Telemonitoring system for home rehabilitation of patients with COPD

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Abstract— **This papers presents a flexible, user friendly, multi-tenant health care platform, which enables remote monitoring of vital signs of patients with Chronic Obstructive Pulmonary Disease (COPD) by integrating a series of heterogeneous data collection sources (medical devices), while offering to authorized professionals secure access to patients' Health Electronic Records (EHRs) in real time and from any location, further empowered by an automated alarm system. A pilot study, with duration of one year has been conducted in Greece to examine the degree to which patients adhere to the home rehabilitation protocol and its potential benefits for patients with COPD.**

***Keywords*— telemedicine, home rehabilitation, healthcare network, rehabilitative technology, COPD.**

I. Introduction

The technological advances and fast-increasing communication capabilities are currently opening a new market to the healthcare industry, which is under severe pressure due to lack of resources (financial crisis) combined with a steadily increasing prevalence of chronic conditions of an ageing population at global level. Home care for patients with chronic conditions is becoming an integral part of the new healthcare strategies in most of the countries world-wide, with an estimated number of over 5 million connected end users of telemedicine systems [1], [2]. Chronic Obstructive Pulmonary Disease (COPD) is a long term respiratory condition, usually characterized by a high frequency of exacerbations which requires patient hospitalization for several days. COPD is associated with a severe decrease in daily physical activity and psychological problems, which result in poor patient health-related quality of life. Recent studies have shown that patients who attend hospital-based, multidisciplinary, pulmonary rehabilitation program have lower rates of hospital admissions, shorter hospital length of stay and less use of health care services [3]. Furthermore, the benefits of a pulmonary rehabilitation program tend to diminish after a relatively short period of time following its discontinuation, if not followed by an efficient maintenance program.

Although COPD is an important health problem for Greece, with a percentage of 8.4% average prevalence of COPD in people over 35 years old, the implementation of hospital-based pulmonary rehabilitation programs is highly unrealistic, due to the very low number of specialized rehabilitation centers combined with the high cost of the programs, as pulmonary rehabilitation is not reimbursed by the national health insurance system.

The work presented concerns the TELECARE project [4][5], which has implemented a flexible, user friendly, multi-tenant health care platform. The platform enables remote monitoring of vital signs of patients with COPD by integrating a series of heterogeneous data collection sources (medical devices), while offering to authorized professionals secure access to patients' Health Electronic Records (EHRs) in real time and from any location, further empowered by an automated alarm system. A pilot study, with duration of one year has been conducted in Greece to examine the degree to which patients adhere to a home rehabilitation protocol and its potential benefits for patients with COPD. A total of 167 patients were recruited and divided into three groups for the pilot study: (a) no rehabilitation, usual care group; (b) hospital-based rehabilitation group; and (c) home Telecare rehabilitation group. The current paper focuses on the presentation of system design and implementation, while interim study results are briefly discussed.

II. System Design and Implementation

A. Technical Requirements

The design and implementation of the Telecare system considers a user-centered approach, with incremental steps and active involvement of end-users from the early stages. The end-users of the system are not only the patients, but also the various medical expert groups and support personnel (e.g. phone operators, technicians). Thus for each group the user requirements have been collected and analysed, to further derive the technical requirements.

Taking into account that the vast majority of the patients are elderly, there are some basic user requirements to which the system design and implementation should obey: the patient-system interaction time and complexity should be minimized, as the failure to handle complex technologies discourages the senior users and decreases the patients desire to use the system; the application interface and instructions for the senior users should be easily understandable; the system should foresee for possible wrong choices/actions and provide corresponding help; patients should feel safe and independent while using the system, as the need of help from others discourages them to use the technology; the system should provide security methods and measures to protect the personal data; the design of the system and protocols to be followed at home should follow similar patterns with the ones the patient faces at a hospital visit.

At a more specific level, the mobile application for the patients, except of the user-friendly interface and data flow, the application should: allow for real-time data collection and transmission; provide flexible and remote management with respect to type of data (to be collected) and their scheduling; allow for emergency data collection/transmission at patient's initiative; allow for data collection in multiple small sessions, according to patient's abilities; allow for automatic data transmission and foresee for possible network problems (automatically retry on failure); provide mechanism to ensure data authenticity and integrity.

With respect to the medical experts' category of users, the implicit patient data handling workflow and user-friendly interfaces are a pre-requisite, especially regarding the handling of EHRs. The key issue in relation to the remote medical data collection is the real-time access to patient data and flexibility with respect to metrics and schedule.

Last, but not least, certain technical requirements were derived with respect to the selection of technologies and type of medical devices to be used for home data collection: the fewer the better (e.g. one device should allow both oximetry and spirometry); automatic data transmission to the mobile application (the patient shouldn't be requested to write down or remember numbers, etc.); provide reliable measurements, similar to those recorded in medical centers, provided that the patients have been trained to correctly use the devices; long life of batteries and small size to be easy for patients to carry the devices.

B. *Overall Architecture Design*

The design of the generic architecture of the Telecare system was based on the technical requirements and the various actors and actions are coordinated by the Central Server (RMServ), as shown in Figure 1. The mobility of the end users (i.e. patients, medical staff, etc.) is supported through adequate secure interfaces and data transmission protocols over 3G/4G mobile network and over the internet.

The access interface implemented by the RMServ is based on the Simple Objects Access Protocol (SOAP) for data exchange and Secure Hypertext Transfer Protocol (HTTPS) for secure communication between the mobile devices and the server. The RMServ coordinates the data retrieval/storage activities, and it connects with various data bases: system specific storage database (non-sensitive usage data), Telecare local database (protocols, users, teams, tasks, short-term EHRs storage), hospital information systems (HISs) where the patient EHRs are long-term stored.

C. *Patient Mobile Application*

The mobile application designed and implemented for the patients' use takes into account the technical requirements imposed both by the user requirements and by the devices selected. For the pilot study that took place during the project

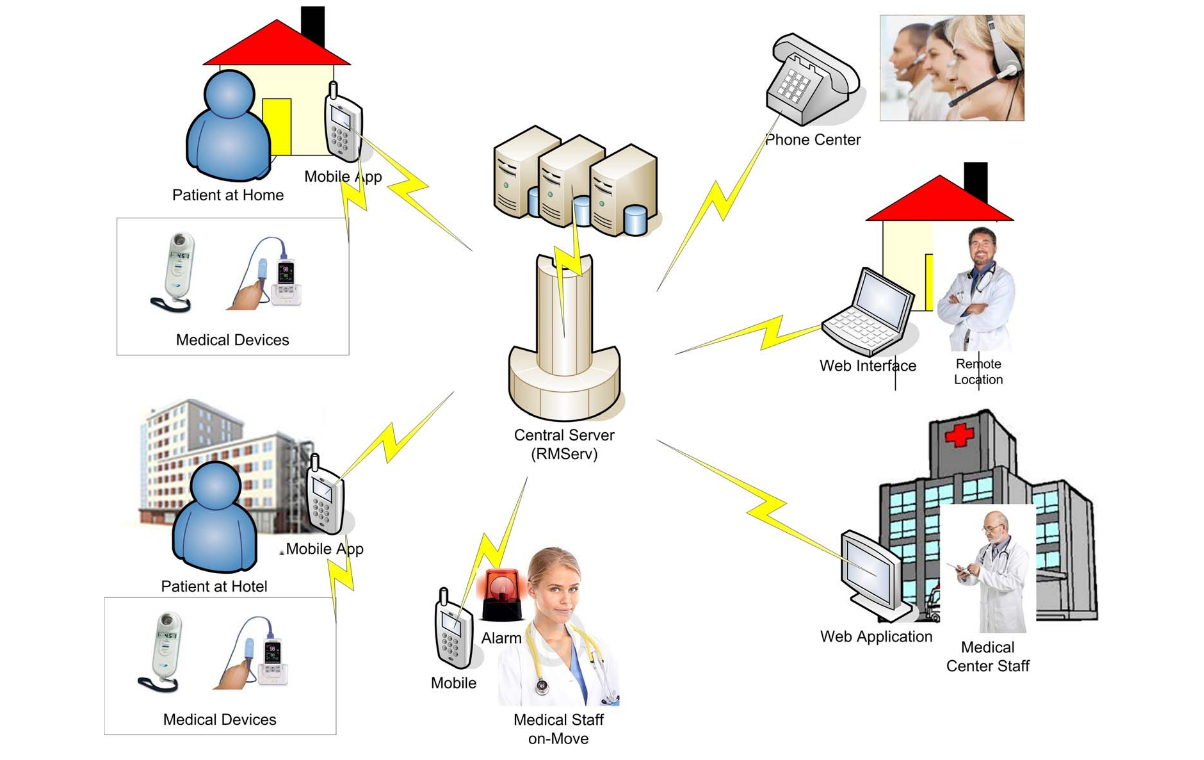

Figure 1. The overall architecture of the Telecare system

implementation of the Spirodoc Spiro+Oxi medical device [6] was selected for the measurements, and a Lenovo Tablet, running Android 4.0 operating system, for application deployment, additional data collection, and extended functionalities (i.e. video-conference calls). The selected Spirodoc model is equipped with: (a) complete spirometer permitting an advanced functionality mode for the medical experts (FVC, VC, IVC, MVV, PRE-POST), (b) pulse oximeter which allows SpO2 and HR measurements, and (c) 3D accelerometer with motion analysis, which allows for daily activity estimation (step counter, movement estimation).

The communication between the Spirodoc and the Lenovo mobile device is supported by Bluetooth communication protocol, which doesn't require any expert technical knowledge from the patient, and data are automatically retrieved by the mobile application from the Spirodoc device.

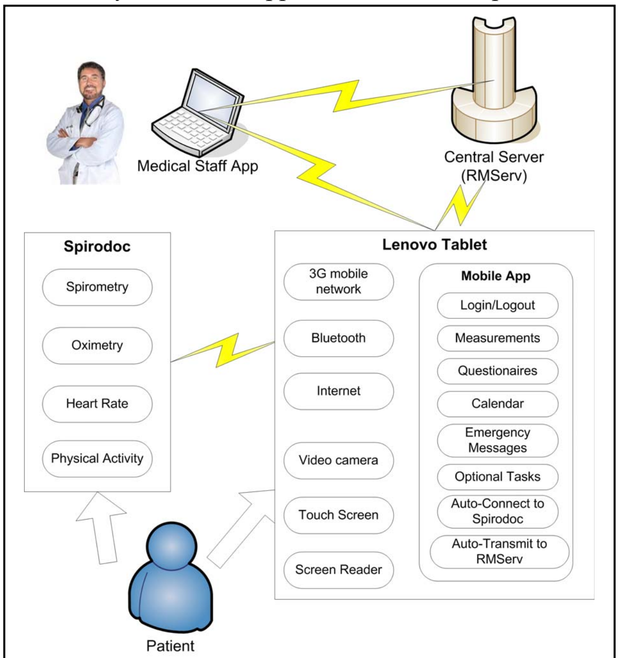

Figure 2. The Telecare architecture of the Patient Application

The patient mobile application (see Figure 2) provides a high degree of adaptability, flexibility and robustness with respect to use of available resources: switches between mobile and WiFi networks, uploads/downloads tasks in real-time and automatically re-connects upon failure, automatically connects to the medical device, patient is prompted with help whenever needed, sound and visual alerts are used for emergency messages, touch screen and screen reader technology improve the patient experience, etc. The application provides clear visual indications (color coded) to the patient with respect to completed and pending tasks, calendar view and selective view of pending tasks.

D. Users' Web Interface

The other categories of users (medical staff, administrative and technical personnel, call operators, etc.) of the Telecare system are provided with a web-based application, which can run on any device (iPhone, laptop, desktop) which has internet access, as shown in Figure 3.

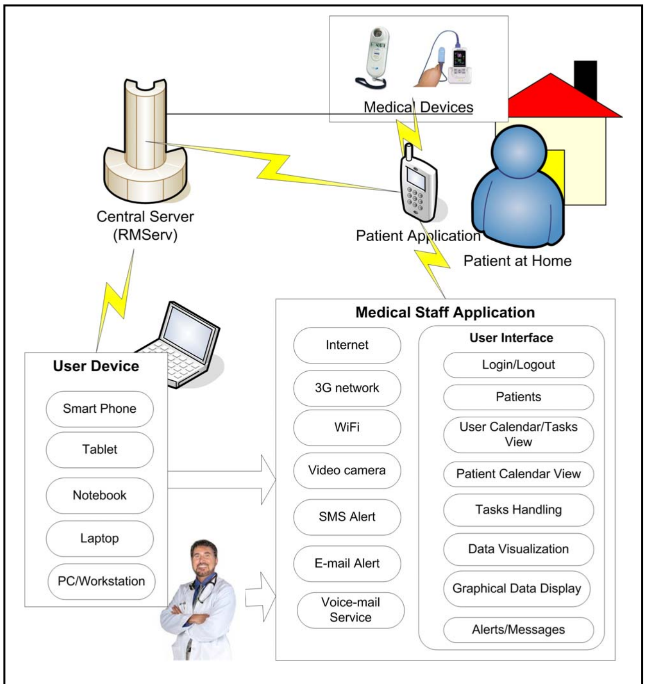

Figure 3. The Telecare architecture of users' Web-Application

Except of the implicit workflow related to patients home monitoring, the users' web-application and interface allow for task handling, messaging and alerting between the Telecare personnel, to ensure timely and consistent monitoring. Except of the human alerts/messages, the system has the option to raise patient personalized alerts upon detection of certain rule-based patterns in the measured or estimated parameters. The connection to the HIS allow to the authorized personnel to visualize selectively (depending on user rights and data sensitivity level) data related to the current condition, also by means of graphical inspection of time-series.

The system is not bounded to connectivity to a certain medical center, hospital or service provider. Medical staff and support personnel can be employed at any of the collaborating actors, while their access rights and tasks in the system depend on the assigned role.

III. Pilot Study

A pilot study with duration of one year has been conducted in Greece to examine the degree to which the patients adhere to the home rehabilitation protocol and its potential benefits for patients with COPD. Here interim results are shown.

E. Populations and Study Design

A total of 167 patients were initially recruited and divided in three groups for the pilot study: (A) no rehabilitation, usual care group of 50 patients; (B) hospital based rehabilitation group of 60 patients; and (C) home Telecare rehabilitation group of 57 patients. The inclusion criteria for all groups are: 1) post-bronchodilator FEV1<80% predicted and FEV1/FVC<70% without significant post-bronchodilator reversibility (<10% FEV1 % predicted normal), and 2) absence of other significant diseases that could limit daily physical activity. Before the pilot study, for duration of 2 months, all patients followed a hospital based, supervised rehabilitation program. Some patients resigned after a very short time at the start of the preparatory phase: 10 patients in group A, 10 patients in group B and 7 patients in group C.

During the pilot, each group followed a different protocol: group A followed a self-maintenance program at home, following doctor's instructions given at the end of the outpatient rehabilitation; group B followed a hospital based supervised maintenance program (2 weekly visits); and group C followed the Telecare home based rehabilitation protocol, as detailed bellow. At baseline, at 2-month, 6-month and 12-month time points, patients were clinically assessed for pulmonary function, exercise tolerance, fat free mass and other health parameters related to quality of life.

F. Telecare home based rehabilitation protocol

The patients of group C, who joined the home rehabilitation protocol, followed a similar setup of physical activity tasks to that followed by group B (hospital based). Data collection included: spirometry task twice per week; pulse oximetry measurement twice per week; respiratory symptoms self-assessment twice per week; COPD assessment test (CAT) twice per week; Hospital Anxiety and Depression Scale (HADS) self-assessment every two weeks; heart rate measurement twice per week; home exercise assessment (heart rate and pulse oximetry before and after home exercise) three times per week; daily steps; mMRC dyspnea scale assessment twice per week; monthly dietary habits assessment; weekly body weight measurement.

At the end of the first phase (outpatient rehabilitation) patients were given self-maintenance instructions, including types of physical activity exercises, daily steps target, dietary indications/constraints, etc. Upon need, these instructions were adapted to progress and reminded to the patient during the second phase, through weekly messages and telephone call reminders. Patients followed a training seminar of 2 hours to get used to the technology and the correct usage of the medical device. In a very few cases (over 70 years old patients that never used a smart mobile phone before) an additional personalized training session of 1-2 hours was needed. During the second phase of the study, patients of group C, had also access to technical support through phone or video-conference.

IV. Results and Discussion

The design and implementation of Telecare system was a multidisciplinary effort, demonstrated in a comparative pilot study [7]. The clinical results demonstrated that the initial two-month supervised rehabilitative exercise-training program significantly improved chronic dyspnea (mMRC) and the total score of both CAT and quality of life (SGRQ) questionnaires in all patients. Six months later home tele-rehabilitation was equally effective to hospital-based rehabilitation in terms of maintaining the initial significant improvement in mMRC (2-months: 1.7±1.0 versus 8-months: 1.6±0.9), CAT score (2-months: 13.13±8.01 versus 8-months: 13.02±7.55) and SGRQ score (2-months: 42.22±19.17 versus 8-months: 41.35±21.28). Patients of group C that completed the second phase of the pilot study adhered to the home rehabilitation protocol, by reaching a percentage of 94.8% of tasks completed. More specifically, the spirometry tasks' completion reached the level of 93.0%, the pulse oximetry tasks' completion reached 94.7%, the CAT questionnaire completion reached 97.4%, respiratory symptoms questionnaire completion reached 97.3%, the home exercise assessment tasks completion reached 91.7% and the HADS questionnaire completion reached 87.9%. By the end of the pilot study the drop-off rates of patients in groups B and C were not significantly different, indicating that home rehabilitation involving technology use on a daily basis doesn't discourage the patients, despite of their age.

The large number of telemedicine applications being build more and more all over the world to not necessarily imply their increased adoptability and use, both by patients and professionals. Thus, adequate studies which prove their usability and efficiency compared to the clinical setup are mandatory. The clinical results of the this work encourage future work on development and integration of home care protocols targeting to other chronic diseases, where the patient self-management plays a crucial role in improving on long-term the quality of life and minimize the requirements for hospitalization and expensive clinical rehabilitation.

V. Conclusion

The proposed multi-tenant home rehabilitation platform enables remote monitoring of vital signs of patients with COPD, by integrating a series of heterogeneous data collection sources, while allowing to authorized professionals secure access to EHRs in real time from remote locations. The patient-centered design leaded us to a flexible system which is not bounded to connectivity to a certain medical center, hospital or service provider. The future home care services should be patient-focused, integrate multidisciplinary efforts, and provide a higher degree of flexibility.

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