Available online at www.sciencedirect.com
ScienceDirect
Journal of Electrocardiology 40 (2007) S165 – S168
JOURNAL OF Electrocardiology
www.jecgonline.com

Potential and challenges of body area networks for cardiac monitoring

Bert Gyselinckx, MSEE,* Julien Penders, MSEE, Ruud Vullers, PhD

IMEC-Nl/Holst Centre, Eindhoven, The Netherlands

Received 19 April 2007; accepted 6 June 2007

Abstract This article gives an overview of results of the Human++ research program related to cardiac monitoring (http://www.imec-nl.nl/). This research aims to achieve highly miniaturized and nearly autonomous sensor systems that assist our health and comfort. It combines expertise in wireless ultra–low-power communications, packaging and 3D integration technologies, Micro Electro Mechanical Systems (MEMS) energy scavenging techniques, and low-power design techniques.

Keywords: BAN; Microsystem; Wireless; Autonomous; Integration

Introduction

In this text, we analyze the personal body area network (BAN)[1] that provides medical, lifestyle, assisted living, sports or entertainment functions for the user. This network comprises a series of miniature sensor/actuator nodes, each of which has its own energy supply, consisting of energy storage and scavenging devices. Each node has enough intelligence to carry out its task. Each node is able to communicate with other sensor nodes or with a central node worn on the body.[2] The central node communicates with the outside world using a standard telecommunication infrastructure such as a wireless local area or cellular phone network. Experts may then provide services to the individual wearing the BAN, such as management of chronic disease, medical diagnostics, home monitoring, biometrics, and sport and fitness tracking. Next generation of BAN will include feedback loops for disease management or drug and treatment delivery within so-called closed-loop systems and will provide feedback to the individual about her lifestyle and health status, eventually leading to human-in-the-loop systems.

The successful realization of this vision requires innovative solutions to remove the critical technological obstacles. First, the overall size should be compatible with the required form factor. This requires new integration and packaging technologies. Second, the energy autonomy of current battery-powered devices is limited and must be extended. Further, interaction between sensors and actuators should be enlarged to enable new applications such as multiparameter biometrics or closed loop disease management systems. Next, intelligence should be added to the device at the node level so that each node is capable of storing, processing and transferring data continuously or on an event-triggered basis. Intelligence should also be introduced at the network level to deal with issues such as network management, data integration, and data interpretation. Finally, the energy consumption of all building blocks needs to be drastically reduced to allow energy autonomy.

The Human++ program is looking into all of these generic BAN challenges. In the following sections, we will give an overview of our ambulatory multiparameter monitoring system and then show how advances in micropower generation can in the future provide more autonomy to such systems.

Ambulatory multiparameter monitoring system

We selected ambulatory multiparameter monitoring as a driving application for Human++. The target of such a monitoring system is to acquire process, store, and visualize a number of physiological parameters in an unobtrusive way. In one case, we focused on the simultaneous wireless acquisition of electroencephalogram (EEG)/electrocardiogram (ECG)/electromyogram (EMG) biopotential signals. Traditionally, such signals are either captured in a clinical setting for immediate interpretation or they are recorded in an ambulant setting for post factum analysis via a Holter monitor. With a wireless ambulatory monitoring system, we want to combine the real time features of the clinical system with the benefits of ambulatory monitoring from a Holter monitor. Our setup consists of the following:

- One EEG sensor node that can acquire, process and transmit 1 to 24 EEG signals;

* Corresponding author.
E-mail address: bert.gyselinckx@imec-nl.nl

0022-0736/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.jelectrocard.2007.06.016

- One ECG sensor node that can acquire, process and transmit 1 to 6 ECG signals;
- One EMG sensor node that can acquire, process and transmit 1 to 2 EMG signals; and
- One base station that collects the information from the 3 sensor nodes.

All the sensors have very similar functionality. First, the incoming signals are amplified and filtered. The resulting signals are sampled at 1024 Hz with a 12-bit resolution. If required, the biosignals are then processed locally to extract relevant features, for example, heart rate, energy expenditure, or force. Finally, the digital signals are transmitted over a wireless link operating in the 2.4 GHz Industrial Scientific Medical band. Because the sensors are very similar, they can be realized with the same programmable hardware, as shown in Fig. 1.

The base station acts as a data collector. The collected data are passed on to a PC or PDA through a USB interface. Furthermore, the base station also acts as a master node for the network, which manages the data flow through the network. Body sensor networks are typical star topology networks, for which a time division multiple access scheme is well suited.

A key design criterion for such system is the power of the sensor nodes because this will directly determine the size and the operational lifetime of the system. Analysis of the operation of the sensors shows that they are alternating between 4 different modes of operation:

1. Listen: the sensors receive their parameters from the base station;
2. Processing: the biopotential signals are monitored and processed;
3. Transmit: the sensors send their data to the base station;
4. Sleep: power save mode—most of the electronics are switched off.

The time spent in each of these modes is very much application dependent. In this particular case, it is clear that the idle time is very important and that the system needs to have a very low stand by power consumption.

Each of these modes has its own power consumption. The current consumption in listen and transmit mode is much higher than in processing or sleep mode. This is a direct consequence of the radio which is switched on in these modes and which consumes about 90% of the power when it is active. Bringing all of these data together, we get to the total average power consumption for the sensor: with the current system consisting mainly of off-the-shelf components, a prototype can be designed that consumes less than 1 mW of power if the measurement interval is longer than 1 second. If we assume that we use 2 AA batteries in series with a capacity of 2500 mAh, the battery lifetime becomes approximately 3 months.

This clearly shows that, with today's technology, first realistic demonstrators with a reasonable lifetime can be manufactured. However, a couple of major challenges still have to be solved in order to come to a widespread deployment of BANs.

- Miniaturization: in most of current systems, batteries are the single largest contributor to the sensor node size. AA batteries are good for demonstration, but one would like to work with a coin or planar type of battery. These batteries have roughly 100 times less capacity than the AA cells. To keep the same battery lifetime, the power of the electronics has to be reduced by a factor 100. Furthermore, development of advanced integration technology is required to achieve compact, flat, and flexible sensor nodes for embodiment in textile or clothing accessories. Making body sensor networks invisible and nonintrusive is likely to determine their acceptance as a support for personalized healthcare and independent living.
- Autonomous systems: the system we demonstrated can run for months. However, to come to a truly autonomous system, it should be able to operate over its full lifetime without maintenance. At a given battery capacity, lifetime can be increased by reducing the power of electronics. Alternatively, one can scavenge energy from the environment during the operation of the system. If the average scavenged energy is larger than the average consumed energy, the system can run eternally, with the battery or a supercapacitor acting only as a temporary energy buffer. A combination of these technologies appears as the optimal solution for achieving autonomous body sensor networks.
- Integration of novel sensor and actuator concepts: the quality of the information resulting from a BAN is only as good as what you measure. Today, often only simple

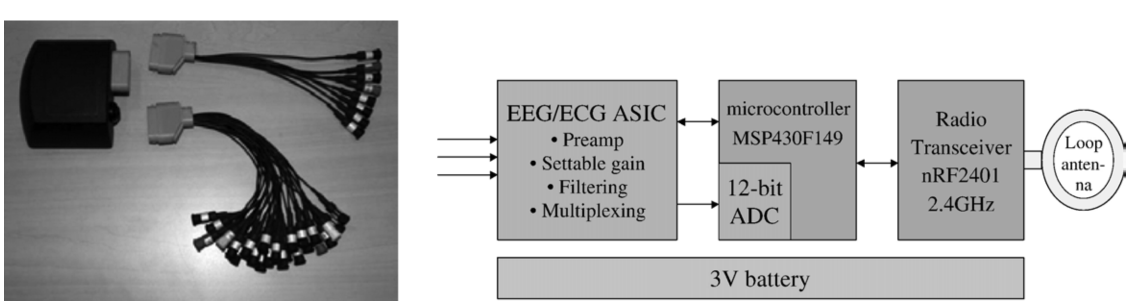

Fig. 1. Close-up of the sensor node. On the left, a picture, and on the right, a functional diagram.