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Bluetooth Portable Device for ECG and Patient Motion Monitoring

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Abstract

The cardiovascular disease does harms to person's health, and most of them are concerned with arrhythmia which is the leading cause of death. The chances of suffering a myocardial infarction are great and increase up to fifteen times after the first occurrence. During a heart attack, heart muscle is depraved of oxygen and will literally die if the artery remains blocked. The first few hours are critical in saving much of the dying heart muscle and preventing permanent heart damage. Unfortunately, the symptoms vary and the most common reason for critical delays in medical treatment is lack of early warning and patient unawareness.

It is possible to detect the onset of a heart attack and eliminate patient error. In this paper, we present a portable miniature wireless device for ECG measurements. The patient will only be required to carry a cell phone equipped with Bluetooth. When the device detects a heart attack, it will alert the cell phone which in turn will automatically call for help and provide the patient's location. The goal is to provide early heart attack detection so that the patient will be given medical attention within the first few critical hours, thus greatly improving his or her chances of survival.

Keywords: ECG; wireless medical applications; Bluetooth; embedded systems; home healthcare.

1. Introduction

According to the U.S. Food and Drug Administration (FDA), home healthcare is the fastest-growing segment of the medical device industry. Longer life spans, an increasing number of patients with chronic medical conditions, and rising health costs are the main forces behind the trend of immersing the consumer home market with "smarter" and "friendlier" medical devices, Figure 1.

For the management of various pathologies it can be very important to monitor patient for long periods during his normal daily activities. A continuous personal monitoring of chronic patients can reduce hospitalizations and improve patients' quality of life; cardiac long monitoring (e.g. ECG shown in Figure 2) can help in diagnosis and identification of syncope and other paroxysmal arrhythmias; long-term patient's activities monitoring can help in elderly people management; combining cardiac activity (e.g. heart rate) and body-motion, patient's physical activity and energy expenditure can be estimated.

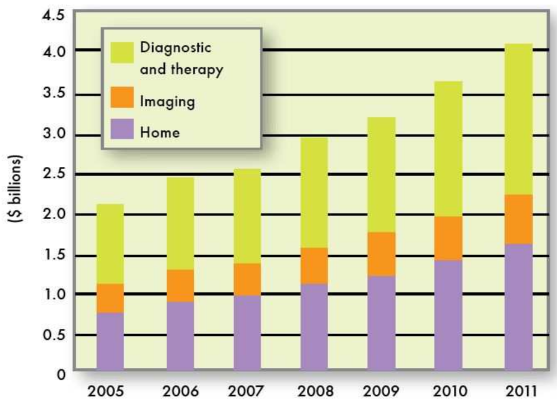

Fig.1 The worldwide semiconductor market for medical electronics is increasing, with a significant portion going into home medical products (source: Databeans Corp. *www.databeans.net*)

It is also worth mention that continuous monitoring can help in drive and regulate therapies and treatment (e.g. monitor blood glucose and insulin injection control). To accomplish these tasks personal patient's monitoring equipment have to comply with some specific requirement: reduced dimension, portability and/or wearability (light weight, specific sensors, body compatibility etc.), long-term signals or parameters monitoring (battery consumption, long-term electrodes, etc.), continuous signal acquisition and real-time processing and feature extraction, transmission capability (band, range, wireless, etc.), provide data integrity and security (communication protocols, identification, encryption, etc.), compliance with medical devices regulation (electrical safety, electromagnetic compatibility, etc.) [1].

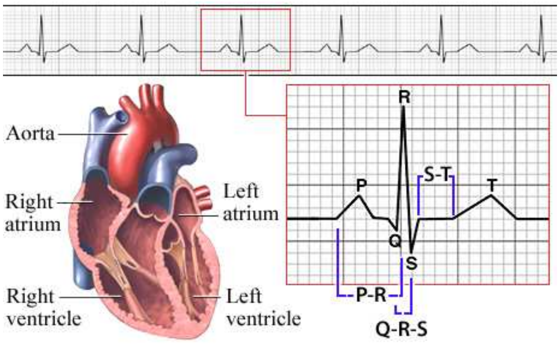

Fig 2. ECG components and intervals.

Recently are becoming more and more available on market wireless monitoring devices, such as hospital patient monitors, ambulance or portable equipments, some homecare devices and, more in general, devices to be used in the every-day life, which often use available telecommunication channels to communicate with external environment.

In particular, Bluetooth standard offers important advantages: low cost, low EM interferences, reduced power consumption, confidentiality of the data, dimensions of the transmitter and it is capable of generate small pico-net of some devices [2]. Also it is embedded in most of portable, palm computers and mobile phones and already used in a great number of wearable devices (e.g. mobile phones wireless headsets). The emerging ZigBee standard [3,4] offers enhanced capabilities especially in term of power consumption, number of connected devices, etc. but, currently, it is not so widespread as Bluetooth.

This paper describes a low cost, portable system with wireless transmission capabilities for the acquisition, processing, storing and visualization in real time of the electrical activity of the heart to a mobile phone, a PDA or a PC (Figure 3).

Several groups have developed applications to monitor the ECG in mobile devices, where the samples have been obtained from standard databases [5], or they have development the ECG module [6, 7]. Other works [8, 9] have proposed techniques for signal processing via software to reduce noise or classify heart pathologies. In this work we describe both the implementation of the acquisition module with wireless transmission capabilities, the tool for real time ECG processing and visualization in mobile devices, and patient's location.

The structure is the following. In the following section system architecture, employed technology and development environment are described. In sections 3 and 4 hardware and implemented software will be explained in detail. Results and final prototype, together with the conclusions are shown in section 5.

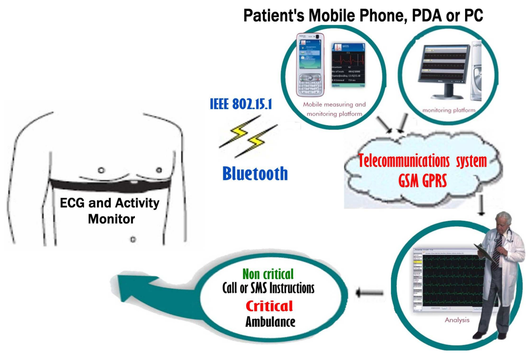

Fig3. Mobile healthcare Framework.

2. System Architecture

The system architecture can be seen in Figure 4, of which the prototype encompasses the on-person platform. The overall goal is to have viable context information processed on the dsPIC and then sent to a smart phone in order to be further aggregated and stored in a remote context management infrastructure. Local processing is performed in order to abstract the received data from the acquisition circuit as well as reduces the overall wireless traffic in the system. As shown in other research [10], this will decrease the possibility of congestion on both wireless links in addition to the overall power consumption of the system.

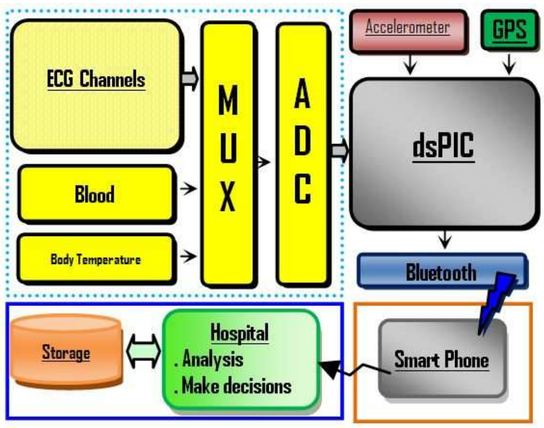

Fig4. System Overview.

2.1. ECG Acquisition

There are two forms of circuit for measuring ECG signals. One comprises amplifier ICs, resistors and capacitors to design a circuit board. The other uses ASIC to achieve the measurement, and Analog to Digital Converter

(ADC) and serial communication ports are integrated. In this design, we choose the CARDIC (p/n AuM441Cx), which is an integrated circuit developed mainly for the acquisition of electrocardiographic signals [11]. This single chip permits the implementation of ECG systems with up to twelve leads. CARDIC (Figure 5) is a low-power multisensor front-end acquisition system with on-board ADC (12bit@83KS/s) and serial interface communication protocol. It contains a fully configurable multi-channel ECG block, front-end channels for blood pressure and body temperature signal processing, analog channel for battery level monitoring and the possibility of direct access to the input of internal ADC through dedicated pins.

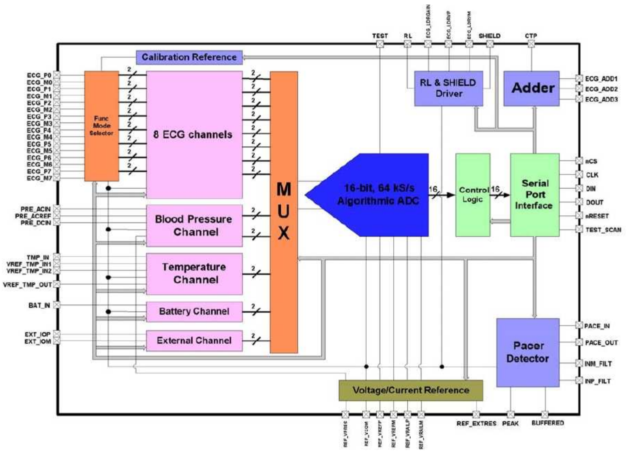

Fig5. The CARDIC circuit and its functional block diagram.

2.2. ECG Processing

There are many microcontrollers used in ECG monitors, from 8-bit to 32-bit microcontrollers, as well as DSPs [12, 13]. In this design, we propose the use of dsPIC microcontrollers (*dsPIC30F6010*), which are able to acquire and process the signals needed in monitoring applications. Owing to the cost-effectiveness of the devices, it is economically feasible to embed any number of them within a machine or process. In the system design, the speed of computation and memory capacity are considered as the two most important characteristics. Since the dsPIC30F6010 device has these properties, it has been chosen for our design. This chip has the following specifications:

- *30 MIPs processor speed*
- *10 bit ADC*
- *4 kbyte EEPROM and 8 kbyte SRAM*
- *144kbyte program memory,24bit instruction bus and 16bit data bus*
- *1 clock cycle DSP processing*
- *Optimized instruction architecture with versatile addressing modes*

Microchip MPLAB is used for software modules with C30 compiler.

2.3. Bluetooth Data Transmission

Several wireless technologies can be used to transmit ECG signals, such as GSM/GPRS, Bluetooth, ZigBee, WLAN IEEE 802.11, and so on [14,15,16,17,18]. In this proposal we choose Bluetooth technology and other possibilities can be tested in future works.

To provide Bluetooth we choose BlueSmirf module provided by Sparkfun Electronics [19]. It is a class 1 model that has an approximate range of 100 meters. The asynchronous data from the dsPIC microcontroller are delivered to the BlueSmirf Bluetooth module on the serial port. The Bluetooth module is configured as a slave and the mobile phone is considered to be functioning as a master. The signal acquisition unit sends data to the Bluetooth module, which transmits data continuously, in blocks of ECG samples plus temperature reading and blood pressure as shown in figure 6. The data are sent as raw binary bytes.

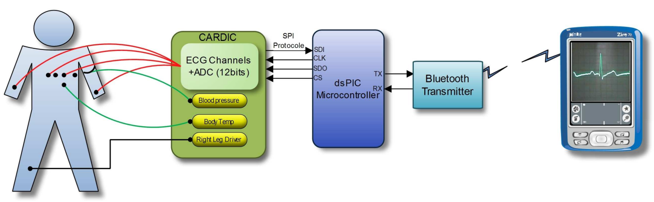

Fig6. Overall system diagram.

2.4. Patient Location

In a healthcare system accuracy of positioning is the most important element regardless of costs, because the indoor error should be at least less then 1m to find an accurate location of patient [20]. A patient can move freely by putting on a sensor. His data measured by a sensor through a portable terminal such as a mobile phone is transferred to a remote place through CDMA or WLAN.

When the transferred data are sent to a hospital, an immediate contact is made to an emergency center to trace a patient's location in order to be moved to hospital as soon as possible.

3. Mobile Unit Application Software

The software developed can be divided into two programs: a program associated to the microcontroller, and the second is for the applications in the mobile phone.

3.1. Microcontroller Software

The microcontroller has been programmed to perform the following functions: capture the ECG signal from the ECG ASIC, establish the connection to the Bluetooth phone and send the data (Figure 7).

This Bluetooth module allows provides an API for communication through the AT level, freeing the programmer from implementing the complete Bluetooth

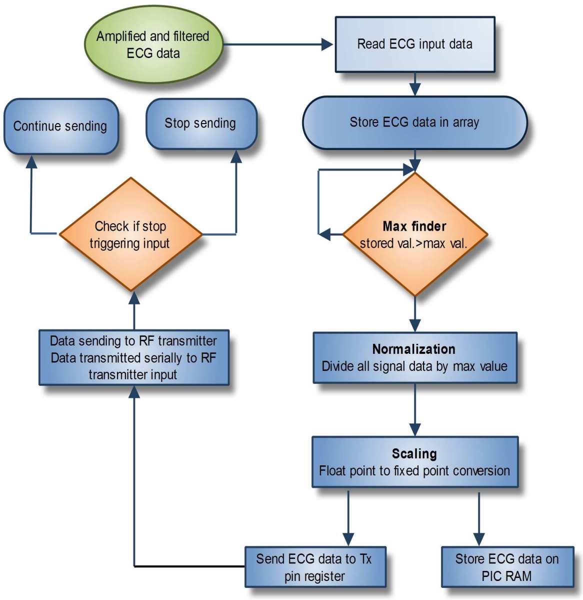

Fig7. Software assembly code flowchart for encoding dsPIC.

stack. The following submodules constructed the main software module:

- *ECG data reading program,*
- *ECG data processing : normalization and scaling,*
- *Sending data program to the Bluetooth transmitter.*

3.2. Mobile Phone Software

The application for embedded devices, such as mobile phones or PDAs, offers a service in the SPP port via Bluetooth. It will allow us to monitor the patients ECG in real-time. The mobile device can be used as a client or as a server depending on the operation mode. When the medical staff requires ECG data on demand, the mobile device operates as a client. On the other hand, when alarm condition comes up, the wearable device can start the communication with the mobile terminal. (Figure 8)

For this purpose different signals from the MIT Physionet database were downloaded and used to check the algorithm used to detect the pick R and calculate the heart rate. The application has been developed using the Java platform for embedded devices, J2ME. The Bluetooth communication was programmed using the Bluetooth API. Binaries were obtained using the J2ME Wireless Toolkit [21]. The software application takes the received bytes from the buffer and plots the ECG samples, displaying the body temperature and the blood pressure.

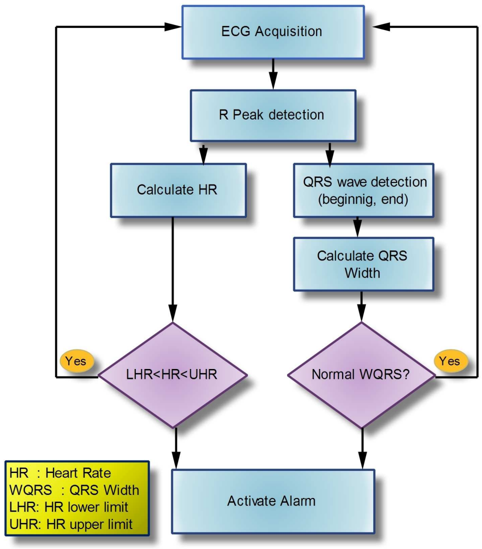

Fig8. Signal processing and alarm activation block diagram.

4. Power consumption

One of the limiting factors on the functionality of the telemetry system is the power supply. This is because of the limited battery capacity that might be used. The power consumption in such systems comes mainly from the amplifiers and the PIC microcontroller. The power consumption of the patient detection circuit was minimized in the hardware design in a way that all electronic parts used were selected based on supply current rating. The current level of the amplifier used was 20 mA for the Cardic circuit. For the PIC microcontroller, power consumption can be minimized by introducing the sleeping mode, but this was not used in this study.

In this work, the patient device is powered by rechargeable lithium batteries. Because continuous powering of real-time ECG transmission system is difficult, one solution was to use the low battery alarm integrated in the Cardic circuit. When the battery is low the device sends an alarm telling the patient to replace the battery and recharge it.

5. Result and discussion

We tested our system by wiring the electrodes to a subject's chest. A motion node was placed on the subject's right leg. The subject was allowed to move freely within the radio range. The synchronization of the real-time ECG and the motion information was displayed on the mobile phone.

Figure 9 shows the mobile phone display of a trace of ECG signal that was sampled at 360Hz. The output ECG signal is clear and of high quality (no visible noise superimposed on the ECG signal).

Fig9. Mobile phone display of wireless ECG from a healthy subject.

6. Conclusion and recommendations

In this paper, we presented the design of a mobile personal electrocardiogram monitoring system with patient location and motion. An ECG signal acquisition circuit was integrated in a module that communicates with a smart mobile phone via Bluetooth. The wireless ECG system presented in this work was able to detect and transmit the basic elements of the ECG waveform with high quality and efficiency. The current system has the advantages of low cost and low power consumption. To further reduce power consumption, the sleep mode can be effectively used with the dsPIC microcontroller. Application software running on the smart phone was also developed to receive and plot ECG signals and display body temperature and blood pressure with patient location. Software functionality can also be boosted by adding several algorithms of diagnostic capabilities, which would check abnormalities in the ECG waveform and thus assist medical stuff.

As for battery life, a study could be conducted to experimentally and/or analytically estimate the life of a battery used under this particular systems operating conditions. Currently we are testing this system.

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