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Development of a ECG remote monitoring system.

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Abstract. The continuous monitoring of cardiac activity using conventional electrocardiography systems restricts signals acquisition to specific locations such as hospitals and medical clinics, and Holters systems don't transmit the information about the electrocardiogram to the doctor and don't react if the patient suffers from a cardiac abnormality, they only record the information. Portable remote systems have shown to provide mobility and comfort to the patient by allowing signals acquisition anywhere. This paper shows a remote monitoring system of the cardiac activity capable of performing the acquisition of ECG signals using a smartphone having Android, Bluetooth® communication and 3G technology for processing and visualizing ECG signals. The designed system is battery powered and three electrodes are attached to the patient's chest to obtain the signals. It was developed a low consumption electronic circuit for acquiring and conditioning these signals using instrumentation and operational amplifiers. The processed ECG signal is then digitalized by an Arduino Nano, and transmitted by Bluetooth from Arduino to the patient's smartphone so it can be sent to a workstation through 3G technology where the electrocardiogram may be analyzed by a physician. The results obtained on the tests performed validate the developed prototype regarding the acquired ECG signals in the oscilloscope and the developed Android application, which were compared with the ECG signals obtained using a conventional electrocardiography system. The proposed system aims to perform signal acquisition and transmission independent of time and the patient's location, allow early diagnosis of cardiovascular diseases, reduce the number of the doctor's visits required, besides providing a device more comfortable to the patient during the monitoring of electrocardiogram signals while performing daily activities.

Keywords: *Electrocardiography, acquisition, conditioning, monitoring, wireless streaming, Android.*

Introduction. According to the World Health Organization (WHO), cardiovascular diseases (CVDs) such as acute myocardial infarction, coronary artery disease, arrhythmias and heart failure are the main causes of death in the according to the Brazilian Ministry of Health, are responsible for 29.4% of deaths per year, ranking Brazil among the 10 countries with the highest rates of mortality due to CVDs [1].

WHO advises that individuals diagnosed with CVDs and those with high cardiovascular risk, that have risk factors such as diabetes, hypertension and tobacco use are identified early and perform the appropriate guidance and medication [2]. In addition, certain cardiovascular diseases manifest themselves most commonly under normal conditions of daily activities. Of this, remote and continuous monitoring of cardiac activity is an important tool, because it enables a fast and efficient medical intervention in cases of health risk events of these individuals, thus ensuring more effective medical treatment as well as possible reduction consequences of manifestations of cardiovascular disease. However, the most traditional healthcare institutions in Brazil do not offer the level of supervision required for such a group of individuals, as electrocardiography systems conventional devices currently used impose restrictions on patients' restricting the acquisition of signs of such activity to specific locations such as hospitals and medical clinics. Holters systems record information about the electrocardiogram for later diagnosis, however, do not transmit such information to the doctor and do not react during the occurrence of any abnormality patient's heart rate or during some discomfort, making the development of remote and continuous monitoring systems of major cardiac activity importance [3, 4]. In addition, enormous pressure has been placed on health care to maintain the quality of care while the costs are reduced [5, 6, 7, 8].

Electrocardiography result, cardiac activity (represented in the electrocardiogram), when remotely transmitted, may provide diagnostic early CVDs and prompt medical care for people at risk of attack sudden heart, for example. Monitoring of electrocardiogram signals during patients' daily activities, it also has the advantage of reducing of the number of medical visits required. The remote system can be used by doctors to monitor patients recovering from a heart condition, presenting cardiac discomfort and risk. This directed at remote monitoring and the aforementioned benefits that this project was purchasing selected ECG signals that are independent of patient. ECG signals are the most accurate data for investigating a condition of the heart, electrocardiography systems used have great clinical value for the monitoring of signs of cardiac activity. In this way, for the systems to ECG can be used as a reliable diagnostic tool, it is development of a device capable of acquiring, amplifying, filtering and process the cardiac electrical signals used [9, 10, 11, 12].

The development of the remote monitoring system of the signals of electrocardiography of this study was divided into two periods. In the first, it was developed and implemented in an electronic system circuit. Three were used electrodes to perform the acquisition of these signals and the phases of amplification and filtering conditioned us requests for future processing. In the second stage, an arduino board microcontroller was used for preprocessing and continuous transmission of acquired ECG signals smartphone using Bluetooth® communication. The ECG tracing was then rebuilt on smartphone for real-time responses to electrical activity and their corresponding data were stored in a file for sent to the doctor later.

The objective of this work is the development of a monitoring system remote electrocardiography signals with continuous and wireless transmission of signals cardiac electrical activity through Bluetooth® communication and capable of recording these signals in a smartphone application of provide individuals with heart disease and those at risk the possibility of being monitored remotely by the physician without displacement is required to acquire cardiac signals.

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Materials and methods. The first stage is composed by acquisition system, conditioning and visualization of the developed ECG signals. It consists of three electrodes connected to the body, right-leg circuit, instrumentation amplifier, high pass filter, low pass filter, Twin-T Notch filter, gain stage with automatic control and offset circuit. The second stage of the project is development of microcontroller, Wireless transmission and smartphone applicative.

First stage: The developed ECG signal acquisition system is composed of an electrode reference electrode and two active electrodes that record the electrical activity by measuring the electrical potential difference between two points of the body surface, giving the characteristic of a single derivation system. To perform the pre-amplification of the ECG signal, the INA118 [13] instrumentation in the electronic circuit of the conditioning acquisition. In this project, a voltage gain of 17.6 V / V was configured with the value of the resistor RG equal to 3 kΩ to amplify the input signal so that it is possible to processing. The circuit designed to perform acquisition and amplification ECG signals was based on the scheme proposed by the amplifier datasheet in question, being powered by a 3.7 V battery.

The circuit of the ECG signal filtering step developed in the project consists of a Twin-T Notch 60 Hz filter and a bandpass filter consisting of a cascade association between two filters: a passive high pass, and a low pass Butterworth type asset. Prototype of the system proposed in this work is intended for remote monitoring of cardiac electrical activity, the bandwidth of frequency adopted was 0.5 Hz to 50 Hz. A high-pass filter with cutoff frequency of approximately 0.5 Hz, with the function of eliminating such low frequency signals and allow the passage of the components that make up the ECG signal.

A fourth-order active Butterworth low-pass filter was developed based on the association of two second-order filters, Sallen-Key topology, with a cut-off frequency of approximately 50 Hz and a quality factor of 0.7 in order to eliminate high frequency signals and allow the passage of the components that make up the ECG wave. The operational amplifiers used in the electronic circuit of the respective filter were LMC6036 integrated circuit (IC) circuit from Texas Instruments, which consists of four operational amplifiers [14]. Twint-T Notch active filter electronic circuit designed to eliminate the 60 Hz noise caused by interference from using a CI LMC6036 Operational Amplifier, as well as the resistors and capacitors present in the circuit. After amplified sufficiently the low and high noises frequencies can be eliminated by the filtering step, the ECG signal is amplified again by the gain stage, raising the output signal to order units of Volts, so that it can be processed by means of a microcontroller. The gain stage circuit was developed using a CI LMC6036 operational amplifier with the topology inverter and a digital potentiometer of the MCP41010 IC to provide a range of 4 to 44 V / V gain automatically controlled by the microcontroller to the ECG.

An offset circuit was developed to add a continuous voltage level. (DC) to the ECG output signal, being formed by an IC operational amplifier LMC6036 with non-inverting adder topology and a 20kΩ potentiometer. The output voltage of the offset circuit is determined by the sum between the output voltage of the amplification and filtering circuit ECG signal (VECG) and the

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continuous voltage supplied by the circuit developed in this section. In order to ensure protection and prevent possible damage to the microcontroller, Zener diode (D3) was added at the end of the circuit to ensure that the voltage of output is within the operating range of the microcontroller, never below 0V or above 5V, events that can be caused by patient's movement.

The designed and built electronic circuit contains active components INA118, LMC6036 and MCP41010. In relation to the needs of INA118 operates with dual polarity supply voltages between ± 1.35 V and ± 18 V, while the LMC6036 requires voltages between ± 2 V and ± 15 V To power the electronic circuit developed in this project, a Polymer Lithium-Ion battery with rated voltage of 3.7V and 4.1V, when fully charged, and 1500 mAh capacity. To generate the negative voltage required for amplifier ICs from the battery used, an inverter DC / DC converter circuit was developed which converts the positive voltage supplied by the battery to a voltage stable and constant negative.

It was using the Ultiboard software to develop the circuit board layout. (PCB or PCB) of the circuit of the acquisition and conditioning system of the ECG signals. The board was developed in a single layer area with an area of 14 cm by 5 cm where the copper trails were routed responsible for conducting the electrical current of the circuit. So eliminate ground loops, electromagnetic couplings and high frequency noise during the operation of the developed circuit, ground (large PCB covered areas) and decoupling capacitors between the pins supply voltage and reference of the integrated circuits used.

Second stage: Arduino was the card used to perform A / D conversion, preprocessing and Bluetooth® sending of the ECG signal. Arduino board features can be expanded using shields, which are generally small boards specific to each application. Arduino Nano does not have intrinsic Bluetooth® transmission, it was the use of a shield is necessary to obtain such functionality [15]. The chosen Bluetooth® shield was HC-06. For the HC-06 to be able to receive data sent by the Arduino Nano, you must connect the HC-06's “RXD” and “TX” (digital pin number 1)

Arduino Nano using a lead wire. Similarly, for the shield to be capable of sending data to the Arduino, the shield “TXD” pins must be connected to the “RX” (digital pin number 0). Since the supply voltage of the HC-06 is 3.3 V, the “VCC” pin of the shield must be connected to the Arduino Nano “3.3 V” pin and the reference (“GND”) on the HC-06 must be connected to the Arduino “GND” pin. Since the recommended supply voltage of the HC-06 is 3.3 V and the pins are Arduino digital devices offer 5 V voltage, voltage divider to condition the input signal of the shield “RXD” pin. Given away the circuit of figure 3.17, where Vin is the 5 V voltage of the Arduino and Vout pin “TX” is the input voltage of shield “RXD” pin. The project firmware was developed in C programming language in the

Arduino IDE development environment. It was segmented into two phases. In the first step, commands for reading and scanning were implemented. ECG analog signal, transforming the digital data to the desired format and data transmission to the Bluetooth® shield. In the second step, commands for automatic control of the digital potentiometer are implemented Arduino will continuously read the analog signal from pin A6 (pin on which the ECG signal will be input). With

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each reading, input voltage is converted by the Arduino A / D converter to a number of 0 to 1023 to facilitate the implementation of the communication protocol between Arduino and the smartphone, the signal is sent by Bluetooth® in four-way format. Two digits together with an exclamation mark at the end. Two thresholds were established for increasing or decreasing the gain of the potentiometer. The gain is increased if the maximum value read is less than 600, and is decreased if the maximum is greater than 950 (on the digitized scale from 0 to 1023). The maximum gain is defined, established through saturation tests of the acquired signals.

An Android app has been developed for graphical visualization an ECG signals storage on smartphone. The Android Operating System was chosen for its popularity today. The app is responsible for:

• Connect the patient's smartphone to the HC-06 shield;

• Receive, via Bluetooth® protocol, scanned ECG signals transmitted by shield HC-06;

• Perform processing of received data;

• Rebuild the ECG signal;

• Store the data in a file on the smartphone for later sending to the doctor or specialist.

Two applications were developed to achieve the above features. The first app was developed using MIT App Inventor 2 (inventor of applications at the Massachusetts Institute of Technology). Because of platform limitations, such an application did not meet project needs and therefore, a second application was developed using the IDE (Desktop Environment). Integrated Development) Android Studio. The limitations of the first application and the The results of both will be discussed later in the Results and Discussions.

Java language code for the developed application has been added on the GitHub platform in the repository from the following address: https://github.com/Nathyunkim/MonitorECG. Three classes were implemented in the software development. The “MainActivity” class, the application's main class, the “DeviceList” class, responsible for creating a list of devices paired with the smartphone, and finally the “ThreadConexao” class, which implements secondary thread for the Bluetooth® connection.

Results and discussion.

To perform the acquisition of ECG signals, were placed in the body of the authored three Ag / AgCl Meditrace 200 electrodes from manufacturer Kendall in the form of a triangle. The ECG signals acquired and conditioned by the developed circuit, were monitored on its output and viewed through a digital oscilloscope Tektronix TDS 1012C-EDU model with 100 MHz frequency response and sampling frequency of 100 Ms / s. Such characteristics of the respective the oscilloscope allows the real-time visualization of the ECG signals as the sampling frequency exceeds the frequency band of the chosen ECG signal. In this job. Figure 1 shows the monitored ECG signals on the board output circuit board of ECG signal acquisition and conditioning system.

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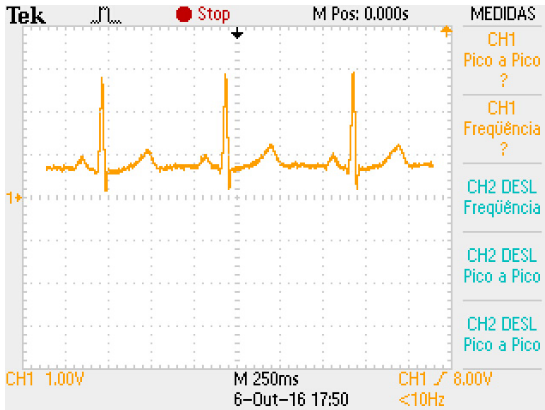

Fig. 1: ECG signals monitored by oscilloscope, on circuit output.

Figure 2 show the prototype monitoring system remote of electrocardiography signals and smartphone with Android app used during the tests and analyzes, both developed in this work. It is possible to identify the waves P, Q, R, S and T of the ECG signal. The graphics obtained in the second application are substantially similar to conventional electrocardiograph charts.

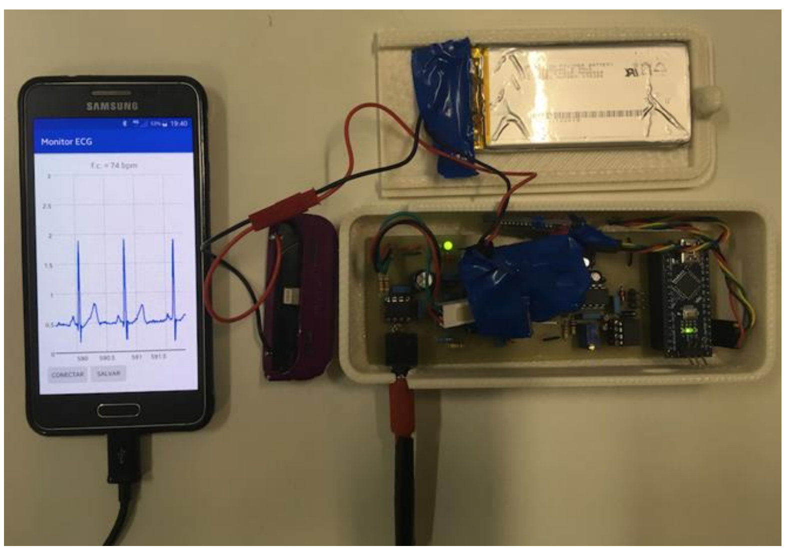

Fig. 2: Prototype tests, mobile phone and ECG system module developed.

The prototype of such developed system is powered by mobile phone battery with period continuous operation around 60 hours, and composed of three electrodes responsible for obtaining the ECG signals, acquisition and conditioning module, processing and transmission module and module for displaying such signals on a smartphone.

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One of the features of the second Android app is storage data received in a text file for later expert. In the file, both the received data and the time that is enough information to plot ECG graph. Figure 3 shows the ECG trace plotted on computer from an application-generated file.

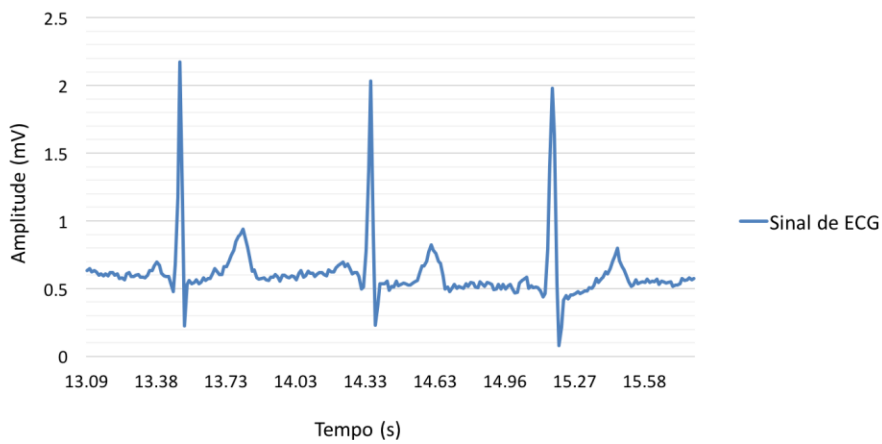

Fig. 3: ECG signal at the computer, acquired by the app.

Conclusion.

The system proposed in this work for the remote monitoring of the signals of ECG using a smartphone with Android system, Bluetooth® communication and 3G technology to process and visualize such signals has been successfully developed. The ECG signals obtained electrodes used were amplified and properly filtered by the circuit, low noise level and were processed by the Arduino Nano properly. Thus, the signal acquisition and conditioning module developed ECG met the expectations and enabled the acquisition of the signs of cardiac electrical activity efficiently and satisfactorily. It is also possible to identify the P, Q, R, S and T waves of the ECG similarity to conventional electrocardiograph charts and provides important information on heart activity such as frequency and rhythm. One can conclude that the remote and real-time monitoring performed by the second application was sufficient to achieve the objective proposed by the project.

Disclosure. The authors report no conflicts of interest in this work.

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