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Unobtrusive and longitudinal Parkinson's monitoring using smartphones

First Year Short Report

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PDPM

The aim of this project is to assess the progression of Parkinson's Disease (PD) by monitoring daily-living activities using smartphones and wearables (S&W). Our hypothesis is that there is a correlation between PD progression and a patient's social interactions and activities; this is why, we use mobility data coming from S&W's sensors (GPS, Accelerometer, Gyroscope, Heart rate, etc.) to make intelligent inferences on social activities and interactions performed by a patient, such as walking, running, dressing, eating, cleaning, travelling, among others. Finally, as these inferences are mapped to a clinical PD scale, health professionals can quantitatively measure the progression of the disease. `http://wel-data.cs.manchester.ac.uk/investigations/8`.

PDPM Reports

This report is in the series of IAM PDPM technical reports. Other reports in this series may be found in our data repository, at `http://wel-data.cs.manchester.ac.uk/investigations/8`. Reports from other Interaction Analysis and Modelling Laboratory projects are also available at `http://wel-eprints.cs.manchester.ac.uk/`.

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License

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1 Abstract

Traditionally, the progression of Parkinson's Disease (PD) is assessed through subjective clinical evaluations during short and regular visits of patients to health institutions. These evaluations are usually not an accurate representation of the current state of the disease as its symptoms vary along the day. There have been efforts supported by electronic sensors and devices that enable a preciser and more objective assessment of the disease, nevertheless, they require the patient to perform disruptive and intrusive evaluation routines. Our approach will be longitudinal, totally non-disruptive, non-intrusive, multi-domain, naturalistic and macro-scale and will enable a continuous monitoring of patients' evolution. Our solution will employ the sensors contained in smart phones and smart watches to collect personal, social and environmental low-level interaction data. We will then make intelligent inferences about patients' physical and social activities, routines and behaviour based on this data. We hope that from these inferences we will be able to detect behaviour proxies that are significantly correlated to the progression of one or more symptoms of the disease.

2 Introduction

2.1 Parkinson's Disease

Parkinson's Disease (PD) is a clinical neurodegenerative syndrome first described by James Parkinson in his 1817 essay ([Parkinson, 2002]). It is the second most common neurodegenerative disorder after Alzheimer's, has an estimated prevalence in developed countries of 0.3 % of the entire population ([de Lau and Breteler, 2006]) and has higher mortality rates than subjects unaffected by this disease [Rajput et al., 1984], [de Lau and Breteler, 2006].

2.1.1 Symptoms

According to [Jankovic, 2008], PD symptoms can be divided in motor and non-motor features. Motor symptoms includes four cardinal features: rest tremor, bradykinesia (slow movement), rigidity, and postural instability.There are also secondary motor symptoms such as, among others, voice and speech alterations, gait alterations, neuro-ophtalmological abnormalities, presence of primitive reflexes and slow execution of activities of daily living (ADL). Non-motor symptoms include cognitive impairment, behavioural and psychiatric problems, sensory symptoms, autonomic dysfunction, weight loss, and sleep disorders. For a complete list of PD symptoms please refer to Appendix A.

2.1.2 Diagnosis

PD is diagnosed based on clinical criteria because a definitive test does not exist [Jankovic, 2008]. As in an earlier stage PD shares signs and symptoms with other diseases, the diagnosis is difficult if the patient does not have a classical presentation. There are four types of Parkinsonian disorders: primary, secondary, heredodegenerative and multiple system degeneration.

2.1.3 Monitoring

Traditionally, patients with PD are assessed in regular clinical visits to health institutions. The severity of the disease is measured quantitatively using clinical scales, which are focused on the assessment of the motor symptoms of the disease and their related impairment in the patient. For example, the Hoehn and Yahr scale [Hoehn and Yahr, 1967] has been used for a gross classification of PD patients within five stages. The Unified Parkinson's Disease Rating Scale (UPDRS) [Fahn et al., 1987] has been the golden scale in research and clinical environments. It produces a total "score" that represents patient's mentation, behaviour, mood, motor performance, performance of activities of daily living and complications of therapy. After a revision made by the Movement Disorder Society and presented in [Goetz et al., 2007], a new scale called MDS-UPDRS was introduced in [Goetz et al., 2008] making corrections and unifying criterion and rating scales inconsistencies present in the UPDRS.

Some problems arise from this traditional approach to PD monitoring. For example, memory-bias from patient self-assessment, uncomfortable assessment techniques for the patient, subjectivity in clinicians measurement and time consuming routines for both the clinician and the patient. But most importantly, one of the main issues is the variability of PD symptoms throughout the day. This can be due to the natural flow of the disease, the emotional state of the patient, a period of controlled or uncontrolled symptoms induced by medication (ON/OFF state) or just because the patient is under clinical evaluation. That is why, usually, a short assessment session doesn't represent an accurate picture of the state of the disease, and what is more, this could lead to incorrect/non-helpful doses of medication and treatments for the patient because they need to be personalized according to the health condition of each person.

Some of these problems have been addressed by technology-supported efforts. For example, there have been works focused on using inertial sensors such as accelerometers, gyroscopes and magnetometers to objectively assess motor symptoms of PD. Adding machine learning algorithms and other techniques some of these devices have been integrated in systems with the purpose of monitoring PD during longer periods of time than those of traditional approaches. This is the niche in which I expect to make contributions during my PhD (section 3) by addressing some of the issues presented in the previous paragraph. A taxonomy of the relevant research projects and products and more information on previous work can be found on section 5.

3 Research aims and contribution

The aim of this research is to create a system that monitors the progression of Parkinson's Disease in a longitudinal, non-disruptive, non-intrusive, multi-domain, naturalistic and macro-scale way. We hypothesize that a patient's physical and social behaviour is correlated to the current severity of his or her disease. In order to quantify the patient's behaviour, we will generate a "Profile of Living" for each subject, which will be constructed from intelligent inferences based on interaction data. This interaction data will be the output of the sensors and interfaces present in off-the-shell smart phones as well as in those carried and used by the patient. The "Profile of Living" will serve as a personal base line from which we will look for abnormalities or divergent behaviours that we would correlate with a change in the severity of PD. A simplified example regards depression, a symptom of PD. If by taking into account a patient's calls and text messages logs, and GPS location over a period of time, we find that person is communicating with less frequency and is not visiting any more the sports centrer he used to, then we would score that change negatively and correlate it to an augment of the severity of her disease.

To make a strong and meaningful contribution to the pool of knowledge, we consider this project should comply with the following features:

Longitudinal At this point, we think that relevant behaviour changes can be assessed in windows of 7 days of duration. Nevertheless, these changes are gradual and therefore we need a higher observation time frame. This is why we look forward to run our data collection experiments for at least 6 months.

Non-disruptive To the best of our knowledge, there are no PD progression assessment works that don't request the patient to perform some type of regular physical routine or to answer periodical surveys as a part of their monitoring process. This is why we would rely on passive and pervasive sensing, eliminating patient's physical and cognitive burden related to such tasks and trading it off for complexity of the yet-to-be-develop behaviour inferences engine.

Non-intrusive In contrast to alternative projects where a patient must carry sensors and single-purpose devices attached to her body which are totally alien to daily use, we will follow the example of related efforts using the former devices plus smart watches to collect interaction data from patients.

Multi-domain Most of the related literature uses only a combination of one to three data source to assess the progression of PD (e.g accelerometer plus gyroscope, GPS plus accelerometer, only an accelerometer etc.). We think that by using a wider range of data sources (weather near patient's location, call logs, Bluetooth and WIFI access point scans, cellular towers nearby, among others) we can provide a more robust input to our behaviour inferences engine, and thus to be able to identify more complex physical and social behaviours.

Naturalistic A majority of previous experiments were carried under laboratory-controlled conditions. There is evidence that most of these applications have

a lower performance later when tested in the wild. Due to the kind and granularity of changes we want to measure, collecting data in a naturalistic environment (in the wild) seems the best option because we would get a more accurate abstraction of the real behaviour of a patient.

Macro-scale To the best of our knowledge, all efforts towards the assessment of the progression of PD focus on measuring fine motor data related to motor symptoms of the disease. In this research our aim is to find proxies from physical and social behaviour not only to motor symptoms but also to non-motor symptoms such as depression, apathy or sleep and sensory disorders.

4 Importance and potential impact

If a correlation is found between patients' physical and social behaviour and the progression of PD, an accurate assessment of the disease including any variation during the day would be possible. This in turn will enable the possibility to have PD medications and treatments tailored to the health status and needs of each patient, will save money and time to the involved health services and professionals and free the patient of the current problems related to traditional monitoring.

5 Previous work

In this section we review and propose a taxonomy for previous research work focused on technology-supported monitoring of Parkinson's Disease. Firstly, we divide according to the scale in which we look for changes in the progression of the disease (micro and macro scale). The micro-scale approaches look for fine and specific changes in the symptoms of the disease, whereas the macro-scale looks for global or systematic changes.

We divide the micro-scale approach according to the symptom or symptoms measured to look for changes:

- Single motor symptoms. For example: tremor, bradykinesia, gait, voice.
- Combination of motor symptoms. For example: [Cereda et al., 2010],[Chen et al., 2011],[Garcia Ruiz and Sanchez Bernardos, 2008],[Goetz et al., 2009],[Keränen et al., 2013], [Lorincz et al., 2009], [Maetzler et al., 2013], [Pan et al., 2013],[Pansera et al., 2009], [Patel et al., 2007], [Patel et al., 2009], [Patel et al., 2010], [Sanders et al., 2013], [Tzallas et al., 2014], among others.

We divide the macro-scale approach according to the complexity of the abstraction level in which we will make inferences to look for changes:

- Activity This category includes the recognition and discovery of human daily activities such as walking, running, standing, climbing stairs, sitting, jogging

etc. The developments included in this section can be classified by the sensor used to collect the data in which the inferences are based (among others accelerometer, GPS, microphone, a combination).

- Routine We define a human routine as a collection of activities executed during a defined span of time.
- Behaviour We define human behaviour as a collection of activities executed during a defined span of time.

The works on the micro-scale are either invasive or carried out in laboratory settings using single-purpose hardware. This research will be focused on the niche under macro-scale technology-supported PD monitoring based on behaviour inferences. Work is in progress to make a deeper analysis of the research within this topic in order to make a comparison against our approach.

6 Proposed methodology

We propose the following methodology to assess PD progression based on patient's physical and social behaviour: Data collection (using smart phones), Feature extraction, reduction and ranking, Routine/Activity recognition, Behaviour inference (creation of the "Profile of Living"), correlation analysis of behaviour and PD scores, and Evaluation. More work needs to be done to clarify and detail these sections.

7 Project progress to date

The literature review is approximately 75% completed along with the project's aims. We need to read deeply the topics related to behaviour based progression assessment of PD and other diseases. We are also about to begin our first pilot study to collect interaction data (see Appendix B) from a PD patient using an smart phone, this data will be used in a feasibility study of the analysis and recognition of patient's behaviour.

8 Thesis outline and project plan

The thesis outline is in Appendix C and the project plan in Appendix D

9 Concluding remarks

It seams the assessment of PD progression based on intelligent behaviour inferences of interaction data coming from smart phones and smart watches is feasible. An

exploratory analysis should be conducted to identify key proxies from patient's routines to the state of the disease.

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Appendices

A List of Parkinson's Disease symptoms according to [Jankovic, 2008]

- Motor symptoms
  - Cardinal
    - Rest tremor [+]
    - Bradykinesia
      - Slow execution of activities of daily living (ADL) [+]
      - Slow movement and reaction times
      - Lost of spontaneous movement
      - Decreased arm swing [+]
    - Rigidity [+]
    - Postural instability [+]
  - Other
    - Freezing (gait, arm, eyelid)
    - Shuffling gait [+]
    - Festination difficulty arising from chair [+]
    - Turning in bed [+]
    - Micrographia [+]
    - Dystonia (twisting and repetitive movements or abnormal postures caused by muscle contractions) [+]
    - Striatal deformity [+]
    - Scoliosis (deviation of the spine) [+]
    - Camptocormia (forward flexion of the spine) [+]
    - Flexed posture
    - Glabellar reflex [+]
    - Mirror Movements
    - Bulbar dysfunction
      - Dysarthria (difficulty in articulating words, derived from bradykinesia) [+]

        - Hypophonia (soft speech)
        - Dysphagia (difficulty in swallowing) [+]
        - Sialorrhea (excessive salivation, derived from bradykinesia) [+]
    - Hypomimia (reduced degree of facial expression, derived from bradykinesia) [+]
    - Neuro-ophtalmological abnormalities
        - Decreased blink rate from bradykinesia
        - Ocular surface irritation
        - Altered tear film
        - Visual hallucinations
        - Blepharospasm (abnormal contraction of the eyelid) [+]
        - Decreased convergence
        - Apraxia of eyelid opening
        - Limitation of upward gaze
    - Respiratory disturbances
        - Restrictive
        - Obstructive

- Non-motor symptoms
  - Autonomic dysfunction [+]
  - Orthostatic hypotension (head rush) [+]
  - Sweating dysfunction [+]
  - Sphincter dysfunction [+]
  - Erectile dysfunction [+]
  - Seborrhoea [+]
  - Weight loss
  - Cognitive and neurobehavioural abnormalities (Hedonistic homeostatic dysregulation)
    - Depression [+]
    - Apathy [+]
    - Anxiety
    - Fatigue [+]

    - Anhedonia (inability to experience pleasure) [+]
    - Hallucinations
    - Bradyphrenia (slowness of thought) [+]
    - Tip-of-the-tong phenomenon [+]
    - Obsessive-compulsive and impulsive behaviour
        - Craving
        - Binge eating
        - Compulsive foraging
        - Hypersexuality
        - Pathological gambling
        - Compulsive shopping
        - Punding (execution of repetitive and mechanical tasks)
- Sleep disturbances [+]
    - Excessive sleepiness
    - REM disorder
    - Sleep fragmentation
    - Vivid dreams
    - Restless leg syndrome (urge to move one's body to stop uncomfortable or odd sensations)
- Sensory abnormalities
    - Olfactory dysfunction
    - Anosmia (inability to perceive odor) [+]
    - Ageusia (lost of taste) [+]
    - Pain [+]
    - Paresthesia (sensation of tingling, tickling, pricking, or burning of a person's skin) [+]
    - Akathisia (compelling need to be in constant motion)
    - Oral pain
    - Genital pain

[+] Represent the main symptoms of PD

B Collectable data from a smart phone

Device

- Android Info
- Accounts
- Process Statistics
- Activity Services
- Battery Info
- Hardware Info
- Mobile Network Info

Device Interaction

- Audio Media
- Browser Bookmarks
- Browser Searches
- Images
- Applications
- Running Applications
- Videos
- Screen On/Off

Environment

- Audio Features
- Light Sensor
- Magnetic Field Sensor
- Pressure Sensor
- Proximity Sensor
- Temperature Sensor

Motion

- Accelerometer Features
- Accelerometer Sensor
- Activity
- Gravity Sensor

- Gyroscope Sensor
- Linear Acceleration Sensor
- Orientation Sensor
- Rotation Vector Sensor

Positioning

- Location
- Simple Location
- Bluetooth
- Cell Towers
- Wifi Devices

Social

- Call Logs
- Contacts
- SMS Logs

Other

- Battery information (level, voltage, temperature, health, charging status):
- Screen status events (on and off)
- Application usage times
- Network activity per application
- WiFi interface status changes (on, off, scanning, connecting, disconnecting)
- Cellular interface status changes including cell location and signal strength
- Voice call status changes
- Start, end, pause and resume times of activities and services
- Aggregate CPU usage information
- Aggerage memory usage information
- Network traffic statistics per interface
- Activities of Daily Living: Still, Walk, Run, Bike, Drive
- Speech or not speech filter.

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D Project plan

Figure 1: Project Plan