Applications of Smartphones for Ubiquitous Health Monitoring and Wellbeing Management

Mladen Milošević, Michael T. Shrove, Emil Jovanov

Electrical and Computer Engineering Department

University of Alabama in Huntsville

Huntsville, AL 35899, U.S.A.

Original scientific paper

UDC

Abstract: Advances in smartphone technology and data communications facilitate the use of ubiquitous health monitoring and mobile health application as a solution of choice for the overwhelming problems of the healthcare system. In addition to easier management and seamless access to historical records, ubiquitous technology has the potential to motivate users to take an active role and manage their own conditions.

In this paper we present capabilities of the current generation of smartphones and possible applications for ubiquitous health monitoring and wellness management. We describe the architecture and organization of ubiquitous health monitoring systems, Body Sensor Networks, and integration of wearable and environmental sensors. We also describe mainstream mobile health related applications in today's mobile marketplaces such as Apple App Store and Google Android Marketplace. Finally, we present the development of UAHealth - our integrated mobile health monitoring system for wellness management, designed to monitor physical activity, weight, and heart activity.

Keywords: Smartphone, Body Sensor Networks, Health, Wellbeing.

Introduction

Information and communications technologies are transforming our social interactions, our lifestyles, and our workplaces. One of the most promising applications of information technology is healthcare and wellness management. Healthcare is moving from reactive response to acute conditions to proactive approach, characterized by early detection of conditions, prevention, and long-term healthcare management. Current trend places emphasis on the management of wellness and acknowledges the role of home, family, and community as significant contributors to individual health and wellbeing. This is particularly important in developed countries with a significant aging population, where information technology can significantly improve management of chronic conditions and improve quality of life. Demographic trends indicate two significant phenomena: an aging population due to increased life expectancy and a baby boomer peak. Life expectancy has significantly increased from 49 years in 1901 to 77.9 years in 2007. According to the U.S. Census Bureau, the number of elderly individuals over age 65 is expected to double from 35 million to nearly 70 million by 2025, which is when the youngest baby boomers retire. This trend is global, so the worldwide population over age 65 is expected to more than double from 357 million in 1990 to 761 million in 2025. These statistics underscore the need for more scalable and affordable health care solutions. To counter these trends, the Medical Technology Policy Committee of the IEEE USA believes:

"Appropriate adoption of existing and emerging technology can improve the efficiency and quality of health care delivery, restrain cost increases and, perhaps most importantly, improve the quality of life for our aging population" [1].

With advantages in technology and data communications, ubiquitous healthcare systems such as mobile health applications are becoming the quickest solution to the overwhelming problem of the healthcare system issues [2][3][4]. In addition to easier management and seamless access to historical records, ubiquitous technology has the potential to motivate users to take an active role and manage their own conditions. This is particularly important for the management of chronic conditions.

Electronic medical records allow personalization of services and collection of large database of records. Personalized systems will take advantage of data mining, decision support software systems, and context aware systems to facilitate diagnosis, treatment, and care based on an individual's genetic makeup and lifestyle[2][5].

In this paper we present capabilities of the current generation of smartphones and possible applications for ubiquitous health monitoring and wellness management. We describe architecture and organization of ubiquitous health monitoring systems, typical applications, and the development of our iPhone application *UAHealth* for health monitoring and management.

Ubiquitous Health Monitoring

Wearable health monitoring systems integrated into a ubiquitous mobile health system (mHealth), emerged as a technology of choice for ambulatory monitoring [6][7]. This approach facilitates continuous monitoring as a part of a diagnostic procedure, optimal maintenance of a chronic condition, or computer assisted rehabilitation. Traditionally, personal medical monitoring systems, such as Holter

FIGURE 1. SYSTEM ARCHITECTURE OF THE UBIQUITOUS HEALTH MONITORING SYSTEM

monitors, have been used only to collect data for off-line processing. Ubiquitous connectivity allows real-time processing and communication; it also facilitates warnings, computer assisted rehabilitation, and continuous health monitoring.

Important limitations for wider acceptance of the existing systems for continuous monitoring are the following: a) unwieldy wires between sensors and a processing unit, b) lack of system integration of individual sensors, c) interference on shared wireless communication channels, and d) nonexistent support for massive data collection and knowledge discovery. Wireless Body Area Networks of intelligent sensors [2] provide a solution for unobtrusive continuous ambulatory monitoring. Typical system architecture of the ubiquitous health monitoring system is presented in Figure 1. A set of on or in-body sensors monitor a person's physical activity and physiological signals. Sensors are controlled and communicate with the personal server that integrates information from individual sensors and communicate with *mHealth* system [7][8]. *mHealth* is defined as "mobile computing, medical sensor, and communications technologies for health-care" and has the potential to revolutionize health care by allowing inexpensive, non-invasive, continuous ambulatory health monitoring with near real-time updates of electronic medical records via the Internet.

mHealth systems can be used for diverse, unobtrusive monitoring:

- postoperative monitoring of patients;
- monitoring of patients with chronic diseases;
- social networking of relatives and peers for monitoring of elderly;
- lifestyle and general well-being monitoring (e.g., to deal with obesity);
- wellness and exercise monitoring;
- monitoring vitals and status of soldiers and firefighters;
- emergency medical care and mass casualty events;
- computer-assisted rehabilitation and therapy; and
- development of new emergency services with prolonged monitoring.

Body Sensor Networks

Technological advances in low-power integrated circuits, wireless communications, energy scavenging and storage have enabled the design of Body Area Networks (BANs), also known as Body Sensor Networks. Body area networks integrate low-cost, lightweight, intelligent sensors and networking platforms. BANs connect nodes attached to the body surface, implanted into body, or dispersed in clothing. The nodes have sensors for vital sign monitoring (through ECG, SpO2, blood pressure and similar sensors) and motion monitoring (through accelerometers, gyroscopes and similar sensors).

Emergence of the new generation of wearable sensors is particularly evident in cardiac monitoring. Several systems are commercially available, such as iRhythm [9], Corventis [10], Cardionet [11], and Toumaz [12]. Highly integrated systems, such as Sensium by Toumaz, provide both physiological monitoring and activity monitoring on a single, low-power small patch [13]. Wearable systems may integrate several sensors embedded in clothes [4][14] or using smart textiles [15] [16][17]. Capacitive sensing and smart clothes promise an increased level of user's convenience and comfort. Wireless communication within Body Area Network (BAN) or Body Sensor Network (BSN) significantly improves user's convenience and allows integration of implanted sensors, such as pacemakers and future generations of blood glucose monitors. Wireless communication standards commonly used in BANs are Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4 with additional specification of network, security, and application layers on top of the official standard), and ANT. All standards are working on 2.4 GHz (although some Zigbee versions are working on 915 MHz and 868 MHz) with the typical data rate of 1-3 Mbit/s for Bluetooth, 250 Kbit/s for Zigbee, and 1Mbit/s for ANT. There are also other alternative technologies for wireless communication in BAN, such as custom wireless radios, the medical implant communication service (MICS), and ultra wideband (UWB).

Environmental Sensors and Context Awareness

Context represents any information that can be used to describe the state of a person, place, or physical object. Context awareness represents the system's ability to detect a user's state. Context-awareness in BAN describes the ability of a system to sense user's state and the environment, and modify its behavior based on this information [18].

Traditionally, the knowledge of the context of the user is acquired through self-reporting. This method is both time consuming and unreliable, especially for the elderly. Current technology provides context awareness, such as GPS location, light, noise level, position, activity, proximity, social interaction, and connectivity. Context recognition can be formulated as a general pattern recognition process which consists of data acquisition, feature extraction, model construction and inference, and performance evaluation [17].

Due to great diversity of context aware environments, the range of physiological conditions, and the dynamic nature of BSNs themselves, there are many challenges for context-aware sensing. The common issues are overcoming sensor noise, node failure, integration of multi-sensory data, providing long continuous usage, smooth context recognition, and selecting relevant data in BSN [18].

Smartphones

First generations of ubiquitous systems used wearable computers that were worn on the body or integrated into clothes. However, the need for ubiquitous connectivity and integration of multiple devices on a single platform created the need for smartphones as a single universal platform. Mass market created a push for ever increasing performance of smartphones, where recent smartphones use high performance embedded processors. As an example, Motorola Atrix 4G uses the following:

- 1GHz dual core Nvidia's Tegra 2 processor
- Display 4.0-in. (960 x 540)
- Sensors: Acc, GPS, Proximity, and ambient light sensors
- WiFi 802.11 a,b,g, and n.

Smartphone market exceeded 100 million units in Q4 2010. Typical contemporary smartphones and operating systems are presented in Fig. 2 and Table 1.

In today's ever-increasing use of mobile phones and mobile applications, users expect to have their favorite desktop applications on smartphones. In addition, a number of new applications are taking advantage of the specific features and sensors on smartphones. Smartphone manufacturers introduced a major shift in the application distribution by creating application stores. Apple introduced the concept as the App Store in July 2008. Many applications offered free light versions with limited functionality, and reasonably priced fully functional versions. In September 2009, the App Store had over 2 billion downloads, with more than 100,000 applications available [19]. In January 2011, the App Store had over 10 billion downloads, with more than 300,000 applications available.

Figure 2. Contemporary smartphones and operating systems, from left to right: HTC Evo 4G (Android), iPhone 4 (iOS), Blackberry Torch (RIM OS), Nokia C6 (Symbian), and HTC 7 Trophy (Windows Phone 7).

Table 1. Smartphone Operating Systems and Languages [19]

OS	Symbian	RIM BlackBerry	Apple iPhone	Windows Mobile	Google Android	Palm webOS
Language	C++	Java	Objective-C	C#	Java	Javascript

Current statistics of applications in the App store are the following [20]:

- Total Active Apps (currently available for download): 362,306
- Total Apps Seen in US App Store: 439,458
- Number of Active Publishers in the US App Store: 75,358
- Current Average App Price: $4.15
- Current Average Game Price: $1.06
- Current Average Overall Price: $2.46

The revolution introduced by the Apple App Store was quickly followed by others. For example, Google opened Android Market in October 2008. In December 2009, there were over 20,000 applications available, and by the end of 2010 the Android market had over 200,000 applications available and over 2.5 billion downloads.

However, applications that once had to run on full size desktop computers now can run on mobile devices with similar performance. This makes for a challenging task for developers. Not only do yesterday's apps have to run on a smartphones but also have to fit on a smaller screen and run on fewer resources and limited power budget. That is why it is critical that smartphone developers carefully plan application design, not only program organization but also the user interfaces. Most of the smartphone operating system developers, such as Apple, Google, and Microsoft deliver guideline documents to help with the design of the application [21][22][23]. All of these guidelines have three things in common:

- keep the application responsive,
- keep the application consistent with the platform, and
- design for the platform.

If these guidelines are not followed, especially in medical applications, the user experiences problems and frustrations when using the application. As a result, the user may either stop using the application or cause vitals to increase because of the frustrating experience, which defeats the purpose of the application. If doctors can not determine or read vitals because the user stops using the application, they can not treat the patient or may even miss an event that might have been important to the patient's diagnosis. Moreover, the people that need to be monitored are often elderly patients, not familiar with modern technologies. This means that medical smartphone applications have to be intuitive enough for elderly patients to increase compliance and everyday use.

Smartphones are designed to be used anytime, anywhere. Wide area connectivity using a cell phone network provides opportunities for immediate upload of health-critical information and events to medical provider or specialized service. In addition, location capabilities implemented through integrated GPS or cell phone network localization can provide information about the current location of the person in need. As an example, the system can detect epileptic attack and send that information together with the location of the user to the monitoring center.

Another important function of health monitoring systems is prolonged monitoring. Available memory allows smartphones to store physiological data for days and months at the time, even in the case of limited Internet connectivity. Once connection is re-established, all locally stored data may be uploaded to the medical server.

Smartphone Applications for Health Monitoring

With the recent explosion of smartphone application marketplaces and the increase in smartphone performance, a number of health monitoring and wellness applications also increased. As an example, in a six month time span from February to August 2010 the number of health related applications between Google Android Marketplace and the Apple

App Store increased for more than 3,600 newly created applications [24]. At this moment there are over 8,600 health related applications only on Apple App Store [20].

All of these applications can be divided into three main categories:

- Medical Reference
- Hospital Workflow Management
- Health and Wellness Management

Medical reference applications help medical professionals and other users in finding information related to a broad spectrum of medical topics, such as anesthesiology, cardiology, and dermatology. Typical example of a medical reference application is *Netter's Atlas of Human Anatomy* on the Android platform. This application provides detailed information and graphical illustrations of the human anatomy [25].

Hospital workflow management applications assist medical professionals in their everyday activities. Medical professionals can remotely access patients' historical health records, their current vitals, or use it for pharmaceutical calculations. Airstrip Technologies has developed a hospital workflow management iPhone application, *AirStrip Patient Monitoring*, for real time and historical access of patients' physiological data [26].

Most of health related smartphone applications are dedicated to health and wellness management. Such applications include prenatal & infant care, cardio fitness, diet, medication adherence, women's health, strength training, stress, smoking cessation, sleep, mental health, and chronic disease management. Applications as *Wellness diary* are designed to support users in learning about their behavior, and both making and maintaining behavior changes. [27]

FIGURE 3. SYSTEM ARCHITECTURE OF THE UAHEALTH

Applications for physiological monitoring can use internal sensors in smartphone like camera, accelerometer, GPS, or they can use external sensors like chest belts, footpods, or similar sensors. The majority of physiological monitoring applications provide support for heart monitoring. A typical example of a health monitoring application that uses the iPhone's internal sensors for physiological monitoring is *Heart fitness*. This application uses iPhone camera and iPhone's built-in flash light to process reflection from user's fingertip in order to detect heart beats. During measurement the instantaneous heart rate is monitored in beats per minute (BPM) and the physiological photoplethysmographic (PPG) signal is also displayed [28].

Increasing number of sensors is available as low-cost off-the-shelf sensors, and some applications provide support for integration of measurements from a variety of sensors. The DigiFit iPhone suite of applications uses external sensors for physiological and activity monitoring via the ANT+ wireless standard. They provide applications for heart and physical activity, but users are limited to only one physiological signal monitoring at a time [29].

mUAHealth – Personalized Health and Wellness iPhone Application

UAHealth is an integrated mobile health monitoring system designed to monitor physical activity, weight, and heart activity. Most of the existing applications on the market monitor only a single parameter where our system can monitor multiple signals at a time. System architecture of the UAHealth is presented in Figure 3.

The mobile *UAHealth* application (*mUAHealth*) is developed for iPhone. The application communicates with a set of sensors in a wireless body area network (WBAN) to collect information about physical activity and physiological signals. Our WBAN uses low power ANT+ wireless standard with commercially available off-the-shelf sensors, such as Garmin [30] and Suunto [31] chest belts. Since ANT+ is not supported on iPhone, we use Wahoo Fisica Key ANT+ transceiver adapter for iPhone [32]. Collected data is uploaded to the personal health record on a server. Personal medical records on the server can be accessed by the user, medical professionals, or other individuals approved by the user.

mUAHealth was designed to have an intuitive user interface, navigation, and seamless integration of sensors. The user interface was designed keeping in mind the iOS Human Interface Guidelines [21]. When developing *mUAHealth* we tried to automate the most frequently used functions to improve user experience. The system has to provide simple and intuitive presentation of the common parameters in two different formats: smartphone interface for user and remote desktop interface used by a physician. Typical screenshots of *mUAHealth* for heart rate monitoring, heart rate trend and weight are presented in Figures 4, 5, and 6.

Figure 4. mUAHealth – Heart rate monitoring

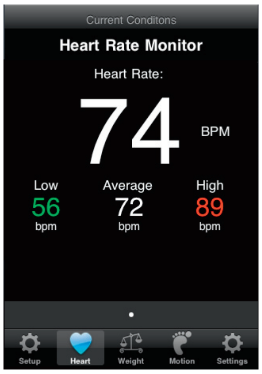
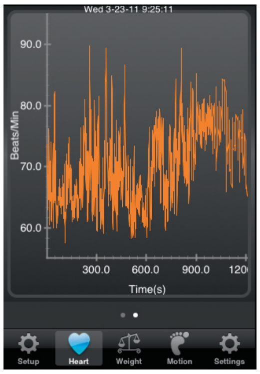


Figure 5. mUAHealth – Heart rate plot



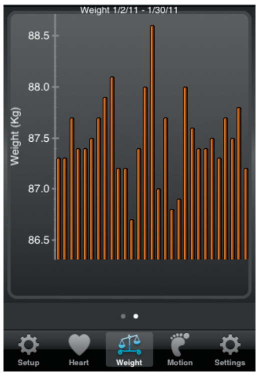


Figure 6. mUAHealth – Weight plot

Ubiquitous monitoring systems have to adapt to intermittent communication. Therefore *mUAHealth* is designed to work both online and offline. Users do not always exercise or perform daily activities near an Internet connection. Consequently, *mUAHealth* monitors Internet connectivity to determine when to submit health related information to the remote medical server. That is why it is essential for smartphone medical applications to have a local and remote database.

Discussion and Conclusion

Smartphones integrate processing and communication capabilities of the recent generation of workstations into a small and wearable form, creating a revolution in the number of fields and applications. The most promising applications of smartphones are health monitoring and wellness management.

Continuous monitoring and real-time, customized feedback on health and behavior will increasingly rely on remote and networked sensors and actuators, mobile platforms, novel interactive displays, and advances in computing and networking infrastructure. Data collected by sensors at point of care or labs needs to be anonymized and aggregated for community-wide health awareness and maintenance. Such data, especially collected over populations, can lead to inferences about best practices and cost savings in providing health services.

In this paper we present the capabilities of smartphone technology for ubiquitous health monitoring, typical applications, and development of our new ubiquitous health monitoring system *UAHealth* that integrates most common functions for ubiquitous health monitoring and wellness management. This is a very promising field with exponentially increasing number of sensors and opportunities in the marketplace that has the potential to significantly change healthcare system and make it more efficient.

Acknowledgements

This project has been supported in part by Grant UAH-RII 234343 “Development of a Real-Time Physiological Monitoring Lab.”

References

[1] IEEE Medical Technology Policy Committee (2009) Technologies for Addressing the Health Care Needs of Our Aging Population. http://ieeeusa.com/policy/positions/healthcaretech1109.pdf

[2] Jovanov E et al (2005) A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. Journal of NeuroEngineering and Rehabilitation, 2(6),

[3] Bonato P (2010) Wearable Sensors and Systems. IEEE Engineering in Medicine and Biology Magazine, 29(3), 25-36.

[4] Bonato P (2010) Advances in wearable technology and its medical applications. In Proceeding of IEEE Engineering in Medicine and Biology Society , pp. 2021 – 2024, Buenos Aires, Argentina

[5] Pantelopoulos A and Bourbakis NG (2010) A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, 40(1), 1-12.

[6] Raskovic D et all (2004) Medical Monitoring Applications for Wearable Computing. The Computer Journal, 47(4), 495-504.

[7] Istepanian RSH. et al (2004) Guest Editorial Introduction to the Special Section on M-Health: Beyond Seamless Mobility and Global Wireless Health-Care Connectivity. *IEEE Transactions on Information Technology in Biomedicine*, 8(4) 405 - 414.

[8] Jovanov E et al (2009) Guest Editorial Body Sensor Networks: From Theory to Emerging Applications. *IEEE Transactions on Information Technology in Biomedicine*, 13(6), 859 - 864.

[9] IRhythm, http://www.irhythmtech.com/ (Accessed: March 2011)

[10] Corventis, http://www.corventis.com/US/ (Accessed: March 2011)

[11] CardioNet, http://www.cardionet.com/ (Accessed: March 2011)

[12] Sensium Toumaz, http://www.toumaz.com/ (Accessed: March 2011)

[13] Wong ACW et al (2009) Sensium: An Ultra-Low-Power Wireless Body Sensor Network Platform: Design & Application Challenges. Proceedings of the 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 6576 – 6579, Minneapolis, Minnesota, USA

[14] Jovanov E et al (2009) Avatar – a Multi-sensory System for Real Time Body Position Monitoring. Proceedings of the 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 2462-2465, Minneapolis, Minnesota, USA

[15] Coyle S et al (2010) BIOTEX—Biosensing textiles for personalised healthcare management. IEEE Transactions on Information Technology in Biomedicine, 14(2), 364–370.

[16] Matthews R et al (2007) A Wearable Physiological Sensor Suite for Unobtrusive Monitoring of Physiological and Cognitive State. Proceeding of IEEE Engineering in Medicine and Biology Society, pp. 5276 – 5281, Lyon, France

[17] Yang GZ (2006) Body Sensor Networks. Ed. Springer

[18] Korel BT and Koo SGM (2007) Addressing Context Awareness Techniques in Body Sensor Networks. 21st International Conference on Advanced Information Networking and Applications Workshops, 2, pp. 798 – 803, Niagara Falls, Ontario

[19] Allen S et al (2010) *Pro Smartphone Cross-Platform Development: iPhone, Blackberry, Windows Mobile and Android Development and Distribution*. Apress

[20] App Store Metrics, http://148apps.biz/app-store-metrics/ (Accessed: March 2011)

[21] Apple Inc (2011) iOS Human Interface Guidelines. http://developer.apple.com/library/ios/documentation/userexperience/conceptual/mobilehig/MobileHIG.pdf, (Accessed: March 2011)

[22] Google Inc (2011) The Developers Guide | Android Developers. http://developer.android.com/guide/practices/ui_guidelines/index.html, (Accessed: March 2011)

[23] Microsoft Corporation (2011) Windows User Experience Interaction Guidelines http://msdn.microsoft.com/en-us/library/aa511258.aspx (Accessed: March 2011)

[24] Dolan B (2011) The Fastest Growing and Most Successful Health & Medical Apps. http://mobihealthnews.com/9396/number-of-smartphone-health-apps-up-78-percent/. (Accessed: March 2011)

[25] iMedicalApps, http://www.imedicalapps.com/2010/10/netter-atlas-of-human-anatomy-app-android-medical-app-review/. (Accessed: March 2011)

[26] Airstrip, http://www.airstriptech.com/ (Accessed: March 2011)

[27] Mattila E et al (2010) Empowering citizens for wellbeing and chronic disease management with wellness diary. *IEEE Transactions on Information Technology in Biomedicine*, 14(2), 456–463.

[28] Heart Fitness, http://heartfitness.senscare.com/ (Accessed: March 2011)

[29] Digifit, http://digifit.com/ (Accessed: March 2011)

[30] Garmin, http://www.garmin.com/ (Accessed: March 2011)

[31] Suunto, http://suunto.com/ (Accessed: March 2011)

[32] Wahoo Fitness , http://www.wahoofitness.com (Accessed: March 2011)