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Electronic Prototype for the Acquisition, Processing, and Visualization of Cardiac Signals

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ABSTRACT

Nowadays, one of the most prominent medical problems are cardiac pathologies, and because of this, the instruments created to study the heart are of great importance. Nowadays, with the advance of technology, it is desired that these instruments are simpler to use, smaller, have more features and obtain the best quality of biomedical signals. This article describes the analysis and processing of heart signals, obtained through an accessible electronic prototype that allows generating a presumptive diagnosis of cardiac signals, such as arrhythmias and heart murmurs. The detection of a valvular lesion would help in the identification of abnormalities in the cardiac period. During the experimental phase of this proposal, the sensitivity and specificity results suggest a low-cost option, which makes it accessible as a presumptive diagnostic tool for the detection of valvular heart disease within the health area, especially in times of pandemic by COVID-19 in the city of Cuenca. Cardiac auscultation is important for the prevention of heart diseases; therefore, the contribution of this prototype is intended to be a support tool for the specialist in heart diseases.

Keywords: Leads, Electrocardiogram, SMD, PCB, Electrodes, SPI, UART, ADAS1000

INTRODUCTION

In recent years, a field of research of great interest has been the acquisition and analysis of electrocardiographic signals and identification of pathological and abnormal events within ECG recordings. Many of these studies are based on the use of databases with pre-acquired signals such as those from MIT, available on the PHYSIONET website. Some research work is focused on the development of computational systems to analyze these bio signals (Ramirez, 2009). Others focus on developing algorithms to identify pathologies related to electrocardiographic signals. (Dubin, 2011). These investigations have established methodologies for both the acquisition and analysis of ECG signals, providing applications such as: segmenting and identifying beats, filtering bio signals, among others, but all this within the limitations that use

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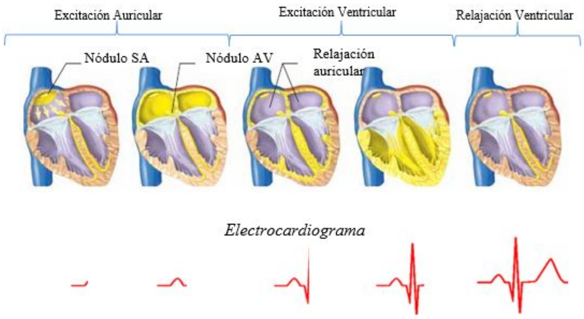

Figure 1: Propagation of the electrical activity of the heart with its respective ECG signal. (Barret et al., 2013).

existing databases, belonging to patients from other regions, with different build, size and weight to that of our region.

The main objective of this project is to develop a prototype capable of capturing ECG signals by means of an integrated circuit ADAS1000, which is low cost and low power consumption, and then transmit the data to a mobile device and a Windows application and plot each of the derivations that the ADAS1000 allows us in its configuration. Subsequently, in future lines, we intend to improve the filtering and acquisition stage to capture high quality signals. These signals can be acquired directly from normal patients or those who present some type of cardiac pathology, to carry out studies for the development of tools that support and facilitate the early detection of cardiac anomalies.

THEORETICAL BASIS

Electrocardiogram

The heart can produce an action potential in the various myocardial fibers. The algebraic sum of each action potential is represented by the ECG (electrocardiogram). Fig. 1 shows the conduction system of the heart and the cardiac signal corresponding to each stage. (Dubin, 2011).

An electrocardiogram is the graphic representation of the electrical activity of the heart, generally to be displayed on a millimeter paper, where the vertical axis is the amplitude of the electrical pulse in millivolts [mV] each millimeter is 0.1 mV, while the horizontal axis represents the elapsed time in seconds [s] each millimeter without 0.04 seconds. (My EKG, 2013).

The ECG is made up of waves that have been named P, Q, R, S, T, U, joined by an isoelectric line, as shown in Figure 2

The P wave has an average duration of less than 0.10 s and a maximum voltage of 0.25 mV. The Q wave lasts approximately 0.04 s in width and 0.2 mV in amplitude. The QRS complex has a duration of approximately 0.06 s to 0.1 s. The T wave has a maximum amplitude of 0.5 mV. The U wave is not very visible and of low importance in ECGs.

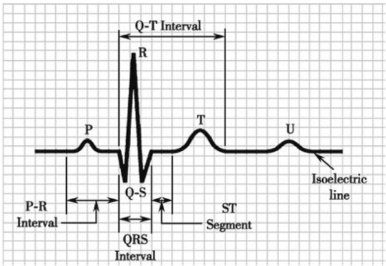

Figure 2: Ondas P, Q, R, S, T y U dentro de un ECG (Barret et al., 2013).

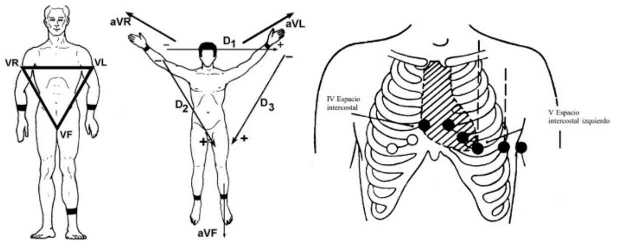

Figure 3: (a) Standard leads (García, 2017). (b) Augmented leads (García, 2017). (c) Precordial leads (García, 2017).

Cardiac Leads

Depending on the location of the electrodes, different projections of the cardiographic vector (vectocardiogram1) can be captured. They can be classified into 3 groups: three standard leads Figure 3 (a) (I, II, III), three augmented leads Figure 3 (b) (aVR, aVL, aVF) and six precordial leads Figure 3 (c) (V1, V2, V3, V4, V5, V6). (García, 2017).

PROTOTYPE DESIGN

Structure of the ADAS1000

This integrated circuit is designed to simplify the acquisition of biomedical signals, specifically electrocardiographic signals and respiration signals through surface electrodes. It operates at a frequency of 8,192MHz provided by an external oscillator connected to the respective pins.

Analog Devices proposes an example of connection to be followed for its correct operation (Analog Devices, 2013).

The input structure of the ADAS1000 is a differential amplifier, allowing users to choose from a variety of configuration options to best suit their application. It also has 5 analog inputs (connection of the LA, LL, RA, V1, V2 electrodes) used for biosignal acquisition, plus 6 inputs to measure respiration rate, and finally a reference unit. (RLD).

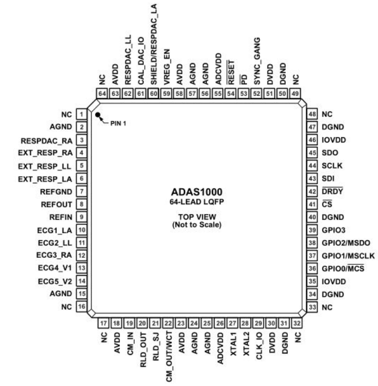

Figure 4: ADAS1000 pin layout (Analog Devices, 2013).

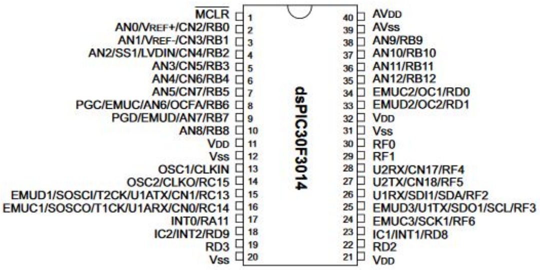

Figure 5: Pin layout of the dspic30F4013 (Microchip, 2012).

Structure of the DSPIC30F4013

It is a digital signal controller working at 16 bits, suitable for various general purpose and audio applications, with a 48 Kb program memory, a 12-bit analog-to-digital converter and communications: I2C, SPI, CAN and 2 UARTs. This device was chosen for the prototype due to its ease of use in programming and communication with different peripherals. (Microchip, 2012).

SPI Communication Protocol

SPI is an acronym for Serial Peripherical Interface (SPI). SPI is a synchronous protocol that works in full duplex mode to receive and transmit information, allowing two devices to communicate with each other at the same time using different channels or different lines on the same cable. Being a synchronous protocol, the system has an additional line to the data line in charge of carrying out the synchronism process.

In the case of this prototype, the ADAS1000 device would act as the slave, while the microcontroller would act as the master.

UART Communication Protocol

Universal Asynchronous Receiver and Transmitter, the communication mode for a serial port refers to the way in which information packets are sent and received. (Microchip, 2012).

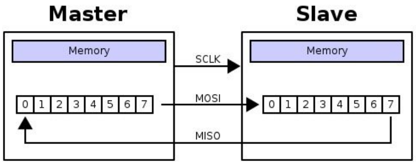

Figure 6: General structure of the SPI protocol (Microchip, 2012).

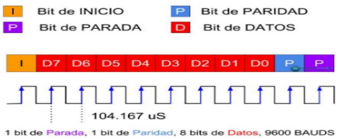

Figure 7: Frame for sending data via 8-bit UART communication.

Table 1. Sending a frame.

Bits	31	30:24	23:0
Function	Read or write bit	Address bits	Data bits (MSB first)

According to the type of connection, a UART has separate transmission and reception lines. This feature allows it to operate the three asynchronous communication modes that exist. The communication modes are: Full-duplex, Half-duplex, Simplex. The latter is the communication mode used for data transmission from the microcontroller to the PC or Android device.

FIRMWARE

Communication Between DSPIC and ADAS1000

The communication between DSPIC and ADAS1000 will be done through SPI, being the DSPIC the master and the ADAS1000 the slave. The ADAS1000 is controlled by 32-bit registers. Since the DSPIC30F4013 has an 8-bit SPI, a communication protocol was established between these two devices that consists of sending 4 8-bit words for each instruction.

The frame accepted by the ADAS1000 is as follows:

In the protocol designed for this prototype the communication is done in the following way:

1. 8 bits are sent [31:24] indicating whether the instruction will be a read/write instruction and the register address.
2. The data bits [23:0] are sent, dividing them into 3 packets of 8 bits.

The ADAS1000 has several registers to be configured in many ways, for this project only the following registers will be used: CMREFCTL, FRMCTL, ECGCTL and FRAMES.

CMREFCTL: configures the common mode and reference.

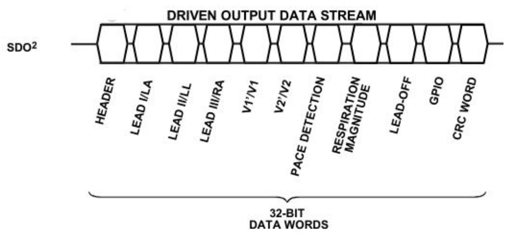

Figure 8: Output frame from ADAS to DSPIC (Microchip, 2012).

Table 2. Modified frame.

Header	LA	LL	RA	V1	V2	PACE

FRMCTL: configures and controls the data header.
ECGCTL: controls the ECG.
FRAMES: register to start transmitting.

For this prototype the ADAS will be configured as follows:

- 5 electrodes
- Gain of x1.4
- Common mode with all electrodes

The output frame from the ADAS1000 is as follows:

Esta trama fue modificada al configurar el registro FRMCTL de esta forma se reduce a la siguiente tabla:

Thus, the data frame has 7 words and each word has a dimension of 32 bits.

Communication Between DSPIC and PC

Each word sent by the ADAS1000 to the microcontroller is 32 bits in size, therefore, each data will be stored in 4 variables of 8 bits to be sent by UART communication to the PC or a SMARTHPHONE.

In this way, to send a complete frame it is necessary to make 4 UART transmissions. It is necessary to implement an identifier and send the data in the correct order, so that when the data is received by the PC, it can be treated and handled in the correct way. In our case, the identifiers are the letters A to E for each lead and the letter F for the cardiac pulse. On the PC we must interpret these data in the correct order in order to be able to plot them.

Communication Between DSPIC and SMARTPHONE

For the communication between the dsPIC and an Android cell phone we will use the BLUETOOTH communication protocol, for this we used a Bluetooth HC-05 module and developed an APP in Android Studio for the visualization of the cardiac signal. To receive the data in the Android device, a scan of the available devices is performed, once this is done, we proceed with the pairing, it will only ask for a password the first time it is connected. Once the

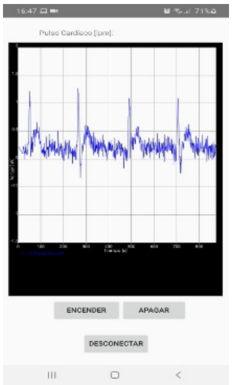

Figure 9: Cardiac signal display in the mobile application.

pairing process is completed, the service begins to receive the signal sent by the Bluetooth module.

The A Chart Engine (ACE) library was used for the real-time charting, since it has several advantages over other libraries, one of which is its ease of use and compatibility with Bluetooth.

CONCLUSION

The design was based on the integrated circuit from Analog Devices, the ADAS1000, an integrated circuit that functions as the first phase in the acquisition of cardiac signals. The circuit, electrical diagrams and other components were designed for the development of this prototype. Likewise, a PCB board was designed with the recommendations and specifications established by the manufacturer. Also, a firmware was created to allow the control and configuration of the ADAS from a dsPIC30F4013. A case was developed to facilitate the handling and use of the prototype. Finally, due to the limitations caused by the COVID-19 virus pandemic, tests were not performed on different patients, but were carried out among the writers of this article.

We have succeeded in developing a device capable of capturing cardiac signals in real time, which can be sent wired and wirelessly to end devices for display. The device is small and low power consumption compared to those available on the market. However, when observing the signals obtained and comparing them with other similar devices, it is concluded that these signals are of low quality, provide little information and present high levels of noise. The configuration of the ADAS1000 integrated circuit is highly complex because the existing documentation is deficient and generalized, the manufacturer provides a data sheet and connection diagrams, but recommends acquiring its evaluation board (EVALUATION BOARD ADAS1000), rather than programming and configuring from scratch as it was done in this project; not to mention that there is little information in discussion forums on the Internet.

Although the signals obtained are not of sufficient quality to be studied by the clinical field, since they should overcome a series of regulations and requirements more detailed than those mentioned in this project; the prototype could be of great utility within the research group of the university, so that in future works a filter or circuit can be developed to clarify the signal.

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