MoveApp: A movement analysis application for the Mobile Health Platform

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ABSTRACT

The MoveApp project aims to develop new tools to support self-management of chronic conditions which are characterized by motor symptoms and loss of motor coordination. The initial application targets Parkinson's Disease patients. The project will be undertaken in two phases, one related to the development of a self-monitoring and visualization tool for patients; and another related to the development of models to support the decision making process for patients and doctors.

1 INTRODUCTION

1.1 The Mobile Health Platform

With the global penetration of smart phones and communication networks, millions of people now use mobile devices as a daily tool for communication, data transfer and much more. As a consequence, possibilities have opened up for new technological advancements to emerge. These technological advancements involve the creation of external hardware solutions that reap the benefits of smart-phones' capabilities in order to become more cost effective and mobile. Devices which enable remote monitoring of patients have been identified as one of the areas most uniquely suited to grow in tandem with this technology. On an international setting, this specific field of technology is often referred to as mHealth and is predicted to grow substantially in the upcoming years. A recent review article by Patel *et al.* [1] highlights the importance of mHealth systems for coping with the future demands for health care. They envision such systems as depicted in Figure 1.

One direct consequence of the availability of mHealth is the creation of large amounts of health-related data. One of the keys to the success of this technology is the management and analysis of the generated data. The knowledge derived from the aggregation of data from different sources or devices greatly surpasses the knowledge generated by each source individually. As an example, imagine a device which measures how active a person is during the day. This data can be combined with a food diary in order to provide guidance for weight loss. This data can even be combined with the person's calendar and work routine in order to suggest the best time for the person to exercise. This system can be further improved over time by noting what actions were more successful in sustaining a positive change in behavior.

The possibilities for mHealth solutions are numerous and cannot all be defined beforehand. Therefore, it is important to store, manage and process this data in a way which allows the incremental implementation of new data mining and analysis techniques as well as new applications. This is the goal of Daralabs' Mobile Health Platform (MHP), which will support different front-end solutions, e.g. user interfaces and new devices, as well as various back-end solutions, e.g. data analysis and data management methods.

This project aims to support the development of the MHP by introducing an application that covers the entire development chain from hardware, to front-end solution, to back-end solution. This project

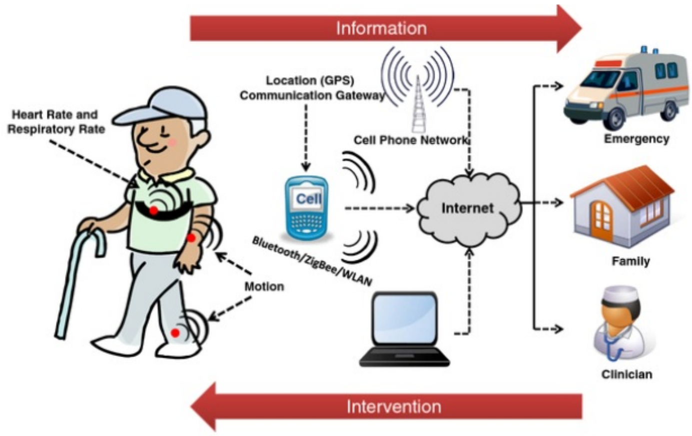

Figure 1: Illustration of a remote health monitoring systems based on wearable sensors by Patel *et al.* [1]. "Health related information is gathered via body-worn sensors and transmitted to the caregiver via an information gateway such as a mobile phone. Caregivers can use this information to implement interventions as needed".

will not only generate a new product for the company's portfolio but it will also provide insight into the features and requirements that will enable the MHP to be easily extended to other applications.

1.2 Self-management of chronic conditions

Given the projections for demographic change and the increased demand for health care resources in the future, there is a need to transition our health care system from one where patients passively receive instructions from the doctor, to one where patients are active in managing their own treatment in a partnership with doctors [2]. This new health care paradigm is often referred to as person-centered care or patient-centric care. In order to speed up and facilitate this process we must empower patients with technologies to support self-assessment and self-management.

Self-management is what persons suffering from chronic diseases do to manage their own illness on a daily basis [3]. It is the ability of the patient to deal with symptoms, treatment, and lifestyle changes. One important part of the process is to actively monitor symptoms and manage their impact on quality of life. Unfortunately, for many of these patients there is a lack of continuous and objective assessment of their symptoms and how they change over time. An assessment of the severity of a patient's condition is usually done at the clinic, very few times a year. In between these session, however, the patient can only rely on his or hers subjective feeling of how their symptoms interfere with their normal daily activities.

One problem which arises is that small, progressive changes in symptom severity are usually not felt by the patient. Another problem is that a person's assessment of their own symptoms is very subjective and can be influenced by mood or other psycho-social factors. Not being able to perceive or quantify how symptoms change can also impact patients' motivation to comply with treatment. In some cases, it may even complicate or delay adjusting the patient's medication dosage.

The importance of objectively quantifying symptoms is well exemplified by the case of diabetes. The development of cheap and easy to use glucose meters that can be used by patients at home has completely transformed the treatment and management of the disease [4]. Unfortunately, similar blood tests are not yet available for a number of chronic conditions. Many such conditions, however, are characterized by motor symptoms and loss of motor skills, which can be monitored with wearable inertial sensors [5] and other coordination tests [6, 7].

Current mobile monitoring technologies combined with decision support systems can considerably facilitate self-management for patients by: 1) providing objective assessment of symptoms and other health-related information; 2) modeling how symptoms affect and are affected by daily activities and other health factors; and 3) supporting decision by predicting the impact of certain actions or treatment.

1.3 Project goals

This project will develop tools for self-management of Parkinson's Disease. This development will be done in two phases:

Phase 1: To create, together with users, a system that monitors symptoms and other health-related information, stores and displays this information in a user-friendly manner. We will develop a wearable accelerometer sensor that continuously monitors motor symptoms, as well as smartphone application for collecting relevant health-related information on a daily basis. Users will be able to use the system for themselves, or share their information with family, doctors, and researchers if they choose.

Phase 2: To model the interactions of symptoms, medication, treatment, and psycho-social factors using the data that patients choose to share for research purposes. These models can be used to support patients and doctors in making decisions by predicting the impact of certain actions or treatment. Models can be created for individuals or for groups, by drawing information from several users.

2 RELATED WORK

Biofeedback can be defined as the technique of providing addition information to the user, above and beyond the information that is naturally available to them, by means of external sensor measurements. A recent review by Giggins *et al.* [8] categorized biofeedback systems into either biomechanical or physiological. Biomechanical biofeedback involves measurements of movement, postural control and forces produced by the body. Biomechanical measurements are most commonly achieved with the use of inertial sensor such as accelerometers and gyroscopes, *e.g.* [9]; pressure sensors such as force plates and pressure sensitive shoe insoles, *e.g.* [10, 11]; and vision systems such as 3D motion capture, cameras, and the Kinect, *e.g.* [12].

Inertial sensors such as accelerometers and gyroscopes are the preferred choice of sensors for mobile movement analysis application. They are small, inexpensive and accessible. Many off-the-shelf inertial sensor nodes are available such as the Shimmer [13], the ActivGraph [14], the FitBit [15], the Philips Actiwatch [16], the Nike + Fuelband [17], the Up by Jawbone [18], among others.

Inertial sensors can be used to monitor general activity levels, such as energy expenditure [19]; or specific movements and kinematics such as joint angles and posture [20]. The latter group of methods can be further divided into two classes: one concerning the recreation of movements in 3D space, and the other concerning the extraction of certain features from the sensor data. These different classes of methods for movement analysis are illustrated in Figure 2.

Examples of methods which reconstruct movement kinematics in 3D space using inertial sensors are [21, 22, 23, 24, 25]. Examples of methods which extract movement features from inertial sensor data are [26, 27, 28] . It is worth noting that certain features can also be used as outcome measures such as gait symmetry, *e.g.*[29, 30], and gait variability, *e.g.*[31].

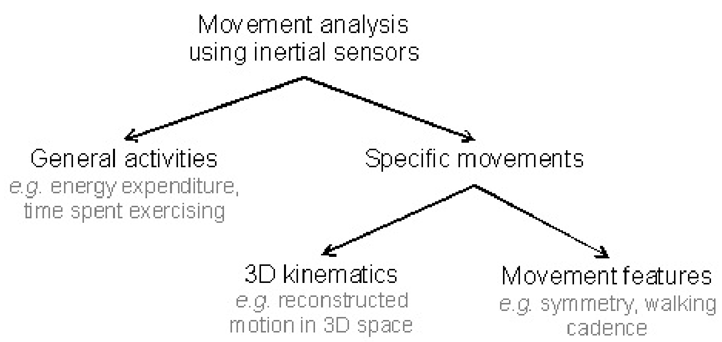

Figure 2: Different classes of methods for movement analysis using inertial sensors.

Many previous research has investigated movement analysis as a means to diagnose and assess the severity and progression of Parkinson's Disease (PD). According to the Parkinson's Disease Foundation (www.pdf.org), the four primary motor symptoms of PD are: resting tremor; slowness of movement (Bradykinesia); rigidity; and postural instability. Some patients also experience dyskinesia, which is the term used to describe unintended, involuntary and uncontrollable movements. Inertial sensors have been used to monitor many of these symptoms.

Gait monitoring in PD has been given considerable attention [32, 33, 34]. Gait instability often leads to falls, which at a certain age, can have grave consequences. One commonly studied aspect of PD gait is freezing of gait [35], when a patient is unable to initiate or continue walking. Tremor is characterized by repetitive involuntary movements withing the frequency range of 4-6 Hz, and can be easily detected using accelerometers. Bradykinesia and dyskinesia are more difficult to detect given their sporadic and non-repetitive nature but have also been studied [36, 37].

Researchers have also invested considerable efforts in diagnostic tests, where a subject performs a number of predetermined tests and activities. They way subjects perform such tests and activities is then used to determine if they are healthy [38, 39]. It is worth noting that sensor-based methods can potentially diagnose PD patients before their symptoms are sufficiently sever to be perceived by clinicians.

3 PROJECT PLAN

3.1 Development overview

In order to support the development of the MHP, it is important to consider incremental development stages. It is also important to consider, at each stage, the scientific relevance and the commercial potential of the work undertaken. One way to visualize the development process is to consider three stages according to the technology required. The first one we will refer to as *Accessible* and it relates to technology that is currently available. The second we will call *Experimental* and it relates to incremental technological development, achievable in a relatively short term horizon. The third and final stage we will refer to as *Challenging*, as it relates to a larger leap in technological development, though not unattainable. These three stages are depicted in Figure 3. Each stage must also consider the entire development chain from hardware, to front-end solution, to back-end solution.

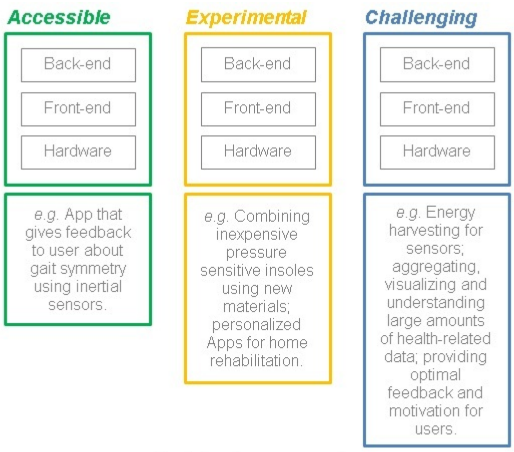

Figure 3: Development overview in three stages: accessible, experimental, and challenging. Each stage is exemplified with possible development paths.

Our application scenario involves the use of small inertial sensor units to assess and monitor motor symptoms in Parkinson's patients. The data from the wearable sensors will be combined with additional health-related information such as medication intake, daily activity and emotional state. In the short-term - *Accessible stage* - users will be able to visualize this data and its trends. In the long-term - *Experimental stage* - data collected from many users will be used to develop models of how symptoms affect and are affected by other factors. These models will be able to support the decision making process of users and doctors by predicting the outcome of different treatments.

As mentioned previously, the project will be undertaken in two phases: 1) development of a self-monitoring and visualization tool for patients; and 2) development of models to support the decision making process for patients and doctors. Each phase can be further divided into incremental and circular steps: a) literature review and business case analysis; b) proof of concept; and c) large-scare test. Steps (b) and (c) are constantly updated and improved based on user feedback.

A literature review of the technology involved will allow us to assess the scientific relevance of the work and situate it with respect to state of the art research. A business case analysis investigating the market value of the application scenario will help ensure its commercial relevance.

The proof of concept is a small scale, and possibly simplified implementation of the application scenario. Ideally, this step should result in a prototype or demonstration that can be used to illustrate the application scenario and facilitate a dialog between developers and prospective users. One important goal for this step is to bring to light issues that must be addressed in order to scale up the system.

Following the initial proof of concept, the system must be put to test with a larger-scale experiment, which is important for determining the stability and scalability of the system. Large-scale tests demonstrate the viability of using the system for acquiring reliable data and for supporting clinical trials. Randomized control trials or other clinical experiments are a good way to ensure the scientific relevance of the work and to show the value and relevance of the system for potential customers.

Activities involved in each of the development steps are outlined below.

3.2 Phase 1: development of a self-monitoring and visualization tool for patients

LITERATURE REVIEW AND BUSINESS CASE ANALYSIS: The first literature review will look into current methods for accelerometer-based assessment of motor symptoms in Parkinson's disease. The initial business case analysis will try to identify who currently requires this technology, potential benefits for patients and clinicians, and the relative value of this technology.

PROOF OF CONCEPT: A proof of concept prototype will be developed together with the members of the Parkinson Association in Falkenberg (PAF). User requirements will be identified during one or two workshops where users can express their ideas and concerns. Initially, the system will acquire information using only a smart-phone. The introduction of a wearable sensor will follow shortly. The prototype system will be tested by the members of PAF, their feedback will be used on improve the system until a stable version is achieved.

LARGE-SCALE TEST: At this stage, we hope to enlist a large number of Parkinson patients in Halland to use the system. The usefulness, adoption and reliability of the system will be evaluated. Large-scale deployment will enable the collection of data related to the daily experiences of Parkinson patients, which we will use to model the relationship between symptoms and other factors.

3.3 Phase 2: development of models to support the decision making process for patients and doctors

LITERATURE REVIEW AND BUSINESS CASE ANALYSIS: The second literature review will look into different techniques for modeling the data acquired from users. Some of the challenges to be addressed at this stage relate to the generalization or personalization of models, the inclusion of different modalities of data in the models, and the relationship between objective and subjective measures. The implementation of data analysis and modeling on the mobile health platform will also be analyzed from a business perspective.

PROOF OF CONCEPT: As we slowly collect data, initial models can be developed for individual users. The first step is to understand fluctuations in motor symptoms and how they are affected by medication and other factors. It is also interesting to explore the relationship between objective measures of motor skills and patients' subjective perception of the severity of their symptoms.

LARGE-SCALE TEST: As more and more data becomes available, more complex models may be explored. One interesting study is the evaluation of the validity and reliability of models in the absence of traditional clinical reference data.

3.4 Time plan

The following is an estimate of the time-plan for the activities outlined in the previous section.

2014	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Phase 1 - literature review									x	x	x	

2015	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Phase 1 - proof of concept	x	x	x	x								
Phase 1 - large-scale test				x	x	x	x	x	x	x	x	x
Phase 2 - literature review				x	x	x						
Phase 2 - proof of concept									x	x	x	x

2016	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Phase 2 - large-scale test	x	x	x	x	x	x						
additional development							x	x	x	x	x	x

4 EXPECTED OUTCOMES

4.1 Research and publications

The long-term research goals for this project are:

- To provide a platform for mobile and long term acquisition of different modalities of health-related data;
- To create methods for modeling individual needs and goals in order to provide optimal support for achieving said goals;
- To discover interesting patterns and relations in heterogeneous health-related data;
- To investigate the relation between subjective assessment and objective measurement, and factors related to compliance, motivation and patient-empowerment;

In the short-term, our publication plan includes, but is not limited to, the following:

- An article describing the Phase 1 proof of concept;
- An article describing the motor assessment algorithm used for the wearable sensor;
- An article describing the large-scale test and an evaluation of the system;
- An article presenting the data from the large-scale test and introducing initial models;

4.2 Product development

In the long run, we would like to develop a MHP capable of receiving data from different sensors and devices; managing and processing this data; and providing appropriate feedback and visualization for users, all the while observing privacy and security issues. In the short-term, we will develop an app for assisting self-management of Parkinson's Disease using smart-phones and wearable inertial sensors.

4.3 Collaborations

During this project we hope to establish a long lasting collaboration with the Halland Parkinson Association as well as neurology doctors at the hospital in Halmstad. This project may also be a bridge to Chris Nugent's research lab, where they are currently investigating feedback modalities for self-monitoring and gait analysis. The MHP could be an enabling tool for a possible Horizon2020 project related to self-management and collaboration with the Physiotherapy research group at Lund University. Within Halmstad University, we may collaborate with researchers from the fields of interaction design; physiology and biomechanics; digital tools for health care; and person-centered care.

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