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Research Article

CardioSmart365: Artificial Intelligence in the Service of Cardiologic Patients

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Artificial intelligence has significantly contributed in the evolution of medical informatics and biomedicine, providing a variety of tools available to be exploited, from rule-based expert systems and fuzzy logic to neural networks and genetic algorithms. Moreover, familiarizing people with smartphones and the constantly growing use of medical-related mobile applications enables complete and systematic monitoring of a series of chronic diseases both by health professionals and patients. In this work, we propose an integrated system for monitoring and early notification for patients suffering from heart diseases. CardioSmart365 consists of web applications, smartphone native applications, decision support systems, and web services that allow interaction and communication among end users: cardiologists, patients, and general doctors. The key features of the proposed solution are (a) recording and management of patients' measurements of vital signs performed at home on regular basis (blood pressure, blood glucose, oxygen saturation, weight, and height), (b) management of patients' EMRs, (c) cardiologic patient modules for the most common heart diseases, (d) decision support systems based on fuzzy logic, (e) integrated message management module for optimal communication between end users and instant notifications, and (f) interconnection to Microsoft HealthVault platform. CardioSmart365 contributes to the effort for optimal patient monitoring at home and early response in cases of emergency.

1. Introduction

Internet has broaden the scope of medical information systems and led to the development of distributed and interoperable information sources and services. In the same time, the need for standards became crucial. Federated medical libraries, biomedical knowledge bases, and global healthcare systems offer a rich information sink and facilitate mobility of patients and practitioners [1].

Medical information systems (MISs) may include medical imaging storage and transmission systems, nursing information systems, laboratory information systems, and pharmacy information systems. To treat patients, medical personnel can use different information systems in accordance with their needs, in order to diagnose and run tests, like blood tests, urine sampling, computed tomography scans, X-ray [2], and so on. A medical information system produces all kinds of medical information in various formats, including texts, numbers, pictures, and static and dynamic images. This heterogeneous information can then be integrated without the need of medical personnel. According to a patient ID, name, or other basic data, the information can be indexed by, for medical use upon request [3].

Additionally, the spectacular penetration of mobile phones in the technological arena and their transformation into smartphones have introduced a new field of software applications' development. Smartphones have been employed widely in health care practice [4]. The level of their use is expected to increase, especially if they are enriched with doctor suitable functions and software applications. The lack of such applications is noticed even in countries with leadership role in mobile technologies, as it is mentioned in [5]. The impact of mobile-handheld technology on hospital physicians' work practices, and patient care is systematically reviewed in [6], where the authors recommend future research about the impact of the mobility devices on work practices and outcomes.

An example which successfully combines MISs with the advantages and capabilities of Smartphones, in Orthopedics, is the integrated system that was developed for recording, monitoring, and studying patients with open tibia fractures [7]. The authors participated in the development of the system, which is based on web and mobile applications. Primary goal was the creation of a system that contains most of the scientifically validated data elements, reducing in this way omission and improving consistency, by standardizing the reporting language among medical doctors. The system's web and mobile interfaces are designed to require almost no text entry and editing and are based on the traditional medical way of acting, thus making it a doctor friendly system.

Artificial intelligence (AI) has significantly contributed in the evolution of medical informatics and biomedicine since it provides a variety of tools available to be exploited, from rule-based expert systems and fuzzy logic to neural networks and genetic algorithms. The earliest work in medical AI dates back to the early 1970s, when the field of AI was about 15 years old. Since then, there is a growing interest in the application of AI techniques in biomedical engineering and informatics, ranging from knowledge-based reasoning for disease classification to learning and discovering novel biomedical knowledge for disease treatment, indicative of the maturity and influence that have been achieved to date [8]. In [9], the integration of AI techniques in biomedical engineering and informatics is presented, especially in the following core topics: (a) feature selection, (b) visualization, (c) classification, (d) data warehousing and data mining, and (e) analysis of biological networks. In literature, a great number of research projects reflect the integration of AI in medicine, from the use of fuzzy expert systems [10, 11] and design patterns [12], to neural networks [4, 13] and decision support systems (DSSs) [14, 15].

This paper presents an integrated system (CardioSmart365) based on web applications, web services, and smartphone applications for lifelong cardiologic patient monitoring, early detection of emergency, and optimal process management of the emergency incident. Cardiologic patient modules with DSSs based in fuzzy logic are developed for the most common heart diseases. The system allows interaction and communication between cardiologic patients, cardiologists, general practitioners, hospitals, and outHospitals health sectors. Everyday clinical practice, medical doctors, cardiologic patients, research and science, and healthcare systems benefit from the proposed system.

The rest of the paper is organized as follows: related work is presented in Section 2 followed by motivation in Section 3. Section 4 presents literature information about the different types of health records, the existing health record providers, and their evaluation. This section can be omitted for expert users. Section 5 presents a thorough description of the implemented system, including its architecture, functionality, components, and software framework. System's added value is discussed in Section 6. Finally, future steps are proposed in Section 7, and the paper concludes in Section 8.

2. Related Work

2.1. Mobile Health Applications. Most health applications in online markets are native applications, patient oriented or medical doctor (MD) oriented. In most cases, the patient-oriented health applications are exploited only by patients, and the information gathered is not available directly to physicians, through a communication channel. Moreover, the MD-oriented health applications serve specific purposes, mostly for educational and quick access to medical literature reasons. On the other hand, frequently, mobile applications that are part of medical research projects, store information, and send it to collaborative servers for additional processing and disposal to physicians.

The use of individual mobile health applications, developed to serve specific purposes, is widely spread. The need for such applications is apparent in every major online market for mobile applications including Android Market, Apple Store, and Samsung Apps. Applications developed for cardiology record blood pressure and cardiac pulses, applications for diabetes record blood glucose [16], and for obesity, they record calories and diet [17], for dementia they use GPS to monitor the patient [18, 19], and applications for chronic diseases target mobile phones with sensors and detect tachycardia or respiratory infections [20].

2.2. Medical Applications for Cardiology. Many mobile applications for cardiology have been developed in order to enhance medical doctors' and medical students' research experience [21–23] such as (a) applications that present a 3D prototype of a human heart and allow users to observe the heart from any angle, (b) calculators with commonly used formulas in cardiovascular medicine, (c) electrocardiography (ECG) guides with samples of different types of ECG, (d) guideline tools for clinical practice and diagnosis, and (e) decision support tools including several criteria and cases. All the above applications are addressed to medical staff, mainly for educational reasons and quick access to literature data, useful for medical doctors. In addition, they are not suitable for cardiologic patients.

A web environment for monitoring cardiologic patients is Heart360 Cardiovascular Wellness Center [24], sponsored by the American Heart Association and American Stroke Association. Heart360 allows patients to monitor their blood pressure, blood glucose, cholesterol, weight, nutrition, and physical activity, while receiving education and information specific to their condition. Heart360 utilizes Microsoft HealthVault [25]. More specifically, patients are able to (a) collect and record their blood pressure, blood glucose, cholesterol, weight, nutrition, and physical activity habits, (b) set goals and track their progress, (c) view their data in charts and graphs that they can print out and share with others involved in their family health, (d) manage multiple user accounts, and (e) get news and articles of potential interest based on their store of health information. This application is patient oriented and does not offer any substantial help to cardiologists or general practitioners.

2.3. Artificial Intelligence in Cardiology. Recently, AI, out of invasive and noninvasive diagnostic tools, becomes the promising method in the diagnosis of heart diseases. In [4], a comparison is presented of multilayered perceptron neural network (MLPNN) and support vector machine (SVM) on determination of coronary artery disease (CAD) existence upon exercise stress testing (EST) data. In [13] neural networks are used as the most suitable solution to outcome prediction tasks in postoperative cardiac patients. An AI-based Computer Aided Diagnosis system is designed in [26] to assist the clinical decision of nonspecialist staff in the analysis of heart failure patients. The system computes the patient's pathological condition and highlights possible aggravations, using four AI-based techniques: a Neural Network, a support vector machine, a decision tree and a fuzzy expert system whose rules are produced by a Genetic Algorithm. Neural networks achieved the best performance with an accuracy of 86%. Another application domain for AI is nuclear cardiology imaging, since the automatic interpretation of nuclear cardiology studies is a complex and difficult task, and a variety of expert systems, neural networks, and case-based reasoning approaches have been attempted in this area [27].

3. Motivation

Although healthcare systems have strongly benefited from the incorporation of new technologies, there is a serious lack of incorporation in the field of clinical medicine. Clinical medicine is involved with patients and their treatment, where medical doctors (MDs) are responsible for the patients' progress.

The direct implication of humans, in particular patients, presupposes that the new technologies incorporated have to be safe, reliable and to offer proven solutions. In addition, MDs are not familiar with new sophisticated applications that change their traditional way of working, justifying in this way the skepticism that MDs present in the incorporation of new technologies.

CardioSmart365 is motivated from the need to proceed in using the advantages of new technologies in the field of clinical medicine. Cardiology is a first-line emergency medical specialty that apart from the emergency incident has to deal with a variety of chronic diseases. Therefore, if CardioSmart365 is proved to be an effective tool in the hands of Cardiologists, general practitioners (GPs), and cardiology patients (CPs), then the same methodology can be used for the development of respective systems for every other medical specialty.

Moreover, to the best of the authors' knowledge, till now there is no any system available that incorporates the following characteristics: (a) to be both patient and medical doctor oriented, (b) to incorporate AI modules, (c) to provide access to end users through multiple channels (web, mobile), (d) to utilize existing and state-of-the-art medical platforms, such as Microsoft Health Vault, and (e) to be easily expandable and deployable. Thus, the detected deficiencies and the willingness to offer enhanced services to patients and medical doctors motivated us to develop a system that incorporates these characteristics into an integrated functionality.

CardioSmart365 is part of collaboration between the Computer Engineering and Informatics Department and School of Medicine of the University of Patras and the General Hospital of Patras "Ag. Andreas" and is currently in testing phase with the following involved parties: (a) nonhospital and hospital cardiologists, (b) nonhospital and hospital general practitioners and (c) cardiologic patients. CardioSmart365 will soon be publicly available at http://www.biodata.gr/cardiosmart365/.

4. Health Records

4.1. Introduction. A personal health record (PHR) is a health record where health data and information related to the care of a patient is maintained by the patient [28]. This stands in contrast with the more widely used electronic medical record (EMR) and electronic health record (EHR) which are operated by institutions (such as hospitals) and contain data entered by clinicians or billing data to support insurance claims. The NAHIT report defines the following [29].

Electronic Medical Record (EMR). An electronic record of health-related information on an individual that can be created, gathered, managed, and consulted by authorized clinicians and staff within one health care organization.

Electronic Health Record (EHR). An electronic record of health-related information on an individual that conforms to nationally recognized interoperability standards and that can be created, managed, and consulted by authorized clinicians and staff across more than one health care organization.

Personal Health Record (PHR). An electronic record of health-related information on an individual that conforms to nationally recognized interoperability standards and that can be drawn from multiple sources while being managed, shared, and controlled by the individual.

In summary, EMRs and EHRs are tools for providers while PHRs are the means to engage individuals in their health and wellbeing.

An EMR or PHR may contain a fairly-wide range of information related directly or indirectly to the health of the user [28], more specifically:

(i) personal information, that is, name, date of birth, and current address,

(ii) names and phone numbers of relatives or people of the owner's friendly environment that can be contacted in case of emergency,

(iii) names, addresses, and telephone numbers of physicians,

(iv) info related to individual health insurance,

(v) current medication (if any) and respective dosages,

(vi) known allergies to foods, drugs, and other substances,

(vii) important events, dates, and hereditary diseases, involving the family history,

(viii) history of the most important diseases encountered by the user in his past,

(ix) results of medical examinations, important medical tests, dental history as well as vaccination history,

(x) recent medical diagnostics: summary of visits to family physician or another specialist,

(xi) information related to physical activity, exercise program, dietary restrictions, and record of medications that do not require a prescription (over the counter - OTC) and/or alternative therapeutic approaches.

PHRs have many potential benefits to patients, caregivers, and institutions [28]. One of the most important PHR benefits is greater patient access to a wide array of credible health information, data, and knowledge. Patients can leverage that access to improve their health and manage their diseases. A critical benefit of PHRs is that they provide an ongoing connection between patient and physician, which changes encounters from episodic to continuous, thus substantially shortening the time to address problems that may arise.

The PHR can benefit clinicians in many ways. First, patients entering data into their health records can elect to submit the data into their clinicians' EHRs. The PHR may also become a conduit for improved sharing of medical records. Finally, asynchronous, PHR-mediated electronic communication between patients and members of their health care teams can free clinicians from the limitations of telephone and face-to-face communication or improve the efficiency of such personal contacts.

4.2. Health Record Providers and Evaluation. In their work, Sunyaev et al. [30] enumerate the existing PHR providers, based on US-oriented and Internet-based PHRs. The two most popular ones are Google Health and Microsoft HealthVault, which are independent products developed by profit-oriented companies or open scientific projects. In [30], these two PHR systems were chosen to be evaluated, due to the relative similarity of their architecture, target markets, and business models. A list of 25 end-user features was elicited, which are necessary for a successful PHR implementation. These features were classified in three categories: patient information, personal control, and additional services. Another work examined and compared the designs of Google Health API and Microsoft HealthVault API [31]. In the evaluation, seven different categories were used: libraries, documentation, authentication, security, data access, data modification, and data messages. The two platforms have advantages and disadvantages and present similarity in some characteristics while they are different in others. However, since Google decided to retire Google Health in January 1, 2012, we can assume that HealthVault will be dominant.

4.3. Microsoft HealthVault. Microsoft HealthVault [25] is a backend cloud-based platform, based on EMR systems, which provides a privacy- and security-enhanced foundation that can be used to store and transfer information between a variety of e-health care customer's applications (desktop, web, and mobile ones), hospital applications, and healthcare devices. It also offers tools to solution providers, device manufacturers, and developers, in order to build innovative new health and wellness management solutions. HealthVault has three major advantages [32]: (a) it presents a low-cost solution in developing and maintaining, (b) it is designed using advanced technology to achieve sustainability, and (c) it offers an easy customization, facilitating programmers to develop customer applications on top of it.

A great number of web and mobile applications that utilize HealthVault are now available. Moreover, many corporations sell portable medical devices (blood pressure monitors, blood glucose meters, pedometers, and more) that take patients' recordings and send them to their HealthVault records. Applications and devices offer a growing range of ways to get the important health information patients that are tracking into their HealthVault record. Many applications let customers analyze and manage that information to help them achieve their health and fitness goals [33].

HealthVault introduces five application connection models in order to help developers decide how their application will integrate with HealthVault [34]: (a) Native HealthVault (Online apps), (b) Linking (Offline apps), (c) Patient Connect, (d) Drop-off/Pick-up, and (e) Software on Device Authentication (SODA).

All these capabilities render HealthVault to be a valuable tool of import and management of health-related information. A major limitation should be stressed; using HealthVault is available only to residents of the United States of America, due to legal obstacles. It is the company's intention to expand its use in other countries, provided that the relevant legal restrictions will be eliminated.

Unlike using it, development of software which supports or uses HealthVault is possible outside the United States as well. For this purpose Microsoft HealthVault Pre-Production Environment (PPE) is available. The PPE is a web server platform that simulates the HealthVault website except that it does not provide access to real user data. It has been designed specifically to support the development of related applications, so that developers can test and evaluate their software. CardioSmart365 uses such an account, created in PPE.

5. CardioSmart365: System Description and Services

5.1. System Architecture. In this work, an integrated system (CardioSmart365) for monitoring and early notification for patients suffering from heart diseases is presented. The system design and implementation use the well-known-service oriented architecture (SOA) to maximize interoperability and scalability, as well as user interface design techniques for optimal presentation. The system consists of web applications, native mobile applications for Smartphones loosely coupled web services and decision support systems, in order to offer its services to the end users: patients, cardiologists, and general doctors. The four main services the system offers are the following.

(1) Creation and maintenance of the complete electronic medical record (EMR) of patients with heart diseases. EMRs are managed by cardiologists responsible for each patient.

(2) Recording and management of patient's measurements of vital signs performed at home on regular basis, such as blood pressure, blood glucose, oxygen saturation, weight, and height.

(3) Detection of out-of-range measurement values using fuzzy logic and alert firing through a DSS.

(4) Formulation of cardiologic patient profiles based on DSS for the most common heart diseases.

(5) Integrated message management module, for optimal communication between end users and instant notifications. The module also includes automated messages.

The system implements a client-server architecture. Authorised end users have access to the integrated system through client applications, a web application, and a native mobile application for smartphones, with friendly- and easy-to-use interfaces. Great emphasis has been given in the design of user friendly and functional interfaces for both physicians and patients. In particular, the interface of mobile devices is designed in such a way to require the minimum volume of typing data. In order to achieve platform independence, the client applications communicate and exchange data with the database through web services, which allow data interchange through heterogeneous systems. The web services provide functionality with which specific information can be accessed by client applications after authenticated access. CardioSmart365 utilizes the Microsoft HealthVault platform as a backend platform, to store and manage important information of patients' EMRs and measurements, into a uniform format. The system's architecture is shown in Figure 1. Since CardioSmart365 has reached version 1.0 offering the aforementioned services, it will be further developed to incorporate an SMS server component, in order to offer an extra channel of communication between end users, as well as an alternative data transfer method between client and server.

5.2. System Functionality. In this section, we proceed to a thorough analysis of CardioSmart365 functionality and the services it offers to end users (Figure 2). The description of the system's functionality and offered services will be accomplished through the presentation of the following generalized services: (a) vital signs measurement, (b) electronic medical records, (c) cardiologic patient modules, and (d) message management module.

5.2.1. Measurements of Vital Signs. Depending on the severity of patients' health condition, their cardiologists advise them to perform measurements of their vital signs on regular basis. The measurement types may include blood pressure, blood glucose, oxygen saturation, weight, and height, and the frequency of measurements depends, in general, on the patient's health condition. CardioSmart365 offers patients tools to record their measurements through web interfaces and mobile applications (Figure 3) and store them to the system's database. Measurements are performed at home and are imported manually by patients themselves or directly from the medical device (when the device supports connection via Bluetooth or Wi-Fi). Patients can also view measurements of a certain type performed in a specified period of time and create charts. The cardiologist, who is assigned to and responsible for each patient, has access to these measurements for a more comprehensive patient monitoring and decision making. Measurements of vital signs are also stored in Microsoft HealthVault.

An extra control module based on fuzzy sets is developed to check out-of-range measurement values and alert the attending MD. Every attending MD, cardiologist or general practitioner is able to define the fuzzy sets of blood pressure, blood glucose, cholesterol, and weight according to every patient's special needs, achieving in this way a first level of personalization. The fuzzification of blood pressure to *very low, low, normal, little high, medium high,* and *very high* is common to all patients, but the triangular fuzzy sets contain different Universe of Discourses. For example, the universe of discourse for the fuzzy set *little high* can be set from the MD for a patient with a history of a recent heart attack to $(100, 120, 140)$. The same MD can set the same values $(100, 120, 140)$ for the fuzzy set *normal*, in the case of another patient with a different medical history than the previous one, such as a patient with hypertension. A fuzzification and control module is also developed for blood glucose, cholesterol, and weight.

5.2.2. Electronic Medical Record. Through CardioSmart365, cardiologists have access to their patients' medical records. In CardioSmart365, an EMR consists of patient's medical history, medication, laboratory examinations, cardiovascular examinations (physical examinations), periodical measurements of vital signals, and demographics.

The medical history for cardiology (Figure 4) consists of detailed information about coronary artery disease (CAD), intervention for CAD, hypertension, heart failure, valvular heart disease, and heart rhythm disorders. It also includes basic information about cholesterol, diabetes mellitus, tobacco use, family history for heart disease, stroke, peripheral arterial disease, thyroid disease, cancer, lung/liver/kidney/neurological/gastrointestinal/autoimmune/hematologic/endocrine/ophthalmologic/psychiatric disease.

Medication (Figure 5) includes information about patient's current and past medicines, dosage, route, duration, and instructions. Laboratory examinations include information for complete blood count, coagulation times, and biochemical examinations. The cardiovascular examination is a physical examination performed at home or in a clinic, by a general doctor or a cardiologist, and consists of information

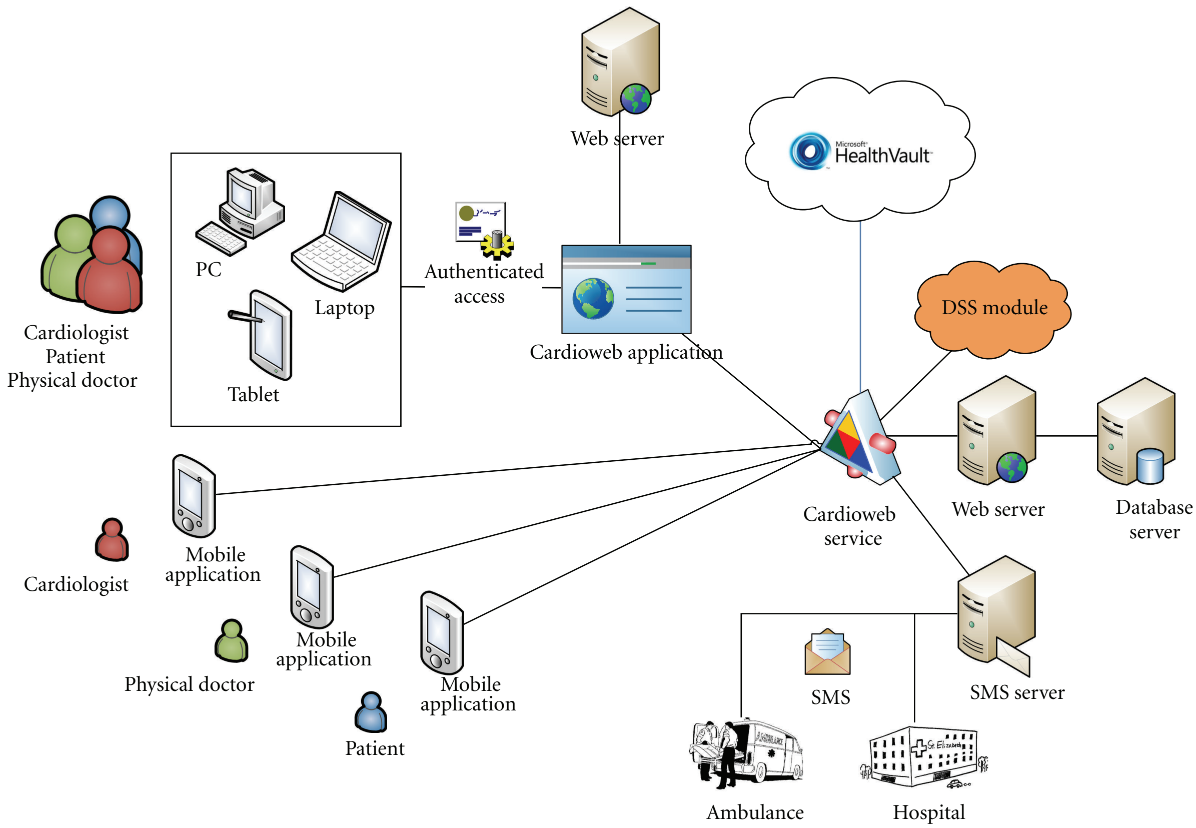

Figure 1: The architecture of CardioSmart365: components interconnection.

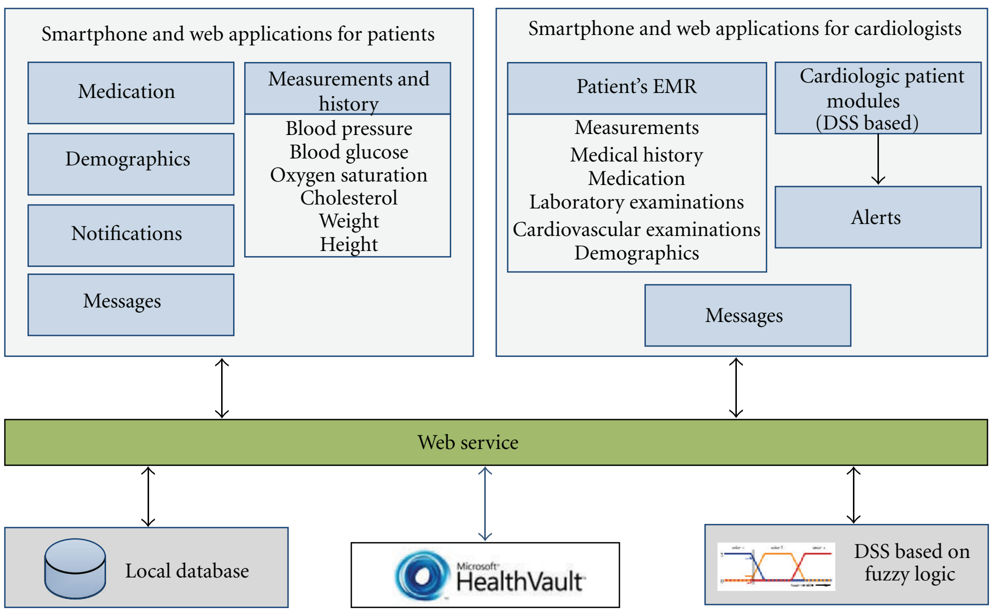

Figure 2: The architecture of CardioSmart365: offered services.

about heart pulse (also femoral and foot pulse), jugular venous pulse, cardiac palpation, and auscultation. The system offers an interface for recording information about the examination the same time it is performed (Figure 6). Measurements of vital signs are performed by patients on regular basis and include blood pressure, blood glucose, oxygen saturation, weight, and height measurements. Demographics include general information for a patient such as name, surname, gender, age, insurance details, contact info and emergency contact details.

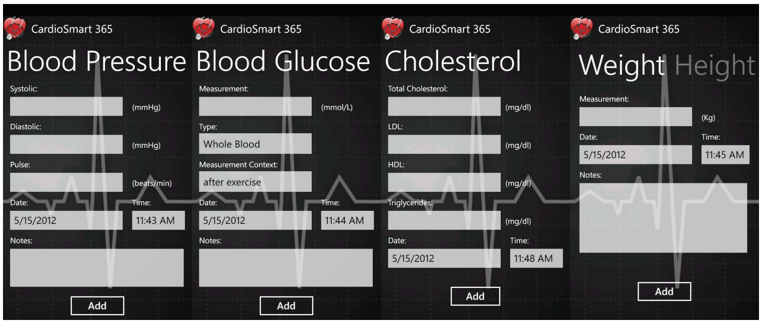

Figure 3: CardioSmart365 mobile interfaces for recording vital signs measurements.

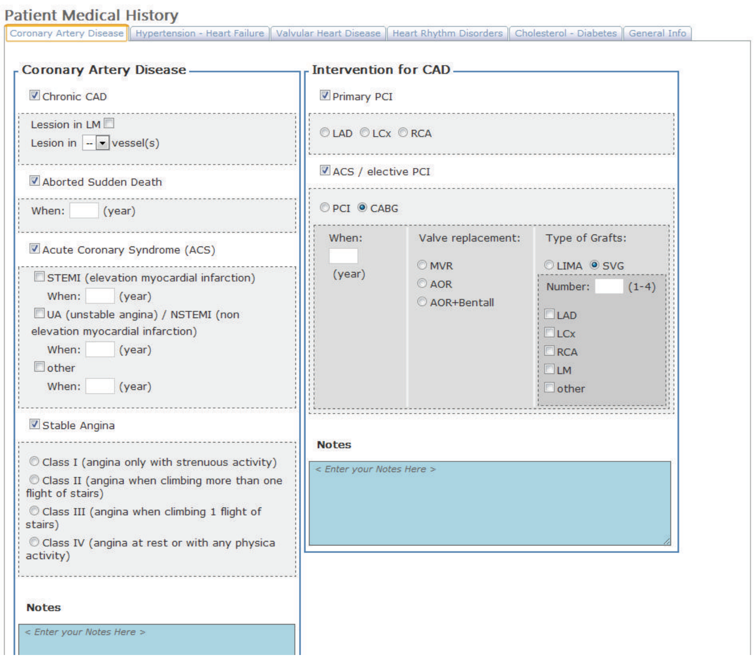

Figure 4: Recording patient's medical history.

A patient's medical history is created in detail the first time the patient visits the cardiologist in his/her office or clinic. Cardiologists have full access to this information and can notify it to general doctors who perform physical examinations in cases of emergency, if it is necessary (read only access permissions). Medication is updated by patients or cardiologists. This information would also be updated directly by pharmacists, as future potential end users of CardioSmart365. Information about laboratory examinations is recorded and stored into CardioSmart365 by patients or cardiologists and in the future directly by clinicians.

Information about a new cardiovascular examination is stored by the cardiologist or general doctor who performs it. Periodical measurements of vital signs are performed at home, are imported by patients, and are available to cardiologists for a more comprehensive patient monitoring and decision making. Demographic information is stored along with the medical history during the patient's first visit to a cardiologist, or by a patient at any time and is updated by patient or cardiologist.

Most of the information described above is also stored in Microsoft HealthVault, including medication, laboratory examinations, periodical measurements, and demographics. This way, the information will be available to third parties after patient's approval. Information characterized as more specific to cardiology, such as the detailed medical history, is stored only in CardioSmart365 database.

5.2.3. Cardiologic Patient Modules. Knowledge from experts, in this case cardiologists, is incorporated in separate modules, focused on the most common heart diseases. The cardiologic patient modules (CPMs) are in fact enhanced cardiologic patient profiles that comprise decision support systems (DSSs) based on fuzzy logic. Fuzzy Logic is used because it offers solutions when a system is so complicated that cannot be mathematically modeled, or when it presents fuzziness. In the case of a cardiology patient and a cardiologist that needs to take therapeutic decisions for him/her, decisions should not be based on rules like the following.

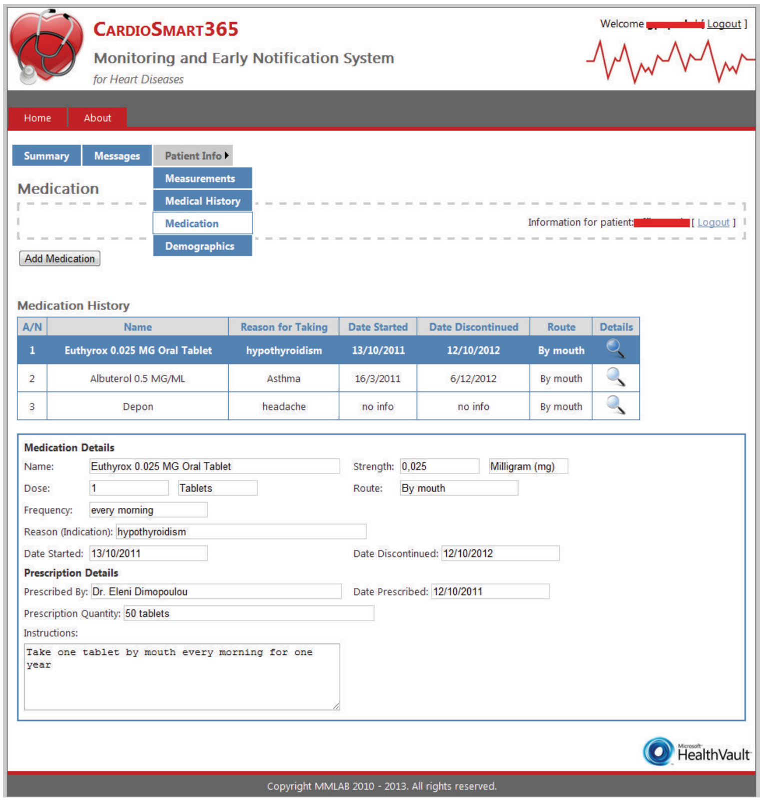

Figure 5: Patient's Medication History and Details from cardiologist's interface.

(1) If *Aortic Stenosis* is 2.5–2.9 m/s AND *Blood Pressure* is 140/90–160/95 mmHg Then *Decision* is . . .

(2) If *Aortic Stenosis* is 3.0–4.0 m/s AND *Blood Pressure* is 140/90–160/95 mmHg Then *Decision* is . . .

It is obvious that different *decisions* result from minor changes. For example, a difference of 1 m/s in the *aortic stenosis* of 2.9 m/s to 3.0 m/s may be the reason for a surgery intervention or not. Therefore, fuzzy sets are designed and fuzzy rules are developed, which imitate better the way MDs think and act. For example, the above decision rules are transformed to fuzzy rules in the form of the following.

(a) If *Aortic Stenosis* is *MILD* AND *Blood Pressure* is *LITTLE HIGH* Then *Decision* is . . .

(b) If *Aortic Stenosis* is *MODERATE* AND *Blood Pressure* is *LITTLE HIGH* Then *Decision* is . . .

The system includes five discrete patient modules:

(I) the coronary artery disease patient module,

(II) the hypertension patient module,

(III) the heart failure patient module,

(IV) the valvular heart disease patient module,

(V) the heart rhythm disorders patient module.

CPMs contain Alert messages and Critical messages automatically arisen when the MD imports data in the DSS. Some decisions from the DSS result deterministically while others require the use of qualitative variables. The qualitative variables are transformed in fuzzy sets used to create fuzzy decision rules. For example, in the valvular heart disease CPM the form of the fuzzy rules is the following.

(1) If *mitral regurgitation* is *ASYMPTOMATIC* AND *LVESd* is *HIGH* then *surgery intervention* is HIGH.

(2) If *aortic regurgitation* is *ASYMPTOMATIC* AND *ef* is *SMALL* then *surgery intervention* is HIGH.

In the Hypertension CPM, Fuzzy Logic is used to help in drugs regulation. The form of the fuzzy rules in this case is:

(1) If *age* is *HIGH* AND *blood pressure* is *LITTLE HIGH* AND *coexisting disease* is Chronic Kidney Disease THEN *Medication* is DIURETIC HIGH.

(2) If *age* is *MEDIUM* AND *blood pressure* is *HIGH* AND *coexisting disease* is Myocardial Infarction THEN *Medication* is B-BLOCKERS HIGH.

Table 1 presents the basic criteria used in the decision mechanism for each one of the five CPMs. Some of the criteria are fuzzified into fuzzy variables, while others are better exploited as crisp variables. The decision includes starting, ending, or configuring medication, limitation of activity, and surgery intervention.

The CPMs are designed to be used from medical doctors, cardiologists and general practitioners. Although

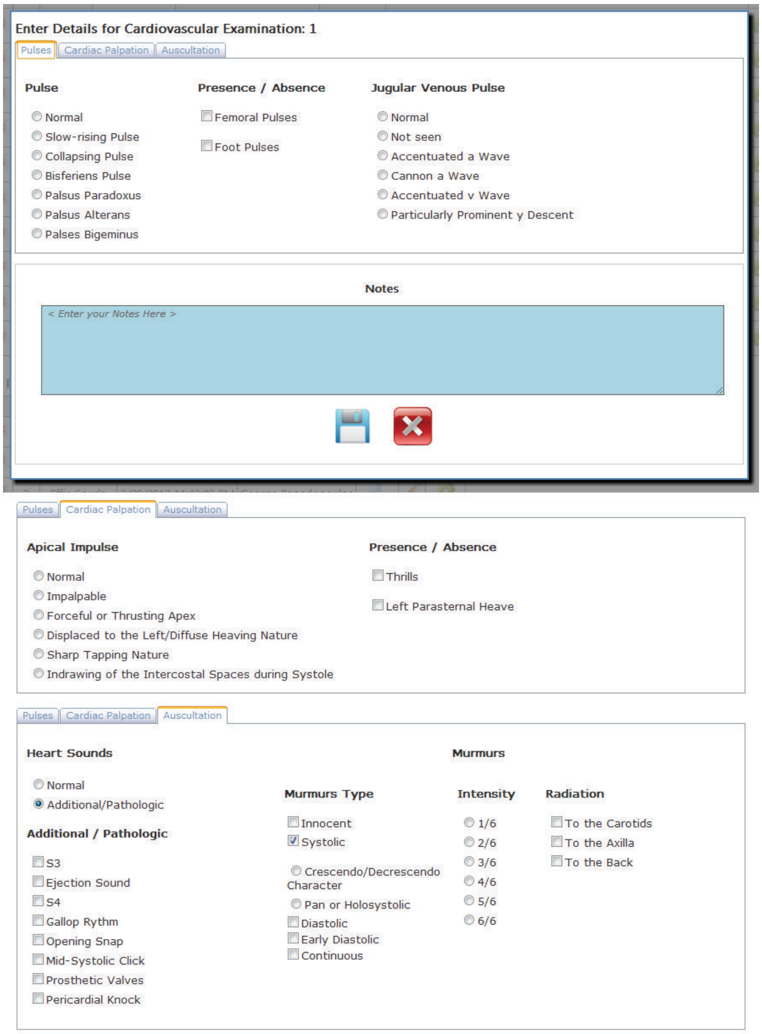

Figure 6: Performing a Cardiovascular Examination.

cardiologists are strongly benefited from the CPMs, general practitioners may find CPMs extremely helpful when they are called to manage a cardiologic patient.

5.2.4. Message Management Module. The message management module is a module of CardioSmart365 that optimizes the communication between end users. The module manages inbox and sent messages of all end users and sends automated messages when necessary. The automated messages are formed by customizing specific message templates stored in the system's database. When an automated message is sent or when one user sends a message to another, three actions take place; a message is created internally in the system database and is visible to all recipients, an email is sent to the recipients who have registered their email addresses, and an SMS is sent to the recipients who have registered the numbers of their mobile phones. Through the messaging module interface (Figure 7), the end user can view his/her inbox, edit and send outbox messages, create, save, or send a new message and delete messages.

5.3. Software Framework. The multimodule software architecture is developed in Visual Studio 2010, using the programming language C#. The web services implementation follows the Windows Communication Foundation (WCF) framework that provides a unified programming model for rapidly building service-oriented applications. The mobile application is implemented in Windows Phone 7, the new Microsoft platform for smartphones, specifically version 7.5 Mango, which is an upgraded version of the initial one. The Silverlight toolkit for Windows Phone was used, which allows rapid creation of Rich Internet Application-style user interfaces. The integrated system's database is developed in SQL Server 2008.

A prerequisite for developing applications interconnecting to Microsoft HealthVault is the use of the corresponding library [25]. The library enables encrypted communication among the application and the server of HealthVault. The respective SDK provides supplementary tools for interaction with the platform, instructions for the programmer as well as some standard applications. Each application is represented by a unique ID, which is received through HealthVault

Table 1: Cardiologic patient modules and decision support.

Cardiologic patient module	Fuzzy variables	Crisp variables	Decision
Coronary artery disease	Class Duration	Category	Medication
Hypertension	Age Blood pressure	Coexisting disease	Medication
Heart failure	Class	Cause	Limitation of activity
Valvular heart disease	Mitral regurgitation Aortic regurgitation LVESd ef		Surgery intervention
Heart rhythm disorders	Rate control Rhythm control	Type	Medication

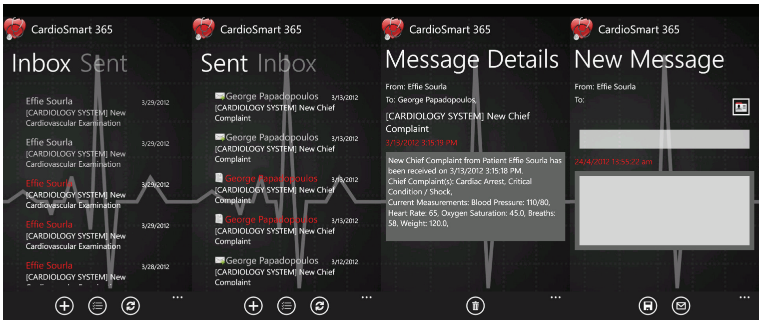

Figure 7: The mobile interface of the Message Management Module.

Application Configuration Center. The DSSs based on fuzzy logic are developed in Matlab® Fuzzy Logic Toolbox.

6. Added Value

CardioSmart365 impact is separated to benefits for five categories, which are thoroughly described below:

Every day clinical practice concerns MDs, nurses, hospital staff, outhospital healthcare organisations, and patients. CardioSmart365's patient modules, forms, and DSS can be used as guidelines that are followed for patients with a specific cardiologic disease, standardising in this way the tasks that have to be done for every patient, each day and by whom. In this way, better collaboration is established between all the involved working teams inside and outside the hospital. In addition, the direct interconnection and fast briefing, between different health sectors supported from the system, reduces fraud and optimizes emergency incidents process management.

Medical doctors many times need to act under stress and to take decisions in a fast way. Therefore, speed is important for MDs. cardioSmart365 is a "doctor-friendly" tool that helps recording data in a systematic and quick way, therefore, helping MDs to work faster and in more safety. In addition, CardioSmart365 benefits young cardiologists and general practitioners (GPs) as an educational and decision support tool, since it provides patient specific guidance in the rapprochement of CPs.

Cardiologic patients dispose a customised EHR. The benefits of EHRs are widely known, but the customised EHR for CPs contains detailed data, formatted in a way that can be easily understood and quickly viewed even from third parties MDs after years. After all, patients suffering from cardiologic diseases, most of the time in reflect chronic pathologies that require medication and followup for the rest of their life. This way, patients receive lifelong advantageous healthcare.

Research and Science strongly benefited towards better monitoring and understanding of cardiologic diseases. CardioSmart365 is a tool for recording and studying scientifically validated data elements of cardiologic diseases. Moreover, CardioSmart365, in the administrator level, can correlate and conclude upon data recorded not only from different places of the same region or country, but from different countries and continents, because it can be accessed from any personal computer connected to the Internet. In this way, maybe for the first time so easily, detailed data from all over the world can be gathered in one database, continuously updated for scientific research.

Healthcare systems are interested in estimating health related economical costs. CardioSmart365 can be used for a reliable estimation of the economical cost that a patient encumbered a healthcare system. CardioSmart365 stores data concerning the examinations of a patient that their cost is usually the higher cost that burdens a healthcare system. Additionally, CardioSmart365 can be used for providing estimations on the cost of every cardiologic disease per patient and to estimate annual costs for every new diagnosed patient.

7. Future Steps

CardioSmart365 was developed to offer advanced added value services for cardiologic patients and physicians into a fast, flexible, and easy-to-use integrated solution. However, many steps towards optimizing the system have to be done. Some direct future evolvements concern (a) healthcare systems and (b) research and science.

7.1. Healthcare Systems. CardioSmart365 is designed to offer an easy way for the incorporation of economic costs customized to different healthcare systems. This future module, apart from the already provided costs of laboratory examinations, will provide costs related to medication, MDs rewards, patients' transportations, and other economic issues important for healthcare systems around the world. Moreover, tools for estimation and various indices used for better monitoring and prediction of health involved costs will be established. For example, questions like "What is the annual cost for a Healthcare system for a patient with a coronary artery disease?" will be answered, or predictions like "How many new diagnosed patients with a coronary artery disease are expected for the upcoming year" will be estimated. AI methods will be closely studied due to the help that they provide in prediction problems.

7.2. Research and Science. Using the web applications and services of CardioSmart365, feedback from institutional centers specialized on cardiologic diseases will be collected and incorporated to future versions of CardioSmart365. The cardiologic patient modules will be continuously updated in an automated way through the tools that will be developed. Knowledge from experts will be further continuously incorporated to the DSS of CardioSmart365, optimizing their support to MDs, leading towards personalized patient profiles and personalized medicine. In this way specialized knowledge and protocols from pioneers in the field of cardiology will be spread all around the world in a direct, fast, and easy-to-follow way.

CardioSmart365 will further adopt clinical data and data involved in healthcare in a greater detail. As a first attempt to collect and group the basic data elements sufficient for a cardiology patient, MDs and the rest staff involved in Healthcare systems, CardioSmart365 will incorporate serious feedback from its end users for optimization and further evolvements.

8. Conclusions

An integrated system based on web applications, Smartphones, and an interconnection to Microsoft HealthVault platform is developed, for (a) monitoring chronic cardiology patients and (b) early notifying and optimizing the process management of an emergency cardiologic incident. The system supports cardiologic patient modules based on common cardiology diseases and customized DSS based on fuzzy logic. The benefits of the system concern patients, MDs, everyday clinical practice, research and science, and healthcare systems.

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