Wearable wireless ECG monitoring

Hardware prototype for use in patients own home

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Recent miniaturization of ECG sensors and other health monitoring systems potentially allowing remote monitoring of certain diseases in the patients own home. Exploiting the full potential of this technology poses several design challenges for both the miniaturized ECG sensor, as well as the required infrastructure for data transport, storage and diagnosis. This paper proposes an ECG sensor prototype allowing experimentation on sensor technology and signal processing as well as infrastructure. The prototype is based on the Blackfin processor from Analog Devices, and uses Bluetooth for wireless communication.

Keywords-ECG; monitoring; wireless; digital signal processing;

I. INTRODUCTION

Cardiovascular diseases are one of the most frequent world-wide causes of death and with an ageing population this trend is likely to continue. Electrocardiograph (ECG) is one of the most widely used biomedical sensing procedures to date. The heartbeat is an excellent indicator for a wide range of physiological conditions, and in addition Cardiac rhythm disturbances have been cited as a potential precursor to major cardiac episodes [1]. Recent miniaturization of ECG sensors and other health monitoring systems has made wearable systems feasible potentially allowing remote monitoring of certain diseases in the patients own home.

Development of low-cost, wearable wireless ECG sensors carefully designed for ease of use allows sustained collection of ECG data as well as an opportunity for real-time diagnosing of critic cardiac events and heart beat anomalies. By fitting the ECG sensor with wireless communication, detected critical cardiac events can be relayed to e.g. a portable PC or a clinical docking station thus allow triggering of an emergency alarm system.

II. DESIGN CHALLENGES

Achieving remote long-term ECG data collection and alarm triggering poses several technical challenges. First of all the wearable sensor must capture an ECG signal of suitable fidelity and provide adequate battery for sustained operation, while remaining light-weight and compact enough to be comfortably worn by the patient. It is foreseen that wireless communications may be unavailable possibly requiring local storage of ECG data until communications can be resumed. Secondly the collected data requires transportation to clinical staff, requiring suitable Information Technology (IT) infrastructure to be implemented. Additionally robust arrhythmia-detection algorithms need to be implemented to reduce risk of false alarms. Since the ECG sensor is intended to be worn for extended periods of time suitable electrodes must be selected, that providing adequate signal quality in spite of movement, perspiration etc. while avoiding or reducing skin irritation. It should be noted that an electrode becoming detached or loosing contact with the skin of the patient will introduce artifacts that significantly reduce the ECG signal quality and thus increase e.g. the risk of false alarms. Using Insulated Bioelectrodes (IBEs) not requiring direct skin contact may reduce the risk of skin irritation while reportedly producing equivalent signal quality as gold standard conventional electrodes [2]. Regardless of the used type of electrodes, a means of detecting sudden degradation of signal quality due to e.g. electrode detachment would be desirable.

III. MATERIAL AND METHODS

We propose a prototype ECG sensor allowing experimentation regarding signal capture and processing as well as data transportation and IT-infrastructure while providing a tolerable experience for the patient. The developed prototype hardware consists of three modules as shown in Figure 1. The three modules are assembled in a sandwiched-structure using connectors and screws.

A. *Analog signal conditioning and digitizing*

This module contains all analog electronics such as ECG signal amplification, precision voltage reference and power supply unit (PSU) as well as an Analog-to-Digital Converter (ADC). The low amplitude ECG signal has a typical peak-to-peak voltage of 2mV which is amplified in two-stages. The first stage is the AD620 [3] instrumentation amplifier from Analog Devices. This instrumentation amplifier has excellent bandwidth and low noise while providing very high common-mode rejection. The second amplifier stage has digital programmable gain, this PGA is build-in the ADC. The amplified signal is digitized using the AD7706 [4] 3-channel 16 bit $\Sigma\Delta$ -converter from Analog Devices. This ADC allows a typical sample rate of 500 Hz providing excellent time resolution of the digitized ECG signal. The PSU is built using a dc step-up converter accepting input voltages a low as 0.8V

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and up to 3V. Further the PSU has reverse battery polarization projection and the input voltage is connected to one of the ADC channels. This provides the opportunity to warn the user on low battery.

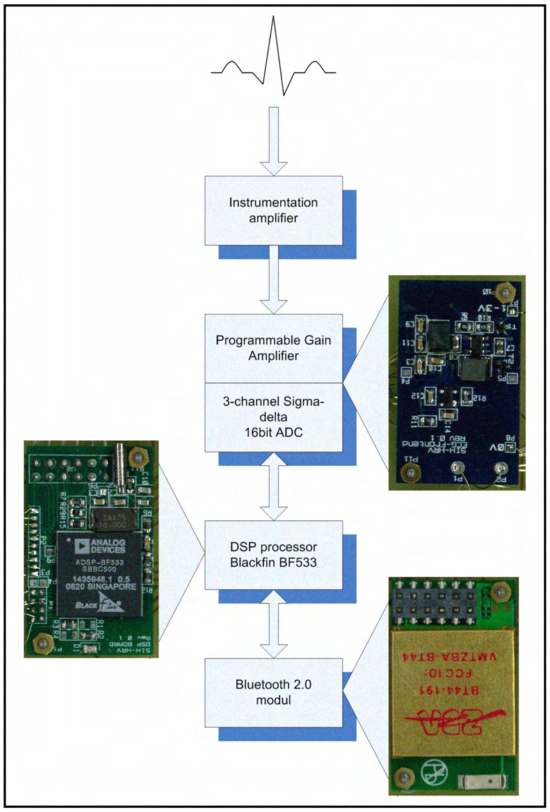

Figure 1. Block diagram of the SIH-ECG prototype, and the pictures are the actual modules. The modules are same size (18mm x 30mm), the three modules are connected in a sandwich structure using small connectors and screws to hold the modules.

B. *Processor module*

The processor module is basically a small foot-print Digital Signal Processor (DSP) platform based on a Blackfin BF533 [5] DSP from Analog Devices. The module includes a M25P10-A serial 1MBIT data flash for code storage as well as a Secure Digital (SD) card for on-board local data storage. The Blackfin BF533 DSP is a high-performance DSP processor capable of clock-speeds exceeding 600MHz. The processor has two 16bit Multiply-And-Accumulate (MAC) units allowing two 16bit precision multiplications to be performed in parallel. The Blackfin BF533 DSP has 148 KByte of on-chip memory and includes many different peripherals. The on-chip Real-Time-Clock (RTC) is connected to a 32 kHz crystal. The program is stored in the M25P10-A serial data flash, on reset the processor boots the program form this flash. The processor may transfer data to the SD-card using the Serial Peripheral Interface (SPI) bus.

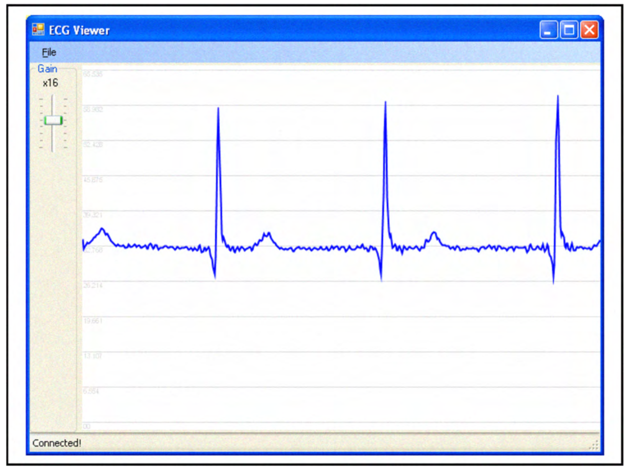

Figure 2. PC application screenshot showing example of captured ECG waveform using SIH ECG prototype hardware.

C. *Wireless communications module*

The wireless communication module is an off-the-shelf Bluetooth 2.0 module. This module is a class 2 type output RF power with a range up to 100 m. It supports data rates up to 3Mbits per. second, and is connected to the DSP processor module through a simple UART interface.

The Bluetooth module has been tested with a PC running a special designed ECG monitoring software application. It has also been tested with a mobile telephone.

IV. Results and Conclusion

The prototype described in this paper has been successfully used for ECG data collection and wireless communication in a battery powered configuration. The received ECG waveform was received by a custom-made PC application using Microsoft Windows XP. An example ECG waveform can be seen on figure 2.

The developed hardware is currently not optimized for low power consumption. Instead the main focus has been development of a flexible and powerful platform in terms of connectivity and on-board computational power to allow a broad range of ECG signal processing algorithms to be implemented, without requiring careful optimization of the software. To this end, the selection of the Blackfin BF533 DSP is a perfect match. In future designs however, low power consumption is a very important issue in order to achieve extended operating time using a battery. In future generations of hardware, the BF533 processor is foreseen to be replaced with alternative low power and therefore less powerful DSP variants. When implementing algorithms using future low power hardware solutions, optimization of the implemented algorithms will become absolutely necessary to keep the computational load and thus the overall power consumption to an absolute minimum

We have used a Bluetooth module in this prototype, in order to facilitate connectivity to PCs, Cell phones and

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Personal Data Assistants (PDA's), since the Bluetooth technology is easy-to-use and is a current standard in wireless communication. Bluetooth is, however, rather costly in terms of power consumption, especially in view of the relatively low-bandwidth requirements of ECG data, In future versions of the prototype hardware we foresee that a custom power efficient wireless communication solution is the best choice for wireless transfer of ECG data. But, since Bluetooth communication is widely adopted, we suggest a solution that allows Bluetooth functionality to be enabled and power consumption to be sacrificed for e.g. allowing an emergency alarm system to be transmitted by means of cell phones within wireless range of the ECG sensor. A such solution would provide the best of both worlds, by using minimal bandwidth for ECG data transfer under normal conditions thus minimizing power consumption and allowing extended operating-time of the ECG sensor.

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