Wireless Micro and Nano Sensors for Physiological and Environmental Monitoring

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Abstract: A practical implementation of a wearable physiological and environmental monitoring system is presented. The technical requirements for wearable electronics and sensors are analyzed. A proposed system includes micro and nano device design, wireless network based on TCP/IP protocol and software application. The result samples from monitoring in ambulatory environment are discussed.

Keywords: wearable computing, medical sensors, wireless network, monitoring, SoC

1. Introduction

Recent advances in miniature devices as well as mobile communication and ubiquitous computing have fostered interest in wearable technology [1, 2, 3]. Radio telemetry of human and animal vital functions, first introduced in the 1950's, has today evolved into microelectronics for remote sensing of patients' motion and location, heart (ECG) and brain (EEG) electrical activity, arterial pulse, blood pressure, and oxygen saturation, intestinal motility and acidity, internal tissue chemistry and gas pressures, as well as orthopedic and dental measurements.

Wearable systems (sometimes incorporated into garments, shoes, costume jewellery, or "bandaids") facilitate noninvasive and unobtrusive monitoring of individuals over extended periods of time. Such systems generally rely on wireless, miniature transmitters with adequate memory capacity to temporarily store data from sensors, than upload/transmit that data to a database server via a secure high reliability receiver link (radio, optical, induction) often through a LAN or Internet connection. New techniques for short range radio communication unencumbered by regulatory restrictions (viz, wideband spread spectrum) enable wireless monitoring of ambulatory subjects both in home care and hospital that is relatively immune to interference.

Wireless sensor networks and biosensors are both subjects of intense current research. Employed together they permit uninterrupted physiological monitoring across broad geography in daily routine as well as emergency medical situations. Significant benefits can be realized in population disease screening, individual diagnosis (especially of unpredictable pathological events with ephemeral symptoms), evaluation of treatment efficacy, and broad delivery of individualized preventative care.

For health care to effectively employ wearable technology, several system criteria all need to be satisfied [1, 2. 3]. Hardware must be sufficiently robust to make measurements reliable during all activities of daily living, including demanding athletics, fitness training and heavy physical work. Data processing and decision-making algorithms need to provide timely communication and trustworthy interpretation, particularly for life-threatening events. Bidirectional communication and interactive control/test is necessary to assess and optimize measurement accuracy to improve user outcomes and care-provider confidence. Finally, electronic technology for widespread deployment must be clearly cost effective compared to more primitive alternatives or to simply ignoring problems.

These criteria create multiple design requirements: compactness and light weight, stability of signal during user motion or location change, tolerance to electrical interference and other environmental disturbances, durability for long life, data storage to allow opportunistic radio communication, and low "just enough" power consumption. Additionally, wearable instruments need to be easy to apply and adjust without assistance, and comfortable enough to wear for extended periods of time. A particular design challenge unique to wearable monitors is the tradeoff between long-term comfort and reliable sensor attachment. Our ultimate objective is to select, refine, design, develop, test and clinically validate those technologies and solutions best suited in this unique environment for reliable, miniature wearable biosensors and behavioral/environmental monitors easily addressable by wireless area networks connected to the Internet.

The overarching goal of this *Wearable Biomonitors* project is to create solutions that will *optimize lifetime wellness of a person*, thereby enhancing quality of life, permit independent living as long as possible, provide real-time support and advice as an electronic "health companion", and (eventually) reduce the overall life cycle cost of health and medical care.

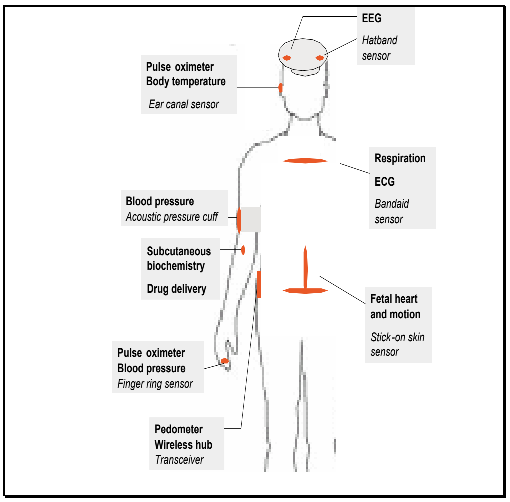

Figure 1. Wearable Body Network with Biosensors and Transceiver.

The proposed wearable biomonitoring system performs the following tasks:

- Reliably measure important indicators of an individual's state of health;
- Process/combine data into time-weighted transmission protocols;
- Provide fault-tolerance, self-test, and self-correction to assure data validity and engender user confidence;
- Develop protocols for intermittent opportunistic transmission of stored data to local receivers networked to the Internet;
- Provide appropriate feedback for care recipients/providers to enable responsive intervention for treatable disorders.

The variety of biomonitors and monitors that are candidates for wearable, long-term use are summarized in Figure 1. Not all of these monitoring devices or ideas have been reduced to practical devices, but those that are not available are either currently being researched or have promise from an engineering and/or medical perspective. Here the focus will be on a most popular ECG sensor and its practical wearable implementation.

2. Proposed Wearable System

Our wireless medical monitors send non-invasive physiologic monitoring signals (e.g. ECG and pulse oximetry) directly from the patient's skin via digital radio to nearby vital signs monitors and/or straight to the hospital network. There are several advantages to our approach. First, providing a means for inexpensively un-cabling the patient will allow the majority of patients, not just a few percent, to be un-tethered from their monitoring equipment. The second advantage of the proposed approach is that no additional equipment will be required; in the long run specialty monitoring equipment can be completely eliminated from the hospital. Third, the system allows much more flexibility for signal collection, transmission, display, printing, and data storage using commercially-available computer equipment. Fourth, where biosensors are designed with digital processing and storage at the sensor site, significantly better physiologic information can be gathered and delivered to caregivers. Finally, since our approach allows patients to be monitored without expensive monitoring equipment, effective monitoring can be implemented in many more instances.

The biosensors and digital radio components replace the patient monitor with a simple network receiver device and thereafter use existing elements of the hospital's IT system to display and record this important patient data, thus eliminating the expensive specialty monitoring equipment required today. Beyond the hospital application additional use include: long-term care (chronic disease) monitoring; in-home and ambulatory monitoring; and specialty screening, monitors, and measurement such as sleep physiology, pediatric apnea, pregnant mom/fetus heart rate monitor, and sports rehab and training.

The multiple benefits result from the developed solution. This includes patients, nurses and other hospital and care providing personnel, and hospital.

- **Patient Benefits:** Minimize slips, trips and falls; Eliminate lead wire entanglement; Provides monitored mobility; Enables easier and earlier ambulation; Increases patient comfort; Reduces risk of hospital acquired infections.

- **Nurse Benefits:** Facilitates ease of patient transport; Improves job satisfaction; Saves nursing time – fewer lead-off events.
- **Hospital Benefits:** Eliminates large cost of specialty monitors; Enhances nurse productivity; Fewer slips, trips and falls reduce adverse events**;** Monitored mobility reduces adverse events**;** Earlier ambulation leads to shorter hospital stays.

3. Technology Development

There are several examples where RF technology is being applied to medical devices. Baxter and others are using RFID tags for hospital equipment management and Precision Dynamics and others have developed and are selling an RFID identity bracelet for hospitals. Medtronic has the “Bravo” swallowed diagnostic capsule and a number of companies are developing implanted devices that can communicate with ex-body receivers. In patient monitoring area, such companies as Philips Medical and others are applying the newly-defined, medical-device-only frequencies to their telemetry monitoring systems. At the intersection of biosensors for medical applications and the new developments in active RFID chip-level technology, however, there is little action. Synergistic designs that fully leverage the latest-available chip-level technology will dramatically change, not incrementally improve, the products to which they are applied. Adigy’s newly developed products fit into this category.

Active RF systems which are used here include, Figure 2: 1) a “chip” element that itself accomplishes RF sending and receiving, analog processing, digital processing, and biological, chemical, or physical sensor elements; 2) remote sender/receiver hardware; and 3) a software application for communications and data collection and display, as shown below.

Active RF “chips” (microelectronic devices) have a long read range for remote read-out, can provide real time status and telemetry, can be integrated with many available sensors, have available memory and may be used as data-loggers, can perform measurements even in the absence of a reader, and are reprogrammable. Their disadvantage is that they require a battery or direct source for power.

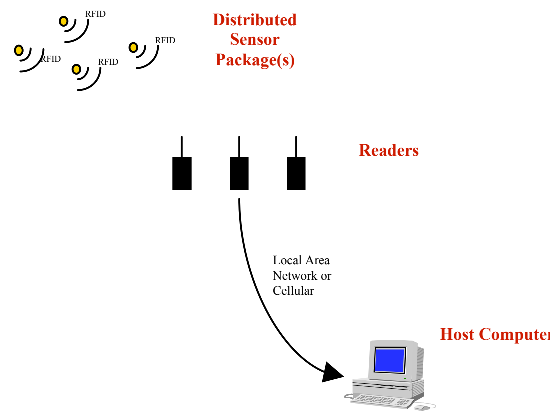

Figure 2. 3-tier architecture for an RF-enabled system

A schematic of the microelectronic device, application specific integrated circuits (ASIC’s), developed for this project is shown below, Figure 3. The device has a sensor, analog circuitry, an analog to digital converter, amplifiers, and references. It has an on-chip clock with 1sec/week precision, and has on-board memory. It has bi-directional RF communication with encryption, anti-collision and error correction. The design has been done in a low power technology resulting in the extremely low standby current of 3 micro Amperes, emission current of 3 mili Amperes, and operating voltage of 3V. The currently used operating frequency is 433.92 MHz and 920 MHz. The transmission mode is programmable with periodic transmission and sensor activated transmission. There is a battery low alarm and easy connection to additional sensors. The transmission range is up to 100 m and life expectation over five years.

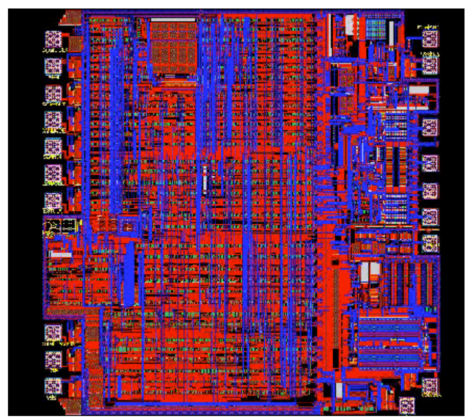

Figure 3. ASIC-based active RF device, a part of wearable system solution.

The developed RF-enabled system requires the readers. The reader is designed to receive, store and analyze data. A memory buffer is available to store captured data, including flash memory, so it will not lose information at power failure. The flash memory is 40 kB. The anti-collision and error detection/correction mechanism have been implemented allowing the reliable communication for up to 16 mln unique codes. Other features include: firmware update through TCP/IP, remote test functions, optional power supply for readers through the RJ-45 connector.

The reader is designed to communicate bi-directionally via TCP/IP interface or cellular wireless band. The reader dimensions are approximately 10x5 cm. The throughput is 50 sensors per second with data rate up to 20 Kbps and sensitivity -103 dBm.

Many system applications also require software database for collection and analysis of system data. The Adigy team has developed these database applications with appropriate user interface. The software establishes active connection with the readers, modifies network configuration, performs network tests, collects data from readers, and performs reader firmware upgrade and configuration.

4. Experimental Results

Specifically, the following innovative solutions are developed: a) low-noise, pre-processing ECG electrode with motion cancellation (Patent Pending); b) self-learning physiologic signal acquisition and transmission (Patent Pending); c) transmission codes for low volume and high reliability; d) new-generation ECG and pulse oximetry sensor; e) pattern recognition technique.

Figures 4 and 5 show the monitoring results in home environment. The variety of places and circumstances are monitored and compared with traditional stationary equipment. The correlation is excellent and there was no faulty monitoring observed.

Figure 4 shows the monitored differences comparing to the established normal patterns for the ECG and oxygen meter monitoring between 9 am and 3 pm from 5 sensors placed on 5 persons representing various health conditions. Figure 6 shows daily summaries from the sensors which represent the differences for the same person health monitoring (ECG).

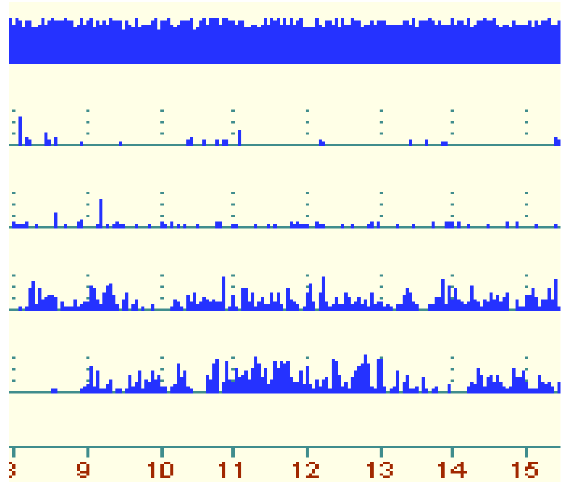

Figure 4. Hourly monitoring example

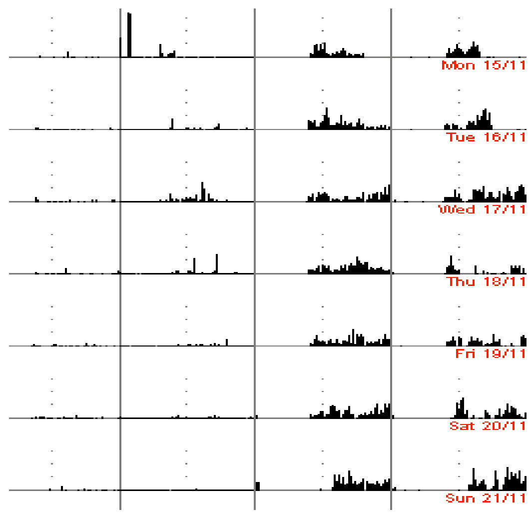

Figure 5. Daily summary monitoring

5. Conclusion

We have defined a set of requirements for a practical wearable and wireless monitoring system. The practical and commercial implementation has been described and the results shown.

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