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ORIGINAL PAPER

Smart Health Monitoring Systems: An Overview of Design and Modeling

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Abstract Health monitoring systems have rapidly evolved during the past two decades and have the potential to change the way health care is currently delivered. Although smart health monitoring systems automate patient monitoring tasks and, thereby improve the patient workflow management, their efficiency in clinical settings is still debatable. This paper presents a review of smart health monitoring systems and an overview of their design and modeling. Furthermore, a critical analysis of the efficiency, clinical acceptability, strategies and recommendations on improving current health monitoring systems will be presented. The main aim is to review current state of the art monitoring systems and to perform extensive and an in-depth analysis of the findings in the area of smart health monitoring systems. In order to achieve this, over fifty different monitoring systems have been selected, categorized, classified and compared. Finally, major advances in the system design level have been discussed, current issues facing health care providers, as well as the potential challenges to health monitoring field will be identified and compared to other similar systems.

Keywords Smart health monitoring · Remote patient monitoring · Wearable health monitoring · Mobile health monitoring

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Introduction

With the rapid increase of the older population coupled with that of its life span, the number of patients who require monitoring also increases. Therefore, it is predicated that the cost of hospitalization and patient care will rise worldwide. In the US, the mortality rate is over 770,000 per year. This includes patients who suffer sentinel events associated with; incorrect medication, dosage inaccuracies, contraindications or critical delays in interventions resulting in hospitalization. The aggregated costs of these events across the US is between $1.5 billion and $5 billion annually [1]. Therefore, health monitoring systems (HMS) can play a significant role in reducing hospitalization, burden of medical staff, consultation time, waiting lists and overall healthcare costs. Health monitoring systems can be classified into three categories which are identified below.

Remote health monitoring systems (RHMS) refer to those with remote access or systems which can send data to/or from a remote location. The function of this particular type of system ranges from a single to multiple parameters which cover a variety of symptoms and can be utilized in individual homes as well as hospitals. Mobile health monitoring systems (MHMS) refer to mobile phones, personal digital assistants (PDAs), pocket personal computer (PC) based systems which are used as the main processing station or in some cases as the main working module. RHMS and MHMS are considered to be more convenient and cost effective than traditional, institutional care, since they enable patients to remain in their usual environment whilst receiving professional healthcare [2, 3]. Wearable health monitoring systems (WHMS) refer to wearable devices or biosensors that can be worn by patients consisting of WHMS, RHMS and/or MHMS. Smart health monitoring systems (SHMS) are often referred to as advanced technology or a new approach to health monitoring. They usually consist of smart devices or a so-called ‘smart’ approach to address heath issues. General health monitoring systems (GHMS) refer to systems which monitor multiple parameters and general disease. Vital signs include heart rate (HR), blood pressure (BP), electrocardiography (ECG), oxygen saturation (SpO_2), body temperature and respiratory rate (RR).

From 1960 to the present day, a number of critical reviews have been conducted, such as those of Roine et al. [4], Lau et al. [5] and Brownsell et al. [6]. In this review, we have selected peer reviewed journals published between 2005 and 2011 which are related to remote HMS, mobile HMS and wireless HMS. From 400 research publications, we identified 300 studies, short listed 80 studies and selected from 50 that best fitted our search criteria. We excluded those studies which lacked practical implementation/testing, validation/evaluation results and did not fit with the above criteria. The research studies were divided into two main sections: smart systems which include WHMS, MHMS, RHMS and GHMS and traditional or wired systems. Figure 1 demonstrates the classification of the HMS and its subsections. Table 1 lists the selected studies according to the classifications made by Fig. 1 according to the year of publication. Table 2 demonstrates the classification of these articles based on their medical applications.

Overview of current state of the art monitoring systems

During the past decade, there has been rapid growth in advanced health monitoring techniques and methods to assist healthcare professionals to more accurately monitor older adults [7–9] in relation to age related diseases such as dementia [10, 11], Alzheimer’s [12, 13] and Parkinson’s [14–16]. Since there are no restrictions to HMS applications,

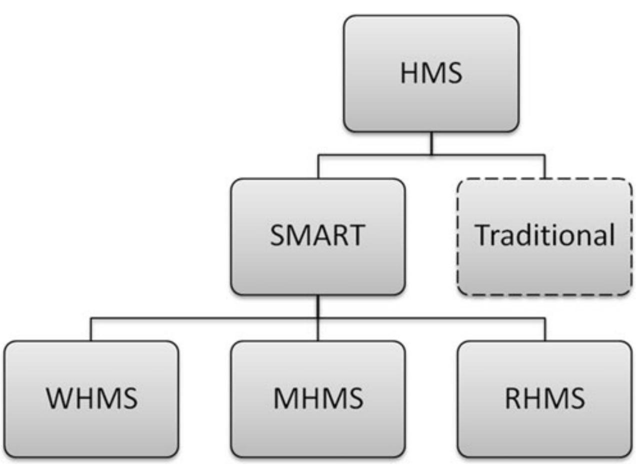

Fig. 1 Classification of health monitoring systems (HMS), where WHMS is wearable health monitoring system, MHMS is mobile health monitoring system, and RHMS is remote health monitoring system

they can be used in hospital [17–20], residential [8, 21–24] as well as outdoor settings using either global positioning system (GPS) [25, 26] or radio frequency identification (RFID) technology [1, 11, 27, 28].

Although this technology is becoming more sophisticated, there are still concerns with quality of medical data, security of patient medical information, stability of complex monitoring systems, usability, acceptability by the medical staff as well as patients and the frequency of false alarms being generated. However, a number of studies have been conducted in the last two decades to reduce these concerns. For instance, Imhoff and Kuhls [29] have identified that up to 90 % of all alarms in critical care monitoring, are false positives. Others researchers have also proposed further measures to further reduce these false alarms, which include; modifying the range of parameters, reducing threshold values, or incorporating a time delay in generating the alarms [30–32]. In the following sections there will be a discussion of the latest health monitoring systems and a critical analysis of the common issues faced by today’s healthcare applications.

The architecture of smart health monitoring systems with the communication technologies are demonstrated in Fig. 2. In general, most of these systems employ similar behavioural models with some modifications to the software and technology. The model in Fig. 2 can be used for different scenarios with some modifications and has proved relatively efficient for most mobile health monitoring systems.

Wearable health monitoring systems

A smart vest [33] is essentially a wearable physiological monitoring system, incorporated in a vest. A variety of sensors integrated into the garment’s fabric, simultaneously collects bio-signals in a non-invasive and unobtrusive way. The parameters measured by the vest include ECG, photoplethysmography (PPG), HR, BP, body temperature, and galvanic skin response (GSR). Furthermore, it is reported that ECG’s can be recorded without using gel and is also free from baseline noise and motion artifacts due to hardware-implemented high pass, low pass, and notch filters. Moreover, BP is calculated noninvasively via PPT, where the implemented detection algorithm is individually calibrated, based on the patient’s ECG. Results from validation trials confirm the accuracy of measured physiological parameters. LOBIN [34], an e-textile wireless healthcare monitoring system to record ECG, HR and body temperature, is a wearable wireless sensor. Similarly, Blue Box [35] is a novel hand-held device capable of collecting and wirelessly transmitting key cardiac parameters such as ECG, PPG and bio-impedance. It also measures RR intervals and QRS duration, HR, systolic time intervals as well as

Table 1 The categorisation of selected studies according to Fig. 1 and year of publication

Year of Publication	SHMS	RHMS		HMS (General)	Total
		MHMS	WHMS		
2011	[36, 93]	[12, 94]		[95–97]	7
2010	[7, 34, 98–101]	[17, 25, 35, 75, 102–105]		[106–108]	17
2009	[109–111]	[8, 112–115],		[68, 116]	10
2008	[33, 76]	[68, 117, 118]		[119, 120]	7
2007–2005	-	[121–124]		[125, 126]	6
<2005	-	[127]		[128, 129]	3
Total	13	23		14	50

assessing their values in correlation with cardiac output measured by an echo-doppler. An in-shoe device has been developed by Saito et al. [36] to monitor plantar pressure under real-life conditions. A pressure-sensitive conductive rubber sensor measures plantar pressure and validation is performed by an f-scan system. SMARTDIAB [37] is a platform designed to support the monitoring, management, and treatment of patients with type 1 diabetes mellitus (T1DM) which incorporates the patient unit (PU) and patient management unit (PMU). The pilot version of the SMARTDIAB has already been implemented and evaluated in a clinical setting. TELEMON [38] is an electronic-informatics-telecom and scalable system that allows automatic, complex and real time telemonitoring by mobile communications for monitoring the vital signs of chronically ill elderly patients. It employs a WristClinic™ device which is connected to a radio interface with a MiniGate™ USB (max radius 100 m) and then to a vital parameter monitor wrist unit (MiniClinic™).

HMS for the home environment

There are several approaches towards assisting the elderly who live independently. A smart home for the elderly has been developed, using pulse rate (PR), BP and sensors to measure weight, light, temperature, the presence of gas or smoke, fall risk and moisture throughout the home. A digital IP camera transmits data via an IP based Rabbit microcontroller with a built-in small web server, and information is accessed via a secure web [39]. Although, this method has achieved a higher accuracy, it incurs higher costs as more sensors need to be deployed around the home setting. Patients exhibiting symptoms of cardiac infarction, sleep apnoea or hypopnea were successfully monitored by body and excretion weight and during sleep [40]. Similar work was also carried out by an ECG monitor on patients in the bath [2, 41] or bed [42–44] without direct skin-contact. Respiration rates and pulse rates were monitored by an air mattress sensor [45, 46], and body temperature and movement by a thermistor [47]. A toilet-seat-installed BP monitor [48–50] and a respiration and cardiac beat monitor fitted under a pillow, using vinyl tubes, filled with silicon-oil, has also been explored [51].

Another smart home system for the elderly developed by the TAFETA group [52] provides a framework for processing and communication of extracted information by using intelligent sensors such as magnetic switches, thermistors, accelerometers, RFID, infrared motion sensors, microphone array, smart grab bars, pressure sensitive mats and electronic noses. Extended duration of monitoring is achievable through various sensors without interfering with daily activities (ADLs). Another frame work, ANGELAH [8], integrates the sensors and actuators required for monitoring and detecting potential acute situations. It also alerts medical

Table 2 Classification of selected studies based on medical applications

Category	Selected papers
General/ Multipurpose	Multi-agents [65], [17], [68], [62], [90], [130], [131], [74], ANGELAH [8], LAURA [53]
Specific Medical Condition	DOA* [128], cardiac [38, 69, 89, 132], diabetes [133], [37], facial changes [18], fall [19, 58, 61], hypovolaemia [134, 135], hyperpyrexia [136] Dementia [10, 11], Alzheimers [12], [13], Parkinsons [14–16], obstructive sleep apnoea [54]
Vital Signs	ECG [9, 79, 80], BP [73, 137], EEG [87], EMG [63], temperature [138], multi vital signs [64, 66, 71], [139]
Smart Technology	Bathtub [41], [2], bed [42–44], air mattress [45, 46], toilet seats [48–50], under pillows [51], TAFETA group [52], LOBIN [34], Blue Box [35], doctor's bag [75], smart vests [33], shoes [36], home [39]

*DOA is depth of anaesthesia

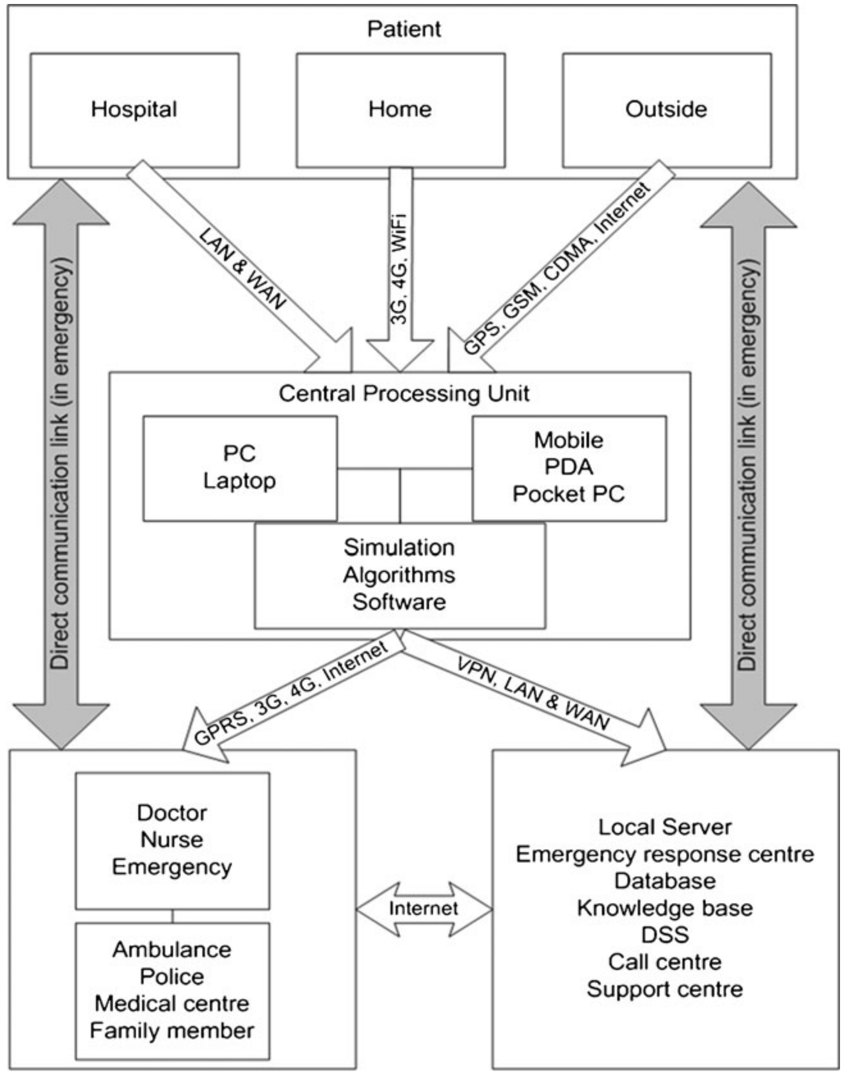

Fig. 2 Overall architecture of smart health monitoring systems

professionals to respond to emergency cases. An RFID reader is used for entry-exit and camera for computer vision based emergency detection. Likewise, LAURA [53] performs localization, tracking and monitoring of indoor patients with an average localization error rate less than two meters in 80 % of cases. In another study, specific to disease detection in a simultaneous measurement of ECG and plethysmography (pleth) involving 29 subjects, the pulse rate variability (PRV) extracted from finger photopleth waveforms can be the substitute for heart rate variability (HRV) derived from the RR intervals of ECG signals during obstructive sleep apnoea (OSA) [54].

HMS for people with Dementia

It has been established that dementia is the most common form of chronic disease in older adults worldwide and is predicated to increase incrementally as life span of the population increases. Currently, there are an estimated 24 million people diagnosed with some form of dementia [55] and several research studies are focusing on improving their quality of life. In 2006, a wireless healthcare service system was developed [10], which integrated the following technologies; RFID, GPS, global system for mobile communications (GSM), as well as a geographic information system (GIS) to construct a stray prevention system without interfering in daily life activities. It was specifically designed for indoor, outdoor, emergency and remote monitoring and mainly employs resident motion sensors and body attached rescue locators. In 2008, this work was further developed by the same researchers [11], with the use of eXtensible-Markup-Language (XML) with RFID technology in disease assessment and safety monitoring of dementia patients. The tame transformation signatures (TTS) algorithm encrypted tag IDs to preserve confidentiality. Participants willingly wore light tags and clinical trialling of the system indicated that the indoor RFID reader had a response time of 0.5 s with 40 tag sensors, whereas the outdoor reader gave a sensing time of approximately 5 s due to power save mode.

HMS for Parkinson's disease

MercuryLive [14] is a web based home monitoring system for patients diagnosed with Parkinson's disease. It consists of a central server which collates data and stores it for web access, as well as a live video streaming (provided by Red5). It also runs on the central server, the patient host computer, and a body sensor network (BSN) called Mercury. Based on the SHIMMER sensor, Mercury includes multiple body worn sensors connected to a base station (laptop) and clinician host computer, as well as a web based GUI, which collates the data via video conferencing using 40 % video compression. A similar system has been developed for the detection and assessment of the severity of symptoms in dyskinesia patients with Parkinson [15] by using small, accurate, and robust accelerometers and gyroscopes. A pilot study has been conducted to estimate the severity of the symptoms (tremor, bradykinesia and dyskinesia) and motor complications in Parkinson's patients using a support vector machine (SVM) classifier [16]. Both systems achieved encouraging results when tested in real-time.

HMS for Alzheimer's disease

The Escort System [12], a safety monitoring system for Alzheimer patients uses a unique approach known as 'Talking Lights'. This system gives optical location information and transmits lights to the patient receiver device via a ZigBee network and an alert (SMS) can be sent to a mobile device. A similar study for the early detection of Alzheimer's, employed Bluetooth access points (APs) situated in each room of the house. All Bluetooth APs are connected to a local database which stores and sends data to another server. This Bluetooth-enabled monitoring device should be carried by the patient for location updates and monitoring [13]. Therefore, it is the patient's responsibility to carry the device at all times and, should the patient not do so or move out of the range then the system fails.

HMS for fall detection

The incidence of falls in the older adult population is significantly higher than other age groups and increases with age. The proportion of patients who sustain at least one fall per year varies from 28 % to 35 % but in the 65+age group it increases from 32 % to 42 % and in the 75+age group, 15 % of the elderly sustain a fall at least twice a year. Incidence rates in hospitals are higher and, in residential care settings, approximately 30–50 % of people fall each year, with 40 % falling recurrently [56]. Stevens et al. [57] conducted a study to estimate the cost of fatal and non-fatal falls amongst older adults, and reported direct medical costs totalling $0.2 billion dollars for fatal falls and $19 billion dollars for non-fatal. Of the non-fatal injury costs, 63 % ($12 billion) were spent for hospitalizations, 21 % ($4 billion) for emergency department visits and 16 % ($3 billion) for treatment in outpatient settings in US.

A quantitative fall risk assessment [58] uses a timed up and go (TUG) test was developed by Mathias et al. [59] and a Berg balance scale (BBS) [60], employs the SHIMMER sensors and Matlab for processing raw accelerometer and gyroscope data. System results indicated that the manual TUG test had an accuracy of 60.6 %, BBS an accuracy of 61.4 % and the mean test, an accuracy of 76.8 % when estimating falls risk in 349 older adults. Another fall detection system was developed [61] as a server based approach where the data was collated from biomedical sensors for control and processing. Linear autoregressive (AR) Burg spectrum estimation was applied as fall detection algorithm. The results from the system reported 100 % sensitivity, 95.68 % specificity with an overall analysis time of four seconds. Furthermore, a continuous monitoring of the eyes in patients, particularly those in a coma in ICU, has been developed, using a fuzzy logic classifier. This system achieved a 97 % eye detection from 300 face images [18] and a wireless webcam, with an attached hyperbolic mirror, captured the omni directional scene to detect any unconscious subjects with an 93 % accuracy [19].

Tri-axial accelerometers or video cameras have been employed in the majority of work in the area of fall detection. However, there was one significant problem related to the use of cameras as they only function in a given view angle and in certain lighting conditions. Moreover, should the subject move beyond these settings then the system cannot record accurately and distinguish a real fall. Even under normal conditions (no fall) and the subject moves, a false alarm will be generated due to lack of other fall related parameters such as vital signs. The standard wireless communication protocols used in the above wireless/wearable HMS are listed in Table 3.

Review and critical analysis

Smart Vest [33] and LOBIN [34] share a similar approach as wearable physiological monitoring systems in terms of using wearable textile, wireless monitoring and patient tracking. Smart Vest uses wireless transmission from the textile to a remote station and LOBIN uses wireless transmission boards and distribution points in patient living areas (indoors). Results show that both systems satisfy medical and usability conditions. Despite the advantages of such systems in health monitoring, there are some concerns with the smart wearable devices as they must o be worn continuously and be restricted to a specified range. Moreover, the quality of the data collected by these devices is usually poor. Patient comfort is another concern as they may find wearing

Table 3 Wireless communication protocols in wearable health monitoring systems

Technique/Parameters	Range	Data Rate	Cost	Frequency
Bluetooth	10–100 m	1–3 Mbps	\$3–\$5	2.4 GHz
Zigbee	10–75 m	20 Kbps	\$2–\$3	868 MHz
		40 Kbps		915 MHz
		250 Kbps		2.4 GHz
Infrared	1 m	16 Mbps	\$2	-
Ultra wideband	2 m	500 kbps	\$3–\$5	400 MHz

garments with wireless or wired sensors physically uncomfortable, restrictive and even irritating. Therefore, there is a need for further research to improve the characteristics of wearable devices as well as their real time clinical features.

The TAFETA, ANGELAH and LAURA groups employed a similar approach to the health monitoring of elderly by using application specific sensors. The TAFETA group utilised nine different sensors in a home setting and collected useful data whereas ANGELAH employed RFID technology and LAURA focused on the localisation and tracking as the main method for elderly monitoring. These three systems provided an acceptable performance in assisting the elderly in their daily activities in the long term.

Although home based health monitoring systems can contribute to the advancement of healthcare, the level of intelligence of the sensors, area of application and internet or mobile data dependency for connectivity require further research and development. Where the subject moves out of range coverage, evades sensor contact or is behaving contrary to the system, a false alarm will be generated even though he/she is engaging in normal daily activities. Furthermore, a delay in the internet connectivity will also result in a subsequent delay in real time monitoring.

Remote health monitoring systems

Remote health monitoring systems (RHMSs) are defined as the use of electronic information and communication technology to support and enhance the quality of healthcare when distance separates the healthcare professionals and patients. RHMSs usually transmit the patient vital data from a remote location to the clinicians in real-time using advanced information and communication technology. RHMSs are combined with mobile communication systems and wearable monitoring technology. This technology has many advantages and provides innovative solutions to deliver healthcare by remote monitoring of patients. The following section describes such systems.

A reliable, intelligent, secure monitoring and management system has been developed to focus on efficient communication, improvement in the reliability of data communication and effective management of wearable medical devices' energy [17]. Another project, developed an embedded mobile ECG monitoring system [9] based on client–server architecture where the server (normally located in a hospital) stores ECG signals from the patient through a patient monitor (located in the patient's house) or an a RFID reader. This embedded system communicates between the medical sensor network and the mobile GPRS interface and Prognosis [62] and is defined as a physiological data fusion model for multisensory WHMS. The latter is based on fuzzy logic for the generation of the prognoses for health conditions by identifying the causal relationship between various disorders and symptoms.

Another system which measures five signals has been developed. These signals are; mean spike amplitude (MSA), mean spike frequency (MSF), mean spike duration (MSD), mean spike slope (MSS) and the mean number of peaks per spike (MNPPS) extracted from the surface electromyographic (sEMG) signal. The basic building block of the sEMG model was the detection of single fibre action potentials (SFAPs) through a homogeneous, equivalent isotropic, infinite volume conduction medium [63]. The continuous monitoring of EMG, MMG, SMG and torque output through nine males was conducted by Guo et al. [64]. In this study, the maximal voluntary contraction (MVC) was identified as the highest value of torque recorded during the isometric contraction. A rest of 5 min was allowed between the two MVC tests and the MVC torque was then calculated by averaging the two recorded highest torque values from the two trials.

Review and critical analysis

Remote monitoring systems not only monitor vital signs but also detect abnormalities and transmit the data in real-time to healthcare professionals. Frequently, these systems send data with a delay either due to the processing of real-time data and/or wireless data transmission. 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 as yet been addressed and there is room for improvement in the design and structure of the system so that it complies with medical and ethical standards.

Mobile health monitoring systems

A multi-agent architecture comprising of intelligent agents for cardio and weight monitoring, based on mobile technology (GSM), has been developed to collate patient data. Intelligent agents collectively send diagnostic information and recommend medical interventions in a mobile environment. Software was developed using a Symbian operating system, Java 2 Micro Edition (J2ME) as (mobile programming) and Java 2 Enterprise Edition (J2EE) for server-side agent programming [65]. Self-powered WSN [66] monitors ECG, pulse-oximeters and BP from a remote location. Crossbow MICAz motes were used to design a robust mesh network that routes patient data to a remote base station within a hospital via a router node. The latter consist of an energy harvesting circuit board and solar panel set up which is located near overhead 34 W fluorescent lights [66]. Another system was developed [67] specifically for the elderly whereby, a call from a mobile phone to a server computer, initiates transmission of a graphical chart via the mobile phone. This system uses low power sensors and tri-axis accelerometers for long mobile phone graphical display charts.

A clinically validated and flexible framework, performing real-time analysis of physiological data to monitor patient health conditions, has also been developed [68]. Physiological parameters were collected by sensors and analyzed by means of data mining techniques. Real-time processing was performed on mobile devices (pocket PCs and smart phones) and a suitable alert could be triggered in emergency situations. A system design has been conducted using clustering algorithms, simple K-means (KM), farthest first (FF), and expectation maximization (EM) algorithms (default algorithm simple KM), with different sampling intervals and time windows. By deploying advanced algorithms to improve the results has been reported. However, the processing impact of these computationally intensive algorithms on the mobile devices such as battery life and delay in data transmission can be considered as a significant shortfall. In a unique approach [69] to measure the heart rate by a non-contact and non-invasive device, a CCD camera was employed in a trial of 14 Asian participants. A 30-sec time-lapse imaging of the body surface was acquired whilst HR was measured by a pulse oximeter and RR by a thermistor. A combination of a time-lapse imaging from a hand held video camera and PC-based image processing software, indicated a 30-sec average HR and RR based on changes in the brightness of the region of interest (ROI). These changes in brightness or movement of ROI play a critical role in accurate measurement of HR.

Review and critical analysis

Mobile health monitoring systems would benefit many patients and medical professionals by providing rapid access to health information, especially in emergency situations. This technology is continuously being enhanced but there are still challenges to improve its clinical application. For instance, raw data can be transmitted efficiently from a mobile phone but the analysis and processing of that data is still a major concern. This is due to the high impact that data processing can impose on the mobile phone's battery runtime and the generating delay in transmission of data. The model of data transmission in mobile health monitoring systems can be presented in two transmission types and three steps as shown in Fig. 3. In type 1, patient data is collated by a mobile device and then transmitted to a remote server for processing. Then, the data is transmitted to the clinician's mobile device directly or via the patient's mobile device. In type 2, the patient data is sent directly to a remote station for processing and then transmitted to other devices. In some cases only the results or alerts will be transmitted. Both types can generate delays in producing results. As indicated in Fig. 3, there will be a direct link between the patient and the clinician (confer dashed line). Continuous data transfer both through sending and receiving by mobile devices significantly reduce battery life. A brief description of similar systems using the latest technology is presented in Table 4.

Discussion and future recommendations

This paper reviews the advancement of smart health monitoring systems and addresses important issues currently being experienced in employing such systems in clinical settings. Although the technology has been significantly improved over the last decade, there are still discrepancies between the readings and the actual values of measuring parameters. Some studies suggest that advanced technology may perform well when tested in a controlled environment but it struggles to meet the required medical standards in real life scenarios. Therefore, real-time patient monitoring

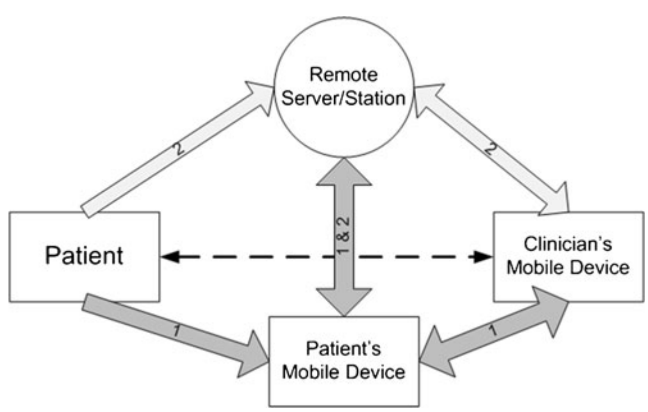

Fig. 3 Data transfer structure for mobile health monitoring

Table 4 Selected Health Monitoring Systems

Title or Author	HW/SW	Module	Parame-ters	Medical Application	Patients*/ Place/Type	System Review and Critical Analysis
TAFETA [52]	Pathway & Austco DCS-2000	Online	9 sensors	General Monitoring	Yes/Home/Sim	Smart home system to assist elderly using various sensors, achieved high accuracy in home settings
LOBIN [34]	E-Textile	PAN	ECG, HR, M, T, L	WSNM	18 months/ Hospital/ Tested	E-textile based hospital monitoring and location system, successful application in medium time monitoring
Smart Vest [35]	E-Textile	Remote	ECG, BP, T, PPG, GSR	General Monitoring	Yes/Outside/ Sim	Remote monitoring system using smart shirt, feasible in outdoor settings
Blue Box [35]	Hand-held device	Remote	ECG, PPG, Bioimpe-dence	Congestive heart failure	24/Remote/Trial	Wireless hand-held cardiac parameters monitoring system, low accuracy with remote access
Lin et. al [11]	RFID	Online	Activity	Dementia	Yes/Home/Trail	RFID based Dementia monitoring system, general approach and not applicable to specific case
The Escort System [12]	'Talking Lights'	Remote	Activity	Alzheimer's	Yes/Home/Trail	Low cost, optic location based safety system, not feasible in general settings
Mercury-Live [14]	Sensors	Remote	Activity	Parkinson's	Yes/Home/Trail	3-Tier, real-time home monitoring system, with remote connectivity
LAURA [53]	Localisation	PAN	Tracking	General monitoring	Yes/Home/RT	WSN based Localization and tracking system for general monitoring but not for specific conditions
TELEMON [38]	E-health services	Mobile	ECG, HR, AP, OS, R, T	Chronic illness	Yes/Pilot	Real-time mobile monitoring system for elderly, piloted for short time period

*Systems trialled or implemented on patient, home or hospital, HW/SW=hardware/software, Sim=simulation, RT=real-time, M=movement, T=temperature, L=location, PAN=personal area network, WSNM=wireless sensor network monitoring, SOFLC=self-organising fuzzy logic controller, SAP=systolic arterial pressure, DOA=depth of anaesthesia, DDMS=diabetes data management system, AP=arterial pressure, OS=oxygen saturation, R=respiration.

and remote data transmission can pose serious challenges to mobile healthcare systems in terms of the quality of patient monitoring, power management of medical devices, context awareness, acceptability, security and patient confidentiality. A recent study [70] of the challenges of wearable sensor systems indicated that there was an advancement in the short time monitoring of wearable smart technology but long term monitoring required the development of novel sensor integration into "smart garments" or implantable systems. The three main barriers of this technology were identified as; reliability and efficiency of wireless technology, quality of physiological data and patient confidentiality and security. These limitations will be discussed in the following sections with some recommendations for improvement of the SHMS.

Wireless or mobile based technology

Undoubtedly, wireless communication, mobile platform and biosensor technologies have proved effective in delivering healthcare in certain areas. However, there are still concerns around security and confidentiality of patient information. The main criteria of patient monitoring systems should include; reliability, efficiency, and context awareness. Some studies have reported high costs with GPRS for data communication [65] and the relatively limited coverage of Bluetooth[13, 71]. This limited coverage is the main drawback of deployed e-Health monitoring systems as patients are 'constrained' within smart rooms, smart textiles and beds fitted with monitoring devices [10, 39, 52, 65]. Some systems entail that clinicians are responsible for interpreting changes in data, making assessments, building up a composite clinical picture for effective patient management and intervention [72]. Other concerns around such systems are; complexity, the necessity for lengthy training, unfamiliarity by users with the apparatuses and confusion with manual instructions, particularly with patients [73].

A major attractive application for WSN based systems is the localization of both devices and patients. Healthcare applications require small lightweight devices with sensing, computational capability and communication features, which need to be unobtrusively and comfortably positioned on the body such as a belt, wrist watch or vest. Most sensors are intended for deployment of stationary nodes that transmit data at a low rate. Typical applications in healthcare require relatively high data rates, reliable communication, and multiple receivers such as PDAs carried by doctors and nurses [74]. Long term use of such systems may pose a serious threat to the mobile device's battery life and seriously compromise the transmission of essential data [17, 65, 75–78].

Quality of physiological parameters

Complying with medical standards as well as providing high quality data is significant in mobile/remote monitoring systems due to the wireless communication factor. Various techniques were applied to collect high quality data [9, 42, 54, 79–82] but, in some studies, data was collected either for a short period of time [40–44], data quality was substandard [69, 80, 83] and high false alarm rates were generated [68]. For example, ECG signals were more accurate when gel electrodes were applied [34] whereas, without gel electrodes, the measuring devices produced poor data quality [33]. To improve the quality of the physiological data, it is recommended that a theoretical framework should be combined with experimental procedures at the initial stages of product development. Furthermore, at each development stage, feedback from medical professionals should be considered and discussed.

Security and patient confidentiality

Security and patient confidentiality are among the most significant challenges with mobile and remote monitoring systems, where patient data communication occurs continuously and remotely. Major concerns regarding security and confidentiality include; prevention of patient data disclosure and only authorised accessibility to patient medical records. Since, m-health systems have open wireless links, shared resources and mobile users, the inherent security risks are considerable. A great deal of research has been conducted to secure this pervasive environment [17]. A secure multicast mechanism, based on a *TrE* trust evaluation model for data communication among mobile medical devices, affords confidentiality protection via symmetrical cryptographic algorithms [84] and is also proposed. Security of medical data should be given the main priority when considering medical worthy applications [17, 84, 85].

In summary, smart health monitoring systems need to consider the following points:

- Data quality: applications must have medically accepted data quality.
- Security and privacy: framework, theoretical models, expert consultation required to develop secure systems.
- Medical professionals' consultation and feedback required at each stage of development. Acceptability: design, operation, user friendliness are key areas for both patients as well as medical professionals.

The overall design consideration for wireless, remote, mobile HMSs is presented in Table 5.

Conclusion

In this review, a wide range of smart health monitoring systems, their applications and efficiency have been identified and discussed. A number of studies supported the effectiveness of such systems both in a hospital setting as well as the home environment. Standardization of and demand for such systems and the applications of telemedicine are a fast growing area for research. For instance, a vital signs transmission system, based on VITAL and DICOM standards for telemedicine applications have already been developed [86]. It was identified that online monitoring and real-time transmission of bio-signals, and related systems require high quality signals without artefacts to be capable of operating without delay. To address such challenges, an online monitoring system was developed using wavelet decomposition and reconstruction [79] techniques for filtering ECG data. The development of a trend detection algorithm for EEG monitoring is another example [87]. Such online or web based monitoring systems are playing a major role in remote patient monitoring producing high quality data and accuracy.

However, the level of monitoring required by medical professionals from remote or online communication is

Table 5 Design considerations for health monitoring systems

Area	Design Consideration
Wearable HMS	User comfort
	Data transmission rate power consumption
	Data quality
	Security and privacy
	Area of movement
	Context-awareness
Remote HMS	Secure data transmission
	Real-time availability
	Middleware design
	User-friendliness
	Security and Privacy
Mobile HMS	Power consumption
	Energy efficiency
	User-friendliness
	Scalability
	Mobility and Reliability
	Security and Privacy

significantly greater than the SHMS are currently capable of delivering. Most remote systems monitor vital signs; collate them in a remote station such as a laptop, PC or local server for processing and transmitting to different devices, thereby incurring delays and/or alerts only in emergency situations. Medical staff use this limited information as initial data and starting point for interventions. Panescu [88] identifies several commercial wireless remote monitoring systems and stipulates the requisite design factors. These include power consumption, communication range, size, cost and security. Moreover, WHMS systems are dependent on the internet (connectivity and speed) or mobile communications (transfer rate and signal strength) using GPRS or 3 G. Development of new generation 4 G [89] and 5 G infrastructure for a mobile devices is also proposed [90]. William and Michael [91] explored methodological guidelines and the importance of data accuracy in computer based patient records, essential for any healthcare system.

Like any other technological advancement, smart health monitoring systems have both benefits and limitations and currently, there is on-going research to improve these systems [84, 92]. Another challenging aspect in the field of HMS is to design further clinical trials to ascertain the effects of monitoring different patient groups according to age, ethnicity, gender and disease specific.

Conflict of Interest The authors declare no conflict of interest.

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