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Ubiquitous Health Monitoring Using Mobile Web Services

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Abstract

The ever-increasing rise in the number of chronically ill people is a growing burden on healthcare institutions. People with chronic illnesses such as heart disease, being among the leading causes for morbidity and mortality, need constant monitoring of their health conditions. Remote health monitoring of patients residing in their homes helps reduce healthcare costs. Current telemedicine solutions are used to remotely monitor vital signs such as blood pressure and blood sugar levels. These systems restrict the mobility of the patient, in addition to being limited in the number of vital signs that they support. The rapid developments in mobile devices coupled with the advancements in wireless access technologies have made mobile devices an increasingly attractive platform for delivering remote patient health monitoring services. This paper demonstrates the capability of mobile devices to provide mobile, low-cost, and efficient remote health monitoring through a mobile Web services-based approach. The proposed approach shows an agile, flexible, interoperable, and economical alternative to existing remote health monitoring systems.

1. Introduction

In order to maintain close supervision of the health conditions of chronically ill patients, long-term (chronic) care facilities provide accommodation and "hotel-style" services to these patients, in addition to long-term monitoring of their health conditions [1].

The rise in the number of chronically ill people has resulted in an ever-increasing burden on long-term care facilities, to the point that the cost of maintaining these facilities has or in the near future will become unsustainable [2].

Leveraging the fact that not all chronically ill patients require accommodation and assistive services provided by long-term care facilities, some patients can be offloaded from long-term care facilities, and allowed to live in their own homes, where their health conditions would be remotely monitored. Recent studies [3] show that not only consumers are willing to pay for remote/mobile health monitoring, but also caregivers are showing more interest in using mobile technologies to provide convenient and agile health monitoring. Throughout this paper, caregivers refers to healthcare professionals, physicians, and any relative in concern of a patient.

Most widely deployed remote monitoring systems, also known as telemedicine, are fixed and so restrict the mobility of the patient. Remote patient health monitoring using mobile devices can help overcome this constraint [4]. Mobile devices, specifically smartphones, have become the most convenient ubiquitous computing interface due to the advancements in their capabilities and functionalities, which have gone far beyond just providing traditional telephony services.

Remote health monitoring typically involves two phases: 1) collecting health parameters of interest from patient and 2) transferring these data to healthcare providers or the patient's caregivers. The first phase is typically performed either manually or automatically. In the manual approach, patients read the data from attached body sensors or supplied tools and report it through an interface on their mobile devices using either GSM or Internet access. In the automatic approach, mobile devices collect the data automatically by communicating with a body sensor network without interfering with the activities of the patient. The second phase is done after gathering the required data, in which mobile devices communicate these data to health monitoring centers. A data sample can be sent on a regular basis or an authorized caregiver may query the system for a real-time reading of parameters of interest.

Mobile devices can be used not only to monitor health conditions, but also as an interactive interface for patients to communicate with caregivers. Patients can receive directions and instructions from their physicians or caregivers on how to deal with certain health concerns or emergencies. Caregivers may require the provisioning of real-time data on-the-fly to better assess the current situation. Such an approach (MWS) would bring significant benefits to a wide range of people including patients who suffer from Alzheimer's; elderly people who are susceptible to the fall risk, women with high-risk pregnancies; people with undergoing drug therapy; kids who need extra care; athletics who are under a rehabilitation program; patients who have chronic conditions that require 24/7 attention, people that seek medical attention in remote inaccessible locations or in disaster situations.

In this paper, we demonstrate the capability of mobile devices to provide mobile, low-cost, and efficient remote health monitoring through mobile Web services provisioning approach. The proposed approach shows an agile, flexible, interoperable, and economical alternative to existing remote health monitoring systems.

The remainder of this paper is organized as follows. Section 2 presents the motivations behind adopting mobile Web services for remote health monitoring. The conceptual architecture and a brief description of the proposed ubiquitous health monitoring system are given in Section 3. Section 4 discusses the prototype implementation issues for the proposed system. Section 5 outlines the related work. Section 6 concludes the paper.

2. Why Mobile Web Services?

Mobile Web services offer the great potential of a multitude of services and opportunities; marking a shift in how everyday businesses interact and perform. Real-time access to context information would facilitate time-critical applications [5], such as healthcare and location-based services. Emergency disaster situations form another rich domain in which mobile Web services may play a critical role. More importantly, mobile service provisioning would expand on mobile device capabilities, such as cameras or GPS units. The adoption of mobile Web services provisioning in remote health monitoring is motivated by the following features that characterize service provisioning from mobile devices.

2.1. Instant Data Access

Mobile hosts are typically equipped with multiple wireless network interfaces and have the ability to communicate over heterogeneous networks such as 3G, WiFi, Bluetooth, etc. Mobile Web services provide a natural opportunity for enabling instant access to real-time data. Vital signs can be collected by medical sensors and transmitted via a short-range link (ex. Bluetooth) to the a patient's mobile device. Hence, what comes after is the responsibility of the mobile device and the system it hosts. Mobile Web services, additionally, can provide real-time access to continuously changing context attributes, such as patient location and other patient-related environment context attributes such as surrounding oxygen level.

2.2. Privacy

The privacy of personal information and security are deemed, until recently, to be at the lowest priority of businesses [6]. Lately, user personal data and privacy preservation have become a global concern. For example, EU (as per Stockholm programme)[7] has laid out legislation to push service providers to ensure the protection of personal data. Users should be given more options and full control on their personal data when being used, hosted or managed by some other party/vendor. Adopting mobile Web services provisioning in remote health monitoring preserves patients' privacy and gives the patient full control of their own personal data.

2.3. Interoperability

Interoperability allows system components, platforms and devices from different vendors to work together. Web applications are platform-independent as opposed to native mobile applications (such as Android or iPhone applications). The former can typically be run on different platforms and use a standard/mobile Web browser as a user interface. Whereas the latter has a customized mobile user interface and is essentially designed for a specific platform. Native mobile applications offer a higher convenience for mobile users than Web applications. The platform incompatibility problem is the major hindrance to having cross-platform applications. In healthcare domain, there are exist lots of different heterogeneous applications that offer a wide range of services for patients. Mobile Web services offer a natural opportunity for patients to benefit from such heterogeneous applications while controlling the way their data is being used or accessed by third-parties.

2.4. Context-Awareness

Context is any information that can characterize the situation of an entity, whether the entity is a person or any other relevant object [8]. Typically, mobile devices are associated with context information and users who have personal preferences. One of the chief motivations of mobile services is the enabling of tailored and adaptable services by exploiting the inherent mobility of the host device and the use of the relevant context information. To effectively employ context in service provisioning, we need to understand what and how context can be used. Dimensions of context information that are relevant to mobile Web services provisioning are:

`User preferences`: Mobile devices are typically associated with a specific user and the user's preferences can be used to personalize the service. A user could also have a dynamic set of preferences that change according to the situation. Healthcare systems can exploit the available preferences to improve the patient care delivered to the user.

`Device profile`: Mobile devices vary widely in terms of their capabilities and form factors. In ubiquitous healthcare systems, a mobile device could be the terminal available to health professionals or patients. A device profile includes available processing power, memory size, storage space, display area size, embedded devices (such as cameras, GPS, accelerometer). In mobile health monitoring, some basic data analysis can be performed at the patient's side (if the mobile device has enough resources) in order to detect immediate and life-threatening situations. Knowing the device profile enables healthcare systems to determine where data processing can be carried out.

`Environment Context`: Information characterizing the surrounding environment is of paramount importance when deciding on taking the appropriate actions in different events. For example, different caching strategies can be invoked based on connectivity levels in different areas. Environment context also includes location information. Location-awareness enables services to provide or access information relevant to the current situation. Patient location is an important context information that is essentially required in healthcare systems and remote health monitoring in particular. Location becomes a crucial context for patients who suffer from memory loss diseases such as Alzheimer's. Having access to the patient location help to provide prompt medical assistance in emergency and life-threatening situations. Besides, in wireless networks, the environment context may change frequently during the active connection between two endpoints. These changes are augmented when either mobile consumers and/or providers are on the move. In such cases, mobile Web services may utilize context information and switch to a better network to sustain reliable service
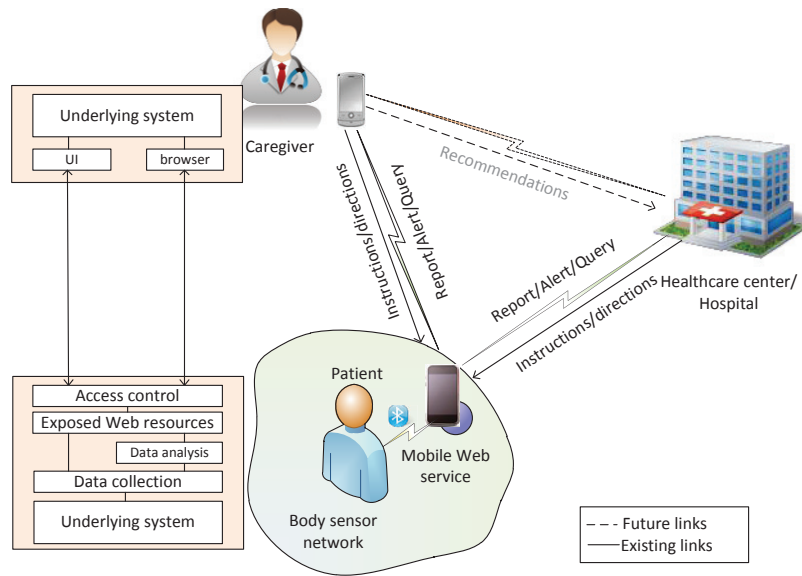
Fig. 1: A high level illustration of the proposed ubiquitous health monitoring system.

provisioning in such critical applications, or alternatively send cached data prior to an expected connection disruption. Therefore, people in charge can take proper actions or arrange for alternatives.

2.5. Mobility

Patients that have chronic conditions and need 24/7 monitoring are, conventionally, monitored using bulky, fixed equipment that may restrict their mobility or inefficiently perform monitoring over pre-determined periods. Ubiquitous computing promises users the increased freedom of mobility while accessing data services in an "'anywhere, anytime'" fashion. The increase in mobility intrinsically results in changing a user's contextual information such as location, and available resources around it. Using mobile Web services offers a natural opportunity for mobility and enables caregivers at remote locations to "'keep an eye'" on patients with critical health signs, even while patients or caregivers are on the move.

2.6. Cost Considerations

Providing such remote health monitoring over mobile phones offer an inexpensive alternative to the traditional telemedicine approaches. The whole set of requirements are: a capable mobile phone (which almost every one has right now), a mobile Web service hosted on the patient's mobile phone, a simple user interface at each side, and a standard Web browser are sufficient in most cases as we demonstrate later in this paper.

3. System Architecture

Figure 1 gives an overview of the overall system architecture and system components of the proposed ubiquitous health monitoring system using mobile Web services. The dashed links represent a future extension to the system to enable caregivers to communicate with hospitals and healthcare canters concerning the patient. A mobile Web service hosted on a patient's mobile device is the core of the system, which achieves interoperability and cross-platform integration with different applications. The Web service collects the data from the sensors attached to the patient's body in order to measure parameters of interest. The Web service can process the data locally and send reports, if sufficient resources are available on the host device, or relay

Resource	Relative resource address	Purpose
Vital signs	/signs/patient_id	Get a real-time reading for vital signs
Alarm threshold values	/thresholds/patient_id	Set threshold for vital signs, on which alerts are issued
Location	/location/patient_id	Provide instant location coordinates
User registration	/register	Allow users(ex. caregivers) to register for data access
User authentication	/approval	Control user access privileges

Table 1: Functionalities and methods exposed by the Web service

row data for remote processing. The patient is able to control who access the data and how the data is being accessed. At the other side, caregivers can communicate with the system using a native mobile interface or a standard Web browser.

3.1. System Description

The system can communicate in two modes, *proactive* and *reactive*. In proactive mode, the system continuously reports sensor readings of interest to caregiver. Reactive mode transmits sensor readings in response to events such as an exceeding threshold for a certain health parameter or a request from a caregiver to retrieve a real-time reading of all parameters of interest. In either mode, an alert could be issued whenever a parameter exceeds a pre-defined threshold, which can be set remotely by physicians or healthcare centers. Instructions on how to deal with the current situation until further medical assistance can be sent to patients in the event of an alert. At any time, physicians may retrieve previous readings for a certain period of time for actively monitored patients. The system may also perform data analysis (if the host has enough computational and storage resources) to detect anomalies and determine if the patient requires immediate medical attention. The system includes a demonstration on how health professionals may remotely change the system configuration and thresholds of certain health attributes, on which alerts are issued, on a patient's mobile device.

4. Implementation Issues

The objective of the proof-of-concept prototype is to show how mobile Web services can be effectively used in remote patient health monitoring. The Web service is designed using RESTful principals in Python programming language and based on the generic framework for mobile Web services provisioning we proposed in [9]. Standard Python library comes with a lightweight Web server that can provide the essential functionalities of HTTP-based service requests and methods (ex. GET and POST). The Python-based REST Framework `Web.py` [10] is used to handle the low-level details of Web service developments such as protocols, sockets, and process management.

The mobile Web service provides the core functionalities of the system. Table 1 shows the basic methods and functionalities exposed by the mobile Web service. Each method is a Web resource that can be accessed using the http-based resource identifier. The general format of the resource address is `Http://root-address/resource-name/[parameters]`. The Web service is deployed on a Samsung Galaxy II smartphone with a rooted Android Gingerbread, connected to a WiFi network.

In this prototype, we simulate four types of vital signs, namely, *oxygen saturation*, *blood pressure*, *heart rate*, and *sugar level*. The data collection phase is simulated by retrieving data samples from a database (as opposed to collecting them from a body sensor network automatically).

In our implementation, we have developed the Web service to offer different representations of the same service response, namely, *xml*, *json*, *html* using the `mimerender` [11], a Python library for RESTful resource representation using MIME Media-Types. We set the html format to be the default representation when no Http Accept header is identified. Therefore, when a Web service resource is called, an html-formatted

(a) User (ex. physician) registration form to access patient's data: the request would be awaiting for approval by the patient before the user is able to access data

(b) Sample vital signs reading (rendered in html representation)
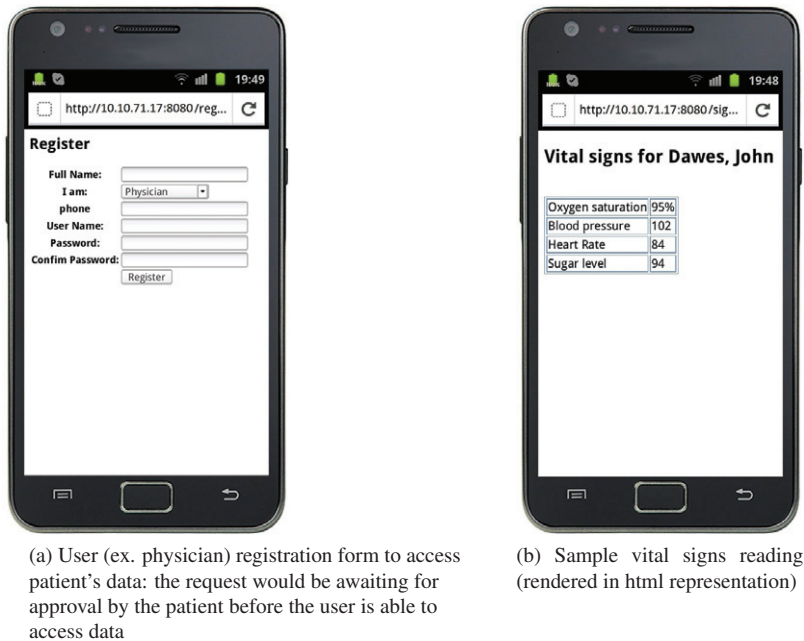
Fig. 2: Screen shots from a mobile Web browser accessing the Web service resources.

response is dispatched to the HTTP request handler's result. Figure 2 depicts some screen shots of a mobile Web browser accessing the Web service resources.

While the system offers an html-based response, Web browsers are not the most convenient interface for mobile users, even with the consideration of HTML5 design principles. Native mobile applications offer a higher level of convenience and superior user satisfaction within the limited mobile display. However, native mobile applications are platform-dependent and compromise system portability. To that end, our system prototype includes an android-based application (user interface) to access the Web service resources. The application has been developed using Android SDK. Figure 3 shows some screen shots from a health professional's application interface. Figurer 3a shows the list of patients currently being monitored by a physician. When a patient name is selected, the application opens up a detailed activity control as shown in Figure 3b. Each activity is linked to one of the Web service resources, offered from the patient's mobile device. For example, `Vital Signs` represents a Web service request to get a fresh real-time reading of the patient's vital signs. It's worth noticing that caregivers can remotely change the thresholds for vital signs, on which alerts are issued, by clicking on the `Threasholds` button.

5. Related Work

Healthcare institutions have recently exploited the advancements in information and communication technology to provide electronic healthcare services, and in particular remote health monitoring. Over the past few years, research in the domain of remote health monitoring can be categorized into three main streams, how data is collected, how data is communicated, and where data processing is performed. We focus here on work concerning the role of mobile devices and their related technologies.

Kulkarani et al. [12] developed a mobile patient healthcare system that aligns with the essential requirements and design spaces they derived for pervasive healthcare systems. The role of mobile devices in this system is limited to a mobile client terminal used to browse healthcare records. The paper proposes a role-based access control mechanism to assign the right access privileges to users at login time. Our proposed approach places the patients at the core of data access control. The prototype we have developed enables

(a) Patients under monitoring as seen at the healthcare professional side.

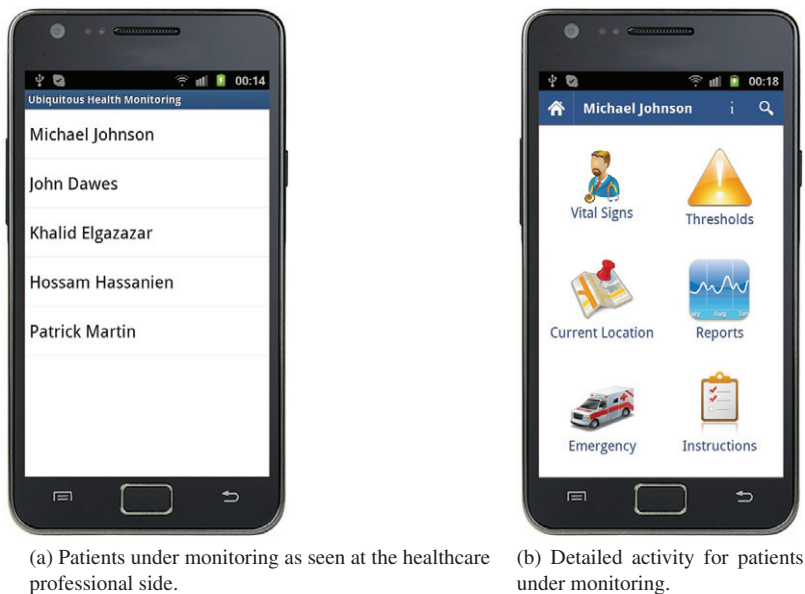(b) Detailed activity for patients under monitoring.

Fig. 3: Screen shots from the an Android-based client at the caregiver side.

patients to allow or deny access to their own personal data to registered users at the service method level based on the users' access privileges.

Dagtas et al. [13] present a framework for remote health monitoring systems in which a mobile devices collect vital signs from a Body Sensor Network (BSN) via ZigBee-based communication links. Mobile devices then send the collected data to a central fixed server for further data analysis and storage. In their architecture, mobile devices may partially process the data in order to detect immediate and life-threatening situations, before sending it to the central server for further processing. All communications are directed to the central server where the patient data is physically stored.

Oleshchuk and Fensli [14] highlight some aspects and new possibilities in the domain of remote health monitoring within the framework of future 5G networks. The authors claim that future 5G communication infrastructure lays the foundation for enhanced healthcare systems due to the improved addressing schemes, extended security services, and higher bandwidth it provides. Their research points out the limitations of current pervasive healthcare systems and how introducing the 5G communication infrastructure overcomes these challenges. Our approach will take advantage of the capabilities of the 5G framework and enable mobile devices and mobile services to take a key role in remote health monitoring.

Agarwal et al. [4] propose a simple conceptual architecture for remote patient health monitoring, in which a Web service serves as a communication medium between a patient's mobile terminal and an online database where heath records are stored. In this conceptual framework, a patient's mobile device collects data automatically from medical senors or, in absence of such communication, patients submit their readings manually to the system through an interface.

Another related research domain exists where researchers address the constraints of mobile devices and challenges of wireless networks when offering critical data services, such as remote health monitoring. Such constraints and challenges include: limited resources on mobile devices, addressability, accessibility, and privacy control. For example, Pawar et al. [15] focus on seamless vertical handover for multihomed mobile devices while providing remote health monitoring. Their approach utilizes context information (such as the application-perceived characteristics of available wireless networks) to make handover decisions.

All these systems lack interoperability and ease of integration with other existing or future systems. To the best of our knowledge, no system exists which utilizes mobile Web services provisioning in remote healthcare monitoring.

6. Conclusion

We propose a conceptual architecture framework for ubiquitous remote health monitoring using mobile Web services hosted on patients' mobile devices. The proposed architecture places the patient at the core of controlling access to his/her own personal data. The mobile Web service provides the essential functionalities of the remote health monitoring system in order to achieve cross-platform compatibility and enable ease of integration with existing or future healthcare systems. Since mobile devices are typically equipped with multiple network interfaces, the data collection phase is easy to carry out via a short-range communication link between mobile devices and biological sensors. A prototype is developed to show the ability of mobile Web services, hosted on mobile devices, to enable remote health monitoring. The opportunities made possible by the development of our preliminary proof-of-concept prototype encourages us to implement the system in real-life and get feedback from health professionals and patients.

Acknowledgement

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