User Interfaces and 3D Environment Scanning for Game-Based Training in Mixed-Reality Spaces

Artur Krukowski[1](✉) and Emmanouela Vogiatzaki[2]

[1] Intracom S.A. Telecom Solutions,
19.7 km Markopoulou Av., 19002 Athens, Greece
krukowa@intracom-telecom.com
[2] Research for Science, Art and Technology (RFSAT) Ltd.,
311 Shoreham Street, Sheffield, UK
emmanouela@rfsat.com

Abstract. Game-based rehabilitation systems gain much interest recently due to fast advancement of natural human-machine interfaces including Augmented and Virtual Reality headsets, near-real time 3D body motion understanding and 3D environmental scanners. Game-based training and rehabilitation has quickly recognized the advantage of improving personal physical capabilities using games and competition as incentives for boosting patient's compliance. Such systems call for new types of user interfaces, which seamlessly engage natural human senses and allow interaction as if one was in his/her natural environment. Furthermore, a possibility to exercise within a familiar home environment further improves the effectiveness of the rehabilitation. The core of the work presented here originates from the FP7-ICT-StrokeBack project and includes more recent advances in 3D scanning of large scale environments and introduces high precision 3D object modelling for realistic gaming environments from Horizon'2020-Reflective-SCAN4RECO project, both co-funded by the European Commission from FP7 and Horizon'2020 programs.

Keywords: Rehabilitation · Mixed reality · Human-machine interfaces
Body motion capture · 3D photogrammetry · MS Kinect

1 Introduction

Vast number of people suffering from both physical and mental disorders have been proven to benefit from rehabilitation training. Until recently this has been done primarily in specialized centers with assistance of trained staff. However, recent advances in ICT technologies including gaming engines, realistic Virtual Environment and intuitive Human Machine Interfaces (HMI) paves a way to possibilities of performing such exercised in a comfort of their own home, at their leisure, while still supervised remotely by their physicians. Such an approach offers much greater advantage in patient compliance with doctor instructions, less stress associated with change of environments and the element of fun and competition.

A. L. Brooks et al. (Eds.): ArtsIT 2017/DLI 2017, LNICST 229, pp. 227–237, 2018.
https://doi.org/10.1007/978-3-319-76908-0_22

The system originally developed through collaborative effort of the StrokeBack consortium [20] comprises a telemedicine system to support ambulant rehabilitation at home settings for the stroke patients with minimal human intervention. It 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 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, to keep patient motivation high. Furthermore, the focus is on increasing patients' motivation when exercising with tools like a gaming console. 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 center 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 analyzed by the medical experts for assessment of the patient recovery. Furthermore, the patient may also receive midterm feedback on her/his personal recovery process. 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.

2 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. 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, diverse 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 [1]. 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 mixed reality visualization.

The environment aims to provide a full 3D physical and visual feedback through Mixed-Reality interaction and visualization 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.

3 Concept Architecture

A concept system architecture is presented in Fig. 1. The Patient System is deployed at home and provides physiological remote patient monitoring, executes rehabilitation games and offers full integration with online Personal Health Record (PHR) used for sharing information between patients and their physicians.

Such a system offers full support to immersive user interfaces like Kinect [6], Leap Motion [7], Emotiv EEG [8] and other ones, combined with a range of virtual and augmentation systems to enable fully immersive gaming experience. As shown in Fig. 2 we support a range of client devices, such as 3D Smart TVs, AR/VR headsets, user interfaces, 3D scanners and 3D screens/projectors. The system offers full support for mobile devices like smartphones, tablets etc. An affordable integrated gaming solution for both near field and full-body exercises, called "Smart Table", was also developed, which supporting use of physical objects along with virtual ones, while providing access

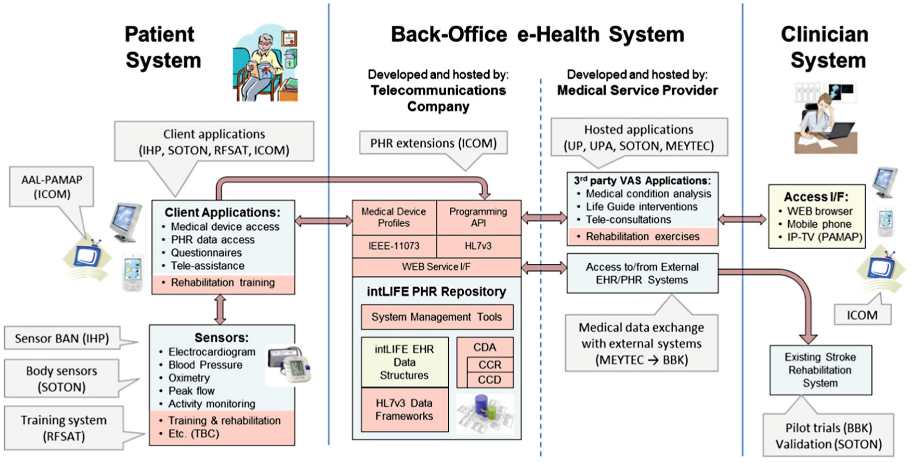

Fig. 1. The architecture of the complete rehabilitation training system from StrokeBack project

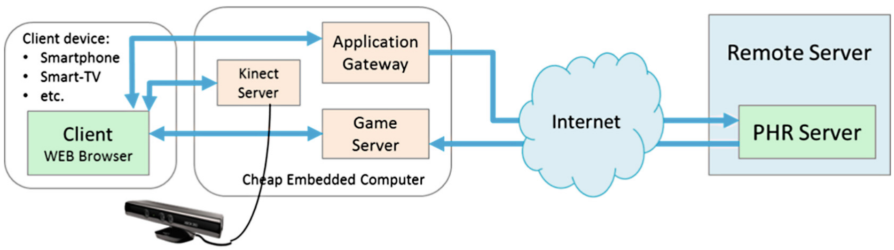

Fig. 2. Kinect Server for game management with game server running locally

to back-office PHR data repository for constant monitoring of patients' condition through the clinician part of the system. 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 [9] platforms.

The 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.

4 Body Sensing and User Interfaces

To track 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. 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. Such are readily available from e.g. Shimmer EMG sensor platform that we use for detecting muscle activity during the exercises.

Muscle activity poses problems for measurement since it has been well known for many years [10] 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 [11]. 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 optimize the signal obtained. Several different solutions have been investigated to offer sufficiently reliable, but economic muscle activity monitoring. We used EMG sensors on 2R Shimmer platform for system development, moving towards a dedicated sensor node by IHP GmbH towards end of the project.

However, EMG is not the only sensor that is needed for home hospitalization 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 optimization of the data extracted.

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. VICON cameras [12] or Xsens MoCap sensors [13]. 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 for wireless, low-cost sensor nodes optimized for information content and spatial location.
- Novel sensing methodologies to reduce the number of sensors worn on the human body, while maintaining information quality. 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.

4.1 Kinect Based User Interaction

The principal user interface used to control our games has been Microsoft Kinect. 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. 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 recognize 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 software was built for both MS Windows and Linux platforms.

The gaming system has been built 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 (Fig. 2). 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 (Fig. 3). 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. The main can restrict the depth of visibility, filtering the background beyond a given distance, to distinguish among individual objects etc. Following the requirements from physiotherapists we replaced the standard keyboard arrows with gestures of the palm

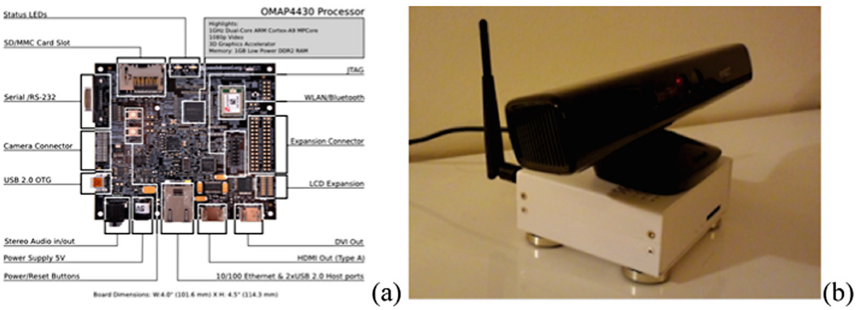

Fig. 3. Embedded Kinect Server (a) deployed on a Panda board (b)

(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 analyzing 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.

Kinect sensors are known for the need for high-performance computers to use them and compatibility with certain Operating systems only. Availability of drivers for other systems has been also limited, making us to investigate alternative approaches.

This has led to the development of the “Embedded Kinect Server” or EKS, implemented on a Panda board as shown in Fig. 3. Using micro embedded computers allowed the client device to run the game by accessing data from the EKS over local network. Such an approach allows also to remove the physical connectivity restriction of the Kinect and allow 3D scanning capability from any device if it was connected to a network. Various embedded platforms were investigated: from Raspberry PI [14] to Panda board [15] (Fig. 5) 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 to power sensors despite separate power supply still required.

5 Rehabilitation Games

The principal user interface used to control our games has been Microsoft Kinect. 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. 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 recognize arms, palms and fingers and distinguish them from the background objects. The attractive game type supported by Kinect Server mixed 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 Fig. 4.

The Kinect sensor synchronized 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. 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 games 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.

Full immersion games were also implemented that used either synthetic virtual environments or 3D scanned environments (Fig. 7). While the former one could be designed from 3D objects from a library, the latter one required 3D scanning of the space for creating its virtual representation for both visualization and real-time detection of collisions between the virtual and real objects.

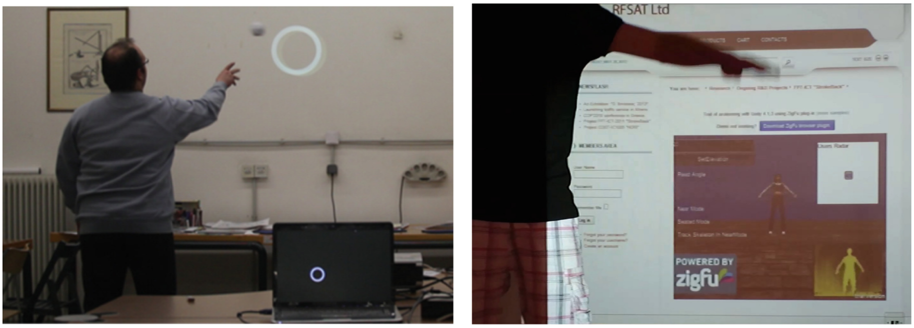

Fig. 4. Mixed-reality game of throwing paper balls at virtual balloons (left) and fully-immersive body exercise (avateering) within Virtual Environment replicating movement of the user (right)

6 Photogrammetric 3D Scanning of Real Spaces and Objects

For the virtual space to resemble the real one, it is important to be able to scan the real environment with high accuracy, especially their geometry. Currently available solutions using high accuracy laser scanning are both expensive and often unsuitable for scanning e.g. small indoor spaces and objects, most attractive elements to be used for immersive gaming. Various technologies have appeared recently, from ranging sensors like Structure [16] to depth detecting visors like MS HoloLens [17].

Fig. 5. Photogrammetric 3D scanning of large areas from UAV (left) and indoor spaces (right)

However, being able to immerse the used into the mixed-reality space, they lack the ability to accurately represent the real objects. The photogrammetric 3D scanning is a way to produce accurate representations of objects and spaces from multiple images taken from different viewpoints, allowing precision of object modelling down to micro levels as it has been proven already in the SCAN4RECO [8] project, subject to following certain rules when capturing images. In this project, objects of Arts have been successfully scanned to 50 µm accuracies with 50MPixel Canon camera and such software like Pix4D [18] or Autodesk ReMake [19], while environments to the levels of single centimeters (Fig. 7). Such spaces can be used to create highly realistic virtual gaming or training environments, like the one in Fig. 5 (right).

7 Evaluations and Conclusions

Both technical system validation tests and subsequent evaluations with real patients have been performed. We tested both assisted (under supervision of a physician) and individual training. In both cases, the PHR monitored and analysed the execution of tasks and exercises and generates respective feedback. Finally, training results and acquired scores are uploaded to PHR. Patients could see the final evaluation and score of an exercise after finishing it. The validation tests have proven the viability of the design approach adopted. The suitability of selected user interfaces and game development under Unity3D has been confirmed. The focus was on the motion capture and recording of the real person (therapist) for subsequent use for demonstration of correct exercises by animating his/her avatar within a virtual space (Fig. 6).

Fig. 6. Virtual Table for limb training (left) and “Endless Runner” game executed on it (right)

Various types of games have been tried, from “Endless Runner” where specific body motion/gestures were translated to control the game, to mind games and full-body training in synthetic environments built from 3D scanned spaces [1, 21]. Alternative exercises used also physical objects (e.g. cubes) transferred into virtual environment, some of those using embedded sensors to detect accurately their movement and orientation, embedding a GHOST micro-sensor developed by IHP. Results of such exercised were compared against classical approaches aimed to manipulate everyday objects while observed by therapists [1].

In the real evaluations, all aspects of therapeutic interventions have been evaluated, from simple limb movements to complicated body motions. Although in rehabilitation we still rely on the common occupational therapy, automatic clinical assessment of patient’s motor skills/recovery progress according to the WMFT is clearly beneficial both for patients and therapists, feasible for occupational training with real objects. Use of such tools in home environments with remove supervision, without a need for

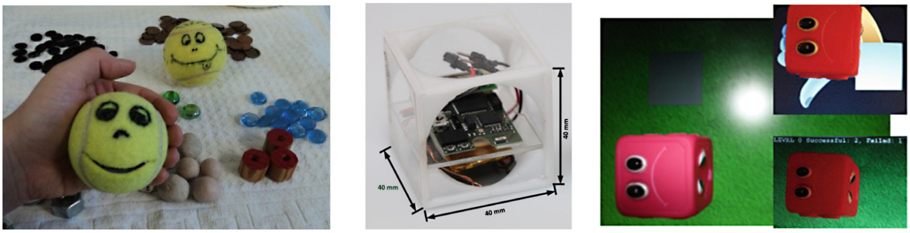

Fig. 7. Playing with standard objects (left), "Smart Cube" (center) in a virtual game (right)

appointment and going to the medical center was outlined as an important benefit by all involved stakeholders. Even that in many cases, physical intervention of the physician is needed for rehabilitation, the use of IT-enabled tools brings benefits especially for patients requiring repetitive exercises that may require less supervision. Having results taken automatically and stored in the PHR, gives an added benefit of providing continuous objective metrics of patient progress in their recovery. Embedding elements of fun and competition was also indicated by patients as providing additional stimulation to performing training exercises with less strain.

Acknowledgments. Research leading to these results has been partially funded by the European Union 7th Framework Program (FP7/2007-2013) under grant agreement n° 288692 "Stroke-Back" and Reflective Societies program of the Horizon'2020 Research Framework under Grant Agreement N° 665091 "SCAN4RECO".

References

1. Vogiatzaki, E., Krukowski, A. (eds.): Modern Stroke Rehabilitation through e-Health-based Entertainment. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-21293-7
2. Virtual Technologies Inc., 17 June 2017. http://www.cyberglovesystems.com/all-products
3. Bouzit, M., Burdea, G., Popescu, G., Boian, R.: The Rutgers Master II—new design force-feedback glove. IEEE/ASME Trans. Mechatron. **7**(2), 256–263 (2002)
4. Rehabilitation Institute of Chicago, 17 June 2017. http://www.ric.org/conditions/stroke/
5. McNeill, M., et al.: Immersive virtual reality for upper limb rehabilitation following stroke. In: IEEE International Conference on Systems, Man and Cybernetics (2004). ISBN 0-7803-8566-7
6. Microsoft Kinect, 17 June 2017. http://kinectforwindows.org
7. Leap Motion, 17 June 2017. https://www.leapmotion.com
8. H2020-SCAN4RECO project WEB site, 17 June 2017. http://www.scan4reco.eu
9. Open EMR, 17 June 2017. http://www.open-emr.org
10. Edwards, R., Lippold, O.: The relation between force and integrated electrical activity in fatigued muscle. J. Physiol. **28**, 677–681 (1956)
11. Enkona, R., Stuart, D.: The contribution of neuroscience to exercise studies. Fed. Proc. **44**, 2279–2285 (1985)
12. VICON Reality, 17 June 2017. https://www.vicon.com/products/camera-systems
13. XSense, 17 June 2017. https://www.xsens.com
14. Raspberry PI, 17 June 2017. http://www.raspberrypi.org

15. Panda Board, 17 June 2017. http://www.pandaboard.org
16. Structure sensor, 17 June 2017. https://structure.io
17. MS HoloLens, 17 June 2017. https://www.microsoft.com/en-us/hololens
18. Pix4D Mapper Pro, 17 June 2017. https://pix4d.com/product/pix4dmapper-pro
19. Autodesk ReMake, 17 June 2017. https://remake.autodesk.com
20. FP7-STROKEBACK project WEB site, 17 June 2017. http://www.strokeback.eu
21. Vogiatzaki, E., Krukowski, A., Gravezas, Y.: Rehabilitation system for stroke patients using mixed-reality and immersive user interfaces. In: European Conference on Networks and Communications (EuCNC 2014), Bologna, Italy, 23–26 June 2014