Usage of Accelerometers in Home Care for multiple sclerosis patients

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Abstract: Pervasive Computing is developing fast and is presenting new opportunities for medical care. Unfortunately, technology selection and adoption in the healthcare sector and by physicians is typically an intricate process. Exemplified by Multiple Sclerosis (MS) this paper describes the assessment of a dedicated PC technology with respect to medical usefulness in real life applicability. MS is a chronic disease that typically affects the patient's mobility and quality of life. Tri-axial accelerometers can be used to gain more information about the particular state of the disability. This technology can provide medical staff with objective and more comprehensive information. We present the design of a real life experiment and how the evaluation is designed to analyse the technology's developmental status, its acceptance, and its medical usefulness.

1 Introduction

Pervasive Technologies (PT) – small components that are equipped with communication capabilities and sensors to interact with their environment [Sa01] – have been developing fast [Bu06] and present many new opportunities for medical care [Va03]. One of the main characteristics of PT is that information like continuous monitoring data – which has hardly been available so far or has been difficult to acquire – can be gathered 'along the way' and exchanged simply.

According to past medical applications, it is easier to collect more objective, more comprehensive and more information in total about a patient's condition with PT. These advancements are due to unobtrusive sensors on the patient's body and in the patient's environment, which allow for more precise diagnosis and form treatment and therapy plans based on automated information analysis.

PT may have considerable potential but the emergence of groundbreaking real world applications is relatively slow – technology selection and adoption by the industry is typically an intricate process. Reasons are manifold: One cause is the laborious communication process between technology providers and medical practioners – while one party aims to transfer existing or new technological approaches to application scenarios, the other is typically sure about insufficiencies of applied approaches but unsure about the new opportunities and chances.

While this situation is not necessarily an exclusive healthcare challenge, the economic, social and legal context in the healthcare sector is exceptional:

- Humans are the 'objects' to be treated and treatment itself is to a large extent an human interaction service;
- quality requirements are very high and legal hurdles often hamper the implementation and realisation of innovative approaches,
- the economic framework has changed quite rapidly during the last years and innovation and technology diffusion processes have rarely adapted to the new stringent demands of healthcare providers and their management departments.

Innovative PT technologies allow technicians and health professionals to think about new approaches for medical treatment. As illustrated in Figure 1, this option for innovation is definitely the most complex one of the four alternatives.

In this paper we present an example of such a scenario: In recent years, the development of activity monitoring systems has increased rapidly. Many companies and research institutions are developing activity systems for use in clinical studies and rehabilitation [Da06] [Da07], elderly care or in general for home care use. With these systems one can assess information about the everyday life activity structure of a patient over a long time. Therefore, the doctor, or the patients themselves, can potentially get a realistic overview of the activity profile. As part of the case study 'MS Nurses' we aim to set up an environment to collect activity data from multiple sclerosis patients to see if a correlation exists between the activity of patients and the degree of disease evolution. Similar activities are being done in a phase IV clincal study in MS [Ha07].

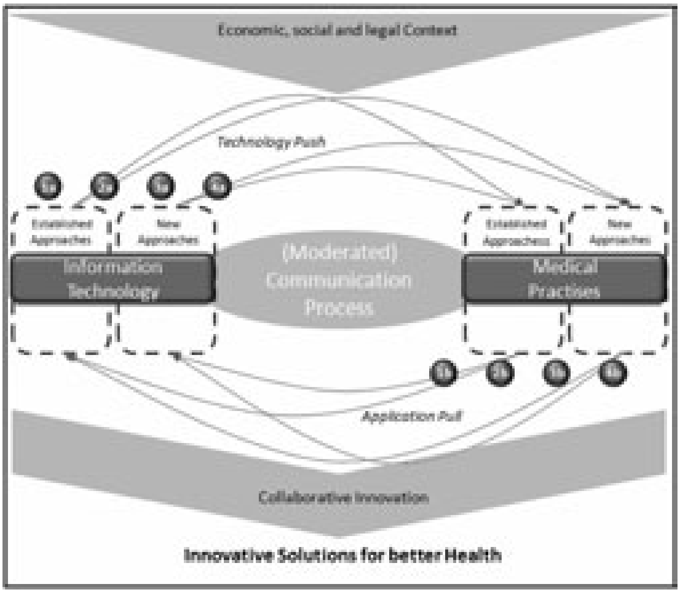

Figure 1: Information Technology and Medical Practises in continuous exchange

The case study is part of the research project PerCoMed[1] (Pervasive Computing in medical care) which started in 2006. This study is driven by the cooperation partners FZI Research Center for Information Technology at the University of Karlsruhe, Sylvia Lawry Centre for Multiple Sclerosis Research (SLCMSR), Trium Analysis Online GmbH and Neurologische Klinik Bad-Neustadt/Saale.

Our work is based on the concept that MS treatment can be supported by state-of-the-art activity monitoring systems. The objective of this paper is to illustrate the results derived from the first phases of the communication between technology providers, research institutions, medical service providers and a moderating research company. The paper points out how:

- MS treatment can be supported by activity monitoring systems
- the selection of an adequate technology is motivated
- the evaluation approach is designed, that will be acted on within the next 1,5 years.

[1] See www.percomed.de, partners are the Institute for Futures Studies and Technology Assessment, Berlin (IZT), the Research Center for Information Technologies, Karlsruhe (FZI) and the Institut for Technology Asseement and System Anaylsis Karlsruhe(ITAS)

This work is structured as follows. First, the medical background of MS is explained, and options of Pervasive Computing for treatment are identified and the requirements for an activity monitoring system to support the MS treatment are elaborated. Subsequently we review available technologies for activity monitoring and explain how the PT solution actibelt® works and why it fulfills the aim of the study. Afterwards, we present how the chosen technical solutions have to be integrated and evaluated. Conclusively, an outlook to further research is provided.

2 Medical background of Multiple Sclerosis

Multiple Sclerosis (MS) is thought to be an autoimmune disorder that leads to the destruction of myelin, oligodendrocytes and axons in the central nervous system (CNS) [No00]. MS primarily affects adults, with an age of onset typically between 20 and 40 years, and is more common in women than in men. Multiple sclerosis may take several different forms, with new symptoms occurring either in discrete attacks or slowly accruing over time. Between attacks, symptoms may resolve completely, but permanent neurological problems often persist; especially as the disease advances [Co05]. MS currently does not have a cure, though several treatments are available which may slow the appearance of new symptoms [Co07].

Axonal degeneration and conduction block cause symptoms such as muscle weakness, abnormal muscle spasms, difficulty to move, poor balance or fatigue. In the further progression of MS, these symptoms aggravate, so that they can be considered to be good indicators for the actual state and progression of the disease. Eventually, impairment of walking ability becomes closely correlated with lower quality of life, disability and early retirement of MS patients.

In multiple sclerosis the Expanded Disability Status Scale (EDSS) is a frequently used disability score for the evaluation of clinical disease burden on progression [Ku83]. It helps monitoring the course of MS and is part of the treatment optimization model recommended for the observation of effectiveness of immunomodulatory therapies. The EDSS score ranges from 0.0 to 10.0 in steps of 0.5 (starting from 1.5) . Between 0.0 and 3.5 patients are able to walk on their own, without limitations. Patients with the scores 4.0, 4.5, 5.0 and 5.5 are able to walk within a maximum distance of 500 meters and above 6.0 they are unable to walk without crutches or a wheelchair. Lastly, the score 10 means death by MS.

Within periodic intervals (in most cases every three or six months), the EDSS score is evaluated by the doctor during basic examination. But even though these examinations are done regularly, they can only give an instant impression of the disease’s status. It would therefore be desirable to learn more about everyday occurrences during the previous three months so that the progression of the patient’s condition can be re-evaluated more precisely.

For example, it would be of interest to know how patients move during this time or if they had any difficulties walking, which they might have forgotten themselves. The sooner the progression tendency of the disease can be detected, the better measures can be taken and therapy can be adequately adapted to preserve the patient's mobility.

Recently, medical studies like [Ei06] have shown correlations between gait parameters and the EDSS score. It therefore seems possible to stage the patients' status of health by the manner of their activities. It is our objective to find a way to monitor patients' activity over a long period by using Pervasive Technology. With the help of the measured parameters and the comparison of activity and EDSS score doctors could be supported in detecting tendencies of patients' aggravation.

3 Technical Review of Existing Technologies

In medical care, different technologies for assessing activity and movement data are already in use. The use of technology in this field can lead to a more impartial observations than a doctor or a patient can provide. In order to choose the most promising technology we need to get an overview of existing technologies and assess them according to the given technological requirements.

3.1 Main Technologies in Movement Analysis

The relevant categories of technologies for movement analysis are Footswitches (a), Accelerometers (b), Electrogoniometers (c), Optical Motion Analysis (d), Force Plats, Gait Mats (e) and Gyroscopes (f). For an overview see Figure 2. These technologies are shortly introduced in the following. GPS, as explained in [DA07], is currently not an option for movement analysis.

- Footswitches are one of the simplest ways to collect gait events and temporal data. Displayed under the feet, footswitches collect temporal information step by step [Bo98]. Similar to footswitches, force plats operate with mats and collect the same data. But Force Plats can only be used for one step if one plat is available or for a stride if two plats are in place.

- One single or a set of Accelerometers can be used to assess information of the body movement in one, two or three axes. Depending on the number of accelerometers one can identify certain events such as walking, sitting, standing, lying, jumping or falling. In recent studies accelerometers where used to asses data about the activity profiles of patients [Da05] [Lo06].

- Gyroscopes attach to the body and record the angular velocity. In doing so, Gyroscopes can assess velocity data and therefore, similar to the accelerometer data, different activities can be detected [Pa04].

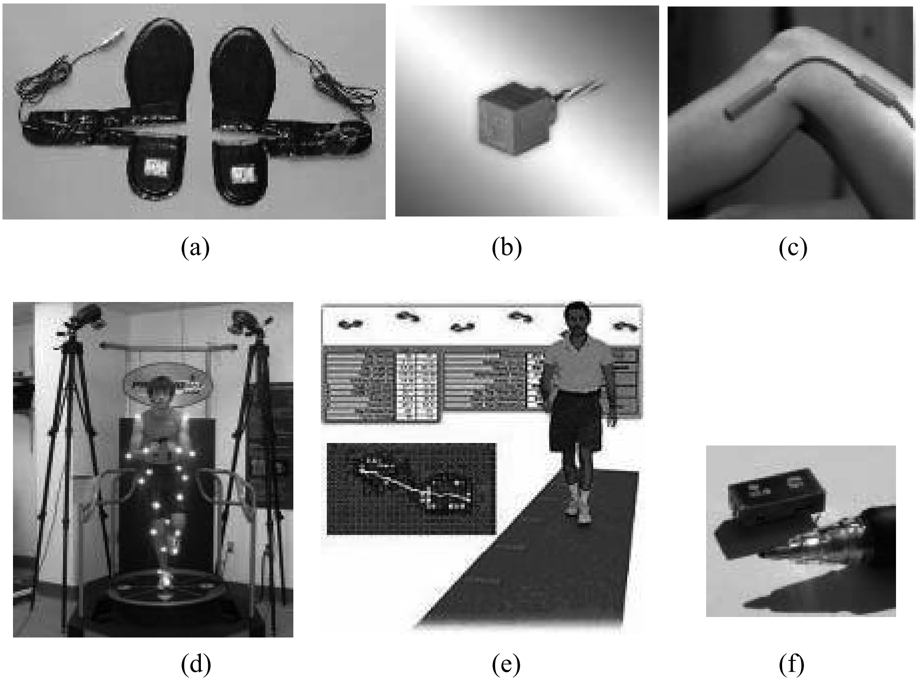

Figure 2: Technologies for movement analysis: Footswitches (a)[2], Accelerometers (b)[3], Electrogoniometers (c)[4], Optical Motion Analysis (d)[5], Gait Mats (e)[6] and Gyroscopes (f)[7]

- Optical motion analysis is the most frequently used technique in clinical settings. The patient is put on a treadmill and is videotaped during the exercise. The patient wears either passive or active markers which represent classical anthropological base points. The signals registered by the markers can be used to identify information about motion and gait.

- Gait Mats are long walking strips that have long arrays embedded of pressure sensitive switches. If a person walks over the mat the switches close under the pressure of the feet. As the position of each switch is known, it is possible to calculate spatial and temporal parameters of gait [Bi03].

- An Electrogoniometer consist of electric potentiometers. These potentiometers produce an output voltage proportional to the angular between the two attachment surfaces. They are used for joint angle measurement.

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[2] http://www.bleng.com/fsw.htm
[3] http://www.sensorsportal.com/HTML/DIGEST/june_05/Accelerometer_356A13.htm
[4] http://www.laboratorium.dist.unige.it/~piero/Teaching/Gait/BONTRAGER%20Instrumented%20Gait%20Analysis%20Systems.htm
[5] http://klab.surgery.duke.edu/modules/klab_rsrc/
[6] http://www.gaitrite.com/
[7] http://www.gyroscope.com/d.asp?product=PIEZO

3.2 Technological Requirements

Based on the challenges of Multiple Sclerosis (MS) described above, the scenario for applying movement analysis in MS treatment can be drawn up as follows. Typically, MS patients who are living at home on their own, live and work as usual and consult their doctor once every three months for their basic physical examinations. In the three months between the check-ups they wear a device, which continuously monitors their movement during daily-life activities. This device should not constrain the patients in their daily life. In the best case, they do not notice that they are wearing the device. At the next regular doctor's visit the data is transferred and analysed. In contrast to the usual check up, the analysis results not only provide information about the momentary health status, but also about the development over the last months.

Life circumstances of MS patients vary. Patients are of all age classes and some are physically very active while others are near bed-ridden. Most MS patients know a lot about their disease and are very interested in its course, development and results. Therefore, MS patients possibly would want to get actual information about their movement analysis at home. As MS patients are typically in close contact with their doctor, they do not see a need to avoid their regular doctor's appointments.

From the previous description several factors can be derived that are crucial for a successful monitoring system. In health care, technological requirements, medical, technical, usability, economic and sociological aspects have to be considered. Our scenario has to meet the critical factors according to medical, technical and usability aspects. As the device will be used in an ambulatory Home Care scenario and will collect information about the every day activity of the patients, all techniques that need a laboratory setting are not applicable. Thus that Optical Motion Analyses, Gait Mats and Force Plates are not applicable and not considered in the following. Furthermore, the device should collect data about patient's general activity that allow for classifying activities he is performing. In particular, running, walking, sitting and standing activities should be detectable. The device shall also include stumbling and fall detection and calculation of gait asymmetry.

Additionally, it must be possible for the patient to use the device easily by oneself at home. As instant data analysis is not required for the multiple sclerosis diagnosis, no online data transfer method or real time analysis is necessary. Therefore, it is more important that the device has a long battery performance and sufficient data storage capacity. The device has to be wearable, to get a reliable information base [Tr00], and has to be wearable without disturbing the patient during his normal activities.

Table 1 summarizes our review. The technologies that could be used in home care are valued by the five axioms "Activity Score", "Activity Classification", "Usability", "Power Consumption" and "Wearability". "Activity Score" describes the ability of the device to asses information of overall activity, if the patient is active or not. "Activity Classification" is the ability of the system to distinguish several activities such as standing, walking or running. This axiom also implies the ability to detect and quantify asymmetric walking and falls. "Usability" means ease of use for patients. "Power consumption" addresses the ability to realize long term observations. At last, the wearing comfort for the patient without feeling disturbed by the device is summarized under "Wearability". A "+" is the indicator for good support of this factor and "-"the indicator of an insufficient support.

Device	**Activity Score**	**Activity Classification**	**Usability**	**Power Consumption**	**Wearability**
Footswitches	+	-	+	+	+
Electrogoniometers	-	-	+	+	-
Accelerometers	+	+	+	+	+
Gyroscopes	+	+	+	-	+

Table 1: Comparison of the main technologies for movement analysis in Home Care

Regarding the technology introduced earlier, one can state that Electrogoniometers are used to measure the angle of hinges during movement. Thus the data does not give information about activity as for instance the accelerometers and gyroscopes do. Gyroscopes have elements that are continuously consuming energy. That results in higher energy consumption compared to accelerometers. That makes gyroscopes unsuitable for long data assembly [Lu04]. Even Footswitches are used in highly complex studies, they are more designated for the assessment of temporal gait information than for activity classification.

Accelerometers appear to be the best choice for movement analysis according to our scenario. They comply with the requirements that are named in this article. Accelerometers used most frequently in early activity studies [Mo06, Ya07].

There are several companies and research institutions such as Bodymedia[8], Actimon[9], Dynastream Innovations[10] and Trium Analysis Online GmbH[11] that are producing activity classification instruments based on accelerometers. With one exception, none of these has attempted to embed the device in standard daily clothing. Trium Analysis Online GmbH in cooperation with Sylvia Lawry Centre for Multiple Sclerosis Research provides the actibelt®, a belt with integrated accelerometers which is specialised in activity monitoring of patients with multiple sclerosis. It has the advantage of being embedded in a daily wearable belt close to the body's center of mass and therefore it ist unobtrusive and does not disturb the test person in it's daily life.

After the decision for accelerometers, we need to draw an applicable solution architecture, including an applicable prototype (product) and an evaluation approach.

4 Solution Architecture

The technical solution consists of a triaxial accelerometer device. For our proposes, we use the actibelt® and a corresponding software environment to collect and analyse the activity data of MS patients. Furthermore, we integrate that solution in clinical settings to perform medical analysis. This chapter introduces the actibelt® solution and the research approach for assessing the data from the patients.

4.1 Accelerometer: actibelt®

The actibelt® has a triaxial accelerometer integrated into its buckle (see Figure 3 (iii)). This measurement device enables the measurement of accelerations along three mutually orthogonal axes at a sampling frequency of 100 Hz and stores the data on the flash memory. The three axes are arranged in such a way that the x value corresponds to the up-down acceleration, the y value to the left-right acceleration, and the z value to the forward-backward acceleration when the test person is standing.

The actibelt® package (Figure 3 (i)) contains a belt buckle with a black measurement box, three belts in different colours, an USB cable, an user manual and short instructions. The belt buckle is made of stainless steel (9.1 x 4.3 x 1.7 cm) and weighs 53 g. The actibelt® black measurement box inside the belt buckle contains the measurement device (back side). The measurement device can be connected to the PC via USB.

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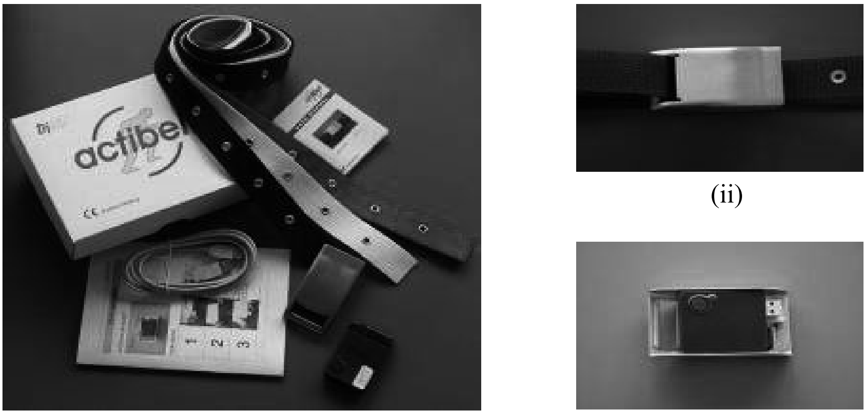
[8] www.bodymedia.com
[9] www.actimon.de
[10] www.dynastream.com
[11] www.trium.de

The black measurement box is made of casting resin, has a size of 6.8 x 4.1 x 1.4 cm and weights 39 g with the chip inside. Currently we use the accelerometer LIS3L06AL from ST Microelectronics with a range of –6 g to 6 g (g=9.81 m/s^2). Our data has a resolution of 0.3 %. The battery operating time lasts about 100 h, the storage suffices for 250 h of continuous measurement (512 MB). The operating time of 100 h allows to measure activity data of 7 days.



(i) (ii) (iii)

Figure 3: the actibelt® package (i), belt buckle front side (ii), belt buckle back side (iii)

The belt can be connected to every PC via the USB-port directly or via the delivered USB-cable. After installing the driver and the client software, the user can communicate with the actibelt®. The client software is written in Java and allows the patient to download files from the belt, to see the battery status, the remaining storage capacity and to clear the storage. After downloading the files to a PC the user can upload them to the actibelt® server via the actibelt® web application. Then, the files are analysed by the actibelt® analysis software written in Matlab. The software currently distinguishes between 6 different movement types: jogging, walking, standing, sitting, lying and undefined movements as standing up or lying down (see Figure 5). For this segmentation the signal is broken up into a series of time segments of 1 second. For all time segments the arithmetic mean value, the robustified range, defined as the difference between the mean of the 10 largest and 10 smallest measurement values, and the absolute deviation are calculated. A type of movement is assigned to every 1-s segment using a threshold method with thresholds depending on multiples of g. These thresholds were determined by exploring measurement values taken from approximately 20 healthy volunteers of different gender, age, height and weight. This segmentation works fine as it gives kappa coefficients of 0.855 (95% CI [0.833, 0.877]) and 0,784 (95% CI [0,758, 0,810]) for the correct differentiation between the five different movements [Da06].

After the first classification, the software makes a detailed analysis of the real movement parts (walking and jogging). To detect steps, all the minima in the signal are found, which are associated with a heel strike (Figure 4). We focus only on minima below a certain threshold and then use the step frequency calculated via the power spectrum to select the correct minimum. There were found kappa coefficients of 0.983 (95% CI [0.979, 0.987]) and 0.972 (95% CI [0.966,0.978]) for the correct assignment of a detected peak to a true step [Da06].

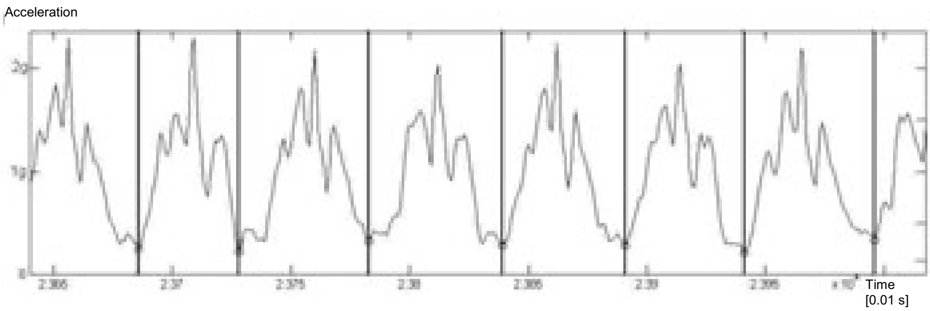


Figure 4: Measurement with the minima associated with a heel strike (vertical lines).

The step number, the duration of every step, the step frequency, the step amplitude and the asymmetry depending on the difference between the duration of right and left steps are calculated. The software also estimates the travelled distance and the maximum distance walked in one draught with an accuracy of approx. +/- 10 % [Da07] and estimates the energy consumption. The number of stumbles and falls is currently detected manually, but will soon be done via pattern recognition.

The results of the analysis are summarized in a report (see Figure 6) and are transmitted to the web application. The measured and calculated parameters are saved in a text file to allow additional user-defined statistical analysis.

4.2 Research Approach

The data provided by actibelt® delivers information about the patient's physical activity and gait quality. As described above, by using the technology we can display the activity ratio as proportions between standing, walking, lying, jogging and sitting. Furthermore, we can calculate step number, the duration of every step, the step frequency, the step amplitude and the asymmetry depending on the difference between the duration of right and left steps. We can also estimate travelled distance, maximum distance walked at one draught and energy consumption.

The next step, after choosing the technology, is to understand how the provided data can be used to make medical statements and to support MS treatment in future. If movement analysis can be used to monitor a patient's status of health, doctors can better detect early signs of deterioration [Ri05].

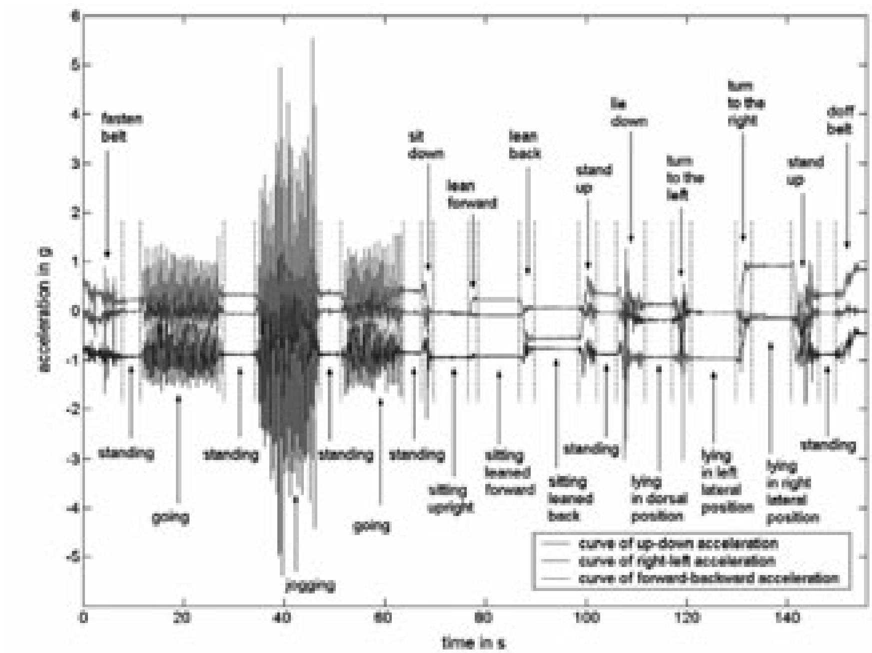


Figure 5: Example for a signal measured by the actibelt®. In this case the segmentation was done by a human observer. The challenge is now to improve the analysis software to detect not only the movements standing, sitting, walking, etc. but also activities and transition phases such as sit down or stand up..

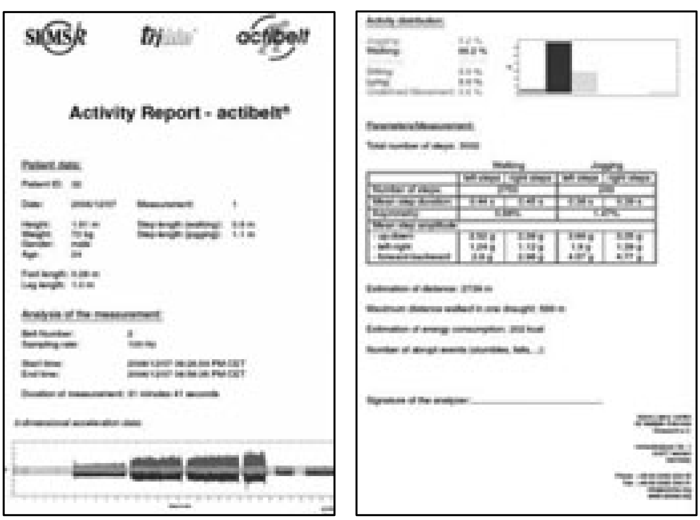


Figure 6: An example for a report created by the actibelt® software.

Therefore, we need to setup a study which aims to associate the actibelt®data with specific MS symptoms. This seems to be the most suitable way to find correlations between the EDSS score and activity ratios as well as to identify patterns of unusual movement like disturbances of equilibrium or to frequent signs of fatigue. This means that many patients with different EDSS scores have to record their activity ratio by wearing the actibelt®. This might result in a correlation table which lists the EDSS scores related to average activity ratios, special events such as count of falls and stumbles or maximum distance walked at one draught.

The clinical study is divided into an ambulant and a stationary setting. In the ambulant setting, MS patients wear the actibelt® one week at home and bring the belt back to the hospital. The stationary patients wear the actibelt® over one day in the hospital. There will be five devices in use for the ambulatory patients and four devices for the patients at the hospital.

The participants of the study are patients with an EDSS score less than five, who can still walk by themselves over a longer distance without further assistance. The data collection is scheduled to be carried out until December 2008. More than 200 samples will be needed in order to apply a t-test and to see if there is a correlation of the activity data and the EDSS classification of the patient.

In addition to the clinical study, the user acceptance of the device will be examined by questionnaires. This user acceptance analysis aims to find out how patients, doctors and nurses feel about the technology and the clinical setting. By means of this analysis, people's attitudes towards this kind of technology will be obtained and at the same time suggestions for improvement can be elaborated.

For this research the Neurologische Klinik Bad Neustadt/Saale will take care of the participating patients and the correct data collecting. The FZI Research Center for Information Technologies is involved in the design of the study and the Sylvia Lawry Centre for Multiple Sclerosis Research and Trium Analysis Online GmbH are responsible for the development and optimization of the technology and for the analysis of the measured activity data.

5 Conclusion and Outlook

We have identified an innovative technological platform to conduct our study. Nevertheless, there are still many risks to be handled. The biggest challenge will be the assembly of accurate data. Obviously, we need to provide a very big data basis to identify data correlations as well as to deal with interferences. Though the actibelt® seems to be easy to use some people might have problems to use it correctly. People are very different in their daily activity, which makes the comparison of their data difficult. For example, some people are more active than others in principle and have a higher general activity level. Another challenge will be that the actibelt® analysis software can not classify all kind of activities (e.g. cycling, hill climbing), yet. This is not critical for our study but needs further research if the actibelt® is used in a broader field.

Furthermore, we have to pay attention to the user acceptance as well as the integration process. Hospital staff and patients must not be bothered by the system in their daily work and life.

In this paper we presented a suitable technology to support MS treatment and elaborated a clinical setting for this technology in order to generate medical value. If we are right, we can achieve an application of movement analysis in a medical scenario through the aid of Pervasive Computing technologies. This study is primarily a medical study and considers some (but not all) real life conditions. After ensuring the medical value of our approach, a second study about real life practicability (robustness, usability, legal formalities, incentives, economic aspects, etc.) will be performed.

Actual developments show that sensors for movement analysis will have medical and economical benefits in the future. As the sensors are integrated in several devices (e.g. gaming console Nintendo Wii, airbag in cars, hard disk protection in notebooks, spacesuits of NASA etc.) the demand and supply of sensors for movement analysis will rise rapidly and sensors will become less expensive.

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