Patient Monitoring Using Personal Area Networks of Wireless Intelligent Sensors

Emil Jovanov, Dejan Raskovic, John Price,
John Chapman, Anthony Moore, Abhishek Krishnamurthy

Electrical and Computer Engineering Department, University of Alabama in Huntsville
301 Sparkman Drive, Huntsville, AL 35899

jovanov@ece.uah.edu

ABSTRACT

A wearable device for 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 a Personal Area Network (PAN). This system organization is unsuitable for longer and continuous monitoring, particularly during the 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, and present a new design of wireless personal area network with physiological sensors for medical applications. 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. Existing growth of wireless infrastructure will allow a range of new telemedical applications that will significantly improve the quality of health care.

Keywords: *personal area network, wireless, intelligent sensors, patient monitoring, telemedicine.*

1. INTRODUCTION

Rapid growth of wireless infrastructure in following years will allow a range of new medical applications that will significantly improve the quality of health care [1][2]. Wider acceptance of physiological monitoring hardware will allow development of devices based on natural human-computer interfaces. Micro Electro Mechanical Systems (MEMS) made possible the development of networks of intelligent wireless sensors for military and space applications [3][4] through the increase of processing power, miniaturization, wireless communication, and decreased power consumption. Defense Advanced Research Projects Agency (DARPA) and Army Research Laboratory (ARL), with their key partners – UCLA Electrical Engineering Department and Rockwell Science Center, are developing Wireless Integrated Network Sensors (WINS) [5]. Department of Commerce, through National Institute for Standards, sponsors Smart Spaces [6]. This is NIST's approach to pervasive computing that is impossible without wireless sensors. DOE, and its Office of Industrial Technology, sponsor Oak Ridge National Laboratory to work on the project named "Intelligent Wireless Sensors for Industrial

Manufacturing”[7]. Among the most important projects are Smart Dust (Berkeley) [4], Sensor Web (JPL) [3], SCADDS (UCS/ISI), and other projects supported by DARPA’s Sensor Information Technology program (SensIT) [8].

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[2]. There are many companies selling patient monitoring systems, like *Agilent Technologies* [9], *Protocol Systems* [10], etc. Their systems often include wireless connection between the portable monitor and the central server, processing of transferred data, issuing of warnings, archiving, etc. These and other commercial and experimental medical systems currently use only wireless data acquisition devices [11][12][13] and wireless data presentation devices, such as palmtop PCs, pagers and cellular phones [14]. A wearable device monitoring multiple physiological signals (polysomnograph) usually includes multiple wires connecting sensors and the monitoring device.

Our goal was to go one step further and to bring in the wireless technology to the whole signal path, including the wireless connection to the sensors. Moreover, we are introducing intelligent sensors that will take part both in signal processing organized in hierarchical network, and in transmission of data. This way we are able to provide hassle-free environment for patients and other users, without excessive wires that limit movement and attract undesired attention during continuous monitoring. The whole system is integrated into hierarchically organized wireless Personal Area Network (PAN). This type of organization is inevitable for promotion of implantable sensors, which are finding their place in the treatment of diabetics and other similar patients [15][16].

Recent development of low-power DSP technology allows implementation of intelligent personal monitoring devices [3]. With further development of bio-sensor technology personal health monitors will become standard part of personal mobile devices. We propose the implementation of hierarchical monitoring in a telemedical environment with power efficient signal processing algorithms and adaptive system configuration and operation. Limited capabilities of different components of our system dictate hierarchical organization. Proposed system organization allows flexible design space for optimum trade-off between processing power, device power consumption and battery life, and storage capacity, sufficient for most medical applications[17].

2. PERSONAL AREA NETWORKS

A collection of wearable medical sensors could communicate using personal area network or body network [1], which can be even integrated into user’s clothes [18]. 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, security and reliability are particularly important issue [2]. Security can be preserved using the data encryption, balancing strength of encryption with power (both in terms of Watts and MIPS), etc. 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 has to be as unobtrusive as possible, to preserve patient’s privacy.

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.

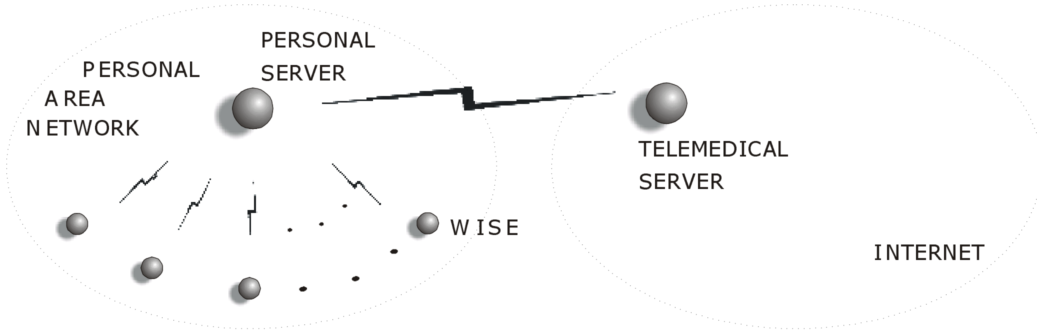

***Figure 1**: Block diagram of wireless personal area network in a telemedical environment*

3. TELEMEDICAL SYSTEM

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 [19]. 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 of the personal area network system architecture in a telemedical environment is presented in Figure 1.

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 a 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.

One possible application of a health monitor in telemedical environment is presented in [17]. Multiple physiological signals (such as ECG, EEG, GSR, and limb movement) are monitored using intelligent sensors and their state integrated using a low-power DSP based personal server [3][20]. Other applications of monitoring in telemedical environment are discussed in [1][21][22].

4. WIRELESS INTELLIGENT SENSOR WISE

The core of our wireless intelligent sensor (WISE) consists of Texas Instruments' microcontroller MPS430F149 that is responsible for A/D data acquisition and processing, analog signal conditioning, the LINX wireless transceiver module TC-916-SC operating at 916 MHz. The controller features 16-bit RISC architecture, ultra-low power consumption (400 μA in active mode, less than 1 μA in standby mode), 60KB flash memory, 2KB RAM, and a small 64-pin Quad Flat Pack (QFP) package. Our current prototype uses either custom-developed biomedical amplifiers on board or 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 internal 8-channel, 12-bit analog to digital converter on microcontroller. Additional analog channels are used to monitor battery voltage, wireless link quality, and other external analog inputs. Therefore, WISE is capable of reporting the battery status and generating low-battery warnings to the higher system levels.

Present prototype version of WISE is given in Figure 2. We are currently developing a new version (v1.1) that will include PCB antenna and will exclude some of the functionality of the old board to decrease the size. Existing boards include both serial and wireless connection to the rest of the network to make extensive testing easier. Ultimately, we are expecting to reduce our intelligent sensor to the one-chip device.

5. APPLICATIONS

Traditionally, medical monitors were limited to data acquisition, typically implemented as Holters [23]. 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. Further need for privacy protection and acceptance of implantable sensors and devices requires the introduction of entirely wireless personal network.

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

- Intelligent portable health monitors, like ECG and ischemia [24][25] or epilepsy monitoring, which can decrease the number of hospitalizations and nursing visits [26].
- Intelligent control of medication delivery using wireless sensing, dosing and compliance monitoring [27].
- Breathing monitor, for polysomnography, sleeping disorders, stress monitoring, biofeedback techniques, and circadian rhythm analysis [28].
- Activity monitoring using accelerometer MEMS devices [29]
- Aids for disabled individuals.
- Computer assisted rehabilitation.
- Battlefield soldier monitoring.

Figure 2: *Wireless Intelligent Sensor (WISE) prototype*

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 were 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.

6. CONCLUSION

Present technological advances make possible development of intelligent wireless sensors that could be used for medical applications, such as heart rate monitors or gastrointestinal tract inspection camera (Given Imaging, Israel [30]) using small camera and wireless link. We propose concept of hierarchically organized network of wireless sensors. Our current prototype includes sensors capable of collecting ECG, breathing, and movement signals. We are preparing to include EEG and GSR into the next generation of WISE sensors [31].

Main research issues include dynamic resource allocation, bandwidth utilization, and secure protocol. Novel solutions are required to improve application performance and to reduce power consumption. We plan to use our system coupled with cellular phone link or wireless PDA and global positioning system (GPS) devices as a development platform for telemedical applications.

7. REFERENCES

[1] E. Jovanov, D. Starcevic, A. Samardzic, A. Marsh, Z. Obrenovic, “EEG analysis in a telemedical virtual world,” *Future Generation Computer Systems 15*, pp. 255-263, 1999.

[2] T. Martin, E. Jovanov, and D. Raskovic, “Issues in Wearable Computing for Medical Monitoring Applications: A Case Study of a Wearable ECG Monitoring Device,” *International Symposium on Wearable Computers ISWC 2000*, Atlanta, October 2000.

[3] K.A. Delin and S.P. Jackson, “Sensor Web for In Situ Exploration of Gaseous Biosignatures,” *Proceedings of the 2000 IEEE Aerospace Conf.*, Big Sky, Montana, March, 1999.

[4] V. Hsu, J.M. Kahn, and K. S. J. Pister, "Wireless Communications for Smart Dust", *Electronics Research Laboratory Technical Memorandum Number M98/2*, February, 1998.

[5] G. Asada, et al, “Wireless Integrated Network Sensors: Low Power Systems on a Chip,” in *Proceedings of the 1998 European Solid State Circuits Conference* (Invited Paper).

[6] `http://www.nist.gov/Smartspace/SmartSpaces`

[7] `http://www.janet.ucla.edu/WINS/`

[8] Sensor Information Technology `http://www.darpa.mil/ito/research/sensit/index.html`

[9] Agilent, `http://www.agilent.com`

[10] Protocol Systems, `http://www.protocol.com`

[11] J. Bai, et al., “A Portable ECG and Blood Pressure Telemonitoring System”, *IEEE Engineering in Medicine and Biology*, July/August 1999, pp. 63-70.

[12] Cleveland Medical Devices, http://www.clevemed.com
[13] *Wearable Polysomnograph*, Advanced Medical Electronics Corporation, http://www.ame-corp.com/Wearable_Polysomnograph.htm
[14] S. Barro, et al., "Intelligent Telemonitoring of Critical Care Patients", *IEEE Engineering in Medicine and Biology*, July/August 1999, pp. 80-88.
[15] W. Morse, "Medical electronics," *IEEE Spectrum*, vol: 34, issue: 1, Jan. 1997, pp. 99 –102
[16] T. Akin and K. Najafi, "A Telemetrically Powered and Controlled Implantable Neural Recording Circuit with CMOS Interface Circuitry," *in Proceedings of IEEE 7th Mediterranean Electrotechnical Conf.*, Antalya, Turkey, April 1994, pp. 545-548
[17] E. Jovanov, J. Price, D. Raskovic, K. Kavi, T. Martin, and R. Adhami, "Wireless Personal Area Networks in Telemedical Environment," in *Proc. of 2000 IEEE EMBS Intern. Conf. on Inform. Technol. Appl. in Biomedicine*, Key Bridge Marriott Hotel, Arlington, Virginia, Nov. 8-10
[18] M. Gorlick, "Electric Suspenders: A Fabric Power Bus and Data Network for Wearable Digital Devices," Proc. of the Third Intern. Symp. on Wearable Computers, San Francisco, CA, October, 1999, pp. 114-121.
[19] J. Agre, and L. Clare, "An Integrated Architecture for Cooperative Sensing Networks," *IEEE Computer,* May 2000, pp. 106-108.
[20] TMS320C54X DSP: CPU and Peripherals, Reference Set, Volume 1 (SPRU131C), Texas Instruments, 1996, http://www.ti.com
[21] D. Starcevic, E. Jovanov, V. Radivojevic, Z. Obrenovic, and A. Samardzic, "Virtual medical devices for telemedical applications", in P. Spasic, I. Milosavljevic, M. Jancic-Zguricas, Eds., *Telemedicine*, Academy of Medical Sciences of Serbian Medical Association, Belgrade, Yugoslavia, pp. 218-244, 2000.
[22] E. Jovanov, D. Starcevic, A. Marsh, Z. Obrenovic, V. Radivojevic, and A. Samardzic, "Multi Modal Presentation in Virtual Telemedical Environments," *High Performance Computing Conference HPCN'99*, Amsterdam, April 1999.
[23] V. Subramanian, "Clinical and research applications of ambulatory Holter ST-segment and heart rate monitoring", *The American Journal of Cardiology*, Vol. 58, No. 4, 1986, pages 11B-20B.
[24] E. Jovanov, P. Gelabert, B. Wheelock, R. Adhami, and P. Smith, "Real Time Portable Heart Monitoring Using Low Power DSP," *International Conference on Signal Processing Applications and Technology ICSPAT 2000*, October 2000, Dallas, Texas.
[25] B. Wheelock, "Autonomous real-time detection of silent ischemia", M.S. thesis, University of Alabama in Huntsville, Huntsville, 1999.
[26] P. Heidenreich,C. Ruggerio, and B. Massie,"Effect of a Home Monitoring System on Hospitalization and Resource Use for Patients with Heart Failure," *American Heart Journal*, Vol. 138, No. 4, 1999, pp. 633-640.
[27] G. Freiherr, "Wireless Technologies Find Niche in Patient Care," *Medical Device & Diagnostic Industry*, August 1998.
[28] E. Jovanov, D. Raskovic, and R. Hormigo, "Thermistor-based Breathing Sensor for Circadian Rhythm Evaluation," *in Proc. of 38th Annual Rocky Mountain Bioengineering Symposium, RMBS 2001*, Copper Mountain Conference Center, CO, Apr. 20-22, 2001.
[29] Analog Devices, http://www.analog.com/industry/iMEMS/index.html
[30] S.K. Moore, "A candid camera for the gut," *IEEE Spectrum*, July 2000, pp. 75.
[31] E. Jovanov, D. Starcevic, V. Radivojevic, A. Samardzic, and V. Simeunovic, "Perceptualization of biomedical data," *IEEE Eng. in Med. and Biology Mag.*, vol 18, no. 1, pp. 50-55, 1999.