MyHealth: a cross-domain platform for healthcare

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ABSTRACT

Health monitoring is changing the way people feel and care about their physical condition in an era where electronic devices and sensors can follow us in a continuous basis. This surveillance process is mainly related to very specific conditions or vital signs, being the collected information stored for later data processing. This paper presents the work undertaken under the central system of the MyHealth project, dedicated to the collection and analysis of information on physiological and hemostatic processes ensuring a source of integrated, flexible and shareable clinical information used to support the decision making process. The proposed system is able to collect and fuse data from different medical specialties, in different formats and with different data collection rates. The development of this work is based on advanced knowledge in the medical field, biomedical engineering, computing and telecommunications, thus benefitting from an interdisciplinary approach that is able to provide added value services and decision support information to the healthcare professionals.

Categories and Subject Descriptors

H.4.2 [**Information Systems**]: Information Systems Applications – Types of Systems – Decision Support.

General Terms

Algorithms, Design, Management, Measurement.

Keywords

Health monitoring; clinical data; data communications; data integration; data analysis

1. INTRODUCTION

Health monitoring is changing the way people feel and care about their physical condition in an era where electronic devices and sensors can follow us in a continuous basis. This surveillance process is mainly related to very specific conditions or vital signs, being the collected information stored in cloud-based databases for later data processing.

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Mobile devices like smartphones are increasingly being used in this context to forward data collected by wearable sensors, or to feed the healthcare surveillance system with information that cannot be automatically collected. After a data consolidation process, particular applications can provide access to the collected data providing specific insights or data analysis capabilities.

The way these data are integrated and analyzed, and the diversity and extension of the collected data, influence the output that can be provided to the users, being those healthcare professionals or patients. As shown in the related work section, although a variety of approaches and systems have been proposed in recent years, it was not possible to find a system with enhanced capabilities to collect data from different medical specialties, in different formats and with different data collection rates, and be able to integrate this variety of types and data formats and provide an added-value view over the collected data, being the provided information a valuable instrument for those that need to take informed decisions.

This paper presents the design and implementation of a healthcare surveillance system developed under the MyHealth project included in the Development and Operation of Translational Research program that created a modular multimodal platform for collecting healthcare information about individuals and, based on this information, characterize the phenotype of an individual in order to develop customized and individualized treatment plans.

The collection of data integrates several sources, automatically and manually, that are included in seven modules that integrate the MyHealth project, each one addressing a specific healthcare or medical domain. These modules, described in more detail later on, are named MyBrain, MySignals, MyHair, MyEndoscopy, MyEnergy, MyBiomarkers and MyLab. A transversal module, the central system, complements these specific modules, and constitutes the main focus of this paper. This central system is responsible for collecting, integrating, storing, analyzing and distributing all the data manipulated in the MyHealth project. As several sensors, mobile devices, communications channels and applications are used in the project, several challenges need to be addressed in order to fully integrate the several components of this system.

The MyHealth project aims at collecting and analyzing information on physiological and hemostatic processes ensuring a source of integrated, flexible and shareable clinical information. Through individual clinical information obtained from multiple sources and means, individualized and more efficient clinical plans can be developed. Moreover, the project is based on advanced knowledge in the medical field, biomedical engineering, computing and telecommunications, thus benefitting from an interdisciplinary development approach that is able to provide added value services and decision support information to the healthcare professionals. To be able to collect and integrate data from a wide range of sensors and medical equipment, communication services, databases, data services and processing applications were developed and integrated into a comprehensive platform for healthcare surveillance.

Another important foundation of this system is its ability to collect clinical information in multiple contexts and environments, including outside the premises of the healthcare provider units such as outdoors and in-house.

This paper is organized as follows. Section 2 summarizes related work, describing some of the existing systems and their main characteristics. Section 3 gives an overview of the overall project and presents the central system architecture and its main components. Section 4 introduces the communications mechanisms adopted in the MyHealth platform, while Section 5 presents the database that integrates the collected data and the main functionalities for data management, also describing the data analysis and the visualization functionalities of the platform. Section 6 concludes with some remarks and guidelines for future work.

2. RELATED WORK

Several systems have been proposed to address the collection and analysis of healthcare data. Although most of these systems address the same concerns and deal most of the times with similar technologies, they diverge on their scope, characteristics and architecture. This section presents some of these systems identifying their main functionalities and limitations.

A platform for the analysis of electronic health record data has been proposed in [1], and is available as an open source healthcare analytics environment, in which an Analytical Information Warehouse (AIW) supports decision support in hospital readmissions. The results obtained from the analysis of the available data allowed the reduction of hospital readmissions. This system, named PROTEMPA [1], supports data retrieval and phenotype detection, extracting information from different sources such as electronic health records (EHR). Although the proposed system allowed a reduction on the number of hospital readmissions, the source of information is mostly composed of the conditions that were billed. Moreover, the information is only made available after the patient's discharge, making it impossible to consider the patient condition during his/her stay in the hospital and, as consequence, to use this information for decision support during the current hospital stay. In the MyHealth platform all the received information is processed in real time enabling the initiation of specific actions, like triggering alerts, when specific values (abnormal or not) are verified.

The HealthNet project, with a System for Mobile and Wearable Health Information Management [2], implemented a prototype that is able to collect data from different sensors embedded in a textile platform. In a sports context, the system collects data about the heart condition (ECG), temperature, humidity and acceleration (movement). An application for smartphones also allows the identification of the user's GPS position to be included in the collected data. With this system, it was possible to exchange data between five runners and a trainer. The proposed approach can be extended to the healthcare domain as the authors showed that health-monitoring using mobile wearable sensors is feasible, and that this can be done in real time and with security and privacy issues taken into account. However, some challenges are still to be solved such as those related with the quality of the sensors, and the minimization of false alarms.

Another innovative proposal in health care services is the CAALYX system [3], which aims to increase the confidence and autonomy of elderly people. The system includes the capability to monitor individuals in roaming and at home, information that is then available to caretakers and relatives. The CAALYX system is divided in four subsystems, namely: i) Caretaker System, the server side; ii) Mobile System; iii) Home system, a personal computer or a TV set top box; and, iv) Wearable Light Device, a small device with several sensors. These subsystems are interconnected and allow the triggering of alerts of probable critical health conditions and remote assistance of elderly people.

As several systems are becoming available, it is important to note that they present limitations associated with the latency between the collection and the availability of data, with the kind of information that is received and treated, and with the services or applications that are provided. In the MyHealth project, data from different medical specialties, in different formats and with different data collection rates are received and processed in such a way that no penalties are added, allowing the collection of huge amounts of data received directly from sensors or mobile devices, or manually introduced by the users. The key point is that different sensors, mobile devices, communication interfaces and the supporting applications interact in a seamless way providing an unified view on data and making available a wide range of added value services and decision support information to the healthcare professionals.

Moreover, in a context where huge amounts of data are collected, in a variety of formats and often requiring real-time processing, several challenges are identified in the era of big data in the healthcare domain. The following paragraphs discuss some of these challenges in this area as the MyHealth platform address, already, some of them.

The collection and storage of huge amounts of data require the development of appropriate tools to analyze these data. The work described in [4] discusses the promise and potential of big data analytics in healthcare. The authors analyze how the growing field of big data analytics is being applied in the healthcare industry by discussing the benefits, methodologies and examples available in the literature, and pointing some challenges and drawbacks. On the advantages side, big data analytics in healthcare can help detecting diseases at earlier stages when they can be treated more easily and effectively, with potential reductions in overall costs on the healthcare public and private systems. While there are many benefits, the authors found several challenges and drawbacks. Most data are available in an unstructured format and comes from heterogeneous data sources. Many of the tools are open-source and free of charge, which means the lack of technical support and, in some cases, minimal security. Also, the needed technological platforms and tools require programming skills that a typical healthcare end-user may not possess. Real-time big data analytics is a key requirement in healthcare, so the lag between data collection and processing has to be addressed. Also governance issues including ownership, privacy, security, and standards have yet to be addressed. Nonetheless, the authors conclude that the potential is huge. Big data analytics in healthcare is evolving into a promising field for providing insight from very large data sets and improving outcomes while reducing costs. It is expected to see a fast, widespread implementation and use of big data analytics across the healthcare organizations and the healthcare industry. Big data analytics and applications in healthcare are in an early stage of development but evolution of platforms and tools can accelerate their maturing process.

3. SYSTEM ARCHITECTURE

The MyHealth platform aims at addressing some of the limitations aforementioned. It ambitions to constitute a platform for real time healthcare surveillance, enabling a new generation of healthcare services addressing both medical professionals and individuals concerned with their own well being. These services support the follow up of patients and the monitoring of general physiological and hemostatic signs.

The MyHealth platform relies on advanced knowledge resulting from an interdisciplinary approach that combines specialist from several fields including medicine, biomedical engineering, computing, information systems and telecommunications.

In its current configuration, the MyHealth platform includes seven modules related with the collection of information from different sources, namely:

1. MyBrain: A module for the characterization of the brain structure and operation, in a longitudinal perspective. It consists of a set of electrodes embedded into a beanie for performing electroencephalograms. This device can be used in a domestic, medical or urban environment, facilitating user mobility and enabling observation over very long time periods and while the patient is living his/her normal life.

2. MyLab: A laboratory on a chip based on spectrophotometric analysis, for the analysis of biological fluids [5]. The collected information is stored in a memory card for later transmission to the central system.

3. MyBiomarkers: Use of integrated techniques for biomarkers detection based in spectroscopic and electrochemical sensors, complementing the information generated by the MyLab module.

4. MyHair: A module for the collection of clinical information and biomarkers monitoring through hair analysis.

5. MyEnergy: A module for recording information about intake and caloric spending (adjusted to each individual), providing feedback according to the nutritional plan previously defined for each individual.

6. MyEndoscopy: A module that integrates a main device constituted by a capsule that capture endoscopic images. This module is responsible for the acquisition, processing, archiving and dissemination of endoscopic examinations [6]. The results are high-definition videos that are analyzed by skilled health professionals.

7. MySignals: A module with a set of sensors embedded in textile clothes for monitoring vital signals and physiological parameters (e.g. fetal ECG).

These seven modules constitute the input subsystem of the MyHealth platform as represented in Figure 1, which features bring up a set of requirements for dealing with the diversity and nature of the collected information; the several information formats; the technologies that support the measurement devices; and, telecommunications protocols to grant operation flexibility.

The information collected through the modules that integrate the input subsystem is gathered, integrated, stored and processed in a chief component of the MyHealth platform: the central subsystem. This subsystem provides to the MyHealth platform the ability to make available a set of healthcare services that include data management (back-office and front-office); emission of alerts; data analysis; and, data reporting.

In a global overview, the architecture of the system that has been designed to deal with the collection and processing of data from multiple sources and using different data formats includes three main subsystems: the input, the intermediate, and the central components (Figure 1).

The input subsystem offers two alternatives for data collection, which include web pages for the manual introduction of information, and communications modules that forward data from wearable sensors, used on the go, to the central server. The clinical sensors have communications capabilities to send the collected data to the central system, namely in situations where the patient is in his/her daily routine in urban environments. To be able to handle this requirement, data collection outside a clinical environment, the system architecture includes various devices that work as communication gateways to the central system. The devices used are mainly smartphones with Android SO, tablets or laptop computers. For the Android gateways, a specific application was developed allowing wireless connection with the sensors (Bluetooth or Wi-Fi). Through this, data can be received, treated and processed, which, afterwards, sends the information, previously compressed and encoded, to the central subsystem over a mobile network (3G or 4G), using the HTTP communication protocol. This approach allows patients mobility. Moreover, the computer-based gateways can use a Python communication API or specific web services to send the collected data to the central subsystem.

The central subsystem includes a web server with a MySQL database designed to store all the data collected in the MyHealth system, which can include automatic readings or manually introduced data. All the collected data is temporally catalogued with one timestamp for the collection time and another for the storage time. Time is a critical requirement in this system, as some health conditions might need to trigger special alarms that must be sent by the central system in a real time basis. Access to the system (using smartphones, tablets, or laptop computers) is always properly checked and authorized as different users have different roles and, as such, different types of access to the

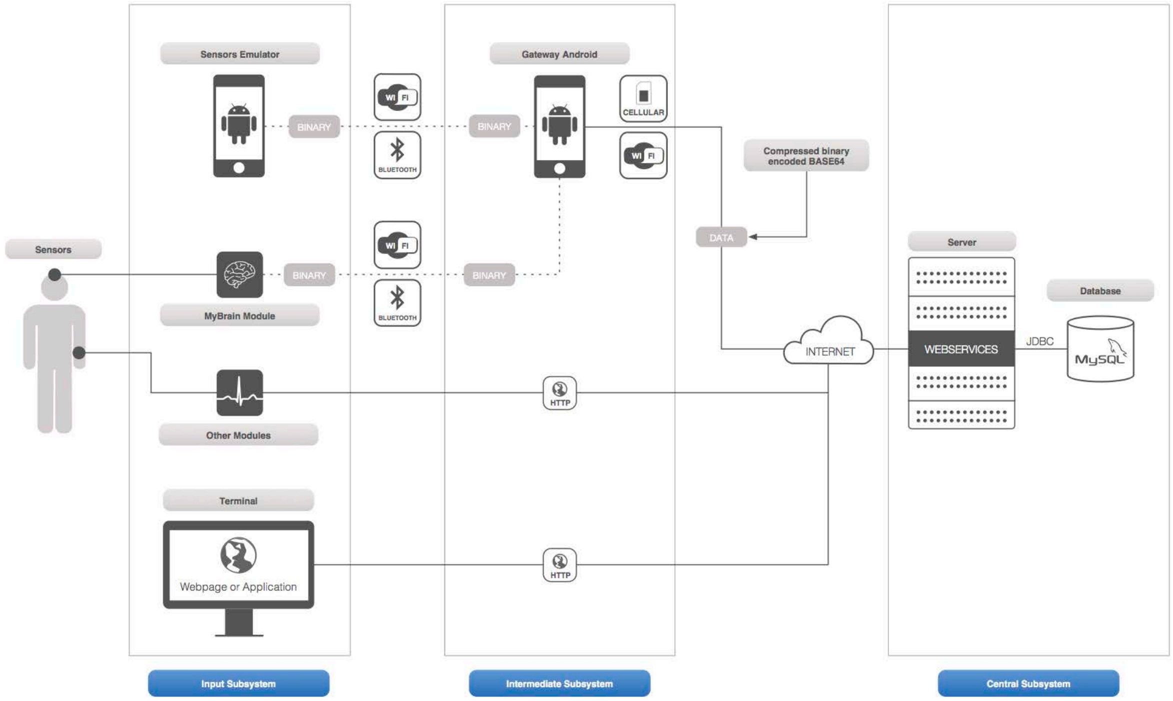

Figure 1. MyHealth platform architecture.

stored information. As security is not only about system accesses, privacy and storage of sensitive data were also addressed (this topic is not further developed in this paper). This subsystem integrates a module of notifications/alerts, integrated in the data repository, which triggers alert messages to specific users (like a patient or a doctor) when specific values are verified.

Being presented the architecture of the MyHealth platform, next sections describe the main components of this architecture, namely data communication and mobile apps, data storage and management, and data analysis and visualization, which implement the functionalities associated to the presented subsystems.

4. DATA COMMUNICATIONS AND MOBILE APPS

The potential of some modules, such as the MyBrain and MySignals modules, can be significantly improved if they can be used in different environments, allowing patients to move around in and across those different environments. Many sensors do not have the necessary communications interfaces to enable this type of functionality. In these cases, smartphones can be used as communications gateways between local sensors and the MyHealth platform. Using a smartphone as a communications gateway allows the acquisition and transmission of the data during the patients' normal routine, even when traveling in urban areas.

In this project, the gateway functionality has been implemented as an Android application. This application is responsible for the connection, authentication, and forwarding of data to the platform, using web services, and supports the communication with sensors via Bluetooth and Wi-Fi technologies. The application includes an interface for the configuration of several parameters, and integrates a set of software-defined components for emulating generic sensors used for testing and validation.

Relying on a smartphone to perform tasks such as compression and transmission of data alleviates the requirements of the wearable sensors in terms of memory and processing power, which are generally quite limited. Therefore it is possible to perform more tasks and perform data acquisition with higher resolution and reduce the delay. The smartphone also provides an excellent interface with the acquisition system and with the user. Using the touch screen it is possible to configure various parameters and to display data related with the acquisition and transmission of sensors' data.

4.1 An Android based Gateway

The Android smartphone gateway, featuring various communication technologies, enables the communication between the sensors and the platform. In an urban environment, for example, Bluetooth technology can be used for communication with the sensor, and the mobile cellular network to send data to the central system.

4.1.1 Bluetooth And Wi-Fi Sensors Support

The developed gateway application supports both Bluetooth and Wi-Fi sensors. When running, the application acts as Bluetooth server, the sensors can connect to the server using the gateway smartphone MAC address or by performing a discover scan. After paired with the smartphone, the module establishes a connection with the Bluetooth service using the gateway service ID. When this process is completed, a RFCOM socket is created for communication between the two parts.

For Wi-Fi connections, the gateway application automatically creates a Wi-Fi Hotspot in the smartphone. The access password for the Hotspot can be configured in the application interface. To establish a connection, the sensors must join the created

Hotspot, using the authentication password and connecting to the service using the IP and Port defined in the application.

Wi-Fi-based communications consume more energy than Bluetooth-based communications (Bluetooth 4.0), both on the smartphone and on the sensor modules. Additionally, providing the Wi-Fi Hotspot implies a very high additional consumption. Moreover, establishing a connection via Bluetooth is faster and automatic after the first pairing, with lost connections having less impact on data transmission. The Wi-Fi connection establishment process is always the same and more time consuming, since the hotspot has to be always created. The recovery of a lost connection is therefore more time consuming, having a greater impact on data transmission.

4.1.2 XMPP protocol and Webservices Communication Support

For sending the data, the Android gateway application can use XMPP (Extensible Messaging and Presence Protocol) used in real time communications, for example, in chat services, or specific created web services.

The XMPP protocol can be used in situations where the display of data in real time is required. However, the implementation of a XMPP-based solution is far more complex, being necessary to have a XMPP server with authentication, and an application that subscribe to nodes of each patient to access data. In the XMPP protocol, the data is structured in XML messages that need to be processed. The use of XML for the XMPP protocol, also introduces some overhead in data transmission.

The approach based on web services is simpler. The data is POSTed, and can be sent structured in JSON format, introducing less overhead compared to XML, which is important in the transmission of data over the cellular network. However, this solution is not as effective in real time, because it is more difficult to do the rendering of signals from the received data without storing it first on a database, therefore leading to longer delays.

4.2 Environments: Communication Technologies Available

As already mentioned, some modules, like the MyBrain, could collect information both inside and outside the patient's home. These two environments have distinct characteristics and challenges, particularly in what concerns the communications technologies available for communication with the central subsystem. Therefore, the transition between two different environments introduces additional challenges.

The MyBrain module has both Wi-Fi and Bluetooth interfaces, which allows the communication with the smartphone gateway. The smartphone can communicate with the central server using a Wi-Fi access point or using the mobile cellular network. Therefore, it was necessary to evaluate which of the technologies is the best option for module-smartphone and smartphone-server communication in both environments.

In a domestic environment, where a Wi-Fi access point with Internet connection is available, the communication between the MyBrain's module and the smartphone can be established through the home Wi-Fi network, which is also used for communication with the central server. In an urban environment we have to presume that no Wi-Fi access point is available to serve this purposes. Thus, to establish the communication module-smartphone via Wi-Fi the creation of a Wi-Fi hotspot on the smartphone is necessary. When the Wi-Fi interface is being used to create a hotspot, the communication with the central server starts to be made across the mobile cellular network. This transition is fast and automatic, not introducing considerable problems.

The use of Wi-Fi for communication between the module and the smartphone presents a problem in the transition between environments. The loss of connection during the transition process from the home Wi-Fi access point to the smartphones' hotspot can result in data loss.

The use of Bluetooth is also an option for the smartphone-module communication. Once paired, the module and the smartphone automatically establish future Bluetooth connections. The communication between the smartphone and the central server can be established via the local Wi-Fi network. When moving from the home to the urban environment, the smartphone-module Bluetooth connection is maintained, while the communication between the smartphone and the server switches automatically to the mobile cellular network. The use of the Bluetooth communication has a clear advantage in the transition between the domestic and urban environment, since the connection is maintained. The process of creating a Wi-Fi hotspot and the setup of a new connection is not necessary, thus there is no data loss (Figure 2).

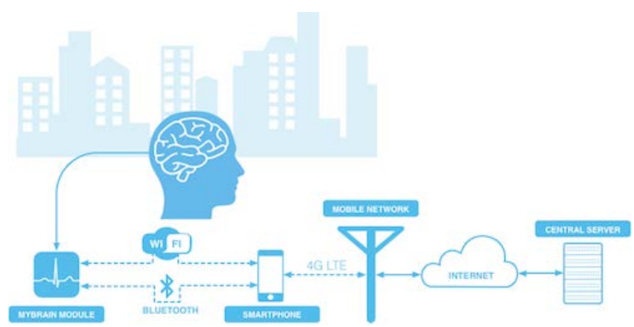

Figure 2. Sensor's data forwarding in urban settings.

5. PROVIDING HEALTHCARE SERVICES

All the information that is collected by the seven modules is stored in a database specifically designed to handle the tasks to be performed by the MyHealth platform. The central subsystem is the module responsible for the integration, storage, processing and analysis of data, which includes the alerts processing functionality. The alerts' processing consists in monitoring specific parameter values, which are here named as readings. When the readings verify a particular condition, alerts are created and sent to the medical or staff team, responsible for monitoring a specific patient. In the central subsystem all the information can be managed through specific web services or using the back office application.

5.1 Database

The central subsystem includes a relational database implemented in MySQL [mysql.com], where data about individuals, healthcare professional, manually introduced data, and automatically collected data, are stored. The database design takes into consideration that future modules might need to be added to the MyHealth platform, thus being possible to collect data from different sources without the need to modify the central database model. For that, specific web services allow the feeding of the system.

This database stores all the collected data and is able to process the incoming data in real-time, thus being able to trigger the appropriate alerts without adding significant penalty in terms of processing time. For multimedia data, like reports or images collected from the MyEndoscopy module, the database stores the path to those documents, which are stored on hard disk to avoid an excessive increase of the database size.

The entity relationship diagram of the implemented database is presented in Figure 3. Next paragraph briefly explains its main entities and associated attributes.

reference value. In affirmative case, the parameter is analyzed according to the information stored in the reference values table. Besides the parameter identification and module, to which the reference value is associated, this table stores the condition that must be satisfied to send alerts/notifications beyond the Java class name responsible for determining the level of emergency.

Once identified the emergency level, the health care professional associated to this level will be notified. It is important to mention that all the alerts are sent to specific destinations, previously identified in the back-office application. The alert message contains the patient information, the parameter with abnormal value and the timestamps of the parameter value reception and the alert sent. A sample message is shown in Figure 4. As we can see in the figure, the alert is sent in the same second of the collection.

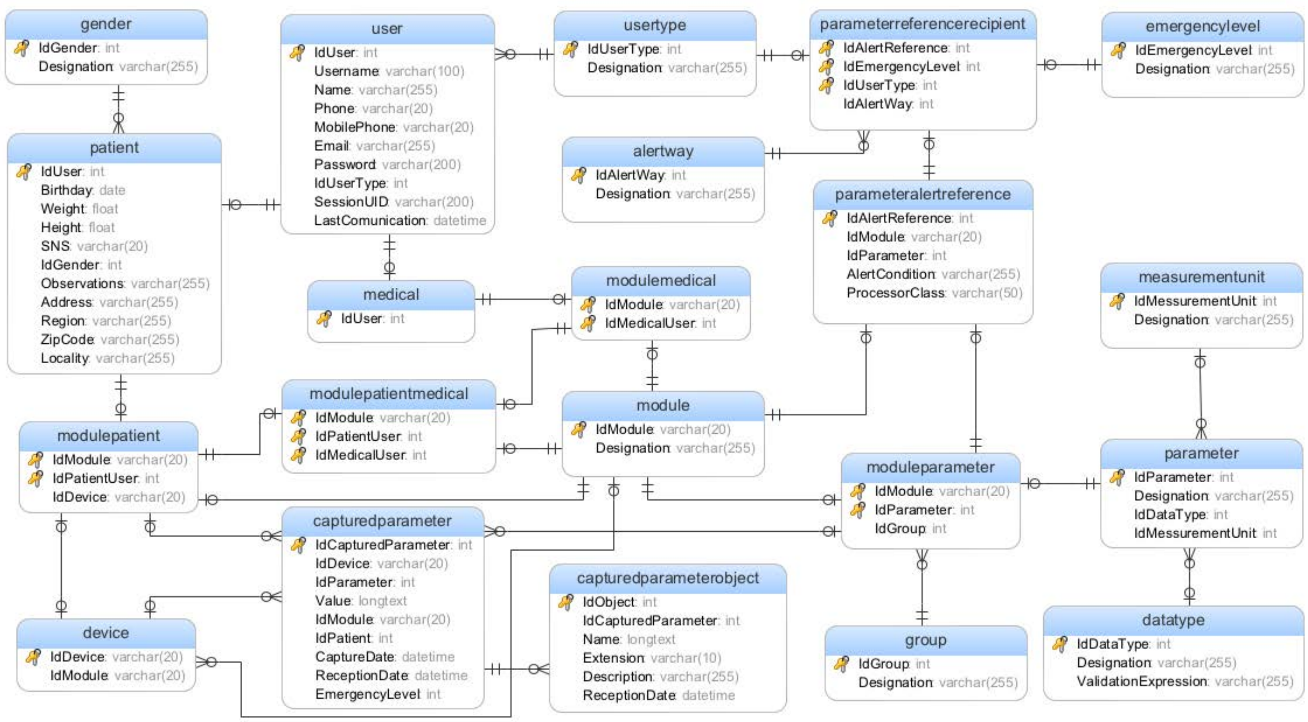

Figure 3. Database structure.

The system has as users patients and health care professionals like doctors, nurses or technical staff. Each patient is characterized by some personal information like gender or birth date. Each module includes the collection of a set of parameters, for example heart rate in the MySignals module. For each parameter, a data type and a unit of measure are specified. Moreover, each parameter may have associated reference values that are used to test and trigger alerts. A specific reading is associated to a module and is tested against the reference values of that module, in order to trigger alerts that can have different levels of emergency depending of the target destination as several health professionals can be notified through an alert message, sent through SMS or email, with different emergency levels.

5.2 Alert processing

Whenever readings are received, the collected values are tested verifying if the corresponding parameter has an associated

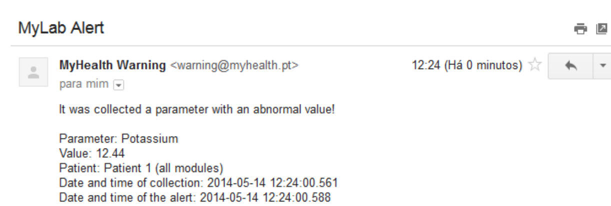

Figure 4. Sample of alert message.

5.3 Back-Office

To ensure data consistency, and since each module can have its own subsystems, all accesses to the database are constrained to the use of the web services specifically designed and implemented for this purpose. Web services for inserting data and reading data, for example, are available. All the modules can manage their specific data using the back-office web application (Figure 5), which is implemented through the integration and interaction of a set of web services. The back-office application is implemented in Dojo and with the JavaScript Toolkit [dojotoolkit.org]. In order to speed up the implementation of web services providing several operations on data, the implemented platform integrates the Restlet [restlet.com] framework, facilitating the development of web services for managing and querying data.

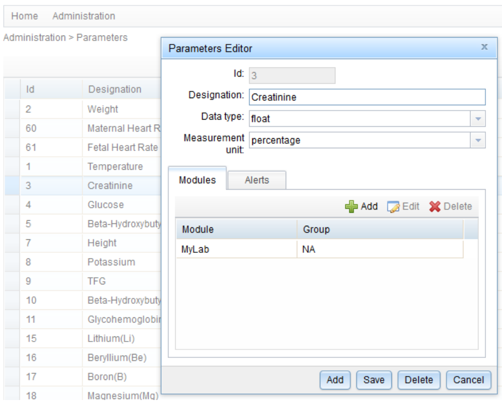

Figure 5. Back-office web application.

5.4 Front-Office

Besides the back-office web application, there is a front-office application for querying and analyzing data. This web application, which provides several views on the available information by integrating the data sent from the different modules, allows the electronic monitoring of patients and will allow the identification of patterns and specific conditions, which can prevent the onset of diseases or health complications. At this moment, the front-office application is under development, but already provides the integration of information collected by the several modules and the integrated analysis for a specific patient. The front-office application (Figure 6) is being implemented using the same technology as the back office application.

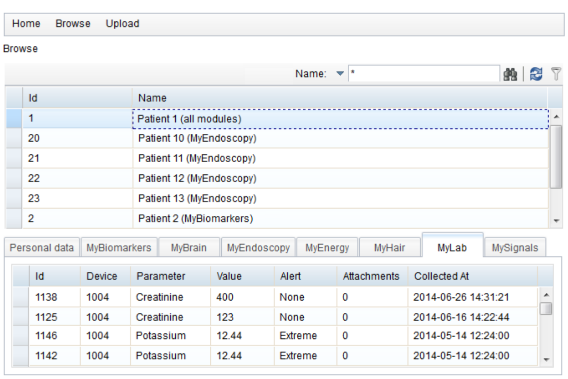

Figure 6. Front-office web application.

6. CONCLUSIONS

This paper presented the design and implementation of a healthcare surveillance system developed under the MyHealth project, proposing a modular multimodal platform for collecting healthcare information about individuals. Health monitoring is changing the way people feel and care about their physical condition. In the MyHealth project, mobile devices are used to forward data collected by wearable sensors or to feed the healthcare surveillance system with information that cannot be automatically collected. After a data integration and consolidation process, particular applications provide access to the collected data providing specific insights or data analysis capabilities. At this moment the communication and processing capabilities are fully implemented, and the central subsystem is able to integrate and made available a wide range of clinical data. Future data collection modules can be integrated without any penalty, as the implemented web services and applications provide such capability.

Future work includes the enhancement of the data analysis and visualization capabilities, which are essential components in providing to healthcare professional a holistic perspective of the patients' clinical condition.

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