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Front-End Circuit For Six ECG Precordial Leads, With Signal Processing And Graphic Interface

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Abstract **–** On this paper we propose a system for 6 precordial ECG leads acquisition, the system intends to offer a portable, stable, and low noise electrocardiograph, energized with a self-designed power source focused on biopotential signals conditioning and a mean for transmission, storage, and processing the signals. The whole system consists of a development board that has the low noise power source and a microcontroller for data digitization, a 6 precordial lead acquisition system with patient security circuit complying with IEC normative, an USB-TTL communication device for data transmission, and a graphic interface for managing, saving and signal processing. This work focuses on the integration of a whole system that could significantly ease the acquisition and processing of ECG signals, and on making the system viable for portable applications, also it intends to facilitate the recognition of some valuable characteristics of the signals, so that it can be used on places where there are no specialty doctors, and people can be faster addressed to be treated for possible cardiac diseases.

Keywords**:** Biomedical instrumentation - Electrocardiography - Signal processing - Precordial leads

1. Introduction

In Mexico in 2021, there were 177 thousand deaths related with cardiovascular diseases, most of these have to do with myocardial infarction, but some other are related with infections, endocarditis, valvulitis, cardiac insufficiency and arrythmias [1]. This gives a big importance on the early detection or accurate monitoring of ECG signals irregularities. For this purpose, on this work we give an electrocardiographic system proposal that should accomplish electrical regulations required for medical equipment, given by the IEC 60601-1 rule.

The electrical protection circuit intends to offer a discharge path for current in case the voltage energizing the circuit overpasses the clamping voltage of varistors, these elements show a high resistance at low voltages and a low resistance at high voltages [2]. When the proposed circuit is functioning, the protection will work towards the ECG equipment and the patient at the same time. Also, the system works with precordial leads, thus a Wilson's Central Terminal (WCT) circuit was added to the design, to give the reference for these leads [3], WCT functions as a reference point for unipolar leads, and gives the average signal from three limbs, on Figure 1 the diagram of the virtual point that the WCT makes in the body is shown.

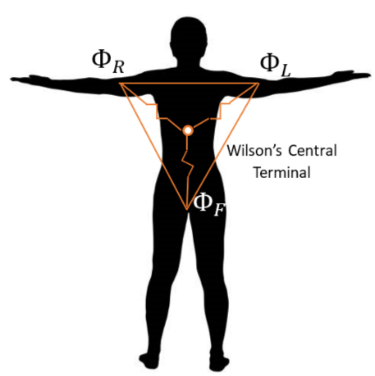

Fig. 1: Schematic of WCT, virtual reference for precordial leads.

For the processing of signals, the transmission was made via an USB-TTL converter, the processing of signals for computing the cardiac frequency was made employing the Pan-Tompkins algorithm [4]. This one consists of isolating the

QRS complex, and counting the amount of QRS complexes present within a period. Pan-Tompkins algorithm functions making a high-pass filter and a low-pass filter, then it applies a derivative filter, where the components of higher amplitude are accentuated, later a squaring function is applied, here the absolute value of the signal point by point would give the same result, finally an integrating filter leaves only the envelope of the signal, which makes it easier to count the QRS complexes.

2. Methodology proposed

The system was divided into 5 main stages, first we ensured that the power source used for the acquisition system was stable, and low noise, hence the system uses a self-designed development board that has a symmetric, low noise voltage source. Afterwards a patient security circuit was tested and added, this one to guarantee a current maximum, in case of short circuit occurring. Later, the system has conditioning for the input signal that includes filters, amplification, and offset. As a next step there is analogue-digital conversion using the microcontroller from the development board, and serial communication with a computer and finally the last stage of the system is a graphic interface that makes possible the signal storage, and processing. These five stages are further explained on the Figure 2.

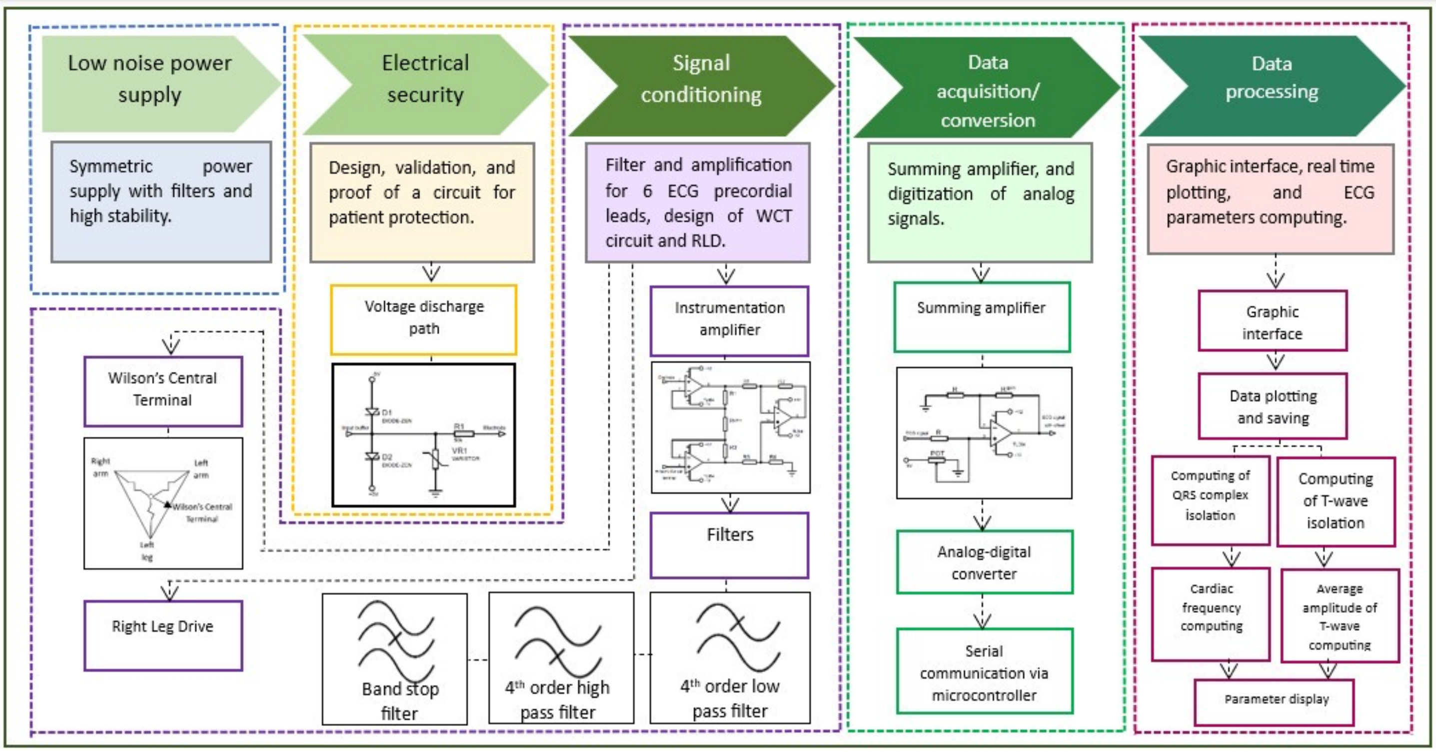

Fig. 2: Diagram block of the ECG system.

2.1. Development board

The chosen architecture for this system was a microcontroller, more specifically the ATmega328P, for its characteristics of having analogue-digital converters, being low cost, and reliable. This microcontroller was embedded on a self-designed circuit [5] which included a low noise symmetric voltage source, which is a development board, this one is schematized as a block diagram on Figure 3.

This tool made possible the signal conditioning circuit, which needs a symmetric voltage source, this source is designed targeting biopotential acquisition, so it has a good SNR, and a power source that is stable. Also, through the microcontroller the serial communication with a PC was made, this for the need of displaying the signal in real-time and to make the signal processing.

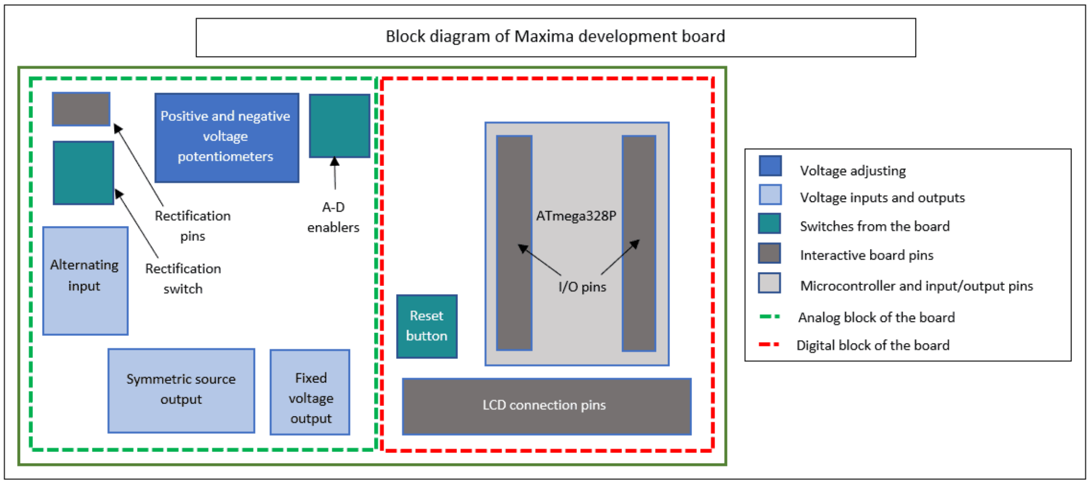

Fig. 3: Block diagram of development board.

2.2. Cardiac biopotential acquisition system

The signal acquisition was made through a conditioning circuit, which was powered with the development board previously mentioned, this circuit was designed for precordial lead acquisition, so that it included a patient security circuit, a Wilson's Central Terminal circuit, and a Right Leg Drive to enhance the common mode rejection ratio. The patient security circuit was tested on short circuit conditions, the circuit consists of two Zener diodes, a varistor and a resistor, all of this placed before the electrode as it is shown on Figure 4.

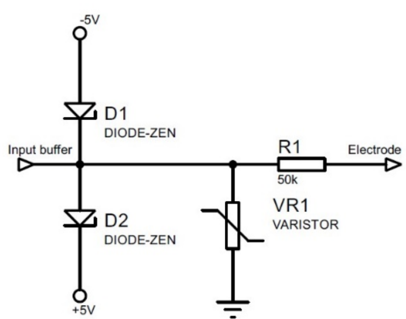

Fig. 4: Protection circuit.

The conditioning system includes an instrumentation amplifier with a gain of 39 [dB], a band-pass filter of 8th order, a Notch filter for supressing the power line frequency, an additional amplification of 33.97 [dB] and finally a summing amplifier, this last one was added for the purpose of digitizing the signal.

2.3. Graphic interface

The graphic interface was designed to allow a more user-friendly way to interact with the acquisition system, the interface was developed using App Designer from MATLAB, with this it is possible to plot the signal on real time, later the acquired signals are saved to a .csv file, once they are saved, they are processed to acquire the cardiac frequency and the T-wave amplitude. The frequency was computed through the Pan-Tompkins algorithm and then the standard deviation between the frequency computed for each lead was obtained.

For the T-wave amplitude computing a low-pass filter was applied, this one allowed the T-wave to be isolated, later the signal was sectioned, and the average of the signal was subtracted, the maximums at each interval were computed and finally an average was acquired to show the result of the T-wave amplitude; finally, the graphic interface has a function to show the results of this calculations.

3. Results

The complete system was tested, with different incoming signals, to check for correct functioning of its different stages. The conditioned signal at the output of the acquisition circuit, was an analogue signal, with a voltage between 0 and 4 [V], with minimal level of noise, the SNR was measured, and gave an average value of 31. 08 [dB]. This output had the characteristics to be accurately digitized; the digitized signal was finally returned to its original voltage values, through code.

The graphic interface designed is shown in Figure 5. There are different parts to this one, with the possibility to visualize previously stored signals, but also to save the new ones that are being acquired on real time. It has two buttons to directly visualize the simulations done with Simulink and MATLAB, these buttons are the ones that compute de BPM and T-wave amplitude, and when there are values of BPM and T-wave amplitude that are locally stored, there's the possibility to save them to a new file.

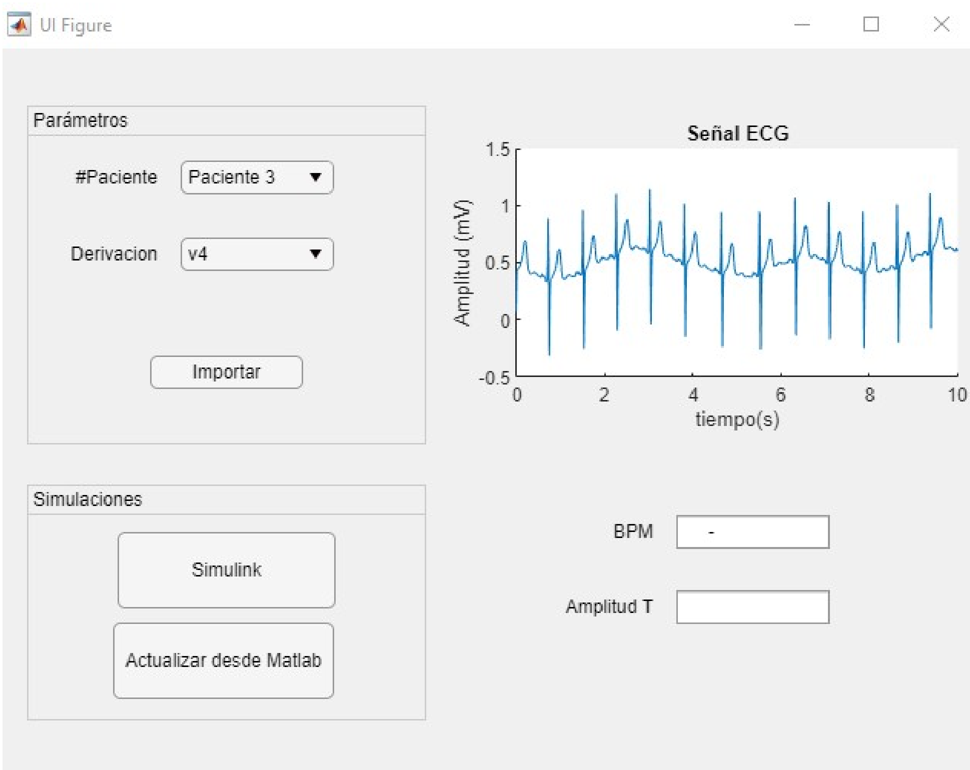

Fig. 5 Graphic interface developed with App Designer.

Finally for the signal processing, the algorithm was validated with signals acquired from the PTB Diagnostic ECG Database from Physio Net [6], we took signals from 10 patients and the algorithm was tested for all leads of a common medical ECG. The cardiac frequency and the T-wave amplitude was compared between the reported value and the one computed by the algorithm. The results for only one patient of this are shown in Table 1, as for the cardiac frequency the standard deviation of the computed result was calculated, given the signal for all leads is taken at the same moment, the frequency should be equal in all leads. The average value of the cardiac frequency was of 72.64 BPM and a standard

deviation of ±2.69 BPM. The algorithm for computing the cardiac frequency worked with a good precision although it can be improved, also the deviation was higher for standard and augmented leads, so specific treatment of this leads would be needed. The value of the T-wave could be measured directly on the Physio Net page, so that value was compared with the one the algorithm computed to calculate the accuracy.
The 12 different leads, have different nomenclatures precordial leads are distinguished with a V, giving V1-V6 leads, standard leads are distinguished by I, II, and III and finally augmented leads are written like aVR, aVL and aVF.

Table 1: Results of performance for computing algorithms.

Cardiac lead	BPM	T wave amplitude by algorithm [mV]	T wave amplitude by database [mV]	Accuracy on T-wave amplitude %
V1	71.09	0.24	0.20	77.36
V2	70.92	0.47	0.35	90.11
V3	70.92	0.85	0.48	61.14
V4	70.83	0.41	0.40	91.81
V5	71.00	0.44	0.45	93.02
V6	71.09	0.45	0.45	91.83
I	70.75	0.07	0.10	85.46
II	78.74	0.30	0.40	91.51
III	75.37	0.30	0.25	95.45
aVR	71.00	0.70	0.35	78.63
aVL	75.00	0.10	0.07	93.31
aVF	75.00|	0.40	0.30	92.93

4. Conclusion

A precordial lead ECG system with graphic interface and signal processing was successfully developed, the system uses a low noise power source and a microcontroller to make correct A-D conversion and serial communication. This system could be further used for remote, or portable applications and it makes it easy to identify some very important characteristics of ECG signals, furthermore the processing stage could be applied for a system for all 12 ECG leads. The computing algorithm proved to have overall an accuracy higher than 75% for all leads, but this performance could be enhanced by adjusting parameters for each derivation.

The system shows a good performance for acquiring ECG signals for the 6 precordial leads, and for making signal storage and processing, overall, the performance could be enhanced, by using A-D converters of higher resolution, and making some adjustments to the algorithms.

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