TeleRehabilitation: a novel service oriented platform to support Tele-Supervised rehabilitation programs for ICU patients

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Abstract— **this paper introduces a novel service oriented pilot platform developed to support Tele-Supervised rehabilitation programs for patients after hospitalization in Intensive Care Units. The platform is developed under the framework of the TeleRehabilitation project funded by the Cross Border Cooperation Programme Greece Cyprus 2007 – 2013 in order to successfully meet the main technological and clinical objectives of the project. The design and development of the platform is based on composite service architecture (aggregates smaller and fine-grained services such as Web Based applications, Clinical Information Systems and Video Communication Systems). The platform delivers sustainable, maintainable and high quality services and enables multiparty, interregional bidirectional audio/visual communication between clinical practitioners and post-ICU patients, enables patient group-based vital sign real time monitoring, individualized and group-based patient online training and patients clinical record bookkeeping.**

Index Terms— *Telesupervision, Exercise, Rehabilitation, Intensive Care, Vital Signs Tele-monitoring, Tele-presence, post-ICU patient care.*

I. Introduction

On annual basis, approximately one thousand and two hundred (1200) critically ill patients are hospitalized in Nicosia and Heraklion General Hospital Intensive Care Units, of whom ~1000 survive. A significant number of these patients (annually 700-1000) are discharged from the ICU with severe reintegration problems and are not able to return to their work, family and the local community. Even though these patients have the need of cardio-respiratory rehabilitation programs with multidisciplinary support, access to such programs is either impossible or it requires important financial costs and traveling overheads. The Intensive Care Unit of Nicosia's General Hospital, as the coordinator of the "TeleRehabilitation" project [4], in cooperation with the Herakleion University Hospital of Crete and the Computer Science Department of the University of Cyprus have defined as a primary purpose the development of a novel pilot application of cardio-respiratory rehabilitation services in the community based on telemedicine, for patients after ICU discharge. Furthermore, the project "TeleRehabilitation" along with its scientific collaborators (St George's Medical School – University of Nicosia and the Hellenic Society of Ergospirometry Exercise and Rehabilitation) aims at a) the creation of a supportive high quality and low cost technological infrastructure (2-way audio/visual communication, real time vital sign monitoring and analysis and patient clinical record), of for update and expansion, b) the publication of the scientific results regarding aerobic capacity, evaluation methodology as well as the structure and effectiveness of the individualized rehabilitation program, c) to setup the underpinnings for the evolution of the pilot project into viable and sustainable service and d) to further develop the inter-border cooperations in terms of medical services accessibility, secure social rehabilitation and novel research, and development of medical services.

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II. Motivation And related work

Many of the patients hospitalized in Intensive Care Units (ICU) return home suffering from reduced functional capacity, exercise tolerance, health related quality of life and social function [1]. Although the evidence demonstrates a clear need for rehabilitation for those patients [2], it seems that is not often possible for them to join rehabilitation multidisciplinary supported programs [3]. The main reasons are the absence of such programs provided by the public or private health sector, the high cost of participation and mobility problems due to the medical condition of the patient, the community location or the traveling overheads.

Over the years state-of-the-art telemedicine solutions for life support (e.g. home mechanical ventilation), real time vital sign parameters and waveform monitoring (e.g. electrocardiograph, pulse oximeter, blood pressure meters) have been introduced in order to deliver high quality, real time medical support to community located patients (home care service).

At [6] Clifford and Clifton provide an overview of current wireless technology used for patient monitoring and disease management. Further they identify some of the major related issues and describe some existing and possible solutions. Further detailed surveys and several examples of tele-monitoring based on wireless sensors and bio signals are presented in [6] – [8]. Monitoring of adults with chronic heart failure has been an issue examined through many research projects, examples of which are presented in paper [8]. Furthermore, monitoring of children with chronic diseases has also been proposed in [9] where a large scale Pilot study [15] has been conducted in four Member States of the European Union (Italy, Spain, The Netherlands, Poland) to demonstrate the feasibility of a Tele-rehabilitation service using Habilis, a general-purpose software platform.

Although in their vast majority, telemedicine services and systems meet the objectives they were built for, that is to monitor patient vital sign parameters and waveforms at home, lack of bidirectional communication (audio and video) between the clinician and the patient and limited interoperability between home care and clinical information systems limit the application scenarios and fail to satisfy the requirements of ambitious medical services such as the tele-rehabilitation service.

The aforementioned limiting factors and the necessity to provide high quality and sustainable services to support tele-supervised rehabilitation at home motivated us to develop the TeleRehabilitation platform. The platform facilitates group-based tele-supervised (physiotherapist, nurse, doctor) patient rehabilitation (each group consists of 6~8 patients).

III. User Requirements

The service description, based on the aforementioned use case scenario, the user requirement analysis (Table 1), the market analysis and cost-benefit analysis governed the process of the design and served as a communication bridge between the technical and the clinical experts.

Market and Cost-Benefit

Market Size: 1200 critically ill patients are hospitalized in Nicosia and Heraklion General Hospital Intensive Care Units, of whom 700-1000 are discharged from the ICU with severe reintegration problems (not able to return to their work, family and the local community). 20~30% of these patients meet the inclusion criteria to join a critical care rehabilitation program.

Market Trend and Growth Rate: Rehabilitation is a hot topic in clinical practice and recently is gaining ground in post hospitalization treatment. Recent critical care research have highlighted promising results. In [10] exploratory analyses showed the rate of change over time and mean between group differences in 6 minute walk test from first assessment were greater in the intervention group.

Cost-Benefit: The cost to introduce a novel multidisciplinary service such as the telerehabilitation is not high compared to other health services. In total, the equipment cost of the infrastructure (video communication service, vital sign monitoring service, IT infrastructure, patient station, web applications development and exercise equipment) is less than €600K. On average and based on the worst case scenario electronic equipment lifetime is estimated to 5 years thus, we can calculate a draft annual cost of the infrastructure at €60K. The annual labor (clinical experts, IT support and homecare support) cost, building cost and high speed network infrastructure cost is less than €150K.

Table 1: User Requirements

Service	Description
Video	- High quality, full motion and pixelation free picture. - Tutor Mode video communication (patients-clinicians in N:1 association) to satisfy confidentiality.
Audio	- High quality full duplex audio with echo cancellation, automatic gain control and noise reduction.
Vital Signs Monitoring	- Wearable, battery powered with wireless communication capabilities monitor device able to monitor real time 3-Lead Electrocardiogram, Heart Rate, Oxygen Saturation (SpO2) and Non-Invasive Blood Pressure. - No need for waveform storage for further analysis - Group-based vital sign central station monitoring
Clinical Record	Demographic data, ICU scores, post-ICU evaluation, Rehabilitation Session Records (clinician evaluation, vital sign records), post-Rehabilitaion evaluation.
Clinicial Intervention during session	The clinician must able to project during the session training material and/or demonstrate an exercise.
Training	On line individualized training sessions and training material in textual, visual (images and video) format.
Patient Station	All in one service support device with simple user interface with accessibility features.
Sustainability	The telerehabilitation session must address power outages (home network, ISP provider) incidents.

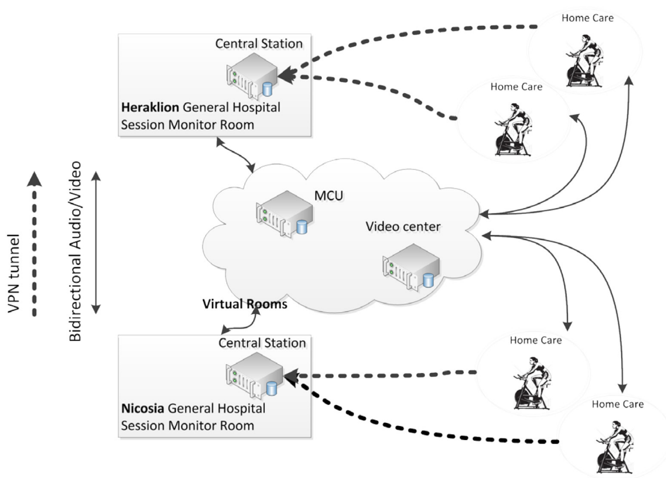
Current platform resources capacity can support 75-96 patients on annual basis. Therefore, the cost per patient can be approximately calculated at €2,1K which is the ICU patient daily cost. A detailed service viability and cost-benefit analysis effort is in progress to include socioeconomics factors to furthermore demonstrate the cost effectiveness of the service.

IV. Service Overview

The service's main objective is to support multiparty telerehabilitation programs with high quality audio/video communication, vital sign monitoring, online training and demonstration and first line support. An overview of the communication channels and the flow of data is depicted in Figure 1. Two types of network paths are classified based on data security and confidentiality. Audio and Video services utilize bidirectional transition over IPv4 layer 2 network tunnels.

Two major platform components, Multiparty Control Unit and Video Center, introduce virtual communication rooms services where Clinicians, located in hospital based session coordination rooms, and Patients at home communicate in 1:N relationship. Clinicians can monitor the patient group in tile window views (Tutor mode) while the patient view is restricted to a single window view (Student mode). Therefore, patient confidentiality is safeguarded and network capacity needs are limited. The Vital signs (in form of parameters and waveforms) are unidirectional transmitted over IPSec Layer 2 network tunnels from the patient vital sign monitor to the central station console. Using this technique we have achieved to translate a Clinical Information System into homecare service over ADSL home connections (4Mbps/768Kbps) while maintaining security, sustainability and protection of patient personal data.

Figure 1: System Overview

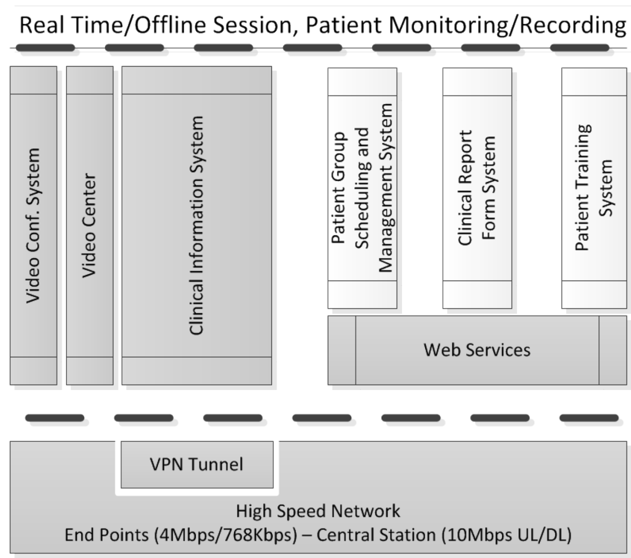


During the service design phase we have identified the major success factors. The most important ones are sustainability and ease of use. Thus the design is compliant with the composite service architecture. Therefore, core services such as the video communication and the vital sign monitoring are based on mature solutions (Video Conference Systems and Clinical Information Systems respectively) while patient clinical records and online training services were customized designed and implemented to meet the requirements. Figure 2 depicts the service architecture where mature, fine-grained service support is colored dark grey.

A. *Clinical Information System*

Patient clinical data are monitored during the telerehabilitation session using in-hospital clinical information system solutions and wearable light-weight, battery powered wireless (802.11b) devices over VPN (IPSec no-compression) tunnels. The VPN site-to-site access point is hardwired to the local network infrastructure. The vital signs (3-lead ECG, Heart Rate, Oxygen Saturation and Blood Pressure) parameters and waverforms are transmitted utilizing less than 100Kbps. The central station console is configured to monitor the patient group in parallel and export the local view in high definition format to the video conference system to achieve interregional monitoring and data storage. Vital signs parameters are exported offline to the Clinical Report Form System in HL7 format.

Figure 2: Services Architecture



B. *Video Communication System*

Video and audio communication is established using business solution VoIP video conference (VC) systems. Three major components are deployed to provide high quality video/audio communication and recording.

The MCU (Multiparty Control Unit) enables the creation of virtual rooms. The unit automatically establishes calls with all participants (Telerehabilitation patients and clinicians), configures the clinician's view in tile window layout and starts session recording based on pre-scheduled scenarios.

The call is established using the H.323 communication protocol. Video and presentation transmission is succeeded using the H.264 video compression codec while audio utilizes the G.722.1C (Polycom© Siren14™) audio codec in stereo mode.

NAT barriers at the patient resident are overcome using external H.323 Gatekeepers. H.323 Gatekeepers function just like telephone centers using the Global Dialing System (GDS). VC clients register with their unique identifiers to the gatekeeper. The gatekeeper in turn updates the local database with corresponding network information such as IP address, QoS parameters, UDP ports etc.

The Video Center Telerehabilitation sessions are recorded for further evaluation and secure broadcasting.

Total bandwidth requirements for both services does not exceed the 768Kpbs uplink communication path. Video resolutions can be further downgraded without significant loss of quality e.g. 640x480@25fps.

C. Web based services

Patient management system (PMS) effectively and securely manages patient medical data. The design follows the model-view-controller (MVC) software architecture. PMS is a web application written in php, based on apache web server and leverages the MySQL relational database management system for medical record storage.

Table 2: Bandwidth Requirements

Codec	**Quality**	**Bandwidth**
H.264	912x512 pixels @ 30fps 1024x576 pixels @ 30fps	384Kbps~512Kbps
G.722.1C	32 KHz	~48Kbps
	Total Bandwidth	432Kbps~560Kbps

Patient data are classified in private and non-private and are stored and processed at different physical servers. Each clinician is assigned a role prior accessing the system such as physiotherapist, nurse, doctor. Clinician's access rights are also based on its granted permissions given to her/him for specific patient records. The patient management system consists of the following components: (a) Patient Group Scheduling and Management system, (b) Online Training System and (c) Clinical Report Form System.

Patient Group Scheduling and Management System organizes patients into rehabilitation groups, each of which is consisted of 6~8 patients, books reservations for tele-rehabilitation sessions and eliminates race conditions for shared resources. A clinician can enroll a patient in a rehabilitation group only if she/he has access to the patient's record.

Online Training System facilitates telesupervised individualized or group based training sessions. Patient site web application sends requests (Patient ID using AJAX calls) on specific sampling rate to retrieve appropriate training material (single page textual or/and visual information) or consultation. The clinician in charge is able to assign the appropriate training material to a group of patients and/or to each patient individually during a session or in offline.

Clinical Report Form System (CRF) manages private and non-private patient medical data. It consists of two individual services each handling only one class of medical data (private and non-private). CRF stores more than 100 individual fields and 8 health surveys and medical examinations. Non-private data are exported in comma separated values (csv) files for further processing using statistical analysis software such as SPSS. The most important information is summarized in:

- ICU scores (Non-Private). The system stores the ICU scores (SAPS II, Glasgow Coma Scale, SOFA and APACHE II) as well as the allergies and diseases, following the World Health Organization ICD-10 codes [11].
- Patient evaluation (Non-Private). Health standard surveys (i.e. SF-36, Rivermead Mobility Index, Mini Mental Scale Examination) and standard medical evaluations (i.e. tests of respiratory muscle strength such as Maximum Inspiratory Pressure) are also stored. Health surveys and clinical evaluation reports can be filled online and offline. The results are used for pre/post-Rehabilitation evaluation.
- Tele-Rehabilitation Session Records (Non-Private). Each session record stores evaluation parameters and vital sign parameters based on key-value tuples. A key is a combination of an evaluation parameter id or a vital sign id and a timestamp. Vital sign parameters can be also imported directly from the Clinical Information System using the HL7 protocol.
- Free text notes (Non-Private).
- Group Exercise Program and Individualized Exercise Program (Non-Private)

Private Data can be accessed only from inside a vault where the private data service is located.

User roles (*Doctor, Secretariat, Physiotherapist, Nurse, Psychologist, Research Coordinator, IT administrator and Homecare support group*.) are of major importance and are assigned by the IT helpdesk. Users have access to specific data views based on their role (i.e. psychologists cannot view demographic data and ICU scores). Access rights are stored in the database in pair values <user role, view> and <patient_id, user_id>. The Research Coordinator has full access to the data.

D. Clinical Record Safety

According to Hellenic Data Protection Authority (HDPA) and European Union [12][13], private data are any data that refer to a person whose identity is known or can be verified. "A person whose identity can be verified" is one who can be identified, directly or indirectly, by an identification number (i.e. identity card number, passport number, etc.) or by one or more factors that specify his physical, physiological, mental, economic, cultural or social view (i.e. demographic data).

The private and non-private data are stored and processed at separate web application servers. Both servers use encrypted file systems to avoid direct access to the data or the source code. Moreover, private data are also encrypted, using AES symmetric-key algorithm, prior storing in the database. The encryption/decryption key is retrieved on the fly by applying a php function to encryption/decryption phrase stored locally. Hence, private data decryption requires both the php source code and the database, which are actually stored in an encrypted file system. Furthermore, backups are created and securely stored on regular basis and data are transferred only using secure protocols (i.e. https, scp). Lastly, both servers are safely locked in a server room with highly restricted access level. User passwords are subject to password policies (i.e. must be changed periodically, complexity requirements, etc.). Finally, the private data server is accessible only from intranet (actually, only one VLAN in the hospital network infrastructure) and transmits private data only in localhost mode.

E. Patient Station

The patient station carefully meets the generic ergonomic principles which apply to the design of human-machine-interaction systems. These principles are summarized to a) suitability for the task, b) suitability for learning, c) suitability for individualisation, d) conformity with user expectations, e) self-descriptiveness, f) controllability, and g) error tolerance [14]. Patient station hardware is an all-in-one multi-touch PC at at eye height with build-in wide angle HD camera. No keyboard or mouse is installed. The interaction is done using 1-finger simple clicks. The PC, which is electrically powered by a 1KVA UPS to address electricity power outages, runs Microsoft Windows 7 pro. On power-up the PC enters in special operation mode using user group policies to restrict all irrelevant to the program functionality and services.

Interacting inside this protected environment the patient and the caregiver are able to communicate with the clinicians in order to participate in telerehabiiltation sessions and get online support and training through a customized design web application.

The patient is able to navigate through the training material and find corresponding resources using the self-described web application or follow the training program scheduled by the clinician (group or individualized training program). Training material has been carefully designed to fit in a single view to limit scrolling actions.

Maintenance and service recovery asynchronous procedures executing in the background guarantee an error tolerant system.

V. CONCLUSIONS BASED ON UNIT TESTS & EVALUATION

The full feature scenario is still under evaluation and testing since we just recently completed unit, integration and functional testing of in house developed software components (software testing). Each software component has been also tested and evaluated from the clinicians (usability and accessibility and performance testing) based on real scenarios. The IT experts tested the functionality of the components and identified problems with the development, configuration, deployment and interworking procedures. The clinicians have evaluated the components from the user perspective to identify misconfigurations, misinterpretations or luck of features in the development based on user requirements. Evaluation will continue with non-IT, healthy population participating in real tele-supervised group exercise programs to highlight service usability issues and unforeseen problems. Even though we have not yet completed real-life scenario testing and the detailed cost-benefit analysis report is in progress we can draw some conclusions based on current information.

The main outcome of this study is the feasibility of such complex and multidimensional project. We have achieved to compose fine-grained services with customized developed services into a sustainable, maintainable, expandable and error tolerant cost-effective platform. Furthermore, we have defined a complete set of Standard Operating Procedures (SOP) for every team involved (clinicians, IT, patients, coordinator etc.) to guarantee service sustainability and error tolerance. Also, patient homecare services have been carefully designed to execute under near disaster situations. Home caregivers are well trained and equipped to address several issues.

Based on the aforementioned strong points of the design and current test results we can be optimistic about the final outcome of our effort.

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