A Telemedicine Service Platform Exploiting BT/BLE Wearable Sensors for Remote Monitoring of Chronic Patients

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***Abstract*— This paper presents a telemedicine hardware/software platform for data acquisition, communication, processing, presentation and storage, aimed to remotely monitor lifestyle, vital signs and in general the clinical status of patients affected by chronic diseases. Such platform is useful to support an innovative ICT-based application of the Chronic Care Model (CCM). The platform exploits wearable sensors, a BT/BLE connectivity to the local gateway and then a connection, using standard formats and cyber-secure protocols, to a server-based application and repository. The platform allows clinicians and practitioners to realize aggravations and act promptly, before they become irreversible and lead to hospitalization. The system also implements data analysis, by processing multiple parameters in parallel. As well as monitoring the state of health, the proposed telemedicine platform can be also used to monitor the emotional and psychological state of the patient.**

Keywords: Telemonitoring, Telemedicine service platform, Wearable sensors, Bluetooth (BT), Bluetooth Low Energy (BLE)

I. INTRODUCTION

The advances of wearable sensors and mobile devices development, along with the diffusion of short-range wireless technologies such as Bluetooth (BT) and Bluetooth Low Energy (BLE), and the mobile Internet connectivity, provide the possibility to implement new solutions for the management and the remote monitoring of chronic patients, according to the Chronic Care Model (CCM) [1]. This model is based on personalized care planning, on the presence of a multi-disciplinary care team (general practitioner, medical specialist, nurses, etc.), on the patient self-management of care, on the exploitation of domiciliary assistance and periodic visits. The latter are usually performed by professional caregivers. The CCM approach is based on the sharing of clinical information to support the decision making [2]. It is acknowledged in literature that the CCM improves the management of chronic conditions and reduces the healthcare costs [3].

The enabling technology for an effective implementation of CCM is a hardware/software telemedicine system that collects all patient's biometric parameters and signals through wearable sensors, and provides all relevant data to medical personnel in order to improve the decision process with clinical evidences. In addition to monitor the health status of chronic patients, the same system can be also used to monitor the mood and the psychological status of the patient. The provisioning of a telemedicine service that meets the CCM model requires a scalable platform for the secure circulation of clinical data among all personnel involved in the patients' care, including the patient himself/herself.

While lot of work has been done in literature with reference to wearable sensors [4]-[13] (already commercially available as COTS devices), the development of the telemedicine platforms and effective services for the remote monitoring of chronic patients is still an open issue.

To solve the above issue, this paper presents a hardware/software platform for data acquisition, communication, processing, treatment and storage, aimed to remotely monitor lifestyle, vital signs and in general the clinical status of patients affected by chronic diseases. Hereafter, Section II presents the architecture of the hardware/software platform. Section III deals with wearable sensors and the proposed monitoring kit. Section IV presents the development of the server application and repository. Conclusions are drawn in Section V.

II. HARDWARE/SOFTWARE PLATFORM

The proposed platform is composed by several monitoring kits distributed on the territory and a centralized software application with storage capabilities. Its overall architecture is shown in Fig. 1.

The monitoring kit is organized as a sensors network. It includes a set of BT/BLE wearable sensors and an Android

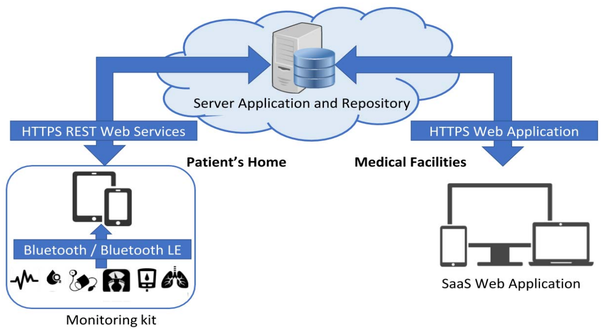

Fig. 1: Architecture of the hardware/software platform

device (i.e. tablet or smartphone) [14], [15] called gateway [16], hosting a dedicated software application in charge of managing acquisition, local storage and transmission of physiological data and lifestyle parameters.

The server application and repository part of the system represents the central node of the platform. It provides the resources for the communication, elaboration, configuration, presentation and long-term storage of clinical data, generated alarms and personalized care plan. The server application exposes some REST (REpresentational State Transfer) web services that allow the gateways to upload acquired data and to receive configuration updates remotely. Additionally, it runs algorithms for data analysis and alarm situations detection and it offers a multi-access multi-profile web application according to the Software as a Service (SaaS) paradigm. Such an application enables medical staff to visualize and manage all data concerning the patient's care (e.g. vital signs, parameters, plans, generated alarms, etc.). The repository, implemented via a relational database, handles the persistence of the patients' electronic health records (EHR). It contains all data acquired through the monitoring kits and generated by the platform algorithms during the monitoring period.

Both the web services and the web application use HTTPS protocol and basic authentication to enforce confidentiality, authenticity and integrity of the communications flows.

III. Monitoring Kit and Wearable Sensors

The monitoring kit is the part of the telemedicine system that allows the acquisition of vital signs and parameters at patient's home. It also transmits collected data in secure way, making them remotely available for medical personnel using the server SaaS application. It is composed of commercial BT/BLE sensors and a gateway device that contains all the computation and communication resources. The gateway also provides an helpful user interface to guide the user to follow the activities defined in the personalized care plan.

The set of supported sensors comprises several non-invasive wearable medical-qualified devices for the measurement of the main vital signs (i.e. ECG, blood pressure, oxygen saturation, pulmonary capacity, weight, glycemia, heart rate) and some lifestyle parameters (i.e. calories intake and consumption, steps and activities tracking). The setup of sensors group is selected

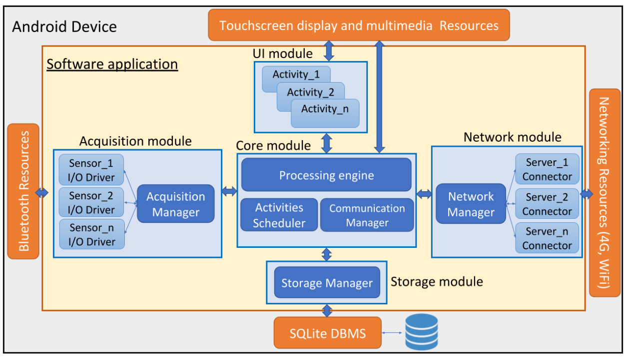

Fig. 2: Architecture of the gateway software application

according to the kind and severity of the disease and may change during the monitoring time.

The gateway is the central node of the sensor network. Its primary task is to coordinate the phases of acquisition, elaboration, local storage and secure transmission of data coming from the configured biomedical sensors. Additionally, it provides a smart user interface developed in order to minimize and simplify the interactions with the system and to help the user to carry out the planned activities: measurements, messages, questionnaires, drugs, etc.

The architecture of the gateway software application is shown in Fig. 2. In particular:

- the acquisition module handles the I/O operations via sensors-specific drivers activated on-demand by a manager;
- the storage module manages the persistence of all collected data into a local database;
- the network module manages the bidirectional communication with the server application (i.e. upload of data and download of configurations);
- the user interface module manages the application front-end (e.g. screens, audio-visual feedbacks, user interactions, etc.);
- the core module is responsible of the activities scheduling, the data processing and the coordination of all the application tasks.

Two kinds of monitoring kit have been developed. The first is dedicated to patient self-acquisition and is usually delivered directly to the patient when enrolled in the telemedicine service. The second is designed to support medical operators during the planned periodic home visits. They differ in the version of the gateway and usually in the set of sensors included in the kit depending on the target user of the system.

The patient-oriented gateway (see Fig. 3a) is conceived to maximize the usability and to minimize the impact on the patient. It enables the patient to follow autonomously the personalized treatment plan, defined and updatable by the care team members via the server application, thanks to audio-visual reminder messages and helpers. The data acquisition, elaboration and transmission are completely automatic and transparent. Moreover, the gateway is able to collect out-of-plan activities performed on a personal basis.

The professional-oriented gateway (see Fig. 3b) supports assistance operators and simplifies their work during routinely domiciliary visits of chronic patients. It allows the management of the large list of patients (e.g. 50 or more), specifying for each of them the personalized plan of activities to be performed. This gateway extends the functionality of the previous version including more sophisticated data viewers and interaction modes suitable for the professional user (e.g. signals and trendlines viewers, manual recording of measures, etc.).

The two types of gateway rely on different software applications. They have the same software architecture and mainly differ for the implementation of the user interface module. Both versions have been implemented with the native Android SDK and are compatible with mobile devices with operating system version ≥ 4.3. They require minimal processing power, 1 GB RAM, dual-mode Bluetooth chipset, network connectivity (i.e. Wi-Fi and mobile broadband) and at least 4 GB of storage memory.

IV. Server Application and Repository

The server application and the repository represent the central elements of the telemedicine platform. In particular, the server software application is in charge of:

- managing the bidirectional communication with the gateways to receive collected data and send care plans;
- providing different versions of the web-based graphical user interface to manage the monitoring of the patients;
- elaborating and analyzing incoming data to detect potentially dangerous situations for the patient;
- synchronizing the data with the electronic health record and other third party information systems;
- interfacing with the repository to store and retrieve data.

The repository provides long-term storage of data received from the gateways and generated by the analysis algorithms.

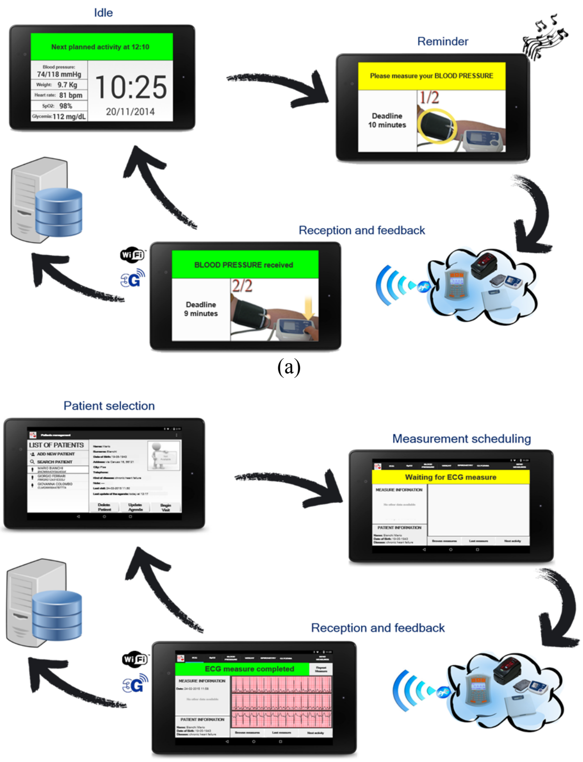

Fig. 3: Example of acquisition with patient-oriented (a) and professional-oriented (b) gateway

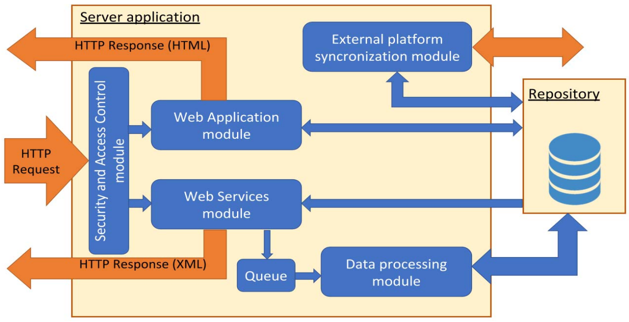

Fig. 4: Architecture of the server application and repository

The architecture of the server application and the repository is shown in Fig. 4. It consists of five main software modules and a relational database implemented with MySQL DBMS.

The security and access control module receives the HTTP requests from the clients and manages the authentication according to the basic strategy (i.e. username and password). Moreover, it restricts the access to the resources basing on the role of the logged user (i.e. general practitioner, medical specialist, nursing operator and patient).

The web application module provides the user interfaces that allow all medical staff involved in the patients' care (i.e. care team members) to manage all the phases of telemedicine service provision. It enables the enrollment and classification of new patients, the definition and updating of the treatment plan for each patient, the establishment of personalized vital signs analysis profiles, the visualization and interaction with current and past measurements of vital signs and lifestyle parameters, etc. Moreover, it permits to manage alarms or critical situations. This web application is available via a common Web browser according to the SaaS cloud paradigm.

The web services module exposes a series of endpoints (i.e. URL) that allow the gateway to exchange contents with the server application according to the request-response HTTP protocol. Operations that requires data writing into the repository (e.g. upload of data collected by the gateway, etc.) are buffered through a FIFO queue and served asynchronously by the data processing module. Instead, query requests for data are immediately served (e.g. download of patient care plan, daily activities, summary information, etc.).

The data processing module is in charge of elaborating the incoming data, extracted from the queue, in order to store them into the repository. Additionally, it uses specific algorithms and patients' personalized analysis profiles to find critical situations or dangerous alterations of vital signs and to generate alarms.

The synchronization module allows the integration of the platform with third-party applications, such as hospital information systems or other repositories, in order to import/export data. It uses standard HL7 CDA format [17].

The server application has been developed with Java Enterprise Edition (JEE) and the Spring Framework. The web application modules uses HTML5, CSS and Javascript for the pages, while the web services module uses a custom XML

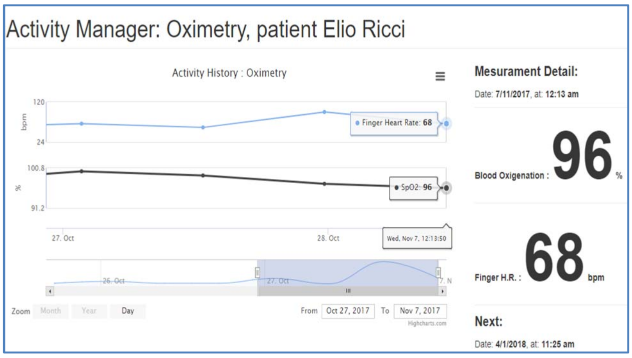

Fig. 5: Example of the web application: pulse-oximetry activities results

schema for the request-response messages. Both have a three-tiers structure: control, service and data access.

As an example, Fig. 5 shows a page of the web application. Specifically, this page enables a member of the patients' care team to monitor a specific activity assigned to a patient. The chart trendlines show the activity results history, with the possibility zoom-in, zoom-out and select a specific period of interest. For each point of the chart it is possible to obtain detailed information (i.e. acquisition date, values and connected alarms if present) Moreover, the page provides information on the future planning of the activities.

V. Conclusions and Future Works

The paper has presented a telemedicine service platform which allows an effective application of the Chronic Care Model (CCM). Indeed, at the state-of-the-art the CCM is not often implemented through a fully integrated ICT-based information system, with a seamless digital data flow from the sensors worn by the patient to the desktop of the remote caregiver. The platform exploits monitoring kits that includes wearable sensors with BT/BLE connectivity to the local gateway and a connection, using XML and standard HL7 CDA formats, to a server based data processing and repository. The monitoring kit is available both in patient-oriented and professional-oriented versions. The server SaaS application allows the care team members to manage the enrolled patients and to monitor at distance their vital parameters according to personalized care plans. The aim is continuously supporting the medical staff with updated data, thus moving from a medicine of emergency to a proactive healthcare model. The system generates alarms on vital signs thresholds violations and multi parameters analysis, enabling the medical staff to realize diseases aggravations before they become irreversible and lead to hospitalization. In this way it is possible to reduce the rate of hospitalization, and hence the cost for the health system. Outside the hospital, the quality of life of the patient will be improved as well as the mortality rate decrease. Moreover, the platform is ready to integrate specific algorithms for risk and danger situation prediction using AI techniques. As well as monitoring the state of health, the telemedicine platform can be also used to monitor the emotional and psychological state of the patient. Further clinical tests are on-going in collaboration with general practitioners and medical specialists involving 100 patients.

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