Ana Miriam Meireles Ferreira Cabrita

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Enhancing physical activity coaching through personalized motivational strategies and self-adaptive goal-setting: development of self-adaptive processes in a monitoring and coaching smartphone application

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Orientador: Miriam Vollenbroek-Hutten, RRD-UT, Holanda
Co-orientador: Pedro Vieira, FCT-UNL, Portugal
Reinoud Achterkamp, RRD-UT, Holanda
Harm op den Akker, RRD-UT, Holanda

Juri:

Presidente: Doutora Maria Adelaide de Almeida Pedro de Jesus
Arguente: Doutor Mário António Basto Forjaz Secca
Vogais: Mestre Reinoud Achterkamp
Mestre Harm op den Akker

FACULDADE DE CIÊNCIAS E TECNOLOGIA
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"I'm a scientist and I know what constitutes proof. But the reason I call myself by my childhood name is to remind myself that a scientist must also be absolutely like a child. If he sees a thing, he must say that he sees it, whether it was what he thought he was going to see or not. See first, think later, then test. But always see first. Otherwise you will only see what you were expecting. Most scientists forget that."

Douglas Adams *in* The Ultimate Hitchhiker's Guide to the Galaxy (Part IV)

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Abstract

The rising age of the European population brings increased costs in healthcare mainly related to the management of chronic diseases. Regular physical activity has been shown to help in the prevention and control of disease risk. Mobile phones have provided promising and emergent ways of promoting healthy lifestyles, allowing real-time monitoring and coaching to be delivered at any time and any place. The presented work adds new features to the Activity Coach, an ambulatory feedback system that aims to encourage physical activity. The Integral of the Modulus of Body Acceleration (IMA) is the unit used as an estimate for energy expenditure. Although previous research demonstrated the potential of this system, results also showed that adherence drops after a few weeks. The primary goal of this research was to design, implement, and test adaptive goal-setting and personalized feedback strategies in order to encourage physical activity. Regarding the self-adaptive goal-setting feature, the goal for each day is defined automatically based on the physical activity performed at that day of the week since the beginning of the intervention. Hence, the intention is to help the user to increase or maintain his level of physical activity taking his daily routine as a reference. The second element added to the system regards motivational feedback messages, a key factor in interventions aiming at behavior change. Based on the levels of self-efficacy, stage-of-change, and daily activity, the user is assigned to one of the six pre-defined feedback strategies in the system. The content of the motivational cues depends on the selected feedback strategy.

The evaluation of the system focused on providing better understandable and more accurate feedback to the user. To do so, we evaluated the challenge and attainability of the goals provided to the user with (1) data acquired during previous studies, and (2) newly gathered data from a single-subject study. As part of the evaluation, we translated IMA counts into 'steps', a commonly understandable measure for physical activity, comparing the data acquired from the Activity Coach sensor with a Fitbit, a commercially available pedometer. Although further tests with more subjects and different activities should be performed, we suggest that the default values set to the system are in agreement with the Goal-Setting Theory providing challenging and attainable goals.

The results from this research will be used in future experiments using the Activity Coach and can be adapted to other ambulatory feedback systems regarding promotion of physical activity.

Key-words: ambulatory feedback system, coaching, goal-setting, mHealth, monitoring, physical activity

Resumo

O envelhecimento da população europeia tem induzido custos acrescidos para os sistemas de saúde, sendo a gestão de doenças crónicas um dos principais factores. Diversos estudos sugerem que a práctica de actividade física regular pode ajudar na prevenção e controlo de doenças deste cariz. Os telemóveis e *smartphones* surgem como uma nova forma de cuidados de saúde permitindo a monitorização de parâmetros fisiológicos e o acompanhamento contínuo ao longo do dia. O trabalho apresentado nesta tese é uma actualização do *Activity Coach*, um sistema de monitorização e *feedback* contínuos desenvolvido para incentivar a práctica de actividade física. A unidade de medida utilizada para estimar o nível de actividade física é o IMA, do inglês, *Integral of the Modulus of body Acceleration*. Um dos problemas associados a este tipo de serviço é o progressivo desuso do sistema após algumas semanas. Estudos recentes sugerem que tanto a continuidade como a efectividade deste tipo de intervenções podem ser melhoradas através da personalização dos sistemas. O objectivo principal deste trabalho é desenvolver, implementar e testar (1) estabelecimento automático de metas (*goal-setting*) para actividade física diária e (2) estratégias de *feedback* personalizáveis de modo a promover a práctica de actividade física. Com a nova aplicação, a meta de actividade física diária é definida com base na actividade física realizada nesse dia da semana desde o início da intervenção. Deste modo, o objectivo é ajudar o utilizador a aumentar o seu nível de actividade física tendo como base a sua própria rotina. Relativamente às estratégias de *feedback* personalizáveis, estas condicionam o conteúdo das mensagens motivacionais mostradas ao utilizador. Cada utilizador é alocado numa das seis estratégias pré-definidas no sistema dependendo do nível de auto-eficácia, estágio de mudança comportamental e dos hábitos de práctica de actividade física.

De forma a obter os resultados desejáveis, o *feedback* dado ao utilizador deve ser totalmente perceptível pelo próprio e também justo e exacto. A avaliação do sistema contemplou estes pontos testando a dificuldade e atingibilidade das metas propostas. Para isso, procedemos a dois tipos diferentes de estudos. No primeiro caso recorremos a dados adquiridos em estudos previamente realizados e testámos a dificuldade das metas propostas. No segundo caso, estabelecemos uma tabela de conversão entre contagem de IMA's e 'passos' através da comparação de dados adquiridos pelo Activity Coach e dados adquiridos por um pedómetro disponível comercialmente (Fitbit). De acordo com os resultados do estudo, o novo algoritmo define metas desafiantes mas alcançáveis. Ainda assim sugere-se a realização de novos testes incluindo um maior número de indivíduos e diferentes tipos de actividade física (p.e. ciclismo, corrida, etc).

Os resultados deste trabalho serão aplicados em estudos futuros usando o Activity Coach e podem ainda ser adaptados a outros sistemas de incentivo à prática de actividade física.

Palavras-chave: actividade física, *goal-setting*, *coaching*, *mHealth*, monitorização, sistema ambulatório de monitorização e *feedback*

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Acronyms

BAN:	Body Area Network
FBS:	Feedback Strategy
GP:	General Practitioner
GPS:	Global Positioning System
GUI:	Graphical User Interface
ICT:	Information and Communication Technologies
IMA:	Integral of the Modulus of body Acceleration
mHealth:	Mobile Health
RRD:	Roessingh Research and Development
SCT:	Social Cognitive Theory
SWELL-WP5	Work-package 5 from the SWELL Project
TTM:	Transtheoretical Model
WHO:	World Health Organization
XML:	eXtensible Markup Language

Glossary

Balance activity percentage:	Percentage of deviation between the physical activity measured by the sensor and the goal line
Baseline Period:	Time interval during which the user does not receive any kind of feedback
Body Area Network:	Communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical
Daily activity pattern:	Distribution of physical activity throughout the day
Daily-end-point:	Cumulative end point of the measured physical activity (measured in IMA)
Desired-end-point:	Cumulative end point of the goal line (measured in IMA)
Goal Line:	Desired distribution of physical activity over the day
Intervention Period:	Time interval during which the user receives real-time feedback and motivational cues in order to increase the physical activity level and to balance activities over the day
mHealth:	Medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices
Module:	Building block of the Activity Coach smartphone application
***Persona*:**	Fictional person that serves as a vehicle to illustrate envisioned use of technology in scenarios
Personalized Feedback Module:	Module responsible for identifying the most suitable feedback strategy to a specific user at a certain moment and managing the real-time motivational cues given to the user
Pervasive Technology:	Technology that fits the human environment everywhere and anywhere
Self-efficacy:	One's belief in the capability to perform an action
Smart Reference Module:	Module responsible for analyzing the IMA data of each day and creating a new goal line for the upcoming day
Stage-of-change:	Level of the Transtheoretical Model
User Model Module:	Module responsible for collecting, storing and providing all the information regarding the user to other modules
Weighted-end-point:	IMA value calculated as the linear weighted averages of the daily-end-points of a weekday

1. Introduction

“A healthy workforce is a happier and more productive workforce”.

(SWELL Project)

1.1 Background summary

The presented research took place at Roessingh Research and Development (RRD) a private research center for rehabilitation technology and telemedicine in Enschede, the Netherlands. The Telemedicine group is involved in the SWELL Project – Smart-reasoning systems for well-being at work and at home – a project supported by the Dutch national program COMMIT that aims to “develop user-centric sensing and reasoning techniques that help to improve physical well-being (mostly in a private context) and to improve well-working (in a work context)”[1]. This research is included in the SWELL Project.

The implementation mentioned in this thesis represents an extension of the Activity Coach, a smartphone application designed and developed at RRD that intends to encourage physical activity, explained in more detail in Chapter 2.3. The output used for estimating physical activity is the Integral of the Modulus of body Acceleration (IMA), a unit that is scientifically proven to correlate to energy expenditure. The outcomes of this thesis can also be used by other projects in RRD using the same system or even adapted to other ambulatory feedback systems encouraging physical activity.

1.2 Problem definition

The average age of the European Union population has continuously increased over the last decades (European Comission 2012) raising social, economic and cultural challenges when combined with a decrease in the working age population (aged 20-65). Economies and societies should adapt to these changing demographic conditions (Lee et al. 2012).

From the socio-economical point of view, the remaining labor force is responsible for covering the costs of a growing number of dependent elderly. This means that those who work have to continue their jobs till a later age and for longer periods of time, even when not feeling in their healthiest condition. According to the European Commission, nearly 25% of the European working-age population suffers from a longstanding problem which restricts their daily activities (Directorate General for Health and Consumers: EU Health Programme 2011), chronic illnesses being the principal cause. Therefore, policy makers, occupational health providers and general practitioners (GPs) must work together in order to provide policies and initiatives addressing chronic illness management. Return-to-work and reintegration tools should also be considered for those who had to stop their jobs for a long period of time.

[1] http://www.swell-project.net/about-swell/objectives

Prevention of longstanding problems must be taken as a priority in the healthcare research. Several research studies state that regular physical activity can help in the prevention/control of both chronic diseases (e.g. Thorp et al. 2012; Warburton et al. 2006), and mental health conditions (Taylor et al. 1985). It is not surprising that encouraging the practice of regular physical activity became part of the international and national guidelines for the promotion of healthy lifestyles (NHS: National Institute for Health and Clinical Excellence 2009; EU Working Group “Sport & Health” 2008). Over the last decade, structured national and regional initiatives are increasingly preoccupied with the maintenance and/or increase of daily physical activity (Cabrita & Cabrita 2013). Although such initiatives show impact on a community level, their lack of tailoring to individual’s needs limit their potential effectiveness.

At an individual level, the spread of mobile and wireless technologies, such as mobile phones, smartphones, or tablets, (WHO 2011) lead to a rising number of mobile phone health interventions (Klasnja & Pratt 2012). Especially in developed countries, where mobile phones have become ubiquitous over the past years, the population seems to be accustomed to, or even dependent on, mobile applications that directly or indirectly monitor the user’s health information, including, for example, weight trackers, diet applications or sports and exercise trackers (Klasnja & Pratt 2012).

Although there is a significant acceptance of fitness-tracking applications for those who are already physically active (e.g., RunKeeper[2], Beeminder[3], Runtastic[4]), the solutions to encourage appropriate and sufficient physical activity throughout the day remain nearly unknown and still face many challenges. The majority of these applications limits their feedback to objective measurements (e.g., calories counting, distance covered and velocity) and does not take into account other subjective measures relevant to health behavior change and chronic disease management (Klasnja & Pratt 2012). Examples of subjective measurements can be the necessity and willingness to increase the physical activity level and, even the belief about the capability to do so. One example of applicability of social theories in behavior change is Goal-Setting Theory (Locke & Latham 2002), that has been used in several studies aiming the promotion of healthy lifestyles (Consolvo et al. 2009; Colineau & Paris 2010; Normand 2008; Shilts et al. 2004). However, to the best of our knowledge, there is no experimental study published taking into account the correlation between different behavioral change theories and the content of the feedback messages given to the user.

Furthermore, so far, there are no studies published where users are their own control. Using a goal line based on the data from healthy control subjects does not seem the most accurate way to encourage physical activity. Chronic patients could conclude that their efforts were not enough and possibly never reach their goal and simply give up (Achterkamp et al. 2013).

Contrarily, the physical activity pattern, i.e. the distribution of physical activity throughout the day, is an issue frequently addressed in literature (Evering 2013; Cooper et al. 2000; Dixon-Ibarra et al. 2013; Arnardottir et al. 2013). Previous research at RRD showed that chronic low back pain patients (Dekker-van Weering et al. 2012) and patients suffering from chronic fatigue (Evering, van Weering, et al. 2011) struggle to balance their physical activity pattern. Both studies suggest that patients spend all their energy during the morning and become exhausted for the rest of the day. Considering that this shows

[2] http://runkeeper.com/
[3] https://www.beeminder.com/
[4] http://www.runtastic.com/

subjects' unawareness about their physical activity habits, we hypothesize that these users would benefit from a goal line for physical activity that would help to balance their daily activity pattern over the day.

The last point that deserves our attention is the fact that the activity pattern during a work day is probably different than during the weekend. It seems reasonable to define different goal lines for each day of the week. Arnardottir *et al.* (2013) analyze the daily pattern of Icelandic older adults concluding that members of the non-working population also show different daily patterns of physical activity depending on the day of week, Sunday being the least active day.

To sum up, although most of the activity trackers include user targeting factors in their applications such as age, gender, weight or height, there is a general lack of user-adaptation features (Kennedy et al. 2012; op den Akker et al. 2014). The third element missing in the majority of the available applications is context awareness – e.g. daily routine of the user and day of the week. Tailoring is the upcoming field that explores the combination of the three previous concepts – user targeting, adaptation and context awareness – and consists of the design and development of a service/intervention that matches the individual user (op den Akker et al. 2014). There is a trend in nowadays research exploring the effect of the lack of tailoring in the long-term adherence to a system designed for behavior change interventions. Fogg's Behavioral Model for Persuasive Design (Fogg 2009), for example, suggests that the personalization of a system can lead to a higher level of adherence to the service. In addition, when the "novelty effect" wears off the adherence to these services decreases abruptly (Antypas & Wangberg 2012).

1.3 Research Questions and Relevance

Based on the issues identified in the problem definition, the goal of the work presented in this report is to:

combine tailoring features in order to increase the long term adherence and impact of the system.

Aim of the research

As a mid-term objective, we intend to make users aware of their physical activity level and the way it is balanced throughout the day, providing solutions/suggestions to increase activity level when necessary. In the long-term, we believe that the regular practice of physical activity can improve the health of office workers and the overall productivity of workplaces, especially those suffering from chronic diseases. Therefore, the primary aim of this research is as follows:

Design, implement and test adaptive goal-setting and personalized feedback strategies with respect to an activity based ambulatory feedback system.

Primary aim

Hence, the first outcome of the thesis is to extend a smartphone application for monitoring physical activity in a way that it becomes able to determine the most suitable feedback strategy for a new user of the application, and is also able to adapt this strategy over time. This first outcome intends to answer to the following research question:

Does the incorporation of adaptive goal-setting and personalized feedback strategies based on the combination of constructs from health behavior models and daily activity pattern increase subjects' long-term adherence to the service?

Long term research question

Due to time limitations we decided to focus our short-term research questions in the adaptive component of the goal-setting to the system. Therefore, four sub-research questions arose:

- ✓ *Can an automatically adaptive goal line provide more challenging but attainable goals for encouraging physical activity, when compared to fixed goals defined exclusively based on data acquired during the baseline week?*
- ✓ *Is it possible to establish a reliable conversion factor between IMA count and number of steps in order to provide more understandable feedback to the user?*
- ✓ *What is a reasonable threshold for deviation between averaged end point and new end goal?*
- ✓ *What is an appropriate threshold for classification of percentage of activity balance as either 'proper' or 'improper'?*

Short term research questions

1.4 Objectives

The research questions identified will be answered through the concretization of the following objectives:

1. Implement standard questionnaires of models of individual behavior change to determine the levels of self-efficacy and stage-of-change;
2. Classify the daily activity pattern;
3. Based on point (1) and (2), determine the best feedback strategy for a specific user among the pre-defined feedback strategies developed in a parallel research;
4. Define an automatically adapted goal line for each day combining data acquired from the sensors and data pre-defined by the healthcare professional;
5. Design the application in a way that it allows adaptation to the users' routine and to their progress through time regarding the psychological constructs;
6. Test the algorithm.

1.5 Thesis Outline

This report is structured as follows: chapter 2 gives the information necessary as background for this research (information about the research center where the project took place, as well as a description of the project including what was already done at the moment of the start of this research); chapter 3 consists of the literature review focusing on three topics – physical activity, the models of individual behavior change used in this research, and the potential of mHealth in individual interventions with a main focus on motivation for physical activity. After this, chapter 4 gives insight into the requirements elicitation and the design of the algorithms, while chapter 5 makes a detailed description of each one of the modules added to the ambulatory monitoring and coaching system. The evaluation of the modules designed in chapter 4 and described in chapter 5 is done in chapter 6. Chapter 7 states the conclusions from the research and, finally, chapter 8 presents recommendations for future research.

2. Background Overview

“Research builds a bridge into a new future.”

Roessingh Research and Development

This chapter will provide information on the background of the present research. The work was performed at Roessingh Research and Development (RRD), a renowned research center on healthcare technology located in Enschede, the Netherlands. The use of ICT in healthcare is one of the research lines of RRD and in particular of the Telemedicine cluster. As such, this cluster is involved in the SWELL Project, a multi-disciplinary project funded by the COMMIT Program that aims to promote healthier lifestyles among working population through new technologies. RRD’s role in the project is to develop a smartphone application with the aim to encourage the practice of physical activity. For that, the Activity Coach, an application fully developed at RRD, was used as starting point. The research presented in this report adds new functionalities to its previous versions.

2.1 Roessingh Research and Development

Roessingh Research and Development[5] was founded in 1991 and became the largest research center on rehabilitation technology in The Netherlands. Its aim is to be “internationally recognized [as a] research institute which develops knowledge and innovations concerning rehabilitation technology and telemedicine, and helps introducing these in rehabilitation/health care”. This mission has two main objectives: “anchoring of research and innovation” and “stimulus to implementation”. For that, the institution relies on a strong link between universities, healthcare centers and industry.

Nowadays RRD holds a multidisciplinary medical and technical staff of about 45 people divided into two clusters: *Telemedicine* and *Rehabilitation Technology*. The work presented in this report is part of the Telemedicine cluster.

2.2 SWELL Project: Smart Reasoning Systems for Well-being at Work and at Home

The SWELL Project[6] is the seventh project of the COMMIT[7] program, an Information and Communication Technologies (ICT) research community which includes fifteen different public-private

[5] http://www.rrd.nl
[6] http://www.swell-project.net/
[7] http://www.commit-nl.nl/

multi-party projects. This project consortium consists of various Dutch R&D groups: Philips, TNO, RRD, Almende and Sense, University of Twente and Radboud Universiteit Nijmegen. It aims to promote physical and mental well-being in the working society. The project is divided into six work packages (WPs):

1. WP1: Requirements, Architecture and Impact
2. WP2: Person Centric Reasoning for Physical Well-being
3. WP3: Person Centric Reasoning for Mental Well-being
4. WP4: Context Aware Adaptive Privacy
5. WP5: Well-being Applications for Physical Lifestyle Changes
6. WP6: Well-being Applications for mental Lifestyle Changes

The present work is part of WP5. Its aim is to promote an active lifestyle within the working society, including both healthy individuals and those suffering from a chronic condition. To reach that goal, the idea is to develop a service that increases the user's level of physical activity and that is not abandoned after three or four weeks but can be used for extended periods of time (SWELL Project 2012b). One of the objectives of this WP is to identify effective feedback strategies and incorporation into technology-mediated behavior change smartphone applications using a person-centric approach (i.e. easy to experience and designed around the end-user). The target group includes knowledge workers who already experienced first complaints or are completely out of their work environment because of their physical condition (Figure 1).

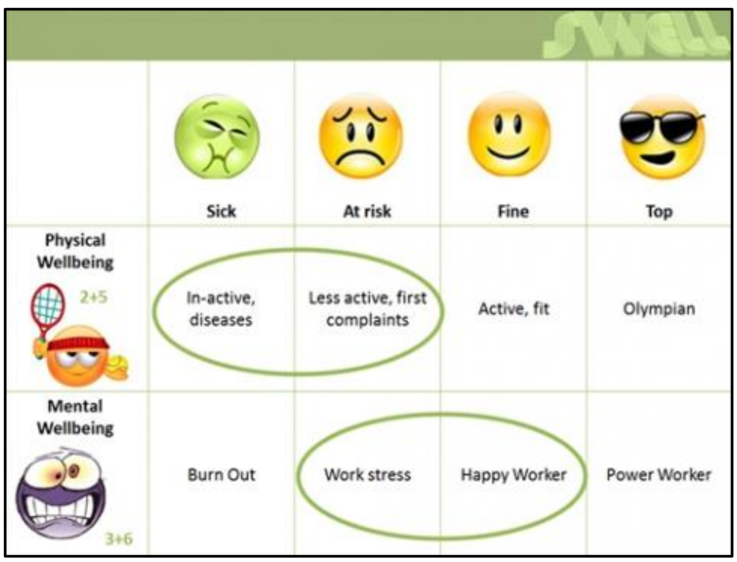

Figure 1 - Target group of the SWELL Project.

2.3 Activity Coach

The Continuous Care & Coaching Platform (C3PO) is a platform developed at RRD that integrates ambulant sensing to measure relevant bio signals and provides feedback to both patients and care providers. The platform aims to support elderly patients and patients with chronic disorders in “developing and maintaining an active lifestyle and improving their physical condition, either independently or supervised remotely by their healthcare professionals” (op den Akker et al. 2012).

The high level architecture includes three actors – patient, server and care provider – and comprises four components: sensor, smartphone, server and web portal (Figure 2). The presented research only uses the first two components mentioned.

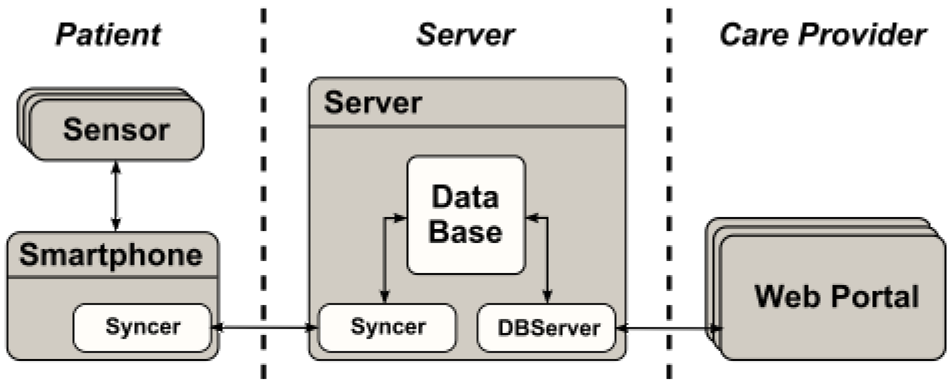

Figure 2 - High level architecture overview of C3PO (op den Akker et al. 2012).

C3PO’s modular architecture permits the simultaneous use of multiple sensors, such as heart rate monitor and accelerometer. The ProMove-3D (Figure 3), developed by Inertia Technology[8], is a sensor to be worn on the hip and is used to monitor physical activity. It includes a tri-axial accelerometer and a Bluetooth chip that allows wirelessly connection to the smartphone. Physical activity is measured on the sensor by calculating the Integral of the Modules of body Acceleration (IMA) output, expressed as IMA counts per minute (Bouten et al. 1996) with a_x, a_y, and a_z the accelerometer output in the three dimensions and T the time interval of integration. The configurability of the Activity Coach allows changing the value of T according to the desired outcome. Nevertheless, in this study T remained set to 10 seconds.

Equation 1

$$IMA(t) = \frac{1}{T}\left(\int_{t-T}^{t} |a_x| \; dt + \int_{t-T}^{t} |a_y| \; dt + \int_{t-T}^{t} |a_z| \; dt\right)$$

The variability of IMA values over the day is shown to the user in a real-time plot where the abscissa corresponds to the time and the ordinates to the cumulative level of physical activity (Figure 3). Besides, the user’s own goal is drawn as another line, so that he/she can compare the actual performance

[8] http://www.inertia-technology.com/

to the recommended one. The application also provides the percentage of deviation between the real-time cumulative IMA value and the goal line.

Before the implementation of the work mentioned in this report, the goal line was fixed throughout the intervention period and was based on data acquired from a group of healthy control subjects or, in the most recent versions, based on data acquired during the first week of the intervention.

An Android-based application is responsible for analyzing and displaying the information. Together with the ProMove-3D sensor it constitutes the Activity Coach system. This application runs on the latest smartphone models and has a highly modular architecture. It can also be linked to a remote database which, in turn, can be accessed by the user and healthcare professionals.

Figure 3 - Activity Coach consisting of a smartphone (*left*) and the sensor ProMove-3D (*right*).

The basic version of the Activity Coach includes the visualization of messages that can be either suggestions (e.g. “Is there anything to clean around the house?” or “Take a nice walk!”) or real-time feedback (e.g. “Well done.” or “Your activity level is sufficient.”). The content of the message would exclusively depend on the difference between the activity level of the user and the goal line over a period of time. As such, there are three categories of messages: ‘encouraging’, ‘neutral’ and ‘discouraging’.

Moualed (2012) proposes an improvement to the feedback component of the system analyzing the compliance levels from the user as a result of the feedback messages, i.e. the content of the message at a certain moment would depend on user's reaction to the same type of message at earlier moments. As an example, one user could feel more motivated with formal messages whereas other would prefer a friendly speech. This work was an important step for a personalized system.

However, none of the previous versions included neither correlates from behavioral models nor adaptive goal-setting. With the presented research we intend to improve the feedback component of the Activity Coach (by means of adaptation to the user) and make the system more appealing and interesting to the user in order to increase the long term adherence (by means of context awareness).

3. Literature review

“A smartphone is a cognitive prosthetic.”

(Anthony Sterns, Ph.D., iRx Reminder LLC)[9]

Chapter 3 will define physical activity and revisit the reasons why people adopt inactive lifestyles, following an overview of the models of individual behavior change applied in this research: Social Cognitive Theory, Transtheoretical Model and Goal-Setting Theory. Chapter 3.3 will focus on the impact of pervasive technology in healthcare, enumerating the advantages of mobile phones when compared to traditional ways of providing healthcare. The chapter ends with a general overview of systems that use Body Area Networks for monitoring physical activity, with particular interest in the ones similar to the Activity Coach.

3.1 Physical Activity

The impact of technology and environmental developments over the past few decades has severely affected the amount of physical activity people do on an hourly basis. People use cars no matter the distance they have to travel, spend more time in front of the computer or television than outside, and the traditional playgrounds are substituted by virtual environments where kids can ride virtual dragons and play in real-time with children from other parts of the world. Although at a first sight this worldwide interaction may seem appealing, the fact is that the lack of regular physical activity is leading to a global public health problem.

It is necessary to remind people how important it is to move at least every two hours either at home or at the workplace. There are more and more sedentary jobs that require diverse mental tasks and time waiting for machines to complete tasks. It is necessary to find ways to overcome this trend identifying the most suitable way to incorporate some movement in everyday life. In fact, the so called ‘knowledge society’ is turning the workplace in a key setting in which it is possible to reduce adults’ sitting time (van Uffelen et al. 2010). Whether it is a short stretch after a period of sitting or a walk during the lunch break, the mote is: “Move!”.

In 1994 Astrand warned for the fact that “there is virtually no way of reverting to our ‘natural’ way of life, but with insight into our biological heritage we may be able to modify the current, self-destructive,

[9] Interview available at: http://www.zoominfo.com/CachedPage/?archive_id=0&page_id=5849562501&page_url=//medsider.com/interviews/using-smartphone-apps-to-empower-patients-and-illuminate-clinical-research-interview-with-dr-anthony-sterns-ceo-of-irx-reminder/&page_last_updated=2012-11-09T10:46:33&firstName=Anthony&lastName=Sterns

elements of our modern life" (Astrand 1994). As the scientific community became aware of this, several studies started trying to identify the biological mechanisms responsible for the health effects of physical activity; however, less effort was put on the psychological benefits that could arise and the ways to promote behavior change (Biddle & Mutrie 2008).

More recently, national and international groups are devoting their time to write guidelines that aim to help government agencies and private bodies to work together in order to promote physical activity. Table 1 shows the recommendation from WHO (WHO 2010). According to another report from the WHO[10], in 2002 around two thirds of the adult citizens in Europe did not reach the recommended levels of physical activity.

Table 1 - WHO Recommendations on physical activity for health organized by age of population. The full dose can be accumulated in bouts of at least 10 minutes (WHO 2010)**.**

Age	WHO Recommendation
5-17	• Minimum of 60 minutes of moderate-to-vigorous physical activity daily • Most of daily physical activity must be aerobic. • Vigorous-intensity activities should be incorporated, including those that strengthen muscle and bone, at least 3 times per week.
18-65	• Minimum of 30 minutes of moderate-intensity physical activity 5 days a week OR at least 20 minutes of vigorous-intensity physical activity 3 days a week; • Activities to increase muscular strength and endurance should be added 2 to 3 days per week
>65	• Same goals as for healthy younger adults in addition with strength training and balance exercises to prevent falls

The EU working Group "Sport & Health" defines physical activity as "any bodily movement associated with muscular contraction that increases energy expenditure above resting levels" (EU Working Group "Sport & Health" 2008). This broad definition includes all types of physical activity from leisure-time to occupational activities. Our research, however, requires a more accurate definition. Consolvo *et al.* (2006) distinguish *opportunistic physical activity* from *exercise* stating that the former concerns to "activities that a person can incorporate into her normal everyday life to increase her overall level of physical activity (e.g.: walking instead of taking the car to work, taking the stairs, and parking further from the destination)" whereas exercise relates to an activity in "which a person elevates her heart rate for an extended period (e.g.: going for a run or swim)". This means that exercise usually refers to more structured leisure-time physical activity such as 'keep-fit' activities and recreational sports.

The reasons for not practicing regular physical activity go from socio-demographic (e.g.: gender, age, socio-economic status) to personal factors, lack-of-time being the one most mentioned (Browning & Thomas 2005). Therefore, it is important to teach how to conjugate the 30 minutes of moderate-intensity physical activity recommended into common daily tasks, such as taking the stairs instead of the lift. Nevertheless, all the aforementioned barriers have a common cause: self-motivation. Active living approaches focus on incorporating activity into daily lifestyles considering the context and location (Browning & Thomas 2005). Moreover, the EU working Group "Sport & Health" adverts: "there is

[10] http://www.euro.who.int/__data/assets/pdf_file/0011/87545/E89490.pdf

evidence that anyone who increases their level of physical activity, even after long periods of inactivity, can obtain health benefits irrespective of their age. It is never too late to start" (EU Working Group "Sport & Health" 2008).

The concern with physical activity habits is not only the *amount* but also the spread of activities throughout the day. Several empirical studies suggest that, when compared to healthy subjects, chronic disease patients have an improper pattern of physical activity over the day (Dekker-van Weering et al. 2012; Evering, van Weering, et al. 2011). The highest levels of activity are reached in the morning with a continuous decrease to afternoon and evening. Vollenbroek-Hutten & Hermens (2010) emphasize the importance of a telemedicine service that helps users to balance their activity levels over the day.

3.2 Models of Individual Behavior Change

The principal behavior change frameworks used in the promotion of healthy lifestyles can be classified as social cognition models and stage models. While the former considers that people move along a continuum of behavior change, the latter assumes that people can be classified according to a discrete stage and can move between stages to achieve the desired behavior (Browning & Thomas 2005). The aforementioned models attempt to define the correlates of physical activity, i.e. "the factors that affect, or are thought to affect, participation in exercise and physical activity" (Biddle & Mutrie 2008).

3.2.1 Social Cognitive Theory

Social Cognitive Theory (SCT) is one of the most generally accepted theories used for physical activity promotion (Biddle & Mutrie 2008). One of the constructs of this theory is self-efficacy. Bandura (1994) defined self-efficacy as the belief in one's capabilities to organize and execute the courses of action required to produce given attainments. In other words, one can say that self-efficacy is the subject's belief that a particular behavior is, or is not, within his/her control. Moreover, SCT defends that one's self-efficacy level can predict behavior change. As an example, high level of self-efficacy to start exercising is predictive of actually starting an exercise program.

In 1977, Bandura identified four factors that affect the self-efficacy level: enactive mastery experience, vicarious experience, physiological state and social persuasion (Bandura 1977). Enactive mastery experience refers to performance accomplishments that happened in the past; vicarious experience is based on peer modeling; the physiological state relates to the physical and mental state of the individual and, finally, the social persuasion concerns coaching and/or feedback from family, friends and professionals. Table 2 shows how each one of these factors affects the individual's self-efficacy level.

Health behavior change interventions incorporating self-efficacy focus on convincing the individuals that they have the personal resources necessary to act in the required manner (Browning & Thomas 2005). As such, many interventions set smaller goals, for which the self-efficacy of the participant is close to 100%, and the difficulty of the goals increases by small increments.

Table 2 – Self-efficacy determinants and their influence in individual's self-efficacy level. Adapted from (Bandura 1977) **and (Ashford et al. 2010).**

Past experiences • Success raises self-efficacy; failure undermines it	**Physiological State** • Negative emotional states (e.g.: anxiety) and misinterpretations of bodily states raises self-efficacy; the opposite undermines it
Self-efficacy Judgments	
Vicarious experience • Success of the peers raises self-efficacy; failure undermines it	**Social Persuasion** • Faith from others in the individual's capabilities raises self-efficacy; disbelief from others undermines it

3.2.2 Transtheoretical Model

The Transtheoretical Model (TTM) is the most popular stage model applied in the promotion of physical activity (Prochaska & DiClemente, 1983). It suggests that a behavioral change process, whether it means recovering from problematic/addictive behaviors or adopting a healthy behavior, involves movement through a series of five discrete stages:

- *Pre-contemplation*: at this stage there is no intention to change behavior in the foreseeable future. Individuals at the pre-contemplation stage are frequently not aware or 'underaware' of their problem. Peer pressure is of significant importance in moving out of this stage, taking into account that, in most of the cases, family, friends and relatives are well aware of the problem. Prochaska *et al.* (1992) suggest that the hallmark of this stage is resistance to recognize or modify a problem.
- *Contemplation*: at this stage there is intention to change within a middle-to-long term period of time. It takes in individuals who are aware of the problem, most of the times know the solution, but have not yet made a commitment to take action.
- *Preparation*: at this stage individuals are committed to start a behavior change process within one month or have already started some changes but not an effective action. This stage commonly includes individuals who have unsuccessfully taken action in the past years.
- *Action*: at this stage individuals modify their behavior, experiences or environment in order to overcome their problems.
- *Maintenance*: at this stage the individuals successfully maintain their behavior for more than six months. The biggest worry is to prevent relapse.

Table 3 combines the information about the different stages considered in the model, the directions of change allowed and the strategies that can be addressed to promote step forward changes. One should bear in mind that subjects can enter and exit a stage at any point. The stage-of-change can vary in the descending direction (*progress*) or in the ascending order (*relapse*). Whereas one could think that the progress direction is the desirable one, Prochaska *et al.* (1992) defend that some subjects could benefit from a 'cycling' back and forward through the processes considering that this movement would "help strengthen behavior change in the long run as people learn from their mistakes and relapses". As far as we know, there is no literature available proving this idea.

Self-efficacy plays an important role in the model considering that it reveals one's confidence in maintaining the new behavior and resisting the temptation to relapse. Furthermore, literature suggests that high self-efficacy is associated to later stages of the Transtheoretical Model (action or maintenance) leading to the conclusion that self-efficacy and stage-of-change are intrinsically related (Marshall & Biddle 2001).

Although the TTM was first proposed to analyze the behavior change through smoking cessation process, its field of application has been largely broadened since then. Several systematic reviews showed the effectiveness of this model in the promotion of physical activity in adults of different ages (Kroeze et al. 2006; Biddle & Mutrie 2008).

Table 3 – Levels of stage-of-change and respective processes of change in the promotion of physical activity. The arrows represent the possible changes between stages. Adapted from (Browning & Thomas 2005; SWELL Project 2012a).

Stage-of-change	Processes of Change
Pre-contemplation No intention to change behavior within six months.	Elicit possible and positive aspects of target behavior(s) and provide simple information
Contemplation Intention to change behavior within the next six months.	Motivate and elicit commitment Enhance self-efficacy Identify physical activity classes
Preparation Intention to take steps to change behavior within the next month.	Identify goals and plan start date and type of physical activity. Use social support
Action Has changed behavior for less than six months	Review goals and suggest coping strategies for fatigue, discomfort, lack of motivation, etc. Praise high self-efficacy
Maintenance Has changed behavior for more than six months.	Review coping strategies and reassess goals and physical activity type

3.2.3 Goal-Setting Theory

Goal-Setting is the third theory of behavioral change applied in the presented research. Locke and Latham's Goal-Setting Theory emerges as the result of nearly forty years of empirical research on the relationship between conscious performance goals and task performance level (Locke & Latham 2002). Although the research focuses mainly on the work setting, this theory is among the most used in interventions aiming at the promotion of healthy lifestyles in general.

Goal-Setting Theory defends that individuals are more likely to change a behavior the higher the specificity and (achievable) difficulty of a goal. The authors suggest that urging an individual to "do his best" is not the most effective approach. Instead, individuals should be given specific goals that – even in the cases when the specificity does not lead to higher performance – reduce the ambiguity of what is aimed for.

Locke and Latham's work focuses on the core properties of an effective goal. The authors describe how individuals respond to goals assigned from different sources (self-set, assigned by another person and participatively set goals) and identify the mediators and moderators of behavior change. For instance, individuals seem to achieve higher performances when committed to the goals. This commitment to a goal can be increased either by emphasizing the importance of the goal's outcome or increasing the self-efficacy level for the desired task. Two ways that lead to increase the perceived importance of a goal are public commitment to the goal and providing incentives.

Last but not least, the authors point out the importance of feedback as a reinforcement mechanism to achieve the goal. Individuals cannot correct or adjust a strategy for achieving a goal without assessing their progress towards the goal. However, not all the feedback provided has a positive effect. Literature shows that introducing negative effects or punishments to discourage behaviors does not lead to behavior change. For example in *Fish'n'Steps* (Lin et al. 2006) the negative reinforcement resulted in system avoidance. Concluding, "*goals plus feedback is more effective than goals alone*" (Locke & Latham 2002).

Shilts *et al.* (2004) report significant positive effect of using Goal-Setting Theory on dietary intake and physical activity encouragement. Moreover, in the same literature review, the authors identify five steps in the process of goal attainment/behavior change: self-assessment, goal setting, goal commitment, goal feedback, and promotion of self-efficacy (Figure 4). From this framework, our main focuses are the importance of goal-setting, goal-feedback and promotion of self-efficacy.

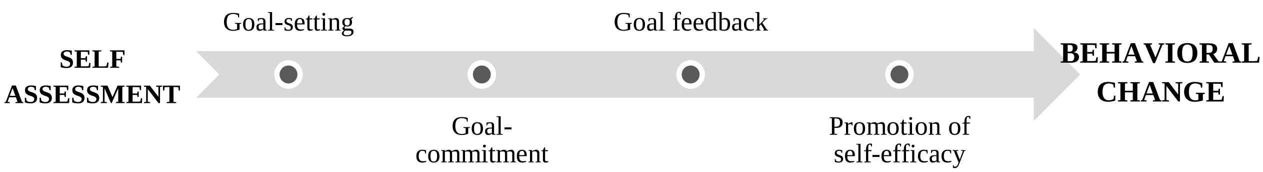

Figure 4 - Proposed Theoretical Framework for the Goal-Setting Process proposed by Shilts *et al.* (adapted from (Shilts et al. 2004)).

3.3 Pervasive Technology in Healthcare

Pervasive or ubiquitous computing was first mentioned by Weiser in 1991 when referring to "machines that fit the human environment instead of forcing humans to enter theirs" (Weiser 1991). During the last decade, pervasive technology has been applied in all sorts of fields from motor traffic to security systems. However, it is in the healthcare sector that pervasive technology is reaching its higher potential.

3.3.1 Mobile Health

The most recent report available from the International Telecommunication Union estimates that in 2013 the mobile phones penetration rate stands at 96% worldwide, 128% in developed countries and 89% in developing countries. According to the same report, 77% of the population in the developed world is online when compared to 33% in developing countries, Europe being the region of the world with the highest Internet penetration rate (75%) (ITU 2013). This data confirms the ubiquitous and pervasive impact of ICT systems in developed countries. Health care services and information found a new way to be accessed, delivered, and managed. The use of pervasive technology not only enables the access to medical care in regions of the world where it was not possible before but also increases the possibility of greater personalization and citizen-focused public health and medical care (WHO 2011).

The concept of mobile health, commonly known as mHealth, was first introduced by Istepanian & Lazminaryan as “unwired e-med” in 2000 (Laxminarayan & Istepanian 2000). More recently, the Global Observatory for e-Health of the WHO defined mHealth as “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices” (WHO 2011). mHealth interventions include, but are not limited to, topics as smoke/alcohol cessation (Whittaker et al. 2009; Free et al. 2011), self-management of chronic illnesses such as diabetes (Kouris et al. 2010), weight management (Hurling et al. 2007), and cancer diagnosis (e.g.: SkinVision[11] application) .

mHealth comes to light as an emergent trend of the twenty-first century finding its place alongside web-based health behavior interventions. The most recent mobile phones with computer operating systems (smartphones) offer a broad range of advantages when compared to traditional ways of providing health care. While minimizing the face-to-face interaction, this technology benefits from an increase in cost-effectiveness through greater accessibility.

Mobile phones enable real-time or near-real time interaction via short message services – commonly known as SMS – or via online services as e-mail or web-server. Text message is a pervasive and low-cost solution for interventions aiming at behavior change. Mutsudi & Connely (2012) conducted a study in which text messages encouraging physical activity based on personalized step goals were sent to young adults (age 18-24) during a period of three months. The study showed promising results even beyond the novelty period, with young adults increasing their daily physical activity and their motivation over the intervention period. The same study, having as theoretical framework the Transtheoretical Model, revealed a positive progress in the stage-of-change of most participants through time. As other example of an advantage of real time communication between patient and health professional, users who use remote health monitoring devices report feeling reassured with the knowledge that their health is being monitor and their care provider would contact them in case of alert, as in e.g. (McCann et al. 2009).

Over the last years mobile phones have begun to ship with internal sensors, such as accelerometer and Global Positioning System (GPS), as well as other location-determination features that, combined with powerful processors and large storage capacities, allow both processing and storage of large amounts of data. Additionally, these devices incorporate different ways to transfer information (1) to the sensors, (2) between devices and (3) to the computer using technologies such as Bluetooth or Wi-Fi. One of the

[11] https://skinvision.com/

biggest advantages of mobile devices when compared to laptops or desktop computers is that, in most of the cases, they are carried by the user, collecting data throughout the day, being used as a hub for receiving bio-information from medical mobile sensors (Fernández et al. 2012). Among the most used devices are digital scales, blood pressure monitors, glucose meters, portable electrocardiograms, pedometers and gym equipment.

Mobile phones are not only pervasive, but also deeply personal. They can also provide an important role as reminders for medical appointments (Chi et al. 2006), exams, or even to take medication at the proper time (e.g.: (op den Akker et al. 2011)).

Moreover, many of these devices integrate video and/or voice recording that can be accessed on the phone or transferred to one's computer and accessed at a later moment. One example is the study of Smith *et al.* (2010) where dietary intake was assessed and recorded with video input. The authors suggest that, although there seems to be significant adherence from the adolescents who participated in the studies, the design of the mobile phone food records needs to accommodate the lifestyles of its users to ensure useful images and continuous use throughout the day or multiple days. Whittaker *et al.* (2008) developed a multimedia system that encourages smoking cessation among youth through small videos. Some videos were recorded by a role model talking about her personal experience while quitting smoking whereas others gave information from tobacco industries and the effects of smoking. In their pilot study, 60% of the participants quit smoking during the program.

Information technologies emphasize the importance of social interaction, collaboration, and sharing information through online support groups, social networks, or, the new *in-vogue* term, virtual communities (Varlamis & Apostolakis 2006; Eysenbach et al. 2004). Interventions that draw on social influence commonly use one, or a combination, of the following strategies: peer-to-peer influence, i.e. influence from people who are working on the same goal either as a support or competition; social support from family and friends, and; peers modeling through change of information among users in the same situation.

To sum up, the context awareness and high-level of interaction allowed by the smartphones make them strong candidates to be used as 'biodevices' for monitoring different parameters related to personal health. Moreover, mobile phone interventions have the capacity to interact with the individual with much greater frequency and in the context of the behavior, contrarily to what happens in e-Health interventions. In other words, when compared to e-Health interventions, mHealth allows not only the analysis of data from self-reports but also from embedded sensors, and personal information memorized in the mobile-phone (e.g. calendar, pictures, video) establishing a complete scenario of psychophysiological state, social context, activity level, and behavior patterns over time. In this way, it is possible to create just-in-time interventions that support the user when most needed.

In their study, Klasnja & Pratt (2012) point out some of the issues resulting from automated sensing for tracking, such as calibration and measurement errors, connection problems and the misclassification of different activities (e.g.: cycling, walking, and running). Mosa *et al.* (2012) add some other challenges faced by smartphone-based healthcare interventions: "limited battery life, small screen size, potentially erroneous data input, computer viruses, magnetic interference with medical devices, potentially inefficient patient-physician interactions, loss or theft, and breaches of data privacy and security". This last concern relates to health data security and confidentiality. Who can access the personal data and with which purpose? The World Health Organization stresses the importance of guaranteeing the security of citizen information by programs using mHealth technology (WHO 2011). Whittaker (2012) also reminds that the policy and regulatory environment must be adapted to fulfill the questions concerning privacy, security, and regulation of mHealth interventions. Although not directly related to technical problems, Patrick *et al.* (2008) advert to the risks inherent with the ubiquitous use of smartphones originated by a lack of focus in daily activities, such as calling/texting while driving or walking .

It is not unexpected that the number of healthcare related smartphone applications (apps) increases every day. Promotion of healthy lifestyle is one of the most recurrent topics. Applications such as myfitnesspal[12] and sparkpeople[13] help people in tracking nutrition and physical activity routines using features such as calorie intake and energy expenditure counting, reminders for special dietary needs, suggestions for exercising, etc. These native journaling applications differ from traditional health behavior interventions in a way that they tailor the process of changing to the individual's baseline status using, for that purpose, models of individual behavioral change. Social Cognitive Theory is the primary theoretical basis in intervention literature (Riley et al. 2011). The adaptation of the intervention to the current status of the individual is either auto-adjusted based on computer algorithms or manually adjusted by health professionals.

3.3.2 Body Area Networks and Related Devices

A study from 2006 reports that, at that time, individuals were within arm's reach of their mobile phones on average 58% of the time (Patel et al. 2006). Considering the growth in number and sophistication of mobile phones, these devices assume an important role as the hub of a Body Area Network (BAN), formally defined by IEEE 802.15[14] as "a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics/personal entertainment and other". In this report, only the medical application is considered. A wireless interface to a mobile phone enables monitoring, centralized tracking of data over time and near real-time data processing. This data can subsequently be analyzed by a health professional or provided exclusively to the subject/patient.

In the recent years the way to promote and evaluate daily physical activity evolved from written self-reports to step counters, ambulatory activity sensing tools and interactive social games, often mixing real and virtual environments. Compared to the traditional physician involvement, the computing technologies developed lately are not only cost-effective but can also be delivered anytime and anywhere. Consolvo *et al.* (2006) identify the key design requirements for technologies that encourage physical activity:

- Assure that users receive proper credit for their accomplishments;
- Allow real-time self-monitoring and over past behavior;
- Support social influence (pressure, support and communication);

[12] http://www.myfitnesspal.com/
[13] http://www.sparkpeople.com/
[14] http://ieee802.org/15/pub/TG6.html

- Consider practical constraints such as the size of the sensor and the usability of the application;

Among the most used sensors are pedometers – small battery operated devices that track the amount of movement (steps) of an individual over the day. A pedometer considers a step to be any kind of manipulation that alternates ascending and descending accelerations. This method has a serious limitation with regards to its accuracy. The biggest critics to these devices refer to the lack of information about frequency, intensity or duration of physical activity (Trost 2001). However, due to its easy wearability, usually clipped to the user's waistband, these are perhaps the most common commercial devices that detect physical activity throughout the day. *Fish'n'Steps* (Lin et al. 2006) is a BAN consisted of an interactive computer game where the user's step counting is linked to the size and facial expression of a virtual fish in a virtual fish tank that includes the fishes of other users (Figure 5). The larger the number of steps, the bigger and happier the fish is. This study uses the Transtheoretical Model and almost ¾ of the participants either advanced in the levels of stage-of-change or increased the number of daily steps.

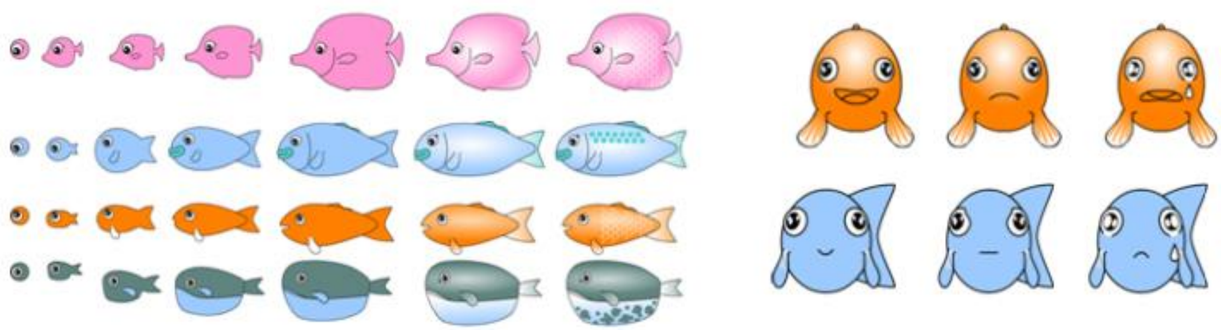

Figure 5 - Different growth levels (*left*) and examples of three facial expressions of the virtual characters (*right*) (Lin et al. 2006).

Another example of a BAN application is the UbiFit Garden. *UbiFit Garden* is a system to encourage regular physical activity that uses on-body sensing, real-time statistical modeling, and, a personal, mobile display also called glanceable display (Consolvo et al. 2009).This non-literal and aesthetic representation of physical activities resides on the "wallpaper" of a mobile phone in order to provide a subtle, but persistent, reminder whenever and wherever the phone is used. The algorithm was programmed in a way that recognizes activities as walking, running, cycling, using an elliptical trainer, or a stair machine. The amount, variety and size of flowers in the garden depend on the type and amount of exercise performed during the week (Figure 6).

A more complex example of an activity promotion tool is the one proposed by Bielik *et al.* (2012). *Move2Play* combines elements from theoretical frameworks (Goal-Setting Theory) with more interactive methods such as gamification, and social interaction. It uses all the capacities of a smartphone: works with built-in accelerometer, the information can be seen either in the mobile-phone application or on a web portal in order to be assessed by the parents and peers, promotes social encouragement and competition and still allows the connection to third-party applications. Till the moment of this research, there were no results from this study.

Figure 6 - *UbiFit Garden*'s glanceable display. Pictures on the left show the screen at the beginning of the week without any workout (*top*) and, after a while, a garden with workout variety (*bottom*). The big butterfly on the top-right corner of the screen (*right*) indicates this week's goal was met (Consolvo et al. 2008).

One challenge repeatedly mentioned in physical activity interventions is the long-term adherence to the programs. After the novelty effect, both adherence and effectiveness seem to decrease. In their systematic review, Muller-Riemenschneider *et al.* (2008) evaluated the effectiveness of physical activity interventions to increase levels of physical activity over 1 to 2 years. Tailored strategies concerning cultural differences between populations showed increased effectiveness but no conclusions were drawn regarding personalized interventions. Achterkamp *et al.* (2013) proposes a new approach that intends to overcome this issue by developing a personalized system both in terms of context-awareness and personalized feedback provided to the user. Results from this research are expected during the second half of 2013.

4. Requirements and Methodology

"Without requirements or design, programming is the art of adding bugs to an empty text file."

Louis Srygley

Chapter 4 will provide the requirements elicitation and the methodology adapted to fulfill such requirements. The requirements elicitation was performed according to the Sociotechnical Approach which defends that both patients and technical staff should be involved in all the steps of the technology development. A scenario in how the system can function will be also presented. The requirements identification resulted in three new modules that should be added to the system: the User Model Module, the Smart Reference Module and the Personalized Feedback Module. An overview of each one of these modules will be given in sub-chapter 4.2.

4.1 System design: sociotechnical approach

Designing a technology with applicability in healthcare raises specific challenges. More than 75% of telemedicine services fail after the pilot phase (Berg 1999). This means that a small number of telemedicine services become routinely used. One of the main barriers identified is the lack of user-acceptance (Broens et al. 2007). To combat this trend, Berg fosters the use of a sociotechnical approach in the design of healthcare technology.

The sociotechnical approach defends that the development of a new technology must start with the needs assessment (*meaning*) and lead to the technology through an iterative process of several steps (*bottom-up approach*). This is the reverse of the traditional design philosophy where technology comes first and meaning at the end (*top-down approach*) (Berg 1999). When applied to healthcare systems, both professionals and patients must be involved in specifying their needs and judgments during every stage of the development process. Therefore, a multidisciplinary team must work permanently together from the requirements elicitation to the final evaluation of the technology. The early phase of requirements elicitation should start with a user-centered perspective and end up with the technician-perspective in order to combine social and technical features of the system, i.e. functional and non-functional requirements.

In a multidisciplinary team communication difficulties arise. Patients, medical professionals and technicians lack a common language where all intervenients can easily understand each other. A scenario-based design technique can be the solution for this problem (Figure 7). Huis in't Veld *et al.* (2010) define a scenario "as a concrete description of an activity that the users engage in when performing specific tasks". Scenarios include agents or actors with specific goals or objectives. To achieve these goals, the agents take actions and interact with the technology (Carroll 2000). The 'agents' or 'actors' are called *personas* and represent "fictional persons that serve as a vehicle to illustrate envisioned use of technology in scenarios" (van 't Klooster et al. 2011). Scenarios are useful for understanding requirements, discuss systems' properties, the behavior of people interacting with the system and the interaction context (Sutcliffe, 2003; van 't Klooster et al., 2012).

In early design stages, the scenario is written from a user-centered perspective revealing PACT (People, Activities, Context and Technology) properties. A second phase, or scenario refinement, includes a FICS approach. FICS stands for "Functionalities, Interactions, Content and Service" and describes the scenario from the perspective of the designer/technician. The functionalities represent the abilities of the system; the interaction describes the interactions between people (either user or professional) and technology; the content consists of the data, information or knowledge that should be stored in the system, and finally the service respects to the functional and technical requirements on the system (van 't Klooster et al. 2012).

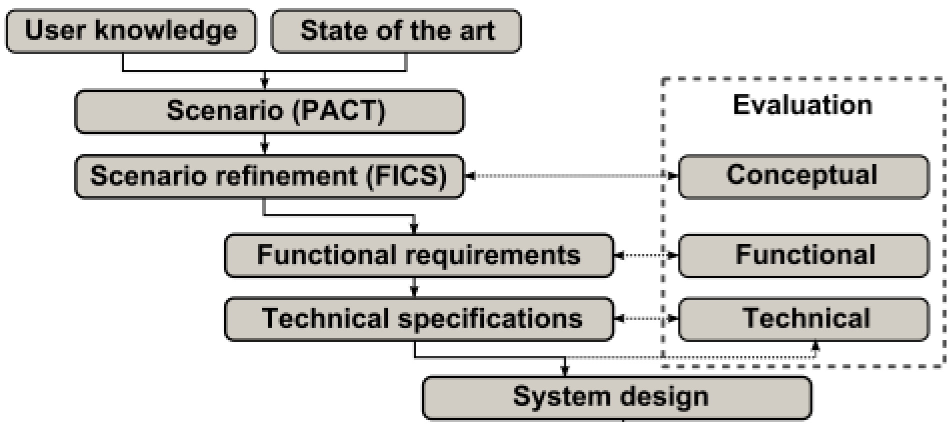

Figure 7 - Overview of a scenario-based method to define user-requirements (op den Akker et al. 2012).

The scenario and PACT & FICS analysis should be performed in a cyclic and iterative process. Aiming a better understanding of the framework, in the presented research it was decided to first introduce the scenario, followed by the PACT analysis. Additionally, a FICS analysis was made for each one of the activities identified in the PACT.

4.1.2 Scenario and Requirements elicitation

The requirements elicitation of the present research results from previous research performed at RRD, combined with brainstorming with RRD employees involved in the development of telemedicine systems. The brainstorming sessions lead to the scenario in the text box below.

Peter is a 40-year-old knowledge worker whose office job has led to a decrease of his physical activity level over the last years. Since a few months ago, Peter has been feeling demotivated and lacking energy especially at the end of the day. He knows something is wrong and wants to change it, but does not know how to do it. Aware about his weight gain, Peter decides to meet his GP for a general check-up. Peter's doctor advises the Activity Coach, a new system that has shown good results in other patients in similar situations. The Activity Coach consists of a body wearable sensor and a smartphone application that allows Peter to monitor his physical activity level throughout the day, providing achievable daily goals.

Peter got the system this morning. He starts the smartphone application for the first time and is prompted with two questionnaires developed based on theories of individual behavioral change. The questionnaires aim to classify his self-efficacy level as well as his current stage-of-change.

Peter was informed by his doctor that during the first week there would not be any kind of feedback. This is the ‘baseline period’, a period when the system will analyze his daily activity habits in order to choose the most appropriate feedback strategy for Peter.

One week has passed and Peter starts receiving messages on his smartphone. At the end of the day, Peter compares his performance with what he should have accomplished. The graph on the screen confirms his suspicions. Most of his physical activity occurs during the morning. After work, Peter feels exhausted and normally stays on the couch after dinner. Peter feels stimulated by the goals set by the system; he feels that the goals are challenging but still achievable. Furthermore, Peter receives messages periodically giving either feedback on his current level of physical activity or suggestions of activities that would help him reach his goals. Peter is now also able to recognize that short breaks from work can make the difference. Every two hours, Peter tries to make a small walk around the office. He feels better, and sees the results on the screen of his smartphone.

Peter does not work on Wednesdays. His physical activity pattern is completely different from the other working days and the system recognizes it stimulating him to work out more on this specific day.

Peter was never a sporty person; he has had problems with his physical activity levels since his adolescence. The motivational messages have helped him to face some personal barriers and now Peter feels much more confident on his way to a healthier lifestyle. Peter even started playing football with his colleagues twice a week. The system has automatically set his goals higher on these weekdays.

Three weeks passed since Peter got the system. Now he has to answer the same questionnaire provided at the first time. This time Peter feels much more confident about himself. During the last three weeks, he has accomplished his goals and feels able to evaluate himself much better now.

During the following days Peter recognizes that the feedback he is receiving is not the same as during the first two weeks. The system now identifies him as another *persona* and, contrarily to what happened during the first weeks, now he receives more messages reassuring that his levels of physical activity are becoming better.

After a few months Peter visits his GP again. The general level of physical activity has increased and Peter's GP sets now a higher upper limit for Peter's daily goals of physical activity in order to keep challenging goals.

Peter has the impression that the system was designed for him and is motivated to continue using it.

Table 4 presents the requirement elicitation from the user-centered approach (PACT) considering the framework proposed by (Huis in 't Veld et al. 2010). A technical analysis was performed for each one of the activities identified (Table 5).

Table 4 - PACT analysis of the scenario presented in the text box.

People	**Patient population: socio-demographical variables**	- 40-year-old - Male
	Patient population: pathology	- Sedentary lifestyle - First complaints (fatigue, demotivation, weight gain)
	Patient population: tele-treatment skills	- Unknown
	Professionals involved	- Peter's GP
	Clinical benefits: patient	- Peter's PA increases and also his mental well being - In the long term the chance that Peter suffers from a chronic disease is reduced
	Clinical benefits: professional	- Give a more accurate medical advice based on the level and pattern of Peter's physical activity - Peter will be healthier without the intervention of his GP
Activities	**Treatment protocol: professional procedures**	- Advise a new device - Inform about the system specifications and instructions - Set upper limit for the goals
	Treatment protocol: patient procedures	- Answer the questionnaires
	Treatment protocol: quality of treatment	1. Monitor physical activity throughout the day 2. Classify self-efficacy and stage-of-change 3. Analyze activity habits 4. Include different feedback strategies 5. Provide real-time feedback based on physical activity 6. Provide motivational cues based on real-time activity level

		7. Allow goal-setting based on context awareness 8. Update the feedback strategies with a certain periodicity
Context	**Rationale behind medical innovations** (Socio-medical relevance of the service)	- Increase treatment intensity - Quality of care - Save healthcare professional's time in routine measurements and follow-ups[15]
	Privacy considerations	- Who owns the data? How is it stored? How is it accessed? How is it transferred? Who can access it?
	Safety considerations	- Do not provide advices that could be harmful for the patient
	Locations	- Use of the system is independent on location and time of the day except of underwater environments
Technology	**Measurements** (input content)	- Physical activity - Questionnaires for behavioral constructs (stage-of-change and self-efficacy)
	Measurements (output content)	- Real-time physical activity - Motivational messages
	Measurement communication (protocol)	- Plot or text (feedback on physical activity) - Vibration and sound of the smartphone when receiving a motivational cue

Table 5 - FICS analysis of each one of the activities identified in Table 4.

Activity 1 - Monitor physical activity throughout the day

Functionality	- Measure physical activity throughout the day
Interaction	- Sensor measures the physical activity of the user
Content	- Physical activity expressed as IMA counts per minute
Service	- Three-axial accelerometer that measure 3D acceleration

Activity 2 – Classify stage-of-change and self-efficacy

Functionality	- Classify stage-of-change and self-efficacy
Interaction	- User answers the questionnaires
Content	- Self-efficacy and stage-of-change levels

Service	- Graphical User Interface:
	  - Display a questionnaire on the screen to classify stage-of-change in a set of multiple choice questions
	  - Display a questionnaire on the screen to classify self-efficacy with eight questions presented as a visual analog scale

[15] Although not mentioned in the scenario, this is the motto of Telemedicine.

	- Smartphone application

Activity 3 – Analyze activity habits

Functionality	- Verify if there is data to analyze - Calculate averages over different periods of the day (morning/afternoon/evening/day) - Combine daily data with the data from the same days of the week
Interaction	- No interaction with patient or healthcare professional
Content	- Average over different periods of the day - Combined averages of data measured in the same day of the week
Service	- Smartphone application connected to three-axial accelerometer via Bluetooth

Activity 4 & 8 – Include different feedback strategies

Functionality	- Based on stage-of-change, self-efficacy and daily activity analysis, choose the best feedback strategy for the user - Update the feedback strategy periodically
Interaction	- User answers the questionnaires and sensor measures physical activity
Content	- Feedback strategy adopted to the user - Stage-of-change - Self-efficacy level - Daily activity data
Service	- Smartphone application connected to three-axial accelerometer via Bluetooth

Activity 5 – Provide real-time feedback based on physical activity

Functionality	- Compare activity with the goal line
Interaction	- Display feedback in plot representation
Content	- Daily activity data - Goal line
Service	- Graphical User Interface - Smartphone application connected to three-axial accelerometer via Bluetooth

Activity 6 – Provide motivational cues based on real-time activity level

Functionality	- Based on the feedback strategy adopted to the user and in the comparison of real-time physical activity with the goal line, provide motivational cues to the user
Interaction	- Display feedback in text representation
Content	- Feedback strategy adopted to the user - Daily activity data - Goal line - Motivational cues
Service	- Graphical User Interface - Smartphone application connected to three-axial accelerometer via Bluetooth

Activity 7 – Allow goal-setting based on context awareness

Functionality	- Based on the feedback strategy adopted to the user and in the comparison of real-time physical activity with the goal line, provide motivational cues to the user
Interaction	- Display feedback in text representation
Content	- Feedback strategy adopted to the user

	- Daily activity data - Goal line - Motivational cues
Service	- Graphical User Interface - Smartphone application connected to three-axial accelerometer via Bluetooth

4.2 Algorithms

The aforementioned requirements were implemented in the Activity Coach system developed at RRD. The Activity Coach has a modular architecture that allows the easy incorporation of different modules in the system. This work adds three modules to the system described in (op den Akker et al. 2012): the *User Model Module* – responsible for collecting, storing and providing all the information regarding the user to other modules, the *Smart Reference Module* – responsible for analyzing the daily IMA data and for creating a new goal line for the upcoming day and, the *Personalized Feedback Module* – responsible for identifying the most suitable feedback strategy to a specific user at a certain moment and managing the real-time motivational cues given to the user. The three modules are described in detail below.

4.2.1 User Model Module

The *User Model Module* gathers all the information from the user. Any module that measures and/or collects user-related data – either from a sensor (e.g. heart-rate sensor) or from direct user-input (e.g. questionnaires) – can send the information to the *User Model Module*, which will store the data and keep track of the updates for future analysis. Inversely, any module of the Activity Coach can request all sorts of information from the *User Model Module* at any time.

The presented implementation only receives data from the *Personalized Feedback Module* and from the *Smart Reference Module* but the idea is that, in future improvements, all the data regarding the user would be sent to this module. The idea of a module collecting the data from the user is supported by literature as in e.g. (Bielik et al. 2012).

The data is stored in an Extensible Markup Language (XML) file and can be accessed by all the modules at any time.

4.2.2 Smart Reference Module

The purpose of the *Smart Reference Module* is to define a goal line for each day. In the previous versions of the Activity Coach, the goal line was based on a combination of data acquired from healthy control subjects and data measured from the patient. The healthcare professional could update the goal line manually via the web-portal and configure the exact date when the new goal line should be used. Although a new goal line could be configured every day, this would be highly time-consuming which contradicts one of the objectives of telemedicine: to reduce the time spent by healthcare professionals in routine (measurements) procedures. Actually, in several cases, the goal line remained the same throughout the whole intervention.

The new version suggests an adaptive approach that automatically creates a new goal line every day based on (1) parameters defined in the configuration file and (2) the data of the user from previous days. The basic idea is that each day of the week has a different goal line, taking into account the weekly routine of the user.

✓ *Daily Summary*

At the beginning of the new day, the *Smart Reference Module* creates a summary of the previous day that includes the average of different periods of the day (morning/afternoon/evening/day), the last IMA value registered, as well as a summary of IMA values spread equally over the day. The *Daily Summary* also includes the variables necessary for the classification of the daily activity pattern, either as ‘proper’ or ‘improper’, as a result of the comparison between the real activity pattern and the goal line.

The two factors influencing this classification are (1) the amount of activity that the user did on that day and (2) the variation of activity throughout the day. The amount of activity is considered ‘good’ if the ratio between the end point of the activity and the end point of the goal line is lower than the value defined by a certain threshold. This value can be adapted for each case and is set to 10% as default. If the user closes the application before the ending time of the goal line, the system calculates an interpolated end point using the weighted averages of the different periods of the day from previous data of the same weekday (see section 5.3).

The method used for classification of the activity pattern is the same as used by Tabak *et al.*(2013). The first step is to calculate the absolute difference between the activity line and the goal line for each point. Then the line is translated vertically with a constant ‘c’ to obtain the smallest difference. This mean smallest cumulative deviation from the goal line is divided by the mean cumulative activity value of the goal line and expressed as a percentage – *percentage of activity balance* (Figure 8). This percentage is 100% if the activity line resembles exactly the goal line. A daily pattern was considered ‘good’ if the percentage is higher than the value defined by a certain threshold. By default this value is 70%.

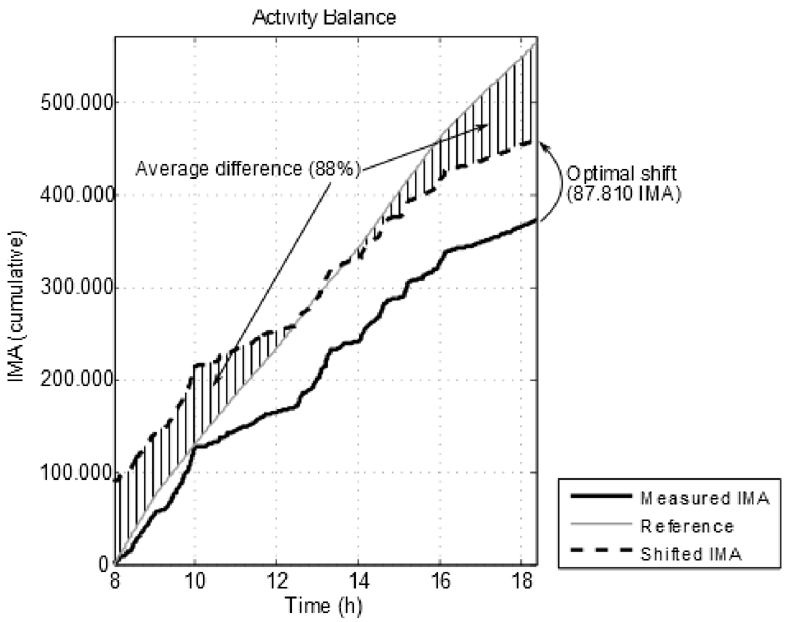

Figure 8 - Example of calculation of the percentage of activity balance. Adapted from (Tabak et al. 2013).

✓ *Goal Line*

A *goal line* is a function that represents the cumulative variation of IMAs that the user should achieve on a specific day. The goal line is characterized by its end goal – the last cumulative value of the plot, and pattern – variation of IMA values through the day (Figure 9). This function is visualized in a plot where the abscissa corresponds to the time, in hours, and the ordinate to the cumulative IMA values.

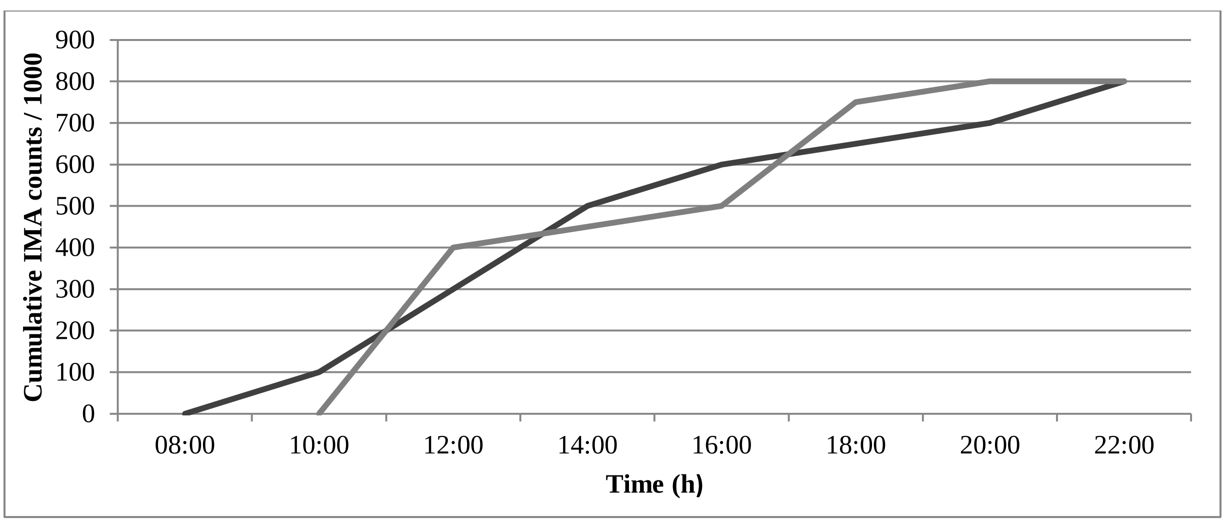

Figure 9 - Example of two goal lines with the same end goal but different pattern.

Empirical research suggests that chronic disease patients struggle to balance the activity level throughout the day (e.g. Evering et al., 2011; Tabak et al., 2012). In a case control study, Evering *et al.* (2011) conclude that patients with Chronic Fatigue Syndrome, when compared to control subjects, have normal levels of physical activity in the morning and reduced levels in the afternoon and evening. The authors suggest that patients are not aware that they spend a lot of energy during the morning and do not have energy left for the afternoon and evening.

This module intends to help users adjusting the activity pattern, for instance, lowering the activity in the morning and increasing in the afternoon and evening. However we are aware that, for example due to their jobs, users are not able to have the same activity level during the working and non-working hours. The difference in activity levels between working and non-working days is taken into account in our application. Thorp *et al.* (2012) studied the different activity habits on working and non-working days of Australian office-workers. This study reports that on working days between 09:00 and 16:59 subjects tended to be highly sedentary and suggests that the best period to encourage physical activity is immediately after work. Therefore, different levels of activity should be translated in different end goals and patterns. Our application aims to solve this issue by setting different sub-goals during the day. The *Smart Reference Module* also allows specific configuration for each day of the week.

The GP, physiotherapist or the user define the daily end goal of the user in terms of a cumulative IMA value and different *breakpoints*, i.e. the percentage of total IMA that the user should accomplish at certain moments of the day. The idea is to help the user to adopt a balanced physical activity pattern throughout the day. For instance, a user should be able to accomplish 500.000 IMA on Mondays and 40% of this value should be achieved before 12 o'clock and 70% before 16 o'clock, leaving 30% of the desired physical activity to the evening (Table 6). In this way, the goal line will not be a linear function, as in its previous versions, but several linear functions connecting the breakpoints. The number of breakpoints is not restricted and can vary between the different days of the week. Following the same example, the new goal line will be used on the next Monday.

Table 6 - Example of configuration for Mondays and Tuesdays. One can see the daily goal and the breakpoints that will be considered when generating the goal line. The configuration for Tuesday is appropriate, for example, for a user who goes jogging every Tuesday morning.

Day of the week	Monday		Tuesday	
Daily Goal (IMA)	500.000		700.00	
Breakpoints	*Time*	*Percentage*	*Time*	*Percentage*
	08:00	0%	07:00	0%
	12:00	40%	08:00	15%
	16:00	70%	13:00	50%
	22:00	100%	18:00	80%
			22:00	100%

If the user does not use the application for one or more days the system defines the respective goal lines based on previous records or on the data from the configuration.

- ✓ Weekday Data Record

After creating a Daily Summary, the application combines the new data with previous data from the same day of the week. For instance, if yesterday was Monday, the system combines this data with the data from previous Mondays. The average of each period is calculated using Linear Weighted Moving

Average (LWMA) (Equation 2). This method was chosen instead of an arithmetical average to take into account the evolution of the user. In this way the more recent a measurement, the bigger its weight in the calculation of the average.

$$LWMA(newPoint, N)_i = \frac{\sum_{j=1}^{N} newPoint_{i-N+j} \times (i-N+j)}{\sum_{j=1}^{N} j} \qquad \text{(Equation 2)}$$

The system updates the XML file of the respective day of the week with the new daily summary information.

4.2.3 Personalized Feedback Module

Different users require different feedback approaches. Dekker-van Weering *et al.* (2012) suggest that personalized messages have the potential to influence activity behavior. This study analyzed the response of Chronic Low Back Pain patients to different types of messages (*encouraging*, *neutral* and *discouraging*) and whether this response was influenced by the stage-of-change and the pain intensity level. The authors concluded that patients in different stages-of-change respond differently to the feedback messages. For instance, one patient in the *contemplation* phase (see chapter 3.2.2) showed the lowest response to the feedback messages while patients in the preparation or maintenance phase showed high response to the messages. This suggests that the content of the messages should be personalized to improve the outcomes.

Work-package 5 from the SWELL Project (SWELL-WP5) suggested three variables that should be considered in a way to provide adaptive messages to the user: self-efficacy level, stage-of-change and baseline activity (SWELL Project 2012a). For example, a user with high-level self-efficacy who is able to balance his physical activity through the day does not need the same guidance as another user with low-level of physical activity and who spends all the energy in the morning and does not have any energy left for the afternoon or evening.

Based on the different variables, SWELL-WP5 identified eight different *personas* (Table 7), who can be assigned to one of six different feedback strategies (Table 8). A user has 'intention to change' after recognizing the need to change his daily physical activity and if he is planning to do so within the next 6 months, the next month, or if he already started taking action (stage-of-change: *contemplation*, *preparation* or *action*). If a user is not aware of his problem or if he has already been active for the last six months, then it is considered that there is 'no intention to change' (stage-of-change: *pre-contemplation* and *maintenance*). For more information on the Transtheoretical model see chapter 3.2.2.

Table 7 - Overview of *personas* identified by the SWELL-WP5. It is considered that subjects have an intention to change when their stage-of-change is *contemplation*, *preparation* or *action*. If the stage-of-change is *pre-contemplation* or *maintenance* it is considered that there is 'no intention to change'.

			Activity Pattern	
			IMPROPER	PROPER
INTENTION TO CHANGE	Self-efficacy	LOW	Persona 1	Persona 2
		AVERAGE/ HIGH	Persona 3	Persona 4
NO INTENTION TO CHANGE	Self-efficacy	LOW	Persona 5	Persona 6
		AVERAGE/ HIGH	Persona 7	Persona 8

Table 8 - Feedback strategies (FBS) for each one of the personas identified in Table 7.

			Activity Pattern	
			IMPROPER	PROPER
INTENTION TO CHANGE	Self-efficacy	LOW	FBS1: Increase self-efficacy By vicarious experience/feedback and letting users experience success	FBS2: Increase self-efficacy Reassure users that level of activity is high enough
		AVERAGE/ HIGH	FBS3: Take action Support user to achieve better balanced life-style. Provide tools that can help the user to distribute activity better	FBS4: Maintain situation Let the user set goals. Keep challenging and fun
NO INTENTION TO CHANGE	Self-efficacy	LOW	FBS5: Make aware and increase self-efficacy Confront with actual level of physical activity. Increase self-efficacy by vicarious experience/feedback and letting users experience success.	FBS2: Increase self-efficacy Reassure users that level of activity is high enough
		AVERAGE/ HIGH	FBS6: Make subject aware and take action Confront with actual level of physical activity. Provide tools that can help the user to distribute activity better	FBS4: Maintain situation Let the user set goals. Keep challenging and fun

The *Personalized Feedback Module* consists of the technological implementation of the requirements identified beforehand. In the presented implementation, the content of the messages given to the user depends on (1) the feedback strategy chosen to this specific user based on his level of self-efficacy, stage-of-change and daily pattern of physical activity, and (2) the current level of physical activity when compared to the goal line.

The levels of self-efficacy and stage-of-change are determined using the answers to the questionnaires presented in Table 9 and Table 10, respectively. The final score of the self-efficacy level is determined summing the answer to each one of the questions. As each question can be answered with a score between 0 and 100, the final score of the self-efficacy level ranges between 0 and 800. A final result below 270 is considered 'low' and above 542 is 'high'; in between is considered 'average'.

Table 9 – Questionnaire implemented to determine the self-efficacy level of the user. The user scores each of the eight questions with a score from 0 to 100. The sum of all the answers indicates the self-efficacy level. This questionnaire was adapted from (Rodgers et al. 2008) and (Marcus 1992).

On a scale of 0-100 how confident are you that you would be able to…
… exercise when you are lacking of time?
… exercise when you lack energy?
… exercise when you feel discomfort?
… exercise when the weather is not good (for example rain or snow)?
… include exercise in your daily routine?
… consistently exercise three times per week?
… arrange your schedule to include regular exercise?
… exercise when you have a lot of things to do?

Table 10 - Questionnaire implemented to determine the stage-of-change of the user and respective levels. This questionnaire has one only question and its answer indicates the stage-of-change of the user. Adapted from (Prochaska & DiClemente 1983).

Are you at least 5 times per week physically active (walking, cycling, or doing sports) for more than 30 minutes each time?	***Classification***
Yes, I have been for MORE than 6 months.	Maintenance
Yes, I have been for LESS than 6 months.	Action
No, but I intend to in the next 30 days.	Preparation
No, but I intend to in the next 6 months.	Contemplation
No, and I do NOT intend to in the next 6 months.	Pre-contemplation

In its current version, the questionnaires are provided to the user every three weeks, probably resulting in a new feedback strategy. To our knowledge, till the present moment there is no conclusive literature on the most appropriate time interval to measure self-efficacy and stage-of-change. We decided for three weeks between questionnaires and possibly adjust in the future according to the results of the first trials.

When the user answers the questionnaires, the *Personalized Feedback Module* requests the variables for the classification of the activity pattern (ratio between real end point and end goal and the balance of physical activity) from the *User Model Module* since the last feedback strategy update. It averages each one of the variables and using the thresholds defined in the configuration classifies the activity pattern as either ‘proper’ or ‘improper’.

For this research, the target group consists of individuals with a low level of self-efficacy. Therefore, although six feedback strategies were identified, the presented research only concerns FBS1, 2 and 5. The feedback strategies influence the content of the messages given to the user. FBS1 suits users who show intention to change the physical activity routine but have an improper activity pattern in combination with low level of self-efficacy. Therefore, the strategy to these users must be to increase self-efficacy level by letting them experience that similar users are also able to maintain a balanced level of activity (vicarious experience). These users benefit from easily achievable short-term goals in order to experience success. Feedback messages should be positive and complimenting.

On the other hand, FBS2 is appropriate for users who show a proper level of physical activity but have a low sense of self-efficacy, regardless the stage-of-change. The biggest concern in this case is the achievability of the goals. For instance, users can feel the need to change even when they already have a proper activity level which can lead to unachievable goals and consequent lack of motivation. In this way, FB2 focuses on letting the user experience success by complimenting and positive messages.

FBS5 intends to motivate and create awareness for those users who have an improper level of physical activity, low self-efficacy and no intention to change. This FBS aims at creating intention to change physical activity. In this case, messages should be complementing and informative in order to make the user aware of the necessity of changing the physical activity pattern and what would be the rewards from this change. Users should also be confronted with their improper level of physical activity. Self-efficacy level should be increased with the same strategies mentioned in FBS1 (vicarious experience and experience success).

The intention is to provide real-time motivational cues. In line with previous research conducted at RRD (Dekker-van Weering et al. 2012), the messages are divided into three groups: *encouraging*, *discouraging* and *neutral*. Encouraging and discouraging cues are given when the real-time activity is below or above the goal line, respectively. Neutral messages can be suggestions of activities or compliments if the deviation of the real-activity and the goal line is lower than the pre-defined threshold. Additionally, context factors – such as weather, day of the week, personal preferences of the user – can be considered when choosing the message to give to the user at a certain moment. The complete list of messages can be found in APPENDIX II.

Consider as an example a user that has recognized the need to increase his daily physical activity and is planning to do so within the next month (*preparation*), but is not convinced about his ability to change the behavior (low self-efficacy). After the first week, the Activity Coach determined that the user’s physical activity pattern should be adjusted considering that the user spend too much energy in the mornings and shows sedentary behavior during the evenings. Then, this user corresponds to *Persona 1* (Table 7) and is assigned to *Feedback Strategy 1* (Table 8). The motivational cues given to this user focus on increasing the self-efficacy level (e.g.: “You are well on your way to be more active, very good! Try to schedule a daily walk for the next week!”).

4.3 Evaluation protocol design

The intervention with users is divided into two distinct periods. The first one is the baseline period. During this time interval, normally constituted by seven days, the user does not receive any feedback. This is essentially a monitoring period that aims to establish a baseline of the user's physical activity as well as his/her daily activity pattern. When the baseline period is over, the actual intervention starts. The user receives real-time feedback and motivational cues throughout the day in order to increase the physical activity level and to balance activities over the day. It involves monitoring, coaching and feedback components.

In the previous version of the Activity Coach, the end-goal was set to be 110% of the average daily activity in the baseline period. This goal remained fixed throughout the intervention. In order to properly evaluate the new version, the algorithm needs time to adapt to the user's routine. For a reliable evaluation of the system, it would be necessary to perform a longitudinal study in order to evaluate both the self-adaptive and the behavior change component of the application. The time pre-defined for a master thesis research is not adequate for a longitudinal study, and as so, it is out of the scope of the presented research.

5. Design and Implementation

"Healthcare is a complex field to implement technology"

(Berg 1999)

Chapter 5 will focus on the implementation details of the modules introduced in Chapter 4. First, it will be given an overview of the system architecture of the Activity Coach allowing a better understanding of the interaction between different modules. Each one of the three other sub-chapters refers to one of the modules added to the system, covering input/output data and all the configuration details.

5.1 System Architecture

The Activity Coach – briefly introduced in section 2.3 – is a smartphone application developed at RRD to remotely monitor physical activity. The Activity Coach is implemented in Java with a hub-architecture, i.e. there is a central entity, the hub, which receives and sends messages from/to the other entities (Figure 10). The major building block in this architecture is the 'module'. Each module concerns a specific part of the software and can receive and/or send content from and to other modules. The hub operates as a moderator among the different modules considering that all the communication between modules is made through hub-Messages – XML format messages for which the content changes according to the specific need. This highly modular architecture is particularly important to ensure the extensibility of the application.

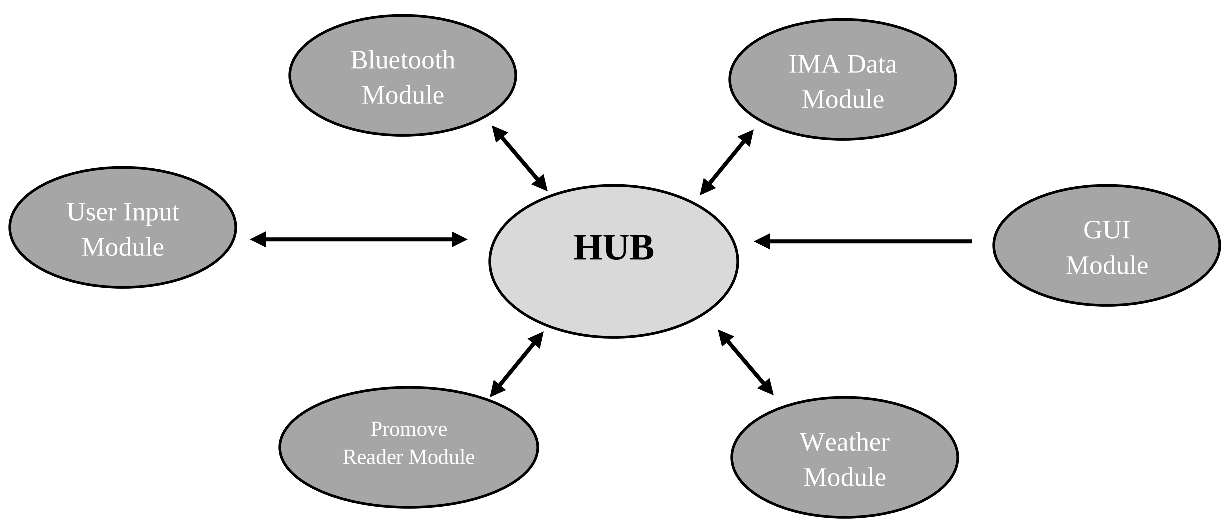

Figure 10 - Simplified architecture of the Activity Coach with some of the modules as an example.

The interaction between the modules in the case of this research will be shortly summarized. The *Promove Reader Module* reads the data from the ProMove sensor and sends it to the *IMAData Module*. The data is analyzed and stored by this module and can be accessed, via hub-message request, by any of the other modules. The *GUI Module*, as the name says, is the module responsible for the Graphical User Interface (GUI). Usually it shows the goal line and the activity of the user but it is also this module that provides the questionnaires and shows every kind of action on the screen. Inversely, the *User Input Module* reads the data entered by the user (e.g. answers to the questionnaires), stores the information and makes it available to the other modules. Figure 11 shows an early design of possible application configurations with different data streams and interactions between modules.

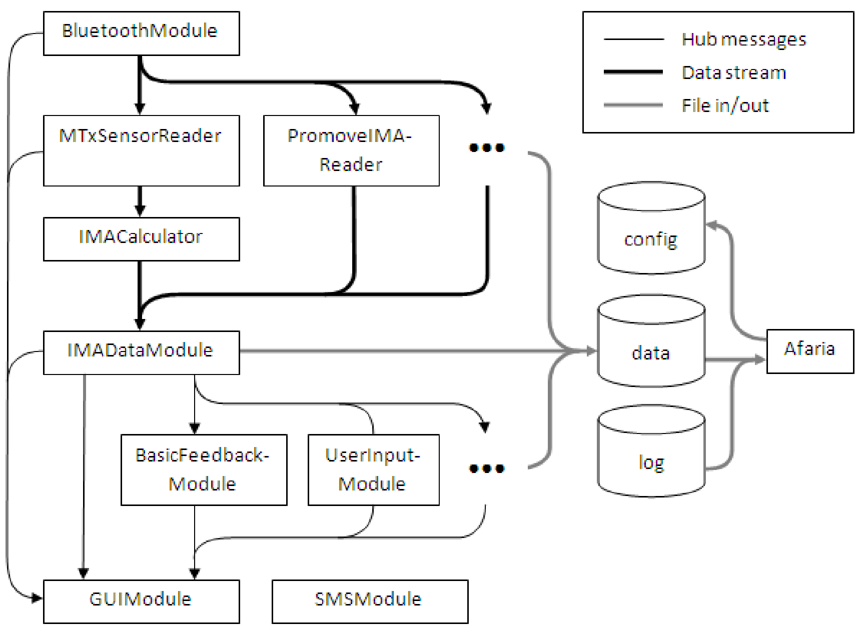

Figure 11 - Current configuration of the Activity Coach.

The ‘config’ directory (Figure 11) contains all the configuration details necessary to a specific situation. The configuration contains a list of pre-defined scenarios – a collection of configuration files that together determine the setup and behavior of the application. Each scenario uses specific modules. For example, some scenarios need the *Weather Module* while others do not. Each module also contains a ‘data’ directory where the data is stored.

The scenario presented in this research uses five modules previously developed at RRD (*Bluetooth Module*, *Promove Reader Module*, *IMAData Module*, *GUI Module*, and *User Input Module*) and three modules developed for this research (*User Model Module*, *Smart Reference Module*, and *Personalized Feedback Module*). The next three sub-chapters will describe the implementation of these modules in detail.

5.2 User Model Module

The *User Model Module* is the newly introduced module responsible for gathering, storing and providing the information related to the user. Its configuration file contains the parameters that the module will keep track of in this specific scenario (Figure 12). The parameters are aggregated into groups according to their topic/relevance. The new values of a parameter can be continuously stored (`enableHistory="true"`) or just store the last value updated (`enableHistory="false"`). The number of groups and parameters is not restricted, allowing specific configurations for each scenario.

```
<UserModel>
    <group name="behavioral_theories">
        <parameter name="selfEfficacy" enableHistory="true"/>
        <parameter name="stageOfChange" enableHistory="true"/>
        <parameter name="feedback_strategy" enableHistory="true"/>
    </group>
    <group name="daily_data">
        <parameter name="averageMorning" enableHistory="true"/>
        <parameter name="averageAfternoon" enableHistory="true"/>
        <parameter name="averageEvening" enableHistory="true"/>
        <parameter name="averageDay" enableHistory="true"/>
        <parameter name="endPointDay" enableHistory="true"/>
        <parameter name="percentage_pa_balance" enableHistory="true"/>
        <parameter name="ratioEndGoal" enableHistory="true"/>
    </group>
</UserModel>
```

Figure 12 - Example of the configuration file of the *User Model Module* for a specific scenario.

The *User Model Module* is also a provider of information to other modules. When it receives a request from one of the other modules, the User Model Module reads the last file stored in the data directory of this specific module (e.g. Figure 13) and sends a hub-message created specifically for this kind of interaction – the *User Model Message*. The *UserModelMessage* contains the name of the parameters requested and all the values available in a `<time,value>`-pair. It is possible to request all the values available of a certain parameter or only after a specified time (e.g. request the values of self-efficacy registered after the 1st of March, 2013). Several parameters can be provided in the same message. As an example, Figure 21 shows the interaction between this module and the *Personalized Feedback Module*.

```xml
<UserModelRecord>
  <Groups>
    <daily_data>
      <averageMorning time="76140000" value="0.5177622437477112" />
      <averageAfternoon time="76140000" value="0.626926600933075" />
      <averageEvening time="76140000" value="0.6111738085746765" />
      <averageDay time="76140000" value="0.5844427347183228" />
      <endPointDay time="76140000" value="456.8739013671875" />
      <percentage_pa_balance time="76140000" value="85.06511688232422" />
      <ratioEndGoal time="76140000" value="0.6555090546607971" />
    </daily_data>
    <behavioral_theories>
      <selfEfficacy time="1376661494886" value="49.0" />
      <stageOfChange time="1376661494843" value="precontemplation" />
      <feedback_strategy time="1376661495041" value="FEEDBACK_STRATEGY_2" />
    </behavioral_theories>
  </Groups>
</UserModelRecord>
```


Figure 13 - Example of User Model Record XML file. It contains information from both *Smart Reference* and *Personalized Feedback Module*.

5.3 Smart Reference Module

The main purpose of the *Smart Reference Module* is to create a goal line that motivates and encourages the user to engage in a properly balanced amount of physical activity. With that purpose, attainable yet challenging goals are provided to the user, taking into account the different days of the week. Other functionalities were added to the module foreseeing future versions of the application. This sub-chapter will describe in more detail the main functions of the module.

Figure 14 shows the flow of the initialization process of this module. When the application is launched, this module initializes automatically and, firstly it checks whether there is a *GoalLine* XML file in the 'ref' folder with the date of one week from yesterday – this means that if today is Monday, the algorithm checks if there is already a goal line for next Sunday. If yes, the module finishes the initialization immediately. This case would mean that this is not the first time the user starts the application on the current day. If there is no goal line defined, the *Smart Reference Module* checks the date of the last IMA data processed and sends a hub-message to the *IMAData Module* requesting all the data since that day till the beginning of the current day (00:00). If that is the case, the data is divided into different days. This way it is guaranteed that all the data is analyzed even if the user does not start the application during one or more days.

In the next step, the data of each day is analyzed separately and in chronological order. If the data of the day is not valid, the module checks if there is a *WeekdayDataRecord* XML from the same day of the week (e.g.: if yesterday was Sunday, the system searches from files from previous Sundays). If such a file exists, a new *Goal Line* XML file is created based on the data from the *Weekday Data Record*. If not, the module creates a default goal line based on the parameters from the configuration file. On the contrary, if the IMA data is valid, the module creates a new object *Daily Summary*. If there is a *WeekdayDataRecord* XML for the weekday of yesterday, the module reads the XML file and updates the parameters. After that, the new data is sent to the *User Model Module* and finally creates a new goal line that will be used in six days from the current day. The module finishes its initialization when all the data is analyzed and respective goal lines created.

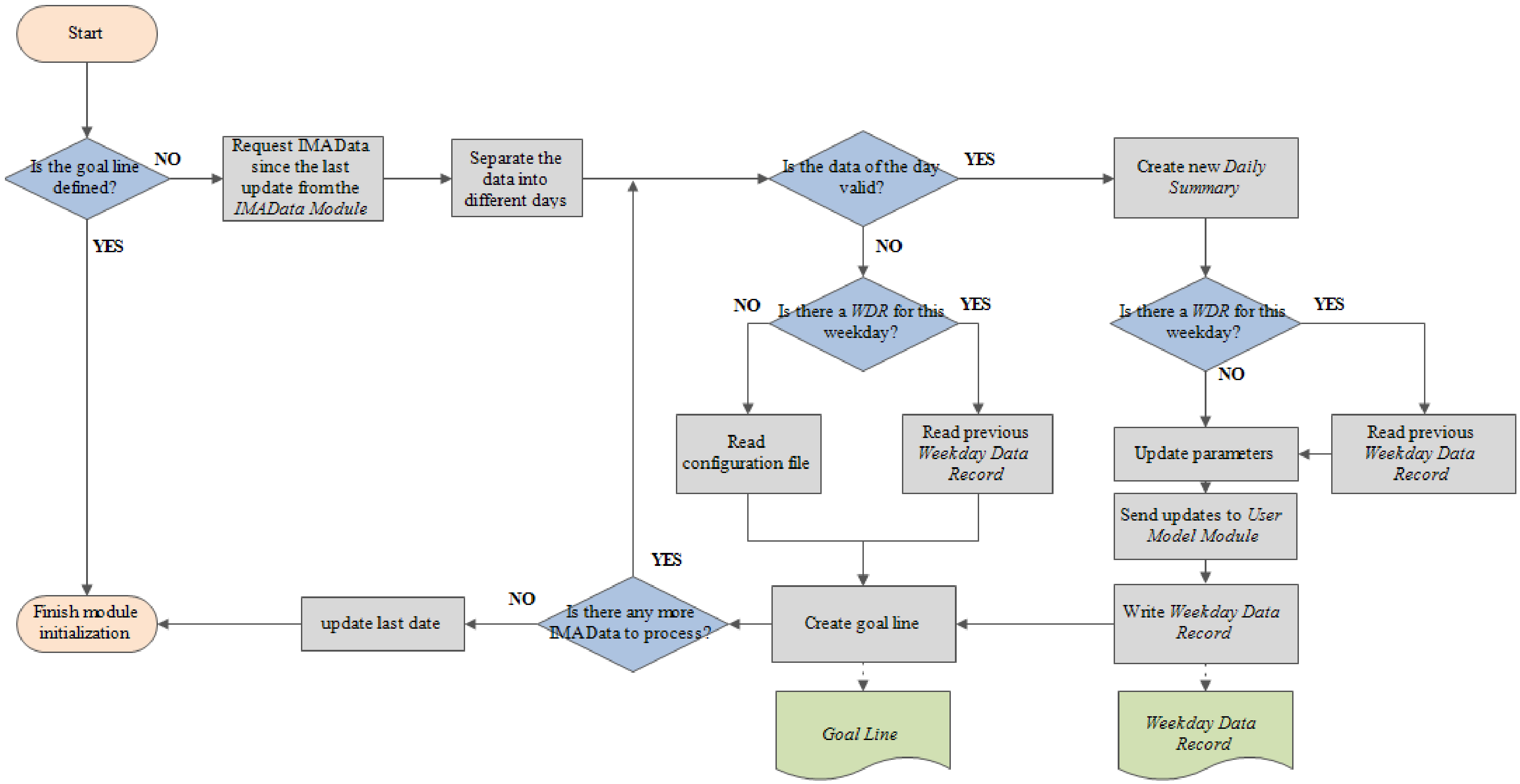

Figure 14 - Flowchart of the initialization of the Smart Reference Module. The initialization is concluded when all the previous data is processed and respective goal lines are created.

✓ *Daily Summary*

A new *DailySummary* is created if the IMA data from the previous day is valid, i.e. if there is a significant sample of data acquired from the sensor. As the name suggests, a *Daily Summary* contains the most relevant parameters of the day: date, end point of the day – *daily-end-point*, arithmetical average of IMA data per minute during a daily period, percentage of activity balance and several IMA values spread throughout the day – *saved-IMA-data*.

There are two possible scenarios regarding the definition of the end point of the day – *daily-end-point*: if the user switches off the application after the endpoint defined in the configuration file (it would be at 20:00 in the example represented in Figure 15), then the daily-end-point corresponds to the cumulative IMA value at that time. On the contrary, following the same example, if the user switches off the application, for example, at 17:00, the system interpolates an end point. Two implementation possibilities were considered in this case:

1. add a linear function from the last point acquired (in this case at 17:00) where the slope of the function corresponds to the daily IMA average per minute. This means that, in the same example, if the daily average per minute was 50 IMA, then the interpolated daily-end-point would correspond to the last value measured plus 9.000 IMA ($3x60x50 = 9.000$ IMA). Or,
2. consider different averages of the daily period per minute. Assume that the user closes the application at 13:00 and the end point should be at 20:00. In this case, the system will consider a linear function which slope corresponds to the IMA average per minute during the afternoon from previous days till 17:00 (pre-defined end of the afternoon) and, after that, another linear function with the slope corresponding to the IMA average per minute during the evening.

The second option was chosen considering that from previous research, users tend to show decreasing levels of physical activity from morning to afternoon and evening. The second method seemed to be the most accurate.

The algorithm also performs the calculation of the arithmetical average of IMA per minute during a daily period. Four different daily periods were defined: morning, afternoon, evening and the complete day. The time of the beginning of the afternoon and beginning of the evening is defined in the configuration file of this module. The other points are taken from the data; the start and end of the day correspond, in a normal case, to the time of the first and last measurement from the sensor, respectively. The averages of the periods are calculated considering these times. For example, if the user switches on the application at 11:00 and the end of the morning is defined at 12:00, the average of the morning will be the arithmetical average of IMA's per minute from 11:00 to 12:00. The calculation of the averages is based on the IMA values per 10-second interval instead of the cumulative values shown in the GUI. In the future, the start- and end-times of the periods should be taken from the agenda of the user (e.g.: beginning of the afternoon could coincide with the end of the lunch time).

The classification of the activity pattern is based on the work from Tabak *et al.*(2013). The goal line of that day is taken as a reference to classify the physical activity pattern. For this calculation, once again, only real-IMA-values, i.e. the values acquired by the sensor, are considered. The first step is to sort the real-IMA-values according to their distance to the reference line. The index of the median of the sorted list is found in order to calculate the required shift – constant 'c' – and translate vertically the real-

IMA-values line. After that, the average of the absolute difference between the real-IMA-values after the shift and the values from the goal line is calculated – defined as the real activity balance. Finally, the percentage of activity balance is calculated from the ratio between the real activity balance and the average of the goal line per minute. This percentage is 100% if the activity line resembles exactly the goal line. See Figure 8 (Chapter 4.2.2) for a better understanding of the method. The percentage of activity balance is sent to and stored by the *User Model Module*.

In each *Daily Summary*, the system stores a group of IMA points which periodicity corresponds to the parameter *paceIMAData* defined in the configuration file of the module. In the case represented in Figure 15, the system would store the data every 15 minutes (`paceIMAdata='15'`). To do so, the system calculates the arithmetical average between the points within that time interval. For example, the first point stored would be an average from the points from 08:00 to 08:15, the second from 08:15 to 08:30, and so on. These points are used to define the goal line.

- ✓ *Goal Line*

The configuration file of the *Smart Reference Module* includes the configuration details of the Goal Line. Following the same example given in sub-chapter 4.2.2, consider a user that should be able to accomplish 500.000 IMA on Mondays and 40% of this value should be achieved till 12.00 and 70% till 16.00, leaving 30% of the desired physical activity to the evening. Figure 15 shows part of the configuration file of the goal line of this user. The configuration file represents the ideal situation for this user. When there is no *Weekday Data Record* file stored in the system, the goal line created is based on the data from the configuration file.

```
<GoalLine
    paceIMAdata = "15"
    deviationAllowance = "10" >
    <DailyEndGoal monday="500000" tuesday="400000" wednesday="400000"
    thursday="500000" friday="400000" saturday="500000" sunday="400000" />
    <BreakPoints>
        <monday>
            <br time = "08:00" percentage = "0.0"/>
            <br time = "12:00" percentage = "0.4"/>
            <br time = "16:00" percentage = "0.7"/>
            <br time = "20:00" percentage = "1.0"/>
        </monday>
        <tuesday>
            <br time = "07:00" percentage = "0.0"/>
            <br time = "08:00" percentage = "0.15"/>
            <br time = "13:00" percentage = "0.5"/>
            <br time = "18:00" percentage = "0.8"/>
            <br time = "22:00" percentage = "1.0"/>
        </tuesday>
```

Figure 15 - Part of an example of a configuration file showing the goal for each day of the week and the breakpoints for Mondays and Tuesdays.

The first step when defining a new goal line is to find the end point of the new goal line – *desired-end-point*. If the deviation between the weighted-end-point from the same weekday and the daily goal defined in the configuration file is lower than the deviation allowance also pre-defined, the desired-end-point will be 100% plus the deviation allowance. In the case shown on Figure 15, the desired-end-point would be 110% of the weighted-end-point. Otherwise, the desired-end-point coincides with the daily goal from the configuration file. After that, the definition of a new goal line follows several steps:

1. From the saved-IMA-data aforementioned, the algorithm selects the points that are closest to the time of the breakpoints from the configuration file from each one of the *Daily Summaries* of that weekday. Following the same example, the points chosen would be (08:00, 12:00, 16:00, and 20:00);
2. The system calculates the weighted average of the data for each one of these breakpoints and divides this value by the desired-end-point in order to get the percentage of physical activity performed till that time;
3. If the IMA average for a certain breakpoint is zero, the percentage considered for the new goal line at that time is the same as defined in the configuration file. Otherwise, the algorithm calculates the arithmetical average between the percentage that the user accomplished and the one defined in the configuration file. The only exceptions are for the first and last breakpoint in which case the percentages are always 0 and 100, respectively;
4. Based on the percentages mentioned above and the desired-end-point, the system defines the new goal line and writes an XML file with the data.

✓ *Weekday Data Record*

The *Weekday Data Record* keeps track of the information of the same weekdays. For example, if yesterday was Monday, when initializing, the module checks if there is already an XML file stored in the system regarding previous Mondays. If yes, this file is read and the data is combined with the data from the new *Daily Summary* if the data of the day is valid.

The IMA averages per period explained above and the daily end-point are averaged with the data from previous days using the LWMA provided earlier in Equation 2. These values are sent to the *User Model Module* and the *Weekday Data Record* XML file for this weekday is updated (e.g. Figure 16).


```
<WeekdayDataRecord>
  <DailySummaries>
    <DailySummary Date="2012-05-06T08:00:00.000" avMorning="0.51776224" avEvening="0.6111738" avDay="0.58444273"
    ratioEndGoal="0.65550905" percentage_pa_balance="85.06512" endpoint="456.8739" avAfternoon="0.6269266">
      <ima time="2012-05-06T08:00:00.000" data="0.23248163" is-real="true" reference="6.5099993" />
      <ima time="2012-05-06T08:15:00.000" data="0.73366195" is-real="true" reference="20.459997" />
      <ima time="2012-05-06T08:30:00.000" data="1.2306379" is-real="true" reference="34.41" />
      <ima time="2012-05-06T08:45:00.000" data="1.7231083" is-real="true" reference="48.359997" />
      <ima time="2012-05-06T09:00:00.000" data="2.2183611" is-real="true" reference="61.375504" />
      <ima time="2012-05-06T09:15:00.000" data="2.705823" is-real="true" reference="73.323" />
      <ima time="2012-05-06T09:30:00.000" data="15.030924" is-real="true" reference="85.94445" />
      <ima time="2012-05-06T09:45:00.000" data="47.734173" is-real="true" reference="97.217995" />
      <ima time="2012-05-06T10:00:00.000" data="79.820045" is-real="true" reference="108.987015" />
```


Figure 16 - Part of a Weekday Data Record file.

5.4 Personalized Feedback Module

The *Personalized Feedback Module* is the third module added to the Activity Coach. The module requests the last feedback strategy from the *User Model Module* during its initialization. If the user was already assigned to a feedback strategy, the *Personalized Feedback Module* checks the last entry and updates it as the current feedback strategy. If this is not the case and there is no information about feedback strategies stored in the system, the *Personalized Feedback Module* asks the *User Input Module* to provide the questionnaires on self-efficacy and stage-of-change. The *GUI Module* receives the answers from the user and forwards them to the *Personalized Feedback Module* where they are analyzed. The *Personalized Feedback Module* also requests the variables necessary for the classification of the physical activity pattern from the *User Model Module*. Finally, the most suitable feedback strategy is chosen taking into account the criteria in Table 8 (Chapter 4.2.3). The same questionnaires are answered every three weeks. When this happens, the algorithm only considers the classification of daily pattern since the last feedback strategy update. Figure 17 represents a simplified sequence diagram of this process. The feedback strategy chosen determines the content of the feedback messages that the user will receive.

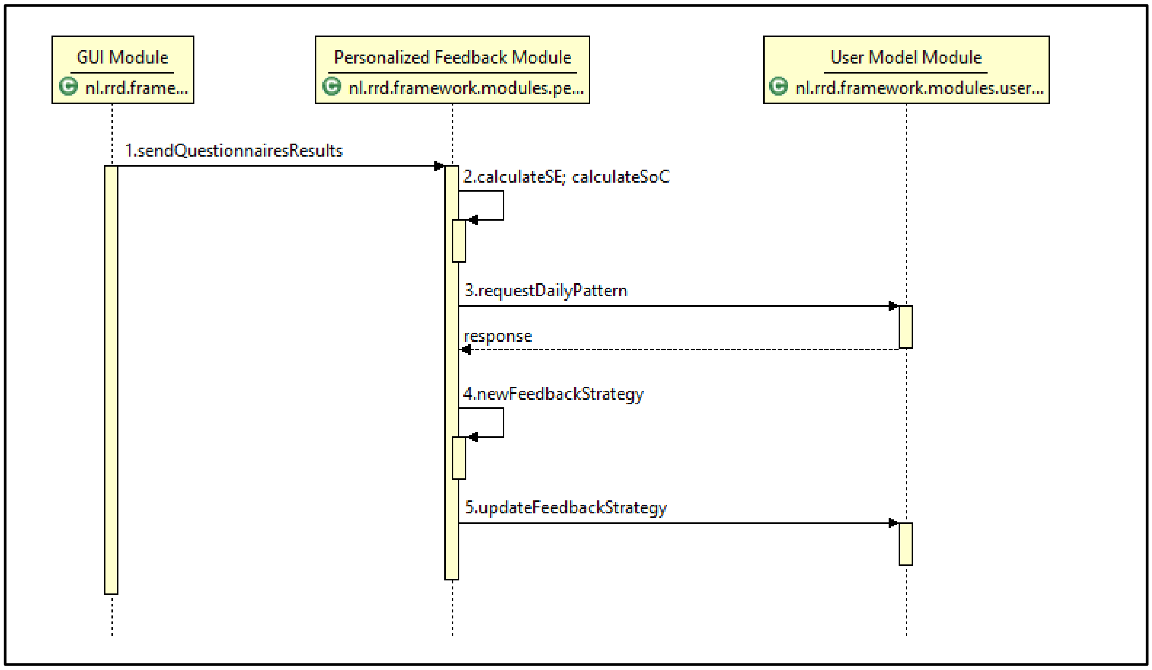

Figure 17 - Sequence diagram of the interaction between the *Personalized Feedback Module* and the *GUI Module* and the *User Model Module*.

✓ *Self-efficacy and stage-of-change assessment*

The self-efficacy level and stage-of-change are assessed by questionnaires given to the user every three weeks (Chapter 4.2.3). The self-efficacy level is determined by the sum of eight questions given to the user presented as a visual analog scale (Figure 18) and classified in high, average or low in accordance with the thresholds defined in the configuration file (Figure 20). The questionnaire to assess the stage-of-change is given as a multiple choice question (Figure 19).

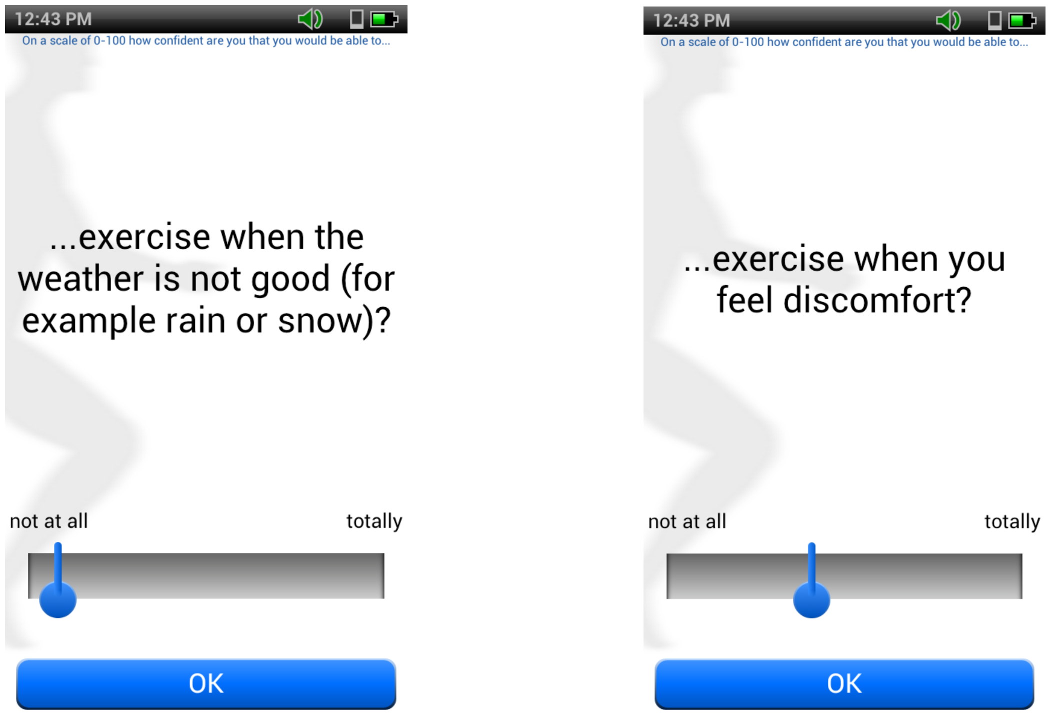

Figure 18 - Screenshot of two of the questions used to determine the self-efficacy level based on the questionnaire of Table 9.

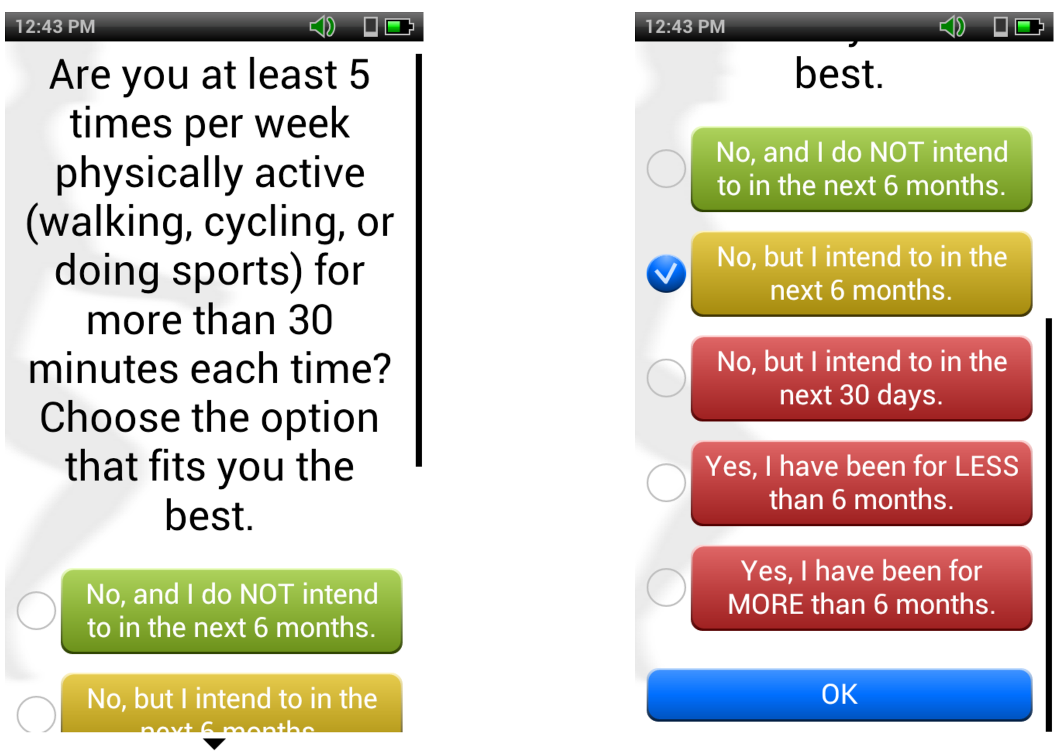

Figure 19 - Screenshot of the multiple choice question used to determine the stage-of-change based on the questionnaire of Table 10.

✓ *Classification of the activity pattern*

When the *Personalized Feedback Module* receives the answers from the questionnaires, it requests the variables necessary for the classification of the activity pattern from the *User Model Module* – ratio between end point of each day and the end goal, and the percentage of activity balance. The module averages each one of these values through time since the last feedback strategy update and compares them to the thresholds defined in the configuration file of this module – activity balance deviation allowance and end point deviation allowance (Figure 20). These parameters can be adjusted in the configuration file at any point, supporting the adaptability and personalization of the system. If both values are below the threshold, the activity pattern is considered 'improper'; otherwise it is 'proper'.

✓ *Message Manager*

The messages given to the user are based on (1) the deviation of the physical activity to the goal line and (2) the feedback strategy adopted. The full list of messages can be seen in APPENDIX II.

The configuration file of this module specifies the deviation allowance, i.e. the percentage that the user can deviate from the goal line before receiving encouraging/discouraging feedback. In the example of Figure 20, this value is set to 10%; this means that the user will receive encouraging messages if his activity level is more than 10% below the value of the goal line, and discouraging messages if his activity level is more than 10% above the goal line. Otherwise, neutral feedback will be given.

```
<PersonalizedFeedbackModule>
    <GeneralSettings
        feedbackDeviationAllowance="10"
        activityBalanceDeviationAllowance = "30"
        endpointDeviationAllowance = "10">
        <selfEfficacy
            lowThreshold="270"
            highThreshold="542"
        />
    </GeneralSettings>
    <FeedbackMessages>
        <message id="1" text = "Probeer vandaag eens een korte wandeling te maken, van bijvoorbeeld 10 minuten.">
            <constraint type="activity_level" value="encouraging"/>
            <constraint type="feedback_strategy" value="FEEDBACK_STRATEGY_1"/>
        </message>
        <message id="2" text = "Is er nog plaats in je planning om straks een korte wandeling te maken?">
            <constraint type = "activity_level" value = "encouraging"/>
            <constraint type="feedback_strategy" value="FEEDBACK_STRATEGY_1"/>
        </message>
```

Figure 20 - Example of configuration file of the Personalized Feedback Module.

The configuration of the *User Input Module* defines the periodicity in which feedback messages are given to the user. By default, this time is set to once every hour. The *User Input Module* sends a feedback request via hub-message that is recognized by the *Personalized Feedback Module*. Then, this module checks the constraints defined to a specific situation, chooses a group of suitable messages and, from this group, randomly selects one message to give to the user. The *GUI Module* receives the message and displays it on the screen. This process is illustrated in Figure 21. Additionally to the messages automatically generated every hour, the user can always see the percentage of deviation between his activity and the goal line. This percentage can be based on the whole day, the last hour or an even shorter timespan to represent the instantaneous deviation (i.e. over the last minutes).

Each message is defined by a unique identifier (message-id), the text that will be shown to the user, and an optional set of constraints – rules that define conditions that must be fulfilled when sending a specific feedback message. These constraints can be context related (e.g. sunny/rainy weather), personal preferences (e.g. preference to indoor/outdoor activities) or any other category. In the case of Figure 20 only the activity level and the feedback strategies are considered. For example, a user would receive any of the messages shown in the figure if his activity level was below 10% of the goal line and he was assigned to FBS 1. A message can have as many constraints as desired.

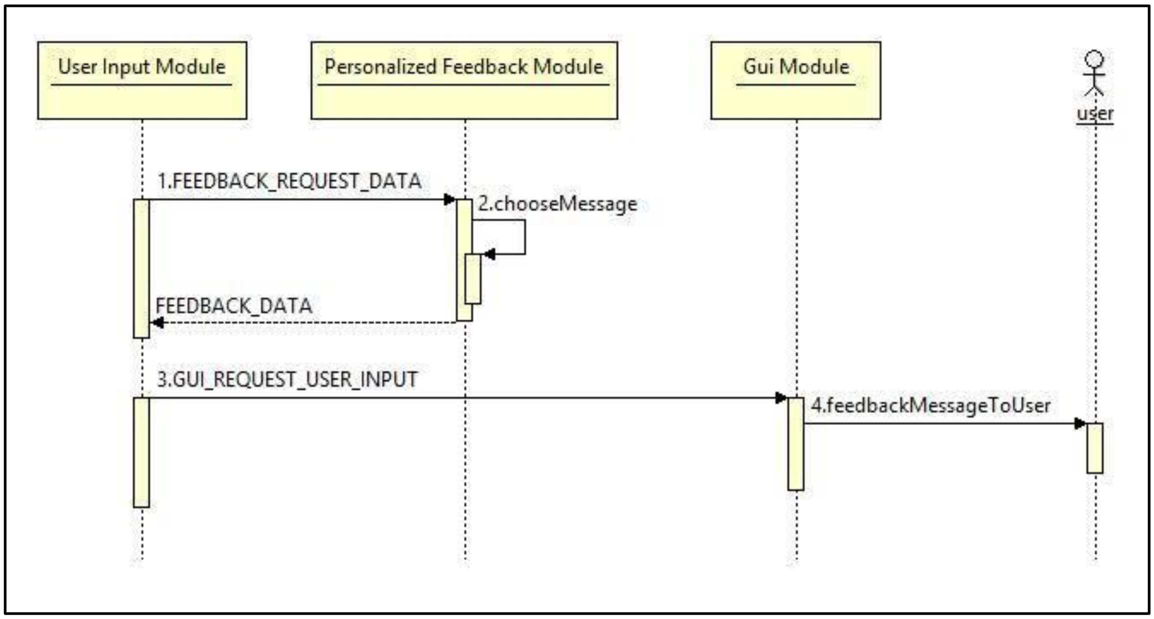

Figure 21 – Sequence diagram of the process of provide a message to the user.

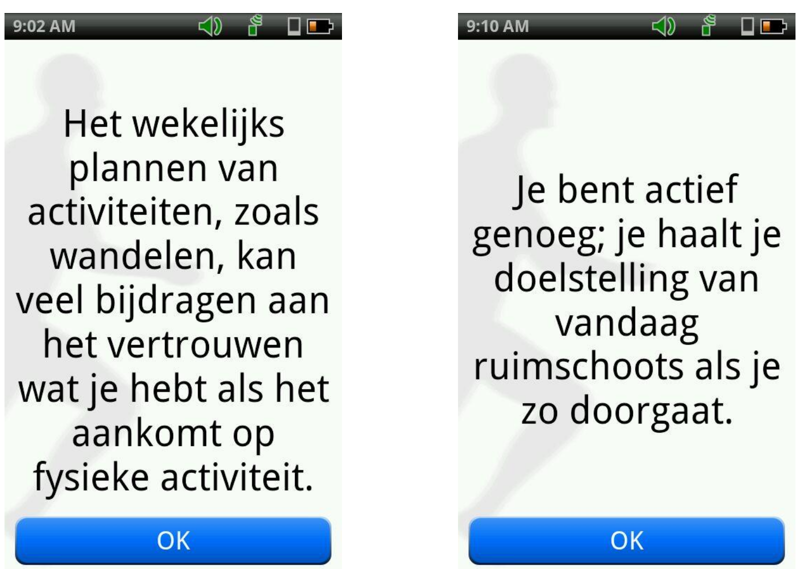

Figure 22 – Example of messages provided to the user.

6. Evaluation

"Don't worry if it doesn't work right. If everything did, you'd be out of a job."

Mosher's Law of Software Engineering

Chapter 6 will present the evaluation of the system designed and described in Chapters 4 and 5, respectively. The aim of the presented research is to promote behavior change in order to achieve a healthy lifestyle. A proper evaluation of a behavior change tool would require a longitudinal study and, considering time limitations, the evaluation of the behavior change component of the Activity Coach is out of the scope of this research. Walid *et al.* (1996) suggest that the evaluation of a telemedicine service should pass through four different stages: technical evaluation, usability tests, behavioral change component, and at last, a large randomized controlled trial. The presented evaluation covers the first stage of this framework. Moreover, literature suggests that tailoring features enhance the adherence and performance of the user through physical activity interventions. Along these lines, our evaluation regards the adaptation of the system to the user. The presented evaluation intends to answer the short term research questions stated in Chapter 1.3 focusing on three different aspects. The first is the effectiveness of self-adaptive *versus* fixed goal-setting, followed by a translation of IMA values to a measure more understandable to the user. Finally, an evaluation of the default thresholds for deviation allowance for goal-setting and classification of the daily activity pattern will be performed.

6.1 Self-adaptive *versus* fixed goal-setting

In the previous version of the system, the daily goal was set based on the averages of the daily end points during the baseline week and remained the same throughout the whole intervention. The new version of the system aims to adaptively set daily goals considering data from previous days. Bearing in mind the statement from the Goal-Setting Theory that goals should be challenging but still attainable in order to promote the desired behavior change (Locke & Latham 2002), the presented evaluation intends to compare the new and recent methods answering the following question:

> *Can an automatically adaptive goal line provide more challenging but attainable goals for encouraging physical activity, when compared to fixed goals defined based exclusively on data acquired during the baseline week?*

To answer this question one should start by defining what challenge and attainability means in terms of physical activity. For the presented evaluation, we consider that a goal is *challenging* if its value is at slightly higher than the daily end point; in other words, this means that the ratio between the activity performed by the user and the goals set by the system should be lower than 0.95. Regarding attainability, a goal is considered *attainable* if the aforementioned ratio is higher than 0.75. To sum up, in the presented evaluation, a goal is considered challenging but attainable if the ratio between the user's activity and the goal falls within the range [0.75;0.95[.

The evaluation was performed analyzing data from subjects with Chronic Obstructive Pulmonary Disease acquired in a longitudinal study that occurred between May and November of 2012, for the European Project IS-Active[16]. The IS-Active project intends to design a person-centric healthcare solution for patients with chronic conditions based on wireless inertial sensing systems. The objective is to promote an active lifestyle, with a main focus on the elderly generation, providing real-time support to patients in order to monitor, self-manage and improve their physical condition according to their specific situation.

From a sample of 10 subjects, only the data of 7 was used, excluding three subjects as a consequence of the limited amount of viable data available. This reveals the difficulty associated with the continuous acquisition of qualitative data in a longitudinal experiment for physical activity habits. From the 7 subjects remaining, two were female, four were not working at the time of the study and all of the subjects had low levels of physical activity evaluated with Baecke questionnaire (Baecke et al. 1982). For the data analysis the following five steps were performed:

1. Calculate the average IMA count per minute for each one of the days of the baseline period (*average of baseline period*). All the days with less than 300 data points were excluded (frequency of acquisition is 1 data-point per minute);
2. Set a daily goal for the intervention period based on the previous version of the system: the end goal was defined as 110% of the average of the daily-end-points during the baseline period. This goal remained the same through the whole intervention (*fixed goal*);
3. Set an ultimate goal, i.e. the daily goal defined in the configuration file, as 200% of the average of the end points of the baseline period;
4. Set automatically adaptive daily goals based on the algorithm described in Chapter 5.3 (*adaptive goal*);
5. Compare the daily IMA averages during the intervention period and the average of the goals set by the previous (2+3) and recent version of the system (4).

Considering the assumptions made beforehand, the ratio between the user's activity and the goal must be in the range [0.75;0.95[to guarantee both challenge and attainability. The results in Table 11 give an insight on the level of challenge and attainability of the goals. First, the analysis of the data from the three first subjects ('isa07', 'isa09', and 'isa10') shows that the goal set based on the data from the baseline week is lower than the average of physical activity through the intervention period. Clearly this is not the desired situation considering that the goal for this subject would not be challenging. One can see that both methods guarantee the attainability of the goals with exception of the self-adaptive goals in the case of subject 'isa14'. However, Table 11 shows that the amount of data available during the intervention period is limited.

[16] http://www.is-active.eu/

Table 11 - Results of the evaluation performed with data from subjects of the IS-Active project. The number of days stated in the table corresponds to the number of days with more than 300 data points. The table provides the IMA average of daily data during both baseline and intervention period, and the average of the goals defined by the previous (fixed) and recent (adaptive) version of the Activity Coach. All the averages were calculated per minute. The last two columns show the ratios between the IMA average during the intervention period and the fixed and adaptive goal, respectively.

		Averages				Ratios	
Subject	Nr. of days	Baseline period	Intervention period	Fixed goal	Adaptive goal	$\frac{\text{InterventionPeriod}}{\text{Fixed goal}}$	$\frac{\text{InterventionPeriod}}{\text{Adaptive Goal}}$
isa07	40	354	408	389	491	1.05	0.83
isa09	30	733	996	806	1018	1.24	0.98
isa10	38	501	695	551	687	1.26	1.01
isa11	61	636	661	700	735	0.94	0.90
isa12	53	941	1028	1035	1110	0.99	0.93
isa13	59	631	617	694	686	0.90	0.90
isa14	36	382	385	420	519	0.92	0.74

Figure 23 to 26 show the daily average of IMA counts per minute (*black*), and the respective fixed (*dashed dark grey*) and smart goals (*light grey*). As smart goal we mean the self-adaptive goals. The days shown in the plot are the same considered in Table 11. Both adaptive and fixed goals start after the baseline week.

Figure 23 regards subject 'isa07' and shows that, at first, the fixed daily goal is set to approximately 400 IMA per minute. The adaptive goal, starts at 700 IMA per minute and, after the first week of intervention, drops to adapt to the routine of the user. Several examples can be taken from the plot. For instance, one can see that at the middle of the second week the daily activity is considerably lower than the average of the activity during the baseline period. From the therapeutic point of view, as the subject becomes inactive, he/she should be stimulated in order to encourage an active lifestyle, providing gradually increasing challenges. The adaptation of the system to this is clear during the following weeks (dark green arrows). Another example occurs at the middle of week 4 when the daily goal also decreases (light blue arrows). The daily goal of the correspondent day in week 5 adapts to this decrease. After the sixth week of intervention, the subject stops using the system (with exception of two isolated days) and the goals remain approximately the same for four weeks. After that period, the subject uses the system again and the daily goals slightly increase.

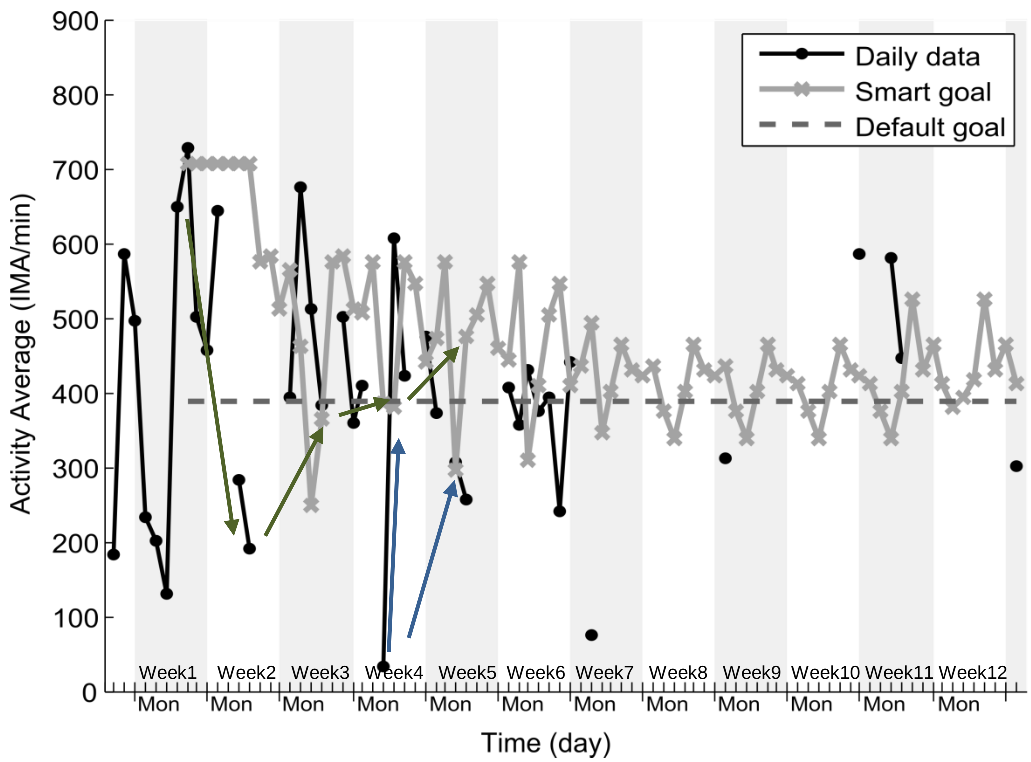

Figure 23 - Daily average of IMA counts per minute and respective fixed (*default*) and self-adaptive (*smart*) daily goals of subject 'isa07'.

Figure 24 relates to subject 'isa09'. The first thing that points out in this figure is that the user does not use the system on Saturdays. As such, the daily goal for this weekday remains the same as the ultimate goal (200% of the daily average during the baseline period). Additionally, it is clear that the physical activity during the baseline period is significantly lower than during the intervention period. As a result, the fixed goal line (default) is, in the majority of the days, lower than the average of physical activity reflected in the ratio shown in Table 11. Thursdays deserve special attention in the data analysis of this subject. During week 2, the daily average on Thursday is higher than the ultimate goal. As this is the only value saved in the system regarding Thursdays (note that during the baseline period there is no data on Thursday), in week 3 the algorithm limits the daily goal to the value of the ultimate goal. However, during the following week (week 4) the daily average is considerably lower and, as a result, the goal for the following Thursday decreases. During weeks 4 and 5 the average of physical activity remains almost the same but the daily goal decreases. Keeping in mind that the daily goal is calculated as a percentage (higher than 100) of the weighted daily end points with the more recent data having higher weight than older data, one can understand that this decrease of the daily goal happens as a result of the decrease in the weight of the data acquired during the first Thursday (week 2). This can also be seen during week 6, where the physical activity on Thursday increases again and daily goal follows this in week 7. In general, this plot also shows the clear adaptation of the goal to the different days of the week and both challenge and attainability are assured in agreement with the results from Table 11.

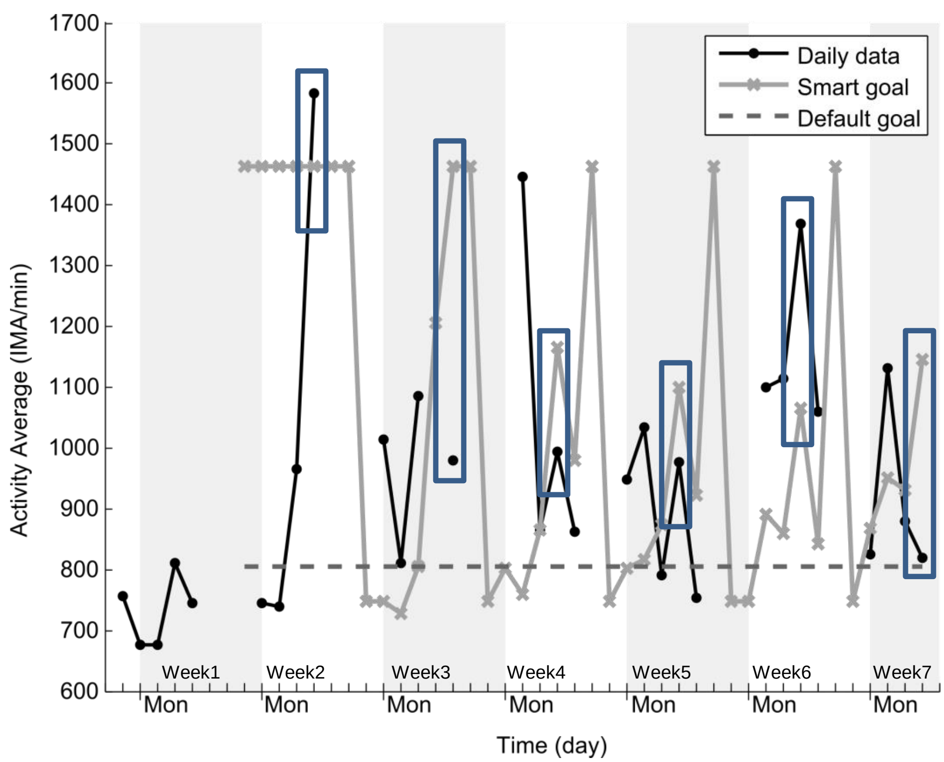

Figure 24 - Daily average of IMA counts per minute and respective fixed (*default*) and self-adaptive (*smart*) daily goals of subject 'isa09'. The dark blue rectangles refer to Thursdays.

Figure 25 shows the data from subject ‘isa10’. Once again, in agreement with the results from Table 11, the fixed goals calculated from the data of the baseline period are lower than the average of the intervention period. After the baseline period, the ultimate goal is set to approximately 1000 IMA per minute. When the intervention starts, this value is automatically adapted to the data from the baseline week creating a weekly pattern for the following four weeks considering that the user (barely) uses the system from week 3 to week 5. The daily goals in week 6 are still the same. In week 6, the user restarts using the system with an average of daily activity considerably higher than during the baseline period. The system adapts automatically to this fact. One clear example happens on Thursday (dark arrow). During weeks 8, 9 and 10 the goals remain the same again.

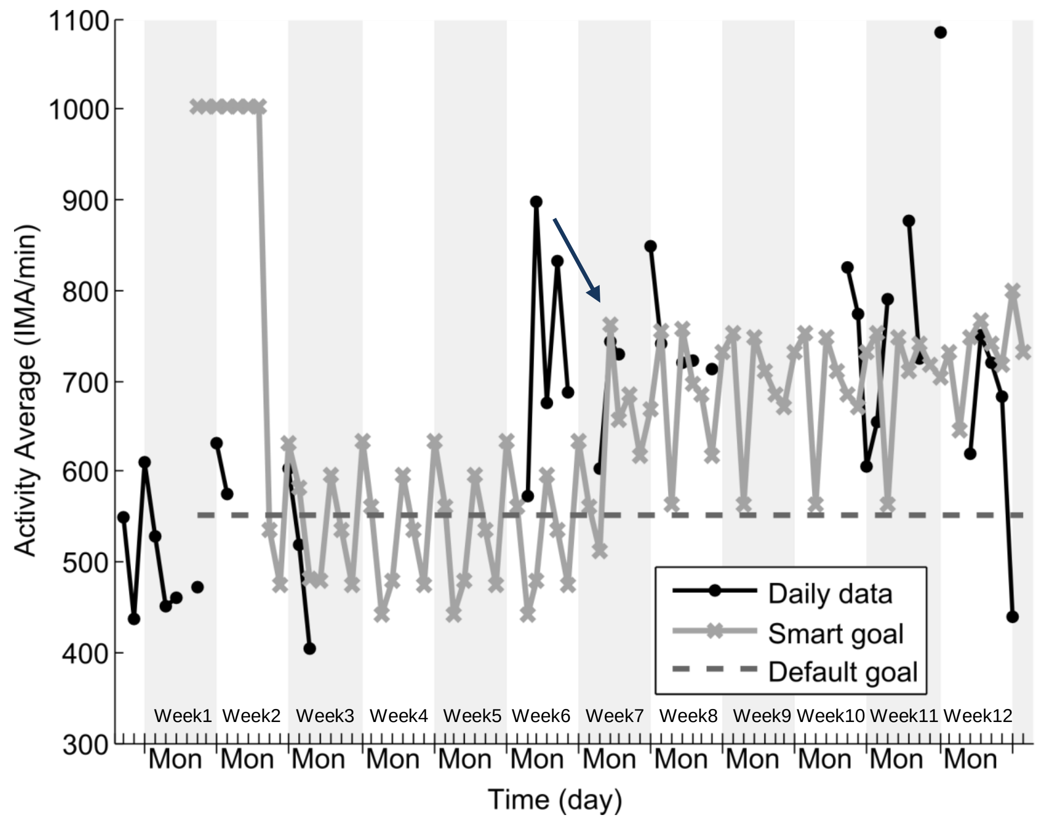

Figure 25 - Daily average of IMA counts per minute and respective fixed (*default*) and self-adaptive (*smart*) daily goals of subject ‘isa10’.

Figure 26 shows the data from subject 'isa14'. After the baseline week the fixed and ultimate adaptive goal are set to 420 and approximately 775 IMA per minute, respectively. After the first week, the smart goal adapts to the user's routine decreasing considerably the daily goals. A good example of the adaptive component of the system is shown for Wednesdays (dark blue rectangles). During week 4, the average of daily activity is lower than during the previous Wednesdays. As a result, the daily goal for this weekday in week 5 decreases. On the same day, the average of physical activity decreases considerable and the goal for Wednesday in week 6 also decreases. Between weeks 5 and 7 the subject barely uses the system, and the goals remain the same.

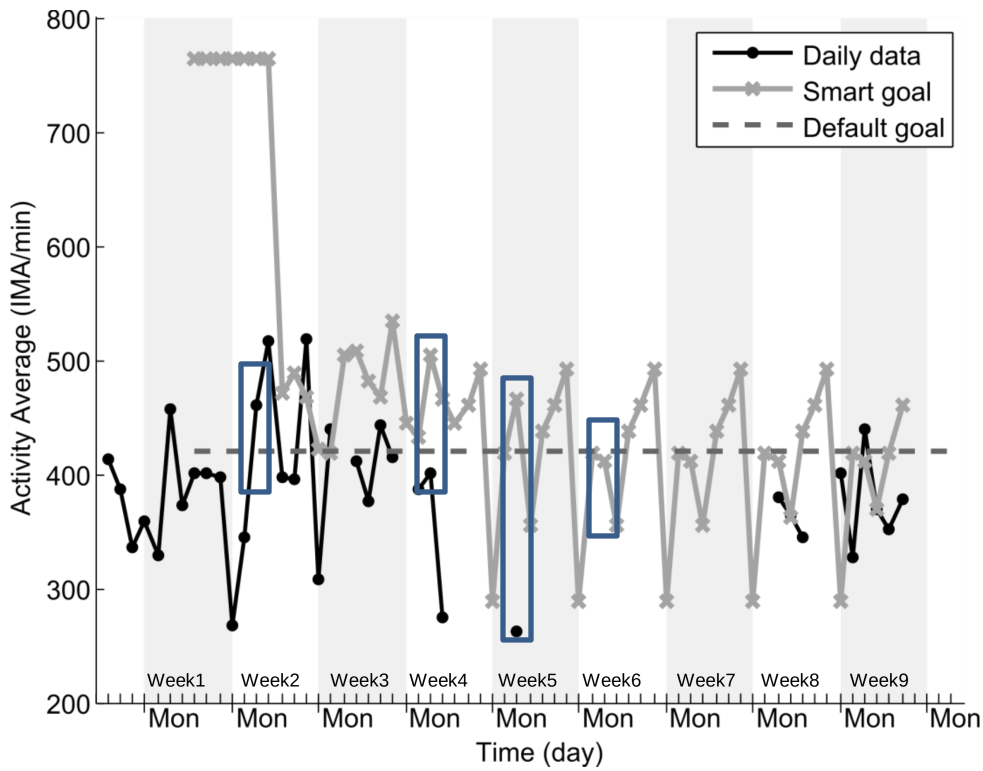

Figure 26 - Daily average of IMA counts per minute and respective fixed (*default*) and self-adaptive (*smart*) daily goals of subject 'isa14'.

To conclude, the four figures above demonstrate the adaptive behavior of the goal-setting performed by the new version of the Activity Coach. Combining the results from Table 11 and the figures above, the adaptive process not only gives more challenging goals but also personalizes the system considering that it adapts to the routines of the user. We recognize the potential of the system and recommend a study to evaluate how the users would respond to this new feature.

6.2 Conversion between IMA and steps counting

One aspect that must be considered when providing feedback is the language used between the device and the user. Problems in communication can lead to misunderstandings or can even be harmful to the user. In the presented research, and foreseeing new updates to the Activity Coach, it is crucial to understand what IMA counts mean in terms of physical activity, in order to provide an understandable advice to the users. For example, considering the scenario in Chapter 4, if Peter would receive a message saying that to reach his goals he would need to do 10.000 IMA more, one can guess that he would not know how to interpret this message. It is necessary to have a common language and provide feedback based on variables that are understandable for the users. These commonly known measures are, e.g. calories expenditure, distance or number of steps performed. In our evaluation we decided to analyze the correlation between the IMA counts throughout the day and the number of steps. Therefore, the current sub-chapter aims to answer the question:

Is it possible to establish a reliable conversion factor between IMA count and number of steps in order to provide more understandable feedback to the user?

To do so, a single-subject study was performed during eleven days. The subject wore simultaneously the Activity Coach system and a step counter. The IMA data from the Activity Coach was compared with the data acquired from a Fitbit Zip™ [17] (Fitbit Inc., San Francisco, CA, USA), a commercially available three-axial accelerometer capable of detecting physical activity and energy expenditure. The Fitbit gives as output the number of steps, distance and calories burned. The data syncs wirelessly and automatically with the computer and/or smartphone via Bluetooth and can be accessed with a log in in the website. The number of steps is reported in five-minute intervals (Figure 27).

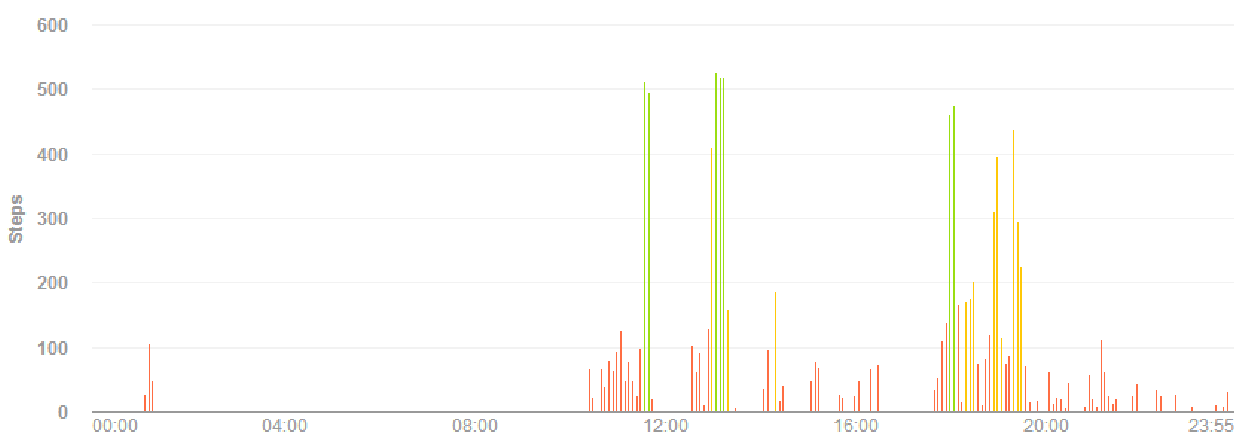

Figure 27 - Daily step counting in a five-minute based interval taken from the Fitbit's web-portal.

The first step to analyze the data was to establish the correspondence between the steps and IMA counts for the same time interval. For that, we used the RRDToolkit, a Graphical User Interface

[17] www.fitbit.com/zip

developed at RRD for sensing/monitoring systems (Figure 28). It does not only read the physical activity files but also stores all the information about the subjects, allows the addition of new information and performs data analysis.

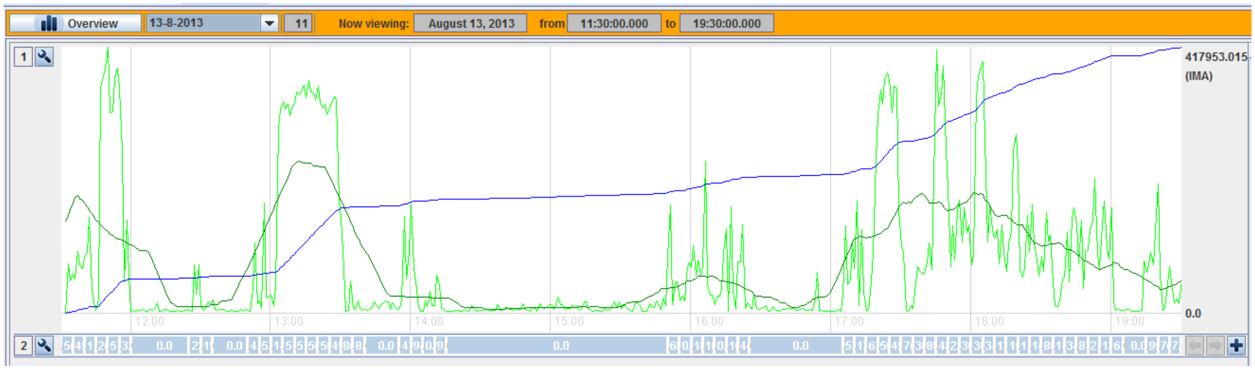

Figure 28 - Correspondence between steps (blue bar on the bottom) and IMA activity during one day of the experiment. Shown in this plot are: the raw IMA signal (light green), the filtered signal (dark green) and the cumulative values (blue).

Each time interval has 5 minutes. Consecutive time intervals with zero steps were clustered for a matter of convenience. From this analysis resulted 611 time-intervals with a total of 64540 steps and 3120449 IMA counts. Figure 29 shows the scatter plot resulting from this first comparison where each data-pair <numberOfSteps, IMAcounts> corresponds to one time interval. The data was analyzed in MATLAB® 2012 and the best fit corresponded to a r-squared value of 0.6912.

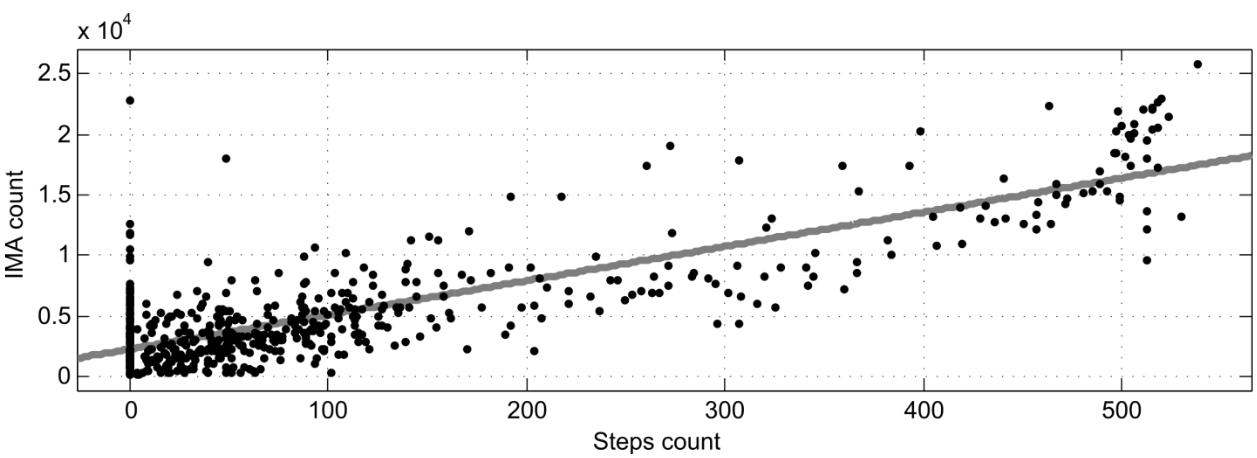

Figure 29 - Scatter plot with the correspondence between number of steps and IMA count for the same time interval. All the intervals were considered for this analysis. R-squared of the best fit: 0.6912.

In the second analysis, we removed the intervals where the number of steps was zero. The result from this analysis is shown in Figure 30. In this case the r-squared increased to 0.7631 ($p < 0.0001$). In this case we also analyzed the residual plot (Figure 31) and verified that there is a trend to overestimate the amount of IMA per step. The final correspondence between IMA and steps counts is as follows:

Equation 2

$$IMA_{count}(steps_{count}) = 30.24 * steps_{count} + 1680$$

The limits for the first and second coefficients with 95% confidence bounds are respectively (28.78, 31.75) and (1314,1933). For a matter of convenience, the previous equation should be written in the form:

Equation 3

$$steps_{count} = \frac{IMA_{counts} - 1680}{30.24}$$

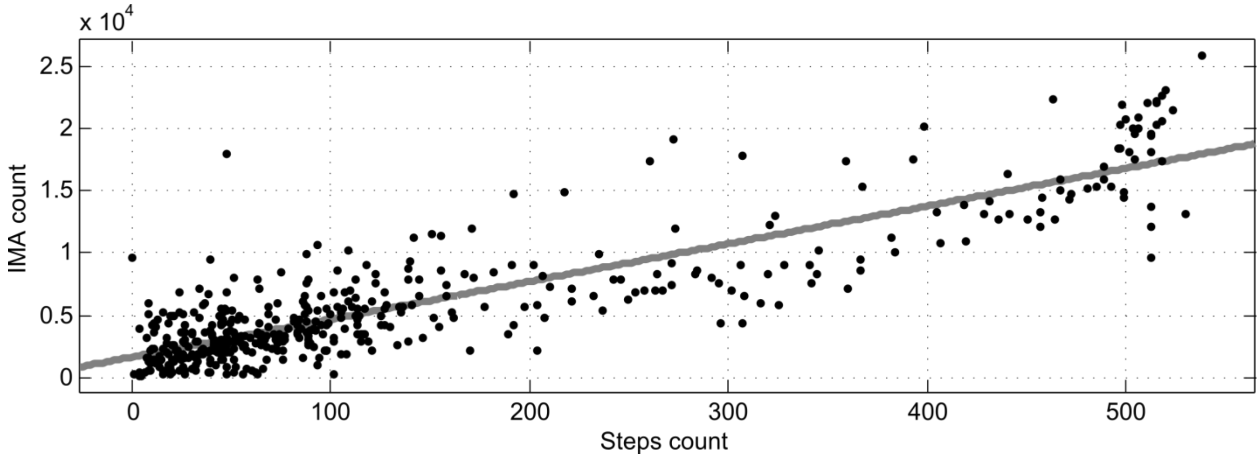

Figure 30 - Scatter plot with the correspondence between number of steps and IMA count for the same time interval. Intervals with zero steps were kept out of this analysis. R-squared of the best fit: 0.7613.

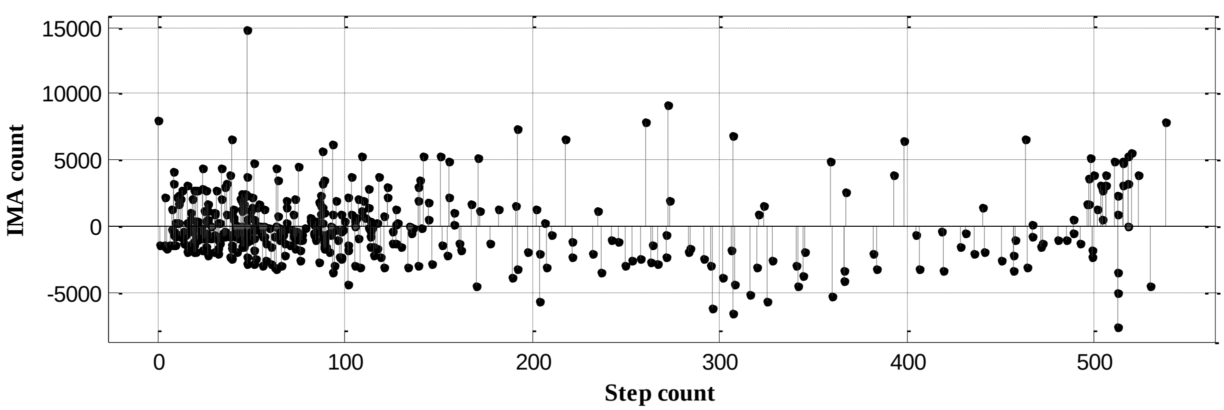

Figure 31 - Residuals plot of the data shown in Figure 30.

Many issues are associated with the dispersion of data found in this relation. First, it is important to take into account that the ProMove sensor does not measure the amount of steps but the acceleration. Whereas the IMA is an accurate measure of energy expenditure, the Fitbit is a step counter that would filter out slower movements. Literature confirms the underestimation of the Fitbit in what concerns to energy expenditure (Danneker et al. 2013). In this way some errors are unavoidable. The ProMove sensor is placed on the hip and there is a large amount of movements that it captures and should not be considered as steps. For example, bearing in mind that knowledge workers constitute our target group, one can imagine that the simple rolling movement of an office chair would be measured by the accelerometer but would not be taken as a step by the Fitbit. Second, one can say that the distribution of number of steps is not equal; there is a higher amount of intervals with respect to low intensity activity (< 300 steps per 5-minute-interval) than to moderate-to-vigorous (300-450 steps per 5-minute-interval) or to vigorous activity (> 450 steps per 5-minute-interval)[18]. Furthermore, it is intuitive to think that the biggest amount of steps corresponds to higher accuracy considering that, in these cases, the subject is in fact walking. Intervals with lower amount of steps, or even zero, are more susceptible to errors. Recommendations for a further analysis can be found in Chapter 8.

Table 12 shows a conversion between IMA count, steps count and time walking (minutes). There is not a commonly accepted guideline for the conversion from steps to minutes walking. One should bear in mind that this table should be personalized considering that it depends on the health status of the individual. The WHO recommends 30 minutes of moderate physical activity at least 5 times a week (Chapter 3.1). In this way, for the following conversion, we considered that one minute of moderate physical activity corresponds to 100 steps based on the American Journal of Preventive Medicine[19].

Table 12 - Conversion between IMA count, steps count and minutes walking. The conversion from IMA to steps was done with Equation 3. We considered a person walks 100 steps per minute at moderate intensity.

IMA count	Step Count	Minutes walking
10.000	275	3
20.000	606	6
25.000	771	8
50.000	1598	16
100.000	3251	33
150.000	4905	50
200.000	8212	82
300.000	9865	99
500.000	16.479	165

As an example, if a subject is 50.000 IMA below his daily goal, the system can provide the following message: “To reach your daily goal you can go for a 15-minute-walk.”

[18] Classification of activity intervals taken from: [United States of America Department of Health and Human Services] Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) (pdf available at: http://www.cdc.gov/nccdphp/dnpa/physical/pdf/PA_Intensity_table_2_1.pdf)
[19] Source: http://www.reuters.com/article/2009/03/17/us-walkers-steps-idUSTRE52G3UL20090317

6.3 Threshold for deviation allowance between cumulative end point and end goal

When determining a new goal line, the end goal corresponds to the average of the daily end points of that day of the week plus the percentage defined in the configuration of the *Smart Reference Module* (sub-chapter 5.3). This sub-chapter intends to answer the following question:

What is a reasonable threshold for deviation between averaged end point and new end goal?

By reasonable we regard the attainability of the goal following the study started in sub-chapter 6.1. In this evaluation we consider “reasonable” a goal that suggests an increase of activity up to 20 minutes of walking.

In order to provide a guideline for the healthcare professionals, using the same data as in sub-chapter 6.1, we analyzed the case for the default threshold: 10%. The data analysis was as follows: first we determined the cumulative end point for each one of the days of the baseline period using the method described in sub-chapter 5.3. Second, we averaged the daily end points and calculated 10% of that value. Finally, the correspondent values in number of steps and minutes of walking were determined using Equation 3 and Table 12, respectively. Table 13 provides the results of this analysis. As an example, subject ‘isa10’ would have to walk, in average, 14 minutes more than he/she did during the baseline period in order to reach his/her goal.

Table 13 – Analysis of the default deviation allowance for goal-setting.

Subject	Nr. of days	Average of end point during baseline period	10% end point (IMA)	10% end point (steps)	10% end point (minutes walking)
isa07	6	298.227	29.823	931	9
isa09	5	624.929	62.493	2011	20
isa10	6	435.169	43.517	1383	14
isa11	6	550.715	55.072	1766	18
isa12	5	644.846	64.485	2077	21
isa13	5	554.187	55.419	1777	18
isa14	7	420.227	42.023	1334	13

As expected, subjects with higher level of physical activity (e.g. isa12) will have a higher expected goal than subjects with lower level of physical activity (e.g. isa07). Considering our assumption that a reasonable threshold is the one that encourages an increase of activity till 20 minutes we confirm the default deviation allowance for goal-setting as 10%.

6.4 Threshold for classification of daily activity pattern

The classification of the daily pattern of physical activity, as either ‘proper’ or ‘improper’, is one of the variables taken into account when choosing the most appropriate feedback strategy for a user. This classification is performed comparing the daily activity with the goal line (method described in section 4.2.2). The result of this method gives the percentage of activity balance. The final classification results from the comparison between the percentage of activity balance and a threshold defined by the healthcare professional. But what is the most appropriate threshold? With the following evaluation we intend to provide a guideline for this value.

What is an appropriate threshold for classification of percentage of activity balance as either ‘proper’ or ‘improper’?

The first step for the analysis of the percentage of activity balance was to verify what happens in the corner cases. In the first simulation, we consider a straight goal line, without any breakpoints (Figure 32). In this scenario, if the user would not perform any activity during the day, meaning that the IMA data counting would constantly be equal to zero, the percentage of activity balance would be 50%. On the other extreme, if the user’s activity follows exactly the goal line, the percentage of activity balance would be 100%. As expected, if the user’s activity follows the goal line half of the day and after that is zero, the percentage of activity balance is 75% (Figure 33).

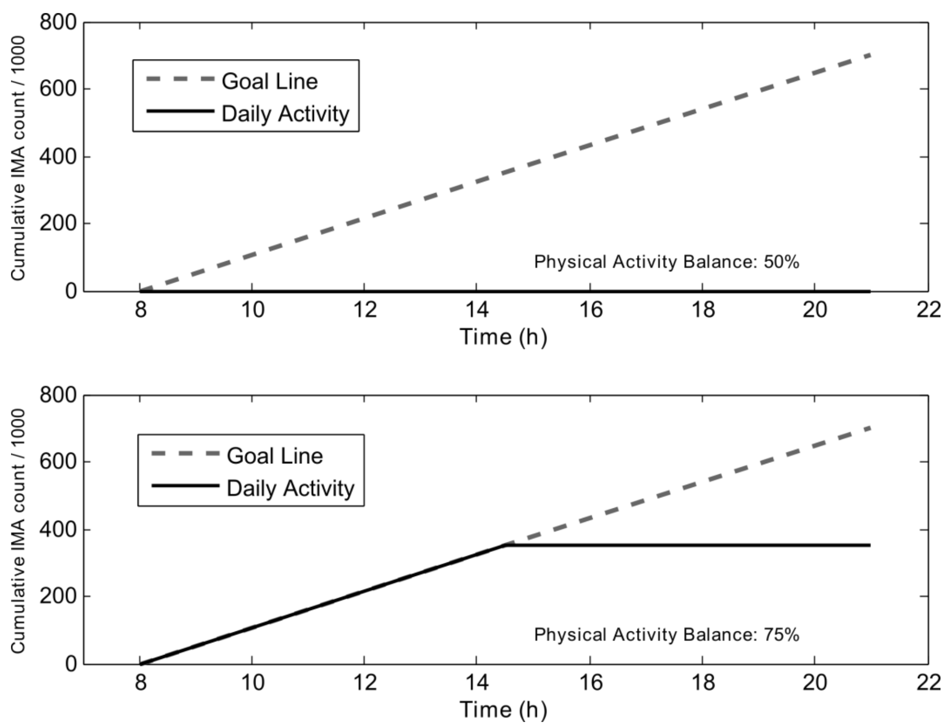

Figure 32 - Analysis of the percentage of activity balance considering a straight goal line. The first case considers a day without physical activity (top) and the second a day when the goal line is consistently matched till half-day and no activity is performed after that (bottom).

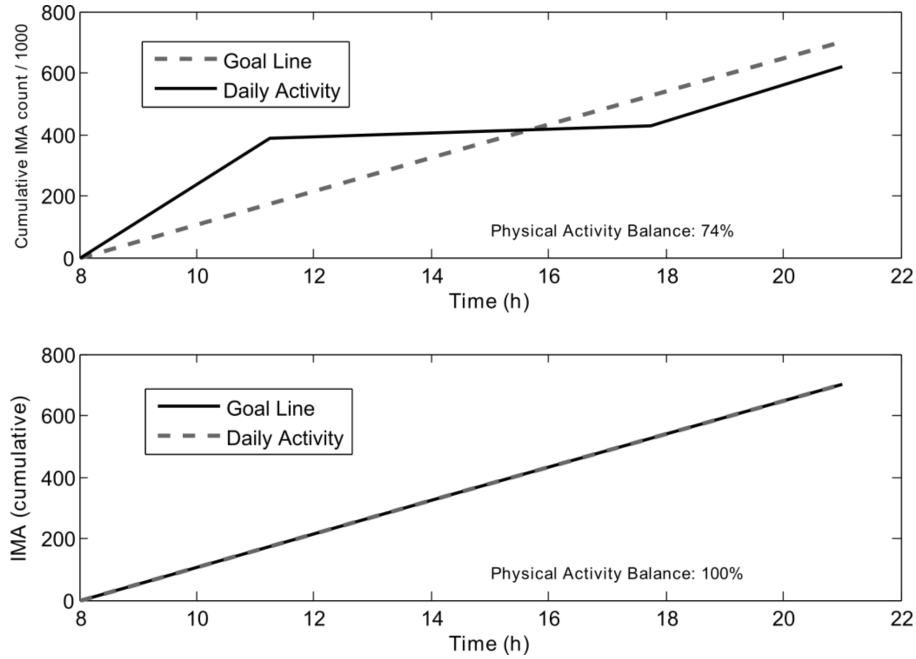

Figure 33 - Analysis of the percentage of activity balance considering a straight goal line. The first case simulates a working-day from 11.00 to 18.00 (top) and the second case a day when the measured activity consistently coincides with the goal line (bottom).

In the second simulation (Figure 34), two breakpoints were introduced and the measured activity data was assumed as zero (first case) and as a linear function (second case). In this case, a no activity would mean 65% of activity balance and 88% for the case of a measured activity data as a linear function.

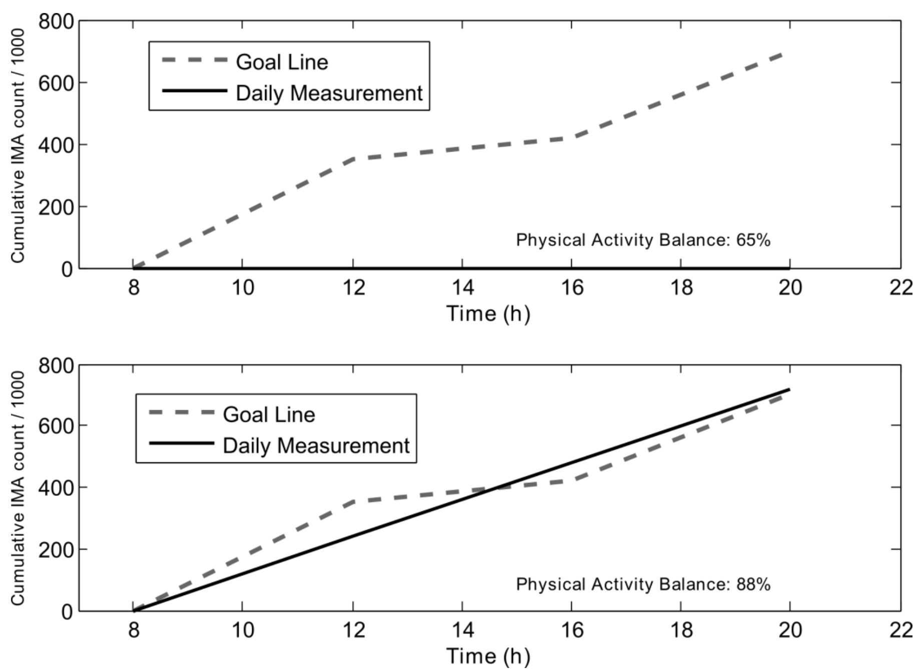

Figure 34 - Analysis of percentage of activity balance considering a goal line with two breakpoints. In the first case there is no measured activity (top) and in the second case the physical activity follows a linear function (bottom).

Still considering the same goal line, we simulated the percentage of activity balance during a common working day of an office worker (Figure 35). The main difference between the two plots is that in the second one it is considered that the user performs some moderate-to-vigorous physical activity after work.

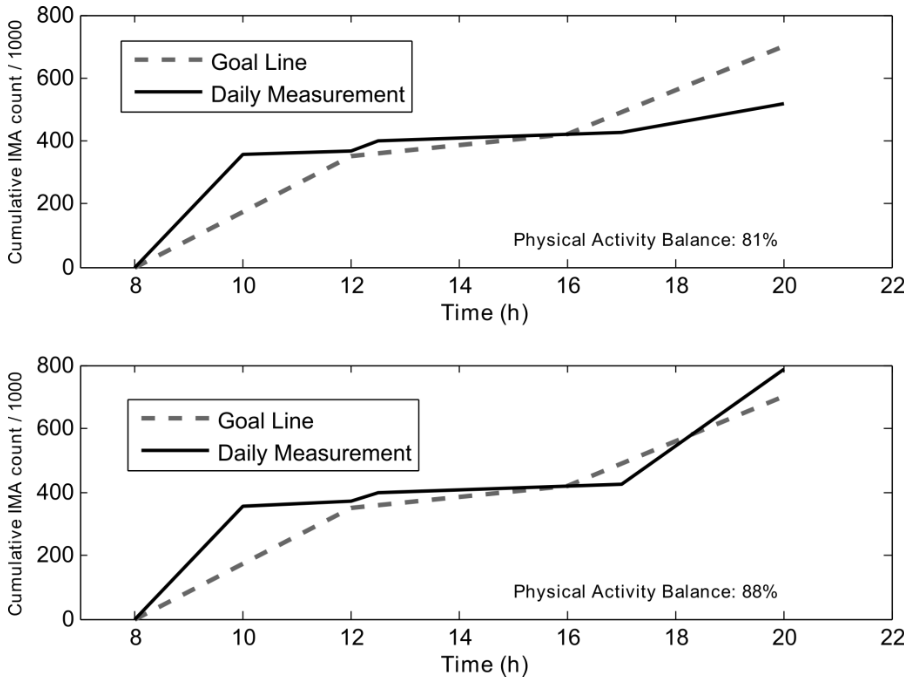

Figure 35 - Analysis of percentage of activity balance considering a goal line with two breakpoints. Both plots simulate a working day from 10:00 to 17:00. On the top figure, the user adopts a sedentary behavior after work while in the second figure he/she performs a moderate-to-vigorous activity in the late-afternoon.

In the third case, we simulate a working day from 09:00 to 17:00 having into account the traveling home-work-home. We consider that the user would perform a moderate-to-vigorous activity from 07:00 to 08:00 followed by work from 09:00 to 17:00 with a short walk during the lunch break (12:00 – 12:30). After work, the user would take 30 minutes to go back home and do not perform any kind of moderate or vigorous activity till 21:00. Figure 36 considers a straight goal line and emphasizes the importance of setting an achievable goal. Figure 37 introduces breakpoints spread through the day.

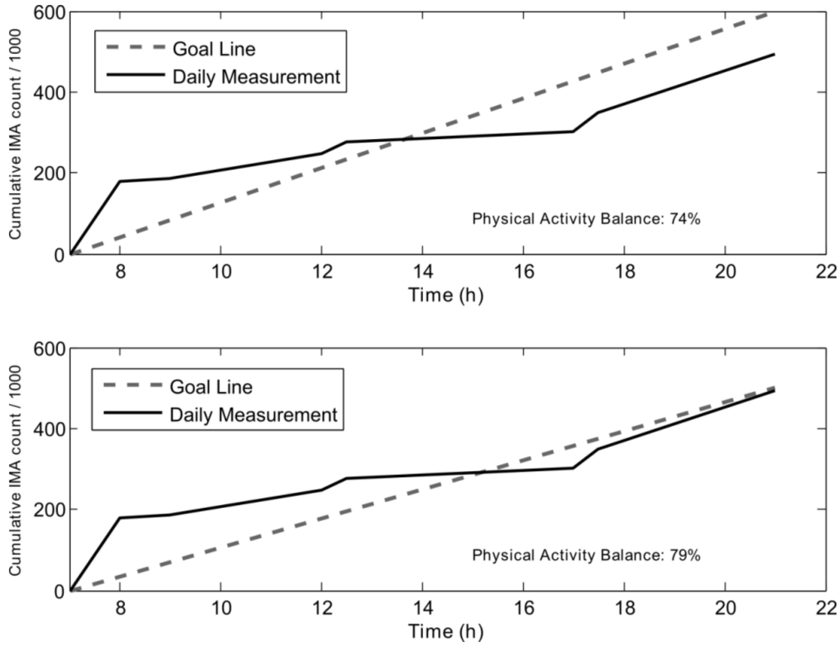

Figure 36 - Analysis of the percentage of activity balance considering a working day from 09:00 to 17:00 and a straight goal line. The goal set in the top figure is higher than the one in the bottom figure. The percentage of activity goal is affected by 5%.

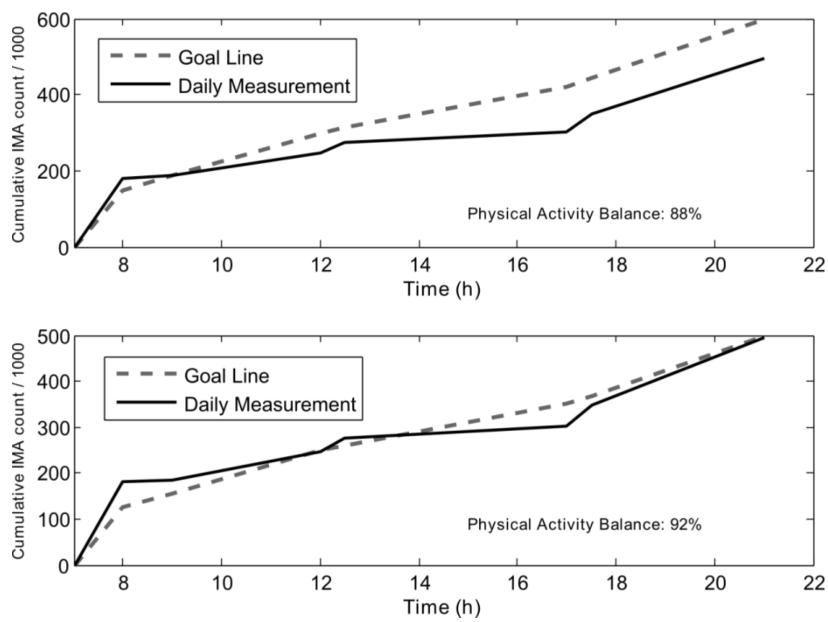

Figure 37 - Analysis of the percentage of activity balance considering a working day from 09:00 to 17:00 and a goal line with three breakpoints (08:00 – 25%; 12:00 – 50%; 17:00 – 70%). The goal set in the top figure is higher than the one in the bottom figure.

From the analysis of the previous scenarios, we conclude that, as a first approach, the activity pattern should be classified as ‘good’ if the percentage of activity balance is higher than 80%, and ‘improper’ in the other cases.

7. Conclusion

"Health and intellect are the two blessings of life."

Menander (ca. 342–291 BC)

Although the assignment description (APPENDIX I) only concerned the feedback strategies, soon we realized that it would be interesting to add other features to the system. Therefore, after brainstorming sessions with researchers from RRD, it was concluded that one of the features needing improvement was the goal line of physical activity given to the user. A fixed goal line through the whole intervention, sometimes even based on healthy control subjects, was clearly not the best solution. Furthermore, it would be interesting to tailor the system not only in terms of adaptation (using constructs of behavior change models) but also in terms of context awareness (adapting to the user's routine). Previous versions of the system already included context awareness elements such as weather information or location. Along these lines, we decided to develop a feature that would be responsible for the daily data analysis and the goal line displayed on the screen of the smartphone.

In Chapter 1 we set the objective of this work as to *combine tailoring features in order to increase the long term adherence and impact of the system* through the *design, implementation and test of adaptive goal-setting and personalized feedback strategies with respect to an activity based ambulatory feedback system*.

This chapter starts with the discussion and limitations of the work developed. We analyze each one of the components of this research separately: literature review, requirements elicitation and, design, implementation and evaluation of the User Model Module, Smart Reference Module and *Personalized Feedback Module*. The chapter ends with a concise conclusion of the work including the contributions of the presented research.

- ✓ *Literature Review*

To reach the aforementioned objective, the research started with a literature review focusing on physical activity, models of individual behavior change and the use of Pervasive Technology in Healthcare. The increasing number of social and individual interventions regarding the promotion of a healthy lifestyle demonstrates the preoccupation with the decrease in the physical activity levels of the population. The development of new technologies and spread of mobile technology over the general population opens a whole range of new possibilities combining real-time monitoring and coaching. Around the world, several research groups evaluate the efficiency and efficacy of tailored interventions using pervasive technology. The majority of these systems includes user-targeted features – such as age, gender and, physiological characteristics – and a few also include constructs from models of behavior change – with the main focus on Social Cognitive Theory, the Transtheoretical Model, Goal-Setting

Theory and, Implementation Intentions. However, to our best knowledge, the number of systems incorporating self-adaptive processes is still low.

✓ *Requirements elicitation*

The system developed in this research was an upgrade of the Activity Coach, an ambulatory system consisting of an accelerometer and smartphone application used to monitor and coach physical activity. In this way, it was necessary to start by analyzing the features already available in the system (sub-chapter 2.3) and develop requirements elicitation in order to identify the components that should be added (sub-chapter 4.1). This elicitation was performed based on previous research executed at RRD and we used a framework based on the Sociotechnical Approach. From this requirement elicitation we concluded that two modules should be added to the system, one regarding feedback and another regarding data analysis on a daily basis. From this resulted two modules: the *Smart Reference Module* and the *Personalized Feedback Module*. During the designing process, we realized that it would be interesting to add a module that would gather all the information regarding the user – the User Model Module. The following section will discuss each one of the modules separately.

✓ *Design, implementation and evaluation*

- <u>User Model Module</u>

The *User Model Module* was designed not only for gathering information but also to increase the level of personalization of the system contributing to our main goal. This module assumes the role of a communication bridge for all the information regarding the user. In the current version of the Activity Coach, the *User Model Module* keeps track of the constructs of behavioral change (self-efficacy and stage-of-change) as well as the parameters regarding the daily activity of the user (averages of the different periods of the day, daily-end-point and, percentage of activity balance). The evaluation of the User Model Module was part of the simulations as described in Chapter 6.

- <u>Smart Reference Module</u>

The *Smart Reference Module* is one of the two most important features of this research. The aim of this module is to analyze and summarize the daily activity of the user as well as to define the goal line for each new day. The module constitutes one of the self-adaptive components of the system. The algorithm gathers the information of each day of the week in order to adapt to the routine of the user (context awareness). This was done in order to consider for example, cases when the user practices some exercise at specific days of the week and so, during those days the cumulative IMA end point would be higher than on the other days. To evaluate the self-adaptive goal-setting we used data from a previous experiment performed at RRD with subjects suffering from Chronic Obstructive Pulmonary Disease (Chapter 6.1). The data analysis showed that the previous way of goal-setting (110% of the average of the activity performed during the baseline period) tends to fail in the "challenge" attribute considering that, in most cases, the physical activity of the subjects during the intervention period was higher than the goal set by the system. From the comparison between the two methods we concluded that the self-adaptive goal setting offers a benefit to the system especially if the system is used for longer periods of time.

The generation of the new goal line starts with calculating the cumulative daily end point and, based on the parameters from the configuration file (which can be set on a web portal), defines a new goal line considering data acquired previously. The cumulative end goal is the main parameter necessary for the generation of a goal line. According to the Goal-Setting Theory, to get the best results, one should set challenging but still attainable goals. The question of the attainability should not be left out considering that, if the user does not reach his goals, he can get demotivated and stop using the system. In other words, the goal must be higher than the average of the activity (*challenge*), but how much higher (*attainability*)? This question was evaluated in two ways. First we found a conversion between IMA and steps ($p<0.0001$), and then, based on the default threshold of 10% we verified if this was, or was not, a reasonable value (sub-chapter 6.3). We concluded that adding 10% to the average of activity resulted in goals that would add between 9 and 20 minutes of walking. These values are also in accordance with the literature. In a recent study, King *et al.* (2013) propose a smartphone application for encouraging physical activity that allows personalized goal-setting in the range from 30 to 90 minute per week (equivalent to 4 to 13 minutes per day) in moderate-to-vigorous physical activity. As so, we maintain the default value of 10%.

Another important question to analyze was the balance of activity pattern. This was one of the main difficulties faced during the development of the work. At the moment of the publication of this research, there is no guideline that defines what a proper daily pattern of physical activity is. Literature suggests that the physical activity should be evenly spread throughout the day. In terms of goal line, this is represented by a linear function. However, we are aware that this is not suitable for most of the population, especially those who have office jobs. In this way, it is necessary to counter-balance the two ideas and find the best answer. We decided to leave this question open in a way that the classification of the daily pattern is done in comparison to the goal line. This means that, if future research gives insights into the most suitable distribution of physical activity throughout the day, the breakpoints of the goal line can be adjusted via web-portal and then be coherent with the new results. However, it was necessary to make an assumption of the threshold of the percentage of activity balance that would define the limit between 'proper' and 'improper'. For that, we made a few simulations with special attention to the corner cases (Chapter 6.4). If the user does not perform any kind of activity during the day, in the worst case, the percentage of activity balance equals 50%. If the daily activity follows strictly the goal line, this value is 100%. After the simulations we decided that days with a percentage of activity balance above 80% should be considered as having a 'good' activity pattern. Bear in mind that the final classification of the activity patter as either 'proper' or 'improper' also depends on the ratio between the daily-end-point and the end goal.

Finally, some of the aspects of this module are not visible to the user (e.g. daily and weekly average of the physical activity).

- Personalized Feedback Module

One common aspect in the diverse theories regarding behavior change is the importance given to the feedback provided to the user. Although the majority of the interventions for promotion of physical activity provide feedback, to our best knowledge, till the moment of the publication of this report there were no studies evaluating the incorporation of constructs of behavioral change in the content of the feedback messages. In the presented research the content of the messages is adapted to the users taking into account their levels of self-efficacy and stage-of-change and the classification of the daily activity pattern as either 'proper' or 'improper'. Six feedback strategies were created by the SWELL-WP5 combining the levels of self-efficacy, stage-of-change and the daily activity pattern. Our contribution was to incorporate the questionnaires and the classification of the daily activity pattern into the Activity Coach, as well as the associated message manager. Thinking about future implementations, the *Personalized Feedback Module* was designed in a way that an unlimited number of messages can be added to the system and categorized according to different constraints, i.e. rules that define conditions that must be fulfilled when sending a specific feedback message. Together with the *User Model Module*, the system can provide messages tailored to the user's preferences. For example, a user who has a dog can be prompted with a message suggesting to go for a walk outside with the dog.

The main limitation of this work is the time necessary for the evaluation of the behavior change intervention. Due to time limitations, it was not possible to evaluate this component; however, a technical evaluation was performed using simulations to test if the algorithm was working properly.

- ✓ *Contributions*

From the presented research resulted a poster (APPENDIX III) and a paper to be presented at the HealthCom conference, October 2013 (APPENDIX IV). The poster "*Promoting a healthy life style: personalized feedback approach*" was presented in April 2013 in Lunteren, the Netherlands, during the annual meeting of the COMMIT/ program. This meeting gathered around 200 people involved in each one of the 16 different projects. During this meeting the SWELL Project obtained a Valorization Award [20] where one of the criteria was the poster presentation during the meeting. The same poster was received with interest and curiosity by the audience, receiving the highest Synergy score [21].

To conclude, we believe that the incorporation of the adaptive goal-setting and personalized feedback strategies in the Activity Coach will benefit users in their way to become more active, but also healthcare professionals by allowing more accurate recommendations to their patients as they are more aware of their physical activity routines. The evaluation performed in this report will be used as a guideline for healthcare professionals and future updates to the system. The self-adaptive processes can also be adapted to other ambulatory systems used for monitoring and coaching physical activity.

[20] http://www.commit-nl.nl/news/the-commitvalorization-awards-2013
[21] http://www.commit-nl.nl/news/the-commitcommunity-poster-with-the-highest-synergy-score

8. Further Research

"Information provided by the system will be more persuasive if it is tailored to the potential needs, interests, personality, usage context, or other factors relevant to a user group."

(Oinas-kukkonen & Harjumaa 2009)

The updates to the Activity Coach are fully implemented and tested. However, there is always room for improvement. Moreover, the system was designed foreseeing future versions of the Activity Coach. Chapter 8 states our recommendations for further improvements divided per module: User Model Module, Smart Reference Module and Personalized Feedback Module. Lastly, general recommendations for the general scope of the Activity Coach are mentioned.

✓ *User Model Module*

Following the intention of tailoring the Activity Coach, the role of the *User Model Module* is to increase the personalization degree of the system. Further versions of this module should focus on the increase of personalization of the system in order to provide more personalized feedback. Some of the topics covered could be:

- *Social-demographic information* about the user in order to provide more personalized feedback (e.g. age, gender, job);
- *Personal preferences* (e.g. preference by outdoor activities to indoor activities). For instance, a user that prefers outdoor activities to indoor activities could be prompt with messages to go jogging, cycle, etc;
- *Personal information* about the user. For example, the fact that the user has or does not have pets; if he/she has a car; if he/she has a garden.

Another important improvement would be the incorporation of the *agenda* of the user. The data from the agenda could be used to create more accurate and personalized goal lines but also to schedule some activities, as for example, go for a walk from 17:00 to 17:30. (Hurling et al. 2007) defends that schedule as a tool for making highly specific implementation intentions can be an effective intervention for behavior change.

✓ *Smart Reference Module*

The recommendations for improvements of the Smart Reference Module are as follows:

- Create the goal line based on the *agenda* of the user. For example, if the user has a meeting from 14:00 to 15:00, the goal line would be approximately horizontal during that period considering that no physical activity is expected;

- Use *pattern recognition* techniques in order to modulate a goal line taking into account the pattern followed on the previous measurements;
- Instead of defining an ultimate goal in terms of IMA values, set a *rate* that should be applied to the average of the end points of the baseline week. For example, 2. In this case the ultimate goal would correspond to 200% of the average of the daily end-points of the baseline week;
- Provide daily, weekly and monthly *summaries* of physical activity;
- Add an option to display on the screen not only the goal line and the real activity but also the average physical activity on that day of the week (*reference line*). This could be done using the weighted averages of the daily activity. In this way the user would have a better insight about the periods of the day when he/she should change routine;
- Based on the results from the evaluation of the classification of the activity pattern, the percentage of activity balance value should be normalized in a way that 50% would correspond to 0% and 100% to 100%.

✓ *Personalized Feedback Module*

We have the follow recommendations regarding the Personalized Feedback Module:

- Incorporation of questions in order to make the system more interactive. In the case of users with low self-efficacy that achieved their daily goal, it could be interesting to ask the user's opinion on his/her performance during the day and then confront him/her with the Daily Summary;
- Improvement and enlargement of the messages database provided to the user. Create messages for different situations and scenarios;
- Incorporation of the agenda would also allow more personalized feedback. For example, if the system knows when the user is traveling and the user normally travels by car even within a short distance way, it would be interesting to suggest taking the bike instead of the car.

✓ *General Recommendations*

Finally, we leave some general recommendations for the Activity Coach:

- Improve the Graphical User Interface in order to reach a broader the population. A quantitative feedback (deviation from the goal line) might not be completely understandable for all users. We suggest a more qualitative feedback, for instance following the idea behind some devices described in sub-chapter 3.3 as the inclusion of a glanceable display (e.g. *UbiFit* and *Fish'n'Steps*);
- Increase the context-awareness of the system using the modules about weather and location in association with the Personalized Feedback Module and User Model Module in order to provide more accurate suggestions. For example, if it is sunny outside and the user has a garden, the system could prompt a message advising some gardening time;
- Extend the application to other topics such as nutrition. The User Model Module could keep track of the nutrition plan and the Personalized Feedback Module could provide suggestions on how to follow the plan, or reminders on the times to eat;
- Improve the conversion from IMA to steps. Use more subjects, more vigorous activity. Include conversion for other activities (e.g. cycling or gardening) in order to personalize the system;

- Perform a longitudinal study to evaluate the behavior change component of the system. It would also be interesting to evaluate the response of the user to the feedback messages following the work from (Tabak et al. 2013).

In such an emergent field as mHealth solutions, new systems appear every day. The possibilities seem limitless. The upcoming years will likely reveal how pervasive and persuasive technology can be used in order to invert the trend of adopting sedentary lifestyles.

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APPENDIX

I. Assignment Description

Title
Development, implementation and evaluation of personalized adaptive feedback strategies with respect to an activity based ambulant feedback module.

Background
The average age of the Dutch population is rapidly increasing. This implies that a decreasing number of the working population (aged 20 to 65) has to 'finance' an increasing number of (healthcare consuming) elderly. As a consequence, the costs of healthcare are expected to rise to even higher levels and further increase pressure on healthcare professionals (CBS, 2010). Furthermore, an increasing number of people tend to live a sedentary lifestyle, which is related to a decrease in health and therefore poses a risk for numerous diseases.

Regular physical activity has a significant positive effect on prevention of chronic diseases such as cardiovascular disease, diabetes, cancer and obesity (Warburton, Nicol & Bredin, 2006), but also on mental health condition through reduced perceived stress and lower levels of burnout, depression and anxiety (Jonsdottir, Rödjer, Hadzibajramovic, Börjesson & Ahlborg, 2010). This means that influencing people to change their sedentary lifestyle to a more physically active lifestyle should lead to a higher level of well-being, less chronically ill and higher life expectancy.

Research into the measurement of daily level of physical activity is mostly performed using tri-axial accelerometers. One key finding with respect to existing technology aided services that support users to increase their level of physical activity is that these typically lack insights from behavioural sciences. We expect that a service that successfully incorporates such insights will be more effective in achieving a real and lasting change in behaviour; several feedback strategies have been developed based on level of Self-Efficacy, Stage of Change and level of physical activity.

Aim & Study
The activity based ambulant feedback system from Roessingh Research and Development helps users gain insight in their level of physical activity and makes them aware of possible imbalances in their level of physical activity over the day. The student will make a contribution to an attempt to increase the effect and possibly also long-term adherence, by development, implementation and evaluation of several personalized feedback strategies.

Expectations regarding tasks and skills of the student

- The ability to formulate scientific research questions within the framework of the project;

- To make a contribution to the development of the feedback strategies;
- To implement and program these strategies into the relevant devices;
- To evaluate the result with end users.

Advanced programming skills are required for this project.

Location:	Roessingh Research and Development, Enschede, The Netherlands	
Relevant studies:	PSY/BMT	
Duration project:	January 2012-July 2012	
Contact:	Reinoud Achterkamp Roessingh Research and Development □ +31 (0)53 4875768 □□ r.achterkamp@rrd.nl	Miriam Vollenbroek-Hutten Roessingh Research and Development □ +31 (0)53 4875703 □□ m.vollenbroek@rrd.nl

II. List of Messages

Feedback strategy 1

1. Probeer vandaag eens een korte wandeling te maken, van bijvoorbeeld 10 minuten.
2. Is er nog plaats in je planning om straks een korte wandeling te maken?
3. Het gaat erg goed vanochtend! Pas wel op dat je ook energie overhoudt voor vanavond.
4. Neem gerust een pauze, je bent actief genoeg; goedzo!
5. Je hebt een pauze verdiend! Neem wat rust. Wat vind je leuk om te doen; de krant lezen, even op de computer, enzovoorts?
6. Laat je niet ontmoedigen doordat je bijvoorbeeld je doel niet haalt, je bent op de goede weg.
7. Neem je vandaag weer de trap? Stap anders eens twee verdiepingen lager uit de lift om verder te gaan met de trap.
8. Goed gedaan, je bent vandaag weer actiever geweest dan gisteren.
9. Is het lekker weer buiten? Probeer een tijd te prikken om vandaag een stuk te fietsen.
10. Je gaf aan dat je actiever wilde worden, heel goed! Probeer voor de komende week dagelijks een wandeling in te plannen.
11. Je bent goed op weg om actiever te worden. Een volgende stap is om de wandelingen die je maakt te verlengen.
12. We merken dat je erg actief bent, houd je ook energie over om ’s avonds leuke dingen te doen?
13. Elke dag een korte wandeling maken, of bijvoorbeeld met de fiets naar werk, draagt veel bij aan een goede gezondheid.
14. Je bent wat minder actief. Meer fysieke activiteit kan onder andere leiden tot een energieker gevoel.
15. Als je je vermoeid voelt kan het helpen om een stukje te lopen of iets anders actiefs te doen.
16. Wanneer je je van tevoren bedenkt op welke dag en hoe laat je een stuk kunt fietsen is de kans groter dat je het ook daadwerkelijk zult doen. Wanneer kan jij?
17. Wanneer heb je vandaag tijd voor een wandeling?
18. Wanneer heb je vandaag tijd om een stuk te fietsen?
19. Je zult merken dat je op den duur fitter wordt als je zo actief blijft zoals je nu elke dag bent. Probeer dit vol te houden!
20. Doe je kleine boodschappen al op de fiets? Kleine beetjes activiteit worden vaak onderschat.

Feedback strategy 2

1. Ondanks dat je hebt aangegeven actiever te willen worden blijkt uit metingen dat je vandaag actief genoeg bent geweest!
2. Je zit rond het gemiddelde niveau van gezonde Nederlanders qua activiteit; prima!
3. Je bent erg actief, vergeet niet af en toe rust te nemen; dat kan gerust zonder daardoor meteen als inactief te worden bestempeld.
4. Ondanks dat je aangeeft niet veel vertrouwen te hebben in jezelf als het aankomt op voldoende actief zijn, blijkt uit metingen dat je juist actief genoeg bent!
5. Je bent actief genoeg; je haalt je doelstelling van vandaag ruimschoots als je zo doorgaat.

6. Je hebt aangegeven nog actiever te willen worden, hoewel je vergeleken met gezonde Nederlanders actief genoeg bent.
7. Het wekelijks plannen van activiteiten, zoals wandelen, kan veel bijdragen aan het vertrouwen wat je hebt als het aankomt op fysieke activiteit.
8. Hoe actief ben je al denk je? Metingen wijzen uit dat je op een gezond niveau zit.
9. Je balanceert je activiteit netjes over de dag. Goedzo!
10. Mocht je nog actiever willen worden, probeer dan eens vaker de trap te nemen.
11. Je bent even actief als gezonde Nederlanders, maar je dagelijkse wandeling verlengen is een goede start om actiever te worden.
12. Ondanks je goede activiteitenpatroon zou je je wandelsnelheid kunnen verhogen om nog actiever te worden.
13. Ondanks je goede activiteitenpatroon zou je je fietssnelheid kunnen verhogen om nog actiever te worden.
14. De intensiteit van een activiteit verhogen is een goede manier om actiever te worden.
15. Je activiteitenniveau is goed op peil, pas op dat je niet koste wat kost nog actiever wilt worden.
16. Je activiteitenniveau is goed, ga zo door!
17. Je hoeft geen veranderingen te maken in je niveau van fysieke activiteit, het gaat al goed!
18. Probeer met jezelf af te spreken hoe laat en op welke dagen je een activiteit, zoals wandelen, fietsen of sporten, gaat doen.
19. Spreek met jezelf af wanneer je een activiteit gaat doen. Op die manier vergroot je de kans dat je het op dat moment ook daadwerkelijk zult doen.
20. Je hebt een goed activiteitenniveau. Weet je zeker dat je nog actiever wilt worden?

<u>Feedback strategy 5</u>

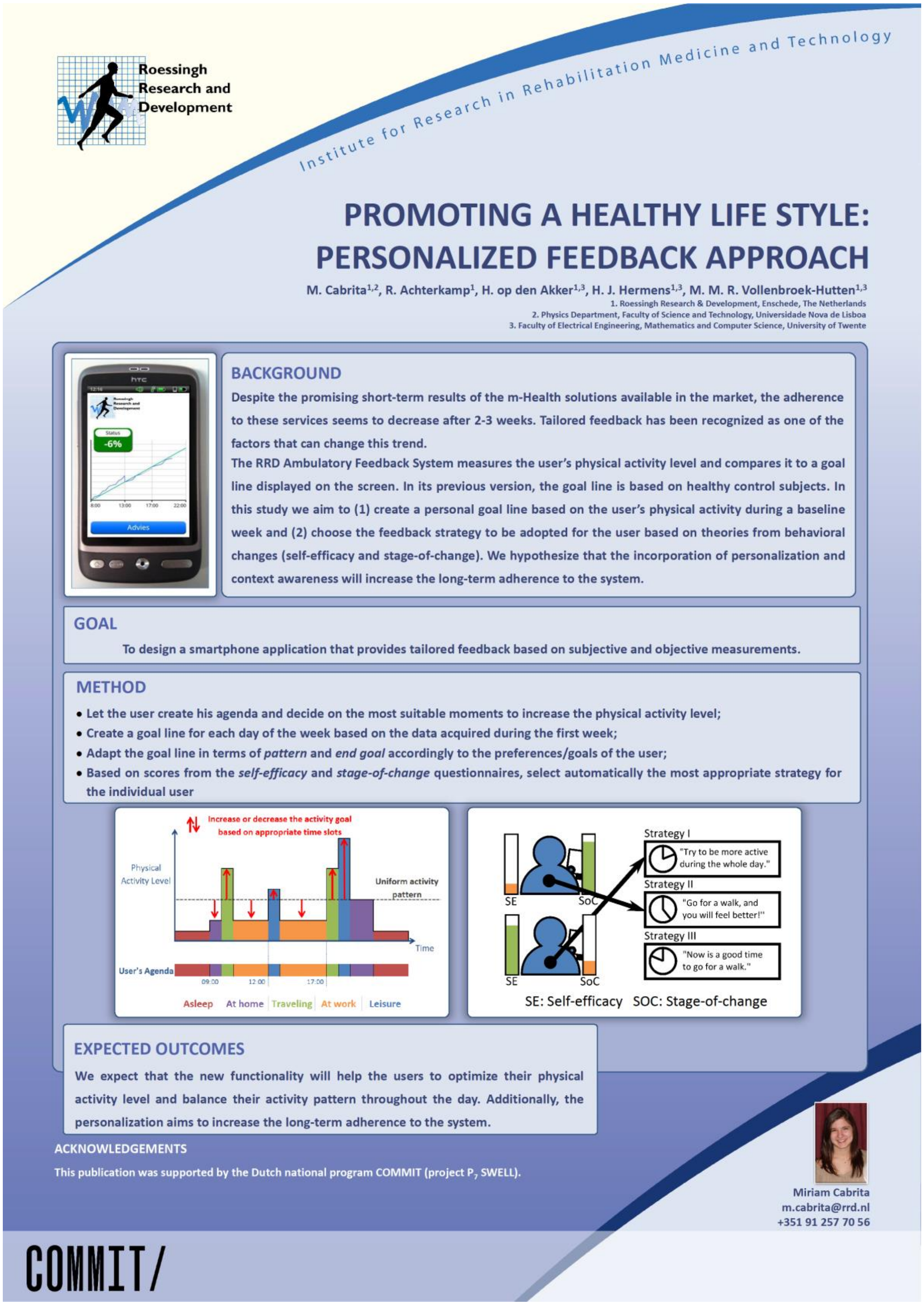
1. De metingen wijzen uit dat je wel wat actiever zou mogen zijn. Neem je altijd de trap?
2. Voldoende beweging zorgt voor verminderd risico op allerlei ziektes. Plan bijvoorbeeld tijd in voor een korte wandeling van 10 minuten.
3. Eerder heb je aangegeven geen intentie te hebben om te je niveau van activiteit te veranderen. Ben je tevreden met je huidige niveau?
4. Uit metingen blijkt dat je actiever zult moeten worden. Dit hoeft geen grote opgave te zijn; neem bijvoorbeeld eens de trap, of ga eens fietsen.
5. Hoe vind je dat je het gedaan hebt vandaag? Was je actief genoeg?
6. Hoe actief denk je dat je bent, vergeleken met een medepatiënt?
7. Je mag wat actiever worden. Fysieke activiteit, zoals wandelen of fietsen, kan juist als je vermoeid bent leiden tot een energieker gevoel.
8. Je hebt aangegeven geen intentie te hebben actiever te worden, terwijl een voldoende actieve leefstijl leidt tot een energiek gevoel en een gezonder lichaam.
9. Je activiteitenniveau is te laag, terwijl je veel winst kunt halen uit een actieve leefstijl.
10. Als je je activiteiten wat meer over de dag verspreidt, houd je meer energie over om ’s avonds leuke dingen te doen.
11. Probeer even rust te nemen zodat je je energie beter verdeelt over de dag.
12. Neem even een pauze. Je bent ’s ochtends erg actief, in tegenstelling tot ’s avonds. Probeer dit beter te balanceren door activiteiten te spreiden.

13. Zoals je ziet is je niveau van activiteit lager dan het niveau van vergelijkbare anderen. Het is gezond om wat actiever te worden.
14. Een hoger niveau van fysieke activiteit kan al beginnen bij een kleine wandeling tussen de middag.
15. Meer fysieke activiteit kan al beginnen bij de laatste twee verdiepingen traplopen, in plaats van met de lift gaan.
16. Je hebt aangegeven geen intentie te hebben om fysiek actiever te worden. Houd in je achterhoofd dat je ook in kleine stapjes kunt veranderen.
17. Ondanks dat je aangaf geen intentie te hebben om actiever te worden is het een goed idee straks een korte wandeling te maken. Begin met een kort rondje.
18. Ga vanavond eens een stukje wandelen of fietsen. Dit zijn kleine stapjes richting een actievere leefstijl.
19. Maak voor jezelf eens een planning voor de komende week waarin je aangeeft wanneer je een activiteit zal gaan doen, zoals wandelen of fietsen.
20. Denk je dat je voldoende actief bent, vergeleken met anderen in je omgeving?

<u>Advice for users with LOW Self-Efficacy</u>

1. Prik alvast een dag en tijdstip in je agenda om deze week een wandeling te maken.
2. De trap nemen in plaats van de lift kan je gezondheid aanzienlijk verbeteren.
3. Door te beginnen met kleine stapjes, in plaats van verre doelen, is het makkelijker een begin te maken om actiever te worden.
4. Denk er ook eens over na om bijvoorbeeld twee verdiepingen eerder uit de lift te stappen en verder te gaan met de trap.
5. Als je je vermoeid voelt kan het extra moeilijk zijn een activiteit te ondernemen. Bedenk dan dat activiteit juist ook leidt tot een energieker gevoel
6. Fysieke activiteit leidt tot meer energie. Als je te vermoeid bent, probeer dan toch een kleinere activiteit te ondernemen. Het mag ook met tussenpauzes!
7. Kleine doelen stellen helpt je om succesvol een actieve leefstijl te ontwikkelen, bijvoorbeeld door dagelijks een wandeling te maken en deze geleidelijk te verlengen.
8. Zoals je ziet ben je net zo actief als mensen zoals jezelf, heel goed!
9. Ten opzichte van mensen vergelijkbaar met jezelf ben je normaal actief, dat is goed!
10. Het kan helpen om concrete afspraken met jezelf te maken wanneer je een activiteit gaan ondernemen: welke dag, hoe laat, wat ga je precies doen?

III. Poster – 'COMMIT/ed to you'



IV. Paper – HealthCom ‘13

Promoting a Healthy Lifestyle: Towards an Improved Personalized Feedback Approach

R. Achterkamp, M. Cabrita, H. op den Akker, H. J. Hermens, M. M. R. Vollenbroek-Hutten

***Abstract*—Technology supported services for achieving a healthy lifestyle have shown their short term effects and are receiving increasing interest from the research community. However, long term adherence to these services is poor. This paper describes research-in-progress regarding the implementation of automated goal-setting and tailored feedback messages into one such technology supported service, which aims to improve the user’s physical activity pattern. Tailored feedback messages for several personas were set up based on theories from behavioral science and categorized by experts during an expert workshop. Results indicate reasonable agreement on the matching of motivational messages to four personas. Additional expert input is discussed descriptively. Future research will focus on examining the effectiveness of the new version of the service under investigation.**

***Index Terms*—Accelerometers, Behavioral science, Physical activity, Telemedicine.**

INTRODUCTION

PEOPLE live an increasingly sedentary lifestyle, resulting in a decrease in health and posing a risk for various diseases (e.g. [1]). On the other hand, a physically *active* lifestyle has significant positive effects on prevention of chronic diseases, such as cardiovascular disease, diabetes and cancer. Also, a sufficient level of physical activity has positive effects on mental health condition through reduced perceived stress and lower levels of burnout, depression and anxiety [2]. Therefore, a physically active lifestyle may lead to less hospitalization, higher life expectancy and improved well-being in general. Currently, many applications that support people in achieving an active lifestyle are available. One such example is the Ambulant Activity Feedback System (AAFS) [3]. The AAFS measures the activity of users during everyday life using an accelerometer-based sensor. Data is sent from the sensor to a smartphone, which displays the information to its user. The user’s cumulative activity is plotted in a graph that also shows a goal line, based on the average activity of a group of healthy control subjects. The system is able to coach the user. Based on the percentage of deviation from the goal line, the system provides motivational cues on whether the user needs to become more active (e.g. take a short walk) or take a break, in order to achieve a balanced, daily activity goal. Previous research indicated the potential of this system [3]. However, it also showed that the adherence to the system dropped substantially after a few weeks. It is expected that this lack of adherence to the system and decrease of effectiveness can be overcome by adding 1) context aware goal setting and 2) personalization of information, i.e. tailoring [4].

BACKGROUND

Context aware goal setting

When Locke and Latham first proposed the Goal-setting Theory [5], it mainly focused on questions regarding motivation in work settings. However, its promising results made it one of the most commonly used theories to promote a healthy lifestyle. According to the Goal-Setting Theory, people are more likely to change behavior the higher the specificity and (achievable) difficulty of a goal. However, one should always bear in mind personal characteristics of the subject, such as goal importance, self-efficacy and feedback. Research regarding physical activity interventions shows that combining goal-setting and persuasive technologies can significantly improve the results of interventions [6]. When setting goals, baseline level of physical activity of the user should be assessed first, based on which a personal goal can then be set. Setting a goal based on the average activity of a group of healthy controls will in many cases lead to users not reaching their goal. Furthermore, considering the applicability of technology supported services to various domains, patients, for example, would struggle to keep up, possibly never reach their goal and simply give up. Therefore, we recommend to automatically adjust the height of a goal and set it slightly higher than the personal baseline.

Another important aspect, next to height of the goal, is the physical activity pattern throughout the day. Research into the physical activity pattern of chronic low back pain patients [7] and patients suffering from chronic fatigue [8] shows that these patients are unable to balance their physical activity pattern throughout the day. Our solution is to incorporate context aware automated goal setting; enabling the technology supported service to automatically detect imbalances in the user's physical activity pattern, set goals and continuously keep these goals up to date.

Tailored feedback messages

Feedback based on subjective measurements can have an equally large effect as feedback based on objective measurements. Research shows that interventions that used tailoring on *attitudes*, *self-efficacy*, *stage of change*, *social support* or *processes of change* showed significantly larger effect sizes than interventions that did not tailor on these constructs [9]. Also, guidelines for designing effective physical activity interventions strongly recommend tailoring feedback [10].

Given the above, providing real-time motivational cues that are based on constructs from behavioral science and the user's current level of physical activity seems a promising solution to the lack of long term adherence to e-health services. Indeed, s*elf-efficacy* and s*tage of change* are already identified as two important constructs from behavioral science [11]; it is recommended that users receive feedback messages based on their individual scores on these variables. Achterkamp et al. [11] identified eight typical users – so called personas – usable for technology supported services that are aimed at improving physical activity. Given a subject's score on a self-efficacy questionnaire, stage of change questionnaire and the user's own baseline level of physical activity, subjects are identified as one of these eight personas. Subsequently, each persona is recommended one of six feedback strategies, which serve as literature-based guidelines to set up tailored feedback messages.

CONTEXT AWARE GOAL SETTING

Whereas in previous versions of the system, the goal line was fixed throughout the intervention period; we now describe the smart reference module that automatically generates personalized and self-adjusting goal lines for individual users of the system.

Baseline Period

The first seven days after users have received the system are considered the baseline period. During this period the system defines 1) a baseline for each day of the week and 2) the best feedback strategy to adopt for the specific user based on the user's daily physical activity pattern and results from questionnaires assessing self-efficacy [12] and stage of change [13] (the use of these feedback strategies is explained in Section IV). We intend to make a continuously adapting system that follows not only the user's routine, but also their progress through time regarding the psychological constructs. This information can be accessed by healthcare professionals through the web portal

Intervention period

During the intervention period, users receive time-related motivational cues. The content of these messages depends on 1) the feedback strategy that is appropriate for this user and 2) the deviation of the user's physical activity level from the goal line. Each feedback strategy has three types of messages: encouraging (meaning to encourage users to increase their activity), neutral (letting the user know that they are performing well) and discouraging (telling the users to slow down their physical activity in order to achieve a good balance over the course of a day) [7].

Taking Monday as an example, the data acquired during the day is averaged over short time intervals. The system then computes the Linear Weighted Moving Average (LWMA) of the data from all the previous Mondays with the new data, as in (1).

$$LWMA(newEndPoint, N)_i = \frac{\sum_{j=1}^{N} newEndPoint_{i-N+j} \times (i-N+j)}{\sum_{j=1}^{N} j} \qquad (1)$$

In addition, the Activity Coach tracks the percentage of total activity that the user should achieve at different times of the day. As an example, a user should accomplish 40% and 70% of the total daily activity at 12.00 and at 17.00 respectively. These points are dynamic and can be changed by the health care professional on the web portal or adjusted according to the user's agenda or other contextual factors.

The new goal line is defined in two different steps: first the end point will correspond to a slight increment of the weighted end point of all previous Mondays. Second, based on this end point, the goal line is defined by calculating an optimal distribution between what the user has accomplished on average and the goals previously defined. The ideal distribution is the one that would give a challenging but achievable goal all throughout the day in line with Goal Setting Theory.

Moreover, the user's physical activity pattern is classified as either balanced or imbalanced according to a minute by minute calculation of deviation from the goal line.

Additionally the LWMA of different periods of interest (e.g. morning-afternoon-evening) is calculated and stored in the system. This information can be considered as additional feedback to inform users about their daily activity pattern.

Subjective measurements

As users will move through various stages of change and levels of self-efficacy while using the Activity Coach, they will be prompted with a self-efficacy questionnaire and stage of change questionnaire every four weeks. Which feedback strategy to apply accordingly is automatically decided by the system by combining these two variables with the classification of the user's physical activity pattern (i.e. how often they achieve their target goals, and how often they show a balanced versus imbalanced activity pattern).

Future work

In order to further personalize the goal pattern (particularly in terms of balance) we will incorporate a user agenda into the system. By asking users to fill in their weekly schedule (sleep, travel, work, and leisure time) we can use this information to determine appropriate times for which we can increase the expected amount of activity performed, effectively raising the goal line at those moments. For example, for typical office workers, such appropriate times are most likely to occur after working hours. Recent developments in automated, semantic location tracking can replace the process of querying for explicit user schedules by automatically determining working hours, travel time and time spent at home. Weather information and nutritional planning are other functionalities to add in the future.

TAILORED FEEDBACK MESSAGES

Tailored feedback messages were set up based on personas and feedback strategies identified in earlier research [11]. See Table I and Table II.

To validate the categorization of messages to the feedback strategies, four psychologists were invited to match the feedback messages to the corresponding feedback strategy or strategies. The focus was on feedback strategies that aimed at personas with low self-efficacy. Participants individually categorized every message to one or more feedback strategies. Next, all messages were discussed with the group to identify flaws and allowing participants to give feedback. Results were analyzed by calculating Cohen's Kappa. Kappa ranged from .373 to .692 and averaged .483 (Table III).

TABLE I – EXAMPLES OF FEEDBACK MESSAGES

1.	"Earlier you indicated that you do not have the intention to adjust your level of physical activity. Are you satisfied with your current level of physical activity?"
2.	"You're doing very well this morning, but keep in mind to save some energy for the evening."
3.	"You indicated that you wanted to become more physically active; very good! Try to plan a daily walk for the next week."

TABLE II – EIGHT PERSONAS

	Intention to change (contemplation, preparation and action)		No intention to change (precontemplation and maintenance)	
	Level of activity		Level of activity	
	Improper	Proper	Improper	Proper
Self-efficacy Low	Persona1	Persona2	Persona5	Persona6
Self-efficacy Average-high	Persona3	Persona4	Persona7	Persona8

TABLE XIVII – COHEN'S KAPPA INTER-RATER RELIABILITY

	Expert 1	Expert 2	Expert 3	Expert 4
Expert 1	-	.373	.459	.417
Expert 2	.373	-	.439	.519
Expert 3	.459	.439	-	.692
Expert 4	.417	.519	.692	-

CONCLUSIONS

Clinical experimental evaluation of the Activity Coach, implementing the smart reference module (Section III) and the tailored feedback messages (Section IV) is planned for the second half of 2013. The tailored feedback messages have been implemented into the system and users are appropriately categorized to the feedback strategy that is best suited for the individual user. Before clinical validations take place, we aim to evaluate the goal setting algorithms through simulation using physical activity data from real users. These users are under supervision of a physiotherapist who will judge their physical activity progress and balance from day to day. This gives us a gold standard of target activity and activity balance, enabling us to fine tune our algorithms to match the expert's opinion. As these users will be wearing the Activity Coach for a period of time, we are also able to observe the self-adjusting behavior of our algorithm.

The experts showed a fair to moderate agreement on how to categorize the feedback messages. Partially, these low values can be explained by the subjective nature of the categorization. Although the experts received detailed information about the personas and feedback strategies, the feedback strategies could still be interpreted differently by the various experts. Another workshop will be organized to categorize messages related to the feedback strategies that were not discussed.

Future directions of research regarding technology supported services should focus on tackling common problems regarding adherence and focus on incorporation of more context awareness and constructs from behavioral science.

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