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STUDY OF BIOLOGICAL SIGNALS MONITORED FROM PATIENTS USING WIRELESS SENSOR NETWORKS

VIJENDER SINGH HOODA[1], AMNINDER KAUR[2] & SANIYA PURI[3]

[1]Research Scholar & Associate Professor, Department of Information & Technology, Dronacharya College of Engineering, Gurgaon, Haryana, India

[2]Associate Professor, Department of Electronics & Communication Engineering, Dronacharya College of Engineering, Gurgaon, Haryana, India

[3]B.Tech Student, Dronacharya College of Engineering, Gurgaon, Haryana, India

ABSTRACT

Humans have five basic senses—hearing, sight, touch, smell and taste correspond to the primary biological sensors, which are the ear, eye, skin, and nose and tongue respectively. Using these sensors, humans are able to make observations, accumulate data and process it into usable information. However, built-in biological sensors have practical limitations of data range and type of observation, and they are not suitable for particular measurements. In comparison, man-made sensors measure characteristics of real-world physical environments and convert them into raw data, which can be processed into information that may be used or kept digitally for later access and analysis. 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 Monitoring of biological signals from Patients based on Wireless Sensor Networks.

KEYWORDS: HMI (Human Machine Interface), Bio-Sensors, Wireless Sensors, Wireless Body Area Network (WBAN)

INTRODUCTION

The average life span of human beings are reducing, this results in a need of medical care, which is costlier for long-term monitoring and long waiting lists for consultations. Hospitals are looking at to recouping the people at home. An emerging application for wireless sensor networks involves their use in medical care. In a hospital or clinic, outfitting every patient with tiny, wearable wireless vital sign sensors would allow doctors, nurses and other caregivers to continuously monitor the status of their patients. In an emergency or disaster scenario, the same technology would enable medics to more effectively care for large numbers of casualties [1]. First responders could receive immediate notifications on any changes in patient status, such as respiratory failure or cardiac arrest. Wireless sensors could augment or replace existing wired telemetry systems for many specific clinical applications, such as physical rehabilitation or long-term ambulatory monitoring. In some specific situations it is desirable that the patient under monitoring does not lose his mobility by the wire connection to the device that captures any particular signal, since this state may interfere with the study. For example, in case you need to measure the heart effort of a person taking a walk or a sprint. It is in this type of environment where new ICT technologies such as Wireless Sensor Networks (WSN) can support the development of biomedical devices allowing the acquisition of various signals for subsequent monitoring and analysis in real time. The constant study and monitoring of biomedical signals, has been an important tool in the development of new medical technology products [2].

Wireless units integrate non-wired communications and mobile computing with transducers to deliver a sensor platform which is economical for various applications. Recently, research is listening carefully about the quality of human life in terms of hygiene healthy life by designing and fabricating sensors through direct and indirect contact with the human body. 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.

WIRELESS SENSOR NETWORKS

Wireless sensor networks (SNETs) consist of small battery-powered "motes" with limited computation and radio communication capabilities. Using SNETs, large-scale ad hoc sensor networks (ASNET) can be deployed among mobile patients, and, thus, can provide dynamic data query architecture to allow the medical specialists to monitor patients at any place via the web or cellular network. In case of an emergency, doctors and/or nurses will be contacted automatically through their handhelds or cellular phones. The wireless sensor networks are formed by small electronic devices called nodes, whose function is to obtain, convert, transmit and receive a specific signal, which is captured by specific sensors, chosen depending on the sensing environment [3].

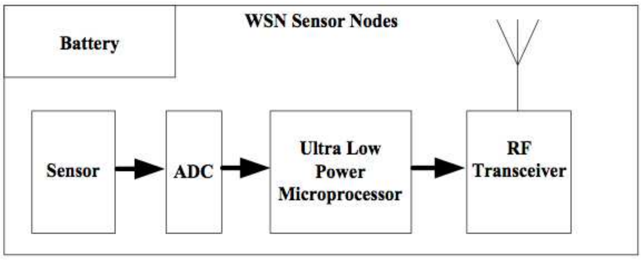

Figure 1: Representation of a Wireless Sensor Node

A typical sensor network consists of a large number of sensor nodes (SNODEs) that are densely deployed either inside the phenomenon or at a close proximity to it. Furthermore, in addition to being capable of sending the raw data directly to the nodes responsible for the fusion, SNODEs, with the help of the onboard processor, are also capable of locally carrying out simple computations and transmitting only the required and partially processed data. Moreover, sensor networks have self organizing and fault tolerant capabilities. Such capabilities make sensor networks suitable to many applications such as health, environmental, military, security, and home applications Sensors are fundamental elements of all machines that gather data, require feedback for their operation or are required to provide a Human Machine Interface (HMI) [4].

Technological developments in materials and electronics have led to the miniaturisation and integration of sensors into intelligent devices and systems that not only measure and analyse but also act on the resultant information. Intelligent sensors can also consolidate observations, and aggregate and analyse data locally to conserve downstream communications and analysis resources. Today, autonomous and connected sensors are able to selectively sample and measure many physical properties such as temperature, force, pressure, flow, position, and light intensity without impacting on the properties being measured [5].

Sensors are generally part of a more comprehensive monitoring or data acquisition system that conditions, processes, converts and transports data. Monitoring is a process that observes a state in time or tracks changes in states over time. Observations may be made by humans or sensor-based instruments to form data sets from which information can be derived. Monitoring is governed by sensor functionality and the data analysis requirements, effectively bridging the two processes of sensing and analysis.

The application of monitoring plays an important role in collecting sufficient relevant information to achieve the desired outcomes of the process. Some monitoring systems are required to make observations from multiple remote and dispersed sensors that in turn require a single communications network path to transport individual sensor data to a point of aggregation and analysis. Where multiple sensors are concentrated over a smaller area, an underlying sensor–mesh network may be used to aggregate data prior to data transport over a communications network. The frequency and accuracy of sensor observations may also determine monitoring system design and particularly the proportion of resources that are sensor-, communications- and analysis-based [6].

Collecting Data

Sensors require a network of interconnecting infrastructure to communicate and process the information required for services and monitoring applications. The availability of fixed-access and wireless mobile networks has guided the evolution of sensing by providing bidirectional connectivity for associated monitoring and control. Third-party integrators dominate systems development to provide novel and fragmented solutions across different industry sectors. These solutions tend to be dedicated, proprietary in nature and lacking interoperability.

Several university and private research project projects, both past and ongoing are related to this work. The Code Blue project, directed by the engineering and applied science department at Harvard University, is the closest of these to our area of research. They are developing technology to facilitate real-time triage in disaster relief situations. By outfitting patients with wireless sensors, they have demonstrated the system’s ability to form ad-hoc sensor networks, collect vital statistics of each patient, and then use system software to identify those patients in most critical need of medical attention [7].

IMPLEMENTATION OF SENSOR NETWORKS

The implementation of the monitoring system of sensor networks 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

Wearable Sensors

Wearable sensing of human physiological signals is becoming an essential part of nowadays monitoring systems.These revolutionary systems should allow clinicians, physiologists, psychologists, social institutions and people themselves to have access to a lot more information on the human body function than ever before. Figure 2 shows a generic platform for monitoring patients. The transmission of data over mobile communication (GSM and GPRS), full mobility is offered to the patient. The system comprises sensors, processing and communication functions worn by the user, interconnected with a portable base station, which is the gateway to the Internet where the collected data are made available to the authorized professionals, i.e., doctors, nurses, etc. [8] The portable system includes local pre-processing close to the physiological signal collection nodes and global processing which takes benefit of the availability of various types of physiological (electrocardiogram (ECG), partial oxygen blood

Saturation (*Sp*O2), skin temperature, etc.) and physical activity signals (acceleration, position, etc.) to perform efficient denoising and classification of the biosignals.

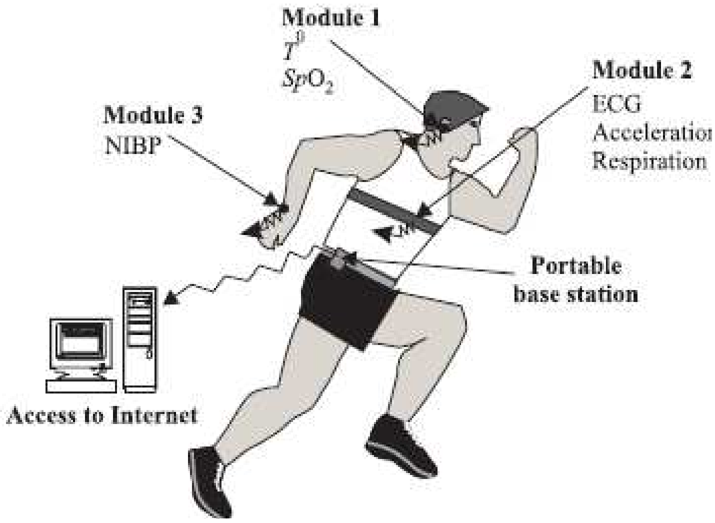

Figure 2: Overview of a Possible Architecture Comprising, Sensors, Processors and Communication Units

To make the sensors and processing really wearable, they have to be embedded in the clothes or worn in natural units such as watch earring, finger rings, headset; which are tailored for the specific heath monitoring needs of the users (sickness, professional, sports) [8].

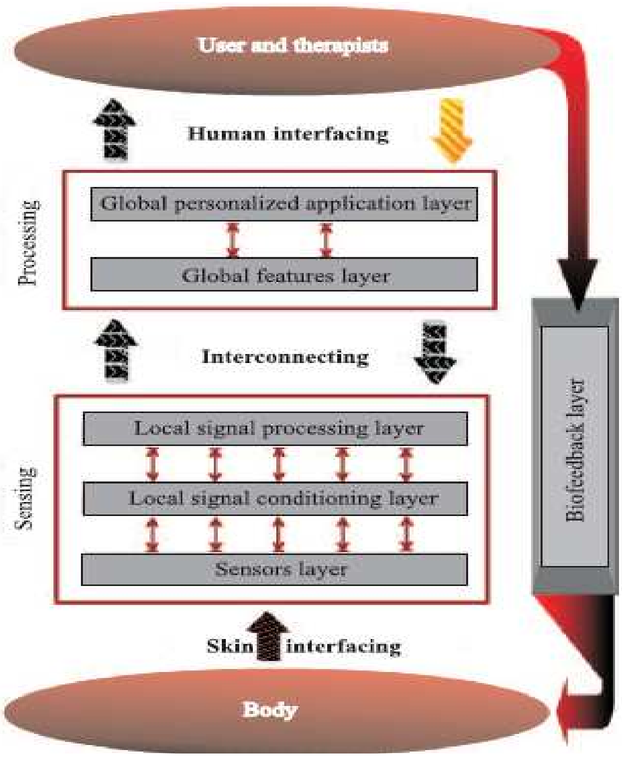

Figure 3: Different Layers Appearing in the Architecture

The architecture of the system may be described as a number of discrete layers. Distribution of functions in the layers and communication between the layers must be done in such a way that the relevant information is always properly extracted and transferred at the appropriate rate. If simultaneous recording of the signals is necessary, synchronization issues between the different sensing units have to be addressed. Figure 3 shows the different possible layers and the interconnections. The low-level sensing layer is divided into three localized sub-layers: sensors, signal conditioning and signal processing. The highest-level processing layer is divided into two global sub-layers: feature extraction. layer and the personalized application layer. The processed signals are then fed to the therapists and/or the user himself. In the low-level sensor layer, new fiber materials and soft electronics technologies allowing convenient long-term monitoring are required. Textile sensors, integrated into garments, are very well suited for long-term monitoring solutions, but also provide lower quality signals implying an increase in the complexity of the analog and digital processing of the signals [9].

Wireless Ban

Wireless Body Area Networks (WBANs) represent a promising trend in wearable health monitoring systems. WBANs promise to revolutionize health monitoring and increase a user's quality of life by offering continuous and ubiquitous ambulatory health monitoring at the least level of obtrusiveness. A WBAN consists of multiple sensor nodes, each capable of sampling, processing, and communicating one or more vital signs (heart rate, blood pressure, oxygen saturation, activity) or environmental parameters (location, temperature, humidity, light). Typically, these sensors are placed strategically on the human body as tiny patches or hidden in users' clothes allowing ubiquitous health monitoring in their native environment for extended periods of time [10]. This offers the freedom of mobility and enhances the patient' equality of life.

System Overview

The proposed WBAN for ambulatory health monitoring is contained within a multi-tier telemedicine system as illustrated in Figure 4. The telemedicine system spans a network comprised of individual health monitoring systems that connect through the Internet to a medical server tier that resides at the top of this hierarchy. The system is not merely a distributed data logger, which in itself would provide great advantage over current systems, but provides distributed data processing and analysis functions. Each tier in the network is intelligent and provides some form of analysis; in some cases it may be possible for on-the-spot real-time diagnosis of conditions.

The top tier, centred on a medical server, is optimized to service hundreds or thousands of individual users, and encompasses a complex network of interconnected services, medical personnel, and healthcare professionals. Each user wears a number of sensor nodes that are strategically placed on the body. The nodes are designed to unobtrusively sample vital signs and transfer the relevant data to a personal server through a wireless personal network implemented using ZigBee (802.15.4) or Bluetooth (802.15.1).

The personal server, implemented on a home personal computer, handheld computer, smart phone, or residential gateway, controls the WBAN, performs sensor fusion, and preliminary analysis of physiological data. It provides graphical or audio interface to the user, and transfers captured health information to the medical server through the Internet or mobile telephone networks (e.g., GPRS, 3G) [11].

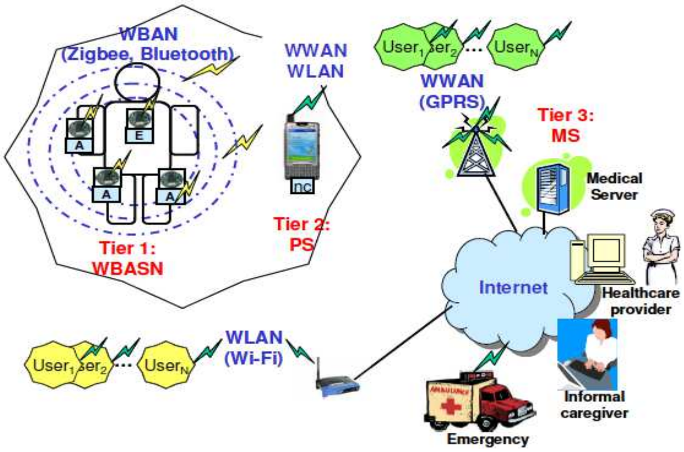

Figure 5: Health Monitoring System Network Architecture

Medical Server

The medical server provides a variety of differing functions to WBAN users, medical personnel, and informal caregivers. The medical server stores electronic patient records in a database, provides a high availability daemon for authenticating registered WBAN users and accepting session uploads, summarizes physiological data and automatically analyzes the data to verify it is inside or outside acceptable health metrics (heart rate, blood pressure, activity) and identifies known patterns of health risks. It is the responsibility of the medical server to interface the electronic patient records and insert new session data, generate alerts to the physician and emergency health care professionals when abnormal conditions are detected, and provide physician and informal caregiver portals via the Internet for retrieving health summary reports remotely. This is especially powerful for the physician who can access the data at a convenient time to determine whether the patient is responding to a prescribed medication or exercise and make updates to those prescriptions and forward them electronically back to the patient where the user's personal server is responsible for delivering such changes to the user [12]. The large amount of data collected through these services can also be utilized for knowledge discovery through data mining. Integration of the collected data into research databases along with quantitative analysis of conditions and patterns could prove invaluable to researchers trying to link symptoms and diagnoses with historical changes in health status, physiological data, or other parameters (e.g., gender, age, weight). In a similar way this infrastructure could significantly contribute to monitoring and studying of drug therapy effects.

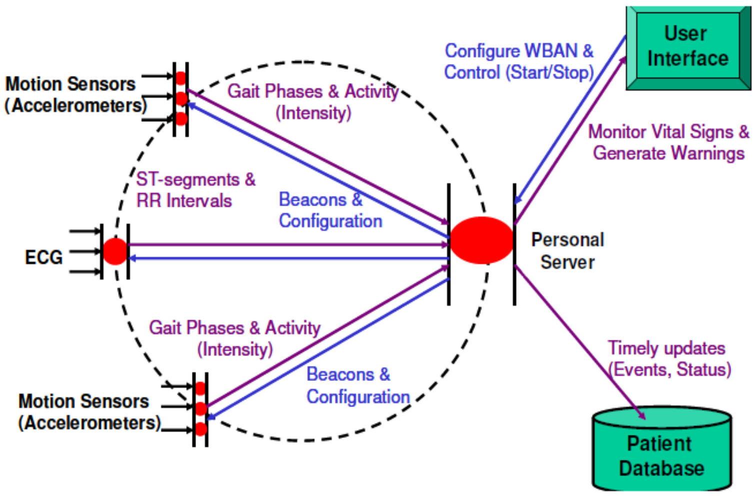

Figure 6: Data Flows in Prototype WBAN

Personal Server

The Personal Server application is responsible for node identification and node configuration (controlling the WBAN), sensor fusion, and provides the user interface. In a full multi-tier network as presented in Figure, the personal server would also be responsible for establishing secure communications with the medical server, upload session files, and download new caregiver instructions. Figure 6 shows the message flow during a typical WBAN health monitoring session. The Personal Server begins a health monitoring session by wirelessly configuring sensor parameters, such as location (left/right ankle, waist, and chest) selection of the type of physiological signal of interest, and specifying events of interest. For example, a motion sensor can be configured to send activity estimate events (AEE) when the level crosses a specified threshold, step recognition events, or raw data. The personal server performs sensor fusion on the multiple data streams, creates session files and archives the information in the patient database. Real-time feedback is provided through the user interface [13].

Sensor Node Identification and Configuration

Sensor node identification requires a method for uniquely identifying a single sensor node to associate the node with a specific function during a health monitoring session. For example, a motion sensor placed on the arm performs an entirely different function than a motion sensor placed on the leg. Because two motion sensors are otherwise indistinguishable, it is necessary to identify which sensor should function as an arm motion sensor and which sensor should function as a leg motion sensor.

Implementation

As stated in the introduction section, the objectives of the case study are to facilitate the use of both medical sensors and wireless mobile network in health applications. The node of the doctor/nurse could be a wireless ad hoc node, a mobile phone device, or a PDA inside or outside the hospital. By facilitating communication between the patient's microcontroller and the doctor/nurse node the system is capable of:

- Sending an urgent SMS message to the doctor/nurse node in case of critical sensors reading.
- Sending an E-mail with the patient profile to the doctor.
- The main features of our implementation are as follows:
- The integration of the infrastructure cellular network, ad hoc network, sensor network and IP network.
- Availability of communication anywhere via the multi-layer hierarchical structure.
- Information is made available to experts at any location via the web [14].

CHALLENGES IN THE IMPLEMENTATION OF SYSTEM DESIGN

- Due to the strong heterogeneity of the applications, data rates will vary strongly, ranging from simple data at a few Kbit/s to video streams of several Mbit/s. Data can also be sent in bursts, which means that it is sent at higher rate during the bursts.
- The wireless communication is likely to be the most power consuming. The power available in the nodes is often restricted. The size of the battery used to store the needed energy is in most cases the largest contributor to the

sensor device in terms of both dimensions and weight. Batteries are, as a consequence, kept small and energy consumption of the devices needs to be reduced.

- During communication the devices produce heat which is absorbed by the surrounding tissue and increases the temperature of the body. In order to limit this temperature rise and in addition to save the battery resources, the energy consumption should be restricted to a minimum.
- The communication of health related information between sensors in a WBAN and over the Internet to servers is strictly private and confidential and should be encrypted to protect the patient's privacy.
- Proper quality of service (QoS) handling is an important part in the framework of risk management of medical applications. A crucial issue is the reliability of the transmission in order to guarantee that the monitored data is received correctly by the health care professionals.
- In most cases, a WBAN will be set up in a hospital by medical staff, not by ICT-engineers. Consequently, the network should be capable of configuring and main training itself automatically, i.e. self-organization an self- maintenance should be supported [15].

CONCLUSIONS

The proliferation of wireless devices and recent advances in miniature sensors prove the technical feasibility of a ubiquitous heath monitoring system. A WBAN is expected to be a very useful technology with potential to offer a wide range of benefits to patients, medical personnel and society through continuous monitoring and early detection of possible problems. With the current technological evolution, sensors and radios will soon be applied as skin patches. Doing so, the sensors will seamlessly be integrated in a WBAN. Step by step, these evolutions will bring us closer to a fully operational WBAN that acts as an enabler for improving the Quality of Life. We feel that this review can be considered as a source of inspiration for future research directions.

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