

Monitoring of motor and non-motor symptoms of Parkinson's disease through a mHealth platform

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Abstract— Parkinson's disease (PD) is a complex, chronic disease that many patients live with for many years. In this work we propose a mHealth approach based on a set of unobtrusive, simple-in-use, off-the-self, co-operative, mobile devices that will be used for motor and non-motor symptoms monitoring and evaluation, as well as for the detection of fluctuations along with their duration through a waking day. Ideally, a multidisciplinary and integrated care approach involving several professionals working together (neurologists, physiotherapists, psychologists and nutritionists) could provide a holistic management of the disease increasing the patient's independence and Quality of Life (QoL). To address these needs we describe also an ecosystem for the management of both motor and non-motor symptoms on PD facilitating the collaboration of health professionals and empowering the patients to self-manage their condition. This would allow not only a better monitoring of PD patients but also a better understanding of the disease progression.

I. INTRODUCTION

More than one million people live with Parkinson's disease (PD) in Europe today and this number is forecast to double by 2030 [1]. The economic impact of the disease is high and its annual European cost is estimated at €13.9 billion [2]. PD is the second most common neurodegenerative disorder and its prevalence in industrialized countries is generally estimated at 0.3% of the

entire population and about 1% in people over 60 years of age [3]. The major motor disturbances in PD are [4]: Bradykinesia (i.e. slowness in movements); Hypokinesia (decreased amplitude movements); Resting tremor (usually in the hand is often described as 'pill rolling'); Rigidity (stiffness of muscles); Postural instability (associated with gait and balance) and Dyskinesia i.e. the unintended, involuntary and uncontrollable movements including twitches, jerking, twisting or simple restlessness. Furthermore, PD patients are affected by a wide range of non-motor signs and symptoms such as loss of sense of smell (anosmia), nerve pain, urination problems, constipation, depression and anxiety, sleeping problems (insomnia) leading in excessive sleepiness during the day, cognitive impairments, visual hallucinations (perception of something that does not exist), delusions (believing things that are not true). Current clinical practice is mainly focused on the management of motor symptoms through pharmacotherapy. The monitoring and assessment of symptoms in PD is mostly based on historical information, home diaries and neurological examination during visits to the clinic that in most countries occur every 6 months. These methods clearly suffer from many drawbacks: data from these sources can be highly subjective, they rely on the patient's memory and perception of his own symptoms (as well as his capacity to identify symptoms and the medical terminology) and they depend on the physician's experience on the field [5]. In an attempt to solve these problems and to find more objective assessments, several rating scales have been designed and used. Among them, the Unified Parkinson's disease Rating Scale (UPDRS) [6] is the most widely used. This rating scale tries to quantify selected symptoms and signs in a 5-points scoring system (from 0 for no sign, to 4 for a marked severity of the sign). Unfortunately, like any other semi-objective rating scale, has several limitations such as intra and inter-observer inconsistencies and bias by subjectivity issues related to the historical information have been demonstrated.

The PERFORM [7], the REMPARK [8] and the SENSE-PARK [9] systems are intelligent closed-loop systems that seamlessly integrate a range of wearable sensors (mainly accelerometers and gyroscopes) constantly monitoring several motor signals of the patients and enabling prescribing clinicians remotely assess the status of the

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patients, adjust medication schedules and personalize treatment. The automatic detection and assessment of the motor symptoms is a topic that has been largely studied [7], [10]–[12] and it used to be the focus when telehealth is considered for PD [13]. The most interesting results of the relevant, on-going research by the authors include: an automated method for resting and action/postural tremor assessment [14]–[16], a methodology for the automated levodopa-induced dyskinesia (LID) assessment [7], [17], [18], a method detecting freezing of gait (FoG) events [7], an automated method for analysis and detection of gait parameters, i.e. gait modelling in PD [19]–[21] and a smart algorithm for the bradykinesia detection [22], [23].

PD_manager project is aimed at building a novel mHealth platform integrating motor and non-motor assessment including cognitive, speech, sleep monitoring and treatment adherence monitoring. It is also aimed at delivering different services for the patients, caregivers and professionals based on this holistic approach. Once the data is processed and symptoms are assessed a knowledge management platform will be developed to provide a Decision Support System (DSS) that suggests modifications in the medication plan. The work presented here expounds the progress during the first year of the project. After the elicitation of user needs [13], and to understand how a mHealth platform could contribute to build a better quality of life for the patients as well as a facilitate the delivery of an integrated care and the collaboration of a multidisciplinary team, the work of the first year focused on the data collection of motor and some of the non-motor (cognitive and speech) data to work on the first version of the monitoring and assessment algorithms which will be integrated in the final PD_manager platform that will be composed of:

- The clinicians’ app will provide periodic reports with major events for the patients suggesting modifications for the medication plan based on the holistic picture of the patient. They also will be able to collaborate with the other health professionals (neurologists, physiotherapists, speech and language therapists, occupational therapists, dieticians) involved.
- The patients’ app through which recommendations for modifications in medication, diet, physiotherapy and activity will be sent to the patient.
- The caregiver app will provide feedback about symptoms as well as the patient’s adherence to the management plan in order to motivate him comply with it and improve his condition.

II. MATERIAL AND METHODS

The approach that is being followed for the development of the symptoms monitoring and evaluation module is:

A. Data collection protocol

A total of 20 patients were recruited in this first phase:

- 10 hospitalized patients at IRCCS Fondazione Ospedale San Camillo (Venice, Italy)

- 5 outpatients at IRCCS Santa Lucia (Rome, Italy)
- 5 outpatients at University of Ioannina (Ioannina, Greece)

The inclusion criteria were: Idiopathic Parkinson’s Disease diagnosis (according to the UK Brain Bank criteria) and Hoehn &Yahr score between 3 and 4 (during the OFF state) while the exclusion criteria were: Co-morbidities with stroke or other brain disease, severe cognitive impairment or dementia and inability to walk without a walking aid. The recordings of each patient (sessions) were distributed in 4 recording days. During each recording day, 2 sessions were performed: 1 in OFF state and 1 in ON. The motor recording protocol and the UPDRS sub-items evaluation were performed in each session (8 in total per patient).

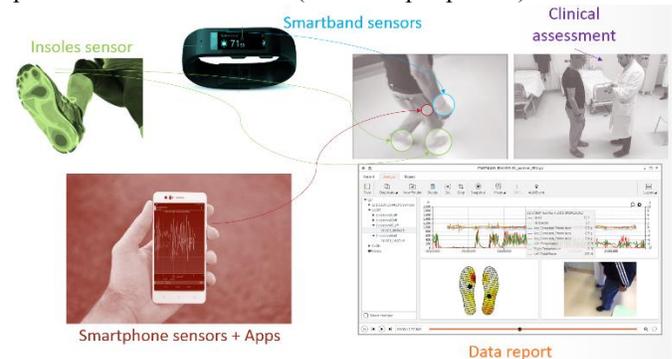


Figure 1: Experimental sensory setting.

The motor recording protocol is a well-defined series of simple motor tasks that the patient have to perform during the recording sessions and that simulate daily activities such as sitting in a chair, opening a door, drinking some water etc. Every task aims to trigger specific symptoms of the disease and to standardize a reproducible recording setting, to collect consistent data across the 3 clinical settings. At the first session clinical information was collected; the information includes age, initial diagnosis, side of onset, disease duration, current symptoms, current treatment (duration, current dosage: Levodopa Equivalent Daily Dosage, Dopamine Agonist Equivalent Daily Dosage) and comorbidities.

B. Data collection setting

During each session, 4 sensor devices were placed on the patient body (two insoles, a smartphone in the pocket and one wristband) in accordance with the literature, where mostly less than 4 sensor devices are used. The setting is depicted in the Figure 1. The insole sensor is manufactured by Moticon [24] and the measurements (up to 16 MB) are stored in the embedded insole memory. In order to collect raw data from the wristband (Microsoft Band [25]) that does not have internal storage capabilities and needs to be synced with a smartphone, an Android app (Figure 2) was developed to temporarily store the raw data in the smartphone memory and send them to the cloud for permanent storage whenever internet connection is available. The app also enables annotation according to UPDRS.

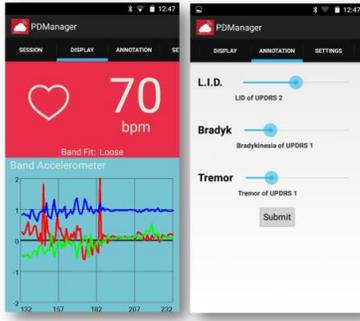


Figure 2: Wristband raw data collection app.

Regarding the non-motor symptoms another Android application was implemented to collect cognitive information and the speech signals were also collected using the smartphone microphone and asking the patients to perform free speech and sustained vowel pronunciation (i.e. “ahhh”). It also implemented a Finger Tapping Test and Alternate Finger Tapping Test.

C. Data

The collected data includes:

- Measurements for distribution of pressure, acceleration, weight-bearing, balance and motion sequences that are collected using the sensor insole manufactured by Moticon [24]. This device is a fully integrated, ultrathin and flexible sensor insole, which can measure with sampling frequencies of 5, 10, 25, 50 or 100 Hz. Sample rates range from 20 Hz to 300 Hz in the considered literature, with a median of 100 Hz. Data rates of 50 Hz also seem to be sufficient, with symptoms related to tremor and FoG being associated with signals of even lower frequencies (3 Hz to 10 Hz). With respect to the analysis of motor symptoms, the sensor insole is capable to continuously measure the centre of foot pressure (COP), the partial weight-bearing as well as the tri-axial acceleration. These parameters can serve for further analysis of staggering, disbalance, gait variance, foot loading as well as for fall detection or position monitoring.
- Continuous heart rate patterns (with optical blood flow sensor), motion (with 3-axis accelerometer and gyrometer), skin temperature, activity (metrics for steps, calories burned, duration accurately measured with the built in GPS) and periods of restful and light sleep are captured with the wristband.
- Motion data (with 3-axis accelerometer and gyrometer) collected with the smartphone BQ Aquaris E4.5 as well as the orientation information provided by the Android SDK [26]. Results of the Finger Tapping Test and Alternate Finger Tapping Test.
- Additionally, to explore the cognitive skills of the patients an Android application was designed and implemented to monitor different cognitive areas such as spatial memory assessment (involving visuo-

perceptive abilities, episodic spatial memory and switching abilities), spatial exploration and visuo-spatial working memory, vision-spatial short term memory, response inhibition (impulse control) [27].

D. Data processing – Motor Symptoms detection and evaluation

The methodology for the assessment of dyskinesia, bradykinesia, gait and posture is on-going work and it will continue our previous works in detection and evaluation [7], [14]–[23] which will be improved by incorporating the additional data from the gyrometer and the insoles data as well as by testing new classification methods such as Random Forest and incorporating new data such as the Finger Tapping tests. The final outcome will be scores according to the respective UPDRS items. The methodology for cognitive monitoring has been detailed in another work [27].

E. Fluctuations evaluation

The fusion of the methods described above and the definition of percentage change of the total score from these differently weighted symptoms that defines ON-OFF states will lead to the implementation of the PD_manager diary that automatically, passively and objectively will detect every 30' the state of the patient deciding whether the patient is in: off-state, on-state without dyskinesias, on-state without troublesome dyskinesias and on-state with troublesome dyskinesias.

F. Further validation

The PD_manager system is expected to involve 200 PD patients, during 2017, for the final study through clinical centres in Ioannina, Surrey, Venice and Rome. Patients with motor fluctuations and significant disability (Hoehn and Yahr stage 3 or greater) and with at least 3 hours OFF time during the day (based on MDS-UPDRS) will be eligible for the study. Eligible patients will be randomly assigned to receive either the PD_manager or to be in the control group (i.e. 100 patients in each group). Separate randomisation will be conducted for men and women to ensure an even gender distribution between the groups. All patients will be daily evaluated according to UPDRS and will keep their 3 days diaries [28]. The acquired data and the respective annotations will be used for the further validation of the methods described in this work for the monitoring, detection and evaluation of motor symptoms and fluctuations.

III. CONCLUSIONS

PD_manager is the result of a multidisciplinary work where different health professionals are working together to design a holistic mHealth platform for the monitoring and management of both motor and non-motor symptoms in PD as well as treatment adherence and the influence of nutrition. The final objective is to use this monitoring data to feed a DSS platform which will be able to support the decision-making process for the clinicians and provide patients and

caregivers with the appropriate and tailored feedback. PD_manager proposes a solution applicable for the monitoring and assessment of PD patients in every-day life. The implementation and validation of accurate methods providing UPDRS scores for bradykinesia, gait, posture and tremor as well as the precise assessment of dyskinesias and the cognitive monitoring, will eventually lead through data fusion to the definition of an automatic and objective diary with patient's fluctuation during the waking day. The diary will be a valuable tool for the prescribing neurologist since it is being used for making decisions for the modification of medication and supporting therapies as well as for the deciding which patients should move to device-aided therapy. Data on the clinical outcomes and from the qualitative feedback and economic evaluation will be brought together in a cost-consequences framework that will show the benefits and costs of the system to different groups (patients, carers and neurologists).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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