InImpact: The Journal of Innovation Impact: ISSN 2051-6002 : http://www.inimpact.org
Special Edition on Innovation in Medicine and Healthcare : Vol. 6. No. 1 : pp.98-109 : imed13-007

Smart Medical System for the Universal Remote Delivery of Rehabilitation

Gorka Epelde[1], Eduardo Carrasco[1], Shabs Rajasekharan[1], Julio Abascal[2], Jose Manuel Jimenez[3], Karmelo Vivanco[4], Isaac Gomez-Fraga[5], Xabier Valencia[5]

[1] *Vicomtech-ik4, Donostia-San Sebastian, Spain*
gepelde@vicomtech.org
[2] *University of the Basque Country, Donostia-San Sebastián, Spain*
[3] *STT Engineering and Systems, Donostia-San Sebastian, Spain*
[4] *Baleuko, Durango, Spain*
[5] *Hospital Donostia, Donostia-San Sebastian, Spain*

Abstract

The provision of care services through remote rehabilitation creates a challenge for medical and healthcare systems that need to consider the user's needs and preferences, especially in the case of the elderly and disabled users.
This paper presents a smart medical system for the universal remote delivery of rehabilitation and an implementation on a joint rehabilitation therapy targeted at the senior population. The main innovations of our technical contribution are a multi-device personalised telerehabilitation platform, realistic avatars for increased treatment adherence and high definition tracking for precise joint angle measurement and monitoring. The paper introduces the innovative technical approach, its implementation and the initial test results with Donostia Hospital therapists and patients.

1 Introduction

Life expectancy of citizens in modern societies is increasing rapidly. The proportion of the global population aged 60 is expected to double from 11% in 2006 to 22% by 2050. Such a trend has a direct impact in the sustainability of healthcare systems, in terms of public healthcare policies and budgets [1, 2].
As a result of these global trends, there is an overload of the care resources and personnel at the hospital due to the need of individual attention. Nowadays, rehabilitation is still a process regarded as strongly linked to facilities available at hospitals or medical centres. Additionally the effort to reach the medical facilities from rural areas where specialised services and resources are not available can be excessive, especially for people with disabilities. As a consequence, due to the travel time required to the rehabilitation sessions, the daily activities of patients are severely disrupted and additional costs for travelling need to be added to compute the total economic cost of the therapy.
There is thus a need for ***remote provision of rehabilitation*** **services** to respond to the needs of users in rural areas and consequently addressing the sustainability of healthcare systems.

In this scenario, telerehabilitation (a subset of telehealth) is defined as the use of telecommunications to deliver rehabilitation services at a distance [3]. Brienza and McCue [3] claim that there are benefits to providing rehabilitation services in the natural environment (where patients live, work, and/or interact socially and recreationally) rather than in clinical environment. In this line, these authors present a collection of studies that report benefits on increased functional outcomes, enhanced patient satisfaction, a reduction in duration and costs, and pathology specific benefits, when delivered in the patients' natural environment.

Recent telerehabilitation challenges and market trend studies [4] point out that the main beneficiaries of telerehabilitation are people with disabilities since they are the ones that face most barriers to reach the medical facilities and combine the rehabilitation with their daily activities. Among the main challenges detected by the study are the high amount of people with disabilities, the diversity of needs and preferences of each person and the economic limitations of these user groups.

To overcome these challenges, is required to provide a **universal remote rehabilitation delivery**, which will adapt to the requirements and needs of these large and diverse user groups.

Human computer interaction studies centred in virtual reality applications for seniors have shown that avatars or virtual characters, (life-like simulation of a virtual assistants generated through computer graphics) improve interaction with elderly users [5], even in cases where seniors have cognitive impairments, such as the Alzheimer's disease [6]. Therefore, research on the usefulness of **virtual assistants for telerehabilitation therapy guidance of the seniors** is an interesting proposition.

Finally, in order to close the rehabilitation cycle, the therapists require quantitative assessment of the tasks performed by the patient. In this sense, several position-sensing and movement analysis technologies have been applied to rehabilitation monitoring and movement analysis [7]. For physical rehabilitation of joints (e.g. knee, hip) the objective is to attain the largest functional improvement. In this case, the joint angle is an important measurement for assessment. In contrast to other rehabilitation therapies, this requires technologies that are able to provide more precise monitoring. Therefore, **high definition tracking and movement analysis technology** is required to provide the joint angle's precise assessment.

This paper responds to the challenges, by (1) defining of a remote multi-device personalised telerehabilitation platform, (2) the use of realistic avatars for an increased senior's treatment adherence and (3) a high definition tracking for precise joint angle measurement and monitoring.

In section 2, we survey the current body of work related to the challenges presented in the introduction. We introduce our approach to solve this problem in section 3 and in section 4 we present an implementation of the approach with joint rehabilitation for elderly users. In section 5 we describe the evaluation setup used in order to test the proposed approach and the results obtained from the user tests. The paper is summarised and concluded in section 6.

2 Related Work

This section will first analyse the evolution of the telerehabilitation architectures, together with the efforts to make these architectures universally accessible. Next, focusing on the validation and implementation with elderly users, the most accurate Human Computer Interaction (HCI) paradigms for telerehabilitation will be analysed. The last literature analysis emphasizes rehabilitation assessment devices focusing on joints' rehabilitation.

2.1 Telerehabilitation architectures

Telerehabilitation applications are categorized into two main operating models. The first application type is named as real-time interactivity application (e.g. videoconference), and it refers to those applications that mimic face-to-face interactivity in a medical facility. The second application type is named as store-and-forward application, and follows an asynchronous communication. For the synchronous communication the evolution to digital technologies has allowed deploying new applications such as shared experiences (e.g. a shared whiteboard). On the asynchronous applications side, the evolution has been from simple communication means, as the email, to Java applet/ActiveX Web solutions [8], and to more conceptual Service Oriented Architectures (SOA) [9].

One of the challenges in telerehabilitation [4] is the need for interfaces that are accessible to all. Winters et al. have addressed the universality of the telerehabilitation architectures [10] as well as the universality of final application setups [11]. Their work is based on the Universal Remote Console standard (URC) [12].

The evolution of telerehabilitation applications to SOA and Future Internet architectures for the delivery of telehealth applications [13] leads to new solutions that use the potential of cloud technologies' at communication and service provision levels to ensure scalability of the solutions. Regarding the universal access to applications Winters and his group have made proposals using the enabling URC technology. However, the approach has some limitations: integration of new categories of input device is limited; it is not possible to deploy non-URC controllers; and solutions that access more than one service are not addressed.

2.2 Seniors and HCI

The main client device targeted to develop applications at home has been the TV especially in the case of the elderly users. With the Information and communications technology (ICT) evolution and the adoption of these technologies by seniors, elderly specific applications have been targeted to PC and more recent advances have led to deployments on mobile devices. (i.e. smartphones or tablets).

With respect to telerehabilitation, these were initially developed as PC based solutions, but have recently evolved to TV based game-console solutions and to

mobile terminals. Statistical studies on European citizens ICT usage [14] evidence the need for an architecture that supports multi-device deployment.
With regard to the type of content used for rehabilitation therapy, the majority of which is applied for post-acute treatment at the clinical facilities, a set of instructions is given to the patient informally by voice or visually through printed material.
Initial telerehabilitation efforts focussed on videophone and videoconference applications [15] and then led to gaming rehabilitation conceived as a tool to increase the motivation and to be able to objectivise the evolution. The evolution of gaming rehabilitation has led to the use of commercially available games for console [16].
Building on the success of the gaming and the traditional videoconference based rehabilitation, the next big step has been in the virtual reality.
In parallel, research on HCI studies centred in virtual reality applications for seniors have shown that virtual humans improve the interaction with elderly users [5]. Within the health sector, virtual humans have been adapted to be used as an initial route into health advice by the United States army members and veterans [17].
Based on the literature review of this subsection, research on the usefulness of high fidelity virtual humans for the telerehabilitation therapy guidance of seniors is an innovative research challenge.

2.3 Rehabilitation Exercise Monitoring Technologies

For physical rehabilitation assessment, traditionally, manual goniometers and the dynamometer have been traditionally used and usually at outpatient therapy.
With the advent of the virtual reality and gaming rehabilitation, a wide variety of robot-aided devices specifically targeted at rehabilitation have been developed [18]. However, the high cost of such therapies makes them unattainable for the home-based rehabilitation.
Therefore, different non-rehabilitation specific interface devices have been used to allow the user to move and interact with objects in virtual environments. The past decade has seen several research projects integrating gaming peripherals and modifications of gaming peripherals to rehabilitation task [19].
In the last few years, with evolution of gaming console controllers (Nintendo Wiimote, Microsoft Kinect), there has been an active research area on testing these devices for rehabilitation [16], [20].
With regard to the rehabilitation of joints, different technologies are used for joint angle estimation. Zheng et al. [7] identified inertial sensors as the best suiting for telerehabilitation because of their efficacy in clinical assessment, their small size, their relatively low-cost and easy interface with computers.
Recently, an inexpensive marker-less vision system (Microsoft Kinect) which enables measurements of joint motion has been released. But as the research by Bo et al. [21] underlines, the Kinect presents irregular performance on non-structured environments. These authors underline that the inertial sensor can also suffer from data corruption, and suggest that this could be fixed by complementing

it with information from the Kinect, or by integrating inertial sensors with magnetometers.

Based on this subsection's analysis, the authors of this paper conclude that the best devices for home rehabilitation of joints are inertial sensors integrated with magnetometers, delivered in reliable wireless units, so that, the least amount of tracking technologies are used, and the configuration needs and home rehabilitation system's costs are kept low.

3 Universal Remote Rehabilitation Delivery Platform

3.1 The URC Framework and the UCH Architecture

The Universal Remote Console (URC) framework [12] was published in 2008 as a 5-part international standard (ISO/IEC 24752). It defines a "user interface socket" (UI Socket) as the interaction point between a pluggable user interface and a target device or service. The framework includes "resource servers" as global market places for any kind of user interfaces and resources necessary for interacting with appliances, and services, to be shared amongst the user community.

Furthermore, the Universal Control Hub (UCH) is a gateway-oriented architecture for implementing the Universal Remote Console (URC) framework in the digital home [22]. The UCH connects non-URC compatible controllers and non-URC compatible target devices/services, bridges across multiple targets and target platforms and provides a choice of user interfaces for various controller platforms.

3.2 Proposed approach

The Universal Remote Rehabilitation Delivery Platform proposed in this paper is composed of three layers: the user layer, the cloud layer and the hospital layer. To guide the reader, the Universal Remote Rehabilitation Delivery Platform's architecture is depicted at Figure 1.

The user layer follows the same approach for the three sought different deployment environments (home environment, hospital environment and the mobile environment). Each client is composed of a URC-based middleware (UCH), a tracking solution and a user interface. The UCH solution allows for the user interface personalisation and easy upgrading. Also, the UCH enables for the definition of a common interface specification for the different tracking systems, enabling the seamless exchange of the tracking systems. The UCH based approach also allows to update the system with new services (health services, home devices' control for Ambient Assisted Living type application or other) in the future and to deploy user interfaces that span across several services.

The cloud layer is in charge of providing scalable services and is composed by the user interface resource and audiovisual content repositories, the hospital information system (HIS) and the rehabilitation services.

The user interface resource repository is based on the resource server concept introduced by the URC technology [23] and follows the implementation guidelines provided by the URC Consortium in [24]. This technology will enable the provision of incremental support for new users with different needs and preferences, and to upgrade parts of the UI or the complete UIs, depending on the evolution of user or maintenance tasks.

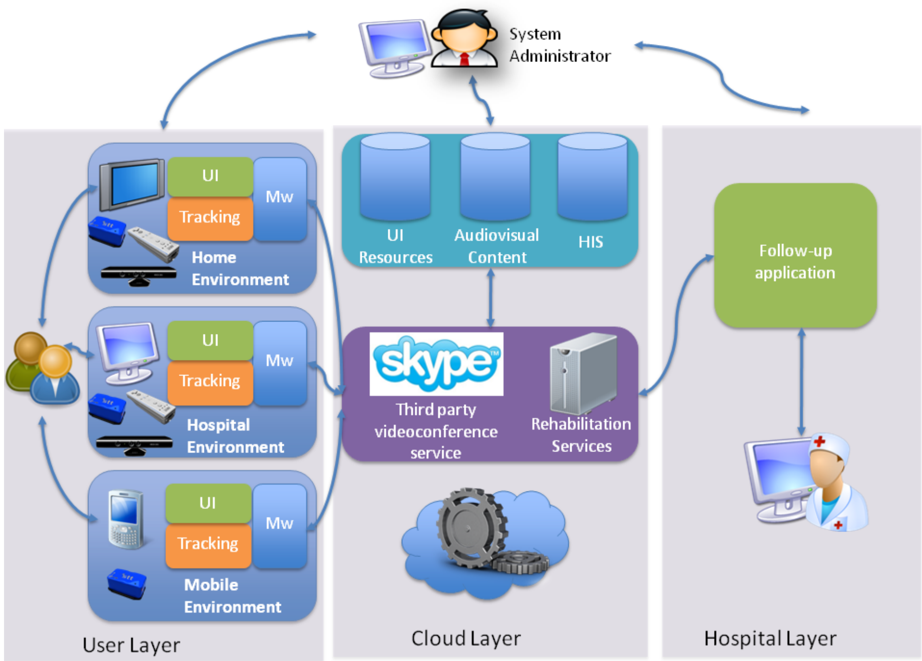

Figure 1: Proposed system architecture

The audiovisual content repository has been designed to support different modalities, in order to respond to all user needs. Furthermore, the most ambitious scenario is targeting the provision of an audiovisual content merging the prescribed exercise with the user's feedback depiction on the screen.

On the first development version, the rehabilitation services includes four web services: (1) Rehabilitation therapy prescription (for the therapist side), (2) Load Therapy Exercises (for the user side), (3) Send Exercise Monitoring (for the user side), and (4) Load Therapy Monitoring and Historical. The application's main flow is described as follows: First, the rehabilitator prescribes a therapy through service (1). Later, the patient loads the therapy and the assigned multimedia content, realises the exercises while being monitored and the monitoring is updated to the cloud through service (3). Finally, the therapy monitoring is loaded by the rehabilitator for assessment using service (4).

These services have been defined following WSDL specification, with the aim to have it open for third party developments and making sure that the implementation is independent from the HIS system implementation at each hospital.

The main data models shared among the developed services are those of patient and rehabilitator user profiles, assigned and executed therapies, and the monitoring values of the executed therapies. The therapies are composed of the targeted joint or injury, rehabilitation phase, and an exercise program with the

identified sets and repetitions per exercise. Each exercise has linked multimodal content for the delivery of the therapy to the patient. System administrators, as well as rehabilitators can define new exercises and assign them multimodal content. From this content, rehabilitators can create new therapies and assign them to patients for their execution.
Initial implementation of the server has been done on our own servers, but the porting to Cloud Service, such as the Amazon EC2 is under study, to provide scalability and improve system's maintenance. Additionally, the Skype videoconferencing service is being used for real-time communication and has been integrated on clients through the SkypeKit API. Thus, a patient-therapist online videoconference will be provided for each considered scenario.
The hospital layer is composed of a follow-up application, which allows the rehabilitators to prescribe a rehabilitation therapy to the patient and to revise the tracking results from the patient's therapy execution.
The presented approach expands the rehabilitation localisations, starting from hospital, moving home and giving the chance to continue outdoors or on travel. Apart from the localisation choice, the presented solution is implemented in three different client devices (PC, Smartphone and TV).
Regarding the choice of client device, the inclusion of the UCH technology enables the easy personalisation of user interface (UI), allows using URC and non-URC controller technologies, maximizes available interaction capabilities and provides a platform for adding new services in the future.

4 Joint rehabilitation therapy client implementation for seniors

The implementation has been focused on the teleorthopaedic rehabilitation for the postsurgical teletraining of body joints. The implementation has been centred on senior users because they are the main user group suffering from this pathology.
The following services have been integrated to the UCH on the user layer: (2) Load Therapy Exercises, (3) Send Exercise Monitoring.
Additionally, the selected tracking system has been integrated with the UCH, and the required modules for the integration of the selected non-URC compatible user interface technology have been developed.
On the hospital layer, an application has been developed to work against the following web services: (1) Rehabilitation therapy prescription and (4) Load Therapy Monitoring and Historical.
The following subsections present the developed UI concept for the seniors and the selected tracking solution.

4.1 Senior targeted UI Implementation. Realistic Avatars.

For the telerehabilitation therapy guidance of seniors, a high fidelity virtual human deployed in TV was selected as the user interface interaction concept. Virtual rehabilitator's look was specifically designed in collaboration with rehabilitators, so that older adults find her both familiar and convincing enough to follow her instructions. Regarding the dummy avatar representing the exercises, a simple model was selected to avoid stigmatisation. Content for the knee rehabilitation has been produced. The developed audiovisual concept is shown in Figure 2.

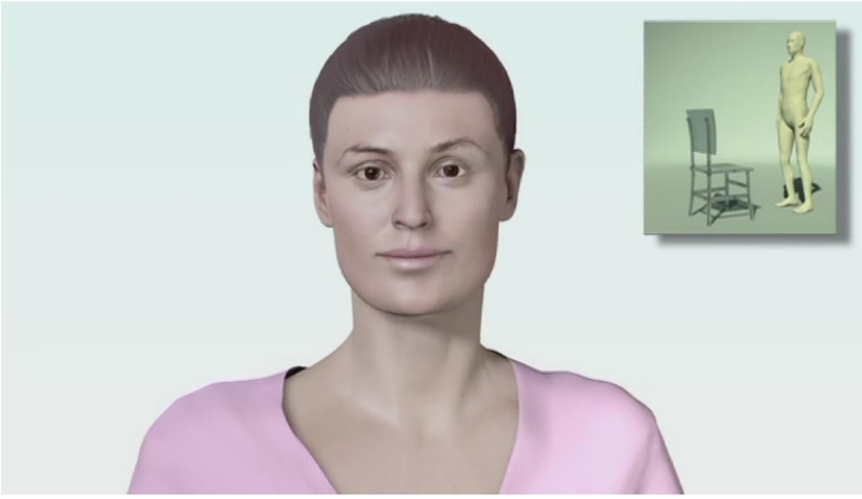

Figure 2: Virtual physiotherapist providing rehabilitation instructions

4.2 Selected Rehabilitation Exercise Monitoring Technologies

Specific joint rehabilitation therapies (elbow, shoulder ...) require precise joint angles measurement. The presented approach supports different tracking systems but for this implementation the authors have selected an innovative product that integrates the inertial sensors with magnetometers [25], therefore, providing a precise and reliable solution, requiring the least amount of devices, configuration needs and home rehabilitation system's costs. The selected solution provides orientations, angular velocities and accelerations with precision in real time, and has been integrated with the UCH through its bluetooth connectivity.

The information received from the inertial sensors is used from a local process in order to calculate the joint angle time-history for each flexion / extension angle for the selected biomechanical model (left and right knee biomechanical models have been used for this implementation). The joint angle time-history dataset is then assigned to the exercise repetition execution and is uploaded to the cloud through the (3) Send Exercise Monitoring service. The therapist's application gathers the monitoring information through the (4) Load Therapy Monitoring and Historical service for the assessment of the performed exercises. Currently, alarms per maximum / minimum joint angle flexion / extension can be defined to ease rehabilitators' assessment but work is being carried out to identify under-activity / under-effort and the recognition of evolution trends to suggest the rehabilitator a therapy / rehabilitation phase change. Reference research in this line includes the adaptive decision support system developed for physical activity of athletes, reported by Brzostowski et al [26].

5 Evaluation

5.1 Method

The system has been initially evaluated with 9 therapists and 7 patients. For the therapists a special meeting was arranged where the system was introduced. Therapists were then invited to a room where a prototype of the client was presented to them. After some minutes, they were asked to fulfil a usability questionnaire. Additionally focus groups were set up to collect more information and detect improvement areas. For the patients the technical setup was similar, but the system was tested by the patient and the monitoring results were reviewed by a therapist. Figure 3 presents the technical setup of the evaluation with patients. After a therapy session the patients were asked to fill a usability questionnaire.

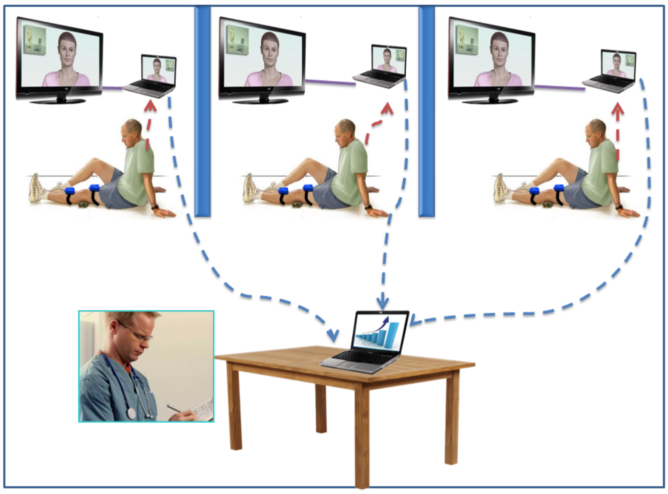

Figure 3: Concept evaluation technical setup

5.2 Results

The overall impression of both therapists and patients was positive in terms of the validity and acceptance of the approach. Therapists' results regarding the virtual humans were very positive on the virtual therapist while the simplicity of the dummy avatar representing the exercises was found as a possible limiting factor for engaging with patients. One of the main comments was "why not use real persons' video recordings instead of the virtual therapist?". Regarding the inertial sensors, they were identified as providing precise information but therapists were afraid of senior patients not being able to put them on correctly. In general the therapists conceived the solution as a valid, motivating and a complementary tool to outpatient rehabilitation at clinical facilities.

Patients' results show a good acceptance of both virtual therapist and the dummy avatar. Comments like "it looks like a serious and adequate character" or patients asking for more exercises confirm the patients' acceptance of the therapist's design. Regarding the dummy avatar, patients underline the easiness to follow the avatar, even if they consider it insipid. Concerning the inertial sensors, the patients said that was not a big problem to put them on, if it was well explained. In brief, patients did not suffer the problems that the therapist predicted, but they asked for improvements and support on the identified areas.

6 Conclusions

In this paper we have presented a new approach to provide remote multi-device rehabilitation services accessible to all. The user layer of the proposed approach is based on the ISO/IEC 24752 Universal Remote Console (URC) standard and specifically on its gateway oriented architecture implementation, the Universal Control Hub. This allows overcoming the limitations of previous URC based rehabilitation works, enabling to use URC and non-URC controller technologies, enabling to interact with interaction and monitoring devices for rehabilitation easily and providing a platform for adding new services on the future.

At the same time, the provision of the rehabilitation services through standardised interfaces, enables integrating with different HIS systems without changing the rest of the implementation. Additionally, it allows third party developers to develop new solutions based on the standard base web service interfaces. What's more, the migration of the solution from an own server to cloud based services ensures the scalability and maintenance improvements of the solution.

An implementation of this approach has been carried out focused on the elderly and the joint rehabilitation therapy. Based on the literature analysis, a virtual human on TV has been developed as the UI interaction concept for the targeted scenario. A highly realistic virtual therapist and a dummy avatar interpreting the exercises have been defined and developed in tight collaboration with rehabilitators. Regarding the rehabilitation devices for monitoring patients exercises and precisely measuring joint angles' evolution, the analysis of the literature revealed two main options, from which the magnetometers integration with inertial sensors has been selected for requiring the least amount of devices, configuration needs and home rehabilitation system's costs.

The initial user tests results have shown that both the therapists and patients have positively received the implementation of the proposed approach for the joints rehabilitation of seniors. Main concerns were expressed regarding the simplicity of the dummy avatar interpreting the exercises, which was identified as a possible limiting factor on patients' engagement. The tests with patients have shown that the predicted problems were not happening, even though, the patients asked for a more personalised exercise guidance avatar. The authors of the paper are working on the personalisation of the dummy avatar to the patient, to increase patients' identification with the avatar, in order to increase the targeted engagement. Additionally, one of the repeated comments from the therapists was the possible difficulty of the patients to place the inertial sensors correctly. Even if this difficulty has not been reflected in the user test, they asked for clear and easy to follow information. Therefore, specific audio-visual content and tests are being developed to guarantee the correct placement of the sensors by the seniors.

Acknowledgements

This work was partially funded by the Basque Government ETORGAI 2011 Programme (eRehab). The opinions herein are those of the authors and not necessarily those of the funding agencies.
The authors of this article will like to acknowledge the collaboration of Bilbomática, Ikusi, Vilau, Teccon, BioDonostia and Osatek in the eRehab project.

References

1. Eurostast European Comission. Active ageing and solidarity between generations - A statistical portrait of the European Union. ISSN: 1830-7906. (2012).
2. World Heath Organization. Global Health and Aging. (2011).
3. Brienza, D.M., McCue, M. Introduction to Telerehabilitation. In: Kumar, S. and Cohn, E.R. (eds.) Telerehabilitation. pp. 1–11. Springer London (2013).
4. Simpson, J. Challenges and Trends Driving Telerehabilitation. In: Kumar, S. and Cohn, E.R. (eds.) Telerehabilitation. pp. 13–27. Springer London (2013).
5. Ortiz, A., Del Puy Carretero, M., Oyarzun, D., Yanguas, J.J., Buiza, C., Gonzalez, M.F., Etxeberria, I. Elderly users in ambient intelligence: does an avatar improve the interaction? Proceedings of the 9th conference on User interfaces for all. pp. 99–114. Springer-Verlag, Berlin, Heidelberg (2007).
6. Carrasco, E., Epelde, G., Moreno, A., Ortiz, A., Garcia, I., Buiza, C., Urdaneta, E., Etxaniz, A., González, M.F., Arruti, A. Natural Interaction between Avatars and Persons with Alzheimer's Disease. Computers Helping People with Special Needs, Lecture Notes in Computer Science, volume 5105. pp. 38–45. Springer-Verlag, Berlin, Heidelberg (2008).
7. Zheng, H., Black, N., Harris, N. Position-sensing technologies for movement analysis in stroke rehabilitation. Medical and Biological Engineering and Computing. 43, 413–420 (2005).
8. Reinkensmeyer, D.J., Pang, C.T., Nessler, J.A., Painter, C.C. Web-based telerehabilitation for the upper extremity after stroke. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 10, 102–108 (2002).
9. Mougharbel, I., Miskawi, N., Abdallah, A. Towards a Service Oriented Architecture (SOA) for Tele-Rehabilitation. In: Mokhtari, M., Khalil, I., Bauchet, J., Zhang, D., and Nugent, C. (eds.) Ambient Assistive Health and Wellness Management in the Heart of the City. pp. 253–256. Springer Berlin Heidelberg (2009).
10. Feng, X., Winters, J.M. An Interactive Framework for Personalized Computer-Assisted Neurorehabilitation. Information Technology in Biomedicine, IEEE Transactions on. 11, 518–526 (2007).
11. Feng, X., Winters, J.M. A Home Rehabilitation Appliance That Integrates Universal Access with Personalized Interface. Distributed Diagnosis and Home Healthcare, 2006. D2H2. 1st Transdisciplinary Conference on. pp. 120–123 (2006).
12. International Organization for Standardization. ISO/IEC 24752:2008 - Information Technology - User Interfaces - Universal Remote Console (5 parts). ISO/IEC, Geneva, Switzerland (2008).

13. Światek, P., Juszczyszyn, K., Brzostowski, K., Drapala, J., Grzech, A. Supporting content, context and user awareness in future internet applications. The Future Internet. pp. 154–165. Springer Berlin Heidelberg (2012).
14. European Commission. Seniorwatch 2 - Assessment of the Senior Market for ICT Progress and Developments. (2008).
15. Nakamura, K., Takano, T., Akao, C. The effectiveness of videophones in home healthcare for the elderly. Medical care. 37, 117–125 (1999).
16. Deutsch, J.E., Borbely, M., Filler, J., Huhn, K., Guarrera-Bowlby, P. Use of a Low-Cost, Commercially Available Gaming Console (Wii) for Rehabilitation of an Adolescent With Cerebral Palsy. Physical Therapy. 88, 1196–1207 (2008).
17. Rizzo, A.A. et al. SimCoach. an intelligent virtual human system for providing healthcare information and support. In: Sharkey, P.M. and Sánchez, J. (eds.) Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies,. pp. 213–221. , Viña del Mar/Valparaíso, Chile (2010).
18. Kwakkel, G., Kollen, B.J., Krebs, H.I. Effects of Robot-Assisted Therapy on Upper Limb Recovery After Stroke: A Systematic Review. Neurorehabilitation and Neural Repair. 22, 111–121 (2008).
19. Johnson, M., Feng, X., Johnson, L., Winters, J. Potential of a suite of robot/computer-assisted motivating systems for personalized, home-based, stroke rehabilitation. Journal of NeuroEngineering and Rehabilitation. 4, 6 (2007).
20. Chang, Y.-J., Chen, S.-F., Huang, J.-D. A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. Research in developmental disabilities. 32, 2566–2570 (2011).
21. Bo, A.P.L., Hayashibe, M., Poignet, P. Joint angle estimation in rehabilitation with inertial sensors and its integration with Kinect. Engineering in Medicine and Biology Society,EMBC, 2011 Annual International Conference of the IEEE. pp. 3479–3483 (2011).
22. Zimmermann, G., Vanderheiden, G. The Universal Control Hub: An Open Platform for Remote User Interfaces in the Digital Home. In: Jacko, J.A. (ed.) Human-Computer Interaction. pp. 1040–1049. Springer (2007).
23. OpenURC Alliance. URC Technical Primer 1.0, http://www.openurc.org/TR/urc-tech-primer1.0-20121022/index.html. [Last Accessed 2013-05-17]
24. OpenURC Alliance. Resource Server HTTP Interface 1.0, http://www.openurc.org/TR/res-serv-http1.0-20121022/index.html. [Last Accessed 2013-05-17]
25. STT. IBS Sensor, http://www.stt.es/en/products/inertial-sensor/ibs-sensor/hardware/. http://www.stt.es/en/products/inertial-sensor/ibs-sensor/hardware/ [Last Accessed 2013-05-17]
26. Brzostowski, K., Drapała, J., Grzech, A., Świątek, P. Adaptive decision support system for automatic physical effort plan generation—data-driven approach. Cybernetics and Systems. 44, 204–221 (2013).