Rehabilitation System for Stroke Patients using Mixed-Reality and Immersive User Interfaces

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***Abstract* — The work presented in this paper addresses stroke, a disease costing the healthcare in Europe and USA over 3% of their entire healthcare expenditure, including inpatient treatments, outpatient hospital visits and long-term rehabilitation and care. The StrokeBack project is a response to those needs offering 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. The game-based training system has been proposed allowing physicians to supervise the rehabilitation of patents at home. The proposed approach empowers patients and their caretakers to execute effectively rehabilitation protocols in their home settings, while leading physicians are able to monitor the rehabilitation progress remotely via 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 training; stroke; mixed reality; immersive user interfaces; Unity3D; Kinect; 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 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. This also increasing costs 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.

II. The Concept of the "StrokeBack" Project

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 of reducing indirect healthcare cost as well.

The concept of StrokeBack is complemented by a Patient Health Record (PHR) system in which training measurements and vital physiological and personal patient data are stored. Thus, PHR provides 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.

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. Furthermore we focus on increasing patients' motivation when exercising with tools similar to a gaming console. The idea is for 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 exercise more if the training is combined with attractive training environments. First the 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, which are then introduced to the patient in the practice again.

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III. THE CONCEPT OF GAME-STIMULATED REHABILITATION

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 as a result 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 the 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 execution of 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 Kinect[1] or Leap Motion[2] user interfaces and 3D virtual/augmented vision.

Immersive environment we develop aims to support full 3D physical and visual feedback through Mixed-Reality interaction and visualisation technologies placing the user inside of the training environment. Considering that detecting muscle activity cannot be done without wearable device support, our partner in the project, IHP GmbH[3], has been developing a customizable lightweight embedded sensor device allowing short-range wireless transmission of most common parameters including apart from EMG, also other critical medical signs like ECG, Blood Pressure, heart rate etc. This way the training exercises become much 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 EHR/PHR platform(s) thus offering means of correlating them with changes of patient's condition, thus showing their effectiveness in patients' recovery process.

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1 Microsoft Kinect SDK: http://kinectforwindows.org
2 Leap Motion: http://www.wii.com
3 IHP GmbH: *http://www.ihp-microelectronics.com*

IV. STROKEBACK ARCHITECTURE

A conceptual system architecture of the StrokeBack system is presented 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).

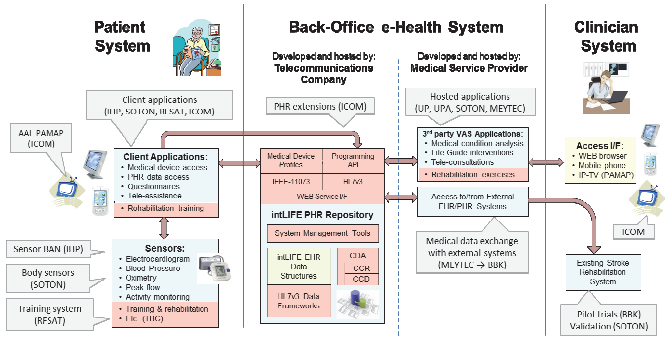

Fig. 1. The conceptual architecture of the StrokeBack system.

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 experience.

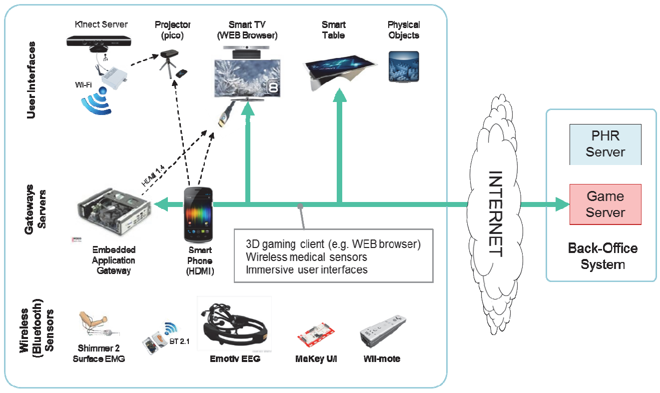

Fig. 2. The physical architecture of the gaming part of a StrokeBack system.

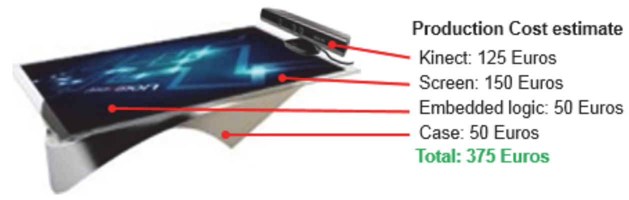

Fig. 3. The concept design of the "Virtual Table"

As shown in Fig 2 we support 3D Smart TVs, AR/VR visors and 3D projectors. The system is geared to offer also fully support usage also on mobile devices like smartphones, tablets etc. We also develop an affordable integrated gaming solution for both near-field and full-body exercises, which we call the "Smart Table". The clinician part of the system 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 back-office services are based on the intLIFE core PHR service platform provided by Intracom S. A. Telecom Solutions[4] from Greece. The overall gaming system has been designed using client-server approach allowing us to store the game repository and game provision of the PHR server, thus maximally lowering the load on the client devices. This allowed us from one side to run games on such devices as Smart TVs or Smartphones, while offering us flexibility of maintaining the latest versions of the games without the need of updating the clients. However, since any networked based system needs to anticipate that connectivity may not be always maintained, we have built into our system two scenarios: when network is constantly available and for the case it is not. In the first case the game server is executed remotely, while in the second case it can be executed locally and use games downloaded earlier. Similarly physiological data and game progress can be either uploaded to the server on the fly or stored and uploaded when link is re-established.

V. Body Sensing and User Interfaces

In order to enable the tracking the correctness of performed exercises automatically without the constant assistance of the physicians, an automated means of tracking and comparing patient's body movement against correct ones (templates) has to be developed. This is an ongoing part of the work due to the changing requirements from our physicians. Although many methods are in existence, most of them employ elaborate sets of wearable sensors and/or costly visual observations. In our approach we initially intended to employ a proprietary approach using visual-light scanning, but the recent availability of new Kinect, Prime Sense and Leap Motion sensors made us change our approach and use existing infrared-LED solutions.

When better accuracy is required that offered by 3D scanners then additional micro embedded sensor nodes are employed, e.g. gyros (tilt and position calibration) and inertial/accelerometers (speed changes). Such are readily available for us in both EPOC EEG U/I from Emotiv (used currently as a U/I, though intended to be used in the future for seizure risk alerting) and on Shimmer EMG sensor platform that we use for detecting muscle activity during the exercises. Considering extremely small sizes of such sensors (less than 5x5mm each) a development of lightweight wireless energy-autonomous (employing energy harvesting technologies) may be possible, which is investigated in the project by IHP GmbH.

Muscle activity poses problems for measurement since it has been well known for many years [2] that the EMG reflects effort rather than output and so becomes an unreliable indicator of muscle force as the muscle becomes fatigued. Consequently measurement of force, in addition to the EMG activity, would be a considerable step forward in assessing the effectiveness of rehabilitation strategies and could not only indicate that fatigue is occurring, but also whether the mechanism is central or peripheral in origin [3]. Similarly, conventional surface EMG measurement requires accurate placement of the sensor over the target muscle, which would be inappropriate for a sensor system integrated within a garment for home use. Electrode arrays are, however, now being developed for EMG measurement and signal processing is used to optimise the signal obtained. A dedicated solution by IHP GmbH has been developed to offer reliable and economic muscle activity monitoring. However EMG is not the only sensor that is needed for home hospitalisation of patients suffering from chronic diseases like stroke. This requires novel approaches to combining building blocks in a body sensor network. Existing commercial systems provide basic information about activity such as speed and direction of movement and postures. Providing precise information about performance, for example relating movement to muscle activity in a given task and detecting deviations from normal, expected patterns or subtle changes associated with recovery, requires a much higher level of sophistication of data acquisition and processing and interpretation. The challenge is therefore to design and develop an integrated multimodal system along with high-level signal processing techniques and optimisation of the data extracted. The Kinect system has potential for use in haptic interfacing [4] and has already been used in some software projects [5].

The existing techniques for taking measurements on the human body are generally considered to be adequate for the purpose but are often bulky in nature and cumbersome to mount, e.g., electro-goniometers, and they can also be expensive to implement, e.g., VIACON camera system. Their ability to be used in a home environment is therefore very limited. In this context we have decided to address those deficiencies by extending the state-of-the-art in the areas of:

- Extending the application of existing sensor technologies: For example, we tend to use commercially available MEMS accelerometers with integrated wireless modules to measure joint angles on the upper and lower limbs in order to allow wire-free, low-cost sensor nodes that are optimized in terms of their context and spatial location.
- Novel sensing methodologies to reduce the number of sensors worn on the human body, while maintaining good information quality. For example, many homes now have at least one games console (e.g. Xbox, Nintendo Wii etc.) as part of a typical family home entertainment system. With the advent of the Xbox Kinect system, the position and movement of a human will be possible to be monitored using a low-cost camera mounted on TV sets.
- Easy system installation and calibration by non-experts for use in a non-clinical environment, thus making this solution suitable for use at home for the first timer and with support or non-trained care-takers and family members.
- Transparent verification of correct execution of exercises by patients may be based on data recorded by Body Area Networks (BAN), correlation of prescribed therapies with medical condition allowing to determine its effectiveness on patient's condition, positive and negative.

VI. System Prototyping

The project has reached two years of its life time already and the prototyping as well as integration of various technologies have already started. This refers to the physiological monitoring with Shimmer sensors, gaming user

[4] *Intracom S. A. Telecom Solutions: http://www.intracom-telecom.com*

interfaces as well as the games themselves, for which we decides to focus on the Unity3D engine.

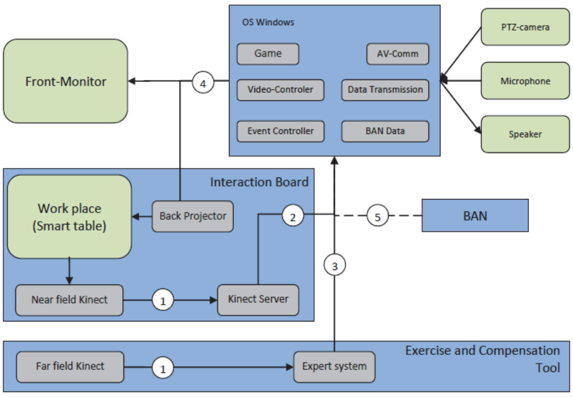

Fig. 4. Integration diagram of the overall home system of StrokeBack

In Fig. 4 the subunit assembly diagram of the “Patients home training place” is depicted. The blue and grey rectangles designate respective elements, while green ones are the user interfaces. The PTZ-camera features pan-tilt-zoom. Arrows show the data flow. The description of the user interfaces shown in this diagram follows below. The principal user interface used to control our games has been Microsoft Kinect, the Xbox version at first and then the Windows version when it has been first released in early 2012. Its combination of distance sensing with the RGB camera proved perfectly suitable for both full body exercises (exploring its embedded skeleton recognition) 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.

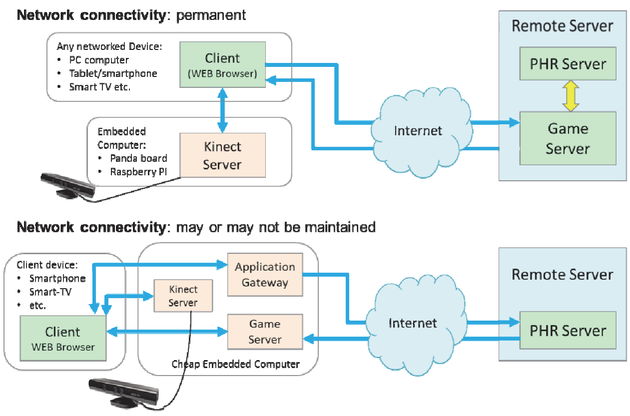

Fig. 5. Online & offline “games” interaction with remote PHR portal

This has led to the development of the “Kinect server” based on open source algorithms[5,6] adapted by RFSAT to run with MS Kinect SDK. This allows the game server is executed either remotely or locally on the same computer and run games downloaded from PHR. Similarly physiological data and game progress info can be either uploaded to the server on the fly or pre-stored and uploaded when network link is re-established. 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 Mario Bros game 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 10).

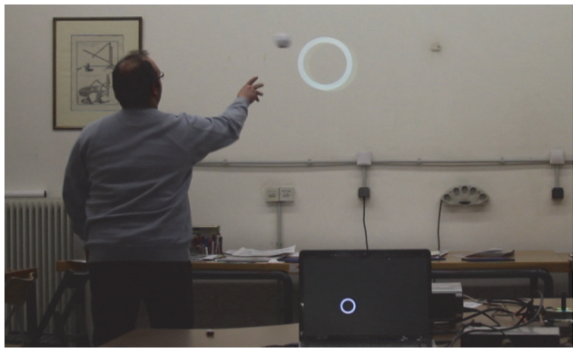

Fig. 6. Game concept #1: real paper ball & virtual targets

Such a game allowed 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.

Fig. 7. Game scenario: real patient controlling patient avatar using Kinect in a home environment replicated in virtual world

Subsequently we have investigated more advanced class of games for stroke patients for full-body exercises. In such a case we have chosen to build such games using 3D engine and employ avateering approach, that is patient’s body motion

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5 *Open Kinect on Git Hub: https://github.com/OpenKinect/libfreenect*
6 *Intrael server: https://code.google.com/p/intrael*

capture and its projection onto a virtual avatar. The prototype system is being currently developed featuring different environments, e.g. familiar home spaces in photorealistic quality[7] (Fig 12). 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 that the patient would need to perform in order to pass the exercise.

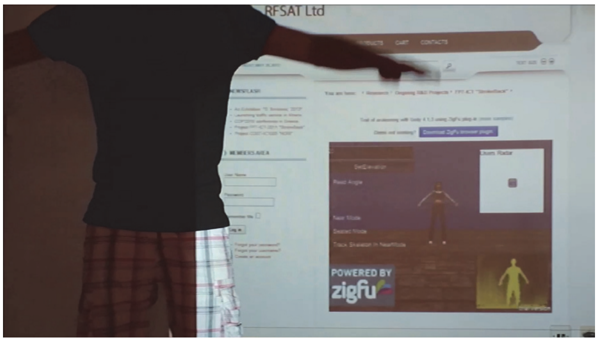

Fig. 8. Game concept #3 (version 1) played online in WEB browser by real patient. Avatar motion controlled in Unity3D using a ZigFu plug-in

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. A use of this feature for exercises with a real patient is shown in Fig 6.

VII. 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 device (Kinect-based "touch table") shown in **Error! Reference source not found.**
- Patient starts the „Tele-rehabilitation" session on the table
- The 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.
- The 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.
- The 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).
- The patient can see the final evaluation and 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 unreliable for near field upper limb tracking requiring frequent re-calibration, while Leap Motion offered sufficient precision for fingers and palm tracking.

VIII. 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 the clinical trials with real patients will be conducted between March and September of 2014. The results of early trials will be presented at the SEGAH'14 conference. 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 (Fig 13). The hand model will need to be developed, rigged and animated in order to allow its use in Unity3D games. Subsequently the overall integration of the gaming system will be performed whereby selection of games and the necessary data exchange mechanism with the PHR system 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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