Development and Usability of a Personalized Sensor-based System for Pervasive Healthcare

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Abstract—**Although a plethora of remote health monitoring systems have been proposed for chronic conditions, the challenge posed by the changing patient needs and the requirement for personalization in health monitoring to move beyond proprietary, difficult to extend, and unsustainable solutions still pertains. In this direction, we describe a mobile health system based on a smartphone, portable/wearable sensors for measuring the patient's physiological parameters, and back-end platforms for the health professionals to monitor the patient condition and configure monitoring plans in an individualized manner. A prototype system was developed based on a Service-oriented Architecture and integrating commercially available sensing devices. An experimental study has been conducted with 53 patients in order to investigate the usability of the proposed system. The patients were able to perform the majority of the target tasks successfully (Success Rate = 77%), while the perceived usability using the System Usability Scale (SUS) was found to be above average (SUS score = 73%), indicating that the patients overall perceived the system as both easy to use and useful.**

I. INTRODUCTION

Pervasive health systems are associated with the provision of healthcare services to anyone, anytime, and anywhere [1]. In this context various portable and/or wearable sensors can be employed providing the opportunity of monitoring the patient's physiological parameters in settings out of the hospital, e.g., at home or even at an outdoor environment, during his/her daily activities [2]. Via properly designed ICT-based tools, both health professionals and patients can monitor closely the health status, detect deteriorations, and initiate actions for improving health.

Even though a plethora of remote health monitoring systems has been proposed [3], [4], their acceptance by the patients has been limited [5], [6]. The majority of the present systems are proprietary, making it difficult to correspond to the changing requirements for effective monitoring of the patient health status. There is an evident need to move to more personalized systems in the scope of pervasive healthcare and continuity of care [7].

In this regard, we present a pervasive health monitoring system based on a smart mobile device and sensors with the following architectural features: 1) a Service-oriented Architecture (SoA) [8] which allows the provision of loosely coupled, extensible and interoperable services for both the patients and the caregivers, 2) patient monitoring plan (schema) definition by the health professionals according to the actual patient status during system run-time operation, and 3) an interface for adding or removing sensors easily. The development of a mobile system with the aforementioned features as well as an experimental usability study with patients, are described in the following.

II. SYSTEM OVERVIEW

In the proposed system, physiological parameters such as the heart rate, breathing rate, skin temperature, blood pressure, and activity, are monitored through the deployment of wearable or portable sensing devices within the patient's environment. A smartphone, referred as Mobile Base Unit (MBU), communicates with the sensors via Bluetooth, forming a Body Area Network (BAN) [9]. The MBU is responsible for managing the collection of the received sensor data (handling data aggregation, processing, and storage), and communicates the monitoring outcome to the patient and the carers. The monitoring outcome corresponds to personalized notifications based on the observed health status and is generated after processing the sensor data, e.g., an alert message delivered to the health professional as a result of observed low heart rate, a message prompting the patient to exercise more/less due to observed low/high activity, etc.

The monitoring outcome can be communicated to two different user groups. The first group involves the Medical Center (MC) operators, who receive the generated notifications, evaluate the severity of the patient health status based on the information received, and manage the telemonitoring process between the patients and the health professionals, thus reducing some of the task overload of the latter. The second group involves the health professionals, who are enabled to view monitoring outcomes through their system referred as the Health Professional Platform (HPP), and in the next step define the patient monitoring plan, i.e., configure the pre-conditions under which the notifications can be triggered as further explained in section III.B.

III. SYSTEM ARCHITECTURE

A. Service-oriented Architecture

A primary goal of the proposed architecture is to enable the easy adaptation to changing monitoring requirements. To achieve this target, the Services Provider Platform (Fig. 1) has been designed meeting three requirements: a) effective machine-to-machine interactions over a network among the internal diverse system nodes, i.e., the MC, the MBU, and

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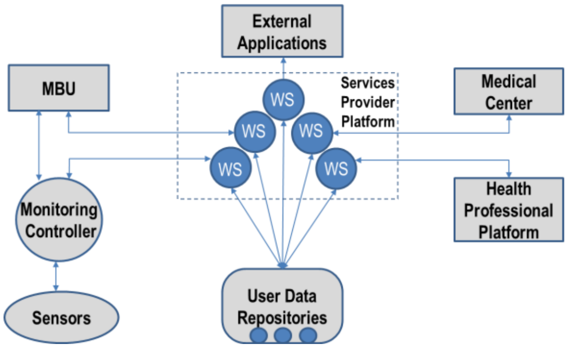

Fig. 1. System architecture

the HPP, b) interoperable operations enabling the communication with other external dynamic services toward autonomous living (e.g., calendar applications, nutrition management applications, etc.), and c) functional scalability and extensibility of the provided services, which can enable easy addition or extension of its current functionality. The afore-mentioned requirements were met by employing SoA and utilizing Web services as communication medium, a technology that provides open Internet standards for implementing business-logic functionality via loosely-coupled and reusable components [8]. In this context, the *User Data Repositories* persist information about the involved system users, the sensor raw measurements and notifications, etc., which is communicated to the information requesters (e.g., the MBU or other internal/external system nodes), through well-defined communication interfaces. In particular, Simple Object Access Protocol (SOAP - http://www.w3.org/TR/soap/) messages over the Hyper-Text Transfer Protocol (HTTP) are transmitted from the requesters, after calling the pre-defined Web service operations within the Services Provider Platform, via communication stubs corresponding to the Web Service Description Language (WSDL - http://www.w3.org/TR/wsdl/) interface.

B. *Personalized Monitoring Schemas*

During system run-time operation, health professionals are enabled to configure plans for personalized health monitoring according to patient condition [10]. A personalized monitoring schema constitutes a set of rules in the form of event-action, defined within the HPP. An event refers to a detected situation which is persistent over a specific time period (e.g., low heart rate, high blood pressure, etc.), and the triggered action corresponds to the forwarding of a notification message to the MBU, the MC, or the HPP, carrying information about the event and/or recommendations for handling it properly.

In our current design, an event follows the generic structured format: <*input[], output, parameters[], severity*>, where an event instance is also characterized by its starting time and duration. The input denotes the sensor(s) which triggered the event (e.g., the heart rate sensor) and the output is conceived as the characterization of the event (e.g., low heart rate). Parameters are the reconfigurable variables required for receiving the output (e.g., sensor data frequency, time windows for calculating sensing parameters, thresholds, etc.,), and severity corresponds to the degree of event significance as defined from the health professional (captured e.g., in a scale 1-5, or other coding systems). SensorML [11] was applied as data representation mean for monitoring schemas based on sensor measurements [12].

C. *Monitoring Controller*

In order to enable the support of multiple sensors within a personalized monitoring schema, we have developed a BAN interface for adding/removing sensors, called *Monitoring Controller*, based on which the sensing devices and the MBU communicate in a request-response fashion. More specifically, the developed interface currently supports the communication of devices based on Bluetooth in a sequence of steps, through which the initialization of communication, the discovery of available Bluetooth services, and the devices' connection based on sensor-specific actuating methods take place. In this regard, a request message can be initiated from the MBU, and sensor data encapsulated in the response message can be transmitted to the MBU, using the sensor-specific APIs.

IV. RESULTS

A. *System Development*

According to the presented functionality and architecture, a prototype system has been developed using specific devices, platforms, and technologies. We successfully integrated in this prototype a Nokia C7 smartphone acting as our MBU, Zephyr BioHarness, which is a wearable multi-sensing device, placed on the patient's chest for the continuous monitoring of the heart rate, activity, posture, respiration rate, and skin temperature, a blood pressure monitor device, as well as a weight scales.

1. Wear on the Zephyr belt
2. Press the power button
3. Press the 'Start button below'

3. Click on "Start"

Confirmation:
The Guardian Angel is running and monitoring your vital signs!

73 pulses per minute
16.2 breaths per minute
0.06 activity VMU(g)
N/A C on skin
18 degrees angle

Your heart rate is low!
49 pulses per minute
An automatic alert will be sent to the Emergency centre in: 22 seconds

I need help now!

(a) (b) (c)

Fig. 2. (a) Instructions to wear the chest belt properly, (b) real-time health status monitoring, (c) low heart rate alert displayed to the patient

Java Micro Edition (Java ME) was used to implement the MBU components in the smartphone (Fig. 2). Java ME is an open system for the development of mobile services and is currently supported by several commercial mobile devices. Java ME provides high-level APIs which can deal with the restrictions found on the mobile devices, e.g., low memory footprint, limited processing capabilities, small screen size,

Fig. 3. A subject participating in the experimental usability study conducted in the controlled hospital environment

etc. More specifically, the Java Specification Request (JSR) 82 API was used as interface that links the Bluetooth hardware to Java and supporting important functionality, like ad-hoc device connection and automatic service discovery. Concerning the MBU communication with the MC and the HPP, the JSR 172 API was used, in order to provide the Web service functionality based on the SOAP/WSDL approach. The Bluetooth protocol native security mechanisms were adopted, in order to protect the sensor data from possible data tampering or hi-jacking. Therefore, a key-based pairing between the MBU and the sensing devices is performed for their mutual authentication during the initial system setup in a supervised environment. In order to ensure the high quality of the received sensor measurements, we have currently used the worn detection circuitry provided by the sensors to identify whether the user wears properly the garment, since this can be a common cause of faulty or inaccurate data.

B. *Experimental Usability Study*

Considering that patients are the primary users of the proposed system, their requirements for usefulness and easiness of use should be met. To this end, a series of experimental evaluation sessions for exploring system usability took place in a 3-day period within a controlled hospital environment at the Pathology Clinic of Ippokrateio, General Hospital of Thessaloniki, Greece, with 53 chronic patients. The usability of the HPP and MC was not assessed.

The patients were enrolled in the study during their waiting in the clinic for scheduled check-ups. According to our inclusion criteria, the target users should be diagnosed with at least one chronic condition (heart failure, hypertension, diabetes, Parkinson, arthritis, stroke, COPD, asthma), not suffer from a known allergy to sensor materials or a known mental disease, and give consent for the conduction of the study procedure.

The participants were firstly asked, if they would like to participate in an anonymous study aiming to assess the value of a remote health monitoring system which could be used out of the hospital. Upon their acceptance, the rationale of health monitoring with mobile devices and wearable sensors was explained to them, followed by the demonstration of the proposed system through videos. The patients were also informed that the system could be easily tailored to additional sensors and applications according to what their physician may want to monitor. Each participant was then requested to perform a series of simple target tasks (Table I) while interacting with the system, and finally answer a usability questionnaire (Table II).

Twenty three men and thirty women were enrolled in the study, with an average age of 62.4 years old. Of the 53 patients 68% (36), suffered from more than one chronic disease. The most common diagnosed chronic condition was hypertension (41% of the patients) followed by arthritis (38%). 58% of the patients (31) reported having no degree, 28% (15) had a high school diploma, and 14% (7) had college education and above. In addition, 38% (20) of them had no familiarity with using mobile phone/smartphone technology beyond calls, 43% (23) were slightly familiar, while 19% (10) reported high familiarity.

TABLE I

USER EVALUATION TASKS AND SUCCESS RATE (S: SUCCESSFUL, PS: PARTIALLY SUCCESSFUL, F: FAILED)

User Tasks	S	PS	F
T1: Once you login to the MBU application, follow the instructions displayed on the screen. Now press the "Turn on" button that's located on the belt and then the "Start" button that is on the screen of the mobile phone.	30	19	4
T2: Wait for the connectivity between the belt and the phone to establish and then read the vital signs measurements taken.	40	5	8
T3: When you are done reading the various measurements, exit the application from the phone and take off the belt.	31	20	2
User Success Rate		**77%**	

During user interaction with the system (Fig. 3), the success rate was applied as usability metric in order to measure the overall system effectiveness by calculating the percentage of user success in completing target tasks correctly. The formula *Success Rate = (S + (PS*0.5))/NA* [13] was used to calculate the success rate, where *S* denotes the total number of successfully completed tasks, *PS* represents the total number of completed tasks with partial success and *NA* is the total number of attempts. The resulted success rate was 77%. Furthermore, the "Think Aloud" method was used which encourages the users to speak about their thoughts, opinion, and comments as they complete their tasks [14]. After the end of the interaction with the system, the users were provided with the System Usability Scale (SUS) questionnaire based on a typical five-level Likert

TABLE II

TOTAL SUS SCORE

SUS Questions	Mean SUS Score
Q1: I would use this system frequently	3.1
Q2: The system is unnecessarily complex	3.1
Q3: The system is easy to use	3.4
Q4: The support of a technical person is needed	2.3
Q5: The functions in this system are well	3.1
Q6: Too much inconsistency	2.8
Q7: The system is easy to learn	3.2
Q8: The system is very cumbersome to use	3.2
Q9: I felt very confident using the system	3.3
Q10: I needed to learn a lot of things before using	2.6
Total SUS Score	**73%**

scale, in order to assess the overall perceived usability of the system. The obtained SUS score was 73%, which is above what is considered average [15]. Success rate and SUS were chosen because they are easy to implement and produce valid usability data [16].

V. DISCUSSION

The presented system is primarily targeting at chronic patients who need close health monitoring, while preserving an independent living and well-being in their daily life. To this end, we implemented architectural features, i.e., a service-oriented architecture, personalized monitoring schema definition by the health professional, and an interface to add/remove sensors easily, for realizing a tailored mobile health system to changing monitoring requirements.

Our experimental usability study with patients showed that the system is usable. The 77% SUS score indicates that the participants did not seem to have encountered any major difficulties in using the system and thus were overall able to complete their instructed tasks.

From further examining the ratings in the SUS evaluation questionnaire, it can be concluded that the participants leaned toward the higher end of the rating scale (4 and 5) in the questions that reflected the ease of use and usefulness of the proposed system (Q1, Q3, Q7, Q8). To this end, the most important conclusion drawn from the conducted study was that the majority of the patients recognized and appreciated the potential benefits from using the proposed system despite their age. Specifically, patients were very positive about their vital signs being transmitted to their physician and that in case of a health status alert, the physician would be notified. This gave them a sense of security and reassurance without raising any privacy concern.

The answers concerning the necessity of assistance by a technician (Q4) seem to diverge (mean SUS Score=2.3). The variance in the responses suggests that some users were not confident in using the system on their own, possibly due to their unfamiliarity with using smartphone technology. This in turn indicates that proper training sessions and technical support would be necessary for the wider acceptance of such systems, especially by the elderly and those with low technology literacy.

The primary aim of this assessment study was to explore the usability of the proposed system as perceived by the patients. It is evident, however, that further longitudinal studies in real conditions are needed in order to assess the effectiveness and efficiency of the proposed system. Such studies should also investigate the usability of the health professionals' tools, which constitute an integral component of pervasive health monitoring systems.

In conclusion, the presented work described a personalized health monitoring system, which was found to be usable by the patients, and can be utilized in the context of patient independent living and pervasive healthcare.

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