BITtalino: A Biosignal Acquisition System based on the Arduino

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Abstract: Our work presents a low-cost biosignal acquisition system, BITalino, based on the Arduino hardware platform; both the hardware and software components are detailed, together with experimental evaluation. This system was designed to be integrated in a biometric platform based on Electrocardiographic (ECG) signals, that will be used for identity recognition. The experimental evaluation revealed that this system is not only capable of ECG signal acquisition, for biometric purposes, but it can also be used as a generic platform for other biomedical applications, greatly extending its applicability. In this paper we describe the proposed platform, with special emphasis on the design principles and functionality. Future work will focus on further developing our hardware, targeting its integration in a prototype system for ECG-based biometric recognition.

1 INTRODUCTION

Biosignal acquisition has been a topic of increasingly growing development, since it constitutes the basis for diagnostic systems, and contributes to a better understanding of the body functions. Nowadays, novel applications of biosignals are emerging in areas where they are not traditionally found, such as the use of Electrocardiographic (ECG) signals for biometric purposes (Biel et al., 2001) (Lourenço et al., 2011). Therefore, the main objective of our work was to develop a low-cost acquisition system, capable of capturing vital signs, using the ECG as a testbed.

There are multiple hardware choices available, however the Arduino is currently the most flexible and easy-to-use hardware and embedded software platform, with low cost, easy communication, and software running on a computer or other devices. Our goal was to integrate the Arduino board with the Android Operating System, targeting the development of a mobile biometric system; as such, the chosen communication protocol was Bluetooth, since it is available in almost every mobile device, and also in computers. The integration between Arduino and Android is not new (Google ADK, 2011), but very few initiatives are based on Bluetooth.

The first use of our acquisition system targets the integration in a biometric platform, allowing real-time recognition. However, it can be extended to numerous other important applications, depending on which signals are to be acquired.

Nowadays, the use of the Arduino in medical and health applications has been widely explored for simple usage scenarios. One particular example is available at (Medicarduino, 2012), where the Arduino is used to acquire EEG signals, measure pulse, detect alcohol levels, and many other examples. Therefore, this project will contribute to the creation of a new system, modular, multi-purpose, easily accessible and with the possibility to be assembled by anyone interested on biosignal acquisition.

In the following sections we describe the acquisition system, designed especially for ECG data collection. The document is organized as follows: Section 2 focuses on the global system architecture, and in Section 3, 4 and 5 the hardware, firmware and software are detailed; Section 6 presents experimental results obtained with this system. Finally, Section 7 outlines the main conclusions and future work.

2 SYSTEM ARCHITECTURE

The proposed acquisition system has two main parts: Hardware and Software. In this particular work, the hardware is composed by the Arduino platform, Bluetooth transceiver and ECG sensor.

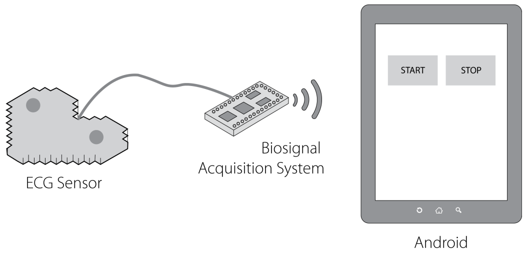


Figure 1: Diagram of the Android Biometric Platform.

In the case of ECG acquisition, the electrical activity of the heart is captured using electrodes placed on two fingers of opposed hands. Those signals are acquired through the analog input ports on the Arduino board, and subsequently converted using the internal analog-to-digital converter. Then, the digitalized data is sent via Bluetooth to the base station (e.g. Android mobile phone). The diagram represented in Figure 1 synthesizes the overall architecture of the hardware subsystem, showing a schematic of the main components.

Regarding the software, there are two main programs developed: the Arduino Firmware, which controls its operation, and an Application Programming Interface (API) in Java, which communicates with the Arduino, controls the acquisition process, allows the access to the collected raw data and enables high-level applications to access both the device and the data. These two parts of the system will be detailed in the next sections.

3 HARDWARE

The main component of this section is the Arduino. Figure 2 shows the final prototype, with main components: one Arduino Pro Mini (3.3V and 8MHz), directly connected to a Bluetooth Mate module; and one Lithium Ion Polymer battery with nominal voltage of 3.7V at 400mAh, as power supply. The ECG sensors are connected to one of the BITalino analog input pins, and its specifications are detailed in (Silva et al., 2011).

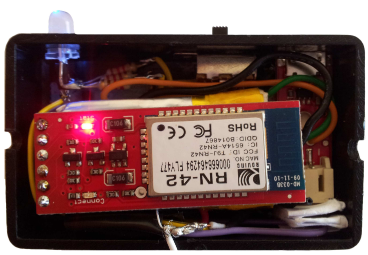


Figure 2: BITalino prototype.

4 FIRMWARE

The firmware development performed in our work was designed to define the behavior of the Arduino microcontroller, setting its parameters, such as sampling rate, baud rate and communication protocol. In this section we will describe the major objectives, problems encountered, and solutions achieved.

The main purpose of the firmware is to control the analog and digital acquisition, using a pre-defined sampling rate; all the data acquired is sent to another device via Bluetooth or USB connection. The open-source Arduino environment makes it easy to write code and upload it to the I/O board, which is one of the main reasons why this platform was chosen as the base for our system. The global operation is represented in Figures 3 and 4.

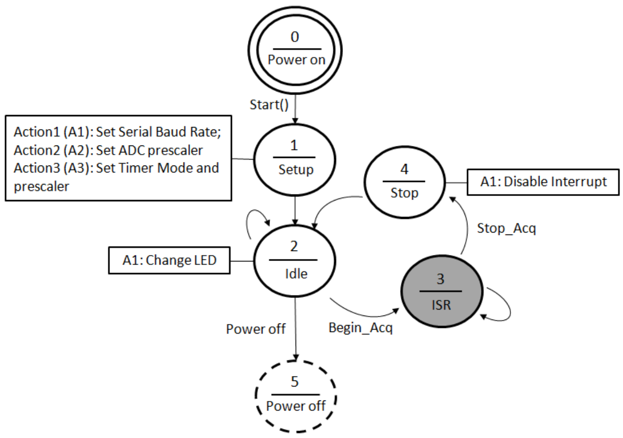


Figure 3: State diagram of the firmware operation.

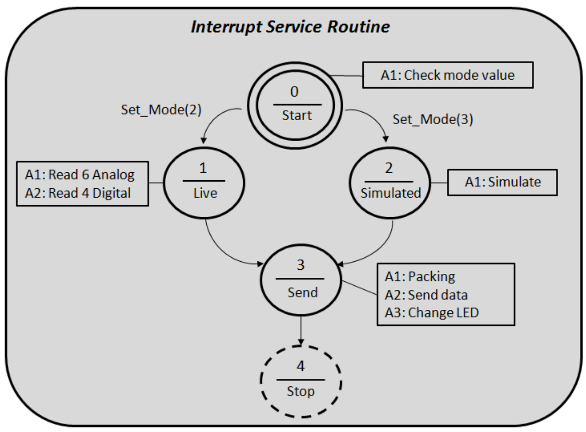


Figure 4: State diagram of the ISR operation.

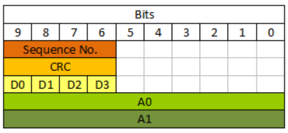
There are three modes in which the Arduino can be operating:

a) *Live*: In this mode, the system continuously samples the physical analog and digital channels, packs all the data, and sends it through the UART. All these tasks should be concluded within a time frame, which is imposed by the sampling rate.

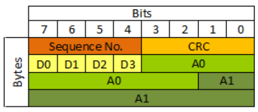
b) *Simulated*: Although it is similar to what happens in acquisition mode, in this mode, the system will simulate the acquisition, transmitting synthesized signals. These correspond to sinusoidal, square and sawtooth waves. This way, the communication and interaction between the base station and the device can be tested.

c) *Idle*: The system disables any mode in which it is in, and stays in stand-by until it receives a command to start the *Live* or *Simulated* modes.

When in *Live* mode, 2 analog and 4 digital input pins are read, and their data saved in an array. In order to make the most efficient of the available bandwidth on the communication channel, those values are packed into 4 bytes, including also a sequence number, and a 4-bit Cyclic Redundancy Check (CRC) value to detect possible errors in the message. This packing process is done using bitwise operators, and its schematic can be seen in Figure 5.



(a) Unpacked



(b) Packed

Figure 5: Data packets schematic.

After concluding this step, all data is sent to the computer through the UART.

One important requirement of this system is the accuracy in the sampling rate. In the live and simulated mode, all the tasks are completed inside a function called at a specified frequency. The approach used was based on timer interrupts.

An interrupt is an external event that stops the running program to execute a special interrupt service routine (ISR). After completing the ISR, the running program is resumed to execute the next instruction. These interruptions can occur at a specific frequency, when associated with timers.

The Arduino Pro Mini has a clock speed of 16 MHz and 3 timers: Timer 0 (8 bits), Timer 1 (16 bits) and Timer 2 (16 bits).It can be configured in 16 operation modes. In this work, we used the Clear Timer on Compare match (CTC) mode, based on comparison, that is, the timer compares a counter value with an output compare register defined by the user, and every time they match, an interruption occurs and the ISR function is called.

5 SOFTWARE

An Application Programming Interface (API) was developed in Java in order to control the Arduino. Its main purpose is to establish Bluetooth connection, and then start or stop the acquisition, receiving the acquired samples, and configuring the device.

An abstract class *Device* was created, which was subdivided into 2 main subclasses: Bluetooth and Test.

a) *Bluetooth*: This subclass establishes a Bluetoothl connection with the Arduino, and control its operation sending commands that activate start or stop methods. When start is activated, all data received from the device is saved in a text file for further processing.

b) *Test*: The Test subclass does not communicate with the device, but is used to test the API functionality.

The configuration parameters used in these subclasses, such as baud and sampling rates, are specified in a document with a standard notation based on JSON (JavaScript Object Notation). It creates an easy, standard, Human-readable and structured way to represent diverse information, and works regardless of the adopted programming language. An example of setup parameters defined using the JSON notation is as follows:

```
{ "BaudRate":115200,"Mode":"Live",
  "Sampling Rate":1000}
```

Focusing on the particular operations that can be performed using the Bluetooth subclass, the main methods are:

1. *Setup*: A JSON Object containing information about Sampling Rate, Acquisition mode (Live or Simulated), and Baud Rate is parsed and, with this information, a Bluetooth connection is established.

2. *Start*: The mode number corresponding to start acquisition, *Live* or *Simulated*, is sent to the system, which will activate its acquisition state.

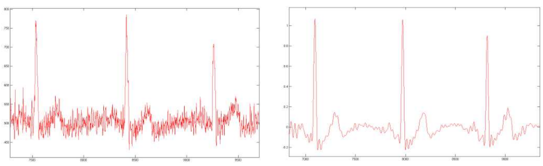
3. *Acquire*: After activating the acquisition state, this method reads the incoming data, and saves each sample in a text file, using the test application described in the next subsection.

4. *Stop*: When this method is called, the acquisition state is stopped, and the system returns to the idle state.

To test the API functionality and benchmark the device, a test application was developed; it creates an applet with Start and Stop buttons, and calls the corresponding methods. Thus, when the application starts, the Bluetooth communication is established, and it remains waiting for a button to be pressed, executing the method `Start` and `Acquire` when the button "start" is pressed, and calling `Stop` method when the button "stop" is pressed.

6 EXPERIMENTAL EVALUATION

Tests were performed to the final system, to check the sampling rate and the quality of ECG signals acquired. Therefore, to verify if the Arduino was acquiring at the specified sampling rate of 1000 Hz, a synthesized square wave with a frequency of 10KHz, duty cycle of 50%, 4 V_{pp} and offset of $V_{cc}/2$ was acquired, and the data was analysed using Matlab. The signals were generated using an Agilent 33220A function generator. The synthesized wave revealed a square wave, as expected, but after measuring the number of samples in each pulse we verified an average loss of 5 samples per second. However, since our main purpose is to acquire ECG signals, and its bandwidth is approximately 100Hz, a much lower sampling rate of 200Hz can be used for data acquisition, leading to a maximum loss of 1 sample per second, which is negligible for biometric recognition purposes.



(a) Raw Waveform (b) Filtered Waveform

Figure 6: ECG signal acquisition.

This behaviour was already expected due to the Arduino's clock accuracy error of 0.2%. However, there are some possible solutions to overcome this problem, which will be a part of future work, and described in section 7.

In what concerns the ECG signals, the acquisition was performed using 2 finger electrodes on opposed hands, with a sampling rate of 1KHz. In Figure 6 the raw 6(a) and filtered 6(b) signals are represented. The filtering was done with a low-pass kaiser filter between 2.5 and 30 Hz. Therefore, it was concluded that this system is able to acquire these signals with quality, being possible to distinguish the different complexes of a characteristic ECG signal, when filtered. Moreover, the battery lifetime was tested, and it operates, on average, 6 hours in constant acquisition.

7 CONCLUSION AND FUTURE WORK

We have designed and implemented a first prototype of an ECG acquisition system, applicable to biometric applications. Experimental results have shown that the data collected through the proposed system, preserves the waveform properties that are used by the ECG-biometric systems. Although this system was designed to integrate a biometric platform, it can also be used to acquire other types of biosignals, becoming a more generic acquisition system.

Future work will be focused on the integration of an external oscillator in the system, separating the execution lines for data acquisition and the data transmission, and increasing the resolution of the system, through an external ADC. However, in it's current state, this prototype system is already prepared for deployment in real-world test beds, and is an adequate low-cost alternative for large-scale data acquisition.

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