Wireless Personal Area Networks in Telemedical Environment

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Abstract

We present a new design of wireless personal area network with physiological sensors for medical applications in telemedical environment. Intelligent wireless sensors perform data acquisition and limited processing. Individual sensors monitor specific physiological signals (such as EEG, ECG, GSR, etc.) and communicate with each other and the personal server. Personal server integrates information from different sensors and communicates with the rest of telemedical system as a standard mobile unit. We present our prototype implementation of **W**ireless **I**ntelligent **SE**nsor (WISE) based on a very low power consumption microcontroller and a DSP-based personal server. In future we expect all components of WISE integrated in a single chip for use in a variety of new medical applications and sophisticated human computer interfaces.

Keywords: Wireless networks, Personal Area Networks, Telemedicine, Intelligent sensors, Signal processing.

1 Introduction

With expected growth to 700 million subscriber units by 2002, wireless infrastructure will allow a range of new medical applications that will significantly improve the quality of health care [1][2], and implement the concept of intelligent health monitoring device that Bell calls "guardian angel" [3]. With wider acceptance of physiological monitoring hardware, it will become possible to develop devices based on natural human-computer interfaces.

Increase of processing power, miniaturization, wireless communication, decreased power consumption and Micro Electro Mechanical Systems (MEMS) made possible the development of networks of intelligent wireless sensors for military and space applications [4][5]. Among the most important projects are Smart Dust (Berkeley) [5], Sensor Web (JPL) [4], SCADDS (UCS/ISI), and other projects supported by DARPA's Sensor Information Technology program (SensIT) [6]. It is expected that a one cubic millimeter device will be built during next year.

The same technology may be used for an intelligent monitor that is able to detect or predict emergency health medical situations. The most critical features of a wearable health monitor are long battery life, lightweight, and small dimensions. Continuous Monitoring during normal activity also requires that the device be hidden to protect user's privacy [2].

A wearable device monitoring multiple physiological signals (polysomnograph) usually includes multiple wires connecting sensors and the monitoring device. In order to integrate information from intelligent sensors, all devices must be connected to Personal Area Network (PAN). This system organization is unsuitable for longer and continuous monitoring, particularly during normal activity. For instance, monitoring of athletes and computer assisted rehabilitation commonly involve unwieldy wires to arms and legs that restrain normal activity. We propose a wireless PAN of intelligent sensors as a system architecture of choice.

Most existing experimental medical systems currently use only wireless data acquisition devices [7][8][9] and wireless data presentation devices, such

as palmtop PCs, pagers and cellular phones [10]. Introduction of commercial wireless patient monitors is expected by the end of this year [11]. With recent development of low-power DSP technology it is now possible to implement intelligent personal monitoring devices [4]. With further development of bio-sensor technology personal health monitors will become standard part of personal mobile devices. However, intelligent monitors will have to find optimal trade-off between intelligence and device power consumption/battery life.

We propose the implementation of hierarchical monitoring in a telemedical environment with power efficient signal processing algorithms and adaptive system configuration and operation. This paper presents our prototype implementation of Wireless Intelligent Sensor (WISE) and integration of personal network of WISE sensors supervised by personal DSP server in telemedical environment.

2 Personal Area Networks

A collection of wearable medical sensors could communicate using personal area network or body network [3]. There are some experiments to integrate communication medium into user's clothes, as an "intelligent clothes" [12].

Intelligent monitor connects to a specialized medical service only in the event of a medical emergency or if an episode requires intervention. The user or doctor or both could formulate triggers that cause even more data to be collected, additional sensors to be enabled, or medical personnel to be contacted.

In the case of wireless monitoring systems, privacy and reliability are particularly important issue. This problem is even more important with wireless networks and in telemedical environment. Privacy could be preserved using the data encryption, balancing strength of encryption with power (both in terms of Watts and MIPS). It is important to emphasize that in the case of medical monitoring applications simply wearing the device may disclose to the user's employer/insurer/acquaintances that the user is suffering from a medical condition [2]. Consequently, the wearable monitoring device be as unobtrusive as possible. The larger and bulkier the device, the more likely it is to be observed by those around the user.

Proposed concept of wireless network of WISE sensors would efficiently hide individual sensors and their connection with the personal server. Intelligent sensors would cover only limited range (in the order of ten feet) and therefore require very low power consumption for communication.

3 System Architecture

Recent advances in microcontroller and sensor technology including low power consumption and good performance to cost ratio made possible a whole range of new applications using distributed sensor networks [13]. We believe that the concept of intelligent wireless sensors would be an excellent solution for a number of biomedical and monitoring applications, particularly in telemedical environment. We developed WISE sensors as a basic building block of future systems. Block diagram system architecture WISE in a telemedical environment is presented in Figure 1.

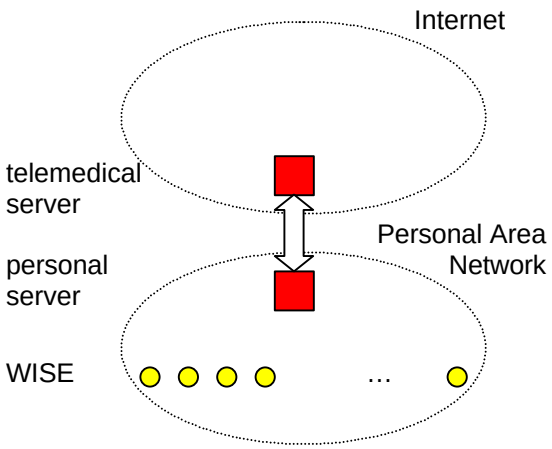

Figure 1: Block diagram of wireless personal area network in a telemedical environment

Proposed architecture features hierarchical signal processing and collaboration in telemedical environment. WISE sensors perform local data acquisition and simple signal processing tasks like filtering. Personal area network is client server network with single server (personal server) and multiple clients (WISE). In our system personal server is DSP board that executes the following tasks:

- PAN control and supervision
- User interface (keyboard input/LCD output), warnings, etc.
- Telemedical server communication using standard cellular link.

- Archive of events and signals; compact flash memory card used as a secondary memory.

As an example, possible application of a health monitor in telemedical environment is presented in Figure 2. Multiple physiological signals (such as ECG, EEG, GSR, limb movement) are monitored using intelligent sensors and their state integrated using a low-power DSP based personal server [4][14]. Possible applications of monitoring in telemedical environment are discussed in [1][15][16].

4 Wireless Intelligent SEnsor WISE

Prototype version of the wireless intelligent sensor WISE is given in Figure 3. It is based on the low power flash microcontroller Texas Instruments MSP430F112. The controller features 16-bit RISC architecture, ultra-low power consumption (400 μA in active mode, and as low as 0.8 μA in standby mode), 4KB+256B flash memory, 256B RAM, and a small 20-pin plastic small-outline wide body package.

The wireless interface is implemented using a high-performance 916MHz RF transceiver from Linx Technologies. It is a bi-directional interface that supports up to 33.6Kbps with a range of few hundred feet and adjustable output power/range. We plan to use minimum output power to cover PAN range only. In the prototype version we use standard antenna (as can be seen in Figure 3); PCB antenna is planned for the next version of WISE.

Our current prototype uses an off-the-shelf two-channel bio-amplifier TETMD A110-1/2 from Teledyne for signal conditioning. It is a battery powered, compact, ultra-low power, analog signal processing amplifier and filter. The signals from the bio-amplifier are converted to digital signals using 8-channel, 12-bit analog to digital converter. Microcontroller communicates with the ADC using serial interface to decrease board space and power consumption. Additional analog channels are used for battery monitoring and other analog inputs. Therefore, WISE is capable of reporting the battery status and generating low-battery warnings to the higher system levels.

Current technology facilitates the hierarchical architecture with capabilities shown in Table 1. It can be seen that the proposed system organization allows flexible design space for optimum trade-off between processing power, battery life and storage capacity, sufficient for most medical applications.

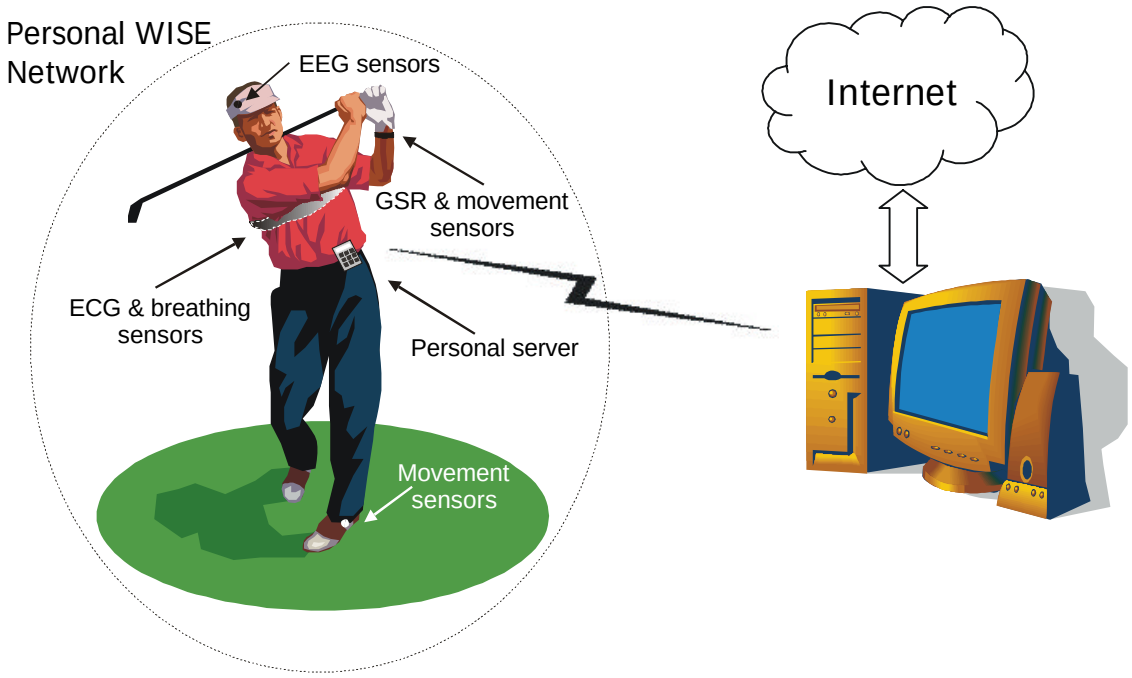

Figure 2: Block diagram of Wireless Personal Area Network

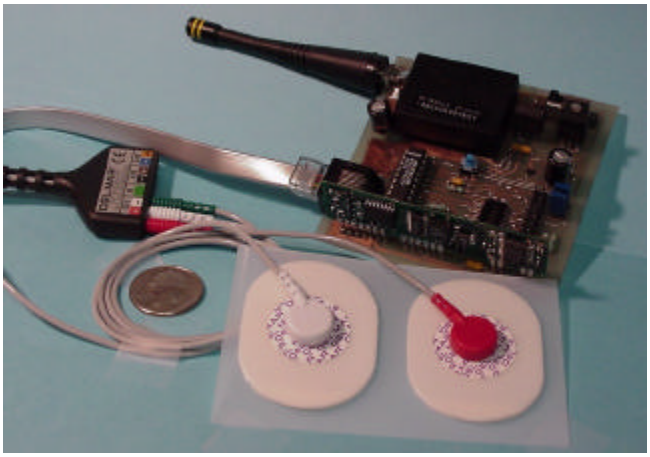

Figure 3: Wireless Intelligent SEnsor (WISE) prototype

Level of Hierarchy	Processing Power	Primary memory (RAM)	Secondary memory	Power consumption	Communication speed
Internet	Unlimited	Unlimited	Unlimited	…	…
Telemedical server	500 MIPS	100 MB	50 GB	100-200 W	100 Mbps
Personal server	100 MIPS	100 KB	100 MB	100-500 mW	56 Kbps
Personal WISE network	1 MIPS	1 KB	-	10-50 mW	30 Kbps (shared)

Table 1: Basic features of hierarchically organized WISE network in a telemedical environment

5 Applications

Traditionally, medical monitors were limited to data acquisition, typically implemented as Holters [17]. Holters are used for 24-48 hour monitoring of ECG, EEG or polysomnography (EEG, EOG, EMG, EKG, heart rate, breathing, body position, snoring, etc.) and recording on cassette tape or flash memory. Recorded signals are then analyzed off-line using dedicated diagnostic systems.

Increased intelligence and low power consumption of new generations of microcontrollers/DSPs make possible a whole range of intelligent monitor applications. We believe that the wireless personal area network organization and sensor miniaturization will further enable new applications in this field.

Possible applications of wireless personal area networks in telemedical environment include:

- Intelligent portable health monitors, like ECG and ischemia [18][19] or epilepsy monitoring, that can decrease the number of hospitalizations and nursing visits [20].
- Intelligent control of medication delivery using wireless sensing, dosing and compliance monitoring [11].
- Aids for disabled individuals .
- Computer assisted rehabilitation.
- Battlefield soldier monitoring.

A patient wears and/or uses a sensor with a wireless communications link which enables it to receive commands and transmit physiological and other data (measured value, time of the measurement) to a remote database (maybe a distributed database?). The patient also wears and/or uses a medication dosing device/recorder with a wireless link that transmits the

dosing history (dose administered and time) to the remote database.

A remote intelligent control system determines when a new measurement is needed and then uses the wireless link to signal the sensor which either automatically makes the measurement or requests that the patient does so. The measured variables are transmitted to the database. An algorithm is used to compute a new desired dosage and time for its administration. The new dosage schedule is received by the dosing device/recorder and is either automatically administered, or the patient uses the dosing device/recorder to administer the dosage. If the communication link is not available to deliver the new dosage schedule so that the schedule can be obeyed, the system would recalculate a new dosage schedule and try to transmit again.

Supervisory medical personnel access the database to monitor the patient measurements and dosing. A supervisory algorithm also monitors operation of the system (including communications link viability) and alerts medical personnel as needed.

Several new rehabilitation therapies would make use of devices used by the patient in their home environment during routine activity. Monitoring of compliance of the patient in using the device and assessing therapy could be accomplished without hindering the patient if wireless communication technologies were used. Supervisory medical personnel access the database to monitor the patient measurements and dosing. A supervisory algorithm also monitors operation of the system (including communications link viability) and alerts medical personnel as needed.

6 Conclusion

Present technological advances make possible development of intelligent wireless sensors that could be used for medical applications, such as heart rate monitors (POLAR, Finland [21]) or gastrointestinal tract inspection camera (Given Imaging, Israel [22]) using small camera and wireless link. We propose a concept of personal area network of wireless intelligent sensors and present our development testbed using WISE prototype in telemedical environment.

Main research issues include dynamic resource allocation and bandwidth utilization that require novel solutions to improve application performance and reduce power consumption. We plan to use our system coupled with cellular phone link and global positioning system (GPS) devices as a development platform for telemedical applications. In addition, the same technology will be used to improve the quality of user interface by sensing user state as a part of "affective computing" [23][24] or perceptual data presentation [25]. This function can be implemented using analysis of user's breathing, heart beat rate, galvanic skin resistance (GSR) and other physiological signals.

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