Telemetry System for Transmission of Electrocardiographic Signals Using GSM

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Abstract

Medical telemetry systems, also known as telemedicine, are evolving rapidly as wireless communication technology advances, evidenced by the commercial products and research prototypes for remote health monitoring that have appeared in recent years. Wireless systems let patients move freely in their home and work environments while being monitored remotely by healthcare professionals. In this context, we have developed a system that monitors mobile subjects' electrocardiogram (ECG). It carries out following tasks: a) capturing the ECG signals by electrodes placed on the skin; b) conditioning the signals by amplifying, filtering and digitizing; c) real-time transmission of the digital signal over GPRS to a central database; d) downloading the sent data from the database and displaying it on the physicians online personal computer/personal digital assistant.

Keywords: ECG, filter, GPRS, database, digital signal processor

Introduction

Innovation in the fields of wireless communication and vital parameter sensors enables the development of revolutionary monitoring systems, which strikingly improve the lifestyle of patients, offering them security even outside the hospital. Focusing on ECG sensors, it is important to see that the new ECG monitoring systems outperform traditional holters. The use of a holter consists in placing electrodes (leads) on the patients' chests; these leads are attached to the holter. After the patient is sent home and goes back to normal life, a tape records a continuous ECG for 24 or 48 hours. One or two days later, the holter is removed and the tape is analyzed. The physician will see each of the patients' heartbeats and if abnormal beats or heart arrhythmias occur during that period, they are identified. Although this solution presents the advantage that patients can continue living a normal life in their houses, it also presents a serious drawback: if the patient suffers from a serious rhythm irregularity, the holter only records it, i.e. it does not react to it. [1] The consequence of this arrangement is that real-time data is not immediately accessible for diagnosis and help. For some people, the lack of timely response to a cardiac event will mean death if emergency response teams are not alerted.

In order to overcome the above mentioned restriction, our system not only captures the ECG signals from mobile patient but also transmits them in real-time using the existing GSM/GPRS network to central database. This database is accessed by the physicians who continuously monitor the signals and determine the electrocadiographic abnormalities leading to early detection of cardiac disorders.

Our system presents a great innovation in the process of online monitoring of heart diseases as it provides real timeness and mobility to both patient and physician.

In the rest of the paper we explain the architecture of the system in detail. At the end of the paper we show our conclusions.

System architecture

The goal of our system is to facilitate the real- time monitoring of the ECG signals for surveillance of "at-risk" citizens. These people are usually patients with stable medical condition that allows a near normal life, which, however, may suddenly deteriorate and put life at risk. The complete architecture of the system is shown in figure 1.

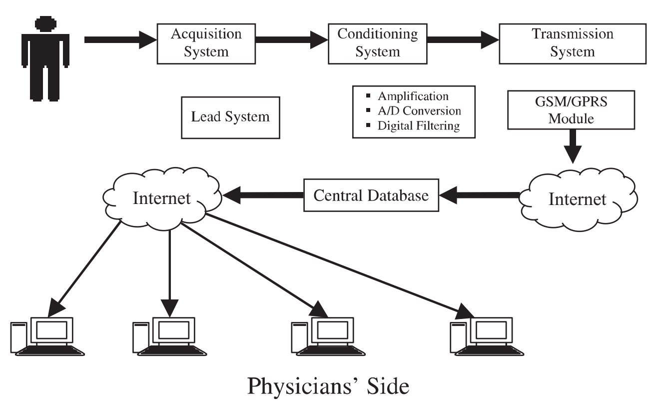

Fig. 1. System Architecture

Starting from the patient's side, figure 1 shows 1) Acquisition system, which consists of electrodes for acquiring ECG signals. 2) Conditioning system, which is responsible for amplification, analog filtering, A/D conversion and digital filtering of the captured signals. 3) Transmission system, the output of the conditioning system is driven to a GSM/GPRS transceiver, which is responsible for the communication part between mobile patient and the central database over the internet. 4) Central database, which stores the transmitted data. 5) Client application, which retrieves the stored data from the central database and displays it on the physicians PC/PDA.

The rest of the paper explains in detail the above-mentioned system.

Acquisition system

ECG signal

The basic structure of the heart is shown on figure 2. Measuring at different region of the heart will retrieve different bio-potential. And, so that it will generate different ECG waveforms. The ECG generated by each cardiac cycle is summarized on Table 1.

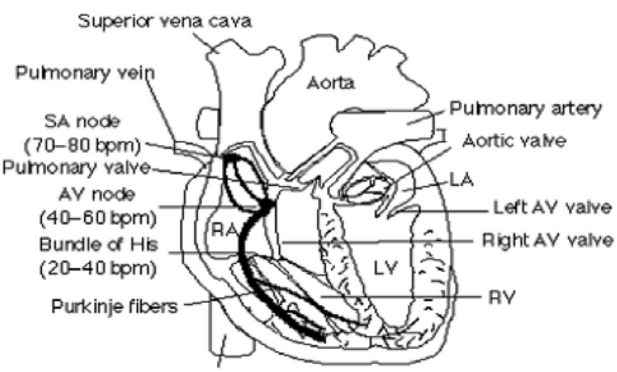

Fig. 2. Basic structure of the heart. RA is the right atrium, RV is the right ventricle; LA is the left atrium and LV is the left ventricle

Table 1. Duration and characteristics of each major event in the cardiac cycle

Event	Characteristics	Duration at 75 bpm (0.8s-cycle)
Arterial Diastole Ventricular diastole	AV valves opened. Semi-lunar valves close. Ventricular filling.	0.4s
Arterial Systole Ventricular Diastole	AV valves open. Semi-lunar valves closed. Ventricular filling.	0.1s
Arterial Diastole Ventricular Systole	AV valves closed. Semi-lunar valves open. Blood pumped into aorta and pulmonary artery.	0.3s

The cardiac mechanism of ECG is shown on Figure 3. In the top figure, the ECG initiates the cardiac cycle. The cardiac sounds are also shown. The bottom figure shows that ejection occurs when the pressure in the left ventricle exceeds that in the arteries. [2]

Electrodes

Surface recording electrodes convert the ionic current within the body to electron current in metal wires, which is then to an amplifier. Electrodes are generally made from metal. We have used silver/silver chloride (Ag/AgCl) electrode. For quantitative analysis of the acquired signals, the use of chlorinated silver (Ag/AgCl) electrodes is preferable. [3]

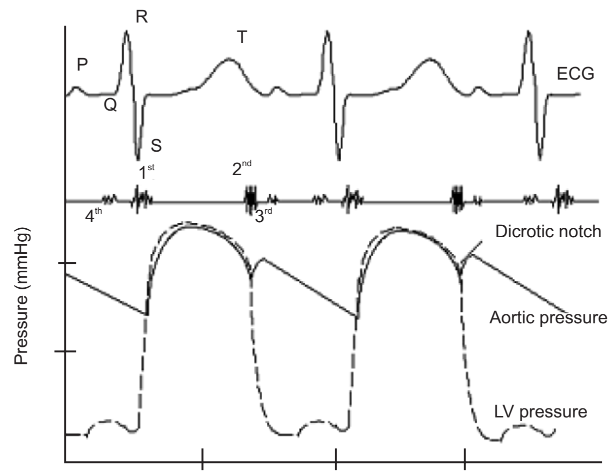

Fig. 3. The ECG cardiac cycle

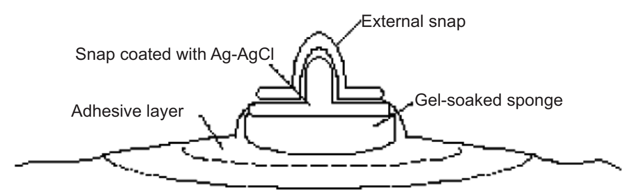

Fig. 4. A disposable surface electrode

Three- lead system

The electric potential generated by the heart appears throughout the surface of the body. We can measure the potential differences between surface electrodes on the body. Different pairs of electrodes at different locations generally yield different results because of the spatial dependence of the electric field of the heart. Physicians attach several electrodes on the surface of the body. A pair of electrodes, or combination of several electrodes through a resistive network that gives an equivalent pair, is referred to as a lead. Almost all ECGs recorded worldwide make use of the twelve–lead ECG system. [3]

For ambulatory (holter) monitor, the number of wires and electrodes applied depends upon the number of leads the physician feels should be monitored---usually one or two. [2] We have applied three-lead system with electrodes attached to chest as shown in figure 5. [4]

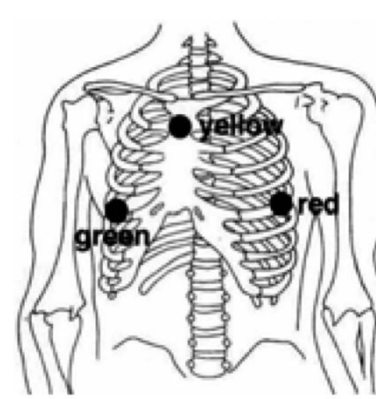

Fig. 5. Three Lead ECG System

Conditioning system

Amplification

The ECG is fed via electrodes and the connecting cables to the ECGamp lifier.

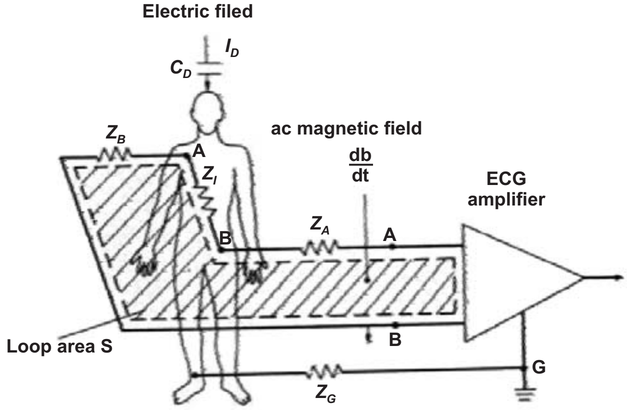

Fig. 6. ECG Amplifier

The most relevant performance specifications of an ECG amplifier are: [3]

a) **Input voltage range:** The voltage to be amplified ranges from microvolts (µV) to millivolts (mV). For body surface ECG measurements, the input voltage reaches ±10mV. Standard output voltages of the amplifier as recommended by International Engineering Consortium (IEC) are 1, 0.5 or 025 V/mV independent of the ECG sensitivity settings for chart recording.

b) **Gain:** The overall gain of ECG amplifiers ranges from 250 to 1000, thus providing an output voltage of 0.250-1.0V/mV.

c) **Input Impedance:** The suppression of interference voltages becomes better as the input impedance of the amplifier becomes larger with respect to electrode impedance. The electrode impedance must not exceed 1 MΩ for amplifier input impedance of 100 MΩ.

d) **Frequency Response:** For research applications, for example measurement of Hz bundle and late potentials the upper cutoff frequency of the amplifier should not be lower than 5-10 KHz. For the lower cutoff frequency, 0.05 Hz is recommended and for the upper cutoff frequency, 2500 Hz is advised. The figures given here for the bandwidth of ECG amplifiers approximately resemble those given in American Heart Association (AHA).

e) **Common Mode Rejection Ratio (CMRR):** The common mode rejection specified by the Association for the Advancement of Medical Instrumentation (AAMI) is 89 dB minimum for standard ECG and 60 dB minimum for ambulatory recorders. [5]

f) **Amplifier Noise:** Normal ECG amplifiers exhibit a noise level of the order of 5-10 µV. The IEC recommends less than 35 µV peak-to-peak noise level.

g) **Non-Linear Distortion:** It is recommended that non-linear amplifier distortions should be less than 1% in order to avoid visible distortion of ECG morphology.

h) **Drift Stability:** The term drift stability refers to the constancy of the baseline. The IEC performance requirements allow for 0.5 mV baseline shift within the first 5 minutes after 1 minute warm up. And not more than 0.05 mV/°C far a range of 10-40°C of ambient temperature.

We have used Analog Devices' AD624 Instrumentation Amplifier to amplify the ECG voltage from electrodes. The features of this amplifier are given below: [6]

Features of AD624

a) Low Noise: 0.2 _V p-p 0.1 Hz to 10 Hz
b) Low Gain TC: 5 ppm max (G = 1)
c) Low Nonlinearity: 0.001% max (G = 1 to 200)
d) High CMRR: 130 dB min (G = 500 to 1000)
e) Low Input Offset Voltage: 25 _V, max
f) Low Input Offset Voltage Drift: 0.25 _V/_C max
g) Gain Bandwidth Product: 25 MHz
h) Pin Programmable Gains of 1, 100, 200, 500, 1000
i) No External Components Required
j) Internally Compensated
k) Input Impedance: 1000 MΩ

The features of AD624 meet/exceed the specifications of an ECG amplifier.

Isolation

The patient must be protected from all kinds of electrical shocks, which are potentially possible when an individual is connected to electrical equipment. The effect is dependent upon the magnitude of current, its frequency and its pathway through the body. In human hearts, currents of 80-600 µA can cause cardiac fibrillation. [3] Fibrillation is an irregular contraction of cardiac muscle, which results in an ineffective propulsion of blood. [2]

We have employed an NEC's PS2501 opto-coupler after the instrumentation amplifier to isolate its output from rest of the system. An opto-coupler is device that uses light to couple a signal from its input (a photoemitter) to its output (a photodetector). [7]

A/D Conversion

For the digital processing of the analog ECGs, we have used TI's TMS320C6713 DSP Starter Kit (DSK). Digital signal processors such as the TMS320C6x (C6x) family of processors are like fast special-purpose microprocessors with a specialized type of architecture and an instruction set appropriate for signal processing. DSP processors are concerned primarily with real-time signal processing. Real-time processing requires the processing to keep pace with some external event, whereas non-real-time processing has no such timing constraint. The external event to keep pace with is usually the analog input.

The DSK board includes the TLV320AIC23 (AIC23) codec for input and output. The ADC circuitry on the codec converts the input analog signal to a digital representation to be processed by the DSP. The AIC23 is a stereo audio codec based on sigma–delta technology. It performs all the functions required for ADC and DAC, lowpass filtering, oversampling, and so on. The AIC23 codec contains specifications for data transfer of words with length 16, 20, 24, and 32 bits. A 12-MHz crystal supplies the clocking to the AIC23 codec (as well as to the DSP and the USB interface). The ADC converts an input signal into discrete output digital words in a 2'scomplement format that corresponds to the analog signal value. [8]

Digital filtering

Artifacts Potentials

Artifact potentials can heavily distort the ECGs. They have following sources: [3]

a) Myoelectric Activity: This is associated with muscle tremor or other mechanical activity resulting from recording in a cool environment or from insufficient relaxation of the patient. Myoelectric signals exhibit amplitudes up to 500 µV with a frequency spectrum from 30 Hz up to several kHz, thus overlapping the ECGs in amplitude and frequency domains. Localization of electrodes at positions with less muscle can help to reduce this noise.

b) Patient Skin: The skin artifacts result from changing potential differences between the inner and outer layer of skin. Abrading the horny surface layer of epidermis results in reduction of both potential differences across the skin as well as skin impedance.

c) Electrode Motion: Electrode motion artifacts are generated electrode motion relative to the subject. As a result, low frequency baseline shifts appear in the ECGs.

d) Patient Cable Motion: Cable motion artifacts result from several phenomena. Is an unshielded cable is moved in the presence of an electric field, the frequency such an artifact can be expected to lie in the range 0.1-10 Hz. Movement of this cable in a static magnetic field, e.g., the earth's magnetic field is associated with induction of an EMF.

e) Interference: The most common low frequency interference, electric as well as magnetic is from the line frequency (50 Hz or 60 Hz).

2.4.2 Filters

The required frequency response of the ECGs is 0.05 to 150 Hz. To avoid motion artifacts and muscle noise the frequency response is reduced to 0.5 to 40 Hz. [2] To remove majority of noises from part a to d mentioned in previous section we have developed an FIR low pass filter having passband from 0 to 40 Hz. The response of this filter is shown in figure 7.

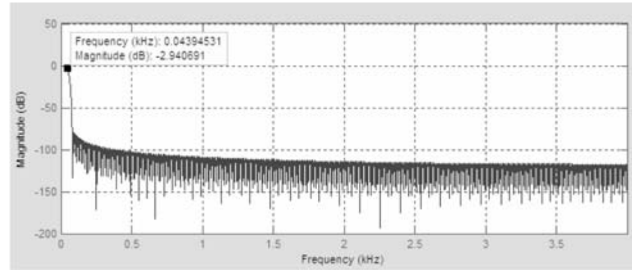

Fig. 7. FIR low pass filter

To remove the interference noise and its harmonics mentioned in the part e of the previous section we have developed IIR notch filters having notches at 50, 100, 150, 200 and 250 Hz. The response of these filters is shown in figures 8 to 12.

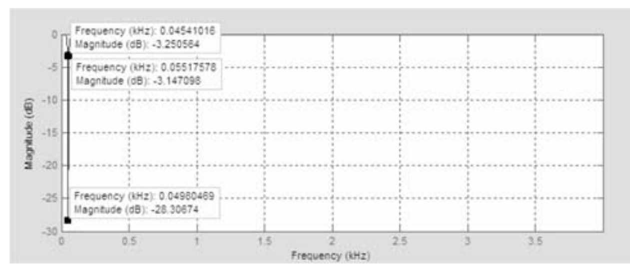

Fig. 8. IIR notch filter (50 Hz)

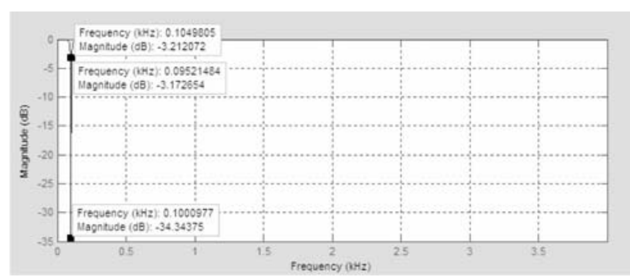

Fig. 9. IIR notch filter (100 Hz)

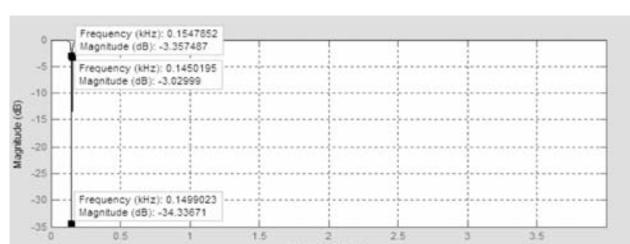

Fig. 10. IIR notch filter (150 Hz)

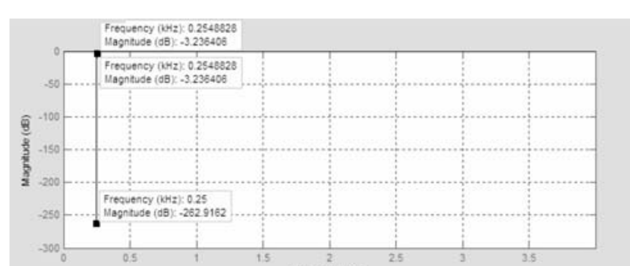

Fig. 11. IIR notch filter (200 Hz)

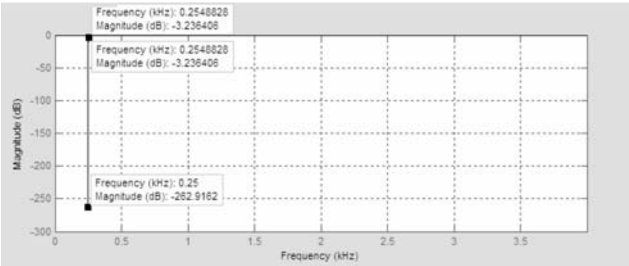

Fig. 12. IIR notch filter (250 Hz)

The above mentioned digital filters have been implemented in TI's TMS320C6713 processor.

Transmission system (GSM/GPRS modem)

For the transmission part we have used MOD 9003 GSM/GPRS Module. The TMS320C6713 DSK is interfaced with the module. The filtered data from DSK is transmitted to a central server using General Packet Radio Service (GPRS). The main benefits of using GPRS are: (1) standardized wireless packet switched Internet/Intranet access available everywhere GSM is available, (2) variable peak data rate, from few bits per second up to 171.2 kbps (the maximum data rate will be manufacturer dependent), (3) possibility for volume based charging enabling the user to stay online all day long and paying for actually transferred data, (4) applicability of the service for existing, as well as new applications, (5) packet radio in the radio interface, optimal sharing of radio resources, (6) packet switched technology in the network infrastructure, optimal sharing of radio resources and (7) ability to extend with future radio protocols. GPRS can be viewed as an enabler of new wireless data services. It is a packet radio system that makes optimal use of the GSM network for the bursty packet mode traffic, such as interactive Internet access. GPRS provides properties that make the use of existing end user applications more attractive. The ability to stay "on-line" for long time periods is a feature that could not be provided with any circuit switched cellular or fixed line access in a feasible way. GPRS creates a platform for new applications as well as for the existing applications. [9]

Central database

The forth part of the project is the development of central database. Transmission of ECG signals using GPRS from mobile device to mobile device is not possible, as GPRS does not have static IP and its IP keeps on changing. [10] So we adopted a modular approach. We divided the entire project into different modules each comprising of different J2ME applications; one was to work on Client's end and one was to work on central database.

The concept behind the three applications was to listen to the incoming data uploaded from the GSM modem and store it in the database, updating the database for the incoming ECG packets and thus creating virtual real time effect [11]. The server side application was developed in J2ME and for that matter we used Tomcat Server, which is a free server, from official sun's website [12]. The first server side application was to listen to the incoming packets through a dedicated socket connection. The second server side application was to update the database with the incoming ECG signals; this is what we call a real time effect. The Third and the final application was developed for the intended client side, it was developed with the concept of translating the incoming packets of ECG signals from Central database, into the ECG graph.

These all applications were developed using J2ME because all the latest mobile phones are java enabled and run on Symbian operating system, and J2ME is that offshoot of JAVA that runs on these micro devices. These applications can easily be downloaded into mobile phones and this gives spirit to the concept of providing mobility to both the patient and the doctor.

Conclusion

This technology has important implications for early detection of cardiac problems, especially in case of individuals situated in areas restricted from established cardiac care facilities.

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