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Rehabilitation after Stroke using Immersive User Interfaces in 3D Virtual and Augmented Gaming Environments

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Abstract

Stroke is one of most common diseases of our modern societies with high socio-economic impact. Hence, rehabilitation approach involving patients in their rehabilitation process while lowering costly involvement of specialised human personnel is needed. This article describes a novel approach, offering an integrated rehabilitation training for stroke patients using a serious gaming approach based on a Unity3D virtual reality engine combined with a range of advanced technologies and immersive user interfaces. It puts patients and caretakers in control of the rehabilitation protocols, while leading physicians are enabled to supervise the progress of the rehabilitation via Personal Health Record. Possibility to perform training in a familiar home environment directly improves the effectiveness of the rehabilitation. The work presented herein has been conducted within the "StrokeBack" project co-funded by the European Commission under the Framework 7 Program in the ICT domain.

Keywords: Rehabilitation; Stroke; Virtual Reality Therapy; User-Computer Interface; Personal Health Records; Experimental Games.

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1. 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 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 increases 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.

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2. 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 to support 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 patient motivation 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 rehabilitation speed is improved. Furthermore, we focus on increasing patients' motivation when exercising with tools similar to a gaming console.

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 been shown that patients train more if the training is combined with attractive training environments [4][13]. 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.

3. Concept of game-based rehabilitation

The use of virtual, augmented or mixed reality 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 the type of a physical interface, different types of exercises are possible. Interfaces like Cyber Glove [2] or Rutgers RMII Master [3] allow the transfer of patient's limb movement into the virtual gaming environment. They employ a set of pressure-sensing servos, one per finger, combined with motion sensing. This allows therapists to perform e.g. range of motion, speed, fractionation (e.g. moving individual fingers) and strength (via pressure sensing) tasks. Games include two categories: physical exercises (e.g. DigiKey, Power Putty) and functional rehabilitation (e.g. Peg Board or Ball Game) ones. They use computer monitors for visual feedback. Cyber Glove has been used by Rehabilitation Institute of Chicago [4] also for assessing the pattern of finger movements during grasp and movement space determination for diverse stroke conditions. Virtual environments are increasingly used for functional training and simulation of natural environments, e.g. home, work, outdoor. Exercises may range from simple goal-directed movements [5] to learn/train for 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 [13]. 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 [6] or Leap Motion [7] user interfaces and 3D virtual, augmented and mixed reality visualisation.

The environment we develop aims to provide a 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, 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 improving effectiveness of patients' recovery.

4. The StrokeBack architecture

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

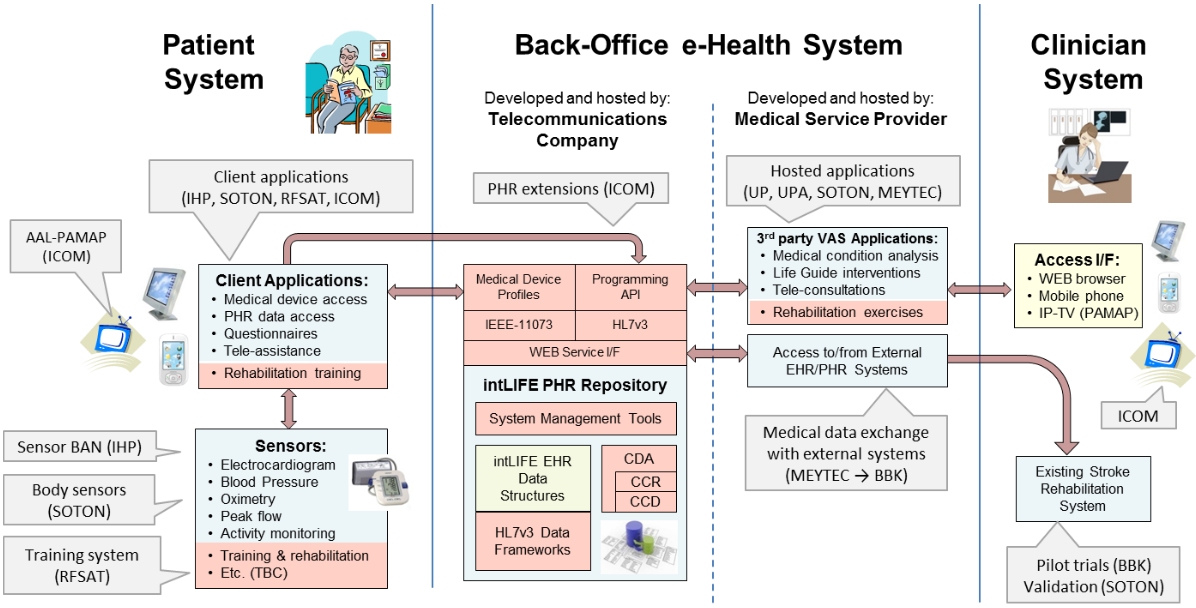


Figure 1. Concept architecture of StrokeBack system

It offers full support to immersive user interfaces like Kinect [6], Leap Motion [7], Emotiv EEG [14] and other ones, combined with a range of virtual and augmentation systems in order to enable fully immersive gaming experience. As shown in Figure 2 we support 3D Smart TVs, AR/VR visors and 3D projectors.

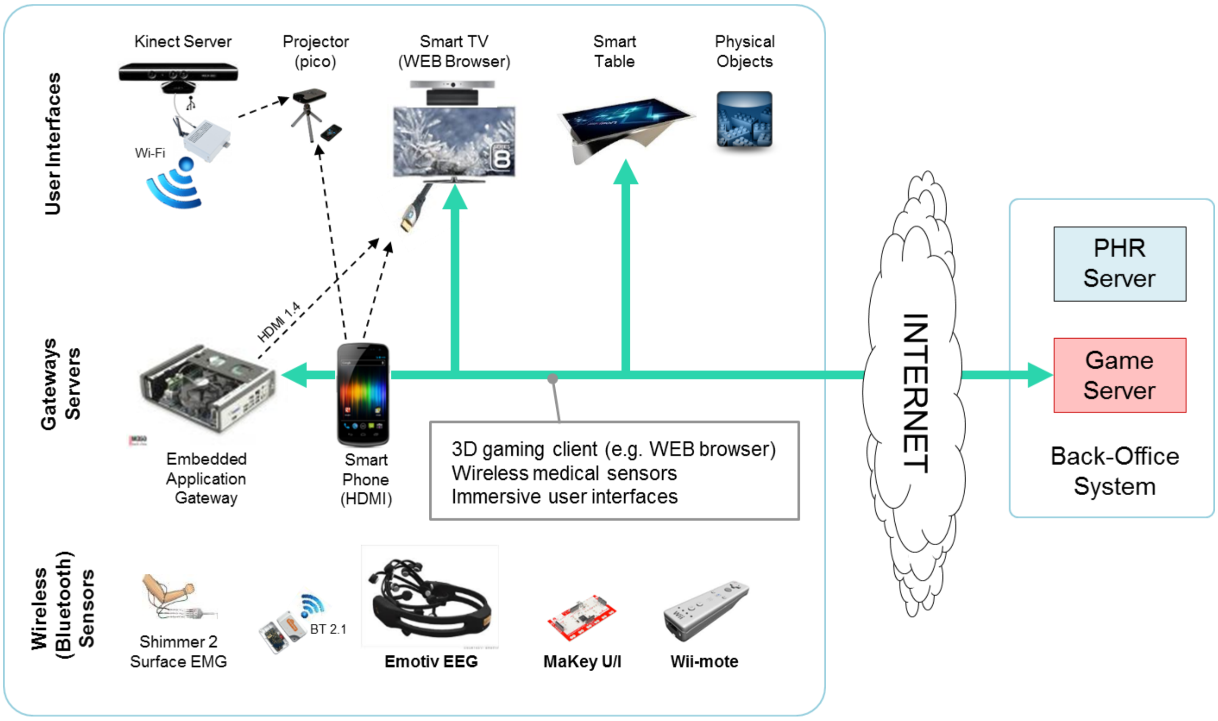


Figure 2. Physical architecture of a gaming subsystem

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 (Figure 3). The clinician part of the system provides access to back-office PHR data repository for constant monitoring of patients' condition. The current design contains two Kinect sensors, one at table level for supporting use of physical objects and one at the top for upper body exercising.

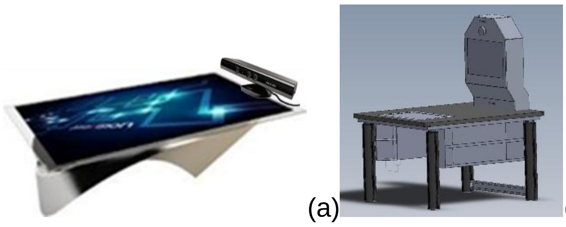

(a) (b)

Figure 3. Concept (a) and actual (b) "Virtual Table"

Two displays are embedded, one flat for physical objects while the top one for displaying more classical board games controlled either with Kinect or other user interfaces.

The progress of their rehabilitation and other relevant physiological data including audio-visual connection are also provided, if needed. The back-office services are currently based on open-source solutions like Open EMR [8] platforms. Ultimately, they will be migrated to the intLIFE core PHR service platform. 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 when it is not (Figure 4).

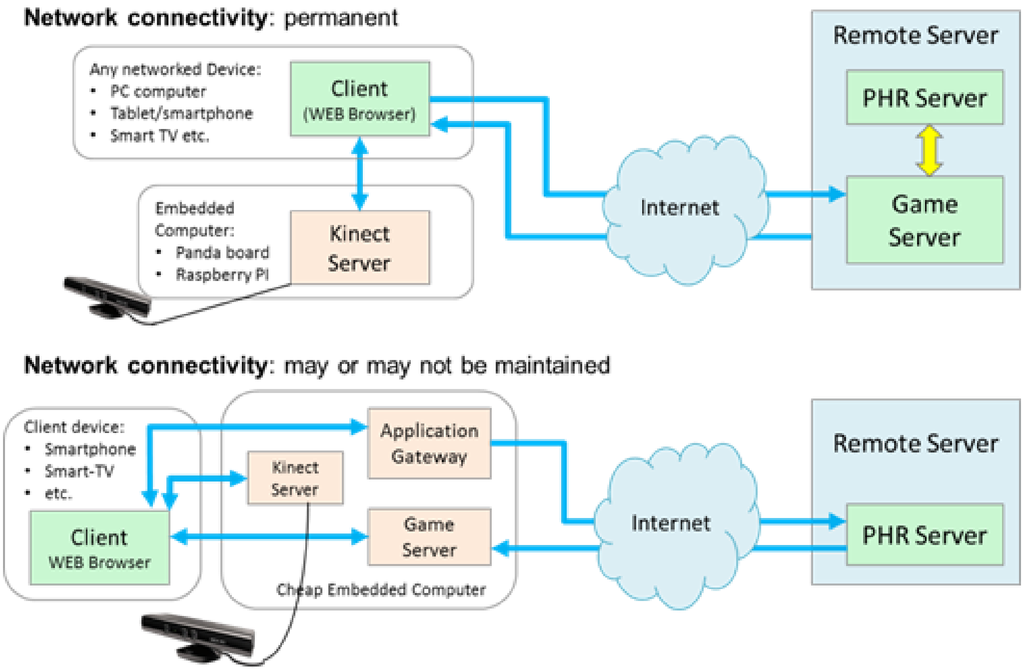


Figure 4. Online & offline "game" management

In the former case, game server is executed remotely, while in the latter one it can be executed locally and use games downloaded earlier. Similarly, physiological data and game progress info can be either uploaded on the fly or pre-stored and uploaded when network link is re-established.

5. 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 very small sizes of such sensors (less than 5x5mm each) a development of lightweight wireless energy-autonomous (employing energy harvesting) may be possible.

Muscle activity poses problems for measurement since it has been well known for many years [9] 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 [10]. 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. Several different solutions have been investigated to offer sufficiently reliable, but also economic muscle activity monitoring. Finally, we concluded on using EMG sensors on the 2R sensor platform from Shimmer for system development purposes, while a dedicated solution made by IHP GmbH.

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 [11] and has already been used in some software projects, and Open Source software libraries are available for browsers like Chrome [12] and demonstrations of interfaces to Windows 7 [13] systems have been shown.

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 information content 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 or below the TV set.
- 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 untrained caretakers and family.
- 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 thus allows to determine their effectiveness on patient's condition, either it is positive or negative.

6. System prototyping

The project has reached two years of its lifetime already and the prototyping as well as integration of various technologies have already started. This refers to physiological monitoring with Shimmer sensors, gaming user interfaces as well as the games themselves, focussing on the Unity3D engine.

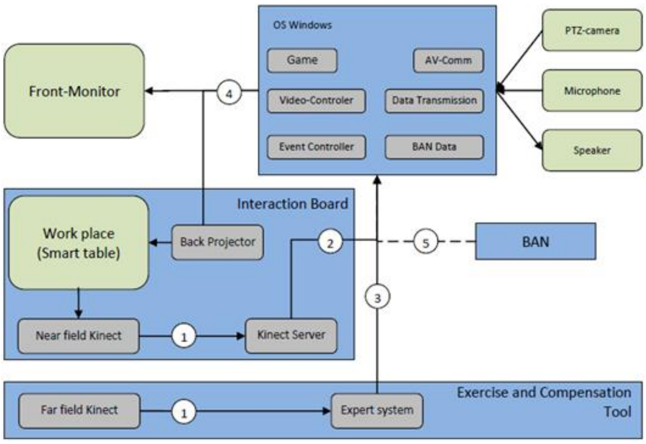


Figure 5. Integration of the overall "home" system

A sub-unit assembly diagram of the "Patients home training place" is depicted in Figure 5. 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.

Physiological sensing

The application support for physiological sensors has been made for both standard and embedded computers as well as mobile devices, e.g. on Android phones (Figure 6). For those we used SDK and relevant example software from Shimmer.

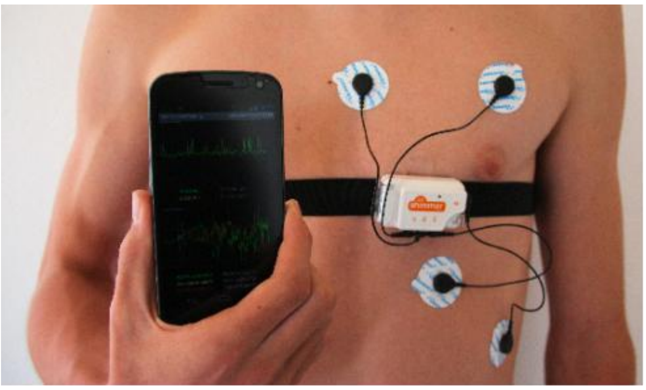


Figure 6. ECG sensing with Shimmer2R

Since home based rehabilitation may increase the risk of stroke re-occurrence we have decided to include EEG sensor, a 2*7-node Emotiv EPOC EEG, which we use for monitoring of brain signals, looking for "flashing" activity between the two brain spheres, indicated by participating physiotherapists as a sign of a likely pre-event condition (Figure 7).

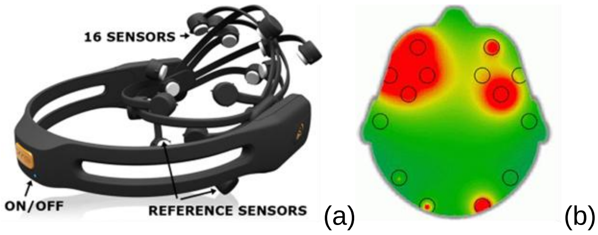


Figure 7. Emotiv EEG (a), sample brain activity (b)

This device offers an additional benefit for being used as a supplementary gaming interface, thus shifting patient's perception from its use as a preventive device to enjoying and using for controlling games with the "power of the mind". It is not without a merit that Emotiv offers also a Unity3D support for its device, not to mention ongoing development of an even more powerful INSIGHT [14] sensor version.

Currently apart from searching for clues indicating pre-stroke risks and as "mouse"-like user interface, we use EPOC for establishing a correlation between the mental intention to move a limb and the physical action. By combining with data from EMG sensors we aim to detect cases when patient's brain correctly issues a signal to e.g. to move an arm, but the patient cannot do it e.g. due to a broken nerve connection.

Rehabilitation Games using the "Kinect Server"

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. This has led to the development of the "Kinect server" based on open source algorithms. The first implementation has used Open NI (closed in April 2014 following the acquisition of PrimeSense by Apple [15]) drivers offering the opportunity for our software to be built for both MS Windows and Linux platforms.

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. The algorithm for analysing wrist position and generating respective keyboard clicks has been developed initially in Matlab and then ported to PERL for deployment along with the Kinect server on an embedded hardware.

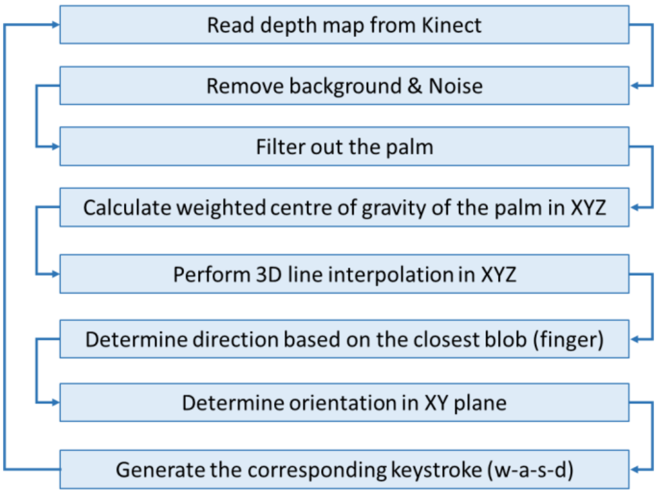


Figure 8. Wrist position detection algorithm

The algorithm is shown in Figure 8. It is based on the idea that assuming that the wrist is placed steadily on a support (requirements from physiotherapists), the patients palm would always have fingers closer to the Kinect than the rest of a hand, this allowing easily to determine the palm position and direction the fingers point. Under such condition, we did not have to pay much attention to Kinect calibration and could avoid fixing the relative position of the hand support with respect to the Kinect device. This allowed us to remove the background simply by disregarding anything more distant than the average palm length centred on the centre of gravity (i.e. centre of the palm itself).

The line was then interpolated through remaining points in 3D, whereby the closest point detected was indicating the tip of the closest finger. The direction of the line was equivalent to the movement of a hand in a given direction allowing us to generate the correct keystroke combination (w-a-s-d for N-W-S-E). Since the accuracy was, better than 1/8 of the circle it allowed us to determine also diagonal movements (double keystrokes, i.e. wd-wa-sd-sa for NW-NE-SE-SW). A predefined time delay was applied corresponding to control detection "speed".

Since classical rehabilitation required the use of physical objects, like cubes of glasses we have implemented subsequently a "cube stacking" game, where patient had to use the physical cubes and place them carefully onto the placeholders displayed on the computer screen positioned flat on the table (later replaced with overhead projection) as shown in Figure 9 where red cubes and placeholders (grey squares) are visible. Here Kinect sensor is placed to scan horizontally at table level, thus allowing to detect XYZ coordinates of the physical cubes. By matching projections with Kinect scan regions this allows detection of correct placement of the cubes.

Figure 9. Game using real cubes on a virtual board

The first level starts with one cube and placeholder parallel to screen edge, then as the game progresses more cubes are used and their requested position could be in any direction. At the end, a score was calculated taking into consideration both the time to place the cubes and the accuracy of placing them over the placeholder. The score was reported in the PHR allowing the physician to track the progress of the patient from one exercise to another. Another variant of the game introduced the possibility of stacking cubes one on top of the other.

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 as shown in Figure 10. The Kinect sensor synchronised with location of projected object detects physical ball reaching the distance of the wall. Combined with its XY coordinated, this allows to detect the collision.

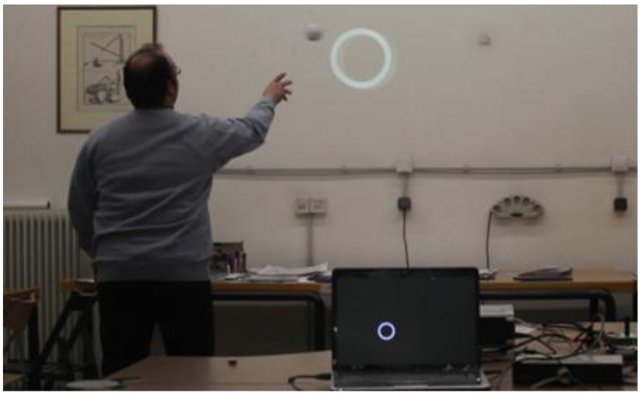


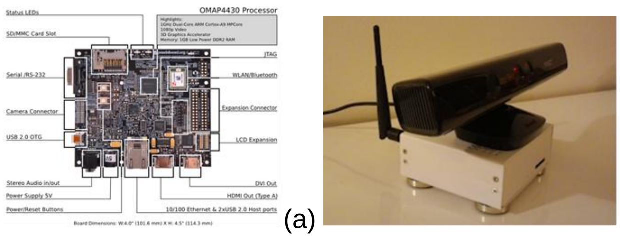
Figure 10. Throwing real paper ball at virtual targets

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, increasing effectiveness of their training.

Embedded Kinect Server

The limitations of the Kinect in terms of the compatibility with certain Operating Systems, diversity of often-incompatible drivers and restrictiveness to high-end computing platforms has pushed us to investigating alternative ways of interacting with Kinect devices. This has led to the attempt to develop an "Embedded Kinect Server" or EKS. Our idea was to use a micro embedded computer like Raspberry PI [16] or similar and allow the client device that was running the game to access data from the EKS via local wireless (or wired) network. Such an approach would allow us to remove the physical connectivity restriction of the Kinect and allow 3D scanning capability from any device as long as it was connected to a network.

Various embedded platforms were investigated: Raspberry PI, eBox 3350 [17], Panda board [18] (Figure 11) and many other ones. The tests have revealed the inherent problem with the Kinect physical design that is shared between the Xbox and the subsequent Windows version that is the need to draw high current from USB ports in order to power sensors despite separate power supply still required.



(b)

Figure 11. Embedded Kinect Server deployment: Panda board (a) and physical prototype integrated with the MS Kinect for Windows sensor (b)

Hardware modifications of the Raspberry PI aimed to increase the current supplied to its USB ports, use of powered external USB hub and other work-around proved all unsuccessful. To date only the Panda Board proved to be the only embedded computer able to maintain the Kinect connectivity and running our EKS. In our tests we have managed to run the Mario Bros game on an Android smartphone and use the Kinect wirelessly to control the game by moving patient's wrists.

Full-Body Games with Avateering

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 capture and its projection onto a virtual avatar. When we have started our first implementation, the MS Kinect SDK was not available yet and hence we have explored various "hacks" built by the Kinect developer community. The most applicable to our needs appeared to be ZigFu [19], which was compatible with Open NI drivers and easy to use under Unity3D [20] editor. It proved easier than using commercial products like Brekel [21] or Autodesk Motion Builder [22]. The prototype system uses different environments, from familiar home spaces in photorealistic quality [23] (Figure 12) to generic hospital environments (Figure 13).

Figure 12. Avateering in a "home" like environment

Figure 13. Avateering aimed to repeat movements of an instructor in a "hospital" like virtual environment

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.

A two-avatar scenario was aimed to offer the side-by-side exercise together with a virtual rehabilitator where patient would need to follow the movements of the "physician" seeing him/her-self at the same time. In both cases, the score would be corresponding to the accuracy of following the expected movements. The two scenarios are being subject to assessment by physiotherapists and the decision as to which one will be used for the final system implementation will be depended on evaluation results.

An important advantage of Unity3D over other 3D gaming engines like Cry Engine 3 or Unreal Engine is the possibility to compile games to run 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 Figure 14.

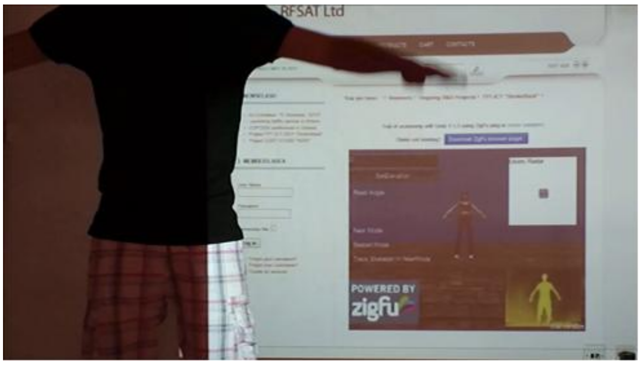


Figure 14. Real patient playing game online using WEB browser using Unity3D engine & ZigFu plug-in

The Kinect Server and wrist controls have been integrated into a number of games under Unity3D in order to evaluate the adopted concepts with end users, such as into an "Infinite Runner" [26], shown in Figure 15. It is incentive based game combining rehabilitation with entertainment. High scores (coins collected) correspond to improvement in recovering hand movement capabilities.

Figure 15. Integrating Kinect Server and wrist-recognition to control the "Infinite Runner" game

3D Stereoscopic Visualisation

In order to enhance the realism of the games developed with Unity3D engine a stereoscopic projection was implemented offering a sense of depth on supported 3D displays. The current approach has been based on the "camera to texture" projection feature available in a PRO version of Unity3D.

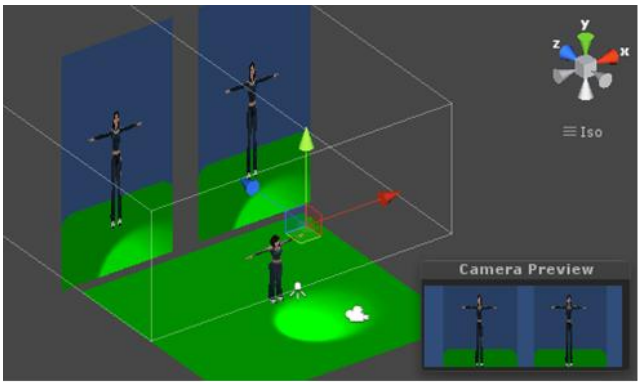


Figure 16. Stereoscopic projection using Unity3D camera-to-texture feature [24]

It has been based on various published experiments [24-25]. A dual virtual cameras placed near each other have their images projected onto virtual screens, in turn captured by a single output camera thus creating a side by side display (Figure 16). Such an image is then suitable for driving common 3D displays such as of the 3D Smart TV (e.g. Samsung UE46F6400) or 3D projector (e.g. Epson EH-TW5910) with frame-switching 3D glasses. Both of those have been successfully tested with our system. In the future tests we will evaluate also panoramic virtual 3D visors (e.g. Oculus RIFT) and 3D augmented glasses (e.g. VUZIX Star 1200XLD) for virtual and mixed-reality games respectively.

Integration of Leap-Motion User Interface

The latest addition to the portfolio of our user interfaces has been the Leap Motion device. It has proven invaluable for rehabilitation of upper limbs thanks to its superior ability to detect close range distances over the Kinect. Our developments have led us to use features already offered by the Leap Motion SDK and the community applications, e.g. the Touchless for Windows allowing controlling mouse-like control of the Windows applications. This has led us to experiments with standard games used for the rehabilitation of stroke patients like memory board game and experimenting with operating virtual objects in a virtual 3D space using only your fingers. Both of those have proven very enjoyable for our patients.

7. 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.
- Patient starts the „Tele-rehabilitation"-session by using the interaction-board (Kinect-based "touch table").
- Patient selects the "autonomous training", i.e. without real time connection to the therapist, or "with supervision". In case of no supervised training is scheduled or there is no connection to internet, an "auto training" mode is selected automatically.
- Patient selects an exercise game and runs it. She/he may consider former trainings scores and adjust the difficulty level. Some exercises may be accompanied by music and the patient may be asked for the desired music title. All actions follow a set of permissions that have been configured by therapist before.
- Patient executes the exercise in the autonomous modus. The PHR monitors and analyses the execution of tasks and exercises and generates respective feedback. Finally, training results and acquired scores are uploaded to PHR.
- Patient executes the exercise with live-supervision of the therapist. She/he is observed by the therapist, may see the therapist on the screen via bidirectional video communication and may receive comments and training guidance in real-time.
- Patient can see the final evaluation and score of an exercise after finishing it.

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.

7. Conclusions and future work

In the frame of the project the most of the technologies have been implemented, including integrated Smart Table as in Figure 3(b), integration with PHR systems allowing management of rehabilitation by physicians as well as a range of user interfaces, not only based on a Kinect sensor.

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 are being conducted since September 2014 into early 2015. Primarily the focus is 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 as shown earlier in Figure 13.

Furthermore a 3D hand model needs 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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