

Telemedicine System for Game-Based Rehabilitation of Stroke Patients in the FP7-“StrokeBack” Project

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Abstract — Stroke is a disease with very high socio-economic impact. In average, the healthcare expenditure cost for Strokes across different countries in Europe and USA exceeds 3% of their entire healthcare expenditure, including inpatient treatments, outpatient hospital visits and long-term rehabilitation and care¹. Therefore, there is an urgent need for devising an effective long-term care and rehabilitation strategy for stroke patients, which would actively involve patients in the rehabilitation process while minimizing costly human support. This paper reports on the results of the FP7-StrokeBack project where game-based training system has been proposed allowing physicians to supervise the rehabilitation of patients at home. The proposed approach empowers the patients and their caretakers for effective application of rehabilitation protocols in their home settings, while leading physicians are enabled to supervise the progress of the rehabilitation (and intervene if needed) through the use of Personal Health Record (PHR) system. The increased rehabilitation speed and ability to perform training at home directly improves quality of life of patients.

Keywords — *e-Health; rehabilitation; stroke; virtual reality; immersive user interfaces; Kinect; Personal Health Record; PHR*

I. INTRODUCTION AND MOTIVATION

Stroke affects about 2 Million [1] people every year in Europe. For these people the effect of stroke is that they lose certain physical and cognitive abilities at least for a certain time. 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. This also increased cost of the health care services associated with hospitalisation, home services and rehabilitation. Therefore, there is a strong need to improve ambulant care model, in particular, at the home settings, involving the patients into the care pathway, for achieving maximal outcome in terms of clinical as well as quality of life.

The StrokeBack project addresses both of the indicated problem areas. The goal of the project is the development of a telemedicine system, which supports ambulant rehabilitation at home settings for the stroke patients with minimal human

intervention. With StrokeBack, the patients would be able to perform rehabilitation in their own home where they feel psychologically better than in care centres. In addition, the contact hours with a physiotherapist could be reduced thus leading to a direct reduction of healthcare cost. 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 aims to empower and stimulates patients to exercise more while achieving better quality and effectiveness than it would be possible today. This way StrokeBack system is expected to improve rehabilitation speed, while ensuring high quality of life for patients by enabling them to continue rehabilitation in their familiar home environments instead of subjecting them to alien and stressful hospital settings. This offers also means reducing indirect healthcare cost as well.

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 rehabilitation speed is improved. Furthermore, we focus on increasing patients' motivation when exercising with tools similar to a gaming console. The 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 been shown that patients train more if the training is combined with attractive training environments. First, patients learn physical rehabilitation exercises from a therapist at the care centre or in a therapists' practice. Then the patients can exercise at home with the StrokeBack system monitoring their execution and providing a real-time feedback on whether the execution was correct or not. In addition, it records the training results and vital parameters of the patient. This data can be subsequently analysed by the medical experts for assessment of the patient recovery. Furthermore, the patient may also receive midterm feedback on her/his personal recovery process. In order to ensure proper guidance of the patient, the therapist also gets information from the PHR to assess the recovery process enabling him to decide whether other training sequences should be used that are then introduced to the patient in practice again.

¹ How can we avoid Stroke crisis:
<http://www.stopafib.org/downloads/News221.pdf>

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II. GAME-STIMULATED REHABILITATION CONCEPT

Use of virtual, augmented and/or immersive environments for training and rehabilitation of post-stroke patients opens an attractive avenue in improving various negative effects occurring because of brain traumas. Those include helping in the recovery of the motor skills, limb-eye coordination, orientation in space, everyday tasks etc. Training may range from simple goal-directed limb movements aimed at achieving a given goal (e.g. putting a coffee cup on a table), improving lost motor skills (e.g. virtual driving), and others. In order to increase the efficiency of the exercises advanced haptic interfaces are developed, allowing direct body stimulation and use of physical objects within virtual settings, supplementing the visual stimulation. Immersive environments have quickly been found attractive for remote home-based rehabilitation giving raise to both individual and monitored by therapists remotely. Depending on a type of a physical interface, different types of exercises are possible [7]. Virtual environments are often used for functional training and simulation of natural environments, e.g. home, work, outdoor. Exercises range from simple goal-directed movements [8] to learn everyday tasks.

Current generation of post-stroke rehabilitation systems, although exploiting latest immersive technologies tend to proprietary approaches concentrating on a closed range of exercise types, lacking thoroughly addressing the complete set of disabilities and offering a comprehensive set of rehabilitation scenarios. The use of technologies is also very selective and varies from one system to another. Although there are cases of using avatars for more intuitive feedback to the patient, the use of complicated wearable devices makes it tiresome and decreases the effectiveness of the exercise. In our approach we have been exploring novel technologies for body tracing that exploit the rich information gathered by combining wearable sensors with visual feedback systems that are already commercially available such as Microsoft Kinect² or Leap Motion³ user interfaces and 3D virtual/augmented vision.

Immersive environment aims to support full 3D physical and visual feedback through Mixed-Reality interaction and visualisation technologies placing the user inside of the training environment. This way the training exercises become more intuitive in their approach by using exercise templates with feedback showing correctness of performed exercises. Therapists are then able to prescribe a set of the rehabilitation exercises as treatment through the PHR platform(s) thus offering means of correlating them with changes of patient's condition, showing effectiveness in patients' recovery process.

III. STROKEBACK ARCHITECTURE

The StrokeBack concept system architecture is shown in Fig. 1. It contain a Patient System deployed at home supporting physiological remote monitoring of patient wellbeing, runs the rehabilitation games and offers full integration with online Personal health Record (PHR) used as a data repository for sharing information between the patient and his/her physician(s). It offers full support to immersive user interfaces

like Kinect, Leap Motion, Emotiv EEG and other ones, combined with a range of virtual and augmentation systems in order to enable fully immersive gaming experiences.

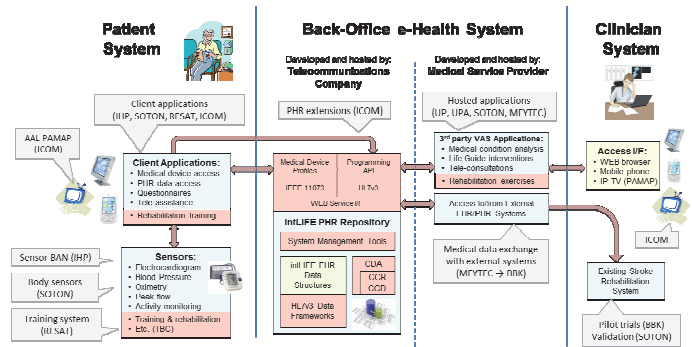


Fig. 1. The conceptual architecture of the StrokeBack system.

The clinician part provides access to back-office PHR data repository for constant monitoring of patients' condition, the progress of their rehabilitation and other relevant physiological data including audio-visual connection if needed. The system supports 3D Smart TVs, AR/VR visors and 3D projectors. The system is geared to support use also on mobile devices like smartphones, tablets etc. An affordable integrated gaming solution for both near field and full-body rehabilitation exercises is developed into table platform by Meytec (Fig. 2).



Fig. 2. The rehabilitation table design from Meytec.

IV. WEARABLE EMBEDDED SENSOR DEVICES

Considering that detecting activities during daily life of patients cannot be achieved without wearable device support, our partner in the project, IHP GmbH, has been developing a customizable lightweight embedded sensor device allowing short-range wireless transmission of most required parameters. Our key goals for developing this platform are mainly driven by the end-user (patients) requirements considering:

- *Plug-and play feeling* so that no cables or other connectors – not useable by stroke patients – are needed to use the sensor node. The integration of standardized Qi wireless power supply gets rid of cables and the necessity to plug-in the sensor nodes for charging. The patient only needs to place the sensor node on a wireless charging station when not worn, e.g. during the night. The node automatically starts gathering data again when removed from the charging station, i.e. most likely after getting up in the morning.
- *Low power consumption* of the whole platform, especially during wireless transmission between the sensor nodes themselves and/or a base station when in reach. To achieve

² Microsoft Kinect SDK: <http://kinectforwindows.org>

³ Leap Motion: <http://www.wii.com>

this, we integrated the Bluetooth Low-Energy (4.0) transceiver CC2541 from Texas Instruments (TI) with a tiny integrated antenna on-board. Its maximum power consumption is less than 20 mA at 3.3V at 0 dBm.

- Extremely *compact and very flat* design since sensor nodes were attached to the wrist and arm reducing the disturbing feeling when worn throughout the day. Our complete sensor platform including the lithium battery packaged in a hard case with a size of $52 \times 32 \times 15$ mm only.

A low cost sensing device empowered by a MSP430F5528 microcontroller of TI has been developed. The sensor node further provides 128 MB flash memory for storing sensor data, support for lithium-polymer battery cells (250mAh single cell used for StrokeBack) and a couple of initial sensors, i.e. 3-axis acceleration, 2-axis gyroscope, 3-axis magnetometer as well as vibration and tilt sensor. The StrokeBack sensor platform is depicted in Fig. 3.

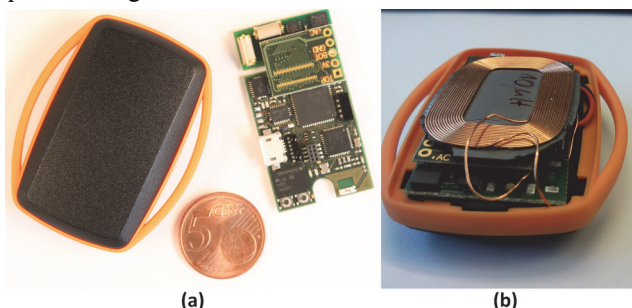


Fig. 3. The StrokeBack sensor platform used for monitoring activities of daily life in comparison to a 5 Eurocent coin, see (a). The fully packed variant of a single sensor node including receiver coil for wireless power transfer and lithium-battery pack is shown in (b).

The primary focus was on inertial and acceleration sensors in the first version of our sensor platform to perform body motion sensing. However, due to given extensibility other common parameters including EMG, critical medical signs like ECG, Blood Pressure, heart rate etc., can be included as adapter-boards later. This part of work is ongoing.

V. BODY MOTION SENSING

The development of wireless Body Area Networks (wBANs) comprised of low-cost, miniaturized, wearable wireless sensors has enabled recording of kinematic movement and physiological data in a ubiquitous and continuous manner within natural environments over long durations. This has enabled efficient and unobtrusive patient activity monitoring while they perform their daily living activities using a minimal number of sensors [12-13]. A prime requirement of such a system is therefore to ensure its long-term operability. It has been shown that in such wearable systems it is preferable that the data analysis be performed directly at the sensor node to yield energy efficient solutions. With this approach, it is imperative to select data analysis algorithms of low complexity since energy consumption is directly proportional to computational complexity [14]. Project partners at the University of Southampton are developing a low power, wBAN to detect, classify and assess the patient's use of their stroke-impaired arm during normal daily activities. In particular, low-complexity classification algorithms based on

the k-means clustering technique are being developed to detect patient-specific arm movements that have been prescribed by the physician as part of a rehabilitation program. The wBAN consists of two sensor nodes worn on the wrist and elbow of the affected arm, and a third sensor node worn on the chest. Each sensor node continuously generates kinematic data from tri-axial accelerometers and gyroscopes, which are processed by the on-board classifier in (near) real-time. Specifically, 10 time domain features are extracted from segments of data from each axis of each sensor, from which an optimum number of features are identified from a ranked list using a sequential feature selection technique.

A minimum distance classifier uses these features as coordinates to generate a point in multi-dimensional feature space, and determines if the originating data is indicative of a target movement by measuring the distance between the point and each centroid of a number of pre-defined clusters in the feature space that characterize each of the prescribed movements. The classifier is initially trained (and then continuously trained) to identify sensor data patterns corresponding to the prescribed movements while the patient plays games or performs instructed movements at the Patient System. This allows it to adapt as the patient regains mobility in the arm. At the end of each day, data is uploaded from the BAN to the Patient System where a quality of movement analysis is performed. This includes movement fluidity, degree of tremor, angle of flexion/extension, abduction/adduction of the elbow and shoulder and compensatory trunk movements. To minimize power consumption, the minimum distance classifier and the associated feature extraction and selection techniques have been coded into a hardware description language (Verilog) aimed at developing an ASIC to be embedded on board the sensors for real time arm movement recognition. This is one of the novel aspects of the StrokeBack system, which provides a quantitative measure on the occurrence of fine-grain movements, performed in daily life.

VI. UPPER BODY REHABILITATION

An exercise evaluation tool has been developed to give real-time feedback while a stroke patient performs an exercise with the upper body. The tool uses the sensor information from Microsoft Kinect and provides an interface to Answer Set Programming (ASP) [15], a popular declarative solving approach in the field of knowledge representation, which is utilized to check the proper execution of rehabilitation training sequences. The tool supports a physiotherapist in creating an individualized rehabilitation training for the upper body. Under supervision of the therapist, movements of upper and lower arms can be recorded and stored as a reference for later. When executing the training without the presence of a therapist, the patient's movements are compared to the reference on the fly with the help of ASP. The accuracy needed to count as a successfully performed exercise can be easily configured. Furthermore, partially completed movements can be detected. It has also been shown that some compensating movements, which hinder the rehabilitation process, can be spotted in the process. The occurrence of a compensation is a crucial piece of information for the patient's therapist.

VII. IMMERSIVE USER INTERFACES

The principal user interface for controlling games was chosen to be Microsoft Kinect for Windows, released in 2012. Its combination of distance sensing with the RGB camera proved perfectly suitable for both full body exercises as well as for near-field exercises of upper limbs. However since Kinect has not been designed for short range scanning of partial bodies, the skeleton tracking could not be used and hence we had to develop our own algorithms that would be able to recognise arms, palms and fingers and distinguish them from the background objects. This has led to the development of the “Kinect Server” an adaptation of open source algorithms from GitHub⁴⁵ by RFSAT, made to run with MS Kinect SDK. The main features of our implementation offers the capabilities of restricting the visibility window, filtering the background beyond prescribed distance, distinguishing between separate objects etc. This way we were able to implement the Kinect based interface where following the requirements of our physiotherapists we replaced the standard keyboard arrows with gestures of the palm (up, down, left, right and open/close to make a click). Such an interface allowed for the first game-based rehabilitation of stroke patients suffering from limited hand control. The tests were first made with Arcady games developed by the University of Pannonia [16-17] where all controls were achieved purely with movements of a single palm. An alternative gaming approach to mixing virtual and real objects was a game where patients were requested to through a paper ball at the virtual circles displayed on the screen (Fig. 4).

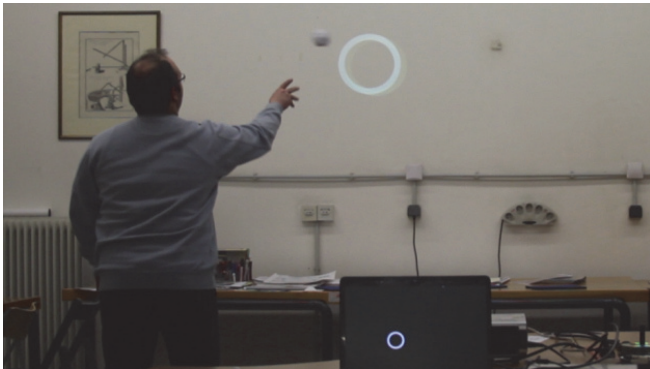


Fig. 4. Game concept #1: real paper ball & virtual targets

Such a game allows patients to exercise the whole arm, not just the wrist. Hitting the circle that represented a virtual balloon was rewarded with an animated explosion of the balloon and a respective sound. Such a game proved to be very enjoyable for the patients letting them concentrate on perfecting their movements while forgetting about their motor disabilities, hence increasing the effectiveness of their training. More advanced classes of games for stroke patients have been investigated for full-body exercises, built with Unity3D⁶ gaming engine and employing avateering that is patient’s body

⁴ Open Kinect on Git Hub: <https://github.com/OpenKinect/libfreenect>

⁵ Intrael server: <https://code.google.com/p/intrael>

⁶ Unity3D game engine: <http://unity3d.com>

motion capture and its projection onto a virtual body (avatar). A prototype system is being developed to feature different environments, e.g. familiar photo-quality spaces (Fig. 5). Scenes with one and two avatars were implemented. The first one was intended as a base for self-training exercises where instruction would be overlaid over the avatar to indicate the movements such that to pass the exercise.



Fig. 5. Game scenario: real patient controlling patient avatar using Kinect in a home environment replicated in virtual world

An important advantage of Unity3D is the possibility to run games either as stand-alone or under from inside a WEB page. The latter approach makes it easier for integrating games as therapies within the PHR system accessible and controllable via WEB browser, as in Fig. 6.

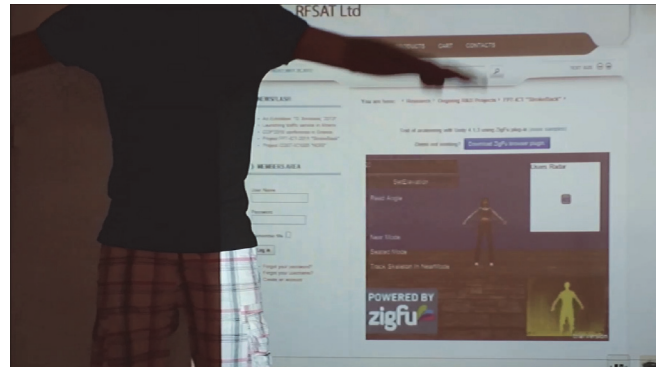


Fig. 6. Concept game played online in WEB browser by real patient. Avatar motion is controlled in Unity3D using a ZigFu plug-in.

VIII. CARE PLANNING TOOL AND PERSONAL HEALTH RECORD SYSTEM (PHR-S)

A StrokeBack concept is complemented with a set of WEB based tools developed by Intracom Telecom facilitating clinicians and patients in tele-rehabilitation routine, namely the Care Planning Tool and Patient Health Record System ((PHR-S), respectively. Care Planning Tool (**Error! Reference source not found.**) is used by the clinicians and therapists to set up and monitor the execution of training plans by their patients. At the clinical assessment phase, healthcare professionals are given the option to fill in standard questionnaires related to the status of their patients (e.g. Barthel Index, Stroke Specific Quality of Life and Wolf Motor Function Test questionnaires).

They can review past entries and get info about what impact has the rehabilitation intervention in these indexes. They can also define specific goals for their patients, in accordance with the International Classification of Functioning, Disability and Health (ICF)⁷.

The therapists use the tool to schedule training periods and introduce their suggestions for activities pursued by their patients (e.g. serious games, music-supported therapy). These recommendations are stored in the PHR-S database and transferred to the Patient Station upon request. Subsequently, an overview of the executed activities is presented to clinicians. The PHR-S includes all the necessary medical and personal information for the patient that rehabilitation experts might need in order to evaluate the effectiveness and success of the rehabilitation, 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 can 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 the motivation of patients high.

IX. VALIDATION AND PRELIMINARY EVALUATIONS

Both technical system validation tests and preliminary evaluations by other project partners have been performed. Regarding the evaluations of the home rehabilitation system, we have used the following regime:

- Patient switches on the rehabilitation gaming table shown in Fig. 2 and starts the „Tele-rehabilitation“ session
- Patient selects an exercise and runs it. She/he may consider former trainings scores. All actions follow a set of permissions that have been configured by the therapist and adapted to patient’s abilities/progress.
- Patient executes the exercise in the autonomous modus. The PHR analyses the result of tasks and exercises and generates respective feedback. Finally, training results and acquired scores are uploaded to PHR.
- Patient executes the exercise once a week with live-supervision of the therapist. She/he is observed by the therapist in real-time, may see the therapist on the screen via bidirectional video link (implemented by Meytec).
- Patient sees the final score of an exercise after finishing it.

Initial tests have proven initial technical assumptions and compliance with pre-defined user requirements. As expected Kinect has proven great for full body motion and less attractive for near field upper limb tracking. Hence, alternative approaches, e.g. using Leap Motion devices have been also investigated that offer better precision for upper limb exercises, especially when it comes to fingers, palm and hand tracking.

X. CONCLUSIONS AND FUTURE WORK

The initial technical validation tests have proven the viability of the design approach adopted. The suitability of Leap Motion for “Touch-Screen”-like applications and game development under Unity3D has been confirmed. Following the success of the technical system tests, clinical trials with real patients will be conducted between March and September of 2014. Primarily the focus will be made on the motion capture and recording of the real person (therapist) for subsequent use for demonstration of correct exercises by animating his/her avatar. Subsequently the overall integration of the gaming system will be performed whereby selection of games and the necessary data exchange mechanism with the PHR-S will be developed. The most difficult work will be related to the real-time comparison of avatar movements for providing an accurate scoring of the correctness of exercises, to be achieved in liaison with the physiotherapists.

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⁷ ICF classification: <http://www.who.int/classifications/icf/en>