A WIRELESS ECG MODULE FOR PATIENT MONITORING NETWORK

BY

***CRISTIAN ROTARIU, ***HARITON COSTIN,
*DRAGOȘ AROTĂRIȚEI and *BOGDAN DIONISIE

Abstract. The current common goal in medical information technology today is the design and implementation of telemedicine solutions, which provide to patients services that enhance their quality of life. Recent technological advances in sensors, low-power integrated circuits, and wireless communications have enabled the design of low-cost, miniature, and intelligent physiological sensor modules. These modules are capable of measuring, processing, communicating one or more physiological parameters, and can be integrated into a wireless personal area network. In this paper we present the realization of a wireless ECG module, as a part of a personal area network for patient monitoring, capable to measure and transmit two ECG leads. The use of wireless ECG is suitable for continuous long-time cardiac activity monitoring as a part of a diagnostic procedure, can achieve medical assistance of a chronic condition, or can be supervised during recovery from an acute event or surgical procedure. For instance, the computer-assisted rehabilitation involves unwieldy wires between sensors and monitoring device that are not very comfortable for normal activity. We propose a wireless module, based on low power microcontrollers and RF transceivers that perform the measurements and transmit the data to a Personal server. Personal server, in form of a Personal Digital Assistant (PDA) that running a heart monitor application, receives the information from wireless ECG module, activates the alarms when the measured parameters are above the limits, and communicates periodically a the central server (part of the telemedicine system) by using WiFi or GSM/GPRS connection. The heart monitor reacts to potential heart risks and records physiological information into a local database.

Key words: patient monitoring, wireless ECG, personal area network, intelligent sensors, telemedicine.

2000 Mathematics Subject Classification: 94C99, 04C12.

1. Introduction

The Telemedicine (also referred to as “telehealth” or “e-health”) allows health care professionals to use "connected" medical devices in the evaluation,
diagnosis and treatment of patients in different locations. These devices are enhanced through the use of communications technology, network computing, video-conferencing systems, a.s.o. Specialized application software, data storage devices, database management software, and medical devices capable of electronic data collection, storage and transmission are all parts components of the telemedicine infrastructure.

The task of patient monitoring may be achieved by telemedicine (enabling medical information-exchange as the support to distant-decision-making) and telemonitoring (enabling simultaneous distant-monitoring of a patient and his vital functions), both having many advantages over traditional practice.

A telemonitoring network (Fig. 1) devoted to medical teleservices, will enable the implementation of complex medical teleservices for a broader range of patients and medical professionals, mainly for family doctors and those people living in rural or isolated regions [1].

![Telemonitoring network – general structure.](image)

Doctors can receive information that has a longer time span than a patient's normal stay in a hospital and this information has great long-term effects on home health care, including reduced expenses for health care. Physicians also have more accessibility to experts, allowing the physician to obtain information on diseases and provide the best health care available. Moreover, patients can thus save time, money and comfort.

Wearable heart monitoring modules allows to continuous monitor changes in ECG signals and provides feedback to help maintain an optimal heart status. If integrated into a telemonitoring network, these modules can even alert medical personnel when ECG parameters are outside the limits. Long-term heart monitoring modules can measure the variations in ECG signals, useful as a recovery indicator in cardiac patients after myocardial infarction or help monitor effects of drug therapy.

During the last few years there has been a significant increase in the number of various wearable hearth monitoring modules, ranging from simple pulse monitors, and heart activity monitors, to portable Holter monitors.

Although Holter monitors are used only to collect data, it still remains the most used device. Data processing and analysis are performed offline, making the device impractical for continual monitoring and early detection of
medical disorders. Devices with multiple sensors for rehabilitation had unwieldy wires between the sensors and the monitoring device which may limit the patient's activity and their comfort.

As for patient monitoring, we propose the development of a flexible wireless ECG module for personal area network capable of measuring, preprocessing and transmission ECG information to a Personal server.

2. Materials and Methods

Our wireless ECG module is realized by using a custom developed ECG amplifier and a low power microcontroller board (eZ430-RF2500 Board from Texas Instruments). The ECG module is wirelessly connected to a personal server (PDA - Fujitsu Siemens LOOX T830) that receives the information from ECG Module.

The eZ430-RF2500 is a complete MSP430[2] wireless development tool providing all the hardware and software for the MSP430F2274 microcontroller and CC2500 2.4GHz wireless transceiver [3].

Fig. 2 shows a simplified block diagram of a wireless ECG module. The ECG module is powered by two AA batteries and has as the features an ultra low power Texas Instruments MSP430 microcontroller, a Chipcon CC2500 radio interface in the 2.4 GHz band, and an integrated onboard antenna with 50m range indoors/125m range outdoors.

Fig. 2 – Wireless ECG module – block diagram.

The MSP430F2274 microcontroller is based around a 16-bit RISC core integrated with RAM and flash memories, analog and digital peripherals, and a flexible clock subsystem. It supports several low-power operating modes and consumes as low as 1μA in a standby mode.

The 2-lead ECG amplifier (Fig. 3) [5] is custom made device. It has for each channel a gain of 500, is DC coupled and has a band limited to 100 Hz.
The high common mode rejection (>90dB), high input impedance (>10 MΩ), the fully floating patient inputs are other features of the ECG amplifier.

Fig. 3 – ECG amplifier – schematic.

In order to have a good signal to noise ratio, differential amplifiers are used. Since the output is proportional to the difference between the two voltages, this circuit has a fairly good common mode rejection. Unfortunately, the differential amplifier’s performance is limited due to low input impedance. This problem has been avoided by incorporating a dual Instrumentation amplifier in place of a differential amplifier.

The instrumentation amplifier used (INA2321), is a microPower,
single-supply CMOS dual device from Texas Instruments. The INA2321 provides low-cost, low-noise amplification of differential signals and boasts a micropower current consumption of just 40µA/channel and a high CMRR > 90 dB, and it is suitable to use in physiological amplifiers, in particular ECG’s.

The impedance between pins 1, 12, and 13 (or 7, 9 and 10), determines the gain of the INA2321. With an internally set gain of 5 per amplifier, the INA2321 can be programmed for gains greater than 5 with gain error guaranteed to be less than 0.1%. Errors from external resistors will add directly to the guaranteed error, and may become dominant error sources. A gain of 10 was chosen for this stage of the circuit.

The INA2321 inputs are protected by ESD diodes that will conduct if the input voltages exceed the power supplies by more than 500 mV. Momentary voltages greater than 500 mV beyond the power supply can be tolerated if the current through the input pins is limited to 10 mA. This is easily accomplished with input resistors (100 K).

The second stage is a low pass filter with a gain of 10 and it is used to eliminate the high frequency noise above 100 Hz.

The frequency response of the ECG amplifier (one lead) is represented in the Fig. 4.

![Frequency Response Graph](image)

Fig. 4 – The frequency response of the ECG amplifier – ORCAD simulation.

The operational amplifier used in the right-leg common-mode feedback circuit is the OPA2366, a dual amplifier. The circuit sends an inverted version of the common-mode interference to the patient’s right leg, with the aim of cancelling the interference and protecting the signals from the leads by shielding the signal cable.
The ECG amplifier is powered by two AAA 1.5V batteries through the Voltage Regulator. The regulator is built around TPS60204 circuit and the schematic is represented in the Fig. 5.

![Schematic Diagram](image)

**Fig. 5 – Voltage regulator – schematic.**

The TPS60204 is a step-up, regulated charge pumps that generates a 3.3V±4% output voltage from a 1.8 V to 3.6 V input voltage. The device is typically powered by two Alkaline, NiCd, or NiMH battery cells and operates down to a minimum supply voltage of 1.6 V. Minimum continuous supply current is 100 mA from a 2 V input. Only four external capacitors are needed to build a complete low-ripple dc/dc converter. The push-pull operating mode of two single-ended charge pumps assures the low output voltage ripple, as current is continuously transferred to the output.

The TPS60204 circuit is programmed by using the EN pin. Setting the EN pin to low disables the device, shuts down all internal circuits, and disconnects the output from the input. Setting the EN pin to high enables the device and programs it to run.

In the Fig. 6, it is represented the block diagram of the personal server. The personal heart monitor is responsible for a number of tasks, providing a transparent interface to the wireless medical sensors, an interface to the patient, and an interface to the central server.

The USB interface (Fig. 7) is realized by using a serial to USB transceiver (FT232BL) from FTDI [4] and enables eZ430-RF2500 to remotely send and receive data through USB connection using the MSP430 Application
UART. All data bytes transmitted are handled by the FT232BL chip. It also contains a voltage regulator (TPS77301) to provide 3.3 V to the eZ430-RF2500.

![UART block diagram](image)

Fig. 6 – Personal server – block diagram.

![USB transceiver and voltage regulator schematic](image)

Fig. 7 – Personal server – USB transceiver and voltage regulator schematic.

3. Results

On the personal server module, visualization and analysis software are implemented. This software has the following facilities: GUI (Graphic User
wave (Interface) for ECG waveforms; displays the patient’s parameters received from the sensors; sends the commands and medical decisions to the patient.

PDA devices typically offer a larger screen area, which is an important feature for quicker reading. Their large screens offer higher resolution than other devices (such as Palm-based).

Usually PDA devices have faster processors that, in combination with the larger screen, cause higher power consumption. Furthermore, the availability of Windows Mobile as operating system allows an easy redesign of an ECG viewer already available for Win32 PC platform.

For example, the ECG amplifier samples the two leads each at a frequency of 250 Hz. The raw data is filtered with a low pass filter to eliminate high frequency and movement artifacts.

![Image](image)

**Fig. 8 – PQRST waves and location important points.**

The process of recognition of the ECG waves (Fig. 8) constitutes a significant part of the most ECG analysis systems. In applications were rhythm detection is performed, only the location of the R wave is required. In other applications it is necessary to find and recognize the features of the ECG signal, such as the P and T waves, or the ST segment, for the automated classification and diagnosis. Many algorithms for the extraction of the ECG features based on the digital filters have been reported in the literature [6], especially algorithms for the QRS complex recognition. The main effort in the ECG features extraction is for finding the exact location of the waves. After that, the determination of the wave’s amplitudes and shapes is much simpler. The strategy for finding the exact location of the waves is to first filter the ECG signal and then recognize the QRS complex, which has a sharper slope. T wave is recognized next and finally is recognized the P wave, which is usually the smallest wave in amplitude. The baseline and the ST segment features are also computed.

In order to test the morphological analysis of the ECG signal, it was applied on the synthesized ECG, and on the synthesized ECG corrupted with 50Hz power line noise and electromyographic noise. A detection error rate below 10% was achieved. The same value was obtained by using MIT-BIH Arrhythmia Database records.
The results obtained by applying the method described in [6] on the DII lead is presented in Fig. 9.

![Image](image.jpg)

**Fig. 9 – Personal server – software.**

### 4. Conclusions

The wireless personal area network focuses on the implementation and exploitation of a modular and ambulatory telemedicine platform, which is using easily wearable vital signs monitoring devices, causing minimal discomfort to patients, and which transfer the information and on-line critical vital parameters to central server and/or medical experts/consultants, regardless of their location, while getting feedback to increase their comfort in case of alarm. The interactive continuous monitoring promises cost effective health services, more active involvement of patients in their own care, and a new sense of realism in making a diagnosis.

The proposed system could also be used as a warning system for monitoring during normal activity or physical exercise. In addition to monitoring of physiological signals, we plan to use the proposed environment for development of a high performance user interface. New user inputs, including correlates of the user's physiological and emotional states could significantly improve human-computer interface and interaction.

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* “Gr. T Popa” University of Medicine and Pharmacy, Iași

**Institute for Theoretical Computer Science
Romanian Academy, Iași

e-mail: crotariu74@yahoo.com
REFERENCES

5. * Heart rate and EKG monitor Using the MSP430FG439, application note at http://www.ti.com/.

UN MODUL ECG FĂRĂ FIR PENTRU REȚEA DE MONITORIZARE A PACIENȚILOR

(Rezumat)

Recentele descoperiri tehnologice în domeniul circuitelor integrate cu consum redus de putere și a comunicațiilor fără fir permit proiectarea senzorilor biomedicali inteligenți. Acești senzori sunt capabili să măsoare, prelucreze și să transmită unul sau mai mulți parametri fiziologici și pot fi integrate cu ușurință într-o rețea personală de senzori. În această lucrare se prezintă realizarea unui modul ECG fără fir care achiziționează, prelucrează și transmite două canale ECG și ritmul cardiac către un server de pacient. Pe serverul de pacient, reprezentat de un PDA, rulează o aplicație de monitorizare a pacientului care activează alarmele când parametrii monitorizați depășesc limitele și comunică periodic cu serverul central, situat la centrul de telemedicină, utilizând conexiunea WiFi sau GSM.