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BODY SENSOR NETWORKS: A REVIEW

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ABSTRACT
Recent advances in wireless communications and electronics has enabled the development of low-cost sensor networks. The sensor networks can be used for various application areas. For different application areas, there are different technical issues that researchers are currently resolving. The use of sensor networks for healthcare is well established; it works even in extreme environments and has long roots in the engineering sector in medicine and biology community. With the maturity of wireless sensor networks, body area networks (BANs), and wireless BANs (WBANs), recent efforts in promoting the concept of body sensor networks (BSNs) aim to move beyond sensor connectivity to adopt a system-level approach to address issues related to biosensor design, interfacing, and embodiment, as well as ultralow-power processing/communication, power scavenging, autonomic sensing, data mining, inferencing, and integrated wireless sensor Microsystems. As a result, the system architecture based on WBAN and BSN is becoming a widely accepted method of organization for ambulatory and ubiquitous monitoring systems. This paper presents a snapshot of the current research and emerging applications and addresses some of the challenges and implementation issues.

Keywords: Body sensor networks (BSNs), sensors, wireless body area networks (WBANs)

I. INTRODUCTION

The first implementation of wireless body area networks (WBANs) [1], though at that time, the prototype was named under personal area network (PAN), a term that was originated from Zimmerman [2] and further developed by IEEE P802.15 Working Group [3]. Soon after, the notation of BAN emerged. A group from Philips was among the first to use BAN instead of PAN and has listed distinct features that should be incorporated into the two types of networks [4]. As the applications of PAN or BAN extended from connecting personal electronic consumer goods for the sake of convenience to the user to medical and healthcare applications, BAN has become increasingly popular and is found to be a key element in the infrastructure for patient-centred medical applications [5].

The launch of projects, such as MobiHealth [6], further accelerates the development of BAN and m-Health service platform. IEEE T-ITB published a Special Section on m-Health five years ago and the section turns out to be well recognized, as reflected in the number of citations.

From a system perspective, the concept of body sensor networks (BSNs) [8] moves beyond sensor connectivity, with specific focuses on ultralow-power processing/communication, power scavenging, autonomic sensing, data mining, distributed inferencing, intelligent on-node processing, and integrated wireless sensor microsystems. The primary motivation of BSN re- search is to provide long-term continuous sensing without activity restriction and behavior modification.

In practice, a collection of sensors on a user can be integrated using wired, wireless, and biochannels or a combination of these approaches. Wired sensor networks are typical for smart clothes that integrate both sensors and sensor interconnections, and achieve ultimate power efficiency. Wireless sensor networks (WSNs) can cover sensors spanning the whole body. They are particularly important for linking with ambient sensors and implantable sensors, such as pacemakers and deep brain stimulators. Biochannels serve as a unique secured means of communication [7], where the human body is used to transmit either exogenous or endogenous information. Since each approach has its pros and cons, a combination of these approaches should be used according to specific applications, i.e., formation of a hybrid network.

Recent technological developments have enabled sensor miniaturization, power-efficient design and improved biocompatibility. Issues related to system integration, low-power sensor interface, and optimization of wireless communication channels are active research fields, as presented in this paper. Other topics related to quality of service, security, multisensor data fusion, decision support, and technological scaling are also important for practical applications of BSNs. The purpose of this paper is to present recent trends and transition of BSN technology from theoretical concepts to emerging applications.

II. PERVASIVE MONITORING

In parallel to the development of sensing and monitoring devices, several research platforms are emerging. One approach is to incorporate physiological sensors into the garment by linking sensors to a wearable processing device, such as the knitted bioclothes developed by the EU Project Wealthy. Similarly, the EU project, MyHeart aims to provide continuous monitoring of vital signs for cardiac patients. The concept of an intelligent biomedical cloth (IBC) is proposed where biosensors are embedded inside clothes for measuring physiological signals and to provide immediate diagnosis and trend analysis [6]. Although embedding the sensors into the garment could provide a convenient wearable system for the patient, the design is not flexible for the addition or relocation of sensors. In addition, different sizes of clothes have to be designed for different persons, which can introduce a significant cost burden. An alternative approach is to use on body sensors such as the Human++ research programme at IMEC and the EU funded project Healthy Aims. Liska *et al* proposed a Bluetooth based wearable ECG server integrated with a GPS (Global Positioning System) sensor, which can report the location of the patient when an emergency event is detected. Other systems include CardioNet and MIThril for remote heart monitoring.

A. Body Sensor Networks

Thus far, most hardware platforms for pervasive healthcare applications are proprietary designed. The lack of interoperability and standards has prohibited a common approach towards the development of pervasive sensing applications. The basic concept of BSN is illustrated in Fig.1 where wireless sensors are either worn by or implanted into the patient, and the sensor data is gathered by a local processing unit, such as a PDA before it is further processed or transmitted to the central monitoring server. With regard to the BSN concept, the hardware platform, BSN node, is designed and developed [5]. Despite providing the wireless communication and local processing capability, the BSN is designed to ease the integration of different sensors, such as ECG, SpO2, and other context awareness sensors. In addition, by adopting the IEEE 802.15.4 standard, interoperability is assured between different sensor platforms.

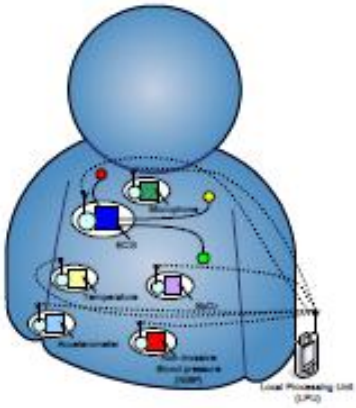

Fig.1. The basic design of the body sensor network.

B. BSN Architecture

Fig. 2 illustrates the basic structure the BSN node. The BSN node uses the Texas Instrument (TI) MSP430 16-bit ultra low power RISC processor with 60KB+256B flash memory, 2KB RAM, 12-bit ADC and 6 analog channels (connecting up to 6 sensors). The wireless module has a throughput of 250kbps with a range over 50m. In addition, 512KB serial flash memory is incorporated in the BSN node for data storage or buffering. The BSN node runs TinyOS by U.C. Berkeley, which is a small, open source and energy efficient embedded operating system. It provides a set of modular software building blocks, of which designers could choose the components they require. The size of these files is typically as small as 200 bytes and thus the overall size is kept to a minimum. The operating system manages both the hardware and the wireless network—taking sensor measurements, making routing decisions, and controlling power dissipation. By using the ultra low power TI microcontroller, the BSN node [9] requires only 0.01mA in active mode and 1.3mA when performing computation intensive calculation like a FFT. With a size of 26*mm*, the BSN node is ideal for developing wearable biosensors. In addition, the stackable design of the BSN node and the available interface channels ease the integration of different sensors with the BSN node. Together with TinyOS, the BSN node can significantly cut down the development cycle for pervasive sensing development.

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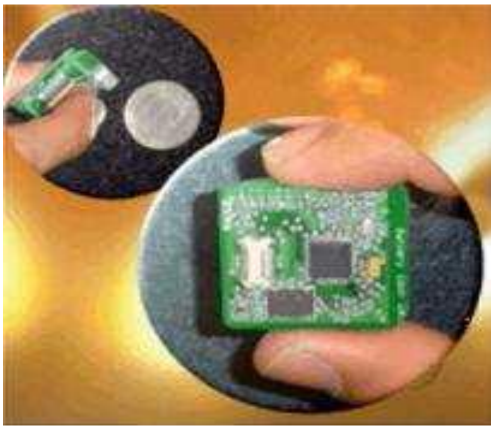

Fig 2. A pictorial illustration of the BSN node

III. EMERGING TECHNOLOGIES AND APPLICATIONS

Earlier prototypes of BSNs tend to use multichip solutions manufactured from off-the-shelf components. Recently, the first system-on-chip (SoC) has been developed specifically for wireless BSNs to monitor vital signs. The SoC integrates a transceiver, hardware media access control (MAC) protocol, microprocessor, IO peripherals, memories, A–D converter, and custom sensor interfaces. The chip can be interfaced with antenna and battery as a single-chip wearable patch [7].

Thus far, long-term and sustainable power supply remains a great challenge to BSNs. New trends in very large-scale integration (VLSI) technology and laboratory prototypes developed by MIT and Texas Instruments promise to decrease processor power consumption 10–20 times and power supply voltage to less than 500 mV in the next five years [6]. When significant effort has been directed to power-efficient processor design and communication protocols, extensive studies have also been carried out in establishing practical techniques for power scavenging from the external environment or the human body [10]. One potential direction is the development of biofuel cells, where biocatalysts are used for converting chemical energy of a fuel such as glucose into electrical energy [5].

Parallel to these developments, new materials and technologies have also been developed for innovative sensor embodiment to achieve reliable, pervasive, long-term continuous monitoring of vital signs. This includes, for example, the development of conductive fabric and weaving technologies [6] or planar fashionable circuit board technique to directly print patterned electrodes and circuits on fabric. Attempts have also been made to model the human body as a communication channel [9]. In addition to the earlier emerging technologies, the widespread use of mobile devices with high-speed Internet connection and GPS location has greatly extended the possible scope of BSNs.

Among the many applications of BSN, healthcare is likely to be an early adopter of the technology for managing both chronic diseases and acute events. This can potentially change the snapshot nature of conventional monitoring approaches, as the current practice is generally limited to the brief time points and often unrepresentative physiological states such as supine and sedated, or artificially introduced exercise tests. Transient abnormalities cannot always be captured reliably. Important and even life threatening disorders can go undetected because they occur only infrequently, and much time and effort is wasted in trying to capture an “episode” with controlled monitoring. The provision of “ubiquitous” and “pervasive” monitoring of physical, physiological, and biochemical parameters in any environment without activity restriction and behavior modification is the primary motivation of BSN research. Such an approach has already shown promising results in monitoring patients after surgery, during rehabilitation, as well as for assessing activities of daily living for the elderly. Further development of BSN will continue to pave the way for implementing population wide, multimodality health records such as the Cardiovascular Health Informatics and Multimodal E-record (CHIME).

The intelligence of the system facilitates the use of physiological monitors as “guardian angels” to provide timely warnings and guidance for a variety of medical conditions or wellness management scenarios. In some situations, a feedback loop can be formed within a BSN that integrates wearable and/or implantable devices [9]. For example, the communication network that forms between a cochlear implant and an external wearable unit that processes speech and sound and transmits control signals to the implant can be considered as a BSN. The wearable unit also supplies energy to the implant, where change of battery is inconvenient. Similar ideas have been adopted for visual implant to restore visual sensations in patients with blindness and retinal degenerations. Continuous real-time control of physiological parameters such as blood glucose and blood pressure is another emerging application of BSN. These systems allow adaptive algorithms to be implemented to avoid hypoglycaemia or hypotension. Proactive sensors such as automatic inflatable protective

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airbag for fall protection have also been developed in BSN research [4].

With the current advances in monitoring devices, several key technologies are essential to the future development of pervasive healthcare systems, they include: Biosensor design and MEMS integration, miniaturized power source and power scavenging, Ultra-low power RF data paths as in Fig.3.

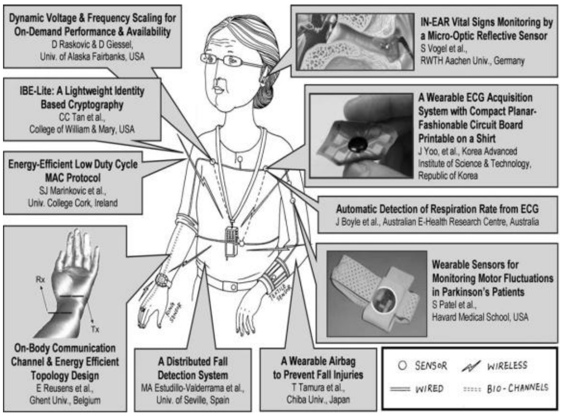

Fig.3. Illustration of the design space on body sensor networks

IV. CONCLUSION

The WBSN is an emerging and promising technology that will change people's healthcare experiences revolutionarily. Data security and privacy in WBSNs and WBSN-related e-healthcare systems is an important area, and there still remain a number of considerable challenges to overcome. The research in this area is still in its infancy now, but we believe it will draw an enormous amount of interest in coming years. We hope this article will inspire novel and practical designs of secure, dependable, and privacy enhanced WBSNs.

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