Health Solutions Using Low Cost Mobile Phones and Smart Spaces for the Continuous Monitoring and Remote Diagnostics of Chronic Diseases

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***Abstract*—Our research group is developing solutions for public health mixing mobile devices extended by low-cost sensing technologies, and ubiquitous computing. We seek solutions for mass distribution that (i) enhance the average investment per patient, (ii) reduce the cost of public health implementation, and (iii) improve end-user experience. Our solutions are tailored to monitoring and diagnosis of conditions associated to chronic diseases such as obesity, hypertension, diabetes and obstructive lung disease. We focus on innovative mobile health (mHealth) that provide one-on-one, in-field diagnostic and monitoring procedures allowing 'good enough' diagnosis. This project is motivated by the need to enhance public and individual health care provisioning for in-development communities and the extensive availability of mobile computing technology in this environment.**

Keywords - Mobile phones; Smart spaces; Chronic diseases.

I. INTRODUCTION

We aim at creating applications that integrate techniques from the fields of mobile, ubiquitous, and pervasive computing in order to create low cost, comprehensive solutions for public health. With that purpose, we are exploiting the advances in mobile computing technology, which is promoting the massive use of phone-based applications by the diverse societal segments. This technology is becoming sophisticated enough to perform tasks comparable to their hospital equivalents, at price points accessible for members of emerging economies [1]. Moreover, solutions based on ubiquitous and pervasive computing enable the creation of dynamic and heterogeneous environments (the so called pervasive spaces or smart spaces. We envision exploiting this technology to automate and/or optimize the patients' daily tasks.

In specific, we are focusing on chronic diseases and risk factors such as obesity and hypertension. These conditions affect over 10% of the Brazilian population [2] and represent a major item in public health expenditures. The side-effects of the obesity (such as hypertension) are points of concern in public health. These condition leads to complications such as clogged arteries, stroke, and heart attacks that represent immediate risk to patients and potential high treatment costs.

In this context, we are developing low-cost solutions that mix mobile applications and ubiquitous computing. This technology will be used for continuous monitoring of risk factors and premature diagnosis of associated conditions. It will support both reactive actions in response to changes of patient' conditions and pro-active measures, such as proposing exercising and right eating habits.

We are exploiting the increasing the capabilities of commodity mobile devices, which are computational powerful and omnipresent. We are extending these devices with software applications and external sensors that provide non-invasive technologies for environmental and vital data monitoring.

The proposed technology provides the following benefits:

- Enhance average investment per end-user (patient), supporting the delivery of public health via mass distribution,
- Reduce costs of public health implementation, through mass distribution and the utilization of commodity devices. The delivery will be composed of free (open sources) software solutions, and low-cost (license free) sensor devices.
- Improve end-user experience by providing easy-to-use mobile computing interfaces and by exploiting the principle of "processing transparency" in ubiquitous computing.

This development is part of a larger research program at the Nossal Institute for Global Health, The University of Melbourne[3]. This work is structured as follows. Section II describes our motivation and related work. Section III presents the solution. The paper concludes in Section IV.

II. MOTIVATION

Several academic, governmental, and commercial institutions are already exploring the mobile and ubiquitous computing technologies for the creation of public health solutions. For instance, the "Compendium of ICT Applications on Electronic Government" [4] by United Nations Department of Economic and Social Affairs has more than 50 solutions being developed in several countries that scope and presentation, "Future of Health" prepared by the group PSFK for UNIFEC

 ISBN: 978-1-61208-119-9

[1]. This fact emphasizes the role of diagnostic and monitoring technologies to improve health systems.

Three facts motivate our research. First, mobile technology is widely available in developing countries, which provides the basis for extensive mobile health solutions. For instance, in Brazil there are over 187 million handsets (statistics from early-2010), present in 90% of municipalities and over 96% of population density [5].

In addition, several academic, governmental, and commercial institutions are already exploring the mobile and ubiquitous computing technologies for the creation of public health solutions. For instance, the "Compendium of ICT Applications on Electronic Government" [4] by United Nations Department of Economic and Social Affairs which has more than 50 solutions being developed in several countries that scope and presentation, "Future of Health" prepared by the group PSFK for UNIFEC [1]. This fact emphasizes the role of diagnostic and monitoring technologies portable and easy to spread to improve health systems.

Finally, there is a demand for home-base health monitoring solutions for chronic diseases. The Brazilian Institute of Geography and Statistics (IBGE acronym in Portuguese) shows that there are 17 million obese people in Brazil, representing 9.6% of the population. The Ministry of Health reported that the proportion of Brazilian adults diagnosed with hypertension increased from 21.5% in 2006 to 24.4% in 2009. Of these, the percentage of hypertensive patients is only 14% of the population until age 34. From 35 to 44 years, the proportion rises to 20.9%. And the rate jumps to 34.5% from 45 to 54, and 50.4%, from 55 to 64 years. This increase in the occurrence of the disease, according to age, is the result of eating patterns and lack of physical activity throughout life, in addition to genetic factors, there also stress and obesity.

Motivated by this scenario, we focus on the research and development of diagnostic solutions based on low-cost technology. It extends the mobile phone's capabilities towards mobile health and ubiquitous computing applications. We aim at solutions to monitor health conditions associated to chronic diseases (*i.e.,* obesity, hypertension and diabetes). We also promote academic research on smart environments and environmental sensors for telemedicine and developed by the authors presented in [6], [7].

This development draws on existing experience from other projects in developing low-cost sensors and associated software and user interfaces on mobile platforms. For example, [8], [9] show that governments, companies, and non-profit groups are already developing mobile health applications to improve healthcare. These reports present several programs, either currently operating or slated for implementation in the near future.

Moreover, [10], [11], [12], [13] propose alternative solutions that address relevant issues of (i) education and awareness; (ii) remote data collection; (iii) remote monitoring; (iv) communication and training for healthcare workers; (v) disease and epidemic outbreak tracking, and (vi) diagnostic and treatment support. We leveraged from these experiences and design principles in composing our solution.

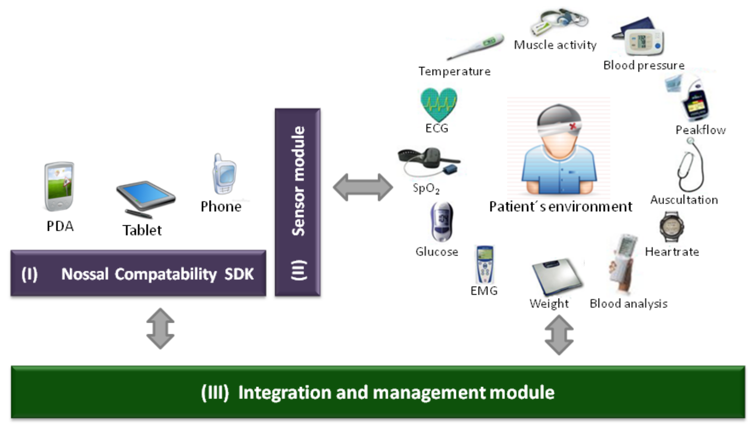

Fig. 1. System Architecture - Adapted from [14]

Next, we introduce the proposed system architecture and present the current prototypes.

III. Proposed Architecture

We propose a model of for an easy development of mobile health applications through a framework of software and hardware components. The new solutions will be composed of software applications that read data being collected by data sensors connected to commodity mobile phones. The solution complies with the existing standards such as programming languages, libraries, and hardware interfaces. These features facilitate dissemination to heterogeneous devices and also help reduce development and distribution costs.

Figure 1 illustrates the system architecture. There are three distinct modules:

- (A) the *Nossal Compatibility SDK* that provides the framework for software application development.
- (B) the *Sensor Module* that provides the (software and hardware) support for external sensor integration.
- (C) the *Integration and Management Module* that provides support for the management of smart space and the integration of software applications and sensor hardware.

These modules are described below.

A. The Nossal SDK Module

This module (Figure 1(I)) provides the execution environment for the application. It allows for applications to utilize abstract, reusable modules. It provides re-usable functionality in the domains of data gathering, data processing, and human interfacing. This component accomplishes our goals of compatibility, integration and standardization. Some of the design principles for this module are:

- Portable to different operation platforms (*e.g.,* Symbian OS, Windows) while preserving the same functionalities and programming interfaces.
- Provides a scripting language that supports basic data processing functionality, fully integrated to the data gathering

and human interfacing functionalities. This provides a "compilation free" enthronement for application writing. That is, applications are developed as scripts (plain text), which are loaded, parsed and executed by the operation environment.
- Provides the basic functionality to support the varying human components available in different devices, as for example keyboard, screen, audio, microphone, and others. The design is flexible to adapt to the available hardware support.
- Extensible through the development of external packages that can be added to the operating environment both during the development phase and at run-time.

B. Sensor Module

The Sensor Module (Figure 1(II)) provides the interface to attach external sensors to the mobile phone. This module is composed of a microprocessor that controls a number of external Analogue/Digital (A/D) ports where the sensors are attached. On the other side, there are the *de facto* standard USB interface and wireless BlueTooth interface (in research) to connect to the mobile phone. Once plugged into the phone, it is recognized as a standard USB device.

The A/D ports allow the connection of "sensor modules" such as the pulse oximeter, ECG, and phonocardiogram. Other sensors can be developed and attached to this interface, as long as they respect the electronic parameters established by the module's configuration. The design allows the integration of up to 12 sensors. Virtually any type of sensor can be plugged in as long as it provides a signal output between 0V and 5V. The electronics are composed of inexpensive elements that cost less than USD10.00 (ten American dollars) in the retail market.

We apply the 32-bit MCF51JM128 microcontroller (which costs around AUD 4.00) from Freescale Semiconductor Inc. This component can be programmed using the C language. It also provides integrated flash and RAM memory for the application and data storage. In addition, it supports interface to external devices via USB interface. Figure 2 has a picture of our current development prototype. We intend to produce this module in a reduced form factor to facilitate distribution and portability.

Figure 2 has a picture of our current *Oximeter sensor prototype*. It displays the following elements:

- (i) *External Sensor Module*, in its prototype version: we intend to produce this module in a reduced form factor to facilitate distribution and portability; the prototype version contains the microcontroller (square in the bottom-left corner), the module's electronics (square circuit board on the right), and a "debug board" (underneath the microcontroller) that will not be part of the final product.
- (ii) *USB Interface*: provided as output by the *External Sensor Module*; it requires a common mini-USB cable to connect this module to the mobile phone.
- (iii) *Mobile Phone*: we use a HTC SmartPhone running Microsoft Windows Mobile 6.1 for the prototype; we opted for this development platform due to hardware availability as Microsoft Research sponsored this project,
- (iv) *Oximeter Probe*: attached to one of the A/D ports of the *External Sensor Module*, which controls its functionality such as activating the LEDs and collecting the results from the light sensors.

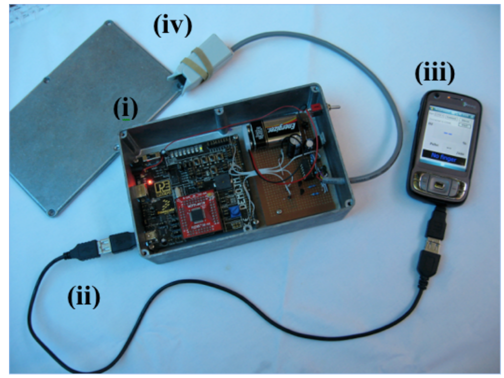

Fig. 2. Oximeter Sensor Prototype

C. Integration and Management Module

The Integration and management module (Figure 1(III)) is mainly responsible for management of smart space. It has internal sub-modules used by context-awareness, discovery, adaptation, localization services and other common services in ubicomp area. This module also is used to provide applications to environment and to integrate sensors and other devices immersed there but that was not connected via sensor module. This module currently is under construction and is the main focus of Brazilian chapter of Nossal Institute project.

D. Current applications and future extensions

Based on this architecture, we are developing applications for data collection, monitoring, and diagnosis of symptoms related to chronic diseases. We are researching and developing the following applications.

The *Intelligent Activities Manager* provides a solution to monitor patient's daily activities. It includes an environment monitor composed of sensors and accelerometers. Once certain conditions are detected, it reminds the patients on the importance of performing certain activities, such as scheduled medical appointments, exams, drug dosage reminding, and even conditions like laziness and lack of physical exercises. The design aims at flexibility, user-friendliness, and context awareness. The goal is to provide a personalized solution to motivate patients to perform physical activities and take care of their health and well-being to prevent the condition escalation.

The *Integrated Solution for Collecting and Monitoring of Vital Signs* provides a solution for integrating vital data from multiple sensor units - *e.g.,* from our low-cost phonocardiogram, our clinical thermometer, our respiratory rate calculator and others. The solutions supports remote monitoring by transmitting the collected information to health centres. The integration of external sensors happens through an open

 ISBN: 978-1-61208-119-9

Fig. 3. “Ready Set” Application Prototypes

interface, as well as the development of the data collecting and transmission applications. Thus, we foresee the integration of multiple sensor coming from different research initiatives, transforming this application into a platform for combined remote monitoring.

The *Low Cost Piezo-Electric Scale* is a hardware-software development initiative that complements the sensing capability required for the monitoring of chronic diseases’ conditions. It provides the tool for continuous weight monitoring and control, communication the measurements to the health central (using the “ Integrated Solution for Collecting and Monitoring of Vital Signs” described above). For example, the application can provide notification of encouragement when the patient looses weight and the other way around. We emphasize that this application is also useful for the diagnosis and monitoring of malnutrition conditions, allowing for further project extensions.

In addition, we will be integrating these solutions to some of the existing applications of the Nossal Institute for Global Health that add-value to our project, *viz.*:

- The *Nossal Oximeter Sensor*: it works by measuring the difference in absorption in two wavelengths of light. With each pulse of arterial blood into the fingertip or ear lobe it is possible to calculate the percentage saturation of haemoglobin with oxygen. The primary use of this sensor is to be in the diagnosis and assessment of the severity of respiratory disease and hypoxaemia in an outpatient setting.
- The *Respiratory and Pulse Rate Calculator*: this application uses the system clock inside the mobile phone to capture the time that the health worker begins and ends counting just 10 respiratory cycles; it provides tools to aid health field-workers counting respiratory or pulse rates.
- The *Formulary/Drug Dose Calculator*: this application records a subset of the information in the local formulary - the names, indications for use, dosing regimens and presentations of drugs available for health workers to prescribe to their patients. When the health worker selects a drug, an indication and a presentation (*i.e.,* capsules, tablets, ampoules, and others) the application calculates the appropriate dose for that patient, along with other supporting information relevant to the prescribed drug.
- The *Drip Rate Calculator*: this application prompts the user for the volume to be infused and the infusion period. It then calculates the corresponding number of drops per minute. No need for calculations or a wristwatch.
- The *Drug Reminder Alarm*: this application makes use of the built-in digital camera that is present in mid-range/sophisticated phones, and in some basic phones as well. It is meant to be used by pharmacists when they dispense complex drug regimens. The pharmacist lays out the correct number of tablets or capsules to be taken at a given time of day, takes a digital photograph, and then adds the photo and the time details to the application’s task list. The alarm will then ring at the set interval, and show the photo on the screen to remind the patient to take the prescribed medication.

As part of the development cycle, each application must be field tested after appropriate testing and debugging. We will perform qualitative research studies using experts to assess the internal validity of the diagnostic and management algorithms, and the correctness of final recommendations. Moreover, the results from each solution will be compared to the current best methods for measuring the same parameters in order to validate the approach.

IV. Conclusions

This project is motivated by the need to enhance public and individual health care provisioning for in-development communities. We focused on creating the software and hardware infrastructure required to facilitate the development of low-cost health-care solutions. We are exploiting the use of commodity mobile phones and ubiquitous computing to create a solutions for mass distribution that (i) enhance the average investment per patient, (ii) reduce the cost of public health implementation, and (iii) improve end-user experience.

The solution contributes to improved health and well-being by providing a comprehensive, flexible, and low-cost mobile health diagnosis, monitoring and management solution. We are bound by the necessities and requirements of the Brazilian government health programs, thus creating a solution that is suitable for immediate implementation by that institution. The solution complies with the existing standards such as programming languages, libraries, and hardware interfaces and operates using minimum computing resources. We anticipate the following benefits from this technology’ implementation:

 ISBN: 978-1-61208-119-9

- To provide the assistance tools to support for home-based health programs, improving end-user experience.
- To improve the performance and scope of the health system, by reducing the costs of health delivery programs, thus enabling the implementation of prevention, monitoring and diagnosis tools by a ubiquitous, pervasive and inexpensive technology.
- To deliver extended support for health programs to prevent chronic diseases, contributing to the larger goal of overall health is to promote the diagnosis, prevention and treatment of health for the largest portion of society possible.The results contribute to promoting an innovation culture and economy with the development of frontier technologies for public health improving health care conditions.

The current implementation is limited by the needs of the immediate problem – *i.e.,* a solution to monitor health conditions associated to obesity. Hence, the prototypes are being developed for a specific purpose and have limited scope. Nonetheless, the framework components – *i.e.,* the Nossal SDK and the sensor interface – are device agnostic and can be used for general purpose. They can be re-used in future projects that we will run in other problem domains.

Future developments include refining the technology and developing new applications for the diagnosis of other diseases and health conditions. We intend to create the distribution device in compact format based on the technology already developed. Moreover, we must extend the Nossal SDK, especially concerning the capabilities of the scripting language and support to hardware technologies. Finally, we intend to conduct extensive tests from the technical and clinical perspectives to ensure the portability, robustness, and accuracy.

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