A TELEMEDICINE SYSTEM FOR IMPROVED REHABILITATION OF STROKE PATIENTS

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Abstract: Analysis showed that costs of long-term care for stroke patients have increased from 13% to 49% of overall costs in average in recent years. Therefore there is an urgent need for devising an effective long-term care and rehabilitation strategy for stroke patients, which will involve the patients actively in the process. The goal of our approach is the development of a telemedicine system which supports ambulant rehabilitation at home settings for stroke patients with minimal human intervention. This system will combine state-of-the-art monitoring devices forming a wireless Body Area Network that enable simultaneous measurement of multiple vital parameters and currently executed movements that are particularly of interest from a Stroke rehabilitation point of view. It will empower the patient to do more for fast recovery than today and provides clinical experts with data not available today. By that, it leads also to a better understanding of the stroke recovery process, higher recovery speed and thus, to reduced healthcare cost while improving patients' quality of life.

1 MOTIVATION

Stroke is hitting about 2 Million people per year in Europe (Kirchhof et al., 2009). For these persons the effect of stroke is that they lose certain physical and cognitive abilities at least for a certain time period. More than one third of these patients, i.e., more than 670,000 people, return to their home with some level of permanent disability leading to a significant reduction of quality of life which affects not only the patients themselves but also their relatives. Thus, the manifesto of the Stroke Alliance for Europe (Stroke Alliance for Europe, 2008) calls on *"all European Governments to improve the availability of short and long-term rehabilitation to enable all stroke survivors to have access to life changing support."* Further, *"telemedicine systems for management of stroke"* are considered to become a key technology to cope with expected challenges in future stroke care.

There is a strong need to improve the ambulant care model, in particular, at the home settings, involving the patients into the care pathway, for achieving maximal outcome in terms of clinical treatment as well as quality of life. In addition to the dramatic effect of stroke for individuals, it has a strong impact on our society as well. The total cost of stroke in the EU was calculated to be over 38 billion in 2006. This figure included healthcare costs (about 49% of the total cost), productivity loss due to disability and death (23% of the total cost) and informal care costs (29% of the total cost) (Kirchhof et al., 2009).

The prevalence of ageing in the European societies will lead to an increased number of people suffering from stroke. For example, (Foerch et al., 2008) predicts that the number of stroke patients in Hessen, Germany; will increase from 20,846 in 2005 to more than 35,000 in 2050 which equals to an increase of nearly 70% within the next four decades. Experts predicted an increase of even 2.5 times (Go et al., 2001; Miyasaka et al., 2006) leading to an enormous pressure on the healthcare systems in terms of cost. The effect on the healthcare cost might be even more significant, since the current trend suggests also the ratio of young and healthy persons to elderly persons to decrease, so that the informal care cost will be shrinking and thereby directly leading to increased direct healthcare cost. This will become a real burden for our economies.

We have just started an EU-funded research project, called StrokeBack, which addresses both of the sketched problem areas. The goal of this project is the development of a telemedicine system which supports ambulant rehabilitation at home settings for the stroke patients with minimal human intervention. In the following, we will introduce objectives and methods to be investigated by StrokeBack before conclud-

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ing with an outlook on the facts and preliminary results that we expect to have available soon.

2 OBJECTIVES

The StrokeBack project aims at increasing the rehabilitation speed of stroke patients while patients are in their own home. The benefit we expect from our approach is twofold. Most patients feel psychologically better in their own environment than in hospital and also rehabilitation speed is improved. In addition, we aim at exploiting the increased motivation of patients when exercising with a tool similar to a gaming console. The ability of doing high quality exercises without the need of being directly monitored by a physiotherapist helps to reduce healthcare cost through minimisation of expensive human contact hours. Currently the quantity of hours performing occupational (ergotherapeutic) and physiotherapeutic sessions are restricted to payable effort for patient's accommodation, transport or visit of therapists in the patient's home. StrokeBack aims at providing new technical means and service structures to enable patients to enhance their healthiness by increasing the number of training sessions while still being monitored by the system. By ensuring proper execution of physiotherapy trainings in an automated guided way, modulated by appropriate clinical knowledge and in supervised way only when necessary, StrokeBack empowers the patients to exercise much more and at better quality than it is possible today. By that StrokeBack improves rehabilitation speed, and quality of life of the patient.

The StrokeBack concept will be complemented by a Patient Health Record (PHR), in which rehabilitation exercises, training measurements and vital data of the patients will be stored. Thus, the PHR provides all necessary information medical and rehabilitation experts need to evaluate rehabilitation success, e.g. to deduce relations between selected exercises and rehabilitation speed of different patients, as well as to assess the overall healthiness of the patient. In addition, the PHR will be used to provide the patient with mid-term feedback, e.g., her/his rehabilitation speed compared to average, as well as improvements over last day/weeks, in order to keep patients motivation high.

To summarise, the project goals are achieved by investigating the following key objectives:

- Telemedicine supervision of rehabilitation exercise.
- Continuous monitoring of impact of the exercises also in "normal" life situations.
- Integration of telemedicine rehabilitation and Personal Health Records for improved long term evaluation of patient recovery.
- Providing feedback to health care professionals on the impact of rehabilitation exercises.

Our system will empower the patient to do more for fast recovery than today, it provides clinical experts with data not available today and by that it leads also to a better understanding of the stroke recovery process, higher recovery speed and thus, to reduced healthcare cost while improving patients' quality of life.

3 APPROACH

Very recently gaming consoles have gained a lot of attention when being used in the area of rehabilitation (Anderson et al., 2010; Decker et al., 2009; Deutsch et al., 2009; Gargin and Pizzi, 2010; John et al., 2009; Miller, 2007). All publications report on very good results in terms of speed of the rehabilitation process and especially patient motivation (Sik-Lanyi et al., 2005; Sik-Lanyi et al., 2006). A first evaluation has shown that even though the majority of the publications deal with "normal" rehabilitation process, e.g., after surgery, that similar results hold true for stroke patients as well (Saposnik et al., 2010).

But most of the published articles about and envisioned applications for computer-aided rehabilitation of patients have revealed one major drawback. Since these approaches target to train fine motor skills only, they require the patients to already possess, or have recovered up to, a certain level of mobility (Anderson et al., 2010). By that, these solutions cannot be applied to patients having limited mobility such as spasticity or partial palsy what is the major issue for patients affected by stroke. These patients cannot be asked to hold a sensing device by hand or to exercise by stand. In contrast to that, StrokeBack aims to already assist in early stage of rehabilitation enabling highly affected patients to profit from our proposed monitoring system as well. Our system is designed for ambulant use and targets to be adjustable to the abilities of the patient - a patient-centric approach. For example, it can be used by hemiplegic, paretic patients as well as wheelchair users, too. By that we intend to shorten the full time, stationary rehabilitation and treatment program and allow patients to be reintegrated into normal life as early as possible.

The StrokeBack concept puts the patient into the centre of the rehabilitation process. It aims at exploiting the fact the patients feel better at home, that it has

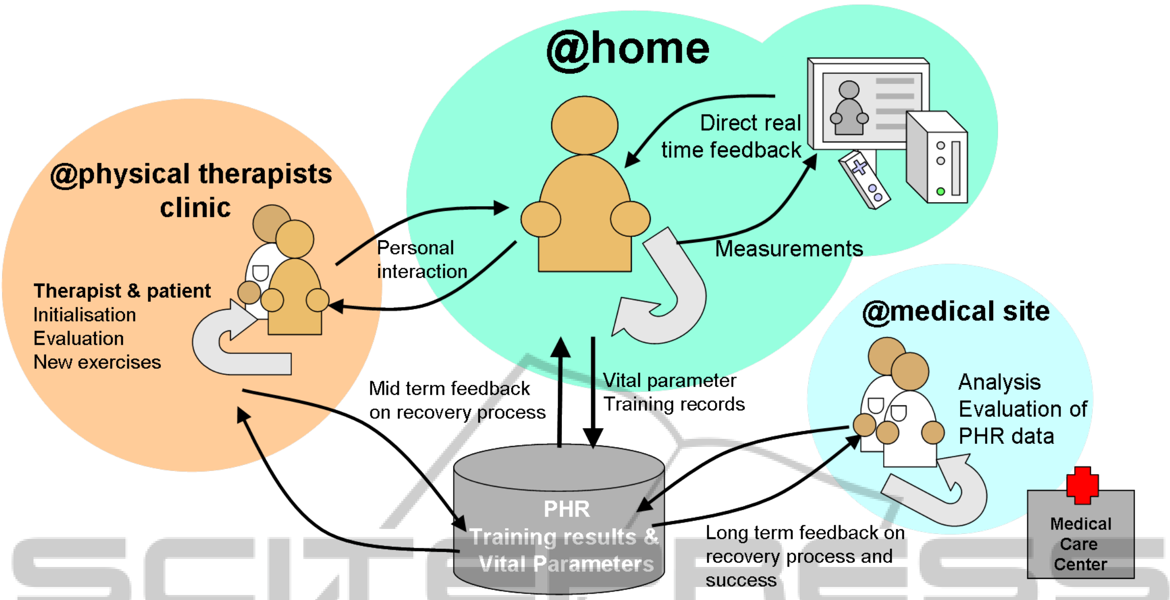

Figure 1: The StrokeBack rehabilitation cycle follows a patient-centric approach. The patient exercises at home while being monitored by the StrokeBack system. The exercise schedule and the exercise results are supervised by ambulant physical therapist care. All data are stored in the PHR to gather long term feedback on the rehabilitation progress.

been shown that patients train more if the training is combined with attractive training environments. Figure 1 illustrates how we think the vision of such a patient centric approach can come true. First the patients will learn physical rehabilitation exercises from a therapist at the care centre or in a therapists' practice (left part of Figure 1). Then the patients will do the exercises at home (middle part of Figure 1) and the StrokeBack system will monitor their execution and provide real time feedback on whether the execution was correct or not. In addition, it records the training results and vital parameters of the patient. These data will be analysed by medical experts (lower right part of Figure 1) for assessment of the patient recovery. Also the patient will get midterm feedback on her/his personal recovery process. In order to ensure proper guidance of the patient also the therapist will get information from the PHR to assess the recovery process and decide whether other training sequences should be used, which are then introduced to the patient in the practice again.

In order to provide remote rehabilitation exercises at gold standard level, i.e., as good as in a face-to-face training with rehabilitation experts, we plan to exploit the advanced features of today's Body Area Networks (BAN). A BAN attached to the patient enables permanent monitoring of patients activity and vital parameters. We aim to monitor and record the patients' activity enabling them to regularly, maybe daily, exercise independently from the guidance of the physical therapist. With a correct instrumentation we expect to be able to detect also unwanted additional movements. In order to achieve a comparable monitoring by cameras at least two of them need to be deployed at the patient's home. This is a costly solution which also bears a privacy risk. Both issues can be solved with our BAN based solution.

As one possible application, the physical therapist has to look after the patient once a week only to exploit the level of rehabilitation, to analyse the results of last exercises based on recorded data and to take corrective action if necessary. Further, the physical therapist may show new exercises and configure a new exercise schedule. By that, we intend to boost the rehabilitation process at home. Finally, it allows the physical therapists and the medical experts to get detailed insights into kind and number of exercises the patient executes during absence of the care persons.

The envisioned BAN can be worn by the patients throughout the whole day, which enables comparing actual movements in their daily life with the correct movement patterns defined in rehabilitation exercises. To simplify the configuration process of the system, we will analyse and evaluate self-learning techniques for exercise recognition, i.e., the StrokeBack system may learn the correct behaviour (patient's movements) itself when exercises are carried out under instruction of the physical therapist.

We will additionally evaluate the feasibility and requirements of using electronic Personal Health Records (PHR) to store and document recorded data and to remotely track the rehabilitation process, e.g., by the attending doctor. This includes the recordings done during rehabilitation exercises and during daily life. The recorded data will be stored and can then be processed by healthcare professionals. The evaluation can be used to deduce detailed information of effects of individual exercises. This feedback can be used to select exercises for other patients, to assess effectiveness of exercises for specific groups of patients etc. In addition the vital parameters can be used to assess the healthiness of the patients which might even help to assess the probability of a further stroke.

4 OUTLOOK

We currently work out the technical and medical basics for realising the ideas behind the StrokeBack project. Until the conference, we will be able to present and discuss insights into the following research areas of the project:

Rehabilitation Exercises. Here, we will focus on a couple of standard exercises that are to be implemented. As it is common practise for rehabilitation of stroke patients, these exercises will lean on movements required for daily live, e.g., grasping at different objects, lifting a cup, etc. Therefore the scope of allowed as well as of forbidden movements have to be determined for each exercise. The most difficult task to be considered is the fact that every type of exercise has to be individually adapted to the needs and capabilities of the patient. To enable such patient-centric individualisation, we intend to experiment with self-learning techniques that would allow the system to monitor all movements made when the patient is exercising under supervision of a physical therapist. By that, the system can learn the ”ideal” or correct execution of the exercise and hence, can give adequate assistance when the patient is exercising alone.

Measurement Methods. Based on the exercises to be implemented, kind of movements and required key evaluation data are assessed, upon which the kind of sensors, e.g., for measuring acceleration and rotation, and their placement on the human body are determined. Suitable body tracing modelling algorithms will be developed to enable feasible real-time training. In general, the sensor system should not only be able to determine correctness of exercises but must rather be able to autonomously detect wrong or evasive movements the patient may carry out. Our idea is to extent the WSN with an Electro-Myo-Gram (EMG) sensing system for providing static/dynamic muscle activity monitoring. For example, such system would allow detecting hidden evasive movements in the shoulder or neck when moving the arm, which are not detectable by acceleration sensors only.

Human Computer Interaction. Human-to-computer interfaces have to be designed for both patients and therapists. This means using the system must be intuitive, clear and self explanatory! On the one side, the methods for initialisation and introduction of exercises must be useable not only by computer specialists but especially by physical therapists. Here, the self-learning techniques of the system should properly deal with these issues. On the other side, our system is to be designed especially for elderly people, since the majority of patients suffering from stroke is older than 50 years. Consequently, the training programs must be kept very simple and attractive to keep the motivation high. We will follow a *”what you do is what you see”* philosophy, where each movement of the patient is displayed also on the monitor in front of the patient. We intend to use avatar interfaces to which the patient interacts with like in a computer game, i.e., the patient's avatar executes the same movements in real time. In addition, we would like to exploit known increased learning effects in rehabilitation, which occur when providing optical inputs for the patient in addition to the movements executed. Finally, the system can replay correct exercise execution at any time, even if no physical therapist or medical staff is present.

In summary, the StrokeBack main goal is to animate stroke patients to do more for fast recovery themselves. Our system provides just technical assistance empowering stroke patients to reach their own rehabilitation goals with adequate means. Last but not least, the StrokeBack system provides detailed feedback about the rehabilitation progress to the patient and medical care staff as well. From the medical view, it provides a unique chance to monitor the effects of various exercises in details. This enables to document the effectiveness of single exercises when applied to different patients suffering from various impairments and hence, it provides stroke experts with high resolution data and knowledge not available today.

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