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A Configurable Home Care Platform for Monitoring Patients with Reminder Messaging and Compliance Tracking Services

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Abstract

This paper illustrates a platform based on a general architecture for implementing home care services for chronic patients composed of a Remote Care Unit located at a patient's home and a Health Care Center Unit located at the treating center. The Remote Care Unit may be deployed on multiple platforms including PCs, mobile phones and even embedded devices not equipped with monitor, and may be configured to support many interoperability issues occurring among the parties involved in a health care delivery process. The platform may be tailored to match the specific issues of any chronic disease supporting either data acquisition as well as customized reminders and notifications from the center. Remote Care Unit platforms are also able to exploit multiple channels for acquiring data, including wireless links with medical devices, speech interaction and graphical user interaction. In this paper a couple of applications addressing the needs of diabetic and nephropatic patients developed on top of that platform are also introduced.

Keywords:

Telemedicine, Reminder systems, Outpatient monitoring

Introduction

All the western countries are concerned about the ever increasing trend of their health care budgets. As pointed out in [1] those expenses are now growing much faster than GNP on a world-wide basis, with an expected trend of 5% per year which may render them rapidly unaffordable even on a short term. Most efforts are thus being directed at finding new and effective ways to cope with this problem, and there is a common belief that a generalized adoption of the Information and Communication Technologies (ICT), despite some initial hardships, might help in streamlining the health care delivery process thus saving costs at the organizational context while preserving or even increasing the overall quality and effectiveness of health services [2, 3]. This is also witnessed by the increasing efforts addressing research projects in the telemedicine and e-health related areas aimed at preserving a close contact of patients with health care providers [4] while not at clinical settings. Furthermore, encouraging treatment of patients at their homes besides saving costs may also reduce the stress they suffer during a hospital stay [5]. However special care should be undertaken in developing those applications since a patient is inherently forced into the role of an application user.

This paper introduces our approach to the problem illustrating the telemedicine platform we have developed. The platform is based on a general telemedicine architecture addressing the interoperability issues of chronic outpatients, and makes use of mobile network devices such as cellular phones, palmtops and PDA's in addition to PC's in order to provide an advanced framework for remote clinical monitoring while also facilitating interaction among patients and their families as well as with the health care staff.

Materials and Methods

Addressing communication issues for chronic patients

There is a long-standing debate about the compatibility of ICT solutions with physicians' clinical routines. While at the beginning telemedicine mainly addressed the live transmission of images and biological signals to support *on-line* remote consultations with questionable success, recent achievements in computing, networking and data storage now account for new scenarios modeled on the so called *store-and-forward* paradigm. This approach seems to be more useful in capturing and facilitating data acquisition and interoperability issues for patients who aren't in critical conditions [6]. Networked mobile devices are particularly useful in that case since their inability to guarantee an immediate delivery of data or messages, due to transient coverage, becomes a stronghold in addressing the needs of people on the move.

Such a paradigm turns out to be very useful also for chronic patients who are required to manage a disease by themselves while also being busy with their daily activities [7]. In fact an otherwise normal lifestyle often results in lessening the tie with the clinical settings in charge for the treatments which eventually become unable to promptly notice any situation calling for attention and fail to issue the corrective actions.

The architecture we devised is highly configurable in order to easily adapt to virtually any chronic disease domain. As shown in Figure 1 it is partitioned into two main interconnected hubs around which several satellite components can be plugged in as spokes. On the left side of the figure the Remote Care Unit (RCU) is located which is centered on the specific monitoring needs of a chronic patient. The RCU exploits mobile devices such as smartphones, PDAs, regular PCs or even plug-computers not equipped with monitors as *gateways* towards the Health Care Center Unit (HCCU) which is shown on the right part of that figure. The information exchanged by the RCU encompasses chunks of the Electronic Health Record (EHR) and log messages about activities to be accomplished on the patient side. The HCCU provides instead reminders about important tasks for a patient concerning his treatment as well as notifications for him about the effectiveness of his/her actions.

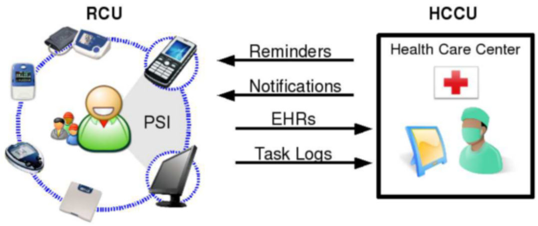

Figure 1 - The functional architecture of the platform.

On the RCU side mobile phones, PDAs and PCs may be interchangeably used as hubs depending on the skills and nomadic habits of a patient. One of their primary purposes is to act as collectors for clinical information required to build up the EHR, which may be acquired through multiple channels in order to guarantee the widest customization possibilities. Among the channels provided by the RCU, the basic one is based on a graphical user interaction. As shown in the figure this requires an explicit interaction of a user with the Personal Service Interfaces (PSI) available on the hub. Since mobile phones, PDAs and PCs greatly differ in terms of the graphical user experience and usability, their selection may be based on the patient profile.

Nevertheless, even though a patient profile may account for successfully adopting PSI for data acquisition, our personal experience has shown that this is definitely prone to errors or cheats especially when young patients are involved. Thus as far as possible we are also supporting automatic data acquisition directly from medical devices towards the RCU gateway exploiting wireless links.

To this aim we use primarily the Bluetooth^{TM} standard which is available on almost every mobile phone and PDAs as well as on a large and ever growing number of medical devices such as scales, blood pressure monitors, heartbeat detectors, pulse oxymeters, glucometers etc. Specific wireless connectivity solutions such as Infrared or ZigBee^{TM} require instead a PC to be used as a gateway.

Finally, we are also supporting data acquisition using the patient's own voice through regular phone calls placed to a dedicated service located at the HCCU. That service is able to model voice dialogues exploiting speech recognition and synthesis capabilities [8]. The possibility of acquiring clinical data with an automated dialogue interview effectively adds voice interaction as a new PSI to the phone gateway and is very important in order to provide a comprehensive PSI suite. This is particularly useful in addressing the needs of those patients whose profiles prevent the use of a graphical interface and no wireless solutions are available as alternatives.

Besides acting as a source of data, the RCU provides reminders and notifications to the patient. Thus a careful tailoring of those functionalities makes it also useful as a monitoring station for a patient's significant person requiring to keep in touch and be always aware of the patient state. Finally the RCU may be endowed with domain specific knowledge for issuing alerts or performing other actions locally without the need to wait for the complete loop involving the HCCU to be accomplished.

The HCCU is responsible for transferring any information acquired into the Hospital Information System, so that it may become available for inspection by the medical personnel. A host of services for monitoring trends in patient data and promptly raising alerts on the physician desktop have already been implemented although they will not be described here since they don't represent the main focus to the paper.

The platform architecture

From an architectural point of view the platform implements a general hardware/software platform which is almost independent from any domain specific data. In that way a particular telemedicine service for monitoring a chronic disease (i.e. diabetes, nephropaties, heart failure, stroke or pulmonary diseases) could be easily implemented on top of our platform exploiting the full power provided by its services with just minor case-by-case customizations required to match domain specific requirements.

The platform is based on the client-server computational paradigm in order to make it available remotely on the territory while at the same time collecting all data at the health care center. The communication between client applications and the server takes place on the internet. In order to enforce the ubiquity of the service, client applications have been mainly developed on mobile platforms with enough computational power and embedding networking capabilities either on a short range (i.e. Bluetooth) as well as on a long range (i.e. GPRS/UMTS and Wifi).

As shown in Figure 2(a) the RCU platform includes a unique pluggable component encapsulating all the Application Logic (AL). This is the only component where domain specific knowledge has been confined, which allows the implementation and configuration of a desired telemedicine service. Any other component shown in the figure and located around AL is totally domain independent. Those additional components constitute the foundation upon which the application relies to exploit local connectivity with personal medical devices (i.e. blood pressure monitors, scales, glucometers, etc.), remote data synchronization with the health care center as well as scheduling and tracking task execution. The Bluetooth Communication Module (BTC) takes the burden of the connection with personal medical devices thereby allowing us to distribute system intelligence and create clusters of local devices directly managed by the AL running on the mobile [8]. The right protocol for communicating with a specific device is hardcoded into it and automatically selected by the Device Driver Recognizer (DDR) so that AL may be totally agnostic about the syntax and the semantics of communication. A Local Database is set in order to contain a personal copy of the patient Electronic Health Records (EHRs) created with all the measurements collected from local devices and patient task reminders (REM) remotely placed by physicians. Finally, within the RCU a Scheduler Agent (Sched) notifies the AL each time a task is hit during the day, storing back into the Local Database any information about its completion status and outcome.

(a) *(b)*

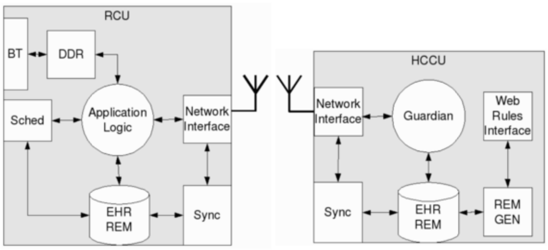

Figure 2 – (a) Remote Care Unit (RCU) architecture. (b) Health Care Center Unit (HCCU) architecture.

A key feature of the architecture allowing RCUs to consistently exchange data with the HCCU is represented by the Synchronizer module (Sync). That module implements a synchronization engine and a protocol based on XML transaction messages for updating, deleting, creating and resolving conflicts within records [9]. Its purpose is to guarantee a regular alignment concerning EHR and REM records stored on the patient side within those available at the treating centre. Finally, a Network Interface module is available for managing communication over the internet. That module, in gateways based on mobile platforms, provides everytime the most convenient channel between GPRS/UMTS or Wifi, while, on gateways based on PCs or plug-computers, it is used to discriminate between ADSL or Wifi connections.

The HCCU architecture is represented in Figure 2(b). Patients' EHRs and REMs are stored on a Local Database which is regularly updated with contributions coming from all remote databases through the Synchronization Agent (Sync) that implements a protocol matching the one available on RCUs. Through the server platform a physician can monitor his patients' health state keeping track of the associated EHRs acquired at their homes according to a personal measurement agenda. The agenda is a task schedule built by the physician through the server Task Definition Interface, a module allowing him to assign the duration and the frequency of a measurement (task) in a human-like way. Once acquired tasks are translated into reminders by a module called Reminder Generator that processes agenda entries and stores the reminders into the database. The server will later exploit this knowledge for monitoring the patients' compliancy to their assigned calendars of tasks through the Guardian. This module analyzes once a day all the EHRs and REMs and rises notifications of value non-compliance or time non-compliance if a patient has taken a measurement whose value falls out of the target range or misses to take the measure altogether. Notifications about non-compliance events are sent to both the physician and the patient through SMS or Email by a Notifier Agent that periodically spools the notifications generated by the Guardian. For those patients being overlooked by a significant other person, notifications may also be sent to that person through an additional RCU acting just as a monitoring station.

The reminder service

Compliance with self-management regimens is often poor, particularly with elderly patients. Nevertheless, since chronic patients play an active role in their treatment, they should carefully take measurements according to the expected time frame mandated by the protocol and avoid missing them altogether [7]. Furthermore chances that patients may forget to take their measurements increases even further for those who are still involved with their daily business.

To overcome the problem a reminder facility has been embedded in our architecture aimed at issuing appropriate warnings to a patient when the due time for a measurement is approaching. The facility is split among RCU and HCCU with different and complementary functionalities. On the HCCU the health care staff responsible for treating a patient may define some rules concerning tasks to be accomplished by the patient. This is based on the rationale that a generic task can be abstracted and applied to any measurement or action to be taken by patients with no concern about which specific chronic disease affects them.

(a) *(b)*

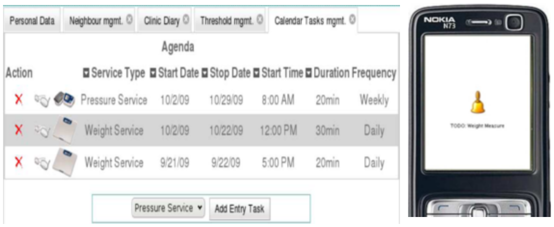

Figure 3 – (a) Task Rule definition interface. (b) A Task Reminder fired up.

As shown in Figure 3 a task rule concerns a specific measurement or action, provides information about its duration (i.e. validity days), its frequency (i.e. daily, weekly, etc..), the time window (i.e. start time and span), and the number of subsequent warnings to be issued within that window if the patient fails to immediately accomplish the tasks. After a rule is acquired, the system starts generating task instances based on it which are then periodically exchanged upon subsequent synchronizations.

The RCU has the burden of tracking tasks by issuing all the expected warnings on approaching due times depending on the platform functionality. Mobile phones and PDAs will do so by emulating an incoming virtual call, while the PC will use loudspeakers and popup alert screens. The RCU monitors if the patient fulfills the request and eventually records the completion status for each task, so that HCCU may be informed about it.

The compliance monitoring service

Monitoring compliance has always been a key issue for chronic diseases, since the better a patient is able to follow a prescribed treatment, the slower the evolution of his disease will be. This becomes an even more important issue in outpatient contexts when patient-staff interactions occur less frequently and the risk of overlooking or missing some important evidence increases. Therefore an explicit service has been embedded within the HCCU with the aim of helping physicians in promptly identifying those patients whose data suggest a critical situation. The information provided by the service may thus be regarded as a fast discriminating mean, so that patients with missing or remarkably abnormal readings can be immediately raised to the physician's attention.

The service is based on warning events which may be triggered by two different information sources. Complying with a given treatment entails first a proper accomplishment by the patient of all the assigned tasks. Since the RCUs inform HCCU about the completion status of each assigned task, rules may be easily provided for generating events concerning missing or missplaced task accomplishments. More warnings may be raised by generic rules checking if any single measurement falls beyond its allowed range or by specialized rules checking some combination of values. The inherent specialization of knowledge required for generating alarms prevented us from building a comprehensive modeling of the whole process for acquiring rules through an easy-to-use graphical interface. Thus while events and their subsequent notifications have been standardized in the system, medical knowledge for raising events must still be represented in terms of small code chunks into the system. This leaves to the interface just the option of enabling/disabling every single rule.

The notification service

After an event has been raised, in order to be effective, it must be notified to the health care staff for proper handling. The first time a physician will connect into the system he will be notified about any pending alarm directly through the graphical interface. Nevertheless requiring physicians to connect it's not an option since even before the availability of a home care system they were accustomed to schedule regular visits for chronic patients just every one or two months with no other contact in between. Thus in order for the system to be really effective we realized that it should proactively send notifications about significant events rather than wait for connections to occur. In order to generalize the solution, the capability of sending notifications has been factored out and encapsulated into a separate module which is dynamically fed up with events raised by the compliance monitor. The physician configures the module by indicating how and when (i.e. preferred time) to be notified about those event. The module collects any notification occurring since the last submission, and forwards them to the physician using the preferred mean (i.e. SMS, E-Mail, etc.) If requested, the same notifications could also be sent to the patient by forwarding them to the RCU.

Results

The platform developed has been used to implement two separate prototypes, one supporting young patients affected by Type 1 Diabetes Mellitus (IDDM) and the other one addressing uremic patients undergoing Peritoneal Dialysis (PD). In the first case young patients are required to measure their glycemia levels several times a day, usually before meals or snacks, in order to adjust the insulin therapy which is administered either through a pump (continuous infusion) or injections (boluses). In this case we have been unable to acquire readings automatically since glucometers are classified as medical devices and to date there is no approval by the Health Ministry for wireless ones. Measurements are thus inserted into the RCU by the patient using the GUI which also offers the opportunity to annotate data with additional information concerning meals and personal notes. Periodical synchronization with HCCU ensures that physicians may have those data promptly available for inspection.

Figure 4 – The Remote Care Unit for the peritoneal dialysis application.

Patients undergoing PD instead of being treated with external hemodialysis at a hospital setting, fill their abdominal cavity regularly at home with a suitable solution cleaning their blood by osmosis. For them it is mandatory to keep pressure and weight under strict control since that information acts as a clue for potential cardiac failure and helps in controlling daily urine volume preventing overhydration. The RCU in that case has been configured for automatic data acquisition since both a scale and a blood pressure monitor equipped with Bluetooth were found on the market, as shown in Figure 4. Given that the dynamics of body hydration is very rapid, according to the protocol it is mandatory to take frequent measurements always at the same time. Thus reminders were used to alert patients when time for the next schedule approaches. This application is currently undergoing an evaluation phase at a major hospital located in northern Italy. Four patients previously accustomed to write down blood pressure and weight measurements regularly were enrolled into the trial. The physician summoned all of them in a single day at the beginning of which he held a short preliminary statement illustrating the benefits of the trial. A short demonstration session was held and at the end each patient has been provided with a personal package including a complete RCU and an operating instruction booklet. Separate session training were then held in order to make sure that at the end of the day each patient was fully convinced to take part in the trial and be able to successfully operate the RCU. The trial is expected to last for at least 6 months with the aim of comparing the decrease in the physician workloads ensuing the reduction of face-to-face encounters with the quality of service delivered to patients.

Discussion

The scientific literature illustrates several implementations of telecare applications addressing the needs of chronic patients. Nevertheless each one of them seems to target a specific problem instance which restricts its applicability to the very same domain for which it was designed despite the potential demand for similar applications. Our efforts have been directed exactly in the opposite direction since they try to address the problem at a higher level by providing a sound architecture and an implementation platform which may be easily configured for building applications in different domains, each one with its own distinguishing features.

In addressing IDDM we configured the patient RCU with a GUI for acquiring data, notifications were adopted just for text messages issued by physicians and no reminders at all were used. Nevertheless, since the application is meant for young patients it has been almost mandatory that parents stay informed about the state of their kids. Within our platform the problem has been solved quite easily introducing additional RCUs for the parents configured with notifications as their only service. In that case notifications include either messages issued by physicians as well as readings so that parents can be informed about their kids even when they are away from home (e.g. at school).

In designing the uremic patient application the wireless module has been exploited for acquiring data on the RCU given the availability of suitable devices. This greatly simplifies data acquisition for elderly patients who are not proficient with the use of PCs or mobiles. Furthermore, since it is important to take measures at fixed times and the application is meant for elderly patients, the reminder service has been extensively used. Finally in both applications, once data become available to the HCCU, additional services have been implemented to help physicians in promptly identifying critical situations.

Conclusions

This paper illustrates a configurable platform for delivering home care services to chronic patients. The platform represents a solid foundation providing several common facilities which may be exploited out-of-the box in order to rapidly assemble and configure specific applications in different medical domains. The platform is composed of several Remote Care Unit stations located at the patients' homes and a Health Care Center Station located at the treating center. Both have been designed in a highly modular fashion in order to keep any issue concerning the representation of medical knowledge and its related processes separate from technological and networking issues. Configuring the platform we were able to implement two prototypes addressing separate medical domains and exploiting different input capabilities. In both cases we were able to provide patients and their family caregivers with proper advice concerning the therapies by embedding separate chunks of medical knowledge on remote stations and at the health care center.

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