MoveApp: A movement analysis application for the Mobile Health Platform

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ABSTRACT

This document pertains to the agreement between Daralabs AB and the Center for Applied Intelligent Systems Research (CAISR). It contains a brief project description and project plan for the period 2014-2015. First, it explains the motivation and background for the project; then it briefly introduces related academic work; it suggests a plan of action for the period in question; and concludes with some expected outcomes, both in terms of research and product development.

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.

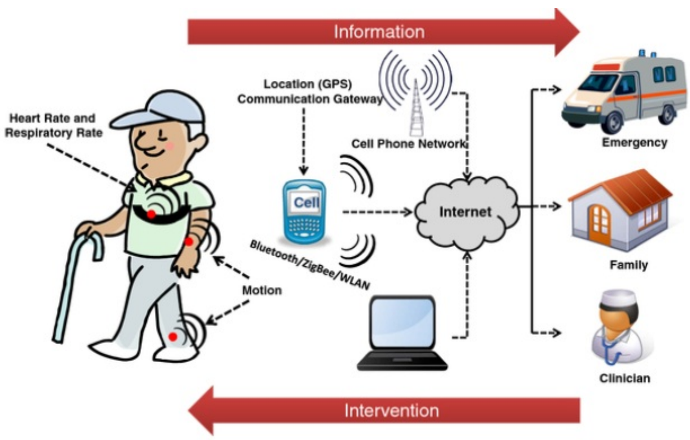

Figure 1: Illustration of a remote health monitoring systems based on wearable sensors by Patel *et al.* [1]. "Health related information is gathered via body-worn sensors and transmitted to the caregiver via an information gateway such as a mobile phone. Caregivers can use this information to implement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

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 inumerous 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 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 Movement analysis and remote physical rehabilitation

The way we move is highly indicative of our health status, reflecting physical, emotional and neurological factors. It is well understood that certain neuro-degenerative conditions, such as Parkinson's disease or Multiple Sclerosis, are characterized by motor symptoms that become more pronounced and debilitating as the disease progresses. We also know that emotional factors, such as depression, have a negative impact on a person's physical activity behavior. Reciprocally, physical activity can improve and prevent depression [2]. We also know that trauma and injury can affect the way we move, mainly due to pain. A twisted ankle or excessive muscle pain often make people limp or move awkwardly for a few days. These are only a few examples of how our health status may affect our movements. Measuring and assessing our movements - often referred to as movement analysis - can therefore provide valuable information about our health and how it improves or deteriorates.

Physical rehabilitation is perhaps the medical field which most closely examines this link between movement and well-being, as it tries to restore an individual to a fully active life through physical activity and exercise. In this context, movement analysis can help gage the accuracy with which the patient performs the assigned exercises; the effectiveness of the treatment; and the rate of improvement of the patient. In addition, it can provide a means for the patient to exercise at home, in between supervised sessions, and still receive an objective feedback about his or her performance. Such home rehabilitation systems are often conceived as serious games, which have been shown to increase compliance and motivation, consequently improving rehabilitation outcomes [3].

This project will target home rehabilitation applications, where the patient performs exercises without the supervision of a therapist. The goal is to make use of movement analysis techniques in order to provide relevant feedback to the patient so as to positively affect recovery and health outcomes.

2 RELATED WORK

2.1 Remote rehabilitation and biofeedback

In remote rehabilitation scenarios, the role of the physiotherapist as an observer and instructor must be substituted by an artificial system. This system should be able to provide not only instructions as to what exercises should be performed, but also feedback about how accurately or how well the person is following the exercises. This is commonly referred to as biofeedback, and often achieved with the help of wearable sensors.

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.* [4] categorized biofeedback systems into either biomechanical or physiological, see Figure 2. Physiological biofeedback refers to: neuromuscular biofeedback such as electromyography, *e.g.* [5]; cardiovascular biofeedback such as heart rate and heart rate variability, *e.g.* [6, 7]; and respiratory biofeedback such as breathing rate and lung dilation, *e.g.* [8].

Biomechanical biofeedback, on the other hand, 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].

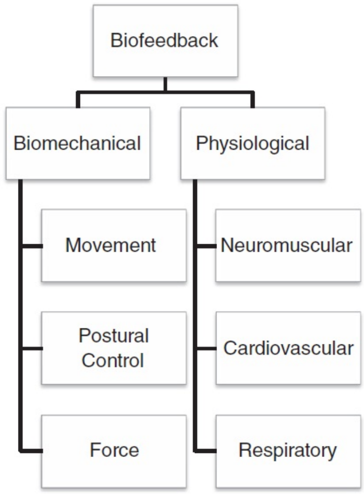

Figure 2: Categories of biofeedback modalities used in physical rehabilitation by Giggins *et al.* [4].

Biomechanical biofeedback in rehabilitation has been successfully used for many different application and user groups, such as balance training and fall prevention in elders, *e.g.* [13, 14, 15]; physical rehabilitation in stroke survivors, *e.g.* [16, 17]; posture and balance training in Parkinson's disease patients, *e.g.* [18]; physical rehabilitation in osteoarthritis patients, *e.g.* [19]; and injury prevention in sports, *e.g.* [20].

Although many research groups have used wearable feedback systems for many specific applications, complete and versatile systems are few. Perhaps the most prominent example is LiveNet, developed by the MIT Wearable Computing Group [21]. The LiveNet system consists of:

- A mobile wearable platform composed of a Linux-based personal data assistant (PDA) called SharpZaurus, a Swiss-Army-Knife 2 (SAK2) data acquisition board that can interface with a number of physiologic sensors, inertial sensors, and other contextual sensors such as IR tags and readers.
- A middleware for distributed, client/server, inter-process communication called Enchantment Whiteboard, capable of processing, receiving updates and decoupling information from specific processes. An additional software layer, called the Enchantment Signal system, facilitates the efficient distribution and processing of higher bandwidth signals.
- An open-source real-time machine learning inference infrastructure called MITThril Real-Time Context Engine, which enables the implementation of lightweight machine learning algorithms for context classification.

This system is being used in several applications, from monitoring of hypothermia and cold exposure in Army Rangers, to Parkinson's Disease monitoring, to depression therapy trending.

2.2 Movement analysis using inertial sensors

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 [22], the ActivGraph [23], the FitBit [24], the Philips Actiwatch [25], the Nike + Fuelband [26], the Up by Jawbone [27], among others.

Inertial sensors can be used to monitor general activity levels, such as energy expenditure [28]; or specific movements and kinematics such as joint angles and posture [29]. 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 3.

Examples of methods which reconstruct movement kinematics in 3D space using inertial sensors are [30, 20, 31, 32, 33]. Examples of methods which extract movement features from inertial sensor data are [34, 13, 15] . It is worth noting that certain features can also be used as outcome measures such as gait symmetry, *e.g.*[35, 36], and gait variability, *e.g.*[37].

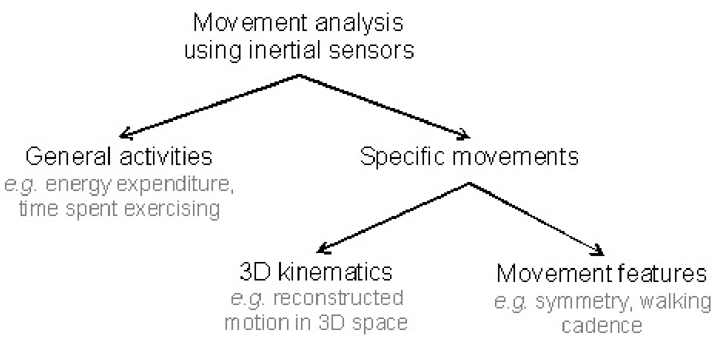

Figure 3: Different classes of methods for movement analysis using inertial sensors.

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 4. Each stage must also consider the entire development chain from hardware, to front-end solution, to back-end solution.

The development process will consist of sequential and incremental steps, namely: Literature review and business case analysis; proof of concept; large-scale test; incremental development; and break-through development. The development process is depicted in Figure5 and each step is further explained below.

SCENARIOS: The first step is always to envision a scenario involving a particular technology and possible applications. We may think of short-term scenarios and long-term scenarios. Short-term scenarios will set the goals for *Accessible* and *Experimental* stages. Long-term scenarios will set the goals for *Challenging* stages.

Our initial short-term scenario involves the use of small inertial sensor units to provide feedback on gait parameters for patients undergoing physiotherapy. Our long-term scenario also relates to feedback for physiotherapy but includes additional sensors such as novel pressure sensitive insoles, energy harvesting for the sensors, and optimized feedback for a number of different exercises and activities.

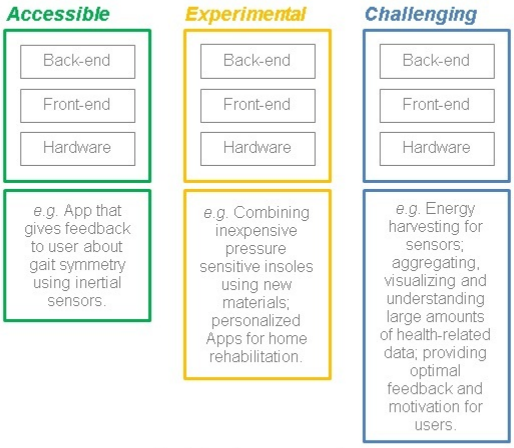

Figure 4: Development overview in three stages: accessible, experimental, and challenging. Each stage is exemplified with possible development paths.

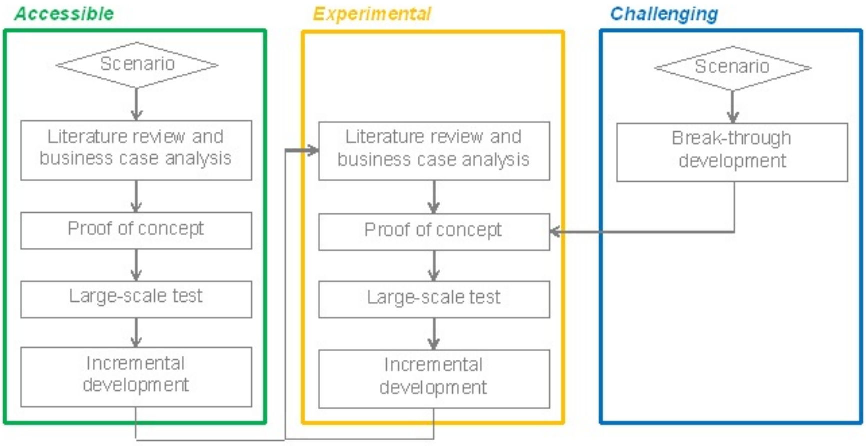

Figure 5: Development process to insure both scientific and commercial relevance. The process builds on incremental developments until a break-through development is achieved.

LITERATURE REVIEW AND BUSINESS CASE ANALYSIS: Based on the envisioned scenarios. 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 applications envisioned in the scenario will help ensure its commercial relevance.

> The first literature review will look into current methods for accelerometer-based gait analysis and visual feedback modalities for physiotherapy. 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: The proof of concept is a small scale, and possibly simplified implementation of the envisioned scenario. Ideally, this step should result in a demonstration that can be used to illustrate the envisioned 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.

> Our initial proof of concept will extract various gait parameters using the accelerometers, based on currently available methods. We will use commercially available sensors such as the Shimmers, and the data processing and user feedback will be implemented using a laptop. This initial demo will be used to start a discussion with patients and clinicians, in order to identify requirements for the large-scale implementation of the system.

LARGE-SCALE TEST: Following the initial proof of concept, the system must be put to test with a larger-scale experiment. Ideally, this experiment should address a particular health-care application, so that the benefits of the systems may be assessed with a clinical trial. This clinical trial could be, for example, a small randomized control trial, measuring health-outcome improvements for a group that had access to the system, compare to a similar group that did not have access to the system. Such tests are helpful for ensuring the scientific relevance of the work, but also as marketing tools that show the value and relevance of the system for potential customers.

> At this stage, the sensors will be connected to a mobile phone (or tablet) which can either process the data and provide feedback, or send the data to a remote server which will process the data and return adequate feedback via the phone (tablet). We will initially target applications related to physiotherapy for arthritis patients or patients who underwent foot, knee, or hip orthopedic surgery. The reason being that we currently have clinical collaborators in these areas. The goal is to determine if and how appropriate feedback regarding gait can improve or shorten recovery.

INCREMENTAL DEVELOPMENT: Based on the experiences obtained during the large-scale test phase, adjustments and improvements may be made to the system. These improvements may relate to hardware, software architecture, and/or data analysis. The idea is to move closer to the envisioned scenario, or an updated and more complex scenario.

> At the first instance of this step, we will probably investigate the development of proprietary sensors, new methods for processing the data, personalized feedback modalities, and new applications.

BREAK-THROUGH DEVELOPMENT: Break-through developments run in parallel with the other steps. In general, we will try to create or combine technologies which will allow us to achieve our long-term scenario.

> Initially, we will look into printable circuits, and textile technologies, in order to develop an inexpensive pressure sensitive insole. We will also look into energy harvesting technologies and investigate whether they can be used to power our wearable sensors.

3.2 Time plan

The following is an estimate of the time-plan for the first round in the development process.

2014	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
literature review							x	x	x			
Business case								x	x	x		
proof of concept										x	x	x

2015	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
implementation	x	x	x	x								
clinical trial				x	x	x	x	x	x			
incremental dev.										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:

- A review paper summarizing previous works on inertial-sensor-based biomechanical feedback for gait rehabilitation by September 2014;
- An article describing the initial proof of concept by January 2015;
- An article describing the system used for the large-scale test by June 2015;
- An article presenting and discussing the clinical results of the large-scale test by October 2015;

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 remote rehabilitation using inertial sensors. We will incrementally add other sensors and applications to the system as the project progresses.

4.3 Collaborations

During this project we hope to strengthen our collaborations with the Lundberg Laboratory for Human Muscle Function and Movement Analysis at the The Sahlgrenska Academy, and the arthritis research group previously situated at the Spenshult Hospital. We may also initiate a collaboration with the Active and Healthy Aging research group at Lund University. 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. Within Halmstad University, we may collaborate with researchers from the fields of interaction design; physiology and biomechanics; digital tools for healthcare; and person-centered care.

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