ISSN(Online): 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2016

Heart Rate Detection Using Bio-impedance Measurement

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ABSTRACT: In biomedical application bio-impedance is proving to be one of the major parameter in detection and analysis of diseases as well as different body conditions. Bio-impedance is the opposition offered by living tissues to the current flowing through it. In proposed work, it is used to detect heart rate. A technique for heart rate detection on a standing subject is presented that depends on electrical impedance variations using a plantar electrode interface with both feet. These electrodes are similar to those electrodes which are used in bathroom weighting scales for body composition analysis. The impedance variations related to heart in the legs come from arterial blood circulation. The filtered bio-impedance signal is processed using ARM7 to detect heart rate. Bio-impedance signal and ECG signal are compared using MATLAB.

KEYWORDS: Bio-impedance analysis, heart rate detection, plantar bio-impedance, monitoring heart performance.

I. INTRODUCTION

In biomedical engineering, bio-impedance is a term used to describe the response of a living tissue to the electric current applied externally. It is a measure of the opposition to the flow of electric current through the tissues. The measurement of the bio-impedance of the humans and animals has proved useful as a non-invasive method for measuring such things as blood flow (often referred to as bio-impedance plethysmography) [1] and body composition (known as bioelectrical impedance analysis or simply BIA).

In bio-impedance plethysmography [5], the measure is sometimes based on pulsatile blood volume changes in the aorta. Bio-impedance is appropriate to the development of devices to measure cardiac output and circulating blood volume. Electrical conductivity can vary as a result of breathing. In cardiovascular studies, bio-electrical impedance measurements allow us to non-invasively obtain information about the stroke volume, cardiac output, venous circulation, arterial compliance, and heart rate. Usually, these measurements are performed on the chest and/or limbs by placing surface electrodes, with cumbersome leads, after skin preparation, which asks for a specialized training [2]. The drawbacks are common to all non-invasive bio-impedance measurements. To overcome them, several systems have been proposed and developed by Delia Diaz, Oscar Casas with simpler body interfaces, such as those in bathroom scales that offer bio-impedance analysis (BIA) for body-fat composition measurement. These systems inject a safe AC current into the patient through the soles of both feet and measure basal impedance, which is related to body composition [4]. The time required for this measurement is very short as it does not require any skin preparation, neither any specialized skill to operate the device. However, the only information obtained is about body composition. We proposed a technique to detect impedance variations in lower limbs from plantar bio-impedance measurements. Here we describe how to measure heart-related impedance changes when standing, by using four platform-type aluminium electrodes. The result is a system able to detect the heart rate without attaching any electrodes to the patient

The rest of the paper is organized as follows, in section 2 some description about previous work done in the similar domain is presented, system model is presented in section 3, Section 4 describes the methodologies for the proposed work and also describes block diagram of the corresponding system along with the implementation of the system, this section includes the hardware portion and software constrains of the system. In section 5 results are shown and at last in section 6 conclusion and future scope is drown.

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II. Related work

Previous work by T.M.R. Shankar, Webster and Shao shows that in lower limbs there are low-level heart-related impedance variations. So far, these variations are detected using cumbersome band-type electrodes attached to the limb, to obtain hemodynamic information (and the heart rate) [12].

Rafael Gonzalez-Landaeta, Ramon Pallas-Areny, [1] proposed a system in which the impedance variations are measured using the four-electrode technique to minimize the effect of electrode contact impedance. They designed a single-ended current source based on a Wien bridge and a current conveyor circuit, which generates a 10-kHz, 1-mA (rms) current, hence innocuous for external application. The first amplifier stage is a fully differential AC-coupled amplifier. The DC impedance component (basal impedance Z_0) is about one thousand times the alternating component. Therefore, the gain of the first stage must be small, otherwise its output voltage would saturate. To preserve the SNR, the signal to be demodulated must be a band pass signal. Once the bio-impedance signal has been demodulated and the basal impedance has been filtered out, it is necessary to amplify the AC component obtained. Because of the low level of these heart-related impedance variations, we need a large enough gain but at the same time not so high as to lead to output voltage saturation because of voltage offsets from the amplifiers [2,4]. Figure shows the electrodes for the plantar bio-impedance measurement in both feet.

Delia H. Diaz, Oscar Casas and Ramon Pallas-Areny [3] proposed a technique to detect heart rate from single-foot plantar bio-impedance measurements in a weighing scale for the people with a single leg or people that wear electronic medical implants.

III. System Model

The system model includes both ECG signal generator and impedance signal generator. ECG we are getting from the ECG electrode and impedance we are getting from plantar interface. The overall flow of processes carried out for proposed system is shown in Fig. 3.1.

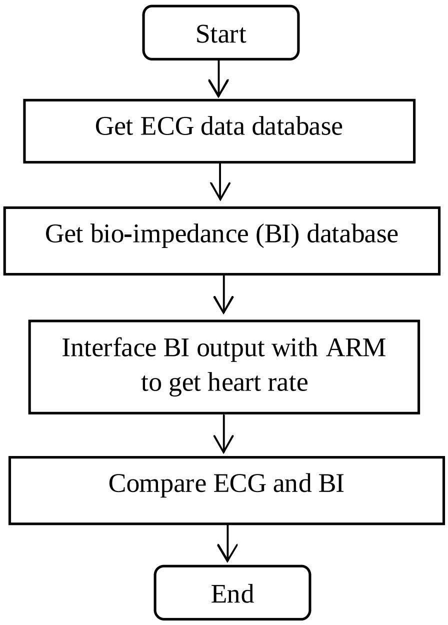

Fig.3.1. Flow Chart of Proposed System

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IV. PROPOSED METHODOLOGY

All blood vessels are abundant. Arterial distensibility helps in providing an adequate peripheral resistance to the arterial blood flow [1], and this distensibility results in an arterial volume change at each heartbeat, more appreciable in the body areas with less overlying tissue. A model in that relates impedance variations to changes in blood volume and resistivity in limbs, assumed to be cylindrical, leads to

$$\Delta V = \frac{-\rho L^2}{Z_0^2}(\Delta Z_\rho + \Delta Z_v) \qquad \text{eq. (1)}$$

In eq. (1) ΔV is the volume changing in arteries, L the length of the section of arteries between the voltage electrodes, ρ the blood resistivity and Z_0^2 the basal impedance of the non-pulsatile tissues. Z_ρ is the impedance variations due to the blood resistivity change. Z_v is the impedance variation due to the volume change.

As impedance changes are heart related, it should be possible to obtain the heart rate from impedance measurements between the two points on the surface of a volume that encloses major blood vessels that is from feet. If an electrical current is injected in both feet soles, and the drop in voltage is measured between the same feet, the current path includes both legs.

Proposed system block diagram is shown in Fig. 4.1. ECG signal and bio-impedance signal is simultaneously measured using the block diagram shown in figure 2 in which we are using ARM7 LPC2138 board. One port of ARM 7 is connected to the ECG circuit and another port is connected to the AD5933 impedance analyzer. Here we are using tetra polar electrode configuration hence using the AD5933 extension circuit which will provide the tetra polar leads and we are connecting these leads to the TUT (Tissue Under Test). Similarly, ECG signal is obtained using ECG circuit and the graph we can plot using MATLAB on PC.

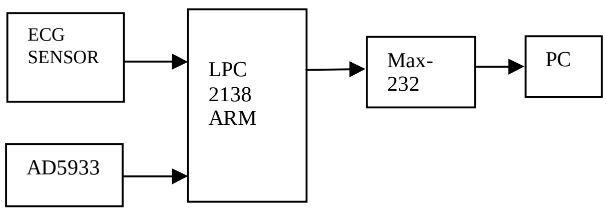

Fig.4.1 Block Diagram of the proposed system

Any system design is a combination of software and hardware. The system proposed in section III is detailed in further two subsections.

A. *Hardware Details:*

The hardware consists of a microcontroller ARMLPC2138, ECG sensor, AD5933 impedance analyzer, MAX232 and LCD to display the final value of impedance measurement.

A.1. Micro-controller

Here we have used ARM LPC 2138 microcontroller. Micro controller is a computer on single chip. The design incorporate the entire feature found in a microprocessor.

Like microprocessor, a micro controller is a general-purpose device, in which data is read, limited calculations on that data are performed and environment based in these calculations are controlled. The prime use of micro controller is to control the operation by a micro controller using a fixed program that is stored in ROM and it doesn't change over the lifetime of the system.

The LPC2138 microcontrollers are based on a 16-bit/32-bit ARM7TDMI-S CPU with real-time emulation and embedded trace support, that combine microcontroller with embedded high-speed flash memory ranging from 32 KB to 512 KB. A 128-bit wide memory interface and unique accelerator architecture enable 32-bit code execution at the maximum clock rate. Due to their tiny size and low power consumption, LPC2138 are ideal for applications where reduction in size, access control and point-of-sale are key requirements. Serial communications interfaces ranging from a USB, multiple UARTs, SPI, SSP to I2C-bus and on-chip SRAM make these devices very well suited for communication gateways and protocol converters.

 DOI: 10.15680/IJIRCCE.2016. 0407019

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Vol. 4, Issue 7, July 2016

A.2. ECG Sensor

The AD620 based module is a cost-effective board used to measure the electrical activity of the heart. This electrical activity can be plotted as an ECG or Electrocardiogram and output as an analog reading. ECGs can be extremely noisy, AD620 Single Lead Heart Rate Monitor acts as an instrumental op amp to help obtain a clear signal from the PR and QT Intervals easily. ECG sensor based on AD8232 use as a sensor for the proper ECG signal detection through the disposable electrode which are attached to both hands and left leg. Electrode connected to the sensor which correctly process the vibrations detected by the electrode due to this gives multiple readings of signals from multiple patients.

A.3. Impedance Analyzer

We have used AD5933 impedance analyzer. The AD5933 is a high precision impedance converter system solution that combines an on-board frequency generator with a 12-bit, 1 MSPS, analog-to-digital converter (ADC). The frequency generator allows an external complex impedance to be excited with a known frequency. The response signal from the impedance is sampled by the on-board ADC and a discrete Fourier transform (DFT) is processed by an on-board DSP engine. The DFT algorithm returns a real (R) and imaginary (I) data-word at each output frequency.

Once calibrated, the magnitude of the impedance and relative phase of the impedance at each frequency point along the sweep is easily calculated. We can use multi-frequency to analyze the tissue properly [7]. The real and imaginary register contents after DFT can be read from the serial I2C interface. AD5933 provide us 2 electrode leads but as we require four electrode configurations we have used AD5933 extension circuit [6].

B. *Implementation*

The hardware schematic is shown in Fig. 4.2. The implementation of proposed system includes ARM7 which is implemented along with the ECG circuit, AD5933, extension circuit, plantar electrode interface, power circuit, and LCD implementation. Fig. 4.3 shows the hardware implementation for ECG and impedance measurements. Here ECG measurement we are getting from the regular ECG electrodes connected to the right arm, left arm, and left leg, whereas impedance measurement we are getting from the plantar interface made of aluminum.

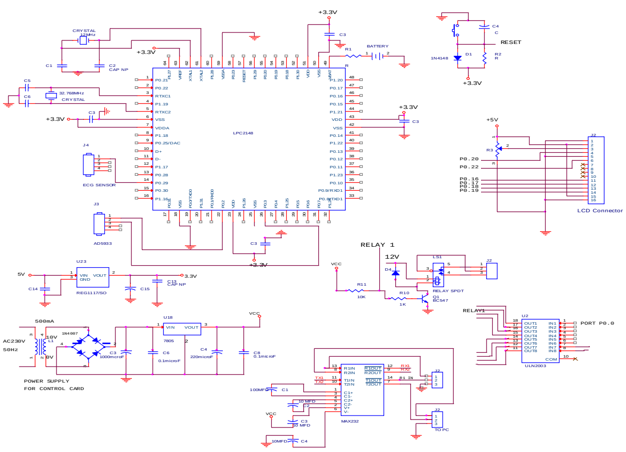

Fig.4.2 Hardware Schematic

Fig. 4.4 shows complete hardware setup with ECG electrode connection and hardware is connected to the PC so as to read data from pc and plot graphs in MATLAB.

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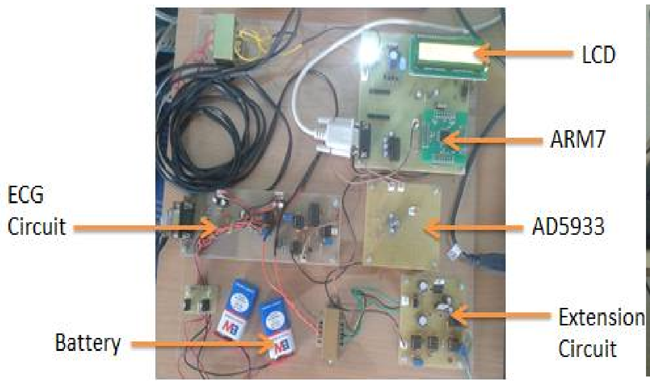

Fig 4.3 Hardware Implementation

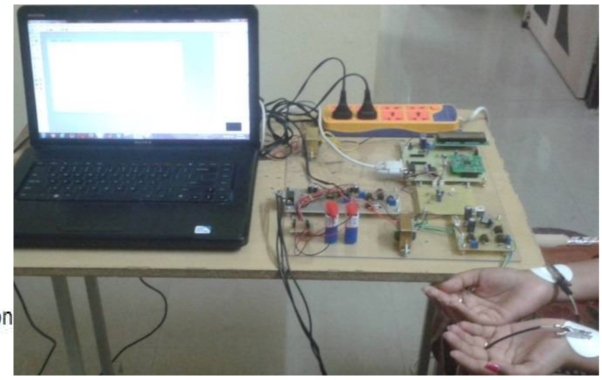

Fig.4.4. Hardware Setup

V. EXPERIMENTAL RESULTS

The experimental result is divided into two parts. First we have obtained ECG and impedance plot from the database and then we have compared the ECG and impedance measurement technique using Bland-Altman plot.

I. ECG and Bio-impedance Signals

We have analyzed both ECG and Bio-impedance signal for various volunteers. ECG measurements are obtained by applying the ECG electrode from ECG circuit and impedance measurements by applying current to the plantar tissue. The database is created and graph is plotted simultaneously using MATLAB as shown in Fig, 5.1 and 5.2.

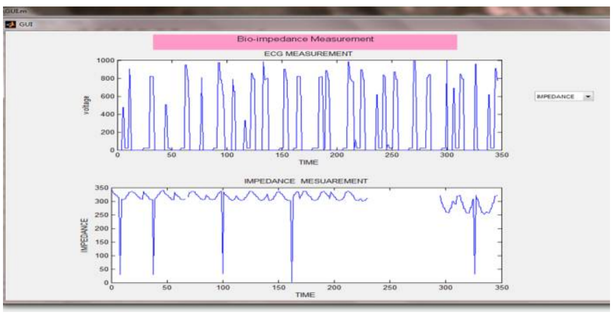

Fig.5.1. ECG and Bio-impedance Plot for Volunteer 1

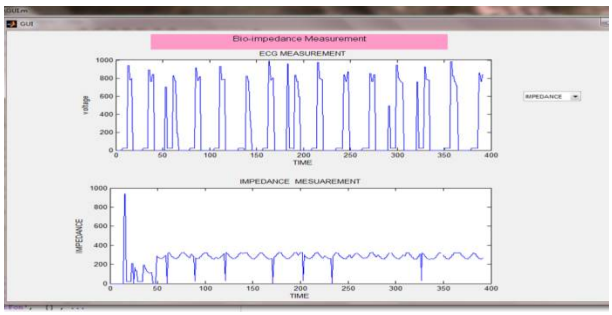

Fig.5.2. ECG and Bio-impedance Plot for Volunteer 2

In both Fig. 5.1 and Fig. 5.2 we can see that upper trace is the plot of ECG measurement and bottom trace is the plot of impedance measurement.

II. Bland-Altman Plot

Bland-Altman plot is used to compare two techniques. In this plot the differences between the two methods are plotted against the averages of the two methods. Here we have compared ECG and bio-impedance signals. To compare these two techniques we have taken some selected values by setting one threshold, RR time interval for ECG signal and bio-impedance signal is calculated and these values of RR time interval are used for Bland-Altman plot. The plot is shown in Fig. 5.3.

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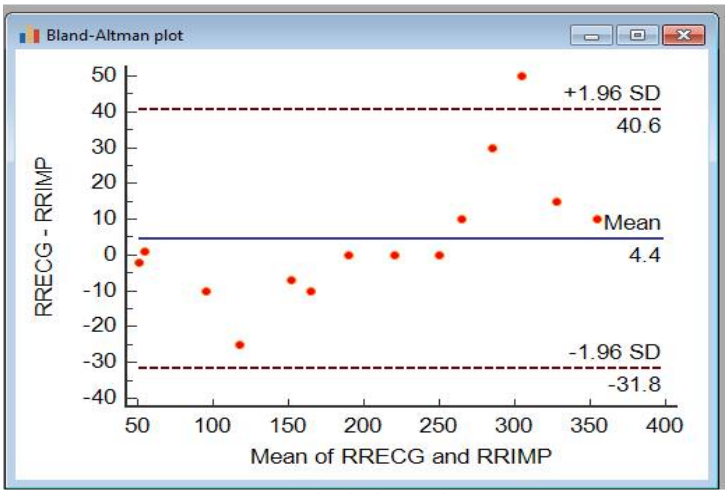

Fig.5.3. Bland-Altman Plot

Horizontal lines are drawn at the mean difference, and at the limits of agreement, which are defined as the mean difference plus and minus 1.96 times the standard deviation of the differences.

VI. Conclusion and Future Work

A non-invasive technique for heart rate detection is presented which uses plantar bio-impedance measurements. The ECG and plantar bio-impedance signals are plotted using MATLAB and results are compared with the help of Bland-Altman plot. From this plot we can say that 95% confidence interval of the mean difference illustrates the magnitude of the systematic difference therefore the heart rate calculated from bio-impedance signal is essentially similar to the heart rate from ECG signal. Hence, this technique can be an alternative for regular heart rate detection. We can use this technique for basic home health monitoring without any conductive gel and skin preparation. In future we can incorporate this technique into the bathroom weighing scales so as to get heart rate simultaneously with the weight and body composition. Implementation of such system will be more comfortable and portable so as to use for regular health monitoring.

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ISSN (Print) : 2320-9798

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