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Circuit Design and Analysis of Wireless Cardiac Analyzer using the concepts of Pulse-Oxymetry

Sayan Dey[#1] , Souradipa Das[#2], Sandipan Chowdhury[#3] , Siddhanta Debnath[#4] , Pinaki Ghosh[#5] and Supratim Dutta[#6]

Dept. of Electronics & Comm. Engineering,
Techno India College of Technology Newtown, Rajarhat, Kolkata-700156, India

Abstract

In the field of medical electronics, non invasive techniques for the measurement of different physical and physiological parameters are becoming popular nowadays. The use of different types of sensors is inevitable to design this type of instruments. The present study deals with such a design based on the concepts of Pulse oxymetry. It is an infra red sensor based wireless module which measures pulse rate, maximum heart rate, blood pressure, physical fitness index and maximum oxygen uptake capacity of an individual non-invasively. It provides a graphical representation of the electrical activity of the heart commonly known as Electrocardiograph (ECG) which helps to detect any existing disorders in the cardiac cycle. In this study, the sensor-receiver module is touched with the subject's finger. The output of the receiver is fed to a series of sensitively tuned electronic amplifier circuit which represents the electrical activities of the heart in the form of voltage fluctuations. Then the voltage fluctuation is passed through appropriate filters for precision. The change in the voltage is due to the fluctuation of voltage within the heart muscles (commonly myocardium) which are amplified and displayed in a display unit. The whole measurement is performed by keeping a single finger of the patient between the sensor-receiver modules for twenty seconds. Each change in blood volume has a fixed curve pattern and depicts one cardiac cycle. The total number of change in blood volume in a minute gives the pulse rate of the patient. Several attempts have been made by researchers to measure the electrical activity of the human heart non-invasively, but it was not possible from a single finger, if preceded in the conventional way. This instrument is a portable device and removes the drawbacks of conventional

Electrocardiograph machines. It is very much cost effective and is fully sensor based digital device providing complete computer interfacing. This is a low power device, designed to provide full cardiac monitoring and is meant to help the medical experts to diagnose any cardiac disorders very easily and within very less time.

Keywords: Pulse Oxymetry, ECG, VO_{2max}, PFI, Differential Amplifiers, Multiple Correlations

Introduction

The advent of precisely designed bio-medical instruments has proven to be a boon to mankind. Electrocardiograph (ECG) is the measurement of the electrical activity of the heart initiated by the Sino Atrial Node (SAN) which results in the contraction of heart muscles. Researchers have designed numerous devices to effectively measure the electrical activity of the heart both invasively and non-invasively. [1,2] Conventional ECG monitors use complex wired structures called leads which are used to pick up the electrical impulses from different positions of the body, It follows the Einthoven triangle and consists of twelve leads for the proper monitoring.[3,4,5] It is not at all cost efficient and requires trained experts for its proper operation. The present study deals with a precise and user friendly instrument for cardiovascular monitoring which uses the concepts of pulse oxymetry to obtain the ECG of a human subject from any peripheral point of the body (in this case, index finger). Along with the ECG curve, in this cardiac analyzer multi various cardio-vascular parameters like systolic blood pressure, diastolic blood pressure, pulse rate, maximum oxygen uptake (VO_{2max}), maximum heart rate and physical fitness index are also obtained. [6] Pulse oxymetry is the method of measuring the concentration of oxygen containing hemoglobin in the blood non-invasively. [7,8] The measurement of oxy-hemoglobin concentration in blood is done by measuring the absorption level of infrared light by oxygenized hemoglobin. Thus by measuring the concentration of oxy-hemoglobin complex at time instant in a fingertip, the volume of blood is obtained at that time instant in the fingertip. The instantaneous fluctuations of blood volume thus obtained are transformed as voltage fluctuations by the sensor module and are amplified using single stage differential amplifiers. This amplified voltage is filtered using appropriate band pass filters and is digitized using the analog to digital converter. The microcontroller module is used to provide proper interfacing with computer using RS 232 port. This device operates on the basis of the concept that the concentration of oxygen carrying blood at any part of the body varies along with the electrical activities of the heart i.e. expansion and contraction of the heart. The concentration of oxygenated blood depends on the volume of blood flowing in a particular region. The microcontroller module obtains the heart rate by counting the numbers of cardiac cycles appearing per minute in the ECG curve. It counts the number of voltage spikes in one minute. The essential blood parameters like systolic and diastolic blood pressure, physical fitness index, maximum heart rate and maximum volume of Thus by providing the age of the subject, the cardio-vascular parameters like systolic blood pressure, diastolic blood pressure, body fitness index, maximum volume of oxygen in the blood and maximum heart rate at the stress condition are obtained. The parameters measured by the device define the cardiac condition of a patient fully within very less time and allows the medical practitioners to start their medical procedures without spending much time in severest conditions. Moreover, the device is a low cost low power design consuming very less powers of about 0.1 Watt and costing as low as $5.00. This cardiac analyzer is applicable in multi various fields including Sports Medicine, Cardiology, Biomechanics and even in daily domestic monitoring.[9] According to the literature, several attempts have been made to realize a non invasive heart rate monitor. The latest heart rate monitor based on pulse oxymetry was developed by Texas Instruments. But that device needs the subject to put his two thumbs on two separate infrared transmitter receiver module. The instrument, described in this paper requires the subject to put only one figure on an IR transmitter receiver module to get his ECG and his pulse rate. By providing the subject's age, the systolic blood pressure, diastolic blood pressure, maximum heart rate, physical fitness index, maximum volume of oxygen in blood of the subject can be obtained. If there is any disorder in the cardiac cycle that can be detected by studying the ECG provided by the device. A device called Sport Tester is also used as a heart rate monitor using the concepts of telemetry but it is not multipurpose and is not very cost efficient. [10] Hence, this design is an attempt to remove such practical problems and aims at the following

- To Design an accurate low cost low power cardio vascular monitor.
- To Display the ECG curve of the patient from a single finger.
- To Make the design multi various and versatile.
- To Make a very user friendly device to be used by everyone.

Methods and Materials

The device is based on the principle of Pulse oxymetry. In pulse oxymetry, the concentration of oxy-haemoglobin in a certain volume of blood is measured. This device also uses another peculiar property of blood. Blood can absorb certain portion of IR radiation and reflects the rest. This is non injurious to human health and hence can be used effectively.

- The Circuit Design can be Subdivided into Two Parts
- The analog Sensor-receiver module and amplifiers
- The Digital micro controller module

The Analog Sensor-Receiver Module and Amplifiers

This forms the main part of the device. The sensor-receiver module consists of infra red LEDs and receivers. This module acts as an input transducer. The LED emits infra red light which is reflected from the surface of the finger. The extent of reflection depends on the volume of blood present in the finger tip at that instant. The receiver picks up this reflected infra red light and gives an equivalent voltage signal of the same. This device uses a peculiar property of blood that it absorbs infra red light to some extent and reflects the rest. The amplifiers are tuned to match the frequency of the human electrocardiograph and the obtained signal is amplified to the amplitudes of the actual ECG thereby calibrating the circuit. This output gives the actual ECG of the patient. Each block is described in brief.

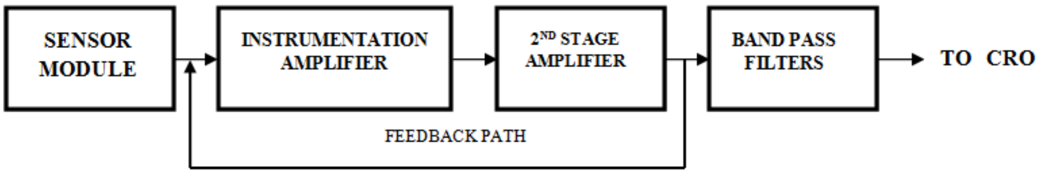

Figure 1: Block Diagram of the Cardiac Analyzer Circuit

IR Transmitter-Receiver Module

The finger of the subject is kept on the Infra Red transmitter-receiver module. At every contraction of heart there is a surge of blood volume within the finger and at the expansion of heart the surge of blood volume within the finger disappears. The LED produces the IR light that penetrates through the skin of the subject's finger. There at the finger of subject the IR light of certain wavelength (approximately of 900 nm) is absorbed by the oxy-hemoglobin. A certain portion of the IR light is reflected out of the finger of the subject and is received by the receiver. At the receiver module the absorbed level of the IR light of wavelength 900nm is represented by certain voltage level. Thus the quantity of oxy-hemoglobin and thus volume of blood at any time instant at the subject's finger is represented by a certain voltage level. As the blood volume at the finger changes according to the electrical activities of the heart a graphical representation of heart's electrical activities can be obtained.

Instrumentation Amplifier

The voltage fluctuation obtained in the previous module is fed to the instrumentation amplifier to match the actual amplitude of 3 to 6 mV of actual Human ECG. The circuit diagram of instrumentation amplifier is shown below.

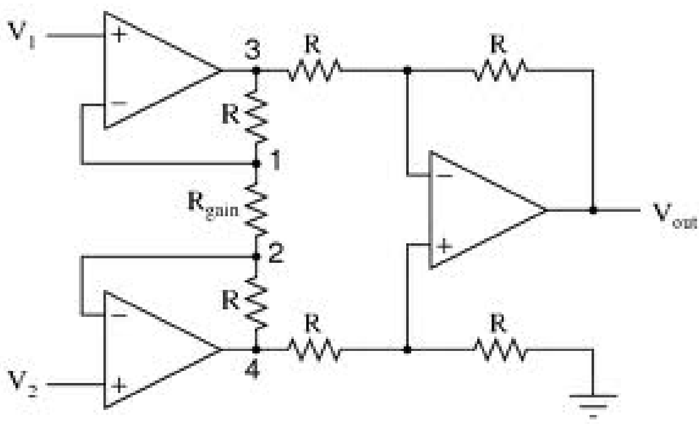

Figure 2: Circuit Diagram of Instrumentation Amplifier

Resistance R_{gain} is selected in accordance with the working range of the device which is 3 to 6mV in this case. In the instrumentation amplifier the output is fed back in each and every step of the circuit. Thus the noises are omitted and the SNR is increased. The output voltage of the instrumentation amplifier can be shown to be

$$V_{out} = (1+2R/R_{gain})\ (V_1-V_2)$$

It can be represented as

$$V_{out} = k\ (V_1-V_2)$$

Where, 'k' is called the gain factor of the instrumentation amplifier.

The amplifier is basically a combination of two buffers and a differential amplifier. The buffers are used for impedance matching to match the signal's impedance with the internal impedance of the circuit. Then the matched signal is amplified to match the amplitude of the actual amplitude of human ECG. This is the step where the calibration of the device is performed to give out a raw ECG curve.

Differential Amplifier

The signal from the instrumentation amplifier gives the raw ECG. This inherently consists of certain low amplitude portions of ECG curve namely the 'P' wave and the 'T' wave, which needs to be prominent. Hence, a single stage differential amplifier is used for this purpose. The figure below shows a single stage differential amplifier.

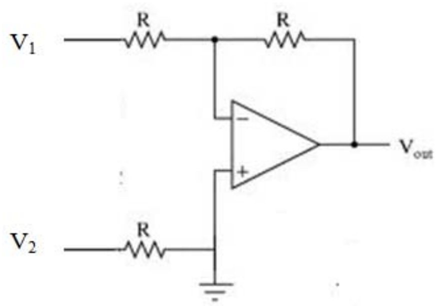

Figure 3: Circuit Diagram of Differential Amplifier

The above diagram shows the circuit diagram of a differential amplifier in single input mode. The output voltage of the differential amplifier can be represented as

$$V_{out}= k\ (V_1-V_2)$$

Where, $k= -(R_f/R_1)$ is called the single ended voltage gain. Thus the output voltage of the differential amplifier is increased by a factor given by single ended voltage gain. After subsequent amplification and filtering using passive R-C filters, the circuit gives the unshaped ECG of the subject as the output. This output is shaped by digitizing in the subsequent module to come.

The Digital Micro Controller Module

The microcontroller module must be fed with digital input. So, the output from differential amplifier is first digitized by applying it to a 16-bit ADC. The microcontroller is programmed with the bio statistical formulae to measure essential cardiac parameters like systolic blood pressure, diastolic blood pressure, Maximum heart rate, physical fitness index and maximum oxygen uptake. The microcontroller must be programmed to measure the heart rate from the ECG curve by calculating the number of cardiac cycles appearing per minute in the ECG curve (i.e. the crests and troughs in the voltage level of the output of differential amplifier). All the formulae are based on the heart rate measured by the circuit.

Bio Statistical Analysis

The cardiac parameters that are to be measured by this device are heart rate, systolic blood pressure, diastolic blood pressure, fitness index, maximum volume of oxygen in blood.

A study of several subjects was conducted and all the above mentioned cardiac parameters were measured by conventional methods. The data obtained were operated on, with multiple-correlation and thus regression equations were generated, relating the parameters to be measured to the heart rate of the subject. To obtain more accurate results, the age of the subject can be included as a separate parameter.

The different formulas generated can be categorized under the following heads.

Systolic blood pressure (SBP):

$$SBP=264.134-2HR \quad (1)$$

Diastolic blood pressure (DBP):

$$DBP=192.962-1.62HR \quad (2)$$

Maximum heart rate (HR_{max}):

$$HR_{max}=6.724+2.657HR \quad (3)$$

Physical Fitness index (FI):

$$PFI=-95.862+2.232HR \quad (4)$$

Volume of oxygen consumption at cellular level (VO_{2max})

$$VO_{2max}= -10.022+0.731HR \quad (5)$$

Results

The circuit is tested and the desired results were obtained. The figure below shows the unshaped ECG curve obtained as the output of the device as observed in the dual storage cathode ray oscilloscope.

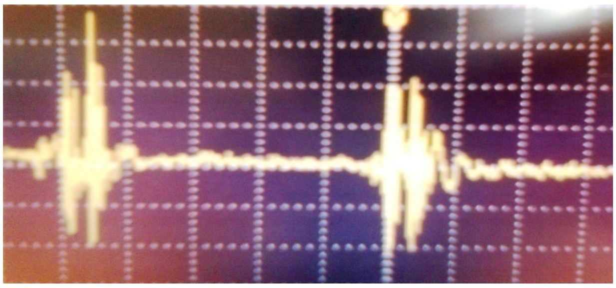

Figure 4: Unshaped ECG Curve Showing PQRST Waveforms

The figure clearly indicates the P wave, the QRS complex and the T waves which are the fundamental parts of the electrocardiogram waveform. These three waves describe the status of the heart within the full cardiac cycle. This ECG wave is shaped and smoothened to form the accurate ECG wave as observed in the conventional ECG machines. The bio statistical analysis and the device's accuracy were also validated. The graph 1 shows the comparison between the actual systolic blood pressure (marked in blue) and the measured systolic blood pressure (marked in red). This shows the level of accuracy of the cardiac analyzer. In the similar manner, the other parameters can also be validated.

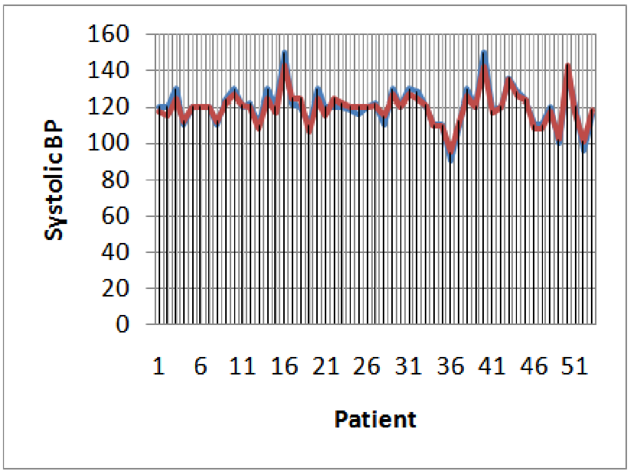

Figure 5: Comparative Chart of Systolic Blood Pressure

The power consumption of the device is found out to be about 0.01 watt which is very less and hence effective and efficient in terms of normal daily usage of the device. The existing devices which serve as only heart rate monitors like the 'Sport Tester' have more power consumption when compared to this device. Moreover, the cardiac analyzer is a real time system and computes its results within 20 seconds. Hence, it can be very useful for essential cardiac monitoring during stress time.

Discussion

It can be concluded from the above results and analysis that the cardiac analyzer is a simple yet cost efficient design which is very much user friendly and can be used commonly in daily life to facilitate exact monitoring of cardiovascular parameters which is indeed very essential nowadays in almost every fields including medicine, sports, biometric studies etc.

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