A Perspective Study on Patient Monitoring Systems based on Wireless Sensor Network, its Development and Future Challenges

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ABSTRACT
Recent advances in wireless communications have set the track for a new paradigm of personalized healthcare based on persistent continuous vital sign data collection and real-time processing of monitored data to derive meaningful physiological parameters. Novel wireless communication solutions based on bio-medical sensors for reliable vital sign transmission and further processing has become an integral part of the medical solutions particularly in the areas of telemedicine and remote health monitoring, due to its accessibility and cost effectiveness. This paper presents a comprehensive survey of the recent works addressing the Patient Monitoring Systems based on Wireless Sensor Networks.

General Terms
Biomedical Instrumentation, Health Monitoring system

Keywords
Patient Monitoring, Bio-sensors, Biomedical sensing, Wireless Sensors

1. INTRODUCTION
Patient Monitoring Systems play a vital role in the monitoring of patients in Intensive Care Units (ICU) and other in-patient wards in hospitals, providing continuous data acquisitions, analysis, interpretation and display of the patient's vital functions. The rapid evolution of Information of Communication Technology (ICT) is resulting in more powerful monitoring systems capable of complex bio-signal processing, interpretation and display.

Since the last decade, centralized patient monitoring systems were set up in the majority of critical care service centers. The emergence of Internet technologies, advancements in wireless technologies and telemedicine also opened new opportunities and came up with new demands for the entire implementation scenario in patient monitoring [1][2][3]. Home-care or remote monitoring that offered faster, more effective and cost-saving rehabilitation and mobilization of patients became more popular. Tele-care monitors could provide real-time, non-invasive monitoring of vital functions.

The increasing demands outlined above, presented new requirements for the implementation of patient monitoring systems, whereby three aspects played the key role: accessibility to information, convenience of use and cost-effectiveness. Wireless sensor technology has emerged as the lead player in the implementation of pervasive monitoring systems - from both the economic perspective and the perception of patient's comfort. This paper presents a comprehensive survey of the recent works addressing the Patient Monitoring Systems based on Wireless Sensor Networks.

2. WIRELESS SENSOR NETWORKS
Wireless sensor network refers to a group of dedicated and spatially dispersed sensors for recording the physical conditions of the concerned environment and organizing the collected data at a central location. It consists of a number of sensor nodes. Each sensor node includes a radio transceiver along with an antenna, a micro controller, an interfacing electronic circuit and a battery as the energy source. Fig.1 shows the schematic representation of a wireless sensor node.

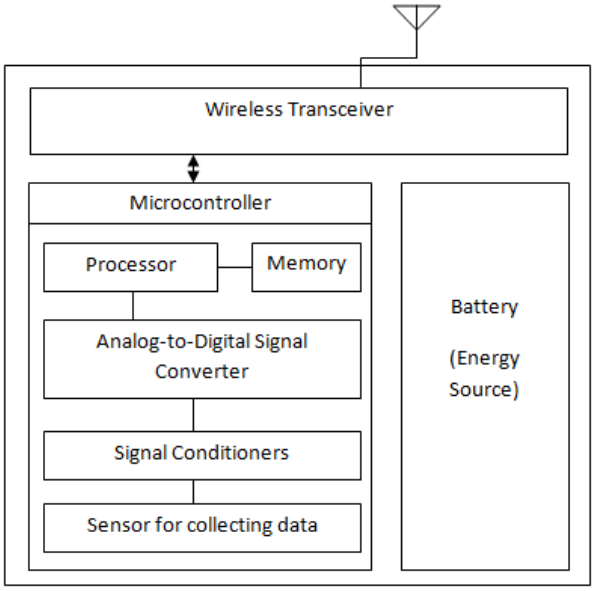

Fig. 1 Schematic Representation of a Wireless Sensor node

The interest in Wireless Sensor Network (WSN) is because of the fact that they are compact, cost-effective and energy efficient [4]. Other technologies like Wi-Fi and Bluetooth focus on applications that require higher bandwidth. Also, wireless nodes using these two communications protocols are much more expensive and power hungry. Bluetooth allows only a limited number of wireless nodes to communicate with each other at any given time. Because of these reasons wireless nodes using these two communication protocols are not very popular in the remote monitoring of the vital signs of the patients. Also the capability to remotely monitor such data

without any expensive wired infrastructure installation overhead is highly desirable.

3. VARIOUS IMPLEMENTATIONS

The implementation of the monitoring system is generally done in two ways, depending on where and how it is used.

- As an array of independent wearable sensors
- As a Wireless Body Area Network (WBAN) incorporating wireless sensor nodes

3.1 Wearable Sensors

The traditional wearable physiological monitoring system that consists of an array of sensors embedded into the fabric of the wearer, to continuously monitor the physiological parameters and transmit wireless to a remote monitoring station. The data is monitored at the remote monitoring station that gives the overall status of the person wearing it. There are many drawbacks for this system, like:

- For bedridden patients, wearing the fabric continually without causing damage to the sensors becomes difficult
- Entanglement of wires is a definite overhead
- The cables used may pick up noise and signals from the electromagnetic sources in its vicinity that might interfere with the physiological signals causing variations that may lead to incorrect readings
- Repositioning as well as replacing the sensors once integrated in the fabric becomes tedious

The use of wireless sensor network has been successful in bringing down these problems to a greater extend. Also, it has made the whole system much user-friendly.

Pandian et all [5] gives a conceptual design of a wearable physiological monitoring system based on wireless sensor network to monitor physiological parameters like ECG, EMG, EEG, SaO_2, body temperature, blood pressure, respiratory rate GSR and movement of the wearer. The acquired signals are pre-processed at each node at the sensor level and transmitted to the wearable data acquisition hardware (sink node) for further processing. It is then transmitted wireless to the remote monitoring station. Fig. 2 gives the architecture of the monitoring system.

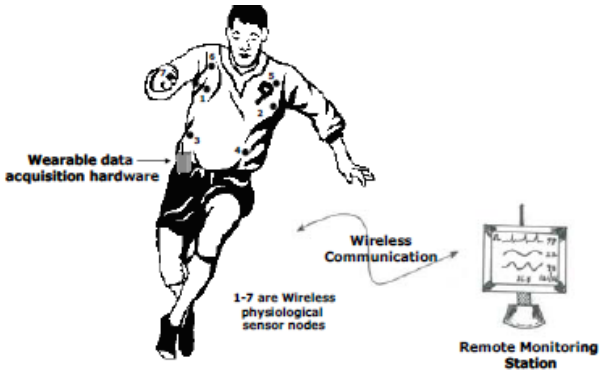

Fig. 2 Overall architecture of the wireless sensor network based wearable physiological monitoring system [5]

Choi et all [6] describes the development of a wearable sensor platform to monitor a number of physiological correlates of mental stress. The tradeoffs in both system design and sensor selection to balance information content and wearability is detailed. Using experimental signals collected from the wearable sensor, a selected number of physiological features that show good correlation with mental stress is described.

Jun et all [7] also describes the architecture of a wearable ECG monitor that is patient location independent and provides continuous monitoring. Fig 3 gives the overview of the system. The signals from the belted detector to which the sensors are connected, are transmitted using Bluetooth to the smart phone in its vicinity, which can in turn be send to the destination via internet.

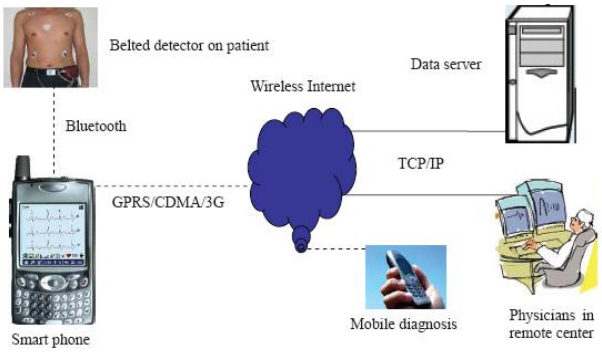

Fig. 3 Overview of the remote diagnosis service system [7]

The idea has also been endorsed by many others in their works [8] [9] [10]. After the popularization of Personal Area Networks (PAN) and Body Area Networks (BAN), the whole system has been incorporated in to one or more BAN.

3.2 Wireless BAN

Various bio-sensors can be integrated into a Wearable Wireless Body Area Network (WBAN), be it a location sensor or the ones that can monitor vital signs or environment sensors that can monitor temperature, humidity and light. These networks comprise of in-expensive, light-weight, miniature sensors and can allow modest, long-term and ambulatory health monitoring with instant feedback to the user about the current health status and update user's medical records on a real time mode.

A range of patient monitoring system implementations using Wireless Body Area Network (WBAN) incorporating wireless sensor nodes have been described by various researchers [11] over the time.

Xin Liu et all [12] proposes a power and area efficient electrocardiogram (ECG) acquisition and signal processing application sensor node for wireless body area networks (WBAN). This sensor node can accurately record and detect the QRS peaks of ECG waveform with high-frequency noise suppression. The proposed system is implemented in 0.18-mm complementary metal–oxide–semiconductor technology with two chips: analog front end integrated circuit (IC) and digital application specific integrated circuit (ASIC). Therefore, this ECG sensor node is convenient for long-term monitoring of cardiovascular condition of patients, and is very suitable for on-body WBAN applications. Fig.4 gives the overview of the system that measures various factors like ECG, respiration rate and temperature.

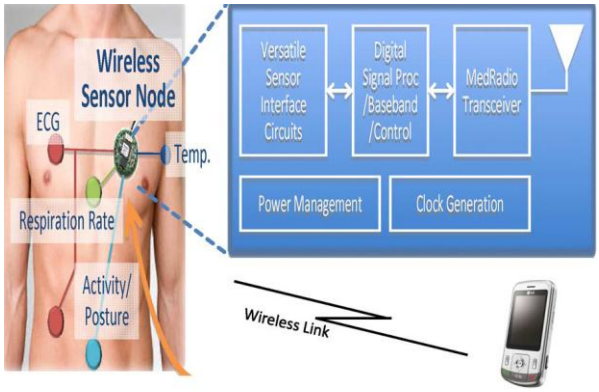

Fig. 4 Demonstration of wireless body area network technique [12]

Otto, Jovanov and Milenkovic [13] in their paper describe a prototype system for continual health monitoring at home. The system consists of a modest wireless body area network (WBAN) and a home health server. The sensors of the WBAN monitor user's heart rate, mobile and locomotive activity and upload the information with time-stamp to the home server at regular intervals of time. The home server may integrate this information into the local database for the user's inspection or it may forward the information further to a medical-server.

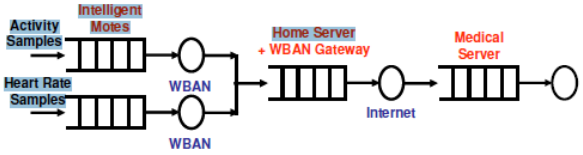

Fig. 5 Data Flow in Wireless BAN [13]

The Wireless Body Area Network testing involved several users wearing the heart and activity sensors for comprehensive periods of time, at home.

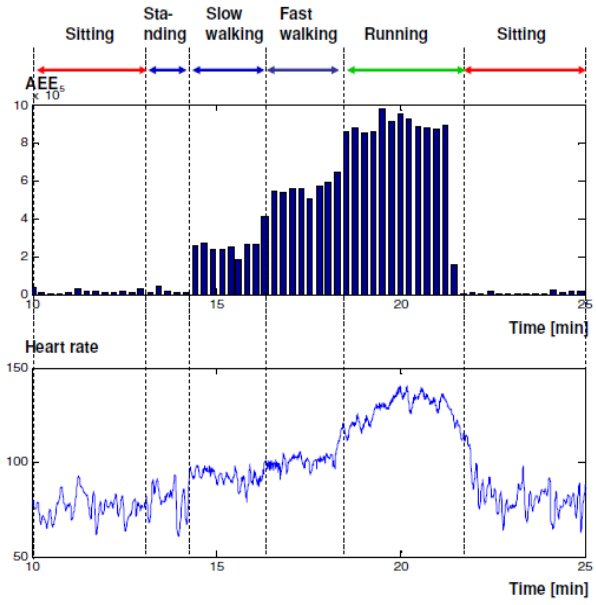

Fig. 6 AEE and heart rate collected on the home health server for 15 minutes with different types of activity [13]

Fig. 6 shows the activity-induced energy expenditure (AEE) and the heart rate of a healthy user in his early thirties during fifteen minutes of increased activity in the laboratory conditions. The experiment included the following sequence of activities: three minutes of sitting followed by a one minute of standing, two minutes of slow walking, two minutes of fast walking, three minutes of slow running and finally three minutes of sitting. Increases in the heart rate can be clearly seen at the beginning of intervals with more activity (slow walking, fast walking, and running) simultaneous with increased activity-induced energy expenditure (AEE).

4. CHALLENGES IN THE IMPLEMENTATION OF THE SYSTEM

An ideal patient monitoring system based on wireless sensor networks should satisfy the following criteria: low power consumption, small size and reliability among others to make it easier and comfortable to use.

One of the major hurdles in the design of the system is low power consumption. It is required to keep the power dissipation to the minimum possible level. Various designs involving communication and on-sensor computation, collaborative protocols and the organisation of the network can yield significant energy savings. Dynamic power management techniques are also handy in order to increase battery life.

Bachmann et all [14] describes the idea of low-power wireless sensor nodes for biomedical applications that are capable of operating autonomously or on very small batteries. Component-level power optimization for the radio and digital signal processing is described in the paper along with a short comparison between radio power consumption and on-node processing.

Abdalla et all [15] provides several solutions for enhancing the reliability and improving the power management of real-time of real-time multi-patient monitoring systems. A reliable wireless Personal Area Network based on digital signal processing has been developed using sleep strategy and other techniques like dynamic voltage and frequency scaling to achieve low power management and assisted power control. Results show that this approach has been successful in outperforming the single WPANs in terms of efficiency and reliability.

Raut and Giripunje [16] give a novel wireless data collection system for health monitoring of patients based on PIC controller and wireless sensors. The unique characteristics of this system such as low power, low cost, and high flexibility make them ideal for this application.

5. CONCLUSION

Kalorama Information, one of the leading publishers of US market research in medical markets, including the biotechnology, diagnostics, medical device, and pharmaceutical industries, has recently published a report entitled *Remote and Wireless Patient Monitoring Markets* [17]. The data is provided for the US market in 2011 and forecasted to 2016. In the report, the researchers predict that the U.S. healthcare system faces a looming healthcare crisis of unseen proportions, and there will be fewer healthcare personnel and funds to address the industry's growing needs. The report notes that in the U.S. there are over 35 million hospital admissions each year, and nearly 120 million people visit a hospital emergency room. The sheer volume of patients requires a significant number of hospital resources such as

staff and available beds, but hospitals are hard pressed to meet these needs. According to the report, hospitals, physician offices, home healthcare facilities and nursing homes will embrace remote and wireless patient monitoring devices, such as blood pressure monitors and glucose meters, to transmit patient data between different locations using wireless networks.

New technologies in patient monitoring are designed to reduce spending and streamline patient care while reducing patient risk such as medical errors and hospital infections. Patient-involved healthcare is on the rise and wireless technologies have catered to this trend. There are barriers to the adoption of the technology, such as privacy concerns with wireless systems, compatibility between systems and financial pressures that come with limited budgets. But the need for patient monitoring systems will far outweigh any excuses not to adopt the new technologies.

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