An ECG Patch Combining a Customized Ultra-Low-Power ECG SoC with Bluetooth Low Energy for Long Term Ambulatory Monitoring

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ABSTRACT

This paper presents the development of an ECG patch aiming at long term patient monitoring. The use of the recently standardized Bluetooth Low Energy (BLE) technology, together with a customized ultra-low-power ECG System on Chip (ECG SoC), including Digital Signal Processing (DSP) capabilities, enables the design of ultra low power systems able to continuously monitor patients, performing on board signal processing such as filtering, data compression, beat detection and motion artifact removal along with all the advantages provided by a standard radio technology such as Bluetooth. Early tests show how combining the ECG SoC and BLE leads to a total current consumption of only 500μA at 3.7V, while computing beat detection and transmitting heart rate remotely via BLE. This allows up to one month lifetime with a 400mAh Li-Po battery.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life & medical sciences – *Health.*

General Terms

Performance, Design, Experimentation.

Keywords

ECG patch, Bluetooth Low Energy, mHealth.

1. INTRODUCTION

It is foreseen that healthcare system and services will radically change in the near future. Small and low power sensors able to monitor vital signs and activity patterns can provide a great opportunity in shifting to a new patient centric paradigm, characterized by the delocalization of care from hospitals to home, and a focus on prevention and just-in-time intervention. Cardiac disease is the leading cause of death in the U.S. and it is well established that early detection is critical for survival. Wearable sensors play a key role in continuous chronic disease monitoring during a person's daily life, allowing for both just-in-time interventions and more accurate diagnosis.

The emphasis on individual health and well-being recently increased, triggering the development of many products and research prototypes targeting this field [1-5]. The first group often employs ultra-low power radios and protocols in order to save power, together with general purpose microcontrollers, lacking wearability, standardization, ease of use, and ultra low power processors for on board signal processing (DSPs) [1-3]. In the latter group, some systems offer reliable, easy to use sensors, equipped with Bluetooth (BT) radios that allow plug and play functionalities with mobile phones and PCs. [4] and [5] are two examples of such systems. The trade-off this time is on power consumption, since these systems can last for only a few hours, in fact limiting significantly practical application and usefulness of the devices for long term monitoring. In this paper, we report an ECG patch based on the combination of an ultra-low power ECG SoC, and Bluetooth Low Energy, overcoming the lack of wearability, standardization or lifetime of previous systems.

2. SYSTEM DESCRIPTION
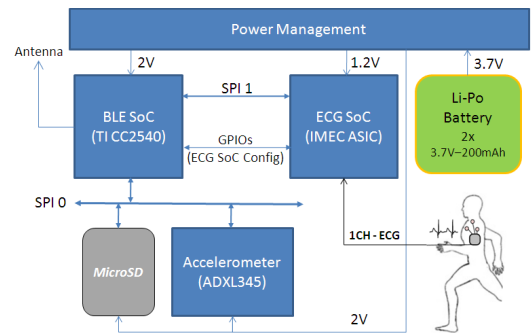### 2.1 System Architecture

Figure 1. Hardware architecture of the ECG Patch.

The ECG patch can be functionally divided into two subsystems. The first one is the mixed signal ECG SoC [6], which in turn consists of three main parts: an Analog Front-End (AFE), a 12 bit Analog to Digital Converter (ADC) and a custom Digital Signal Processing (DSP) back-end. The AFE supports concurrent 3-channel ECG monitoring, with impedance measurements and band-power extraction. The 12-bit ADC with adaptive sampling scheme, capable of compressing the ECG data by a factor of 5, reduces the power consumption due to data processing and transmission. The DSP back-end, using SIMD processor architecture, hardwired accelerate unit, effective duty cycling, instruction cache, and clock gating scheme, provides low power

operation while performing multi-channel ECG processing; additional signal filtering, ECG feature extraction, analysis and motion artifact removal [6]. The second subsystem is the CC2540 BLE SoC from Texas Instruments (TI), which takes care of retrieving the data from the sensors present in the system (i.e. ECG SoC and accelerometer) and sends it to a remote BLE enabled device. In the current set-up data is sent to a PC since no other BLE enabled devices are already present on the market. The subsystems are connected through a SPI interface. Additional components are a 3-axial accelerometer for activity monitoring and a MicroSD card for data logging: they are interfaced to the BLE SoC through a second SPI interface. The system is powered by a 3.7V - 400mAh Li-Po battery (see Fig 1).

2.2 Firmware and data processing

The ECG SoC implements 3 different real-time monitoring applications. In the data collection mode the signals are sampled and sent over the SPI interface. Only the AFE is running. The second mode is beat detection. The QRS complex is detected using an algorithm based on derivative or band-power extraction. The last mode performs an accurate R peak search using a continuous wavelet transform algorithm optimized for robustness to motion artifact [7]. The duty cycle of pre-processing unit and processor during the execution of the R-peak detection is 2% and 3% respectively, leaving plenty of space for the implementation of additional algorithms. Currently, two different operation modes are implemented in the ECG patch:

- Mode 1: beat detection on the ECG SoC and transmission of the heart rate through the BLE SoC;

- Mode 2: streaming of heart rate and acceleration with 40 Hz sampling frequency for activity monitoring.

2.3 Housing and Electrodes Patch

The mechanical casing of the patch has been developed by DELTA [8]. It consists of a disposable patch, hosting the ECG electrodes, and a "smart' cap (2.5 cm of diameter) which contains electronics and 2 batteries (Fig 2). Batteries can be charged by docking the cap onto a proper docking station.
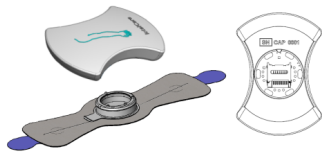

Figure 2. Mechanical casing and electrode patch.

3. CHARACTERIZATION AND TESTS

In this section we present the evaluation of the system in terms of power consumption. The ECG SoC consumes 61.1μW at 1.2V while performing beat detection (2% duty cycle). The power consumption of the BLE chip is highly dependent on the data rate of the application, since the BLE protocol is able to reduce to the minimum the connection management overhead. The average current consumption for Mode 1 is 500μA at 3.7V as shown in Fig 3. Streaming of heart rate and acceleration increases power consumption up to 1mA at 3.7V.
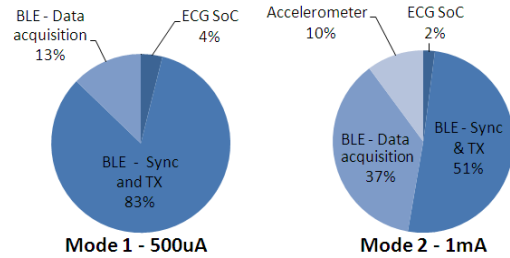

Figure 3. Power consumption breakdown of the ECG patch.

4. CONCLUSIONS

In this paper we presented a demonstrator of a personal health monitor using Bluetooth Low Energy and a customized ultra-low-power ECG SoC. Such a system provides connection to PCs and mobile phones through a standard protocol, and maintains very low power consumption for long-term monitoring in the home environment, closing the gap between research prototypes and commercial products. Other operation modes including real-time artifact reduction, arrhythmia detection and ECG streaming are currently under development.

5. DEMO

During the demo the ECG patch will be shown while computing and streaming heart rate and acceleration. Data will be visualized on a PC and attendees will be able to try themselves the patch.

6. ACKNOWLEDGMENTS

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