A Mobile Health Care Rule-Based System

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Abstract. The relation between patient and physician in most modern Health Care Systems is sparse, limited in time and very inflexible. On the other hand, and in contradiction with several recent studies, most physicians do not rely their patient diagnostics evaluations on intertwined psychological and social nature factors. Facing these problems and trying to improve the patient/physician relation we present a mobile health care solution to improve the interaction between the physician and his patients. The solution serves not only as a privileged mean of communication between physicians and patients but also as an evolutionary intelligent platform delivering a mobile rule based system.

1 Introduction

When faced with the problem of non critical patient monitoring, most modern health care systems, either private or public, rely on a series of meetings between physicians and patients.

These meetings tend to be succinct and rather sparse in time, specially when taking place on an overloaded and inefficient health system scenario, like the ones observed in many countries. Due to the numerous limitations imposed on the quantity, quality and time availability for each of these meetings, often the physician can only get a partial and distorted medical perception about the actual condition of the patient under observation [3]. Such poor quality information can lead to medical misjudgements, late diagnostics and even induce medical decisions with critical repercussions in patients' lives.

Actually, it is often the patients that do not cooperate with the health care system in order to attend more medical meetings and to spend more time in each of those meetings. Again, the reasons for such a behaviour are numerous and obvious, with the most relevant ones lying on the stressful lives that most people from modern societies face. Even more, given the increasing mobility demand in many professional activities, it is also often the case that the patient cannot attend his medical meetings due to his diverse travelling appointments.

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Of course that, when a patient has already experienced some effect of a heath problem he/she becomes more cooperative with the health system. But it is also not less often, that when such a time cames it is already to late, in the sense that precious health care time has already been lost. Therefore, a non invasively system oblivious to the patient that can measure a variety of parameters, and retrieve them to the physician for further analysis, would certainly improve long term patients health.

A third and important observation of the way patient monitoring is performed today, is that a considerable number of medical meetings that do take place are indeed superfluous. This happens mainly because there is no other mean, besides the physical meeting, for the physician to scrutinise the patient current state, or because the patient doesn't feel suitably accompanied by his doctor and has no other mean of getting medical feedback other than attending a traditional medical meeting.

Building up on top of all the already identified problems of health care systems, one may also add the waste of money spent on all the unnecessary medical meetings as well as the waste of time for both patients and physicians involved in such meetings.

Another relevant aspect of today's medical diagnostics and health treatments is that they are often solely based on objective physiological and pathological data, neglecting other important sources of information like the patient's style of living, his life events and human dispositions.

These intertwined psychological and social nature factors cannot be overlooked [7,5,2]. The traditional diagnostic information, although important for the maintenance of health and quality of living, is certainly not the most determinant. An ecosocial approach is needed. Inequalities in health are related with the family social level of the population as a whole as well as with the differences of people's lives and work conditions [4,1]. Thus, one should also be able to capture such factors and provide them to physicians in a useful manner can improve health problems diagnosis.

In order to cope with this problem and given the presented constrains, we propose a rule-based mobile system called *Medicis* that delivers an easy to use mobile solution for the patients and a powerful desktop platform for the physician.

The mobile solution is intended to be used by the patient and it targets the delivering of important medical information from the physician to the patient as well as a user friendly interface permitting the input of several health parameters, requested by the physician, from the patient.

The desktop solution is oriented towards the physicians and it generally serves to suitably analyse the different patients collected data as well as to select new measurements for specific patients.

Contributions. We present a mobile patient/physician interactive rule-based system (section 2), composed of a mobile solution (section 3.1) oriented to the patients and a desktop solution 3.2 targeting physicians requirements. In order to bring communications demands to a minimum, a non-trivial synchronization process between the mobile and desktop solutions was implemented (section 3.4).

Addressing the problem of reducing the amount of information physicians have to deal with, an intelligent mobile rule based system was implemented (section 3.5). Finally, concentrating on the neglected recording of psychological and social nature factors, we have also implemented a personalised health record module working both on the mobile and desktop solutions (section 3.3).

2 Medicis Overview

Medicis is an health care solution with three main entities interacting with the system, namely the physician, the patient and the system administrator. The solution is composed of three main components: a mobile application, a desktop application and a middleware component responsible for all the data synchronization between the mobile and the desktop application.

The typical and resumed operational scenario for Medicis, is one that starts with a traditional physician and patient meeting. In this meeting the physician creates a new entry for the patient in the system and assigns him a mobile device with the mobile Medicis application installed[1].

After this initial meeting, the physician is given the possibility to register measurement requests, according to the patient specific health situation, that will be passed to the mobile application in order to collect instances of such measurements. The measurements readings, for which the mobile application is responsible for, can be performed by patient manual input or with specific sensors [8] that periodically interact with the mobile device feeding it with the requested data.

Besides all the standard patient information management (name, age, clinical history, etc), the physician may associate specific clinical rules, that will be passed to the mobile application for constant querying over the patient readings (the details of rules definition is presented in section 3.5).

On the patient side, when he logins in the mobile Medicis, the application gives him the possibility to update every personal data that his physician as access to. Even more, once in logged in mode, the mobile application will start asking the patient (or silently probing the health monitoring sensors) to insert values concerning the physician's measurement requests. At any time, a patient may consult diverse useful information about his present health situation, doctors advices and measurement readings.

Resuming the physician desktop application requirements, the platform allows the physician to perform the following actions:

- Consult and manage his patients personal and clinical information (fig 1);
- Manage the tradition meetings with his patients whenever he believes it is relevant to do so;
- Define new measurements for the patient to perform and submit the obtained values. This can be for instance, the blood pressure, temperature or heart beats per minute;

[1] Given the growing spread of mobile devices, it is expected that more and more patients use their own devices.

Fig. 1. Patient Information

- Inspect, with suitable visualisation techniques, the requested measurements submitted by the patients in answer to his measurements requests;
- Manage the *Personalised Health Record* (PHR) entries for his patients;
- Administer the rule based system running in every mobile instance, by creating, removing or assigning specific rules to a patient.

Following the same topic requirements enumeration, the mobile application provides the patient with the bellow operations:

- Update is own personal information;
- Submit specific measurement values in answer to the physician measurement requests;
- Insert new PHR entries, reflecting is psychological and social feelings at the moment;
- Read his physician's requests for appointments;
- Request appointments with the physician, referring some particular reason for so;
- Get feedback, either from the physician or from the rule based system, about every action he may have had with the application;

The mobile application holds two different working modes, namely an offline and an online mode. In the offline mode, every operation performed by the user or triggered by the rule-based system is stored internally with specific time and synch stamps. Latter the communication component will be responsible for interpreting this operational stamps and perform a correct information synchronization with the main system. On the other hand, when the mobile application is running under online mode, a direct connection to the main system is available. Therefore, every operation on the mobile application that takes place under such mode and demands an interaction with the main system, it is executed in the mobile device and immediately after it is replicated in the server in a transactional way.

The communication component is responsible for controlling the login process associated to each mobile device as well as for performing every data synchronization between the mobile devices and the main system.

In what respects to the login control, the communication component must be able to cope with the fact that a mobile device that is now assigned to a patient, carrying all the data and functional apparatus for the current patient, may become assigned to a different patient in the future. Even more, such an identity change must take place silently, whenever a different patient is able to login successfully in the application.

Facing such a loose identification scenario, the communication component is responsible for synchronizing the previous patient information and preparing the entire mobile application to start serving the new logged in patient. Moreover, the communication process is also capable of maintaining coherent and updated information concerning measurement requests, measurement values submissions, PHR entries, appointment scheduling and most of all, delivering and installing correctly all the rules from the rule based system running assign to the current user.

The next sections explain in some detail the most relevant parts of the Medicis solution. In particular, one presents the entire system architecture as well as the implementation of the major components inside each application.

3 System Architecture

The architecture of the developed solution is composed of 4 main modules: a mobile application, an ASP.NET Application, a Windows Forms Application and a Main System that acting as a server providing several services for the remainder modules.

Each of this modules is further divided in more fine grained components, as depicted in figure 2.

The main system module is composed by the standard Data Access Layer and Business Logic Layer, which provide isolated data base access and entity management operations respectively.

As explained in the previous, the communication component is responsible for checking all the incoming data from the mobile application, and guaranteeing that the main system keeps coherent and synchronized data about the mobile users.

The PHR component, is responsible for managing the Personalised Health Record operations that are presented in section 3.3.

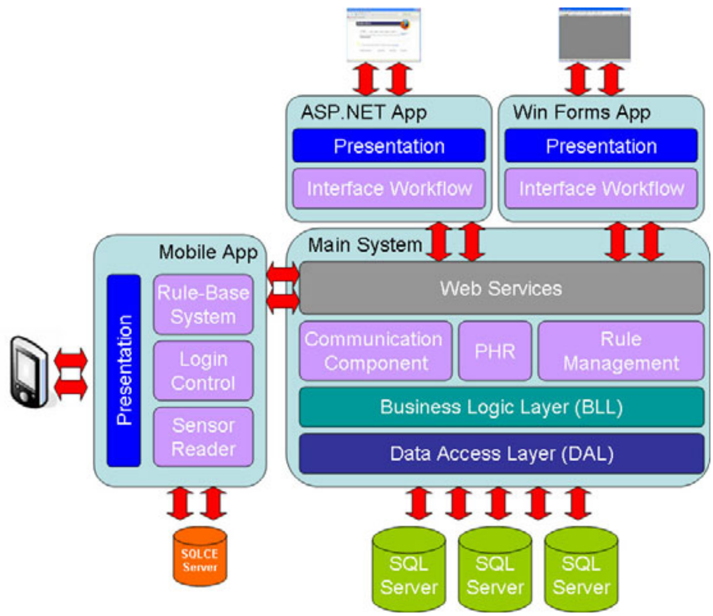

Fig. 2. System's Architecture

The Rule Management component controls a repository of available rules and permits the creation, deletion and update of rules inside this repository. Ultimately the rule repository is materialised in the SQL database, where "if then else"-like rules are stored in a relational manner.

On top of all this functional components, there is a web services layer that makes use of all underlying layers in order to provide specialised services for the different application modules.

The mobile application contains a Rule-Based System component which performs basic rule management as well as a constant verification of rules appliance, based on the data collected by the sensors or the user. The details of the internal mechanisms that handle this operations is given in section 3.5.

The login component, which is another constituent of the mobile application, is in charge for setting up the mobile environment for the user currently logging in, as explained in the previous section. The mobile environment is composed of diverse patient specific information, like personal data, measurements, rules, medical appointments, etc.

The sensor reader component is a small library that interacts with the mobile device COM port for the retrieval of information captured by the medical sensors the patient is carrying. This component acts basically like a selective parser, depending on the sensor it is reading, over the data stream that arrives at the mobile device COM port.

Since most mobile devices do not provide a COM interface, one has chosen to use a COM to Bluetooth converter in order to allow COM communicating sensors to be connected to the mobile application. Once the sensor is connected to the Bluetooth antenna component, the mobile device is able to intercept the wireless signal from the sensor, which is then associated to a COM port on the mobile device.

With this combination of sensors with bluetooth antennas, this probing devices do not have to be physically connected to the mobile device anymore. Thus, the patient may carry a series of this wireless sensors in a very comfortable manner.

The wireless sensor prototype that we have developed as a prove of concept, makes use of a "Parani ESD100"[2] Bluetooth antenna and a COM interface thermometer. Although the size of the developed prototype sensor (about 6 by 4 by 3 cm, excluding the battery) makes it a bit uncomfortable to carry, perspectives are that it can become much smaller with the appropriate support from digital circuits companies.

The Interface Workflow components are responsible for maintaining a state for the the diverse user interface processes that take place in the respective applications. Finally, all the presentation layers in the user interface applications are responsible for generating the graphical user interface for each scenario.

3.1 Mobile Solution

The mobile application was developed to address patient requirements in a mobile scenario. It was developed using Windows Mobile 2005, the .Net Compact Framework and Microsoft SQL Server Mobile Edition.

Several useful features to the patient were implemented, such as the possibility to manage the meetings that are scheduled by the physician, verify and update personal information, register measurements of parameters and the insertion of PHR episodes.

The application also permits the patient to actively request new medical meetings, receive new electronic medical prescriptions and synchronise data via a call to the communication component.

the main goal during the mobile application development was to provide an easy way for patients to understand and work with the application, by giving it a visual and intuitive interaction mode, which can be inspected by the screen shoots of the application.

All the application data demands are provided directly from the mobile database which is kept coherent by the previously presented Communication Module.

The following figures present a brief screen shot overview of the application, with main menu screen (Fig. 3(a)), the form to introduce a new parameter measure (Fig. 3(b)), and also the rule-based system in action (Fig. 3(c))

In what concerns to health monitoring measurements, every parameter request has a time interval, and a periodicity. whenever a measurement request expires, the interface guarantees that the patient cannot submit any more measurement values for that parameter.

[2] Available at http://www.merlinbluetooth.co.uk/merlinbluetooth/parani-esd100-class-1-chip-antenna-p-92.html?osCsid=65bfefd0032dad3354ce2c422745bb90

(a) Main Menu (b) Insert Measurement (c) Mobile RBS

Fig. 3. Mobile Application

3.2 Windows Forms Application

The choice for using a windows application is due to the fact that the hospital unit or clinic needs a direct and privileged connection to the main system, which could not be achieved by any other application relying on a disconnected environment.

Like so, the windows application has been developed with a fair notion of usability, and the concern of providing the right data at the right time. All the administration tasks are available, like the creation, editing and deleting of patients, physicians and parameters. Other features such as the scheduling of new parameters to measure, an electronic medical prescription builder and a rule construction system are also available to the physicians.

All the data submitted by the patients is kept in the SQL Server database. The patient physician has access to this information by browsing the patient record. Here the physician can perform all the clinical management operations as depicted in figure 1.

The analysis of several different medical parameter values cannot be performed in an individual manner, by inspecting each parameter in an isolated scenario. In fact, many clinical parameters are related with each other and for the physician to analyse them suitably, it is of most importance that he should be given the possibility to relate different parameter measurement as easy as possible.

Addressing this problem, the Windows Application provides the doctor with the ability of selecting up to four parameters and with them generate several kinds of graphics for a given time interval. In figure 4 one can see such a case where different parameter measurements submitted by a particular patient are laid out in a graphic.

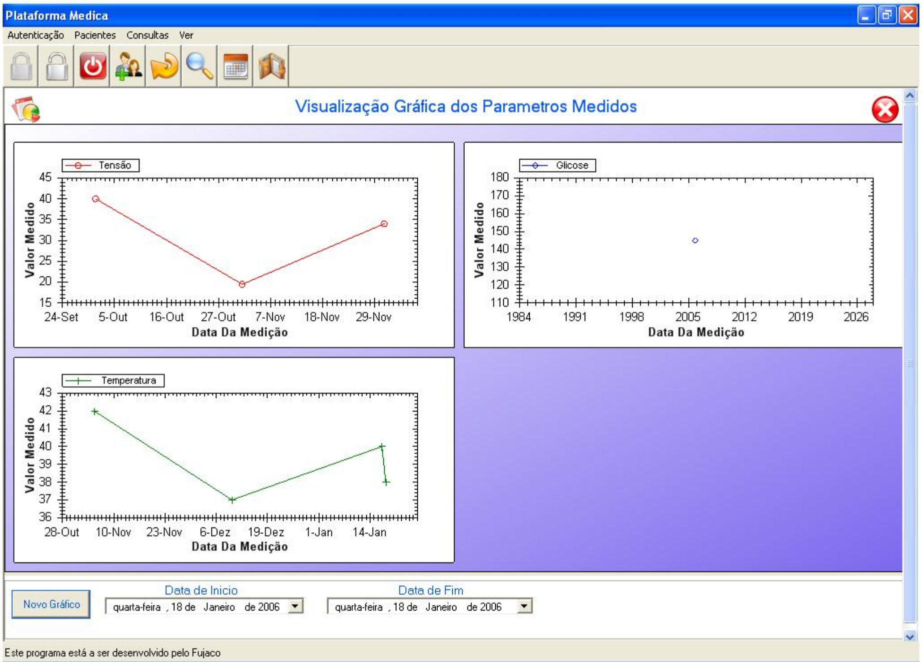

Fig. 4. Measurements Visualization

The Windows Forms Application also delivers a login process enabling the application to authenticate and authorise the users accordingly to their previously collected system permissions. One of the main purposes of such a login system is to control the specific information that users may or may not have access to. Just to illustrate the kind of policies that the systems allows to, it is not possible that a doctor consults information about patients that are not assign to him, nor can he send rules or measurement demands to those patients.

3.3 Personalised Health Record

Targeting the problem of capturing psychological and social nature factors from the patients living reality, Medicis delivers a personalised health record module that follows the guidelines of recent medical research in the area.

Based on a long standing clinical family practice both in outpatient hospital clinics and private practice Machado H.[6] conceived a module that is the expression of a collection of symbols (Fig. 5) related with the following aspects: Life styles, Life events, Disposition.

The module is made of four parallel lines onto which representative symbols of subjective elements are drawn. These are usually negligible on the standard clinical patient records in spite of their recognised importance. The aim of the

Life styles – 1st line	Life events – 2nd line	Disposition – 3 rd line
Smoking habits	Family dynamics	Anxiety
Irrational diet	Housing	Sadness
Alcoholism	Environment	Hostility
Sleep problems	Disease/Illness	Preoccupation
Drug addiction	Society	Stand By
Risk behaviour	Finances	
Sedentary habits		

Fig. 5. PHR Symbols

proposed module is to humanise and personalise the medical record to ultimately attain measurable improvements in clinical practice.

Both the mobile and the desktop application are capable of submitting PHR entries into the system. Nevertheless, entries that came from the desktop application, that is from the physician itself, are marked differently from the ones received from the mobile application which where introduced by the patient. This simple labelling of PHR records will permit the physician to give different confidence values to each of the input PHR entries in order to predict specific health problems.

On top of these user friendly PHR entries registration, the desktop application also delivers suitable visualisations of all the submitted PHR entries for a particular patient. In particular, it is possible to inspect all the four lines at the same time, compare them and even navigate to the detail of a specific episode occurred at a particular point of the patient's life.

3.4 Data Synchronization

One of the main problems in developing a mobile application, providing an offline mode, is certainly that of data synchronization.

In most mobile applications, the synchronization is done via web services and to do so, the mobile device need to be connected to the internet. This limitation is of great inconvenience for the user, so we have opted to developed a solution that supports an online and an offline mode of operation.

By using SQL Server Mobile Edition to store data in the mobile device, the user doesn't need to be connected to the Internet because all the data is stored in the database. SQL Server Mobile is a relational database engine, with similarly features and types as the SQL Server 2000, so synchronization is easier with these two databases engines.

By logging in into the mobile application in online mode, the application perceives that there is a remote connection to the central system and starts synchronizing data automatically. The data to be synchronised is marked with a flag, so that the system knows exactly at each time what data has to be send, avoiding this way, large amounts of data communication overhead and possibly even avoiding the creation of invalid replicated data.

The mobile application sends to the windows application, different kinds of data like new parameters measures, new PHR measures, personal information updates, and medical meetings requests. On the same synchronization event, data is also sent by the windows application to the mobile device, such as new parameters to measure, scheduling of new medical meetings and new rules to the patient rule based system.

There is also the possibility for the patient to start the synchronization in an active way. By accessing the respective option, the patient may actively send or receive fresh data from the hospital unit whenever he thinks is relevant. If the clinic or the hospital unit provides a PDA or another kind of mobile device to a new patient, the entire data download and personalisation of the application to the patient in question is also performed by this synchronization process. Because different users can use the same mobile device, to change user, only new authorisation and authentication (username and password) credentials are required.

3.5 Mobile Rule-Based System

To improve patient experience and to give the mobile application even more flexibility and intelligence, it was implemented a rule-based system (Fig. 6). This mechanism provides the doctor a way to automatically monitor certain parameters and also filter information in different manners.

Rule-based systems are adaptable to a variety of problems. In this case, information is provided by the patient and comes as parameters measurement, PHR measurement and other types of input information. The rule-base system analysis this inputs, determines the possible rules to fire and also where they lead.

Our working memory is composed with different kinds of facts and also facts that result from the firing of other rules. Our approach to implement such a solution was to use a forward-chaining, data-driven, system that compares data in the working memory against the conditions (IF parts) of the rules and determines which rules to fire. It is the doctor responsibility to build this rules and the respective action to fire.

The deployment of these rules to the mobile device is done each time the patient synchronises data. For example, if the doctor sets a rule to be fired when the cholesterol passes over the value of 300 the action could be a warning to the patient or even as SMS or email to the doctor. This way, the patient is being monitored all the time, and the doctor can be notified if a certain parameter or a set of facts fire a determined rule.

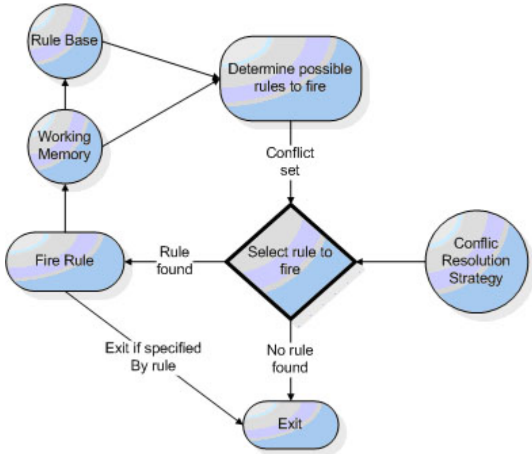

Fig. 6. Rule Based System Architecture

It should be mentioned that this rule base system in running on every patient mobile device, becoming the first rule based system reported to work on a pocket device at the time of writing. Given the specific constrains of both the compact framework capabilities and the limited processing and storage power of pocket devices, this component demanded great work and constant adaptations during development time.

4 Conclusions and Future Work

We have presented Medicis, a health care solution that tries not only to improve the relation between physicians and patients but also to improve the quantity and quality of clinical information a physician may have at his disposal.

Medicis is a cheap and feasible solution with great results in both time and cost reductions from the patient, the physicians and the entire health system sides. In fact, the cost of implementing such a solution passes only by a desktop computer to be given to the physician (which is already a common reality in many health care centres), a mobile device to be assigned to the patient (given the growth spread of mobile devices and the constantly reducing cost of such devices, this does not represent a significant investment) and a mean of communication, which can range from the more expensive GSM networks to the cheapest slower modem connections.

Given the short time between the final implementation of the system and the time of writing, there haven't been any real case test of the entire system. Nevertheless, the entire development phase as well as the major implementation decisions were followed by experienced physicians that gave important feedback to several aspects of the solution.

An interesting topic of future work would be to develop a self learning mechanism implemented in the mobile applications. Such a mechanism should be able to adapt the mobile application to the patient it is assign to, so that for instance, if the measurements of the patient indicate that he his diabetic, then the mobile application should for instance privilege the measurement of glucose.

As a final point of future work, it would also be interesting to implement a common rule data base in order to be given access to every physician using the system. This way, a physician could inspect these data based for some pertinent rules concerning a particular patient of him instead of having to create the rules for every new scenario he faces.

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