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Energy Efficient ECG Signal Acquisition Channel for Ambulatory Patient's Monitoring

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Abstract

Heart diseases and infarct dead are major problems that need to be assessed as often as possible in the modern society. Performing these assessments in ambulatory conditions would be a huge advantage. Unfortunately, the present studies about acquiring ECG signals and interpreting them in an ambulatory dynamic context is not very well known yet and that's why we have designed an IIIrd class protection ECG(Electrocardiograph) system able to be correlated with multiple biophysical and biochemical parameters acquired from the patient.
The present paper describes an ECG system designed to respect the functional and non-functional characteristics and thus, the ECG system has to be reliable, scalable, available and maintainable.
Our major goal was to obtain a wearable ECG system with low power consumption that can be fully embedded in a complex remote monitoring system with low cost and reduced power consumption.
The system has the possibility to alarm the patient if the acquired signal is different from the pattern stored in the local memory. This alarm can be sent to the patient's Personal Digital Assistant (PDA) as a result of doctor's interpretation or as a result of local processing of the acquired data and thus, we have eliminated the risk of dangerous situations.
The main goal presented in this paper is the architectural concept, the system's supply and the power management.

1. INTRODUCTION

Medical devices became more and more important in the health care field and they have been represented by very sophisticated devices that can save the patient's life.

The biggest problem in ambulatory monitoring is the electrocardiogram (ECG) which represents a graphical test that records the electrical activity (action biopotentials) of the heart. [1]

A typical ECG signal is represented in **Fig. 1**.

The appearance of the semiconductor technology has reduced the costs and the dimensions of the electrocardiographs and thus the ECG devices can be placed on the back side of a SmartPhone able to process the medical information and to send/receive alerts to/from a medic.

We have implemented an ECG device in accordance with American Heart Association's recommendations (AHA). The ECG system assures low cost, IIIrd class of patient protection in accordance with EN 60601-2-25/1995 standard, energy management and wireless transmission of the acquired medical data.

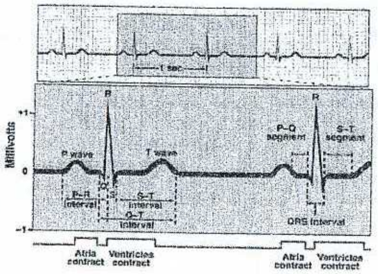

Fig. 1 ECG Signal [2]

2. STRUCTURE

Our solution for ECG ambulatory monitoring system is represented in **Fig. 2** and it consists of an instrumentation amplifier, a band pass filter, an analog to digital converter, a reference and a pre-processing system.

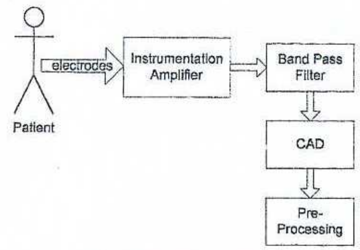

Fig. 2 The system's architecture

The instrumentation amplifier eliminates the common mode noises and amplifies the useful acquired ECG signal.

The band pass filter was designed in accordance with AHA's specifications that recommend the bandwidth between 0.03 Hz and 157 Hz in order to improve the quality of the acquired signal.

3. DESIGN

Some of the biggest problems are the common mode noises and the artifacts due to the patient's movement.

The influence of the common mode noise is shown in the Fig. 3 and this problem was solved by using the instrumentation amplifier specially designed for medical applications.

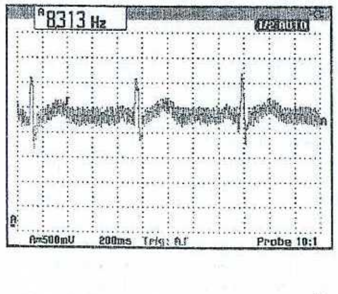

Fig. 3 The ECG signal influenced by the common mode noise

The artifacts that appear due to the patient's movement presented in Fig. 4 are eliminated by correlating them with the mechanical signal obtained from an accelerometer sensor placed on the patient's sternum.

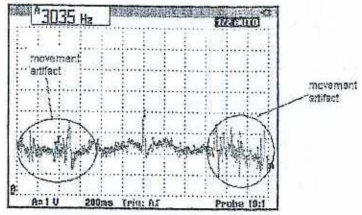

Fig. 4 The ECG signal influenced by the patient's movement

4. SIMULATION

Before being implemented, the system was simulated in PSpice. Some of the problems like the necessity of using dual supply for assuring supplementary electrostatic discharges protection were eliminated.

For example, by using a single supply for the instrumentation amplifier the diodes used as a protection for electrostatic discharges limit the ECG waveform as it is shown in Fig. 5. [3].

Fig. 5 QRS Complex

Thus the necessity of dual supply was assessed and the results presented in Fig. 6 were obtained.

Fig. 6 QRS Complex

5. Implementation and Experimental Results

Because this system was designed for ambulatory monitoring some of the most important considerations are choosing the right power supply, assuring the protection of the patient and of the whole system at electrostatic discharges and implementing a good power management.

Because the ECG device is space-constrained and power-constrained we have used highly integrated analog components with low power consumption and adjustable gain amplifiers to condition and convert the signals into the digital domain so they can be processed and interpreted. [4]

There are 3 protection classes for medical devices [5]:

1. **Class 1 of protection** denotes an equipment in which protection against electric shock does not rely on basic insulation only, but which includes an additional safety precaution such that means are provided for the connection of accessible conductive parts to the protective (earthing) conductor in the fixed wiring installation so that accessible conductive parts cannot become live in the event of a failure of the basic insulation.
2. **Class 2 of protection** - the device denotes an equipment in which protection against electric shock does not rely on basic insulation only, but which includes additional safety precautions such as double insulation or reinforced insulation, there being no provision for protective earthing or reliance upon installation conditions.
3. **Class 3 of protection** – the device denotes an equipment in which protection against electric shock relies upon supply from SELV (Separated Extra Low Voltage) circuit in which hazardous voltages are not generated (extracts from BS EN 60950: 1992).

Being implemented wearable, the ECG system was designed to use as power supply batteries. By choosing components that work at low voltages the necessity of using DC-DC converters was eliminated and thus the power consumption was reduces too. Replacing the power supplies with the batteries we placed our device in III[rd] class of medical device protection and thus the medical standards have been respected.

The acquired signal from the patient by the help of the implemented device is shown in Fig. 7.

The ECG module has the possibility to preprocess the information and to send the medical information to another module for advanced processing. Thus, a Matlab advanced processing is shown in the Fig. 8.

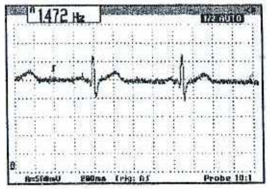

Fig. 7 ECG acquired signal [6]

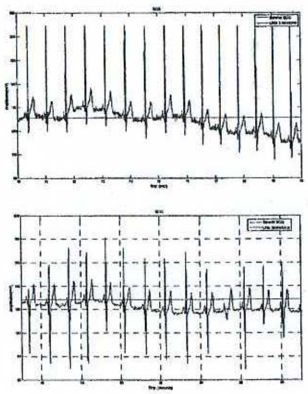

Fig. 8 ECG processed in Matlab

6. Energy Management

6.1. Batteries and power supplies

Because a wearable system has to use as power supply small batteries, available power is limited and thus for the ECG system all the components were chosen to assure minim power consumption. [7]

Simulating the system, the optimal supply levels were established. At the beginning a DC-DC converter was used to assure the differential supply but the noises that the DC-DC converter has introduced and the big amount of energy consumption have determined us to eliminate it. Eliminating this component the power consumption was reduced from 90mA/3.7V to 10mA/3.7V and the spikes produced by the converter disappeared too.

Because the components use different levels of power supplies we have used 2 batteries to assure the differential power supply and for adjusting the voltage levels we have used reference components with low power consumption. Thus, the ECG system has 150

hours autonomy if the system is supplied at 1500mAh batteries.

6.2. Segmentation

All of these wearable medical devices need a low-power microcontroller or/and a software solution for energy management implemented onto the microcontroller. [4]. Because this device was designed to run on batteries, an important goal is lengthening the battery's life.

The ECG system was designed to work on three different situations: *daily monitoring* (normal situation)-when the patient has a stable status or "normal status"-, *alerts* -when the monitored parameters excels the normal threshold of the parameters correlated with the other monitored parameters- and *emergency* -a status that requires medical intervention.

Because of the three working situations described above, in order to improve the patient's vital signs evaluation and to reduce the power consumption for each situation a monitoring schedule was implemented as it is represented in Fig. 9.

a. Monitoring schedule for normal status

b. Monitoring schedule for alert or/and emergency status

Fig. 9 Time schedule for ECG monitoring (on the abscise axis time is given in minutes 1 cycle = 4 minutes)

At every 20 minutes the ECG makes a 2 minutes recording. By making this schedule the energy management is improved and the power consumption is reduced to less than 1mA/3.7V. This means that the ECG acquisition system has 1500h autonomy by using a 1500mAh battery.

An alternative to reduce the power consumption is to use a microcontroller that can parallel process the medical information. Thus, in combination with vector processing, parallel processing reduces the power consumption and is suitable for medical applications. Also, a software technique that partitions the processing algorithm into a number of blocks that can operate in parallel at reduced clock frequency can be implemented and thus it results a higher rate signal processing path and a reduced rate control. [7]

6.3. System's power consumption

The power consumption for the signal-processing component of the wearable medical application can typically be split into the signal conversion/conditioning and the signal processing. The power consumed by the signal conversion is largely determined by the signal-to-noise ratio (SNR) and bandwidth required (sampling rate). [7]

The ECG signal is pre-processed by the help of a microcontroller based module. Because the ECG system was designed to be wearable and to be used in ambulatory monitoring, a Bluetooth solution was implemented for sending the medical information from the acquisition system to the PDA. The whole testing system is presented in Fig. 10.

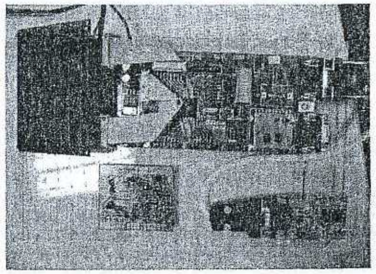

Fig. 10 The testing ECG system

By adding the Bluetooth module the power consumption was increased from 10mA/3.7V to 40 mA/3.7V. The power consumption of the processing unit programmed in Normal Mode is 40mA/3.7V and programmed in Standby Mode is less than 80μA/3.7V. Thus, the testing system has 80mA/3.7V power consumption in Normal Mode. By respecting the schedule presented before, in emergency situations the system has 18 hours autonomy and in normal situations the whole system has 185.64 hours autonomy.

7. Conclusions

Portable medical equipment is improving healthcare for millions of patients and products like heart rate monitors have enhanced the quality of life for those with chronic or acute diseases and conditions. [4]

Medical devices data management systems became a necessity for healthcare because of the continuously increasing complexity of the devices.

We have focused our research on the energetic aspects because this represents a major feature related to the portable and wearable devices. A significant problem was finding the optimal components and chemical power supplies in order to reduce the power consumption and to assure long time availability of the device. A good power management was described too.

This paper presents an optimal ECG architecture as well. A wearable ECG system was designed and implemented in compliance with the BS EN 60601-2-25/1995 medical standard of patient's protection and a dynamic software (scheduling) solution was also described in order to reduce the power consumption.

The successfully distribution of the medical information via a Bluetooth channel with low power consumption increases the self confidence of the patient. A wire communication solution increases the sampling rate and reduces the power consumption and this is adequate for wearable devices.

The whole context of this article is a part of the national project BIOMED-TEL currently under development at the "Transilvania" University of Brasov - Department of Electronics and Computers [8].

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Smart Development Platform For Embedded Systems

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Abstract

Nowadays, a platform for testing development systems became more and more important being assessed by the technological evolution and the wide range of the applications. This is the reason that has determined us to design a multi purpose development platform for genral use in embedded systems suitable for real time signal acquisition, real time signal processing and also, for data storage, data analysis and data transmission.

Even if the platform approach offers a large number of benefits it was designed with low non recurring engineering costs and low manufacturing costs and thus, the platform is suitable for ***testing*** *and for* ***implementing*** *as well.*

The development platform has already proved to be very useful in ***medical, energy, automotive and e-learning applications*** *but the biggest advantage is that it offers the possibility for* ***wireless transmission/receiving data to/from many acquisition systems****, to store data, to concentrate and to locally process an interpret them.*

Embedded system applications require architectures based on microcontrollers combined with I/O components in order to achieve computation and communication performances.

The possibility to execute distributed tasks and to correlate the results increases the range of applications for the development platform.

1. INTRODUCTION

Nowadays, embedded system's field became a necessity.

We focused our research on developing a Smart Platform with low cost and low power consumption able to be used in a variety of applications like data acquisition and data mining, health care field, automotive, energy applications, learning and e-learning.

This platform is based on AVR8 family, a new generation of 8-bits microcontrollers that includes on the same chip a very powerful interrupt control system.

These controllers have in the same time a low power consumption that recommends this family for portable and/or energy intensive applications. For this reason we have adopted these controllers to implement our Smart Platform (SP).

In this paper are presented several applications in the filed of portable medical devices, energy power management and automotive.

2. TECHNOLOGICAL RESEARCH AND ARCHITECTURE

Before implementing the Smart Platform studies about the components behavior were made. A prototype platform was implemented and each module was tested by designing the component's drivers.

We have analyzed a lot of microcontroller's families and we have taken into account the following elements: (i) processability of the CPU represented by ISA, internal architecture and clock performance; (ii) the possibilities to communicate: so-called communication interfaces (serial and parallel ports), converters analog to digital (A/D) and digital to analog (D/A), including the interrupt system.

For these reasons we have chosen AVR8-bits family that also has very low consumption accepting to be supplied between 2.7 to 5V and presents a sophisticated power management on chip (6 different modes) and also a good ratio performance/price. Thus, the system is suitable for portable applications.

The architecture of the prototype is presented in Fig. 1.