Australas Phys Eng Sci Med (2015) 38:23–38
DOI 10.1007/s13246-014-0315-4

REVIEW

# Mobile healthcare applications: system design review, critical issues and challenges

**Mirza Mansoor Baig · Hamid GholamHosseini · Martin J. Connolly**

Received: 6 July 2014 / Accepted: 24 November 2014 / Published online: 5 December 2014


**Abstract** Mobile phones are becoming increasingly important in monitoring and delivery of healthcare interventions. They are often considered as pocket computers, due to their advanced computing features, enhanced preferences and diverse capabilities. Their sophisticated sensors and complex software applications make the mobile healthcare (m-health) based applications more feasible and innovative. In a number of scenarios user-friendliness, convenience and effectiveness of these systems have been acknowledged by both patients as well as healthcare providers. M-health technology employs advanced concepts and techniques from multidisciplinary fields of electrical engineering, computer science, biomedical engineering and medicine which benefit the innovations of these fields towards healthcare systems. This paper deals with two important aspects of current mobile phone based sensor applications in healthcare. Firstly, critical review of advanced applications such as; vital sign monitoring, blood glucose monitoring and in-built camera based smartphone sensor applications. Secondly, investigating challenges and critical issues related to the use of smartphones in healthcare including; reliability, efficiency, mobile phone platform variability, cost effectiveness, energy usage, user interface, quality of medical data, and security and privacy. It was found that the mobile based applications have been widely developed in recent years with fast growing deployment by healthcare professionals and patients. However, despite the advantages of smartphones in patient monitoring, education, and management there are some critical issues and challenges related to security and privacy of data, acceptability, reliability and cost that need to be addressed.

**Keywords** Smartphone based applications · Healthcare systems · Mobile healthcare applications · m-Health applications · Mobile monitoring and mobile healthcare technology

M. M. Baig (✉) · H. GholamHosseini
Department of Electrical and Electronic Engineering, School of Engineering, Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand
e-mail: mirzamansoor01@gmail.com; mirza.baig@aut.ac.nz

H. GholamHosseini
e-mail: hgholamh@aut.ac.nz

M. J. Connolly
North Shore Hospital, University of Auckland, Takapuna, Auckland, New Zealand

## Introduction

Today world is witnessing the increase in the use of mobile/smartphones. A Smartphone generally includes advanced functionality beyond making phone calls and sending text messages. Most smartphones have the basic functionality like; high quality imaging, video streaming, e-mail, and internet access. Users will have plenty of personal computer features in their handheld smartphone with a touch of a button or swipe of a finger; from international to local news, world maps to local area knowledge, phone banking to online shopping, and most importantly the mobile healthcare (m-health) deliveries. There has always been a rapid change in the way healthcare delivers. In nineteenth century, first commercial but bulky electrocardiograph (ECG) device was developed, which later on improved to a 12-lead ECG with smaller size and advance functions. However, today ECG measurement (using two leads) is possible via smartphone and other hand held devices such as tablets and personal digital assistants (PDA) [1–4]. Today's technological change is due to a combination of three factors.

Firstly, the availability of low-cost embedded sensors either in-built or integrated to the mobile phone which allowed researchers to adopt multi-disciplinary approach in their model. Secondly, smartphones are available everywhere and programmable. Thirdly, new applications allow large populations of users across the globe to deploy new applications, collection and analysis of data far beyond the scale of what was previously possible. The combination of these advances opens the door for new innovative research and will lead to the development of sensing applications that are likely to revolutionize a large number of existing business sectors and ultimately significantly impact our everyday lives. Mobile healthcare applications have now enabled the technology to be applied in different and versatile manner which was previously unseen [5–7]. Such technology reduces the platform dependent applications particularly; patient monitoring, early diagnosis, detection and other important medical aspects. Developments in wireless communication technologies and trend towards using hand-held mobile devices are forcing a re-evaluation of existing technology infrastructures within healthcare. M-health systems have potential to provide a variety of opportunities to address public health challenges and reduce the healthcare cost [8]. Based on a comparison between the average cost per day (or per visit) of various healthcare alternatives, it is reported that 'hospital inpatient in the U.S.A. costs $820 per day, while a nursing home costs $100. The average cost of a house call is $74, while a telemedicine "virtual visit" costs only $30' [8]. There are approximately 100,000 health related applications for smartphones are now available on the two major smart phone platforms, Apple's iOS and Google's Android. [9, 10]. Emergence of smartphone based healthcare applications can address key issues/challenges such as; increasing worldwide healthcare related cost, increasing older adults population, high usage of smartphones in our daily lives and to enhance overall healthcare delivery. Some of the key reasons/facts that motivate researchers, developers, and manufacturers to derive research initiative into the advance healthcare applications are discussed below.

### Worldwide healthcare cost

According to US Bureau of the Census [11], within the next decade, annual U.S. expenditure on healthcare is projected to reach $4 trillion/year, or 20 % of the gross domestic product [12]. During this period, all United States healthcare spending is projected to grow at an annual average rate of 5.8 %, 1.1 % points faster than expected growth in Gross Domestic Product (GDP). By 2020, healthcare spending is projected to be 19.8 % of GDP, increasing from 17.6 % in 2010. All healthcare spending will reach $4.64 trillion in 2020 [13–15]. Therefore, health monitoring systems (HMS) can play a significant role in reducing hospitalization, the burden on medical staff, consultation time, waiting time and overall healthcare costs. There is always a constant motivation throughout the world towards the reduction of health related costs. In recent times, one emerging solution which has potential to reduce healthcare cost is smartphone/mobile phone based healthcare (m-health) applications. According to Deloitte research, annual US healthcare spending, including hidden costs, is projected to hit $3.8 Trillion in 2014. Almost 100 million Americans now use m-Health technologies, and 38 % of smartphone users deem their mobile devices "essential" for finding health and medical information. According to Manhattan Research Cybercitizen Health study [16], it is also reported that a significant improvement has been made in their quality of life. Increasing Older Adult population.

In last two decades, the rapid increase in older adult population (65+) has proved to be a major challenge in healthcare. Number of patients now requiring continuous monitoring has raised proportionally with this increase in population and, by 2025, this group will number approximately 1.2 billion. By 2050, there will be 2 billion of this age group, with 80 % in developing countries [17]. Moreover, in developed countries, older adults will constitute nearly 20 % of the overall population according to population reference bureau [18]. According to French National Institute of Statistics and Economic Studies (NISE), 24.4 % of French population is of older age group (65+) [19]. In 2006, in UK, the 75+ age group is accounted for 41 % of population of state pensionable age. However, by 2056, with the increase in age for state pension entitlement, this group will account for 67 % of pensionable population [20]. In June 2010, there were 3.01 million people aged 65+ in Australia [21] and, in New Zealand, by 2031, one in five New Zealanders will be aged 65+, compared to one in eight in 2009. It is projected that the proportion of older adults aged 65+, in New Zealand will increase from approximately 13.5 % in 2011 to 22.3 % by 2031 and 26.3 % by 2051 respectively [22].

### Mobile phone/smartphone usage in our daily life

According to the International telecommunication union (ITU) [23], there are estimated 5.9 billion mobile-cellular subscriptions worldwide with global penetration of 79 % in the developing world. Mobile-broadband subscriptions have grown 55 % annually over the last 4 years [9, 24]. The rapid growth of smartphone medical and health applications demonstrates that developers/researchers see a current market for mobile health [10, 25]. In order to have a fast mobile internet access a total of 159 companies worldwide have launched 3G services commercially and number of active mobile-broadband subscriptions has increased to almost 1.2 billion [23]. Large randomized controlled trials have shown that stable mobile applications have contributed towards the improvement of quality of life, especially using self-monitoring mobile applications, electronic health records and automated alert/reminder based applications [24, 26, 27].

Smartphone based healthcare systems are designed to enhance patient care in hospital, home, or remotely [28, 29]. Certainly, there are some challenges/issues regarding the use mobile phones in healthcare such as; feasibility, reliability, stability, security and privacy, accuracy, user-friendliness and power consumption. This paper is divided into two parts; firstly, smartphone based vital signs and blood glucose monitoring systems as well as sound and image detection systems are discussed with a critical analysis and second part discusses issues and challenges related to the selected smartphone based applications. The development of m-health applications with their challenges and issues is the main focus of this review paper.

## Methods

An extensive search has been carried using major academic research databases, such as; Scopus, SpringerLink, IEEE eXplore, Google Scholar and PubMed for recent articles related to 'smartphone healthcare', 'mobile phone healthcare', 'mobile phone monitoring', 'smartphone health monitoring' and 'smartphone applications'. We considered papers that discussed technical design, innovation, evaluation, or use of smartphones for healthcare professionals but excluded studies which are based on 'SMS', 'phone Call', 'remainder', 'test massage' and 'automated calls'; terms in the abstract with the year of publication between 2007 and 2013.

Among hundreds of studies collected initially, few potential studies were selected for this review based on the above exclusion criteria. Whereas, the application field of smartphones in healthcare is growing fast and attracting lots of commercial interests, we included those smartphone applications with commercial benefit plans. However, search for articles was limited to 'health' or 'patient health' or 'healthcare' or 'health applications'. Moreover, articles dealing with advanced technologies and innovative methodologies were considered especially those articles which focused on; vital sign monitoring, measuring blood glucose and in-built camera applications because these three areas are undergoing significant technological shift. It was found that smartphone based healthcare applications have been emerged since late 2002 and a number of good review articles have been published [30–36]. Therefore, this study incorporates more recent articles that are in conjunction with our methods as stated in this section.

## Overview of smartphone based monitoring systems

M-health applications are beginning to emerge as a useful technology for healthcare delivery. For example, by using a basic cell phone calling service or short message service (SMS), people with type 1 diabetes mellitus were assisted in self-management, by sending a text message on their mobile phone. This method has produced favourable changes in diabetes self-efficacy and adherence to treatment [37] and their behavioural changes [38]. There is also an effective and positive response from smokers, which is one of the world's current biggest problems. This is done through mobile phone based projects such as 'Text2Quit' and 'txt2Stop' [39, 40]. Today m-health applications are available in every area of healthcare such as; physical activity [41], anti-obesity [42], Diabetes self-management [43] and Asthma self-management [44]. However, this research is mainly focuses on smartphone based healthcare applications using advanced technology and therefore, we exclude the applications which uses basic mobile phone features such as; SMS, automated phone calls and reminders, a comprehensive methodological review on basic features of mobile phone health interventions is carried out by Klasnja and Pratt [31]. Moreover, an extensive review of healthcare applications for smartphones has been conducted by Mosa et al. [30].

### Smartphone based vital sign monitoring systems

Vital signs are often referred to, heart rate (HR), blood pressure (BP), electrocardiography (ECG), oxygen saturation ($SpO_2$), body temperature and respiratory rate. In this paper we consider these physiological parameters for mobile phone based monitoring system. Airstrip Technologies [45] has developed an innovative patient monitoring solution, using AppPoint™ software development platform, which is compatible with mostly all handheld smartphones, tablets and PCs. Figure 1a shows the Airstrip Technologies' remote continuous vital sign monitoring via iPhone. According to Topol [46] acceptance of mobile phone in healthcare is possible because of; ever-growing use of smartphones, enhanced bandwidth with third and fourth generation (3G and 4G) mobile data networks and smartphones with computing power equal to that of a personal laptop computer. Ren-Guey et al. [47] has developed a smartphone based healthcare system with alert mechanism using unified modelling language (UML) via Nokia 7610 phone. System detects abnormal parameter and alerts the clinician via SMS using mobile internet data

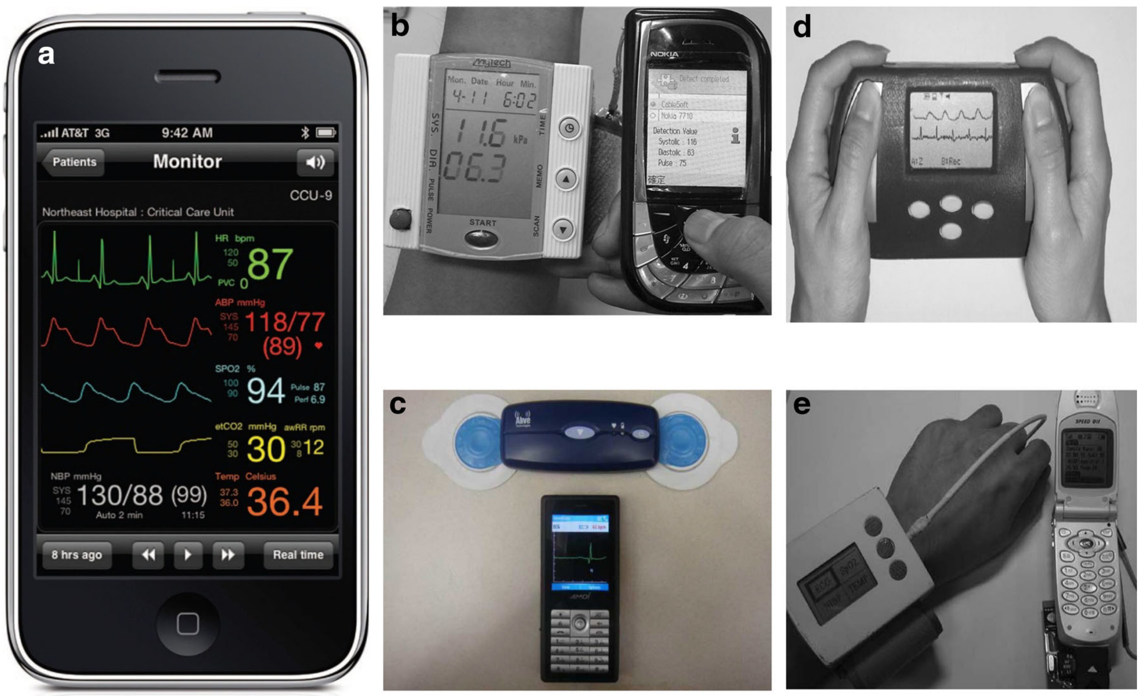


**Fig. 1** **a** Image curtsey of AirPort Technologies [45], **b** a mobile healthcare system with alert mechanism developed by Ren-Guey et al. [47], **c** HeartToGo—a cardiovascular disease detection system developed by Oresko et al. [3], **d** a remote patient monitoring system for heart failure patients called 'Blue Box' [48] and **e** wrist-worn integrated health monitoring device (WIHMD) developed by kang et al. [50]

shown in Fig. 1b. The system achieved R-wave detection of 95 % and it can be further increased by reducing false alarms. This system uses smartphone as the main processing platform, which connects to external hardware/sensor and transmits the alert via mobile data. For the purpose of continues monitoring, mobile communication link should be ON all the time, which is often considered costly and it will also have a huge impact on the mobile's battery life.

By integrating Holter monitor with mobile phone, Oresko et al. [3] has developed a smartphone based cardiovascular disease detection system called 'HeartToGo'. The system employs windows mobile operating system 5 and 6 for smartphones, and MIT-BIH database to test its performance. Its core model is built using C++, C# and detects QRS signals with quite high accuracy as shown in Fig. 1c. Classification accuracy of this system was analysed by three-way cross-validation method which helps to minimise variations due to random sampling of finite-size data samples. It is also reported that the dataset was partitioned for each class randomly into three disjoint subsets of approximately equal size. A similar system called 'Blue Box' [48] has been developed as a novel hand-held device capable of collecting and wirelessly transmitting key cardiac parameters ECG, PPG and bio-impedance (Fig. 1d). It also measures RR interval and QRS duration, HR, systolic time intervals and assesses their values in correlation with cardiac output measured by an echo-doppler. In ECG measurement there is a 30–60 s time delay has been reported. Other common issue reported in literature is, simulation or testing of system by using small sample size and healthy subjects often gives low accuracy results when tested in real-time [48, 49]. Figure 1e shows wrist-worn integrated health monitoring device (WIHMD) developed by kang et al. [50]. WIHMD consists of six vital signals; a fall detector, a single-channel electrocardiogram, non-invasive blood pressure, pulse oximetry (SpO2), respiration rate, and body surface temperature measuring units. It is essential to mention that the size of the WIHMD is 60 × 50 × 20 mm, except wrist cuff, and total system weighs only 200 g, including two 1.5-V AAA-sized batteries. System has achieved high accuracy and works on low power consumption, and tested using 150 simulated cases and five human subjects.

Majority of vital sign monitoring systems uses built-in Bluetooth technology to receive information from various devices and use mobile internet or WiFi to transfer information. Such applications are now easy to build by development kits for smartphone applications using almost all major operating systems. This typical setup limits the mobility of user to its Bluetooth (BT) range only and continues use of BT often reduces battery life.

## Smartphones applications for blood glucose measurement

Today's smartphones not only serves as key computing and communication mobile devices of choice, but they also come with a rich set of embedded and advanced sensors, such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera. Collectively, these sensors are enabling new applications across a wide variety of domains. Tackling diabetes is likely one of the major concerns for global public health community where smartphone can play an effective role. Smartphones using GPRS, 3G, 4G and 5G (under development) for data transfer is a technically attractive solution in establishing reliable communication link between patients and clinicians. Nowadays smartphones can transmit and receive data in real-time, using its widescreen graphical display of data, and keyboard to allow entry of additional data. Figure 2 shows variety of smartphone based blood glucose detection systems which are currently in use and/or available in market today and developed by; (a) Farmer et al. [51], (b) Tatara et al. [52–55], (c) Cho et al. [56] and (d) AgaMatrix [57].

Usually these systems can be connected wired or via wireless BT (Accu-Chek compact plus blood glucose meter) and often record the readings as a text and present data with time and history information on the user screen. Each reading is then converted into a text format which can be sent manually or automatically as a SMS or over the internet to doctors, nurses or family members. For blood glucose meter, user has to buy a user's phone compatible device, a mobile application and a mobile phone service subscription. Smartphone service providers often support one type of device and thus users are constrained to one supplier. However, main features of this technology, such as; low cost, easy to use, simple to adopt are often neglected or ignored in such cases.

## Smartphone based sound and image detection systems

The advanced graphical features of smartphone enable us to see complex medical signals displayed on mobile. For example, ECG signal can be displayed on the mobile screen with heart rate and arrhythmia detection capabilities using standalone simple ECG diagnosis algorithm in smartphone [58–60]. Researchers simplified the m-health platform in such that, microphones of smartphone acts as a stethoscope to get heart sound (data). Figure 3 shows some of the leading ECG and heart rate (sound) detection systems. BlueSpark, an Auckland based company, has developed a smartphone (iPhone) based application which detects heart rate using in-built microphone shown in Fig. 3(a). This application works even better using headsets [61]. Similar heart rate detection application called 'Instant heart rate' was developed by Azumio technologies, which uses in-built camera. User has to place the finger gently over the camera and has to hold it steady for at least 10 s. Instant heart rate application uses iPhone's in-built camera to detect pulse from fingertip. A technique similar to the one used by medical pulse oximeters is now available on smartphones [62]. More smartphone based applications have also been developed using built-in camera and microphone in recent times [58–60, 63]. Usually the phone's camera acts as a scanner, which scans fingertip using flash light and a program analyses heart rate variations. However, there is no reliability and stability in such systems because the output will dramatically change depends upon the finger position and lighting conditions even for a same person. Mobile microphone can be used as stethoscope and data (sound) will be amplified so that user can actually hear the recorded sound. Smartphones are embedded with various sensors such as; acceleration sensors, vibration transducers, or angular transducers, that provide enhanced services like; biometrics authentication, motion detection, or obstacle detection [64].

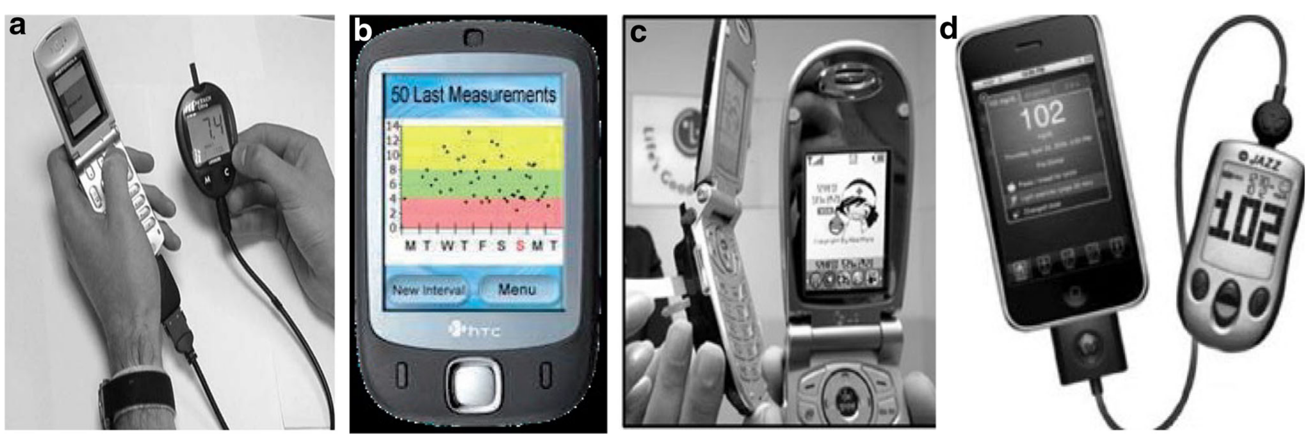


**Fig. 2** Shows the variety of smartphone based blood glucose detection systems developed by; **a** Farmer et al. [51], **b** Tatara et al. [52–55], **c** Cho et al. [56] and **d** AgaMatrix [57]

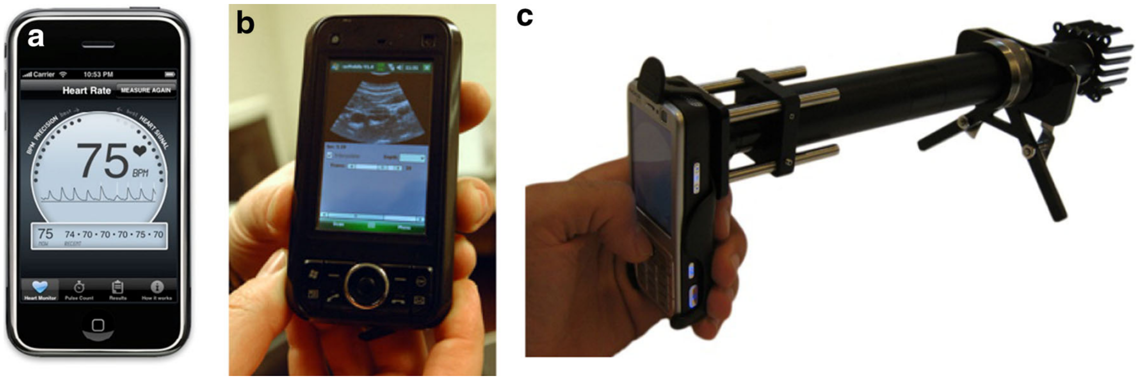


**Fig. 3** Various smartphone based sound and image detection applications. **a** BlueSpark's heart monitor for iPhone [61], **b** Richard and Zar, Washington University developed USB-based ultrasound imaging system [65] and **c** Breslauer et al. developed the clinical microscopy system using smartphone [66]

Imaging is a critical and valuable method in medical care which can be realized through smartphones. Ultrasound imaging using smartphone made the clinical diagnosis simple and advanced. For example, a smartphone works by coupling with USB-based ultrasound probe technology, to enable a compact and mobile computational platform. A medical imaging device that fits in the palm of a hand, has been developed by Richard and Zar, Washington University as shown in Fig. 3b [65]. Fluorescence imaging of tuberculosis and automated image analysis performed on mobile phone provides an immediate efficiency gain analysis as well as a longer term potential for automated microbe and pathogen identification (Fig. 3c) [66]. Quality of such system can be further improved, such that, imaging sensors in the smartphones could be enhanced through software and algorithms. An enhanced imaging system has been developed by Zhu et al. [67], which demonstrated the integration of imaging cytometry and fluorescent microscopy on a smartphone using a compact, lightweight, and cost-effective optofluidic attachments.

Smartphone healthcare network systems are often based on personal area network (PAN) or body area network (BAN) in which the network of intelligent bio-sensors collects biological data from patient. Collected information would be transmitted to smartphone for analysis, detection, monitoring and diagnosis. Wireless technologies in m-health often considered as wireless wide area network (WWAN), which provide standard communication platform over a wide geographical area; and Wireless local area network (WLAN) technologies (e.g., WiFi) which provide over a narrow geographic area [32, 68].

Today, almost every (standard) smartphone has a built-in camera, it is expected that the majority of healthcare applications will focus on using this feature to address the important aspects of healthcare deliveries. Some of the challenges with using camera and image/video processing of captured information are related to camera quality on which the application is built upon. Moreover, complexity of image/video processing handled by smartphone in terms of processing time, battery life and advancement to the already existing systems is currently a hot research topic.

Biofeedback application in mobile healthcare are also an emerging area, especially for sports, physiotherapy and musculoskeletal systems. A lightweight biofeedback system has been developed for Android operating system to continuously monitor outdoor sports activity using GPS, Shimmer sensor and automated labelling algorithm [69]. Such application in real-time provides information of the location as well as the e-health record of the athlete, which in most cases, regarded as the early detection of the decline in the performance related monitoring [70–72]. Another area of concern in the view of biofeedback applications is the mental health and behavioural disorders, which are generally difficult to treat and monitor [73]. Common examples include a variety of addictions (drugs, gambling, food, etc.) as well as anxiety disorders or depression. In order to address the behavioural intervention related to the use of drugs via mobile application, a mobile sensor system has been developed, consists of a sensor band worn on the ankle that continuously monitors electrodermal activity (EDA), 3-axis acceleration, and temperature. The EDA signal from the ankle bands provides a measure sympathetic nervous system activity and used to detect arousal events. In case of a specific arousal event the phone automatically presents therapeutic and empathetic messages to the patient in the tradition of Cognitive Behavioural Therapy (CBT) [74]. To detect the early change in the behavioural response using the body sensors and using activities of daily life (ADLs) and integration of personal health record via telehealthcare application is proposed by Kulkarni [75]. Early detection of abnormal activities was deleted from the ADLs and analysed using the robust statistical measures. The unique combination of telehealthcare and ADLs gave the advantage of real-time early detection of various activity and behavioural changes [76, 77]. Apart from the ADLs analysis, there is also a growing applications on various mental engagement for the Dementia patients in the form of a mobile game or an interactive smartphone application so that the behavioural change can be monitored and measured [78].

A brief summary of m-health systems and its potential benefits is presented in [34, 79], where some successful case studies in the areas of electronic patient records, emergency telemedicine, tele-radiology and home monitoring are discussed. Various scenarios and situation of m-health system for managing emergency circumstances can be found in [80, 81]. Recent studies and surveys on advancements in m-health domain are given in [32, 35, 79, 82–85]. Table 1 summarises the above discussed mobile healthcare systems. The most successful and widely adopted m-health technology networking architecture is shown in Fig. 4. Similar architecture is also adopted by many researchers such as; Liu et al. [86], Lane at al. [83], Kumar et al. [81], Alemdar and Ersoy [79], Ming et al. [87], Mughal et al. [88] and Kulkarni and Ozturk [75].

## Critical analysis of smartphone based healthcare applications

Smartphone based healthcare technology would benefit patients and medical professionals by providing rapid access to health information especially, in emergency situations. This technology is continuously being enhanced while there are challenges to improve its clinical applications. Advantage of mobile phone based monitoring has been proved for data capture and transfer only, whereas data processing on a mobile devices poses serious disadvantage in terms of accuracy, delay and power/battery life [24, 73]. For instance, raw data can be transmitted efficiently from a mobile phone, but the analysis and processing of that data inside the smartphones is still a major concern. This is due to the high impact of data processing on the mobile phone's battery runtime and ultimately causing delay in transmission of data. The model of data transmission in mobile health monitoring systems can be presented in two transmission types. In type 1, patient data is collated by a mobile device and then transmitted to a remote server for processing. Then, data is transmitted to clinician's mobile device directly or via patient's mobile device. In type 2 mobile transmission, the patient data collected using body sensors are directly transmitted to a remote station/server for data processing, then alerts are transmitted to other devices to avoid any delays.

Continuous data transmission by mobile devices can significantly reduce battery life. This scenario particularly is more challenging when compared to low signal strength in rural areas or in case of data transmission charges. Another critical challenge is the security and privacy of user data, especially in remote monitoring systems. These systems not only monitor vital signs but also can detect abnormalities and transmit data to healthcare professionals in real-time. However, a significant threat to these systems is the data security and privacy, in terms of patient identification and confidentiality of medical information. These issues have not been fully addressed yet and there is a need for improvement in the design and structure of these

**Table 1** Selected smartphone based healthcare delivery systems

| Name | Purpose | Smartphone | Wireless technology | Programming language used |
|---|---|---|---|---|
| Ren-Guey et al. [47] | Healthcare system with alert mechanism | Nokia 7610 | Bluetooth class 2 application programming interface, JAVA | Borland C ++ 6.0 ActiveX data objects |
| HeartToGo [3] | Cardiovasc-ular disease detection System | Windows Mobile 5 (Amoi E72) and 6 (HTC) | Blue tooth class, Matlab and LabView | C#, C ++,.NET and used MIT-BIH database |
| Blue Box [48] | Heart failure patient monitoring system | Handheld device | Low-power Bluetooth module | Converter (AD5934) |
| Kang et al. [50] | Wrist-worn integrated health monitoring device (WIHMD) | Samsung smartphone | Personal area network, ad hoc networking | QRS detection algorithms, microcontroller (ATmega103L, Atmel, USA |
| Farmer et al. [51] | Phone based telemedicine system for type 1 diabetes | Motorola T720i phone | Bluetooth, GPRS (2.5G) | JAVA programming |
| Tatara et al. [52] | Self-help tool for Type 2 diabetes | HTC P3450 | Wireless data transmission | JAVA programming |
| Breslauer et al. [66] | Clinical microscopy | Nokia N 73, (with 3.2 megapixel CMOS camera) | N/A | C ++ and JAVA with integrated microscopy image analysis |

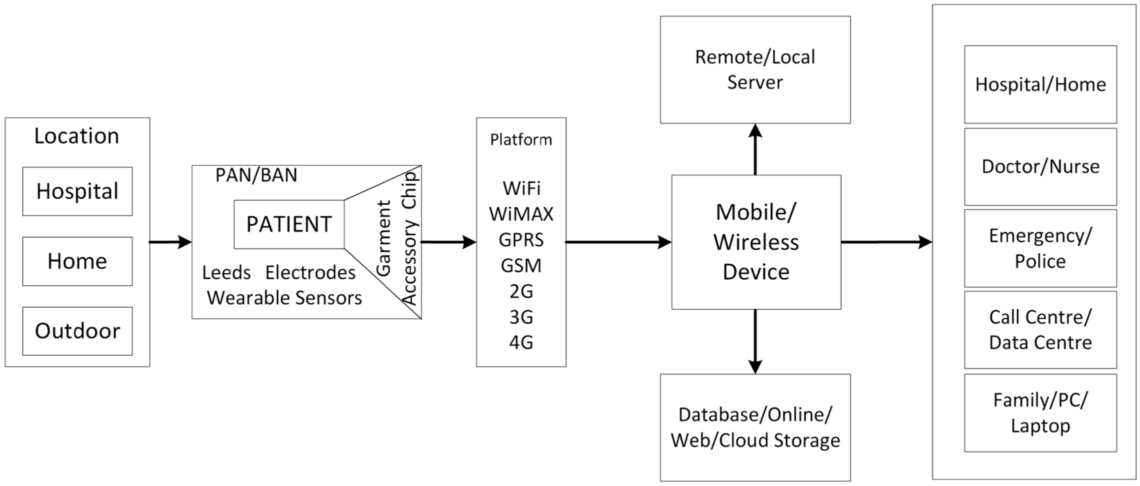


**Fig. 4** Widely adopted m-health technology networking architecture

systems to comply with medical and ethical standards. However, smartphone applications may impact heavily on the staff in the common areas that support some important activities such as patient schedule changes, and discussions related to professional feedback and quality control. This impact in a surgical department was found to be negative and additional socio-technical mechanisms may be required to overcome these issues [89]. However, despite the advantages of mobile/smartphones in patient monitoring, education, and management there are some critical issues and challenges related to security and privacy of data, acceptability, reliability and cost that need to be addressed. Next section addresses some of the critical issues/challenges currently facing by mobile healthcare technology, and recommendations on the identified issues.

## Critical issues and current challenges facing by m-health technologies

A number of critical issues are considered important in m-health monitoring such as: duration of monitoring, frequency of data collection and transmission, amount of data transmitted and nature of monitoring in terms of alert, periodic or continuous. The following overview of requirements of patient monitoring shows the complexity, diversity, and somewhat contradictory nature of the requirements. Some of the current and future challenges that researchers must overcome are investigated in the following sections.

### Reliability, efficiency and acceptability

With the ever growing smartphone based monitoring systems, end-user acceptability is becoming an important aspect in the design of such systems. There is still an open research question to be addressed and the opportunity for a paper to address a particular question such as: Do smartphone based monitoring systems make a difference to the patient's (end-users) well-being? To answer this important aspect of healthcare many researchers have included patients as well as medical professional's consideration at every stage of the design and development [90]. We believe the acceptance of any system in the healthcare industry depends on the user awareness and acceptability. Adaptation of a device within the clinical field is stuck when they are negatively perceived. User-centred design is essential in order to incorporate these perceptions into the product, especially at the earlier stages of the project development. When analysing user's needs, contextual inquiry, user's profiling the designer should consider a number of factors such as; task analysis, surveys, interviews and focus groups to address the user acceptability [91]. We support the proposal of Steele et al. [92] that future studies should document any attitudes, perceptions and concerns of users. It is known that highly sophisticated technology and data analysis techniques become irrelevant if user do not wear the sensor systems for the allocated periods of time [93].

The reliability of monitoring systems is an important and open research question which often considered as a critical parameter for the acceptability of the system. In the context of reliability and efficiency, main purpose is to connect m-health monitoring system to the user within their activity area (Bluetooth range) and model the regular activities. An alert is not triggered when the person is outside coverage area or specific range by more than a predefined threshold range. Several methods are proposed for determining when an alert/alarm should be triggered [75, 94]. Bergmann and McGregor [95] carefully considered several systems and recommended the best and most efficient body worn sensor design. Current trends in m-health applications have produced an innovative and versatile approach to wearable textile based monitoring systems using smart shirts [96], T-shirts [97], electrode-embedded textiles [98–100], worn at home [101, 102], in bed [103, 104] in the form of headgear [105], or footwear [106]. Innovative methods for improving physiological signal processing have also been developed [107]. These include, neural networks [108], fuzzy logic [109, 110], principal component analysis and independent component analysis [111]. In brief, m-health applications must provide reliable and efficient vital data and algorithm for evaluating the patient's needs. The system should be simple, reliable, and user-friendly.

### Smartphone platform variability and cost effectiveness

Software platform is becoming a drawback towards the development and implementation of smartphone based applications due to its multiple/different operating systems. The development environments for handsets cover a wide range of operating systems including, Microsoft Windows Mobile, Symbian, Blackberry, Palm OS, Mobile Linux, J2ME, Apple's iOS and the Android platform by Google. Another issue with use of mobile platforms is variability and compatibility between the programming language and application environment. At present, efforts to make m-health systems fully functional in all available (common) smartphone platforms are slowly approaching [45, 61–63]. The involvement of healthcare professionals in the development of such systems and their participation in the policy discussions would be important in order to achieve full potential of m-health applications [112–114]. Another barrier is mobility of data as most of the smartphone based healthcare systems transfer patients' vital data and/or key physiological parameters via mobile communication links, that are; GPRS, 2G, 3G, 4G and 5G (under development) networks. Costly mobile phone contracts and expensive termination fees could create a barrier to access for a specific service such as medical data processing [115].

### Energy usage and battery life

It is very important to have a low energy consumption device especially for battery operated systems, such as smartphone. With the vital sign monitoring and considering the use for older adults, is one of the main goals to reduce energy consumption for achieving a longer battery life. There is a long lasting debate on the effect of cell phone radiation on the human body, which is beyond the scope of this study. When a device transfers a considerable size of raw data to central processing unit of a stationary computer, a large amount of energy is required which normally supplied by a battery. For example a blood pressure measurement every 10 min require 35 mA/h (consider data transmission, valve and microcontroller), in this case 1,000 mA/h or AAA batteries required which will long last for a day or so. These application requires high quality of data in real-time, sent to multiple devices (PC, laptop and tablet) [116]. Long term use of such systems can pose a serious threat to mobile device's battery life and seriously compromise the transmission of essential data [117, 118]. Researchers are actively developing new low-power, low-energy consumption sensors which can be used in long time monitoring and gives more battery life [68, 79, 119–122]. Proper frame work has to be developed to address the energy consumption issue in smartphones which can be a serious threat not only to system but also m-health technology [123, 124]. In emergency situations when; patient collapsed, or the strength of mobile signal is low, especially in rural areas, or when phone goes off self-automated alert systems should be activated by smartphone's in-built chips [125]. Recent attempts have been made to overcome the mobile power barrier such as ePROF a fine tuned energy profiler, it identifies the unique challenge of asynchronous power behaviour of the open/running applications in a mobile phone to allocate the memory usage and its power impact on the monitoring hardware. This research shed light on internal energy dissipation of such energy profiling apps and reported that 20–65 % energy consumption can be achieved by controlling I/O events within application [126].

### User interface and quality of patient's medical data

From user point of view, graphical user interface (GUI) feature of a smartphone is one of the most appealing functions that should be easy to use, simple and functional. Such feature can be difficult to develop for different types of users including the elderly and handicapped. Today smartphones offer simple and easy process to download an application (by looking at 3–4 screen shots shown by the manufacturer). Thus, there is a possibility that if the user dislikes the application or finds it complicated then the application will be removed as easy as it was downloaded. Therefore it is essential to have a user-friendly and simple to use m-health application for all common mobile platforms.

Using high quality data (according to medical standards) in m-health applications is important for reliable communications. Various techniques were applied to collect high quality data [103, 127–132]. However, in some studies short time data measurement was worrisome [103], because, either the data quality was substandard [133] or high false positive alarm rates were reported [134]. It is necessary for the vital sign monitoring systems to capture and transfer the highest possible data quality. For example ECG signals were far more accurate when gel electrodes were used [99] whereas those measuring devices without gel proved to be inaccurate [135]. It is important that at early stage of application development, a theoretical framework be set in combination with data (simulated or trial) to manage physiological parameters. At each stage of the development, the feedback of medical professionals should also be considered and discussed it in every possible aspect in relation with the end user (patient).

### Security and privacy

Security and privacy is the most important functionality of any healthcare system and often this area is left behind in the development of m-health based healthcare system. Usually m-health application deals with personal information which needs protection in order to have a safe and secure system. Overall, security is a concept similar to the safety of any system. As transmission of data in m-health based application is wireless, it may result in various security threats. Such threats have potential to pose serious problems to social life of an individual. Security issues in wireless sensor networks are a major area of research in recent years and many researchers have specifically addressed security issues with respect to healthcare applications [36, 87, 136–138]. In the following section some of the security and privacy issues related to m-health based system will be discussed along with some recommendation for improvement.

The security issues can be classified into two categories: system security and information security. Ng et al. [139] has classified threats and attacks into two major categories—passive and active. Kargl et al. [140] have mentioned attacks in health monitoring in detail such as; modification of medical data, forging of alarms on medical data, denial of service, location and activity tracking of users, physical tampering with devices and jamming attacks. Security and privacy vulnerabilities are discussed in detail by Williams [141]. Some of the key points mentioned are; ease of network formation, complexity of interactions, duplicitous users, and leakage to third party servers and shared content.

A number of security and privacy frameworks have been developed, designed and tested for their reliability in m-health applications, 22 free web based personal health record privacy and security policies have been analysed by Carrion et al. [138] and reported a high level of user's security is in place with applications such as Google Health, ZeabraHealth, Keas and Microsoft Health Vault. Al Ameen et al. [36] have divided security and privacy into two aspects; firstly, system security, which includes administrative, physical and technical level security and secondly, information security, which includes data encryption, data integration, authentication and freshness protection [36, 87, 136, 137].

A strong and robust privacy-preserving scheme against global eavesdropping for e-health systems called SAGE, works with multiple layer security transit relationship to make current m-health safe and secure [137]. It is also essential to consider; policymakers, certification bodies, manufacturers, public-key infrastructure, distribution and management in order to develop a successful health system. Some of the most reliable security and privacy frameworks to be considered, are discussed in detail by Kotz et al. [136] and Avancha et al. [142] which include; office of the national coordinator (ONC) national framework (2008), health privacy project's (HPP) best principle (1999), HPP best practices (2007), Markel's foundation's 'connecting for health' common framework (2008) and the Certification Commission for Healthcare Information Technology's (CCHIT) certification criteria (2008).

A trust based security framework using encryption and decryption [117], a framework designed to secure mobile wireless-networked sensors with a middle ware component to deliver sensing data and retrieve patient monitoring information securely using a two tier architecture [88], a robust and secure system built on three main functions: data protection on the device, secure authentication and data encryption [142], design consideration for the long term monitoring of vital signs [143], and a work presented at [144] are some of the recent development carried out by the researchers in addressing the most common and vital security and privacy issues. If any of the above frameworks is adopted for an m-health application then the system can be considered to have basic security standards. As times comes there will be more and more advancement in this area because, m-health is getting high acceptance in the general public and development of more secure and reliable applications are under development or already available in the market [31, 86, 118, 124].

## Discussion

Apart from the above mentioned issues, global standardisation among the smartphone usage is another critical issue acquiring more attention due to the increasing use of m-Health applications. It is reported that [145] there are many organisations actively developing global standards and implementation guidelines to achieve interoperability within a specific health domain, such as the international organisation for standardisation (ISDOs), Health Level 7 (HL7) international and integrating the healthcare enterprise. Organisations such as international telecommunication union (ITU), WHO and international medical informatics association (IMIA) are actively contributing towards the global m-health standardisation. Among them, WHO plays an important leadership role by producing the WHO family of international classification (FIC) to provide a common, global framework and language for health information [145]. Smartphone based monitoring systems have been considered suitable for improving the quality of healthcare delivery. Currently, majority of systems focus on capturing information related to a specific health condition and/or parameter monitoring of users' health and physical activities [34, 124]. Enhanced features of smartphones such as; wireless connectivity, high quality images and videos make them suitable for more advanced healthcare applications. Lin's survey [35] on mobile monitoring gives an insight into the various mobile platforms and technologies. With the ever growing research in smartphone based health applications, end-user consideration is often ignored or neglected in the design of such applications. There is still an open research question to be worked on to address the user acceptability issues. Moreover, there is room for research on the quality of smartphone based health applications related to the patient (end-users) well-being.

To answer these important aspects, many researchers have included patient as well as medical professionals' feedback at every stage of the design and development [66, 90]. We believe the acceptance of any system in the healthcare industry depends on the perception of the user. User-centred design is essential in order to transfer the concept into the product, especially at the earlier stages of the project [91]. In the development of smartphone based (m-health) applications, some researchers have certain perception and often consider user-friendliness and user preferences.

It is suggested that m-health applications should be distributed among population for disease, treatment or point-of-care and many such modules could be re-used across applications (platforms) [30]. It is very important to consider broad community, target group/disease, healthcare professional from the early stage of the design so that user centric approach can be implemented throughout the development phase. It is also worth considering the youth and early technology adopters so that the interest/focus towards the application usage can be maintained. It is 'somewhat' proved that successful m-Health applications considered patient and medical professional consultation in the design as well as development stages [30, 33]. As suggested by Steele et al. [92], the theoretical framework should be built based on the user preferences. It is evident that even with advanced m-health systems if the user does not fulfil the requirements such as, not wearing the sensor for the allocated periods of time, then the application becomes immaterial [15, 93, 133].

Although, smartphone-based monitoring is still in its pre-establishment stages and the realization process has merely begun [77, 146], the future work will help to fine tune the concept and bring forth the realization of a smartphone based healthcare environment. Issues of acceptability, security and privacy as well as trust of doctors and patients should also be considered. Security and privacy is crucial phenomenon to the success and adaptation of the m-health systems. This area in particular has raised interesting research issues in wireless, wearable and pervasive healthcare networks. Nonetheless, in order to develop a successful m-health application, the suggested techniques and guidelines proposed in the literature reviews [147–149], surveys [35, 79, 81, 83, 85, 123, 144], frameworks [17, 34, 91, 124, 136] and end-user acceptability [7, 33, 150] can be considered.

## Conclusion

In this paper we reviewed a number of smartphone based applications in healthcare settings. It was found that applications such as; remote access to patient data and information, reducing medical errors, falls detection and early assessment can enhance quality of healthcare service as well as save time and cost. Advanced features of smartphones like wireless connectivity and information mobility are inspiring medical professionals towards the adaptation of m-health applications in clinical settings. However, some studies show that slow adaptation of m-health is due to lack of validation, standardization and positive patient outcome. In addition, majority of researchers believe that there are several factors discouraging m-health adaptation by medical professionals. These factors include; understanding of advanced technology, usability (size, weight and other basic features), medical implementation, lack of clinical adaptation for individual need. Due to the wireless operation of smartphones, security and privacy of the transmitted data are also considered as important issues. Therefore, there is room for further research to investigate the user preferences for m-health systems. Despite some limitations of the selected studies, several general preferences were identified. Using common recommendations by patients and clinicians, it was suggested that the system should be compact, preferably embedded and simple to operate. It should be available alongside the work of health professionals with minimum interruption on normal daily activities. The m-health technology could be extended to support highly personalized healthcare services to people living in nursing homes and aged care facilities while being remote. This review paper discusses current state of the art and open challenges in emerging field of smartphone based healthcare applications. One of the m-health's biggest fears and technical barriers is the security and privacy of the personal information. Once these technical barriers are resolved, m-health technology will emerge as a reliable and trustworthy technology across many health domains as predicted by majority of clinicians, patients (users) and manufacturers.

Some of the related research projects are reviewed and their issues, challenges and barriers are discussed with several recommendations and frameworks. However, the current study highlights the fact that there are still challenges and issues that need to be resolved for such systems to become more applicable to real-life situations and to be accepted by patients and healthcare professionals as a reliable, multifunctional, easy-to-use, and cost effective technology that can enhance their quality of living.

**Conflict of interest** The authors declare no conflict of interest.

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