

Properties	Conflict
Small sensor	The size of sensor is definitely an important factor, especially for portability and mobility matters. However, small sensors may not have enough room for long-lasting battery or storage capacity.
Smart sensor	Sensors possessing many characteristics are often bigger in size, expensive and consume more power
Sensor storage capacity	Due to a limit in storage capacity, sensors have to upload data frequently to the data personal server. So it is important to employ a good wireless communication technology that does not drain excessive power from the sensors.
Sensor processing capability	Because sensors do not often have large processing capability, they may not be able to process all data before the upload to the personal server. This means that large amount of raw data should be stored and eventually sent. Therefore it is important to have an efficient communication channel.
Sensor communication range	Whilst sensors are only able to communicate over short range, it is crucial to define a specific radius of action.

2. Systems for Parkinson's disease monitoring

Most of the research work carried out in the field of PD monitoring focuses on the assessment of the motor status of PD's patients, focused on the development of a wearable system able to objectively quantify the severity of the motor disturbances using motion sensors [8]. An important number of these studies are based on the study of various parameters of motor behaviors [9], while others are focused on the identification of the symptoms fluctuation along the day, combining the objective evaluation of the motor symptoms, through the data gathered from the selected sensors, usually accelerometers and gyroscope. Some research groups are also committed to use electromyogram (EMG) or voice analysis [10]. Even though many advances have been done in the last years, it must be said that there is still a lack of an all-inclusive system able to provide reliable assessment of the status of PD patients being at the same time economically affordable.

2.1. PERFORM system

PERFORM is a project partially funded by the European Commission under the Seventh Framework Program, aiming at providing an innovative and reliable tool that is able to monitor and evaluate motor neurodegenerative disease patients, such as PD patients. The PERFORM project is based on the development of an intelligent closed loop system that seamlessly integrates a wide range of wearable micro-sensors constantly monitoring motor signals of the patients. Data acquired are pre-processed by advanced knowledge processing methods, integrated by fusion algorithms to allow health professionals to remotely monitor the overall status of the patients, adjust medication schedules and personalize treatment [11–15]. Personalization of treatment occurs through PERFORM‘s capability to keep track of the timing and doses of the medication and meals that the patient is taking.

PERFORM moitoring System

The wearable device used to recording the motor signals consists of a tri-axial wearable accelerometers' network (Figure 1) used to record the accelerations of the movements at each patient limb, one accelerometer and gyroscope (on the belt) used to record body movement accelerations and angular rate, and a data logger (also located on the belt) that receives and stores all recorded signals in a SD card (Figure 2).Sensors allow the system detecting and quantifying a wide range of symptoms and measures of Parkinson's disease patient i.e. tremor, bradykinesia, dyskinesias and freezing of gait. All sensors transmit data using Zigbee protocol to a logger device, with 62.5 Hz sampling rate (16 milliseconds between samples).

Figure 1. PERFORM wearable sensors network system

Figure 2. PERFORM system set up on patients

Special attention was paid in order to ensure the monitoring system usability and an easy placement for the patient and the caregivers. The sensor size is not bigger than a small matchbox. Sensors on the arms and legs are attached on specially designed elastic Velcro bands, which allow fixation to any wrist or ankle size. The sensors are placed inside an elastic pocket on the band, which secures it firmly on the patient body avoiding motion artifact due to cloth movement.

The sensor on the trunk is placed within a zipped elastic pocket on a vest. The vest is also equipped with Velcro straps to firmly adjust the sensor on the patient chest. The selected design allows the easy wearing and attachment/detachment of sensors.

Once the data has been stored in the SD card, the patient needs to connect the logger to a PC where the patient unit, called Local Base Unit (LBU) is responsible for the identification and quantification of the patient symptoms and the recording of other useful information for the evaluation of the patient status.

PERFORM symptom detection

The LBU processes patient signals gathered from the wearable sensors and detects the targeted patient symptoms (Tremor, Levodopa Induced Dyskinesia, Akinesia). Symptoms strictly related to the activity of the patients (Freezing f Gait, Gait and Bradykinesia) are detected using the results of the activity recognizer algorithm. For each symptom, a dedicated sub module processes the relevant signals (Figure3), detects the symptom episode and quantifies it into a severity scale from 0 to 4, according to the UPDRS [16] scale for PD's patients. Other features such as duration, frequently and amplitude might also be provided for further clinician review and system evaluation.

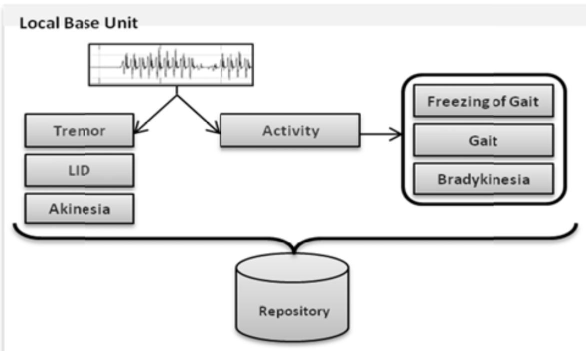

Figure 3. PERFORM LBU schema

PERFORM System Evaluation

PERFORM followed an iterative design process. Three different phases where designed involving 92 PD patients and 20 health subjects. On each phase of the design raw signals were collected using the wearable sensor network.

- **Phase I:** A preliminary version of the system was tested with 20 healthy subjects. Also this initial phase was used to test the technical performance of the platform in terms of data transmission and communication, identify bugs and redesign the system.
- **Phase II:** The second phase was carried out in the hospital under the supervision of the doctors. The goal of this phase was to validate not only the technical performance of the system but also the clinical compliance of the system. A total number of participants of 36 PD patients were involved.
- **Phase III:** It consisted in the evaluation of final PERFORM prototype. In this last phase the final version of the system was tested in everyday practice at patients' home. The total number of participants was 44 PD patients plus 12 patients with Parkinsonisms (Parkinsonism is any condition that causes a combination of the movement abnormalities seen in Parkinson's disease such as tremor, slow movement or muscle stiffness).

3. Results

PERFORM project has released promising results in patients monitoring and status assessment. The system has already been tested in hospitals in Navarra (Spain) in Ioannina (Greece) and in in Modena (Italy).

Obtained results suggest that the wearable sensor solution adopted is a valid solution able to detect PD symptoms based on motor signals, giving a high accuracy level of the overall status of the. Due to the short-term nature of the clinic trials that have been carried out it is difficult to determine the exact future impact on patient management; however it is possible to at least provide a preliminary quantification of the system performances. PERFORM has been designed to assess in an objective way the motor symptoms and the general status of the patients in order to:
determine the activity of the subject
provide a quantification of symptoms severity based on the clinical scales and present such an information to the physician through remote communication

The validation has proved that the PERFORM system is able to provide a very reasonable assessment of the daily activity of the patients using data classification techniques based on accelerometers and gyroscopes. PERFORM system is able to detect and quantify Parkinson's disease symptoms with the following results:

- LID severity classification accuracy: 93.73% [17]
- Bradykinesia severity accuracy: 86% [15]
- Tremor severity accuracy: 87 % [18]

As well as it has been developed a special module for the assessment of the gait parameters i.e. step frequency, velocity, arm swing frequency and entropy of the gait signal [14] and for the detection of the Akiniesia, used as an excellent discriminator of the ON/OFF status, reaching a good correspondence (88.2 +/- 3.7 %) between patient's diary and ON/OFF phases identified by the system.

4. Conclusion

This paper has presented how the continuous monitoring of patients can be achieved using wearable sensors network to improve the following and management of such subjects. Moreover, an example of wearable sensor network for patients affected by Parkinson's Disease has been provided. Clinical assessment is usually done through the analysis of patients' diaries and short punctual tests during the medical examination, this practice cannot give an overall and objective evaluation of the patient's status, as a result, treatment is not adjust following objective data, causing a causing that the treatment modifications are not undertaken in time.

On the other hand, wearable sensors solutions are able to provide quantitative and objective information about the motor complications. Data gathered from sensors, will be used in order to give to clinicians an overall and objective clinical status about each patient, so treatment can be adjust for any case and treatment modification can be applied according to changes in the symptoms fluctuation.

5. Acknoledgment

Authors thank the PERFORM consortium for their contribution to this work, especially the University Clinic of Navarra (Spain), Dr Alexandros T. Tzallas and Dr. Markos G. Tsipouras of the University of Ioannina (Greece), the Nuovo Ospedale Civile di Modena (Italy), the University of Bologna (Italy) and the Technical University of Madrid (UPM - Spain).

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