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Wireless sensor based systems for biomedical monitoring: A review

*N.V. Panicker, **A. Sukeshkumar

*Department of ECE, College of Engineering
, Trivandrum, Kerala, India, (nitha.anil@gmail.com)
** University of Kerala, Trivandrum, India, (drsukeshkumar@yahoo.in)

Abstract

Wireless biomedical sensors have the potential to revolutionize the present healthcare delivery system. These devices require the capability to communicate with an external computer system (base station) via a wireless interface. Recent technological advances in sensors, low-power integrated circuits, and wireless communications have enabled the design of low-cost, miniature, lightweight, and intelligent physiological sensor nodes. These nodes, capable of sensing, processing, and communicating one or more vital signs, can be seamlessly integrated into wireless personal or body area networks (WPANs or WBANs) for health monitoring. These networks promise to revolutionize health care by allowing inexpensive, non-invasive, continuous, ambulatory health monitoring with almost real-time updates of medical records via the Internet. Though a number of ongoing research efforts are focusing on various technical, economic, and social issues, many technical hurdles still need to be resolved in order to have flexible, reliable, secure, and power-efficient wireless networks suitable for medical applications. This paper discusses the research challenges in wireless sensors for biomedical application. Current research and developments in the field of wireless health monitoring are also discussed in detail.

Key words

Biomedical sensors, body area networks, wearable health monitoring

1. Introduction

Sensors play an important role in modern real time systems. They are critical for today’s innovative society by providing the connection between the real world and the world of process control and computers. Biomedical sensors are in place for more than a few decades. Now these sensors utilize the advanced wireless technologies to deliver quality healthcare at remote locations. Advancements in the field of microelectronics micromechanics integrated optics and other related technologies enable the development of sensors with high efficiency and accuracy [1-2].

Wireless sensors, unlike wired sensing system, can be used for long term continuous monitoring even when people move. Wireless biomedical sensors can monitor patient's physiological signals like EEG, ECG, Blood pressure, Blood flow, Glucose level etc. Wireless sensors have many advantages for biomedical monitoring. The measurements are forwarded via a wireless sensor network (WSN) either to a central connection node, such as a personal digital assistant (PDA), or directly to a medical centre. A physician can then manage the patient based on the transmitted data. It does not discomfort the patient for long term monitoring. Also wireless transmission is the only way to communicate with implanted or swallowed biosensors. It is pointed out that numerous research and development efforts are happening in the area of wireless biomedical sensors for biomedical health monitoring applications [2-4].

This paper provides a review of wireless sensor based systems for biomedical health monitoring, describing the current status of research and development of wearable systems by reporting the salient characteristics of the most promising projects being developed. The paper is organised as follows. Section 2 describes the different characteristics of wireless biomedical sensors. Section 3 describes the wireless communication standards utilized for biomedical sensors. Section 4 presents a review of the developed wireless sensor based systems for health monitoring application. Section 5 discusses the issues, challenges and the futures perspectives. Section 6 provides the conclusión.

2. Wireless biomedical sensors and their characteristics

For biomedical application a sensor is defined as "A device that responds to a physical input of interest with a recordable functionality related output that is usually electrical or optical". The area of biomedical smart sensors is still relatively new, a number of interesting proposed applications have emerged. Wireless medical sensors should satisfy some main requirements such as wearability, reliability, security and interoperability. These factors determine the widespread deployment of wireless biomedical sensors.

2.1 Wearability

In order to achieve noninvasive and un obstructive continuous health monitoring, wireless medical sensors should be light weight and small. The size and weight of sensors is predominantly determined by the size of the batteries. Meanwhile the battery's capacity is proportional to its size. Technological advancements in the field of integrated circuits low power wireless communication techniques and batteries will help designers to improve medical sensor wearability. Reduced power consumption will increase the lifetime of each node and it is necessary to reduce power dissipation as much as possible.

2.2 Reliability

The Communication requests of different biomedical sensors biomedical sensors vary with required sampling rates, from less than 1Hz to 1000Hz.There are several approaches for improving reliability. One approach to improve reliability is to perform on sensor signal processing instead of transfer only information about an event like QRS features and the corresponding timestamp of r-peak. This method reduces the bandwidth requirement for the communication channel and total energy expenditures get reduced. This will increase the battery life. A careful tradeoff between communication and computation is crucial for optimal system design.

2.3 Security

Confidentiality of the data received is another issue associated with biomedical sensors. The criticality of data transmitted varies, in contrast with other applications of sensor networks. For example the monitoring of physical activities of an elderly patient is less critical than the heart rate monitoring. Consequently the threats are different in each case, requiring different levels of security.

Security is important in wireless medical sensors and it must meet privacy requirements mandated by the law for all medical devices. It must guarantee data integrity. The viability and long term success of biomedical wireless sensor networks depends upon addressing the security threats successfully. In [5], the various security concerns while transmitting the sensitive patient data are discussed.

2.5 Interoperability

Wireless medical sensors should allow users to easily assemble a robust health monitoring system on the user's state of health. Standards that specify interoperability of wireless medical sensors will promote vendor competition and eventually result in more affordable systems

2.6 Power

Sensors are powered by batteries, usually a couple of standard AA standard batteries that can be replaced upon expiration (this is important since the day of cheap, disposable sensors is yet to come). Battery size usually determines the size of the sensor, so existing hardware is roughly a few cubic centimetres in size. The power issue is reached for all kinds of wireless sensor based systems. Since most such devices are battery powered, one of the major challenges for their design is to optimize their power usage.

2.6 Portability

Integration of sensing components into a wireless sensor node should be conducted in a functional robust, small, light weight, and low cost way. For this reason most WPAN used for biomedical application make use of a small chip system, i.e., SoC, which includes a microcontroller and RF transceiver or single MCU with external transceiver. Currently there are some biomedical systems that suit the requirements of easy to wear or attach on the body for monitoring signals. In SmartVest, Pandian et al [11] describe a wearable multi parameter monitoring system which uses an array of sensors connected to a central processing unit for continuously monitoring of physiological monitoring system. These systems exhibit good portability.

2.7. Network Interference

A wireless link is more sensitive to interference than a wired connection link. In WSN environments, generally two or more different communication techniques are used together in a same network. Usually, WPANs and WLANs coexist using the same Industrial, Science and Medical (ISM) band. Therefore, they can lead to a network interference problem.

2.8. Real time and continuous monitoring

Some physiological data, such as human body temperature, heart rate, Blood pressure, lung sound, ECG, and RIP, should be monitored continuously and in real time. Also, a biomedical sensor is imagined to operate for days sometimes weeks without a user's intervention. A good example is a heartbeat monitoring system for patients who has heart disease. Since the heart rate is reported periodically, a heartbeat sensing device should be always on and transmit continuously with low transmit delay and latency for real time monitoring.

If a sensing device could transmit periodic data discontinuously or transmit continuous data with much delay time, it is hard for doctors to monitor and prepare a patient's heart attack. Therefore, real time and continuous monitoring is critical in handling an emergency patient.

3. Wireless communication standards for healthcare application

There are different types of wireless systems that support the telemedicine services. If the distance between the patient and hospital is very wide then Satellite communication based systems are preferred. Mobile telemedicine is a new research area that exploits recent advances in mobile communication technologies having the potential for highly flexible medical services. Mobile communication systems have medium coverage area. Short range wireless systems are preferred for home health monitoring especially in WPAN and WBAN. These systems have small coverage area.

Depending on an application, various transmission techniques are used for wireless communication such as Wi-Fi, Bluetooth, ZigBee, UWB, and cellular networks. A medical sensor with built-in wireless transceiver provides a bidirectional data/command telemetry link with portable personal healthcare server which can be installed in a personal digital assistant or smart phone. The received vital signals are then forwarded to the doctor through internet for diagnostic and therapeutic purposes. To facilitate more accurate diagnosis, high data rate wireless link up to 10 Mb/s is required for applications like wireless capsule endoscopy or multichannel biosensor signal recording.

The frequency bands used in some existing biomedical data transmission in sub GHz and GHz range is listed below[6].

TABLE 1

FREQUENCY BAND SELECTION FOR DIFFERENT BIOMEDICAL APPLICATION

Application	Frequency used
Med radio	401-402MHz and 405-406MHz for narrowband (less than 100 KHz)
Medical implant communications services (MICS):	402-405MHz for bandwidth less than 300 KHz
ISM	902-928MHz, 2.4 to 2.4835GHz, 5.725 to 5.875 GHz for bandwidth more than 500KHz
Wireless Medical Telemetry System (WMTS)	608-614 MHz (bandwidth more than 1500KHz), 1395-1400MHz, 1427-1429.5 MHz
UWB	3.1 to 4.9GHz or 6 to 10.6 GHz

4. Wireless Biomedical Sensor Based Systems for healthcare application

With the recent advancements in wireless technologies, wearable monitoring systems can operate without wires by integrating wireless modules with on-body sensors. Using wireless communication is beneficial in many ways. First and foremost, real-time monitoring of collected data can be achieved more easily, which is useful for launching alert mechanisms. In addition, wireless on-body sensors are more unobtrusive for patients, allowing them to continue with their daily routine more easily. Moreover, these systems enable out-patient care, potentially even after more significant operations, thus decreasing healthcare costs. Finally, by allowing the individuals to track their own data with real-time feedback through smart-phones or PDAs, chronic disease sufferers can manage their disease more efficiently.

There are three general scenarios for wireless sensors communications for healthcare application

a) off-body, where a device located on a body communicates with one or more devices located offbody.

b) on-body, where a number of devices located on the body communicate with each other.

c) in-body, where some (or all) of the devices on body are implanted, rather than worn.

Wearable systems for health monitoring may occupy various type of miniature wireless sensors wearable (off body or on body) or implantable (in body).

The rapid growth in biomedical sensors, low-power circuits and wireless communications has enabled a new generation of wireless sensor networks: the body area networks. These networks are composed of tiny, cheap and low-power biomedical nodes, mainly dedicated for healthcare monitoring applications. The objective of these applications is to ensure a continuous monitoring of vital parameters of patients, while giving them the freedom of motion and thereby better quality of healthcare.

AMON is a project financed by the EU FP5 IST program [7]. It consists of on body sensors integrated in the form of a wrist worn device capable of measuring blood pressure, skin temperature, blood oxygen saturation and a one lead ECG. It also incorporates a two axis accelerometer for correlating user activity with the measured vital signs. The authors designed a GSM based communication link and also the software for telemedicine centre. AMON aimed at high risk cardiac/respiratory patients who would be confined to the hospital.

AMON was one of the first of its kind. The device was at the time too bulky to be suitable for its intended patient demographic of the elderly or sick, as at the time the technology required to make everything work was quite bulky. In addition, it was also considerably too expensive for the majority of users to afford at the time.

MIT, Cambridge, developed LiveNet[8], a platform aiming at long term health monitoring applications with real-time data processing and streaming and context classification. LiveNet used a Linux-based PDA mobile device, a modular sensor hub (SAK2) for gathering, processing, and interpreting real-time contextual data and an integrated physiological board (BioSense), which incorporates a 3-D accelerometer, electrocardiogram (ECG), electromyogram (EMG), and galvanic skin conductance sensors, and which allows interfacing with a wide range of commercially available sensors. The MIT Wearable Computing Group, in collaboration with several healthcare providers, has initiated various pilot studies using the LiveNet system, which include soldiers' health monitoring in harsh environments, automated Parkinson symptom detection system, Epilepsy seizure detection and long-term behavioral modeling. Overall, LiveNet targets realtime feature extraction and classification of medical conditions as well as closed-loop medical feedback systems.

LifeGuard [9] is a multiparameter wearable physiological monitoring system for space and terrestrial applications, whose core element is a crew physiologic observation device (CPOD), which is capable of measuring two ECG leads, respiration rate via impedance plethysmography, heart rate, oxygen saturation, body temperature, blood pressure, and body movement. Typical off-the-shelf sensors are use for measuring most of the biosignals, which are interfaced through wired connections to CPOD data logger that can either send the data via Bluetooth to a base station or record them for 9 h continuously on a memory card. The data logger is based on a PIC μC and uses 2 AAA batteries. The authors conducted a series of verification and validation tests at extreme environments and tested the ability of satellite transmission of collected data with the obtained results indicating acceptable accuracy for the collected data and real-time transmission of measurements to remote locations.

A real-time wireless physiological monitoring system [RTWPMS] for nursing centers is demonstrated in[10], whose function is to monitor online the physiological status of aged patients via wireless communication channel and wired local area network. The collected data, such as body temperature, blood pressure, and heart rate, can then be stored in the computer of a network management center to facilitate the medical staff in a nursing center to monitor in real time or analyze in batch mode the physiological changes of the patients under observation. The wireless communication used in this system is outdated and the authors recommend for the use of advanced wireless communication technology, GPS and emergency calling system for expansion of this work. The wearable examination system in this prototype is too bulky for ambulatory and continuous monitoring and the utilized RF technology is outdated as identified by the authors[].

Smart Vest[11], a wearable physiological monitoring system that consists of a vest, which uses a variety of sensors integrated on the garment's fabric to simultaneously collect several biosignals in a noninvasive and unobtrusive manner. The parameters measured are ECG, photoplethysmography (PPG), heart rate, blood pressure, body temperature, and galvanic skin response (GSR). Furthermore, it is stated that the ECG can be recorded without the use of gel and that its recording is free of baseline noise and motion artifacts due to hardware-implemented high pass, low pass, and notch filters.

The design and development of a Zigbee smart noninvasive wearable physiological parameters monitoring device has been developed and reported in[12]. The system can be used to monitor physiological parameters, such as temperature and heart rate, of a human subject. The system consists of an electronic device which is worn on the wrist and finger, by an at-risk person. Using several sensors to measure different vital signs, the person is wirelessly monitored within his own home. The device detects if a person is medically distressed and sends an alarm to a receiver unit that is connected to a computer.

Patients in psychiatric hospitals are continuously monitored in [13]. Some psychiatric patients are restless and aggressive, and hence the monitoring device should be robust and must transmit the data wirelessly. Two devices, a glove that measures oxygen saturation and a dorsally-mounted device that measures heart rate, skin temperature and respiratory rate were designed and tested. Both devices connect to one central monitoring station using two separate Bluetooth connections, ensuring a completely wireless setup. A Matlab graphical user interface (GUI) was developed for signal processing and monitoring of the vital signs of the psychiatric patient. Detection algorithms were implemented to detect ECG arrhythmias such as premature ventricular contraction and atrial fibrillation.

An instrumented wearable belt for wireless health monitoring was presented in [14]. The instrumented wearable belt device is composed of the electronics and sensors for the monitoring of electrocardiogram (ECG), heart rate (HR) derived from ECG signals by determining the R-R intervals, body temperature, respiratory rate, and three axis movement (acceleration and position) of the subject measured using an accelerometer. The experimental results showed that the cardio-respiratory signals, the heartbeats, the respiratory cycles and the patient movements can be obtained clearly by the device. The instrumented wearable belt makes possible physiological parameter measurements for telemedicine diagnosis, especially for home health care management of aged people.

The smart shirt which measures electrocardiogram(ECG) and acceleration signals for continuous and real time health monitoring is designed and developed in[15]. The shirt mainly consists of sensors for continuous monitoring the health data and conductive fabrics to get the body signal as electrodes. The measured physiological ECG data and physical activity data are transmitted in an ad-hoc network in IEEE 802.15.4 communication standard to a base-station and server PC for remote monitoring. The wearable sensor devices are designed to fit well into shirt with small size and low power consumption to reduce the battery size. The adaptive filtering method to cancel artifact noise from conductive fabric electrodes in a shirt is also designed and tested to get clear ECG signal even though during running or physical exercise of a person.

The design intricacies and implementation details of a wireless sensors network based safe home monitoring system is discussed in [16] targeted for the elderly people to provide a safe, sound and secured living environment in the society. Programmed system will minimize the number of false messages to be sent to care provider and supports inhabitant through suitable prompts and action to be performed when there is irregular behavior in the daily activity.

A Zigbee smart noninvasive wearable physiological parameters monitoring device has been developed and reported in [17]. The system can be used to monitor physiological parameters, such as temperature and heart rate, of a human subject. The system consists of an electronic device which is worn on the wrist and finger, by an at-risk person. Using several sensors to measure different vital signs, the person is wirelessly monitored within his own home. An impact sensor has been used to detect falls. The device detects if a person is medically distressed and sends an alarm to a receiver unit that is connected to a computer.

A smart shirt able to monitor the biomedical parameters and managing some alarms for a robot-walker is presented in [18]. The authors evaluated the inertial system of the smart-shirt consisting of an accelerometer. Some typical human movements have been tested. The obtained results permit to know the movements and the positions of a patient using the antro-posterior and medio-lateral angles calculated by the acceleration signals. The authors suggest that in the future, this instrumented shirt will be used to indicate to the robot-walker different potential problems, such as a fall or a wrong position. The various challenges in this area are discussed in [19,21].

The system based on smart textiles has the advantage of high wearability and comfortableness to the user and have a high degree of reliability because of the good contact between the skin and the biosensors. These systems are mainly used for cardiac monitoring purpose. These systems must require little or no technical knowledge for proper operation[20,21].

A wireless body area sensor network (WBASN) is a relatively new wireless networking technology that interconnects tiny nodes with sensing capabilities in, on or around a human body [22]. The vital-sign information collected by these sensors can then be used by care-givers to assess the health of a patient. A BAN based on the IEEE 802.15.4 protocol is presented in [22]. The BAN follows a star topology and it is formed of two main types of devices: 1) sensor communication modules (SCM), which are able to interface with both analog and digital sensors; and 2) a personal data processing unit (PDPU), which is in charge of coordinating the BAN, controlling the communication with all the SCMs as well as the communication with external networks (via USB, Wi-Fi, or GPRS). Synchronization in the BAN is handled via the protocol-supported beacon primitives, which are also used to carry commands about sensor configuration parameters (sampling rate, gain, etc.), sensor activation/deactivation and data transmission [23].

TABLE II

Review of selected wireless health monitoring systems

Health monitoring systems	Hardware details	Communication modules	Medical application	Parameters monitored
AMON[7] 2004	Wrist-worn device	GSM link	High risk cardiac and respiratory patients	ECG,BP, R, T
Livenet[8] 2005	Microcontroller	Wires, GPRS	Parkinson symptom& epilepsy seizures detection	ECG,R T,EMG
LifeGuard[9] 2005	Microcontrollers, commercial sensors	Serial cables	Monitoring in extreme environment	ECG, R, T, SpO2
RTWPMS[10] 2006	Mobile physiological examination device	Cordless phone Rs232 cables	General remote monitoring	HR,T,BP
SmartVest[11] 2008	Vest with woven sensors, Microcontroller	Woven wires	General remote health monitoring	ECG, PPG,T
Wearable Belt[14] 2010	Chest worn device	Serial cables	Cardiac and respiratory patients	ECG, T,R
ZigBee based system[17] 2012	Wrist worn device	ZigBee wireless Communication	General remote monitoring	HR,T, Impact
Instrumented shirt[18] 2014	Shirt with woven sensors	Bluetooth interface	Human movement monitoring	ECG, Movement and position

5. Challenging issues in Sensor Based Systems for healthcare application

They use the different wireless technologies for their different health parameters, situation, and areas. For example, some small data such as body temperature and patient ID are communicated by IEEE 802.15.4/ZigBee, even if this standard has low data rate.

The 2.4GHz ISM band is currently shared by WLAN systems, other communication systems (e.g Bluetooth, Zigbee) and non communication systems (e.g. Microwave ovens). There is much concern over the mutual interference between these systems. Studies done by companies thus far indicate that interference will be significant if these systems operate within a distance of 2 meter. This is a major concern for people working in this band.

Wireless systems need more bandwidth, integrated services, QoS support and high security for providing high quality wireless telemedicine services. Transmission of medical data like real-time video or images over 3G link is still a challenging issue. Also, these kinds of data are not much affected by time synchronization in real time. But some physiological data such as ECG, EEG, and EMG, need continuous and real time transmission. Also, they require high data rate for reliable transmission. Therefore, selecting a proper wireless option for each different healthcare monitoring system is very important.

The limited data rate is another challenging issue for some services. Light weight implementation, long battery life, smaller antenna size, software cost, maintainability, usability and reliability are some of the technological challenges faced by existing and developing systems.

Most reviewed systems focused on single hop topologies, and have very limited real time monitoring capability. Also, some systems are hard to attach or carry because of their size and weight. Even if they can monitor the health conditions, they cannot be readily available for real life application.

6. Conclusion

In this paper various key aspects of wireless sensor based system for biomedical monitoring application is discussed. The various requirements and challenges in the deployment of sensors in biomedical application is mentioned. There are still various challenging issues that should be addressed for the design and implementation of health monitoring systems like wireless communication standards, energy scavenging etc. Also the quality of wireless biomedical sensors heavily depends on developments in the field of signal conditioning micromechanical systems (MEMS), transceiver designing and nanotechnology. Current sensors technology for vital-sign monitoring is promising to alter the traditional chronic monitoring routine. However, designing non-invasive body-worn sensors is very challenging, often requiring a broad understanding of the nature of the disease and its effect on physiological parameters.

Most of the system are disease specific and are aimed for high risk cardiac and respiratory patients. Although there are sensors available off-the-shelf for cardiac and blood-pressure monitoring, there is still a need for improvement to achieve continuous and truly noninvasive monitoring of these parameters. Latest developments in the field of information technology can be utilized for wireless health monitoring so that data collected through biomedical sensors can be transmitted to a mobile phone or tablet so that the physician can easily view the results.

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