# An Optimized Infrastructure for Deferred Telemonitoring of Home Rehabilitation in Chronic Rheumatic Patients

Danilo Pani, Gianluca Barabino, Alessia Dessì, Luigi Raffo
*DIEE - Dept. of Electrical and Electronic Engineering*
*University of Cagliari*
*Cagliari, Italy*
*Email: pani, gianluca.barabino, alessia.dessi, luigi@diee.unica.it*

Matteo Piga, Alessandro Mathieu
*Chair of Rheumatology and Rheumatology Unit*
*University and AOU of Cagliari*
*Cagliari, Italy*
*Email: matteopiga@alice.it, mathieu@pacs.unica.it*

***Abstract*—The interest towards telemedicine and its various branches is constantly growing, given the opportunities in terms of costs reduction, efficiency and capillarity in delivering health services. In particular, telerehabilitation aims at improving the quality of life of physically impaired patients, providing the support for home-managed rehabilitation sessions. Moving from an existing outpatient device for the quantitative evaluation of hand rehabilitation exercises, opportunely enhanced to be used in a telemonitoring scenario, in this paper the development of the remaining telerehabilitation infrastructure is presented and evaluated. It includes, beyond the rehabilitation kits, a remote server and a deferred monitoring software application. The kits, entrusted to the patients for rehabilitation in their home, are able to send to the remote server via a GSM/GPRS connection, quantitative measurements of the patients' performance. The physician's monitoring application, retrieving such data and providing an appropriate visualization, allows the evaluation of both the patients' compliance to the rehabilitation protocol and their progresses. The system has been evaluated by a small panel of rheumatologists in order to assess its acceptability in a clinical environment and is currently under test for experimental trials in Italy.**

***Keywords*-telerehabilitation; telemedicine; hand disability.**

## I. Introduction

Telemedicine is a field of medicine which deals with providing health services at distance, exploiting information and communication technologies (ICT) resources to diagnose, treat and prevent diseases and injuries [1]. The interest towards this practice is based on the possibilities disclosed in terms of efficacy, quality and cost-effectiveness of the health services delivered [2] to an increasing number of patients. Telerehabilitation, dealing with delivering rehabilitation services over distance, can be used in a number of different scenarios, from post-stroke to invalidating chronic diseases. In such cases, it is important to step in with personalized kinesitherapies whose effectiveness strongly relies on the patient's rigour in following the medical protocol. Without remote monitoring it is not possible for therapists to assess the compliance to the rehabilitation protocol when it is performed at home and to adjust possible incorrect behaviours which could undermine the rehabilitation effectiveness. At the same time, closely assisting every patient during the rehabilitation (either in person or from remote) would require a huge effort, considerable costs and discomfort for the patients, being hardly practicable.

In fact, several telehomecare systems have been developed including a videoconferencing support in order to interact with the patient, as for the Twoway InterActive TeleVision [3]. This kind of solution requires large bandwidth and it is expensive not only in terms of actual cost but also in terms of time dedicated by the physician to every patient, that is incompatible with the real workload of a clinician. Store-and-forward solutions, where the analysis of the patient's parameters sent to the physician for evaluation is deferred, can be more acceptable provided that a proper data summarization is ensured. In fact deferred monitoring allows keeping track of a large number of patients' therapies with a limited effort. Nevertheless, the introduction of any ICT tool in the clinical practice cannot neglect its overall acceptability from both the patient's and physician's viewpoints. The latter is usually overlooked compared to the former, with the result of drawing unrealistic conclusions about the possibility of exploiting such a tool in a real scenario. Physicians need intuitive and user-friendly software tools able to provide useful, informative data allowing to ease the assessment of the patient's performance, speeding up the evaluation process rather than complicating it. At the same time the system approach must be sustainable in terms of costs for both the patients and the Public Health System.

Moving from the extension of a device for the quantitative evaluation of hand rehabilitation exercises in rheumatology clinics [4], this paper deals with the development of the best suited telemedicine infrastructure able to include such (modified) device into a telerehabilitation scenario. The development of such infrastructure is driven by the need of meeting the requirements of effectiveness, sustainability, acceptability and user friendliness. Such aspects are in depth covered in this paper in order to present the proposed implementation along with its critical appraisal in terms of alternative technologies. The evaluation of the system usability from the physician's perspective has been carried out exploiting a panel of physicians getting in touch with

Copyright (c) IARIA, 2013. 

it for the first time. The proposed system is currently being used for experimental trials in Italy.

The remainder of the paper is organized as follows. Section II presents the proposed telemedicine infrastructure implementation issues, on a specific use case. The critical motivation of the specific choices in the light of possible technological alternatives is presented in Section III, along with the results of a usability test performed on a small panel of rheumatologists. In Section IV the final remarks are presented along with the future developments of this work.

## II. The Proposed Telerehabilitation Infrastructure

As mentioned in Section I, this work moves from the extension of a device for the quantitative evaluation of hand rehabilitation exercises in rheumatology clinics [4]. In such a work, a hardware kit for the outpatient examination of kinesitherapic exercises aimed at restoring the hand functionality in patients affected by chronic rheumatic diseases was presented. That kit enables the therapist to monitor the execution parameters for a set of hand kinesitherapic exercises while they are in progress, by means of a Matlab user interface controlling the device in real-time. The extension of such system to add telemonitoring features requires modification to the hardware kit and the development of the whole telemedicine infrastructure able to include it into a telerehabilitation infrastructure.

The proposed infrastructure is aimed at deferred monitoring, so it is necessarily composed of three main components, as depicted in Fig. 1. A set of rehabilitation kits, in this case modified versions of the portable briefcases presented in [4], are entrusted to the patients. They allow to perform several rehabilitation exercises, extracting parameters characteristic of their execution. The kits are able to send the collected data to a remote server. This is in charge of both gathering and storing such data in a database, keeping track of the progress in the patient's performance over time. The last component is the monitoring software, an application expressly designed for the physicians to access such data and perform some basic analysis. From Fig. 1 it is possible to see how the direct communication over the Internet of the kits with the physician's PC is not allowed. In the following, the different parts of the system are presented.

### A. The rehabilitation kit

The kit provided to the patient allows the execution of different rehabilitation exercises, which include both strength and agility exercises, expressly designed by expert rheumatologists [4]. With respect to its first version, the kit has been enhanced in order to support the telemonitoring features. The set of exercises to be executed, the number of series and the number of repetitions within each series, can be adapted to the patients needs. Following the indications provided

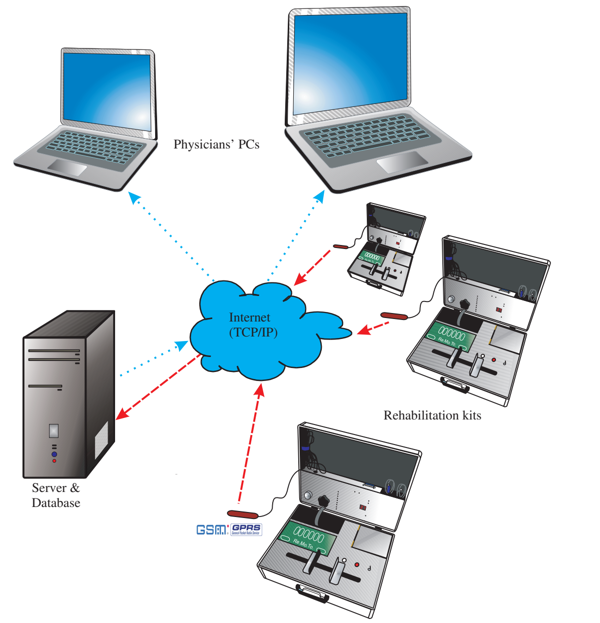


Figure 1. Main components of the telemonitoring system for hand rehabilitation.

by the kit through a simple led-based interface, patients are able to perform a training session autonomously. The kit collects quantitative data representative of the patient's performance in each exercise, summarizing them through a set of statistical values including the mean, standard deviation, maximum and minimum values of the physical quantities of interest for each exercise and the associated temporal information.

The kit has been equipped with a GSM/GPRS module (SIM900 by Simcom) able to provide a wireless connectivity mean to transmit only the summarized data to the remote server over the Internet at the end of each training session without any user intervention. The module is controlled by the central processing unit of the rehabilitation kit via a serial port (USART) interface and is managed exploiting the AT commands. These basically are ascii strings, originally introduced to manage dial-up modems, which encodes operations such as configuring the connection, dialling and hanging up. It first establishes a TCP/IP connection with the remote server and then sends a chunk of data composed of an header and a payload. The header is a unique code extracted from the SIM card installed on the GSM/GPRS module, namely the International Mobile Subscriber Identity (IMSI) code, a 15 digit number. In this way, a patient-SIM couple is intrinsically created, ensuring anonymous data transmissions. The payload is the vector of the training session statistics, in binary format. The amount of data sent is constant, regardless of the actual rehabilitation protocol configuration (the areas corresponding to non-executed exercises are zero-padded), so it is easy to identify the data

Copyright (c) IARIA, 2013. ISBN: 978-1-61208-252-3 

of a given exercise simply relying on their position into the frame. As soon as the server acknowledgement is received, the kit can be turned off, otherwise the data is stored on a persistent storage mean (embedded onto the device) and it is made available for a further try. Hence it is possible to recover the data after an unsuccessful transaction due, for example, to a momentary GSM network malfunctioning.

### *B. The remote server*

The remote server is the software application responsible of collecting the data from the rehabilitation kits and of storing them in a database for an easy retrieval. Furthermore it processes and answers the requests forwarded by the therapist's software tool. The application listens continuously for incoming connections, ready to receive new data at any time (allowing the patients to have no time schedule for their training sessions). The software is a multi-threaded C++ application, developed for a Linux server platform. The server actual functionalities, such as taking care of the data traffic from/to both ends of the system (i.e. from patients' kits and from physicians' PCs) are handled by two parallel threads (S1 and S2), each one listening on a different socket for incoming connections. The first one (S1) is the interface towards the rehabilitation kits. When a new connection is requested, S1 creates a sub-thread which handles the transfer. By default the incoming data frame is accepted, temporarily stored and parsed. If a valid device is recognised the fixed sized data frame is received and analysed to check the data integrity. An error is logged if:

- the client device is not recognised
- an insufficient amount of data has been received
- the received data integrity check fails.

In case of errors the data is written into a separate file (mainly for debugging purposes) but no entry is set into the database. After a successful validation, the acknowledgement is sent to the device, the connection is closed and the data is inserted into the database. The server is capable of managing multiple connections at the same time, since each transaction is handled by a different thread. To avoid issues while accessing the database, all the operations performed on it are protected by mutexes (which implements mutual exclusivity), so only one thread at a time can access it.

The interface towards the monitoring application is handled by the S2 thread. It is capable of answering to nine different queries by which it is possible to request different sets of data. The limited number of allowed queries confers a good flexibility to the therapist in choosing with a fine granularity the data to download, without an excessive increase in the design complexity.

*1) Database management:* The server application relies on a SQLite relational database for the storage of the patients' historical data. This choice eases the system design, being not necessary the adoption of a database manager. Still it can be accessed by means of standard SQL queries and all its contents reside on a single file, which can be backed-up easily for safety reasons. Its structure is fairly simple and consists of 4 tables (Fig.2):

- a table T1 containing the list of registered kits
- a table T2 containing the list of the rehabilitation session recorded by the system. Each row of T2 is related to a unique row of T1
- one table T3 for each exercise containing the data related to the executions of that particular exercise by each patient. Each row is related to a unique row of T2
- a table T4 containing the protocol (i.e. number of series per exercise, number of repetitions, etc.) associated with each kit. Each row of T4 is related to a unique row of T1.

T2 and T3 can be accessed by both the rehabilitation kits (to insert the data) and the physician's monitoring software (read only, through the 9 access queries). The latter can also modify T4 content. Each query issues a SELECT SQL instruction on the tables they identify. Fig. 3 shows the format of the messages exchanged between the server and the client applications. The messages containing the server answers are formatted as depicted in Fig. 3 regardless of the query being answered to. This eases the monitoring application design and possible modifications/enhancements to the communication protocol. Deleting entries from the database, when necessary, must be done at low level by issuing specific SQL queries by the system administrator, in order to avoid accidental loss of data. To improve safety, a copy of the database is automatically backed-up every day via a Secure File Transfer Protocol (SFTP) connection. This avoids loosing the data stored onto the server memory in case of accidental damages to the machine, saving the costs and the hassle of managing a RAID unit, which is in any case a viable option.

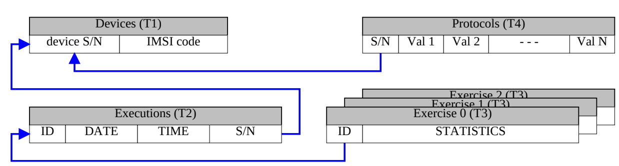


Figure 2. Internal structure of the database.

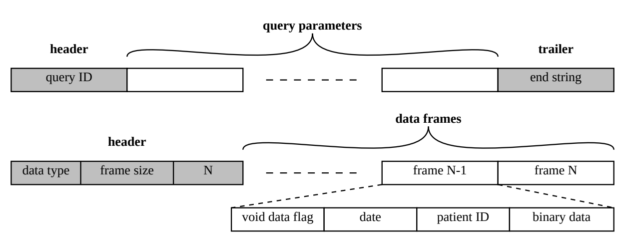


Figure 3. Format of the messages exchanged between client and server applications. From top to bottom, the *request* frame format and the *response* one.

### C. The physician's monitoring application

The therapist can access the data and evaluate the patient performance by means of a custom software. The application is based on the Qt framework, and allows an easy visualization of each patient's data by means of an intuitive graphical user interface (GUI). The GUI is composed of four main views where the user can:

- customize the application settings in the options tab
- send a query to the remote server and download the data
- check the patients rehabilitation sessions
- analyse with more details the historic results achieved by each patient.

The software has been designed trying to achieve flexibility both in terms of data management and analysis. In order to ease the data retrieval, the user can graphically build the query to forward to the remote server by selecting which data he wants to access.

Once the data has been downloaded, the therapist has the possibility to perform different actions. It is possible to verify who is performing the training according to the protocol and who's not. An immediate analysis of the patients' performance can be carried out and the data can be exported in a portable format (a .csv file) and saved locally for a delayed analysis. The first operation can be carried out by means of the Execution tab (Fig. 4), where a table shows which patients do have a correspondent entry in the table T2 of the database (marked with a green "v") and which not (a red cross is shown). This is a fast way to verify if some patients are not following the protocol correctly; the therapist can hence get in touch with them to find out if any problem has arisen.

By means of the Analysis tab (Fig. 5), a more detailed analysis can be performed by selecting specific data subset representative of the historic trend of each patient's performance in the individual exercises. The data are hence plotted on a time chart separately for each hand and series (I and II) executed in the training sessions. In the graphs, each point corresponds to the performance obtained by a patient in a given date. The plotted data are the one mentioned in Section II-A. The performance is quantified approximately by the mean value of the physical quantity relevant for that exercise (e.g.: torque in Nm). The trend of this quantity gives a clue on the patient progresses. Further information such as maximum and minimum values, standard deviation and number of repetitions associated with each series are though necessary to assess the meaning of the mean value. The physician interface makes such data available in an intuitive and easily interpretable way, in order to ease performing such kind of analysis (Fig. 6). For a deeper insight, or statistical data characterization, the data can be exported in order to allow the exploitation of specific external software tools typically used in the medical community.

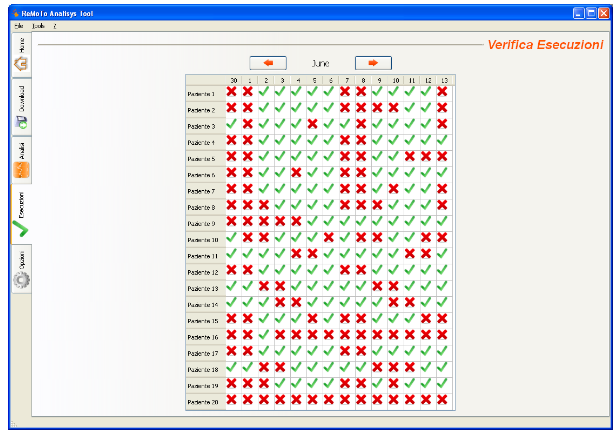


Figure 4. Execution table of the therapist GUI.

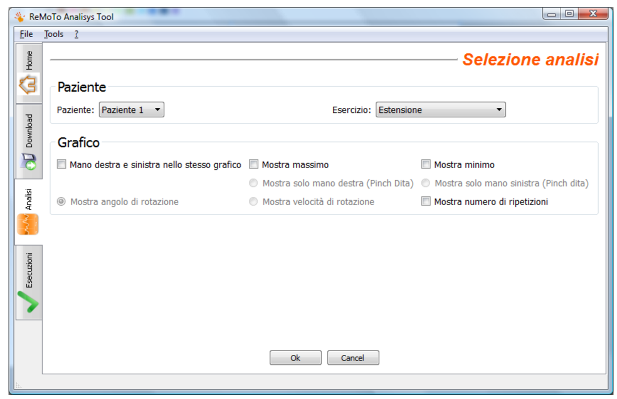


Figure 5. Analysis selection screen of the therapist GUI

## III. CLINICIANS' EVALUATION

The proposed telemonitoring infrastructure is currently under test in Italy by the Chair of Rheumatology and Rheumatology Unit of the University of Cagliari, within a trial involving 20 chronic rheumatic patients. In order to assess the usability of the system, a panel of 9 rheumatologists not directly involved in the trial has been asked to undergo a simple test in order to evaluate the telerehabilitation system. The choice of asking to experts in the field descends from the need to ensure the user has an idea of the usefulness of the system and all the more so he is able to understand what he is analysing in terms of patient's data.

After attending an half-an-hour presentation on the whole telemedicine infrastructure with details on the physician's monitoring application, the rehumatologists had the possibility of using the system for the time required to carry out 3 simple tasks, without any possibility of interacting with the designers, reporting if they were able to perform a given task and their difficulty in performing it (on a scale from 1 to 5). The tasks were a synthesis of common operations included in a normal use case and consisted of: data download, execution data and statistics visualization, and

Copyright (c) IARIA, 2013. ISBN: 978-1-61208-252-3 

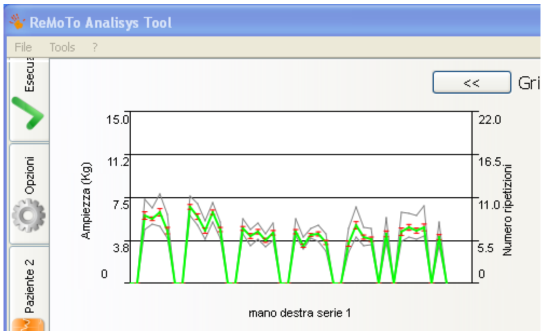


Figure 6. Exemplary historic series for an extension exercise performed by a real rheumatic patient over the first 6 therapy weeks.

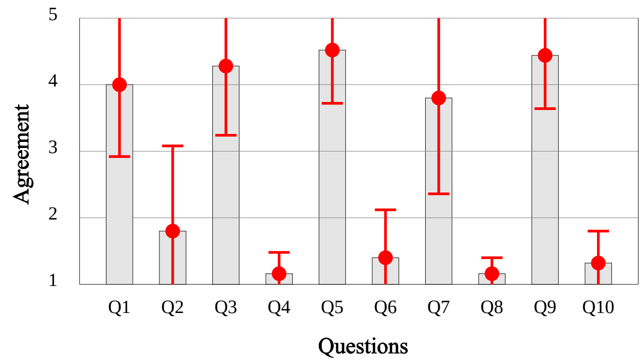


Figure 7. Mean and standard deviation of the answers to the individual SUS questions (the vertical scale represents the level of agreement, with 1 for “strongly disagree” and 5 for “strongly agree”).

raw data comparison through the graphic interface. Then, a questionnaire for the evaluation of the system usability has been administered. To this aim, we chose the System Usability Scale (SUS) questionnaire [5]. Such a scale tries to measure the perceived usability of the system (from the physician’s perspective) within the reference context. In fact, usability can be intended as the perceived appropriateness to a context of a given artefact, and cannot be fairly evaluated outside it (for instance with physicians with a different background and specialization). The 10-item scale yields a single number from 0 to 100 representing a composite measure of the overall usability of the system being studied [5]. The SUS presents 10 statements, the responder being asked to choose the level of agreement within a scale from 1 to 5. The sentences concern the system ease of use and usefulness, e.g. ”Q1. I think that I would like to use this system frequently” or ”Q2. I found the system unnecessarily complex” (the complete questionnaire con be found at www.usabilitynet.org/trump/documents/Suschapt.doc).

### A. *Results and discussion*

In the proposed test all the tasks have been performed correctly by the physicians, and the average difficulty level marked was 1.4. In Fig. 7 the results of the SUS assessment are shown. It is possible to see the distribution of the answers to the 10 questions proposed by the questionnaire in terms of mean and standard deviation (the scale is from 1 to 5, where 1 is for “strongly disagree” and 5 for “strongly agree” with the questionnaire statements). The final score is a mean SUS of 85.3 (minimum value 55, maximum value 97.5) with a standard deviation of 13.8. Taking into account that the system has been used for the first time by the panel of physicians in that occasion, it is overall a very good result.

From a physician perspective the system presents several advantages under different viewpoints. At first, the whole infrastructure is completely standalone, i.e. it can be used as it is, without the need of any additional support device at both ends (patient’s and physician’s), limiting possible additional costs for both the patient and the Public Health System. For instance, as said an embedded GSM/GPRS module provides the Internet connectivity. Among all the different solutions, apt to achieve the same result, the proposed one allows to limit the required telecommunication infrastructure at the patient’s home. He is not required to have neither a Wi-Fi or wired (i.e. Ethernet connectivity) wide-band connectivity nor a dial-up telephone line (with all the security and regulatory issues). Getting rid of any burden such as having and managing additional external tools is also particularly important when dealing with elderly patients. For instance, in [6] a telerehabilitation system somehow similar to the one presented here is introduced, but the patient’s kit is not stand-alone, requiring a PC with an internet connection. The same holds for systems requiring advanced mobile phones as telecommunication gates [7] or specific home entertainment devices such as Nintendo Wii [8] and similar tools. Even telemedicine systems exploiting apparently widespread devices such as DVB-T apparatus for digital TV [9] can pose some problems when specific features are required (e.g. dial-up connection from the set-top-box, embedded smart card reader, etc.). This fact could leave out of a telerehabilitation program those patients who are not accustomed to such technologies, not equipped with the basic infrastructure, not able to pay for the connectivity costs. In the proposed system, pre-paid SIMs allow the hospital to easily manage the connectivity costs.

All the low level aspects of the whole telemedicine infrastructure are completely transparent for the physicians. In this way the physician can better focus on the monitoring aspect and the interaction with the patient. The execution table on the monitoring application allows a birdview of the patients population in terms of execution without entering the details. Further analyses on the single patient are also allowed. The patient-physician interactions are enforced: the physician can correct or stimulate the patient whereas the patient, knowing its monitored status, is motivated and more prone to communicate with the physicians if some physical problems arise.

From a more technical perspective, summarizing the data in terms of relevant statistics at the source implies efficiency advantages not only in terms of connection costs reduction but also in terms of battery life extension (on the kit) and lightweight database (on the server) which means faster queries response time. Such process also avoids overwhelming the physician with data not immediately interpretable, slowing down the monitoring process. Also the choice of sending only binary data with the header composed only by an IMSI code is particularly useful for privacy issues, avoiding expensive and complex systems to cipher the communications between the kits and the server, mainly, since from the physician's side the decryption process could be more easily implemented.

The cost-effectiveness of the proposed infrastructure is demonstrated by the maintenance values: a 24H server with a dedicated hardware machine by an external provider costs 71 Euros/month; every SIM costs 2.5 Euros/week. Then the maintenance cost of the system is about $(71/N + 10)$ Euros/patient, where $N$ is the number of involved patients having a kit, which seems to be reasonable for the level of the service provided.

## IV. Conclusion

The main challenge in designing effective telerehabilitation systems is the correct evaluation of the trade-off between different requirements, such as the medical needs and the economical resources. Within this study a possible solution to these issues has been presented, taking into account both patients' and physicians' needs. The problem of minimizing the system maintenance costs has been carefully taken into account, giving raise to a low cost telemedicine infrastructure which clearly simplifies the system management for patients, exploiting an automatic wireless connection on a stand-alone device. Also, the evaluation of the system therapists' interface by means of the SUS test, performed on a panel of 9 rheumatologists, evidences the efforts that have been done in realizing a system usable in clinical practice.

Although the presented system applies to a particular case of telerehabilitation, the considerations made throughout the paper are common to other telemedicine applications. Telerehabilitation of course does not implies that it is be possible to neglect the patient to doctor human interaction, which still represents an important aspect of health care. In fact, the presented system could evolve just to improve it; for example a web based system where physicians and patients could share opinions, suggestions and possibly also schedule meetings or request assistance could be joined to the existing framework.

## Acknowledgment

The research leading to these results has received funding from the Region of Sardinia, Fundamental Research Programme, L.R. 7/2007 "Promotion of the scientific research and technological innovation in Sardinia" under grant agreement CRP2_584 Re.Mo.To. Project. Alessia Dessì gratefully acknowledges Sardinia Regional Government for the financial support of her PhD scholarship (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007-2013 - Axis IV Human Resources, Objective l.3, Line of Activity l.3.1). The authors wish to thank Salvatore Fara for his cooperation in the preliminary setup of the GSM/GPRS expansion of the rehabilitation kits.

## References

[1] World Health Organization, "A health telematics policy: in support of the who's health-for-all strategy for global health development, report of the who group consultation on health telematics," WHO, Tech. Rep., Dec. 1997, WHO/DGO/98.01.

[2] J. Craig and V. Patterson, "Introduction to the practice of telemedicine," *Journal of Telemedicine and Telecare*, vol. 11, no. 1, pp. 3–9, 2005.

[3] S. Guillen, M. Arredondo, V. Traver, J. Garcia, and C. Fernandez, "Multimedia telehomecare system using standard TV set," *Biomedical Engineering, IEEE Transactions on*, vol. 49, no. 12, pp. 1431–1437, Dec. 2002.

[4] D. Pani, G. Barabino, A. Dessì, A. Mathieu, and L. Raffo, "A portable real-time monitoring system for kinesitherapic hand rehabilitation exercises," in *Proc. of 5th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC)*, 2012, pp. 82–89.

[5] J. Brooke, "Sus: a "quick and dirty" usability scale," in *P. W. Jordan, B. Thomas, B. A. Weerdmeester, and A. L. McClelland. Usability Evaluation in Industry*. Taylor and Francis, 1996.

[6] V. Macellari, S. Morelli, C. Giacomozzi, G. D. Angelis, G. Maccioni, M. Paolizzi, and D. Giansanti, "Instrumental kit for a comprehensive assessment of functional recovery," in *Hand Transplantation*, 2006.

[7] A. Sarela, J. Salminen, E. Koskinen, O. Kirkeby, I. Korhonen, and D. Walters, "A home-based care model for outpatient cardiac rehabilitation based on mobile technologies," in *Pervasive Computing Technologies for Healthcare, PervasiveHealth*, 2009.

[8] J. Burke, M. McNeill, D. Charles, P. Morrow, J. Crosbie, and S. McDonough, "Serious games for upper limb rehabilitation following stroke," in *Games and Virtual Worlds for Serious Applications, 2009. VS-GAMES '09. Conference in*, Mar. 2009, pp. 103–110.

[9] G. Angius, D. Pani, L. Raffo, and P. Randaccio, "KeepInTouch: A telehealth system to improve the follow-up of chronic patients," in *Collaboration Technologies and Systems (CTS), 2011 International Conference on*, May 2011, pp. 311–318.

Copyright (c) IARIA, 2013. ISBN: 978-1-61208-252-3 