



Status and trends of mobile-health applications for iOS devices: A developer's perspective

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ABSTRACT

Modern smart mobile devices offer media-rich and context-aware features that are highly useful for electronic-health (e-health) applications. It is therefore not surprising that these devices have gained acceptance as target devices for e-health applications, turning them into m-health (mobile-health) apps. In particular, many e-health application developers have chosen Apple's iOS mobile devices such as iPad, iPhone, or iPod Touch as the target device to provide more convenient and richer user experience, as evidenced by the rapidly increasing number of m-health apps in Apple's App Store. In this paper, the top two hundred of such apps from the App Store were examined from a developer's perspective to provide a focused overview of the status and trends of iOS m-health apps and an analysis of related technology, architecture, and user interface design issues. The top 200 apps were classified into different groups according to their purposes, functions, and user satisfaction. It was shown that although the biggest group of apps was medical information reference apps that were delivered from or related to medical articles, websites, or journals, mobile users disproportionately favored tracking tools. It was clear that m-health apps still had plenty of room to grow to take full advantage of unique mobile platform features and truly fulfill their potential. In particular, introduction of two- or three-dimensional visualization and context-awareness could further enhance m-health app's usability and utility. This paper aims to serve as a reference point and guide for developers and practitioners interested in using iOS as a platform for m-health applications, particular from the technical point of view.

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1. Introduction

Electronic-health (e-health) applications refer to healthcare-related software applications that provide tools, processes, and communication means to support electronic healthcare practice (Hairong Yan et al., 2010; Hernandez et al., 2001). e-Health applications have been widely used in professional healthcare venues and are gaining increasing acceptance in homecare (Ball and Lillis, 2001; Dixon, 2007; Hsu et al., 2005). More recently, as hardware capacity of smart mobile phones and other mobile devices improve, a growing number of e-health functionalities have been made available on mobile platforms, making mobile-health (m-health) applications an important subset of e-health applications.

m-Health is an umbrella term that covers areas of networking, mobile computing, medical sensors and other communication technologies within healthcare. The concept of m-health refers to "mobile computing, medical sensor, and communications technologies for health care" (Istepanian et al., 2004). In the book

M-health: Emerging Mobile Health Systems, the term m-health was defined as "emerging mobile communications and network technologies for healthcare systems" (Istepanian et al., 2006).

It is widely expected that m-health will become increasingly important in e-health. For example, Norris et al. (2009) did a pilot study on m-health sustainability strategies. They interviewed a wide range of practitioners in healthcare and reached the conclusion that m-health had played and would continue to play a crucial role in healthcare. Separately, a report published by Vital Wave Consulting focused on the opportunities of mobile technology for healthcare in the developing world. After going over the potential of using mobile phones to improve healthcare in the developing world, it demonstrated that mobile technology, especially smart phone-based applications, improved the efficiency of healthcare delivery, and ultimately made healthcare more effective (Vital Wave Consulting, 2009). These papers emphasized that m-health played a crucial role in healthcare. In rural areas in particular, affordable and efficient healthcare could be provided through m-health applications.

Meanwhile, because m-health apps are a recent phenomenon, proven guidelines on what works and what does not in m-health app development have not emerged yet. Both the authors'

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first-hand m-health app development experience (Liu et al., 2010) and the literature review in Section 2 suggested that there was a need to better understand the current status of smart phone- or tablet-based m-health services on the application level so that m-health developers could identify suitable technologies, use them in a way more relevant to end users, and provide a smoother user experience. To develop this understanding, the first step is to identify key components relevant to m-health services. There are three key components in mobile computing, namely mobile computers, wireless networks, and mobile applications (Rebolj and Menzel, 2004). Similarly, an m-health service needs three corresponding key components: mobile devices, software platform (providing basic services such as networking and database), and m-health applications.

Mobile devices typically include PDAs (personal digital assistant), smart mobile phones, and tablet computers such as the iPad. PDAs were widely used in the late 1990s and early 2000s. But as the computational power of smart phones improved, PDA features were incorporated into smart phones. Standalone PDAs became obsolete. Using modern smart phones as the single mobile device of choice could not only save money by not having to purchase a separate PDA device, but also facilitate faster access (Guerra et al., 2009; Mattila et al., 2008; Poropatich et al., 2010). Thus, the focus of this paper is smart mobile phones and tablet computers. They are often chosen as m-health application's target device for the portability of mobile phones or the larger screens of tablets.

Currently, six major platform providers (i.e., providers of operating systems and development tools) dominate the mobile platform market (Holzer and Ondrus, 2010). They are Nokia with its Symbian OS, Google with its Android, Apple with its iOS, RIM with its Blackberry OS, Microsoft with its Windows mobile OS family (the latest being Windows Phone 7), and LiMo Foundation with its Linux Mobile operating system. Symbian OS has the largest market share, but does not have the largest number of available apps, or a centralized app store, which makes it difficult to provide a comprehensive review of existing Symbian OS m-health apps.

Apple's iOS and Google's Android have centralized app stores. Apple's App Store has been the number one app marketplace in terms of the number of apps available. Based on the statistics from mHealth Initiative Inc.,¹ the number of m-health applications on Apple's mobile platform was far greater than the numbers of m-health applications on other platforms by the end of 2009. According to a statistical analysis conducted by Gartner,² Apple with its iOS led in the app market in the year of 2010. Gartner forecasted that iPad would reach 54.8 million units in 2011. iPad, as a new mobile platform in tablet form factor, evolved from iPhone and came with a larger screen, higher resolution, and larger onscreen keyboard. It has attracted health care practitioners' attention since it was released.

At the end of 2010, following Apple, Google also launched a brand new medical category within the Android Market.³ Although it is certain that the impact of m-health apps published in the Android Market will continue to grow (Butler, 2011; Gavalas and Economou, 2011), for now, it is most meaningful to review m-health apps on Apple's iOS platform to determine the status and trends of m-health apps in general.

In light of the discussion above, in this study, iPhones or iPads were selected to represent mobile devices, the first key component for m-health service. The iOS platform was selected to represent mobile software platforms, the second key component. Top 200 apps in related categories from the Apple App Store were selected to represent m-health apps, the third key component for m-health service. In this context, the remainder of the paper is structured as follows to focus on the review of iOS m-health apps from application developer's perspective. Section 2 discusses the related work. Section 3 examines how iOS supports m-health applications. Section 4 covers various mobile technologies that support m-health applications. Section 5 describes the current status of iOS m-health applications based on an examination of the top 200 applications in this area in Apple's App Store. The implications for developers are discussed in Section 6. The conclusion is presented in Section 7.

2. Related work

In 2009, the authors implemented a prototype mobile BMM (behavioral migraine management) app for iPhone to help adolescent migraine patients manage their migraines and communicate with their counselors (Liu et al., 2010). In 2010, when Apple launched the iPad, the authors decided to take advantage of the larger screen offered by iPad and develop an iPad version of this BMM app. During this project, the status of m-health applications and the related literature were reviewed, including: (1) network or network security for m-health apps (Fei Hu et al., 2010; Garawi et al., 2006; Istepanian et al., 2009; Rasid and Woodward, 2005), (2) m-health application frameworks (Laakko et al., 2008; Norris et al., 2009), and (3) specific m-health applications (Gerber et al., 2009; Guerra et al., 2009; Li et al., 2010; Mattila et al., 2008). As mentioned in Section 1, there were no survey papers on the current status of smart phone-based or tablet-computer based m-health apps, and there were no comprehensive papers that provided references to state-of-the-art technologies for m-health apps.

This section does not cover networking or network security-related literature because the goal of this paper is to understand the big picture of smart-phone-based m-health applications and discuss the implications of unique features of mobile development platforms on developers. Typically, mobile development platforms provide encapsulated networking services, which are usually not what app developers need to implement.

2.1. m-Health application frameworks

To deal with the problem of an aging population and the increasing number of chronic patients in China, Poon and Zhang (2008) developed a four-layer (personal, home, community, and hospital) m-health application framework for their application based on mobile devices. They took management of BP (blood pressure) as an example and described wearable intelligent sensors and personal healthcare information systems. In the four-layer system, the medical costs were reduced in two aspects: lower equipment costs and reduced use of medical facilities through new techniques that provided precise diagnosis and targeted therapy. The result of the paper was that innovative technologies in wearable medical devices and BANs (Body Area Network) can be developed to collect information, thus it could provide affordable healthcare for both urban and rural residents. In this case, mobile phones worked for displaying BP.

To support rapid and cost-effective development of m-health applications, Laakko et al. (2008) implemented UPHIAC (Ubiquitous Personal Health Information Access) platform. They proposed an m-health application framework based on UPHIAC, which can be used for information exchange between healthcare professionals,

¹ Exploring the mHealth Application Clusters. Source: <http://www.mobih.org/clusters/> (last verified in January 2011).

² Worldwide smartphone sales breakdown by OS in 2010. Source: <http://www.gartner.com/it/page.jsp?id=1466313> (last verified in January 2011).

³ Google To Add Mobile Health Applications Category To Android Market. Source: <http://www.mobilemarketingwatch.com/google-to-add-mobile-health-applications-category-to-android-market-11998/> (last verified in January 2011).

patients, and measurement devices. The goal of the framework is to provide a set of core classes to accomplish basic functionalities needed in m-health apps. It contains five components: measurement, storage, network, UPHIAC core, and user interface. Mobile phones are used to connect medical measurement devices and back-end information systems in this case. An operational prototype for tele-ECG (electrocardiogram) was implemented as an example use case of the platform. The example use case showed that the platform could be used as a basis to develop new applications for specific purposes.

To support the development of context-aware m-health applications, Broens et al. (2007) presented a framework and evaluated it in an epilepsy patient monitoring system. The ESS (Epilepsy Safety System) scenario was used to derive the application framework's general requirements, which include: (1) mobility support; (2) context-awareness & adaptation support; (3) execution environment. To meet these requirements, the framework first adopted a layered framework proposed by the Freeband AWARENESS (context AWARE mobile NETworks and ServiceS) project (Maarten, 2005), which includes the network infrastructure layer on the bottom, the service infrastructure layer in the middle, and the application layer on the top. Broens et al. elaborated on the application layer proposed by Maarten, and assumed that the lower layers would supply common functionalities, such as connectivity, context management and service management. The application layer contained three main components: application container, generic container, and domain-specific functions. Although the authors claimed that this context-aware application framework provided an application environment that made development m-health applications feasible and improved usability, evaluation results were not presented. In this framework, the mobile phone was used as a MBU (Mobile Base Unit) to offer gateway functionality to connect the BAN to the m-health support system.

2.2. Specific m-health applications from around the world

The U.S. Army explored using mobile phones within the military healthcare system (Poropatich et al., 2010). Ronald et al. used a video cell phone reminder system to improve glycemic control in patients with diabetes. The reminder system prompted the users to take medications and check their blood glucose. They evaluated the result through a trial for twelve weeks. Two groups of people were included in the trial, a group that used the system, and a control group that did not. A1C level, which was an indicator that reflected the average blood glucose level over the past three months, was significantly lower in the group that viewed the reminders. It was argued that mobile devices were superseding desktop and even laptop computers as the tool of choice for communication. In this study, they provided mobile phones for trial users. However, users preferred to use their own phones. So sometimes they missed the reminders because they did not carry the extra phone with them. This paper also claimed that compliance of the health care system could be improved if reminders were placed on the patients' personal cell phones. In this project, the mobile phone worked as a reminder receiver.

In Spain, Guerri et al. (2009) developed a mobile application for low back disorders. It could assess a patient's muscular condition in any environment in a comfortable way. This application was based on a wireless bio-monitor and a PDA or a mobile phone. The application was evaluated in a preliminary usability, reliability, feasibility and communication performance study. The result showed that the system was easy to use, and the users were satisfied with the usability of the app in terms of both functionality and interactivity. One of the conclusions was "*The possibility of using it in a mobile phone has greatly increased its usability.*" In this application,

mobile phones both sent data to and received data from medical devices.

In the same country, Moron et al. (2007) developed a smart-phone-based Personal Area Network to monitor a patient continuously in both indoor and outdoor environments. J2ME (Java Mobile Edition) was used to implement a monitoring network of Bluetooth biosensors connected to a 3G mobile phone. Two Nokia smart phones (initially a Nokia 9500, later a Nokia N93) were used in this project as the central node to compile information about patient's location and health status. In this project, the mobile phone was used to not only receive and send data but also process the data. If certain data received were lower or greater than a predefined threshold, a SMS (Short Message Service) would be sent to a physician or the patient's predefined caregiver. It was concluded that using smart phones to compile information about patient's location and health was favorable due to users' acquaintance with their mobile phones.

In Australia, Li et al. (2010) illustrated how a mobile phone SMS-based application could be applied to facilitating influenza pandemic surveillance in developing countries. In this case, a mobile phone was used as a data receiver. Their conclusion was that mobile phone-based technologies provide an affordable healthcare service in an efficient and reliable way.

In the United States, Gerber et al. (2009) conducted a feasibility study about using mobile phone text messages to intervene in obese people's daily life, promote healthy behaviors and improve weight loss maintenance. In this project, the mobile phone served as a reminder message receiver. According to this study, mobile phones offered a cost-effective means to help people lose their weight.

In Finland, Mattila et al. (2008) developed the Wellness Diary (WD) for Symbian Series 60 (S60) smart phone platform. WD was implemented as a stand-alone application. The smart phones in this project collected data from the users, manipulated the data, and generated graphical feedback for the users. With the help of WD, users took records of wellness-related self-assessments and measurement results. Graphical feedback was automatically generated. The result of the two studies (one was about weight management, the other one was about general wellness management) presented in the paper indicated that WD was well suited for supporting CBT (Cognitive Behavioral Therapy)-based wellness management.

In summary, the literature discussed above shows the following. (1) m-Health applications play and will continue to play a crucial role in healthcare. (2) Mobile technologies benefit their users with improvements in healthcare in terms of portability, immediacy, convenience, comparatively low unit cost and efficiency. (3) Smart-phone-based m-health apps facilitate communication between patients and therapists. m-Health apps can promote users to change their lifestyle. They could be leveraged widely in chronic illness care, and care of elderly and disabled people.

3. The iOS mobile platform

iOS,⁴ known as iPhone OS prior to June 2010, was released by Apple Inc. It is the mobile operating system used by iPod Touch, iPhone, and iPad. It was derived from Mac OS X. It shares the Darwin foundation, and is based on a Unix-like operating system. The technology layers of the iOS platform are illustrated in Fig. 1. There are four layers in the iOS technology architecture. Core OS is the bottom layer and Core services is the second layer from the bottom. They both provide basic support for m-health applications like database and networking support. Media layer contains a set of fundamental

⁴ iOS. Source: <http://www.apple.com/ios/> (last verified in January 2011).

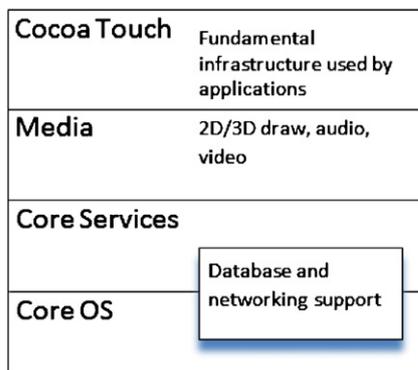


Fig. 1. iOS technology layers.

technologies that can be used to support 2D/3D visualization, and audio or video playback. Cocoa Touch is the top layer. Although iOS was derived from Mac OS X, there was no Cocoa Touch layer in Mac OS X architecture. Cocoa Touch was derived from Cocoa in Mac OS X, and was uniquely designed for touch-based interfaces. Code libraries at this layer provide fundamental infrastructure for developers (Boudreaux, 2009; Buck and Yacktmann, 2009). (Apple refers to these code libraries as frameworks. Since in the paper, the term “framework” refers to application architecture, the term “library” is used instead to avoid confusion.)

All iOS applications, including m-health applications, start from the Cocoa Touch layer. In particular, UIKit and Foundation libraries are used by all apps (Zdziarski, 2008). The classes in the UIKit library are to construct and manage an application’s user interface. The most frequently used interface elements of the UIKit class hierarchy include UIViewController, UIView, UITableView, UIButton, UIAlertView, UIWebView, UINavigationController, etc.

The Foundation library provides a set of classes that work as a base layer for Objective-C classes. Objective-C is the preferred programming language for all iOS applications. The Foundation library includes a small set of basic utility classes. For example, one of the classes provides memory management services such as memory allocation and deallocation. Classes in the Foundation library define data type such as NSString, NSArray, or NSDictionary, provide operating system services such as NSError,NSBundle, NSStream, NSURL, and provide Objective-C Language services such as NSAutoreleasePool, NSException.

When developing m-health applications, developers usually start with frameworks in higher-level layers. Lower-level libraries are only used when more precise control or more powerful capabilities are needed.

In the context of development for m-health, graphics and animation are usually used to improve usability. iOS provide several libraries for this regard:

- UIKit library. With a set of classes, UIKit supports user interface controls and 2D drawing. It is also used to animate the user interface (Zdziarski, 2008).
- Core Graphic library. Unlike the UIKit and Foundation libraries, the Core Graphic library provides a C-based API. It is based on the Quartz advanced drawing engine. It can be used for drawing vector graphics, bitmap images and PDF content (Mark and LaMarche, 2009; Zdziarski, 2009).
- Core Animation library provides an Objective-C based API. It can be used to smooth motion and provide dynamic feedback to the user interface (Dudney, 2008).
- OpenGL ES (OpenGL for Embedded Systems) library provides a C-based interface. It can be used to accelerate 2D and 3D graphics rendering (Mark and LaMarche, 2009; Zdziarski, 2009).

Basically, UIKit can fulfill all basic graphics and animation requirements such as manipulating colors or images, filling rectangles, and animating the user interface. When more powerful 2D drawing capabilities are needed, developers can use the *Core Graphics* library. UIKit uses *Core Graphics* and *Core Animation*, too. That is why typically developers do not need to use the lower libraries directly.

Location-based information is widely used in m-health applications. iOS provides two libraries to support location-awareness applications: one is the *Core Location* library, which provide location services; the other is the *Map Kit* library, which supports display and annotation of maps.

Email and SMS messages are used in many m-health applications as a communication means between patients and therapists. The *MessageUI* library contains classes that provide standard composition interface for email and SMS messages.

4. Enabling technologies on mobile platforms for m-health

Certain technologies available on smart mobile devices are well suited to improve usability, utility, and appeal of m-health applications. This section describes context-aware technology, middleware technology, mobile software architecture, and 2D/3D visualization technology available on smart mobile devices, and discusses how they work for m-health apps.

4.1. Context-aware technology

Context-aware systems, developed to stay aware of their contexts, aim to provide context-specific service for their users by automatically adapting to their changing contexts (Hong et al., 2009). Context is any information that can be used to characterize the situation of an entity, while an entity can be a person, place or object that is relevant to the interaction between users and apps, including location, time, activities, and the preferences of each entity (Dey, 2001). Researchers has studied context-aware wireless Internet applications and developed systems to provide seamless network services for mobile systems according to a user’s location, device, and personal interests (Bellavista et al., 2003, 2006a). To address problems that existed in aging population, the AAL (Ambient Assisted Living) initiative in Europe proposed a series of solutions based on advanced information and communication technologies.⁵ Context-aware was one important feature within AAL (Wojciechowski and Xiong, 2008). According to Wojciechowski and Xiong, a context model consists of three layers: infrastructure layer, service adaption layer, and user interface layer. The infrastructure layer includes context sensors’ description. The context systems work as subsystems of AAL, providing methods and operating the sensors in the infrastructure layer. The user interface layer corresponds to specific services for specific users. The three-layer context model also works for mobile devices. The major difference is in the infrastructure layer, as sensors in the AAL are independent devices, such as water and gas leakage detectors, while in mobile phones the sensors are combined in a single device, such as iPhone.

Smart mobile devices such as iPhone, iPad, and Droid are typically equipped with sensors that can collect contextual information including location (by GPS, WIFI access point and cellular tower location, and digital compass), orientation (by three-axis gyro), movement (by accelerometer), presence of nearby objects (by proximity sensor), and lighting (by ambient light sensor). This enables

⁵ Ambient Assisted Living Joint programme. <http://www.aal-europe.eu/> (last verified in May 2011).

the development of context-aware software applications. Furthermore, mobile devices often operate in changing contexts as device users move around in their daily lives. This creates both the opportunity and the need for context-aware mobile applications to improve their services and add unique values by making use of contextual information. As a simple example, if a phone can automatically display contents vertically or horizontally, depending on how its user holds the phone, it brings convenience to its user. While this is straightforward to implement with the presence of the gyro, and requires no user training, it is an important step forward because previously, functions like this required explicit user input and were not automated. Such functions were therefore often reluctantly or infrequently used. Thus, well-design context-aware m-health applications could speed up adoption of certain m-health features and improve both end user experience and acceptance of certain things that are good for health but not easy to keep up with, such as keeping a diary of the number of steps walked every day, or a headache diary.

Although relatively few context-awareness research groups are involved in healthcare area (Bricon-Souf and Newman, 2007), it is clear that context-aware systems combined with mobile devices is of high value and could improve usability significantly (Baldauf et al., 2007). Sridevi et al. (2010) implemented a context-aware health monitoring system in India. The systems provided the connection between primary healthcare center in rural area and well-equipped medical providers in urban areas. The system was only tested in the lab and there was no evaluation of the system so far. In this project, mobile applications are used for identifying patients and communicating with the wireless medical devices.

Currently, many iOS apps provide context-aware functionality, such as location-awareness and preference-awareness. (Examples will be provided in the next section.) As the hardware of mobile devices improves, additional types of context awareness could emerge. For example, when new sensors like barometers are included in mobile phones, which make it possible to predict weather directly from a phone app,⁶ it becomes possible to develop a weather-aware m-health application for patients who suffer from arthritis to predict and better manage pain.

4.2. Middleware technology

Typically, middleware is computer software that runs on top of operating systems and serves the needs of application software. Middleware usually forms a special layer (Davidyuk et al., 2004). Based on operation systems, middleware usually provides a more functional set of application development interfaces. Examples of middleware include database, Java Runtime Engine, and certain networking packages. Researchers and developers have implemented a number of middleware for mobile applications and healthcare applications (Bagrodia et al., 2003; Bellavista et al., 2006b; Costa et al., 2007; Eugster et al., 2009; Lu and Chen, 2009). From a developer's perspective, the goal of the middleware is to facilitate system development and allow developers to avoid the use of low-level application programming interfaces when feasible. With the help of middleware packages, mobile systems can be developed more efficiently.

iOS is an ideal operating system for developers in this sense because it provides many services traditionally only available from middleware and typically not included in operating systems. For example, middleware related to wireless sensor network, database, media, etc. is highly relevant for m-health applications. iOS covers

all of these functionalities. As discussed in Section 3, Cocoa Touch in iOS provides a number of libraries such as *UIKit* for interface design, *CFNetwork* for WiFi and cellular networking setting, and so on. These allow developers to implement sophisticated services and technologies easily without accessing lower-level layers. Of course, lower layers are still accessible when needed.

4.3. Novel software architecture is emerging to support the development of m-health apps

Innovations in mobile computing technology bring challenges to traditional software architectures. Existing architectural principles need to be adapted and novel architectural paradigms devised to meet the requirement of mobile computing systems (Biel et al., 2010; Bishop and Danzfuss, 2010; Malek et al., 2010; Medvidovic and Edwards, 2010).

In practice, m-health applications, like other mobile applications, run on mobile devices with intermittent network connections and dynamic execution contexts. These applications, deployed on novel computing platforms as compared to traditional computers, offer novel usage scenarios and thus bring amplified software engineering challenges.

Researchers have studied the implication of mobility on architecture design both in mobile system and software architecture areas. However, to a significant degree, there is still largely disjoint sets of traditional architectural styles and mobility styles (Medvidovic and Edwards, 2010).

The community has realized that new, effective mobile software architectures for designing, implementing, verifying, deploying and evolving mobile systems are critical. As discussed in Section 2.1, m-health researchers have experimented with new m-health software frameworks and architectures, and have made progress in this area.

4.4. Data visualization brings more value to m-health apps

iOS provides two primary paths for drawing and printing: one is OpenGL ES; the other is the native rendering, such as Quartz, Core Animation, and UIKit.⁷ OpenGL ES (Open Graphics Library for Embedded Systems) is a graphics library that is used to render sophisticated 3D graphics on mobile devices (Chehimi et al., 2008; Munshi et al., 2008). Quartz is a 2-dimensional drawing engine that provides native rendering. It provides "low-level lightweight 2D rendering with unmatched output fidelity regardless of display or printing device." (Gonzalez-Sanchez and Chavez, 2010).

Differences exist between OpenGL ES and Quartz, even though they overlap significantly (Mark et al., 2011). Quartz is a subset of Core graphics framework; it provides lines, shapes, and image drawing functions. Thus, it can be used to draw charts. Compared to OpenGL ES, Quartz is easy to use. However, it is limited to two dimensions. OpenGL ES can do both two-dimensional and three-dimensional drawing. It is specifically designed to take full advantage of hardware acceleration, thus extremely well suited for graphically intensive programs such as 3D games.

With data visualization, 2D charts or 3D objects are used to present information to the users. *Diabetes Buddy* is a popular app in Apple's App Store. It helps its users track diabetes factors. (More details of this app can be found in Section 6.) *Diabetes Buddy Lite* is the free version of this app. The main limitation of free version is that there are no charts for all tracking factors. It showed that m-health app developers considered visualization a value-adding feature.

⁶ CNN, "Your next phone or tablet could help you predict the weather." Source: <http://www.cnn.com/2011/TECH/mobile/01/13/xoom.barometer> (last verified in January 2011).

⁷ iOS Developer Library. <http://developer.apple.com/library/ios/#documentation/2DDrawing/Conceptual/DrawingPrintingiOS/GraphicsDrawingOverview/GraphicsDrawingOverview.html> (last verified in May 2011).

3D interactive objects are more appealing in many cases. *Muscle & Bone Anatomy 3D* is another app from Apple's App Store. It is an educational tool to help students learn muscles and bones. (More details of this app can be found in Section 5.) It offers 3D lessons, which use 3D effect to demonstrate the human body.

A number of projects (del Puy Carretero et al., 2010; Hachet et al., 2008; Hile et al., 2010; Mosmondor et al., 2005, 2006; Seongah Chin, 2008) explored ways to show 3D objects on mobile devices. Chin and Kim implemented an interactive 3D face on mobile device using Visual C++ and Open GL (Seongah Chin, 2008). However, out of the 200 applications examined in this study, only two claimed that they were 3D-related applications. One is *Muscle & Bone Anatomy 3D*. The other is *3D4Medical's Images*. 3D effect used in the *Muscle & Bone Anatomy 3D* is based on continuous images. So it only provides limited interactivity. Users cannot view the 3D objects from any angle. *3D4Medical's Images* only uses images pre-rendered by other 3D tools. There are no 3D effects inside the application. Clearly, in terms of visualization, especially 3D visualization, m-health apps still have great potential for further improvement.

5. iOS m-health applications

In this section, top two hundred apps in related categories from Apple's App Store were examined to find out features shared by these *most popular* applications. Several representative apps were analyzed to demonstrate the current status of m-health applications on iOS and to identify implications from a developer's perspective.

Apple's App Store classified the applications into twenty categories: Books, Entertainment, Games, Music, Business, Finance, Healthcare & Fitness, Lifestyle, Medical, Navigation, News, Photography, Productivity, Reference, Social Networking, Sports, Travel, Utilities and Weather. m-Health applications were distributed in the categories of Medical or Healthcare & Fitness. There were 1056 applications in the Medical category as of January 14, 2011, and 1004 applications in the Healthcare & Fitness category as of January 18, 2011. These numbers increased every day. Apps in these two categories were chosen for detailed analysis based on three criteria:

- **Popularity.** Applications were sorted by "Most Popular" instead of "Release Data." The top 100 most popular ones in both categories were selected.
- **Rating.** Applications with higher customer ratings (three or more stars out of five) were selected.
- **Relevance.** The goal was to identify the current status of the m-health applications. So only those applications relevant to healthcare were selected.

In the Medical category, out of the top 100 apps by popularity, eighteen had two or fewer stars in customer ratings. Two were not relevant. (One was in numerology; the other was a vet tool.) The 80 apps left were classified into seven classes: (1) drug/medical information database that provides information about drug's shape, function, color, code, etc.; (2) medical information reference that refers to medical articles, websites, or journals; (3) decision support for medical practitioners, including physicians, surgeons and nurses; (4) educational tools for students or people who are learning medical science; (5) tracking tools that track diabetes factors, blood pressures, and so on, and then visualize the tracking data; (6) medical calculators; (7) others, include eye charts, medical images, color test tools and timers remaindering users to take medicine. The subtotals of the numbers of applications in these classes are shown in Table 1.

Table 1

Distribution of apps among different classes of the 80 relevant apps in the Medical category.

No.	Class	Number of apps	Percentage
1	Drug or medical information database	8	10
2	Medical information reference	27	33.75
3	Decision support	3	3.75
4	Educational tools	19	23.75
5	Tracking tools	7	8.75
6	Medical calculator	3	3.75
7	Others	13	16.25

Table 2

Distribution of apps among different classes of the 14 five-star relevant apps in the Medical category.

No.	Class	Number of apps	Percentage
1	Drug or medical information database	1	7.14
2	Medical information reference	1	7.14
3	Decision support	0	0
4	Educational tools	4	28.57
5	Tracking tools	5	35.71
6	Medical calculator	1	7.14
7	Others	2	14.29

Table 1 shows that Medical information reference was the largest class followed by Educational tools and others. Tracking tools, designed to keep track of blood pressure, contraction, diabetes factors, remote patient monitoring factors, personal medical information, and information related to babies, ranked only the fifth.

Fourteen apps out of the 80 apps in Table 1 were five-star apps, as shown in Table 2. There was a significant difference in their distributions among different classes.

Tracking tools' rank rose from the 5th in Table 1 to the 1st in Table 2, which meant that users disproportionately preferred apps that could help turn inconvenient tasks into easy ones, like keep tracking of blood glucose level or body weight. It appeared that medical students, practitioners, or people with similar interest were a large part of the user base. Educational tools kept its position in top 2. The comparison of two different distributions of apps among different classes in Table 1 (80 relevant apps) and Table 2 (14 five-star apps) is shown in Fig. 2. It was obvious that the percentage of medical information reference apps dramatically decreased, and the percentage of track tools dramatically increased.

Out of these apps, ICD9 On the Go, Muscle & Bone Anatomy, Diabetes Buddy, and MediMath Medical Calculator, were selected for further analysis. More details are presented in Table 5.

In the *Healthcare & Fitness* category, out the top 100 most popular apps, 79 applications were rated three or more stars. These apps

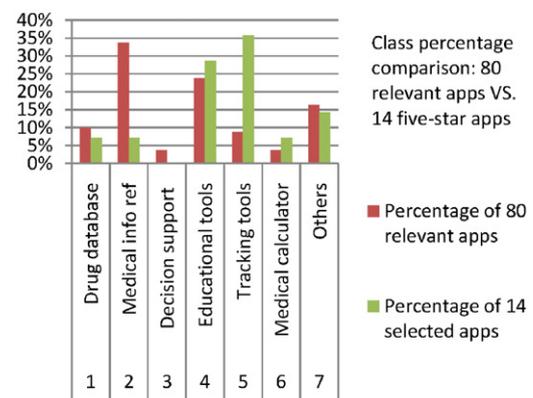


Fig. 2. Class percentage comparison between 80 relevant apps and 14 five-star apps.

Table 3
Different App Classes of 79 apps in the Healthcare & Fitness category.

No.	Class	Number of apps	Percentage
1	Medical information reference	1	1.27
2	Educational tools	3	3.80
3	Tracking tools	10	12.66
4	Fitness	19	24.05
5	Simple tools	46	58.23

Table 4
Different app classes of the nine select apps in the Healthcare & Fitness category.

No.	Class	Number of apps	Percentage
1	Medical information reference	1	11.11
2	Educational tools	3	33.33
3	Tracking tools	5	55.56

were divided into five classes: (1) medical information reference; (2) educational tools; (3) tracking tools; (4) fitness support apps, such as fitness classes, fitness videos, yoga class and so on; (5) simple tools, which include audio players, slide show viewers, and/or timers that provide assistance for meditation, relaxation or stress relief.

The distribution of the applications is shown in Table 3. The largest class of the apps is simple tools. The second largest group of apps is fitness apps, including apps that focus on fitness class, yoga and workout. The 3rd largest class is tracking tools. Eight out of the ten apps in this class keep track of calorie; one tracks mood and habits; the other tracks personal medical information that includes health related spending accounts, location information of providers, claims and so on.

Out of these 79 apps, fitness apps and simple tools were excluded in the further study because the main focus was healthcare. To ensure enough representatives were included from this category, all nine apps with both four- and five-star ratings in the classes of medical information reference, educational tools and tracking tools were selected. The distribution of these apps is shown in the Table 4.

From these nine apps, *Calorie Tracker* (tracking tool, 5-star), the most popular app, and *WebMD for iPad* (medical information reference, 4-star), the second most popular app in this category, were select for further analysis. Overall, six apps from the Medical and Healthcare & Fitness categories were reviewed in greater details. The complete selection process is shown in Fig. 3.

ICD9 On the Go is a medical code database. It provides data service. Once a user inputs a medical code, then the description for that code shows up. It is a universal iOS application, which means it can be used both iPad and iPhone/iPod Touch. Fig. 4 shows the interface of this app.

WebMD helps people check their symptoms, access drug and treatment information, get first aid essentials, and check local health listings on the go or from home. It consists of five com-

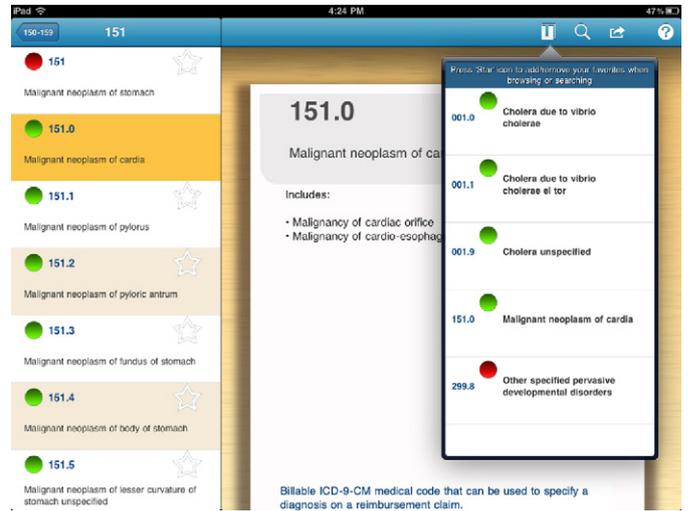


Fig. 4. ICD9 On the Go screenshot. Used with permission from VLR Software.

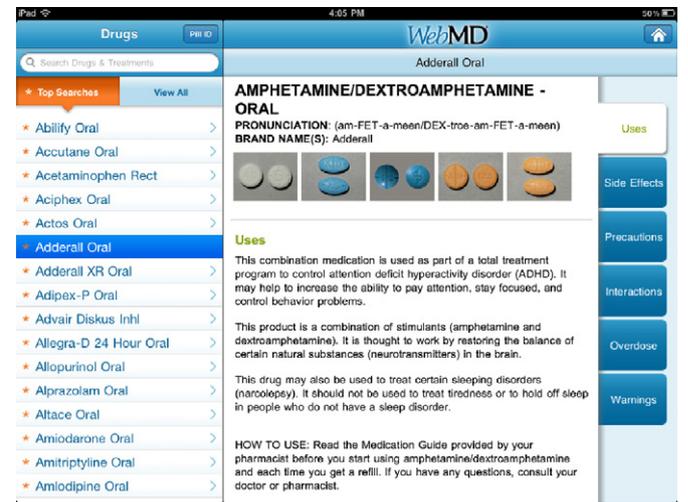


Fig. 5. WebMD drugs and treatment. Used with permission from WebMD.

ponents: (1) symptom checker, (2) conditions, (3) drugs and treatments, (4) first aid information, and (5) local health listings. *WebMD for iPad* works only on iPad. *WebMD Mobile*, a sister version of *WebMD for iPad*, is the version that works on iPhone and iPod Touch. Figs. 5–8 show the user interface of *WebMD*.

Muscle & Bone Anatomy 3D helps students or medical practitioners learn muscle and bones through 3D views and videos. There are

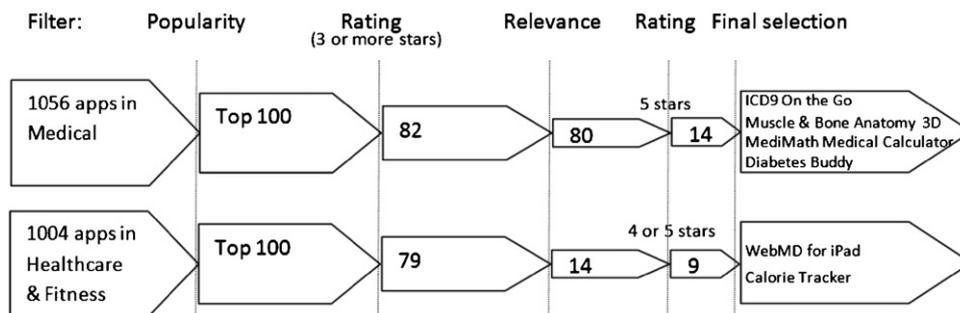


Fig. 3. The app selection process.



Fig. 6. WebMD symptoms.

Used with permission from WebMD.

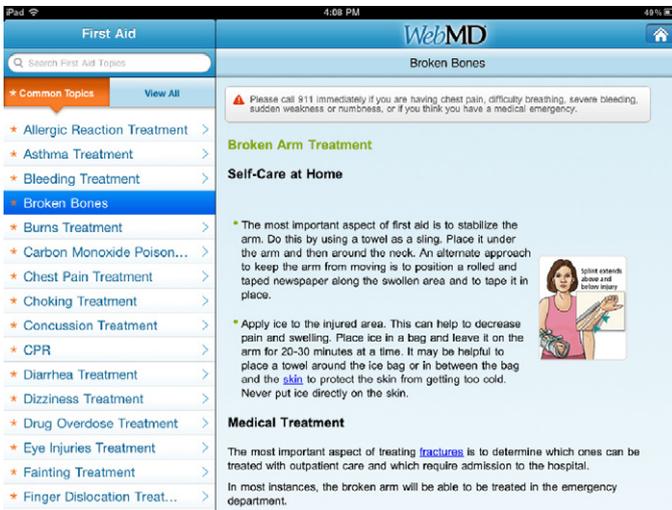


Fig. 7. WebMD First Aid.

Used with permission from WebMD.

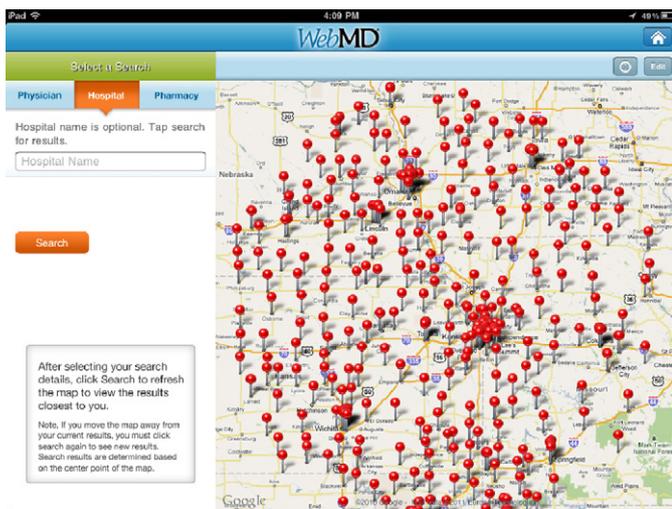


Fig. 8. WebMD Search on Map.

Used with permission from WebMD.

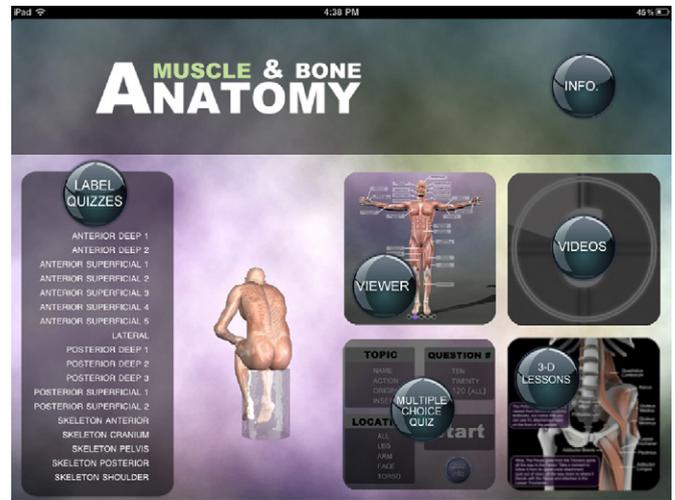


Fig. 9. Muscle & Bone Anatomy 3D start screen.

Used with permission from Real Bodywork.

quizzes for the users to enhance the learning. It is an iPad-only application. Figs. 9 and 10 show two screenshots of this app.

While this app is primarily an educational app, not a pure m-health app, it is included in this review because (1) it was listed as a medical app in Apple's App Store and there were quite a few similar apps in the same category; (2) its contents are related to m-health and could easily be incorporated into a m-health app; (3) its use of 3D visualization is unique and represents a future direction for m-health apps; and (4) its popularity among users shows that m-health developers could use lessons from it.

Calorie Tracker is a diet and workout tracker tool. The app tracks user's diet, weight change, and workout to help people stay fit. A food database was provided by the app. Calorie breakdowns are updated whenever users input the amount of food they ate and the amount of calories they consumed by workout. A 2D weight chart is created by the app to demonstrate the users' weight variation. Fig. 11 shows a screenshot of the app.

Diabetes Buddy is a universal application that helps people manage diabetes. It tracks the factors that influence the blood sugar level, such as glucose, medication, activity, water consumption, and weight. It contains a food database tracking the factors listed above. It monitors the fluctuations of blood sugar level and help users plan

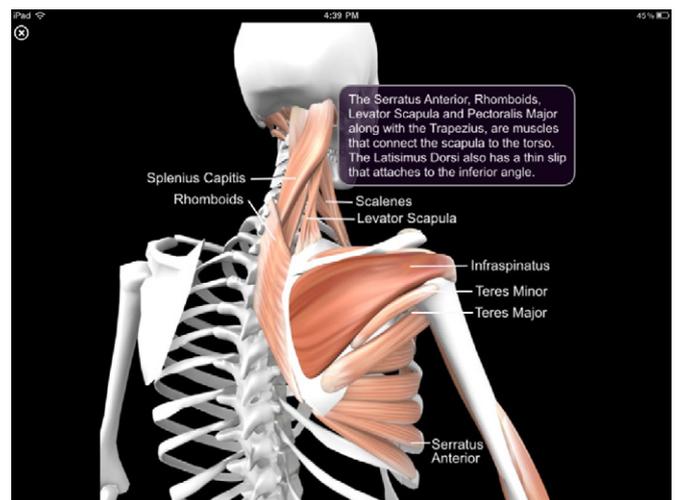


Fig. 10. 3D lessons of Muscle & Bone Anatomy 3D.

Used with permission from Real Bodywork.



Fig. 11. Calorie Tracker.

Used with permission from livestrong.com.



Fig. 13. Diabetes Buddy Overview.

Used with permission from BHI Technologies, Inc.

ahead accordingly. It also helps people sharing the data with their doctors. Figs. 12–14 show the interface of the app.

MediMath Medical Calculator is a comprehensive calculator. It provides 135 medical calculators and scoring tools for iPad, iPhone, or iPod Touch. Fig. 15 shows the interface of the app.

Table 5 shows a summary of features of the six apps discussed above.

Based on the analysis of the apps selected from the top 200 applications, one observation was that m-health users disproportionately favored apps that took advantage of unique features of smart mobile phones and brought real convenience or benefits to users. This is evidenced by the high ratings received by tracking tools, which, when combined with the super accessibility of mobile phones, make it much easier for users to keep track of whatever they have to keep track of for their health.

Many applications in the Medical category are educational tools or medical information reference designed for students or medical practitioners. These are not pure-play m-health apps. Many of them were probably ported from a previous desktop version or web-based version. While they are not currently a favorite type of apps among m-health users, given the need for many m-health



Fig. 14. Diabetes Buddy.

Used with permission from BHI Technologies, Inc.



Fig. 12. Diabetes Buddy main page.

Used with permission from BHI Technologies, Inc.

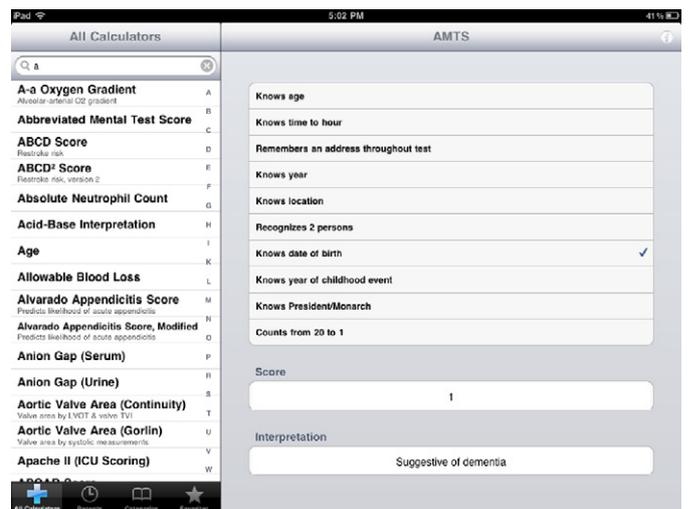


Fig. 15. MediMath Medical Calculators.

Used with permission from Regular Rate and Rhythm Software.

Table 5
Features of the six select m-health apps from Apple's App Store.

Application	ICD9 On the Go	WebMD for iPad	Muscle & Bone Anatomy 3D Medical	Calorie Tracker	Diabetes Buddy	MediMath Medical Calculator
Category	Medical	Healthcare & Fitness	Medical	Healthcare & Fitness	Medical	Medical
Customer rating	5	4	5	5	5	5
Rank in the category	69	2	82	1	61	17
Universal (a universal app runs on both iPad and iPhone/iPod Touch)	Yes	iPad-only	iPad-only	Yes	Yes	Yes
Class	Drug/medical information database	Medical information reference	Educational tools	Tracking tools	Tracking tools	Medical calculate
Class percentage (in Medical)	10	33.75	23.75	8.75	8.75	3.75
Class percentage (in Healthcare & Fitness)	0	1.27	3.80	12.66	12.66	0
Internet requirement	Not required	Limited function without Internet	Not required	Not required	Not required	Not required
Clinical/non-clinical	Applicable for both	Mostly for non-clinical use	Mostly for non-clinical use	Mostly for non-clinical use	Applicable for both	Applicable for both
Data visualization	None	2D human body used to let use point the painful location	3D human body used	2D chart used to visualize the users' weight	2D chart used to visualize the users' diabetes factors	None
Context-awareness	Preference aware	Location aware; preference aware	No	Preference aware	No	Preference aware
Therapist intervention	No	No	No	By email	By email	No
Interaction with other users	Share information via email	No	No	No	Share information via email	No

apps (e.g. migraine management; Liu et al., 2010) to include a patient-education or medical/drug information module, many of their features will likely be incorporated into future feature-rich m-health apps. Keep in mind that the App Store was opened on July 10, 2008 and is less than three-year-old. Pure-play m-health apps designed from ground up just for iOS devices are mostly less sophisticated than their desktop or web-based counterparts, but they are growing and maturing rapidly.

Some of the more focused m-health apps were designed for patients who suffer from chronic diseases (e.g. *Diabetes Buddy* for diabetes patients) or healthy person who care about health (e.g. *Calorie Tracker* for people want to lose weight). These m-health applications covered diseases such as diabetes, cardiomyopathy, obesity, migraine, and so on.

A few projects pioneered the way of providing new services through m-health apps. Examples include *AirStrip* for patient monitoring and providing remote patient monitoring solution for clinicians; *MyHumana* for mobile tracking of health-related spending accounts and helping users to find providers before treatment and deal with the claims after treatment; and *iHealth BPM* for getting users blood pressure and collecting data on iPad through the iHealth Blood Pressure Dock.

Some may question the accuracy of using user ratings to reflect quality and appeal to users, because initially, Apple's app rating functions were not actively presented to users until the apps were uninstalled. This had a negative impact on ratings. It was easier for people who did not like an app to participate in rating than those who liked the app. Although Apple changed this situation later, the old rating results still existed in the system. In general, however, the result was still fairly informative, as evidenced in a comparison between the app survey conducted in this study and a developer survey⁸ conducted by research2guidance,⁹ which showed similar results.

The developer survey was conducted in summer 2010 by distributing an online questionnaire. The survey covered 231 mobile health related companies. It showed that patients were more interested in tracking tools. Diabetes as an example of a chronic disease was considered the therapeutic area with the highest business potential in the developer survey, which also showed that "Android and iOS (would) be preferred mobile platforms for mHealth solutions."

The comparison suggested that both surveys were informative but in different ways. In the research2guidance survey, developers with an average of 27 months business experience in m-health were targeted, while the app survey conducted in this study targeted m-health apps from the Apple app store. The aim of the developer survey was to provide a reference for m-health-related companies to improve their businesses, while the aim of this app survey was to provide a technical reference for m-health developers to improve the development of m-health apps. In a way, the result from the research2guidance developer survey strengthened the result of this app survey from a developer's angle.

6. Implications for developers

The results of the app survey conducted in this study show important implications for app developers.

⁸ Global mHealth Developer Survey. <http://www.slideshare.net/research2guidance/mhealth-survey-summary-whitepaper> (last verified in May 2011).

⁹ Mobile research by research2guidance. Source: <http://www.research2guidance.com/> (last verified in May 2011).

6.1. Implication 1: m-health apps that take advantage of unique smart phone features are more popular (e.g. those with context awareness)

As shown in Section 6, in the top 100 apps in the Medical category, medical information reference apps numbered the most. However, within the 14 five-star ones among those top 100 apps, tracking tools numbered the most. It was obviously that as desktop e-health applications were ported to mobile devices, user preference changed. Medical information references may be convenient to use while a user is near a computer, but tracking tools are more convenient to use when they are deployed on a mobile device that stays with the user all the time. So, there is great potential for m-health applications that can take advantage of unique smart phone features such as context awareness (including location awareness, preference-awareness, and network-awareness) and 24×7 accessibility.

6.2. Implication 2: web-based e-health apps need to be ported

Virtually all smart phones come with mobile web browsers, even though some are more limited than others. Therefore, in theory, smart phone users already have access to all web-based e-health applications. But the usability of these e-health websites is problematic on many smart phones due to the limitations of the mobile web browsers. For this reason, some developers, e.g. *WebMD*, *TrainingPeaks*, and *WalkJogRun Running*, extended the service provided by their websites and offered m-health apps directly, which won user approval. Their experiences show that this is a viable way of improving e-health application usability for mobile users.

6.3. Implication 3: data visualization

Medical information reference and educational tools are the largest classes of medical apps now. Their percentages in the medical category are 33.75% and 23.75% respectively. How to best present the information to make it easier for end users to understand is key for these apps. The review of the current top apps shows that visualizing data using 2D charts or 3D views was an approach favored by users. As discussed in Section 4, the media layer in iOS provides the 2D/3D visualization support for applications. Developers can use Open GL ES or native rendering such as Quartz, Core Animation, and UIKit to implement data visualization.

6.4. Implication 4: health-related financial management is a vacuum to fill

An important factor related to healthcare is cost. Yet healthcare-related financial apps like *MyHumana Mobile* and healthcare management apps like *ICmed* are still rare in Apple's App Store. This presents potential opportunities to app developers because this is an area of great needs from both end users and healthcare providers.

6.5. Implication 5: compatibility with external sensors

The vast majority of iOS m-health apps work only with standard iOS hardware (iPad, iPhone, iPod Touch). Among the apps reviewed in this study, only *iHealth BPM* works with an external sensor, the *iHealth Blood Pressure Dock*. *AgaMatrix*¹⁰ claimed that they would release the *WaveSense Direct Connect Cable* to connect diabetes

meters directly to *WaveSense Diabetes Manger*, an iPhone app for diabetes management. Although multiple apps are being developed to include compatibility with external sensors, this field is so new that no widely accepted solutions can be found in literature yet. Because there are a rich set of sensors and measurement devices on the market, if m-health developers can make more m-health apps compatible with these sensors and measurement devices, it will certainly bring greater value to users.

7. Summary

As discussed above, modern smart mobile devices provide sufficient computing power and offer media-rich and context-aware features that are suitable for mobile electronic-health applications. These devices have gained acceptance as target devices for m-health applications. Many m-health application developers have chosen Apple's iOS mobile devices as the target device to provide more convenient and richer user experience, as evidenced by the rapidly increasing number of m-health apps in Apple's App Store. By examining the top two hundred of such apps from the App Store, several trends were identified.

First, the majority of developers chose to port existing web-based or standalone desktop apps to mobile devices, or develop similar one based on those web-based or standalone concepts. Yet, users gave high ratings to new, innovative apps that could take advantage of unique features of mobile devices, e.g. tracking tools. In other words, while m-health apps are by definition e-health applications running on mobile platforms, m-health apps have their own unique characteristics that warrant corresponding design and development approaches.

Second, mobile devices suitable for m-health apps typically have multi-touch interfaces and include context-aware hardware sensors. It is critical for m-health developers to innovate and integrate support for these features in m-health apps.

Third, although iPhone and iPad can be used with a number of external sensors as discussed in Section 4, those compatible sensors do not include many medical ones. To take advantage of the mobility of mobile devices and to display or track real-time measurement results for users, sensor vendors and app developers need to work together to facilitate interoperability of sensors and apps.

It was clear that m-health apps had great potentials in improving healthcare and health education for the public. There was still plenty of space to grow for m-health apps to take full advantage of unique mobile platform features. In particular, introduction of two- or three-dimensional visualization and deeper integration of context-awareness and external medical sensors could further enhance m-health app's usability and utility.

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¹⁰ *AgaMatrix*. <http://www.wavesense.info> (last verified in May 2011).

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