Personal Health Systems for Patient Self-management: Integration in Pervasive Monitoring Environments

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Abstract. Various personal health systems have been applied in pervasive health monitoring, in which the need for patient involvement and self-management support with appropriate health information management tools has been highlighted. This paper presents a novel approach towards constructing a personalized mobile system, introduced as add-on to existing remote monitoring systems, for the management of health information by the patient himself/herself, with a Personal Health Record (PHR) constituting the system backbone. Particular emphasis is given to interconnection aspects with the monitoring system, so as to enable enhanced customization and management of monitoring-driven information provided to the patients according to their requirements/preferences. Communication issues between the monitoring and the proposed system are handled by using well-defined Web service interfaces for data exchange. Our prototype implementation, along with an application scenario presented, illustrate the applicability and virtue of the current work.

Keywords: Health Information Management; Self-management; Personal Health Records; Pervasive Health Monitoring; Service-oriented architecture.

1 Introduction

Several health monitoring systems enabled by pervasive computing technologies have been introduced for healthcare services delivery [1]. Moreover, various approaches have been proposed targeting on the generation and management of health information by the user/patient [2]. The patients' central role in the management of their health is indicated by a number of educational programmes aiming to provide them with skills and knowledge in order to cope with their diseases on a daily basis [3]. It is expected that patients' participation in self-management activities can be beneficial in terms of enhancing their communication with their doctor, helping them to focus on the treatment plan and be adherent, growing their level of self-confidence, and better managing their well-being [4].

Although various personal health systems have been applied in pervasive health monitoring, patient's participation in the involved procedures has not been systematically elaborated, while the need for better tools for self-managed care has been

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highlighted [5]. Considering in particular personal health information management by the patient, this typically involves user-to-system interactions which are rather limited, tight to the monitoring plan, and dedicated to the monitoring system functionality, all of which reduce actual patient involvement with respect to customization and filtering of information [6]. Moreover, in continuous health monitoring, supported by sensor-enhanced wearable/mobile systems and appropriate medical procedures initiated by healthcare professionals, the monitoring system may not generate appropriate feedback to the patient (e.g., in terms of false alerts in regard with the health status observed), due to a number of reasons associated with the variable context related to the patient (e.g., time, location, activity, situation, etc.) [7].

In the current work, we present a mobile, personal health management system (PHMS) targeted at chronic patients, who are using remote monitoring systems (RMS), are highly aware of their disease, and may wish to play a more active role in their disease management. The system relies on the Personal Health Record (PHR) notion [8] for self-reporting and is interoperable with typical RMSs [9]. This interoperation involves configurations related to patient decisions on the value of the monitoring output, as well as presentation preferences, which may increase system usability and acceptance. A mobile base unit (MBU) is used as the patient's personal terminal for health information display and management, and the communication hub for data exchange between the two systems. The basis of PHMS is a set of appropriately defined communication structures following the service-oriented architecture (SOA) paradigm [10], whereas terminology services are used for medical concept resolution and system interoperability. Thus, the PHMS and the RMS constitute two autonomous, yet interacting systems. The PHMS can be used as an add-on to monitoring systems capable of providing a suitable layer of Web service clients to their back-end infrastructure for chronic patients' self-management.

2 Functionality Overview

The functionality of the proposed PHMS is partially distributed between the MBU, residing in the patient site and aimed at recording patient-provided health information, and the system's server side, for the persistence of information recorded by the patient, as well as the provision of communication interfaces to the RMS and external services/applications. In the current implementation, the particular focus is on recording various conditions or symptoms. The afore-mentioned information constitutes the *Patient-driven Information* (PDI), i.e., information which is recorded manually by the patient himself/herself, as extensively analysed in [8].

In a pervasive health monitoring setting, the feedback provided to the patient via clinical-site initiated procedures is usually related to condition-specific content, i.e., various kinds of event-driven recommendations/alerts (e.g., a prompt message with exercise recommendations upon weight increase), periodic reports (e.g., sets of alerts/recommendations within a time-period), and questionnaires for the identification of subjective symptoms. We refer to this type of feedback as *Monitoring-driven Information* (MDI). In the current work, this information provided to the patient is considered as input to the PHMS, enabling the patient to process and filter it according to his/her needs, aiming to generate a personalized output.

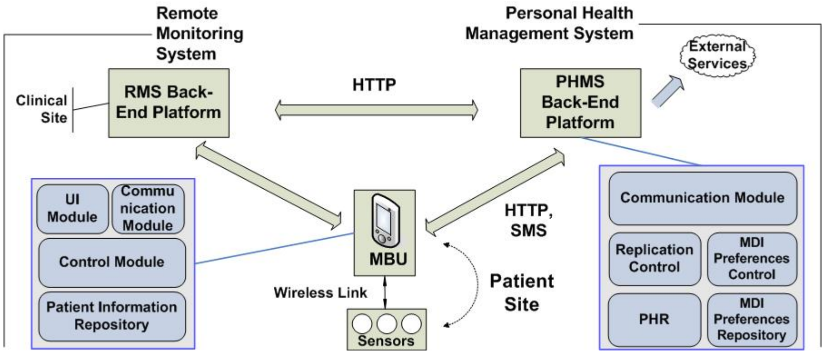

Fig. 1. Overall system architecture

In our current system realization, the patient is supported with advanced options to manage the provided MDI. Thus, the PHMS interacts with the RMS and the patient is able to configure the MDI insertion by providing the decision on whether and when the specified MDI is allowed to be inserted in the PHR. The above-mentioned patient's management operations are independent from the RMS, so as not to intervene with the medical personnel's initiated monitoring procedures. Finally, explicit system adaptations related to the terminology used, the level of MDI detail, and information access rights are provided, as these constitute personalized options, that may have impact on the patient's adoption of the system and long-term commitment. In this context, the patient is provided with a holistic view of personal health information integrating both his/her observations and reports as well as those generated by the RMS as encapsulated in PDI and MDI, respectively.

3 System Architecture

The primary objective of the proposed system architecture is to decouple the monitoring procedures from the PHMS functionality to the extent possible. Thus, the PHMS is conceived as an add-on to existing monitoring systems, allowing easy interconnection and avoiding complex configurations and communication mechanisms. This requirement is addressed via the definition of appropriate interfaces on a service layer upon HTTP, as well as a request/response model.

Figure 1 depicts the overall system architecture, comprising of the MBU in the patient site for patient's management of health information, the PHMS back-end used both as the surrogate host and communication gateway of the PHMS, and the monitoring back-end typically established in the clinical site. The MBU consists of four layered components: a) The *Patient Information Repository* constituting the record management system for persisting information about PDI, MDI and patient's preferences; b) the *Control module*, encapsulating the application logic; c) the *UI module*, responsible for UI adaptations as these apply according to certain patient preferences, and d) the *Communication module*, handling communication with the PHMS back-end. Requested data from the latter may be persisted in the Patient Information Repository or/and delivered to the UI module. Likewise, the PHMS back-end platform consists of an appropriate *Communication module* for connection with the MBU and the RMS, as well as a *PHR* repository and a *Replication Control module* for replicating data persisted in the *Patient Information Repository*, along with the *MDI Preferences Repository* and the *MDI Preferences Control* used for persisting and controlling information concerning patient's preferences, respectively.

4 Communication Infrastructure

For message exchange between the communicating parties, the Simple Object Access Protocol (SOAP) (http://www.w3.org/TR/soap/) encodings are adopted, whereas the definition of the service interfaces is provided via the Web Service Description Language (WSDL) (http://www.w3.org/TR/wsdl/). SOAP and WSDL provide the necessary communication infrastructure, so that the MBU and the PHMS back-end can communicate in an interoperable manner according to the SOA paradigm, offering also loose coupling and extensibility in the proposed approach [10].

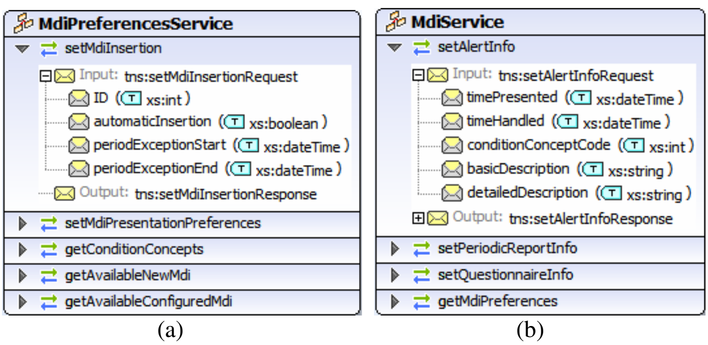

Fig. 2. Example Web service operations for: (a) patient MDI preferences and (b) MDI control

Two distinct service interfaces are offered: a) The *PHMS back-end – MBU interface* (Fig. 2 (a)) that is required for the transmission of user's MDI preferences to the system's back-end, as well as for the replication of data persisted in the MBU to the server side. b) The *PHMS back-end – RMS interface* (Fig. 2 (b)) that allows the RMS to set the MDI and transmit it to the PHMS back-end. Especially for the communication between the PHMS and the RMS, it is important to address interoperability issues in regard with the content semantics embodied in MDI. Although the support of a clinical standard-based format, e.g., HL7/CDA [11] could be applicable, this would introduce an additional layer of information de-serialization, as well as an unnecessary overhead in the transmission of document-based services. Thus, enabling access to widely adopted, medical terminology services was preferred for medical concept resolution. The PHMS back-end can then interpret the relevant concept identifier, e.g., for a condition/symptom, in a dynamic fashion by initiating appropriate connections to the defined terminology services e.g., by using the UMLSKS (Unified Medical Language System Knowledge Source Server) service interface (http://umlsks.nlm.nih.gov/).

5 MDI Insertion and Presentation Preferences

The MDI insertion into the PHR according to patient's preferences and needs is a fundamental element in enabling health information management by the patient in pervasive health monitoring. Thus, the patient can be provided with options to configure the insertion of the MDI to his/her PHR, e.g., with "Yes", "No", or a "Send me a notification to decide" options. A sequence diagram illustrating the afore-mentioned feature is depicted in Fig. 3 (corresponding to the operations of services (a) and (b) depicted in Fig. 2). Additionally, sophisticated preferences are supported, so as to enhance the manipulation of MDI by the patient. For example, these include the configuration of a context dimension, such as time. Thus, the patient may control which MDI can be logged into the PHR by defining e.g., temporal exceptions.

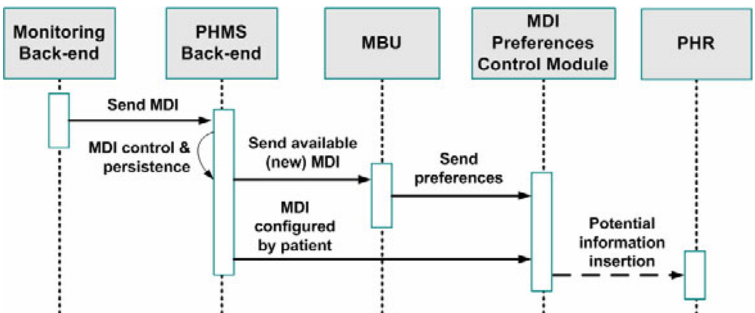

Fig. 3. Sequence diagram illustrating the potential MDI insertion into the patient's PHR

Three are the main dimensions according to which patient preferences are provided: a) the *level of MDI detail* that includes beyond basic information about an observed alert/condition, details, such as the conditions which lead to the MDI generation, description of correlated events, etc.; b) the *medical vocabulary used*, as according to user's configuration, the medical information presented to the patient may contain either user-defined terms possibly used in everyday natural language communication, or formal medical concepts as defined in medical terminologies, and c) *information access rights*, which are associated with the user's permission to view, edit, or delete an MDI instance. Such configuration capabilities can help the patient to focus only on system interactions of personal interest.

6 Application Scenario and Prototype Implementation

Jane, a 53-year old school teacher, is newly diagnosed with a heart condition and is prescribed with the appropriate medication. She is also provided with a wearable RMS to track her condition, and it is suggested to her to use the PHMS for personal health information management. According to her health status, it is decided by her doctor that a number of parameters will be monitored via the RMS, including blood pressure (BP), with the use of a specific sensor, depression, with the use of a short, standardized test, administered every other week, and dyspnoea, with the use of a

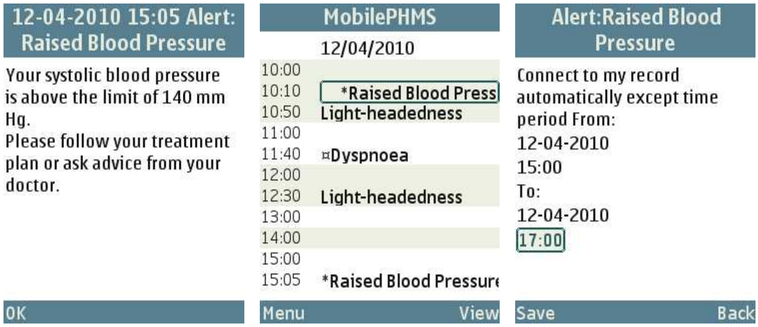

Fig. 4. Screenshots from the mobile PHMS application deployed in a Nokia N95 smartphone illustrating: (a) an alert generated as MDI into PHMS, (b) integration of MDI and PDI in patient's PHR (*: indicates an alert generated as MDI, ¤: indicates answer to a question generated as MDI, no indications correspond to PDI), and (c) patient empowerment to configure the insertion of MDI with temporal exceptions.

simple daily question. The patient also decides to record in her PHMS her medication intakes and, from time to time, a number of subjective symptoms (e.g., light-headedness, night-time coughing, etc.) that she finds relevant to her condition.

Accessing her monitoring system/application, Jane finds out that the RMS has issued a couple of "Raised BP" alerts and that it has incorporated in her periodic report almost daily increases of BP during afternoons. Jane realizes that these high BP bouts coincide with her visits to her local fitness-training center. Soon afterwards, she opens her mobile PHMS application (Fig. 4 (a), (b)) and realizes also that the same bouts have been logged into her personal record, since the default PHMS functionality is associated with the automatic insertion of all kinds of MDI into the PHR. In a next step (Fig. 4 (c)), Jane formulates a rule that no "Raised BP" alerts should be recorded in her PHR during the times and days she is training (while the monitoring procedures remain unaffected). From a technical perspective, the rule activation forces the PHMS back-end to check via the *MDI Preferences Control* module, whether the alert generation time is within the user-defined time period, whenever an alert of this type is received. This includes the resolution of the "Raised BP" concept using UMLS (in this case, "Raised Blood Pressure" with concept identifier 271647008). Following the approach of this hypothetical scenario, Jane is able to view health-related information on her PHR, combining personal observations (i.e., PDI) and objective information (i.e., MDI), filtered according to her personal preferences.

Aiming to explore the technical feasibility of such scenarios, in our prototype implementation, a sensor-enhanced RMS with an MBU, namely the Citizen Health System (CHS), was deployed [12]. CHS particularly targets at patients suffering from diabetes or heart failure, and provides the necessary communication infrastructure, such as mobile communication components, Component Object Model (COM) technology, etc., for information exchange between the patient and the clinical site. The most dominant type of system-generated feedback provided to the patient is the so-called "Tip" in the form of a recommendation, e.g., "Reduce your salt-intake" included in event-driven (e.g., raised blood pressure) educational sessions.

A testing service client layer for Web service consumption was implemented on the CHS back-end infrastructure with which information concerning event-driven educational sessions could be delivered to the PHMS. In the PHMS back-end infrastructure, the Apache Tomcat Server was used as Web application container, Apache Axis2 as the underlying SOAP engine for the Web services enablement, while UMLSKS Web service clients were constructed for dynamic medical concepts resolution. Although this deployment was performed using CHS, any RMS capable of supporting a Web service layer interface with the PHMS could be used.

A Nokia N95 smartphone was used acting as the MBU device, while Java Micro Edition (JavaME) was the chosen development environment to implement a prototype mobile application realized as the front-end of the described PHMS. In regard with the SOAP/WSDL approach, the communication with the PHMS back-end was achieved via JSR (Java Specification Requests) 172 Web Services API that utilizes the generation of appropriate client structures according to the specified WSDL documents. An open source SMS gateway (http://smstools.meinemullemaus.de/) was used for implementing the push operations of back-end requests via SMS, whenever the PHMS back-end initiates communication with the MBU, e.g., in case of sending a notification whether to insert or not MDI into the PHR.

For privacy and security reasons, all data held in MBU memory were encrypted via a 128-bit key based AES algorithm [13]. The key is generated upon the initial user registration in the mobile application via username and password credentials. The above mentioned functionality was implemented via the Bouncy Castle Crypto API for Java (http://www.bouncycastle.org/). Moreover, an authentication Web service was implemented requesting as input the same credentials and returning as response a session key for communication between the MBU and the PHMS back-end.

After the conduction of several communication tests, Web service invocations initiated by the MBU were found to last on average about 1.5 seconds (till reception of response), while service invocations from the CHS back-end lasted on average about 0.5 seconds. Thus, concerning performance, the proposed PHMS was found to provide fast enough request/response times for SOAP messages exchange.

7 Conclusion and Future Work

Although the importance of patient self-management towards effective healthcare has been stressed [4], this aspect has not been systematically elaborated in pervasive health monitoring environments. The current work introduces a novel approach towards building a personalized mobile system as add-on to RMSs for the management of health information by the patient himself/herself. In this regard, interoperability issues with RMSs have been elaborated, so as to enable the provision of customizable, advanced and personalized feedback to the patient.

Our prototype implementation constituted a technical proof-of-concept effort, in the direction of enabling the interaction between PHMSs and RMSs for supporting patient self-management. Such an interaction resulted in an integrated mobile system for patient health information management, aiming to contribute in continuity of care, independent living, and well-being.

The proposed system targets at patients willing to actively engage in their health management processes for the potential gain of self-management benefits [5]. This approach is in line with the notion of collaborative healthcare, where the patient's role is further enhanced in healthcare delivery. It is evident, though, that the presented system has to be evaluated in terms of usability, patient acceptance and medical procedures in appropriate clinical field studies.

The current work constitutes a basic step towards personalized and patient-targeted monitoring adaptations in pervasive health. In this regard, our future work involves the development of a generic methodology introducing patient's observations and personal preferences on the received monitoring feedback, handling of contextual parameters such as time and location, behavioral monitoring, and appropriate clinical decision support methods.

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