Research Article

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Journal of Health & Medical Economics
ISSN 2471-9927

2016
Vol.2 No.3:10

DOI: 10.21767/2471-9927.100010

Mobile and E-Healthcare: Recent Trends and Future Directions

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Received date: June13, 2016, **Accepted date:** July 01, 2016, **Published date:** July 10, 2016

Citation: Kher RK. Mobile and E-Healthcare: Recent Trends and Future Directions. J Health Med Econ. 2016, 2:10

Abstract

In the past decade, wearable sensors and devices have evolved as key technological objects which have dramatically revolutionized the next generation healthcare solutions. This is the era of cut-throat competition filled with immense stress which leads to the detection of various diseases even in the people of early age. Moreover, people are becoming more health conscious in developed as well as developing countries. The miniaturization of sensors and devices and tendency of people to be physician-independent have lead the researchers across the globe to come up with numerous healthcare solutions which are not only ubiquitous but are affordable also. Wearable medical devices (WMDs) capable of monitoring some of the most common physiological parameters- pulse, blood oxygen saturation, 2 lead ECG, heart rhythm, skin temperature etc. have already been popular. Ambulatory and long-term health monitoring for elderly people is another aspect, particularly for countries like China and Japan where population aging is increasing. With the development of networks, collected health information can be sent to the cloud server of the nearest clinic or hospital. Doctors can then provide patients with medical advice. Thus, WMDs or WMD-based applications can help both patients and doctors in daily health monitoring. The paradigm has gradually shifted to the mobile health (mHealth) - an integration of ever advancing wireless communication, ubiquitous computing, and wearable device technologies. The mHealth can be regarded as the most advanced version of healthcare monitoring.

Keywords: e-Healthcare; Healthcare solutions; Wearable; Medical devices

Introduction

The extensive usage of mobile technologies and their user-friendly applications related to health nowadays have given a rise to a new healthcare paradigm of eHealth, known as m-Health. According to the International Telecommunication Union there are now more than 5 billion mobile phone subscriptions in the world, with over 85% of the world's population now covered by a commercial wireless signal. The growing sophistication of these networks – offering higher and higher speeds of data transmission alongside cheaper and more powerful handsets – are transforming the way health services and information are accessed, delivered, and managed. With increased accessibility comes the possibility of greater personalization and citizen-focused public health and medical care [1]. The e-healthcare and now its mobile version, m-healthcare, system basically include wireless body sensor networks (WBSN) or/and wireless personal area networks (WPAN) for providing higher-quality medical services and more efficient medical responses and treatments to patients. In such an e-healthcare/ m-healthcare systems, the sensors placed around patients' body gather the vital parameters (e.g. heart rate, pulse rate, oxygen saturation level, sugar level and many more) andreport them to remote healthcare service provider and/ or physician immediately for real-time and long-term monitoring of patients [2].

The details of earlier days e-healthcare systems are found in [3-8]. The mobile and/or smart-phone based health motoring systems have been reported in [9-14]. The e-healthcare systems have come up with models and formats viz. tele-home healthcare comprising of cuffless blood pressure meter, ring-type heart rate monitor and Bluetooth-based ECG monitor [15], wrist-wearable telemedicine monitor for heart patients (AMON) and a generic belt-integrated computing platform for home and hospital use (QBIC) [16], physiological parameter monitoring through mobile/smart phone [17] and many more reported in [18-25].

There are many aspects as well as challenges associated with the mobile and e-healthcare systems:

- Architectural design and implementation issues
- Integration of data and networks
- Secure and efficient data transmission and management
- Maintaining privacy of patient information and their data

This paper discusses the current status of mobile and e-healthcare systems in context of above aspects and challenges as well as upcoming, future trends. Section 2 describes various e-healthcare models and systems implemented till now along with upcoming technologies; section 3 presents the application domains of mobile and e-healthcare; section 4 briefs the challenges and security issues encountered in mobile and e-healthcare systems and section 5 briefly provides the insight to the future scopes in mobile/e-healthcare.

Various e-healthcare models and systems

Wireless Body Sensor Network (WBSN) based e-healthcare Systems:

There are many reasons for innovating the mobile and e-healthcare systems e.g. a daily monitoring of vital physiological parameters to the detection of an abnormal event accomplished by ambulatory monitoring. A tele-home healthcare system [15], for example, has been proposed for remote patient monitoring. The system utilizes wearable devices, wireless communication technologies, and multisensory (cuffless blood pressure meter, ECG and PPG sensors) data fusion methods. In [26], authors have proposed a body sensor network (BSN) which allocates extra resources for important parameter like ECG maintaining the security of data over the network. The integrated network of IEEE 802.11/ WLAN and IEEE 802.16/WiMAX can bring a synergetic improvement to the telemedicine services on coverage, data rates and quality of service (QoS) provisioning to mobile users. This integrated network will be able to provide services like emergency telemedicine, mobile medical data, mobile robotic system and pre-hospital care [27]. The healthcare and patient monitoring systems based on 2G-RFID, Bluetooth-enabled in-home patient monitoring system and multitier wireless network using 802.15.4 low data rate WPAN with 802.11 WLAN have been proposed in [28-30].

Smart wearable garments like ProeTEX (Protective Electronic TEXtiles for emergency operators) [14] and Heally recording system, having ECG/EMG/EOG electrodes, various electronics modules and NiMH battery) mounted on a shirt [8]. In a sensorized T-shirt is developed automatic sleep classification-wake, rapid eye movement (REM) and non REM- based on heart rate variability (HRV), respiration and movement signals. Wirelessly powered fabric patch sensor system for ECG recording at very low power has been developed in.

Cellular and smartphone based e-healthcare systems:

A Mobicare cardio monitoring system consisting of a cellular phone embedded with real time ECG processing algorithms-detection of QRS complex, Q onset, T offset- (MobiECG), a bluetooth-enabled ECG sensor, a web-based server, a patient's database and a user interface is presented in [6]. In this framework, ECG processing is carried out by MobiECG and it will send the abnormal ECG data over a cellular network (GPRS/3G) to hospitals or care centres to alarm physician only when it detects abnormal ECG signal. Otto et al. [31] have presented a WBAN and TinyOS based architecture for monitoring body motion and heart activity. The system consists of a network coordinator and a personal server running on a personal digital assistant (PDA). HeartToGo- a windows mobile smartphone-based wearable cardiovascular diseases (CVD) detection system; capable of performing real-time ECG acquisition and display, feature extraction, and beat classification has been developed by Oresko et al. [9]. The system is capable of classifying the premature ventricular contraction (PVC) as well as generating the cardiac summary report consisting of the average, high, and low heart rate, and the total number of beats, as well as the number of normal and PVC beats.

Cellular phone based patient monitoring system (C-SMART) [32], mobile phone based fall detection system on Android platform [33], personal heart monitoring and rehabilitation system using smart phones [34], a mobile health monitoring system for elderly people (iCare) [35], MobiHealth- a vital tele-monitoring and tele-treatment system based on a body area network (BAN) and mobile healthcare service platform using next generation public wireless networks [36], smartphone based body area network system (SBBANS) [37], Android based fall detection system with physiological data monitoring [38], mobile based multi-function health monitoring system [39], human activity recognition system combining accelerometer data and GPS of android- based smartphone [40], daily mood assessment using mobile phone sensing [41], a mobile EOG-based human computer interface for assistive healthcare (EyePhone) [42], smartphone-based sleep quantity measuring and modelling algorithm [43], an android-based mobile healthcare system incorporating PSoC and cloud storage [44], smartphone-based continuous monitoring system for home-bound elders and patients [45] have been found in literature which have extensively used cellular phones and smartphones for efficient, wearable and portable healthcare systems.

In addition to above mentioned systems, a portable, light-weight wearable healthcare monitoring systems have been proposed in [4,5,7,46].

System on Chip (SoC) e-healthcare modules:

A portable system on chip for ECG monitoring has been developed [47] which is capable of implementing configurable functionality with low-power consumption. The SoC is implemented in 0.18 μm CMOS process and consumes 32 μW from a 1.2 V while heart beat detection application is running, and integrated in a wireless ECG monitoring system with Bluetooth protocol. A low-power biosignal acquisition and classification system consisting of: 1) a high-pass sigma delta modulator based biosignal processor (BSP) for signal acquisition and digitization, 2) a low-power, super-regenerative on–off keying transceiver for short-range wireless transmission, and 3) a digital signal processor (DSP) for ECG classification is proposed in [48]. In this system too, the chips are fabricated in TSMC 0.18 μm standard CMOS process. An airflow sensing chip integrating the MEMS sensors with their CMOS signal processing circuits is proposed for respiration detection. The airflow sensors have been fabricated using a 0.35 μm CMOS/MEMS 2P4M mixed signal process [49].

In [50], a wearable neuro-feedback system is proposed with a low-power neuro-feedback SoC (NFS) for mental status monitoring with EEG and transcranial electrical stimulation (tES). An embedded chip that supports independent component analysis (ICA) and support vector machine (SVM) is fabricated in 130 nm CMOS technology. Vaidya et al. [44] have developed a system that measures the ECG, blood pressure and heart rate of the patient. After acquiring and filtering the ECG and PPG signals, they are fed to Cypress Programmable System on Chip 3 (PSoC 3) for digitizing them and calculating the heart rate and blood pressure. The capability of mixed signal processing of PSoC 3 adds the compactness and portability to the system. A few more SoC designs for low-power healthcare systems are listed in [51-53].

Cloud-based e-healthcare systems:

With the evolvement of mobile and e-healthcare technologies, the concept of health-cloud has emerged. In [54], patient's health monitoring using Health-Cloud has been presented. When the location of a mobile patient changes, the associated default gateway also changes and, consequently, the optimum mapping between the server and the mobile node also changes. An auction theory based optimal resource allocation framework for health-cloud to monitor patients' health condition is proposed in [54]. Existing cloud-based e-healthcare applications provide accesses to their services using single-sign-on (SSO) protocols. Authors in [55] have proposed a scheme called, chord for cloud (CoC), to overcome the increased execution load on cloud gateway as well as identity provider. Other issues related with the cloud-based e-healthcare systems like data security; compression of data/ images; a combined cryptographic and watermarking techniques for combating the insider attacks on patients' medical data; enhancing computational capacity, particularly for multimedia medical data; database management systems for accessing the sensitive data via private cloud and public data via public cloud, thus forming a hybrid cloud; privacy-preserving protocol for dynamic medical text mining (PPDM) in cloud assisted e-healthcare system have been addressed in [56-60].

Application Domains of Mobile and E-Healthcare

The e-healthcare systems have primarily been developed for observing the physiological parameters like body temperature, oxygen saturation level, heart rate, blood glucose level etc. However, with evolution of wireless technologies there has been a manifold variation and enhancement in the e-healthcare systems. The WBSN based multi-parameter acquisition systems have come up for various applications ranging from ambulatory monitoring to a high-end research.

Tele-Home patient monitoring

It has been observed that, primarily, the mobile and e-healthcare systems have been designed for home-based or remote patient monitoring. Tele-Home patient monitoring is one of the most significant and prevailing applications of mobile and e-healthcare. The majority tele-home patient monitoring systems include recording and observing the cardiac parameters [3-10,13,26,47,48,60]. However, gradually the range of sensors/ data and applications got widen to include other vital physiological parameters (blood pressure, oxygen saturation level in blood (SpO_2), pulseplethysmogram (PPG) signal, blood glucose level, respiration rate) [4,7,11,12,15-18,36,37], EEG/ EOG signals [20,42,50], body movements (physical) activities and stress level [14,40], sleep/ wake detection [8], mood assessment [41], fall detection in elderly people [33,38], weight loss and maintenance [22] etc.

The compact, user-friendly and cost-effective tele-home patient monitoring has become possible after the smart phones with many in-built sensors and integrated technologies have been introduced. Nawka et al. [25] have proposed, SESGARH: a Scalable Extensible Smart-Phone based Mobile Gateway and Application for Remote Health monitoring. Using SESGARH, patients send disease symptoms and other critical health information to a physician, who can analyze this data remotely and prescribe e-prescriptions. SESGARH can significantly minimize the time taken for transmission of healthcare data from patient to physician and vice-versa, and improve the reach and quality of healthcare services. The proposed system is based on the ISO/IEEE11073 (X73) family of standards supporting high quality medical sensors, as well as wireless transport (e.g. Bluetooth, WiFi, Zigbee) for access to faster and reliable communication network resources.

A portable heart monitoring and cardiac rehabilitation system based on smart phone has been developed by Leijdekkers et al. [34]. The system focuses mainly on:

1. continuous heart/ECG monitoring, in which the monitoring device, in case of emergency calls the ambulance/ caregivers intimating the location of a patient.

2. Cardiac rehabilitation, which aims encouraging the patient to perform his/her physical exercises and making lifestyle changes such as getting more active, losing weight, reducing stress or quit smoking through interactive features of a smart phone. K. Wac et al. [36] have developed the MobiHealth-mobile patient monitoring system. The developed system allows the incorporation of diverse medical sensors via wireless connections, and the live transmission of the measured vital signs to healthcare providers as well as real-time feedback to the patient. Ziyu Lv et al. [35] and Megalingam et al. [45] have developed the smartphone based health monitoring systems for elderly patients. The typical features of these systems include wireless body sensors for vital parameters (heart rate, body temperature, ECG, respiration rate, tilt and fall detection) monitoring, smartphone, automatic alert/call to pre-assigned people and ambulance.

Abnormalities detection

With the increased processing power of mobile devices, it has been possible to detect the abnormalities such as arrhythmia or cardiovascular diseases (CVD) from the acquired physiological data/ signals. An early and, in some cases, real time detection of such abnormalities will be able to provide quick treatment to the patient. Fensli et al. [7] have proposed one of the earlier online arrhythmia monitoring systems. The scheme consists of wearable ECG recording system along with a server based arrhythmia calculating and monitoring mechanism, which will let the physician know about the arrhythmic condition, if any. The patient will get the follow up from physician through an internet enabled personal digital assistant (PDA). X Chen et al. [6] have developed cellphone based ambulatory and continuous ECG signal processing systems. The Mobicare cardio monitoring system consists of a cellular phone embedded with real time ECG processing algorithms (MobiECG), a wireless ECG sensor, a web based server, a patients' database and a user interface. The system is capable of detecting the condition of atrial fibrillation (AF) and display the maximum heart rate (MH) and intensity of patient's body movements on GUI.

A real time CVD detection based on smartphone platform has been developed by Oresko et al. [9]. HeartToGo- an experimental prototype consisting of Alive ECG sensor and Windows smartphone has been used for detecting the premature ventricular contraction (PVC) beats. In the process, the LabVIEW mobile module for QRS detection and artificial neural network (ANN) based PVC beat classification have been accurately implemented. Lin et al. [60] have proposed an intelligent telecardiology system using a wearable and wireless ECG to detect atrial fibrillation. A Java based mobile system software for QRS detection algorithm, sinus tachycardia/ bradycardia based on heart rate and two algorithms for atrial fibrillation have been developed.

Specific applications

In this section the mobile/e-healthcare applications discussed are focused on cardiac abnormality detection. Researchers have proposed systems involving other biomedical signals like EEG, EMG, EOG etc. for some specific applications. Accurate estimation of shifts in drivers' levels of arousal, fatigue and vigilance for safe driving has drawn attention in recent times. Chin-Teng Lin et al. [20] have developed a wireless and wearable EEG system for evaluating driver vigilance. The proposed system- called Mindo, monitors in real time, the fluctuations in driving performance with changes in brain activities. The system, implemented using JAVA as mobile application for online analysis, processes the EEG recording to translate them into the vigilance level of drivers. A wearable neuro-feedback system with EEG and transcranial electrical stimulation (tES) based mental status monitoring has been developed by Roh et al. [50]. The proposed system incorporates neuro-feedback SoC architecture for implementing independent component analysis (ICA), FFT and support vector machine (SVM).

Erik English et al. [42] have proposed a mobile EOG based HCI (EyePhone). The prototype, still at early stage, allows users to control mobile phones through intentional eye or facial movements. The graphical window can receive and display continuous EEG data acquired from the headset; a mouse emulator can allow users to move a cursor around the smartphone screen by moving their heads and eyes; and an emergency dialler can allow users to make an emergency phone call through a certain pattern of eye/facial movements.

Recovering the hand functionality lost or reduced by injuries, or chronic diseases requires a kinesiotherapic intervention in addition to beyond pharmacological treatments [61-65]. Pani et al. [66] developed a novel device with remote monitoring capabilities for the needs of rheumatic patients. It comprises several sensorized tools and can be used either in an outpatient clinic for hand functional evaluation, connected to a PC, or given to the patient for home kinesiotherapic sessions. In the latter case, the device guides the patient in the rehabilitation session, transmitting the relevant statistics about his performance to a TCP/IP server exploiting a GSM/GPRS connection for later analysis.

Other specific applications of mobile/ e-healthcare based systems include smartphone based wound image analysis system for detecting foot ulcer in diabetic patients [21]; *myPace:* an integrative health platform for supporting weight loss and healthy eating behaviours [22]; *MoodMiner*- human behaviour pattern and daily mood assessment system using smartphone sensor and communication data (acceleration, light, location call log etc.) [41]; android smartphone based fall detection application which includes collection of accelerometer data, learning the fall behaviour pattern with collected data and alerting the caregivers upon fall detection [33,38].

Challenges and Security Issues in e-Healthcare Systems

Challenges with WMDs and e-healthcare

The e-healthcare systems deal with patient-centric critical medical information, where accuracy of data is of prime concern. Following major challenges are imposed in e-healthcare systems.

Usability: Despite non-trivial efforts from CHI (Computer-Human Interaction) research domain, the unique requirements on the design of user-friendly e-Health monitoring systems raise a set of challenges. Lack of friendly interfaces/GUI for both medical staff and patients is one of the major factors impeding their wider acceptance in practice. In addition, as patient-centric monitoring relies on the cooperation of multiple heterogeneous sensors, ranging from wearable sensors to smartphone and IoT sensors, their configurations must be transparent to the patients, avoiding any confusing or inconvenient settings [67].

Sensor data/ information quality and Cost-effectiveness: Quality of the sensor data/ information collected must be ensured, as the noisy or false data will lead to incorrect action or diagnosis. This will impose a trade-off between the cost of the system and quality of data. The sensors may collect and report false or noisy data due to unexpected hardware failures or unreliable communications issues which will lead false interpretation and analysis of the data. Further, due to several WBANs located in small area, particularly in the hospitals, there could be inter sensor interference or electromagnetic interference with sensor data [67].

One of the major challenges and concerns associated with WMDs and e-healthcare systems is the *affordability and cost-effectiveness*. These facilities should be made available to the low-income and middle-class people as well. In last five years, the cost of electronics and computational hardware has dramatically reduced.

This should be a positive sign for providing the cost-effective e-healthcare facilities to the lower or poor people.

Additionally, several other issues like sensor node failure/ removal, attack on BAN/WBAN from external attacker, environmental interference like signal fading, limited or loss of power/ battery, loss of connectivity/ network failure due to transceiver failure or network interruption, network congestion due to excessive sensor data, and most importantly, compatibility/ interoperability due to different network standards [68,69] should be carefully addressed while designing the e-healthcare systems.

Privacy and security of patients' data and information

To guarantee the security and privacy of patients' physiological data and information is one of the major issues in WBANs. The data security and privacy issues in WBANs have first been investigated comprehensively by Ming Li et al. [70]. They have looked into two important data security issues: secure and dependable distributed data storage, and fine-grained distributed data access control for sensitive and private patient medical data. Lim S [71] reports various security attacks and weaknesses in the wireless topologies like Bluetooth and GSM. For example, vulnerabilities in Bluetooth securities arise due to various attacks like MAC spoofing attack, (2) PIN cracking attack (3) Man in the Middle Attack, (4) Blue Jacking Attack, (5) Blue Snarfing Attack, (6) Blue Bugging Attack, (7) Blue Printing Attack, (8) Blue over Attack, (9) Off line PIN recovery Attack, (10) Brute Force Attack, (11) Reflection Attack, (12) Backdoor Attack, (13) DOS Attack, (14) Cabir Attack, (15) Skulls Worm Attack, and (16) Lasco Worm Attack. Similarly, GSM and over the air voice security and privacy are affected by weaknesses in streaming ciphers like A5/1 and A5/2.

Jun Zhou et al. [57] have proposed a privacy-preserving protocol for dynamic text mining (PPDM) for cloud assisted e-healthcare systems. Based on the proposed protocol, PPDM1-privacy preserving function correlation matching from dynamic medical text mining and PPDM2- privacy preserving medical image feature extraction design have been implemented. The mobility based healthcare systems/ devices allow patients to move easily. Thus, when patients move their topology and path change and in order to stay connected securely, for patients, a secure session-key is highly required. Pardeep Kumar et al. [69] have addressed a secure session-key scheme for mobility supported e-healthcare systems. In the proposed scheme, authors have considered *replay attack, man-in-the-middle (MITM) attack and impersonation attack* for security analysis. The performance analysis of the scheme has been made using the parameters- communication cost and computation cost. Song et al. [53] have combined the orthogonal matching pursuit (OMP) based encryption and compressed sensing (CS) based compression for secure image storage for cloud-based e-healthcare system.

Some more security and privacy issues and concerned solutions in wireless and remote patient monitoring systems are reported in [71-73].

Future Directions

A strategic study at the National Institutes of Health (NIH) has noted: "With the development of miniaturized devices and wireless communication, the way in which doctors care for patients will change dramatically and the role patients take in their own healthcare will increase. Healthcare will become more personalized through tailoring of interventions to individual patients" [74]. Though the challenges of providing high-quality healthcare in developing countries are different than those in developed countries, they share a common goal: to provide access to health monitoring and assessment technologies to people with limited or no healthcare facilities, or with geographically distant or difficult to physically access facilities.

The increasing number of mobile devices, ubiquitous internet and cloud computing will progressively emerge into a new domain called *Wearable Internet of Things (WIoT)*. This will lead to increased capability of sensing, computing and communication. Future generations of WIoT promise to transform the healthcare sector, wherein individuals are seamlessly tracked by wearable sensors for personalized health and wellness information. However, to achieve multidimensional success, WIoT needs not only to overcome the technical challenges of generating a flexible framework for networking, computing, storing, and visualizing, but also needs to consolidate its position in designing solutions that are clinically acceptable and operational [75].

The pervasive use of smartphones and the ubiquity of WiFi connections will enable medical informatics to overcome the time and location barriers. This method should especially be useful in those instances in which a rapid response is critical or when conditions are changing dynamically. A rich set of embedded sensors (e.g., camera, accelerometer, vibrating gyroscope, magnetometer, goniometer, actometer, pedometer, pressure sensor and more) of the smartphones will enable revolution in nearly all aspects of healthcare. The unobtrusive and intelligent smartphone-based healthcare device/ system will make it more popular and cost-effective, too as no extra hardware/ technologies will be required [76]. All in all, the future of healthcare belongs to IoT-centric smart healthcare systems [77] with a possible intelligent self-disease management owing the powerful mobile and smartphone technologies [78]. The assistance and effectiveness of WMDs and e-healthcare systems for the people suffering from chronic/ life threatening diseases should also be properly investigated.

Conclusion

The recent years have shown a tremendous growth in e-healthcare thanks to the ever evolving wireless and sensor technologies. The relatively larger e-healthcare architecture has become light, convenient and cost-effective with the advent of smartphones. The mobile and e-healthcare technologies have many fold applications and spread i.e. from monitoring the vital physiological parameters-heart rate, SpO2, blood pressure, blood glucose level, ECG etc. - to detecting various abnormalities like tachycardia, bradycardia, stress, atrial fibrillation, seizure etc. Indeed, with the available mobile and e-healthcare systems and devices have drastically changed the nature of health management and treatment. However, there many aspects like data security/ privacy and cost-effectiveness need to be addressed. Looking forward to the future of mobile/ e-healthcare systems, it is more than clear that IoT and smartphones with multi-functionality medicinal feature will bring the intelligence, ease and smartness in the global healthcare sector.

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