Development of a Simultaneous Acquisition System for ECG, PCG and Body Surface Temperature Signals

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CERTIFICATE

This is to certify that the thesis entitled "**Development of a Simultaneous Acquisition System for ECG, PCG and Body Surface Temperature Signals**" submitted by Mr. **Suraj Kumar Nayak (213BM1013)** in the partial fulfillment of the requirements for the award of Master of Technology degree in Biomedical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Place:

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Acknowledgement

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Abstract

In the recent years, there has been a tremendous increase in the development of personal healthcare devices. In the current study, we describe the development of a low cost personal healthcare device capable of recording Electrocardiogram (ECG), Phonocardiogram (PCG) and body surface temperature simultaneously. The reading from the device can be stored in any computer with the help of LabVIEW software. The saved data can be sent to a physician for getting medical help. The device would be useful for acquiring the vital signs of a patient located in a far-off place where there is a shortage of healthcare professionals. Hence the proposed device can be useful in improving the healthcare conditions in the remote areas. The device is easy to handle.

Keywords: Electrocardiogram (ECG), Phonocardiogram (PCG), Body surface temperature, Body sensor network, Telemedicine

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Chapter I

Introduction and Objectives

1.1 Introduction

In the current day situation, research for the development of advanced personalized healthcare devices as well as for the improvement of the efficiency of the existing personalized healthcare devices is increasing [1]. This is because, the personalized healthcare devices are helpful in carrying out routine diagnostic tests of the vital parameters of the human body [2]. Among the various personal healthcare devices, devices that divulge information regarding the cardiac health have received greater attention [3]. This is attributed to the fact that, the occurrence of the cardiovascular diseases has increased in recent years. It is important to regularly keep a track of the cardiovascular parameters of an individual, for early detection of any pathological condition. According to an incomplete statistics, nearly 2000 people die due to the physiological conditions associated with the cardiovascular diseases, worldwide. The diagnosis of the cardiovascular diseases is mainly carried out by analyzing the ECG and PCG signals [4]. Any change in the physiology of the heart muscles results in the alteration in the features of ECG signal.

Phonocardiogram is a well-known technique for amplifying and visualizing of the heart sounds using highly sensitive microphones [5]. The heart sounds are produced due to the closing and opening of the atrioventricular and semilunar valves. In healthy individuals, normally the occurrence of two heart sounds are heard, namely lub and dub [6]. The first heart sound (lub) occurs due to the closing of the atrioventricular valves at the starting of the ventricular contraction. On the other hand, the second heart sound (dub) occurs due to the closing of the semilunar valves at the completion of ventricular contraction. During the clinical conditions, that suggests a cardiac failure, a third heart sound is also heard. In addition to the above sounds, the occurrence of a fourth heart sound is also observed due to the atrial contraction and is usually not heard in healthy individuals. Additionally, murmurs are also associated with the defects in the heart valves, which

results in the improper closing of the heart valves to prevent blood backflow during systoles. An orifice in the ceptal valve, which separates the right ventricle from the left ventricle, has also been observed to result in murmurs. The heart sounds can be heard using stethoscope. In recent years, microphone containing devices have been designed that are capable of acquiring the heart sounds. Such devices are known as phonocardiogram equipments [7].

Recent studies suggest that, emotional and physical stresses not only modulates the heart rate but also the body temperature of the patients [8]. The monitoring of the heart rate along-with the body temperature may divulge information about the conditions associated with the Autonomic Nervous System (ANS) and other clinical conditions such as the lack of Thyroid hormone receptor α1 [9]. Hence, it better to monitor the body temperature along-with the ECG signals.

The conventional monitoring systems are quite large and hence are not useful as portable devices. Along-with this, the cost of the devices is also sufficiently high, that makes the conventional monitoring systems out of the reach of the poor people. Recent advances in the field of instrumentation and sensor technology has allowed for the designing of ambulatory devices [10]. Keeping the above facts in mind, in the current study, we have tried to develop a body sensor network (BSN) that acquires ECG, PCG and body surface temperature signals simultaneously.

1.2 Objectives

The prime aim of the present study is to design a low cost personal healthcare device capable of recording the Electrocardiogram (ECG), Phonocardiogram (PCG) and body surface temperature of an individual simultaneously.

This work includes:

1. Developing a low cost system for acquisition of ECG signal.

2. Developing a low cost system for acquisition of PCG signal.

3. Developing a low cost system for measurement of body surface temperature of an individual.

4. Integration of the ECG, PCG and body surface temperature measurement systems to facilitate simultaneous acquisition.

Chapter II

Literature Review

2.1. Principle of Electrocardiography

The human excitable cells behave like tiny batteries. These cells have different ionic concentrations of electrolytes (mainly Na^+, K^+, Ca^{++} and Cl^- ions) inside and outside of their membranes, which results in small electric potentials known as bio-potentials. Whenever there is a disturbance in a bio-potential, an action potential is created which is the depolarization and repolarization of the cell as shown in Fig. 2.1 [11].

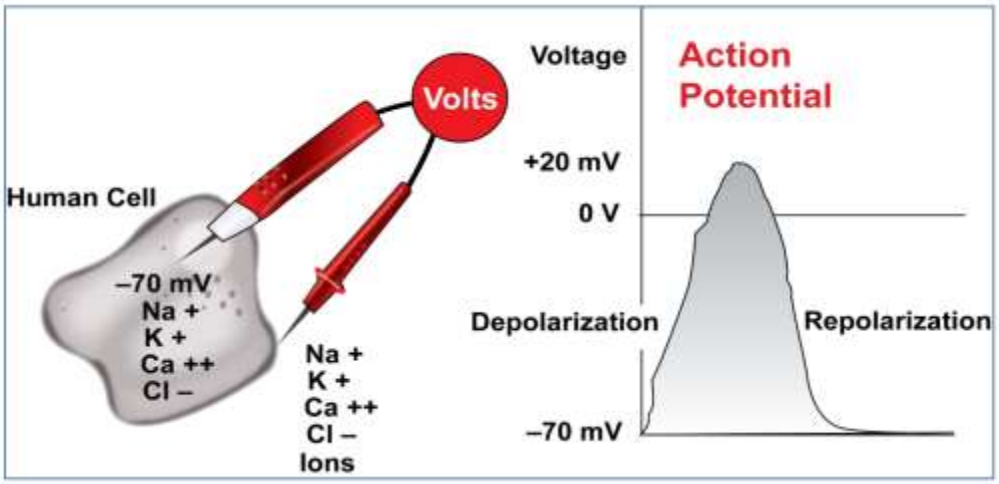

Fig. 2.1 Depolarization and repolarization of a human cell [12].

The rhythmical electrical impulse of the human heart starts from the sinoatrial node. This node has been regarded as the cardiac pacemaker. The impulse generated by the sinoatrial node passes across the atrial tracts and reaches the atrioventricular node. Then, it activates the right and left ventricles in a systematic way. The action potential of sinoatrial node results in self-excitation. Essentially, the action potentials from different nodes of the heart result in Electrocardiogram signals as shown in Fig. 2.2.

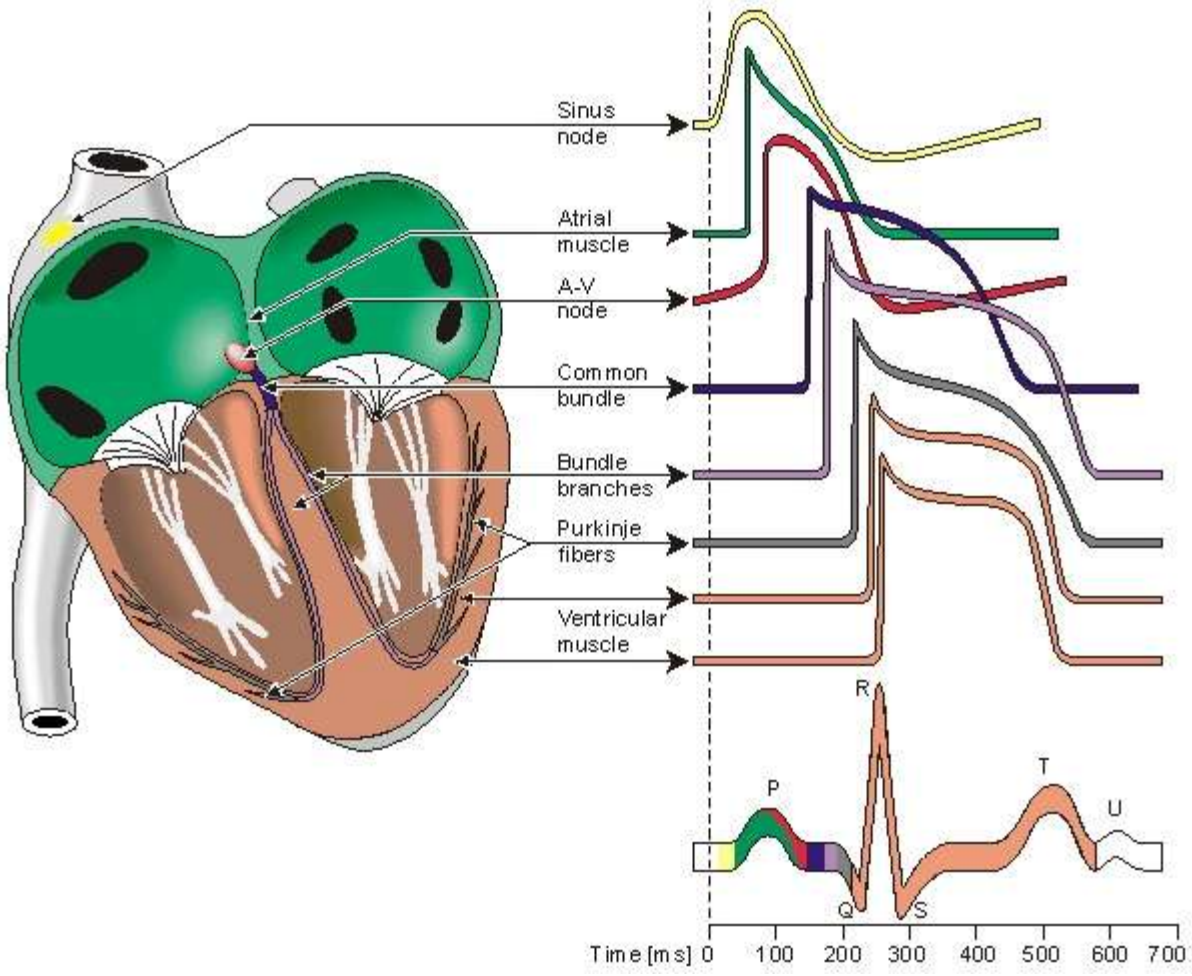

Fig. 2.2 Waveforms of action potential in different parts of the cardiac conduction pathway and their share to the surface Electrocardiogram signal with colour coding [13].

ECG signal acquisition devices utilizes electrodes to convert the bio-signals from the body in to electrical signals which can not only be displayed but also be used for diagnostic purposes. However due to the small amplitude of the signal and interference from external noise, surface ECG signal needs to be amplified and filtered for obtaining high quality signals.

2.1.1. Characteristics of ECG Signal

The important features of the ECG signal can be described by various waves and time intervals as given below:

RR-interval: The RR-interval is calculated in between two consecutive R waves and it describes the duration of an entire cardiac cycle. It is the fundamental rhythmic entity and is utilized not only to characterize the different types of arrhythmias but also to study the variation of the heart rate [14].

QRS-complex: Contraction of the left and right ventricles is described by the QRS-complex [15]. In a healthy individual, the duration of QRS-complex lies in the range of 70–110 msec and is a sharp biortriphasic wave. Q-wave represents the first negative deflection and S-wave represents the second negative deflection of the QRS-complex. The first positive deflection is represented by the R-wave. Even though the QRS-complex can possess less than three individual waves, it is still called the QRS-complex. The morphological characteristics of the QRS-complex are largely dynamic and relies on the heartbeat. The length of the QRS-complex can continue up to 250 msec in a person with heart failure and it is sometimes comprises of more than three waves. The amplitude of QRS-complex can reach up to 2–3 mV and it is the highest magnitude of the ECG signal. Because of the usurious slope, the QRS-complex possesses frequencies that are sufficiently higher as compared to the frequencies of the other ECG waves. The frequencies of QRS-complex are mainly concentrated in the interval of 10–50 Hz.

P-wave: The P-wave represents contraction of the left and right atrium. Generally, the P-wave positive in polarity and possesses smooth morphology. Its amplitude usually remains below 300 μV and the length is smaller than 120 msec. The spectral feature of a normal P-wave is generally observed possess low-frequency, below 10-15 Hz, but various advanced signal processing techniques which result in noise-reduced ECG signals have revealed that much higher frequency components may present in a P-wave, especially in an abnormally working heart. Generally, it is difficult to obtain the instants of time that describes the start and the end of a P-wave due to its low

magnitude and smoothness. Therefore, the analysis of individual P-waves is not done in ECG signals having considerable noise.

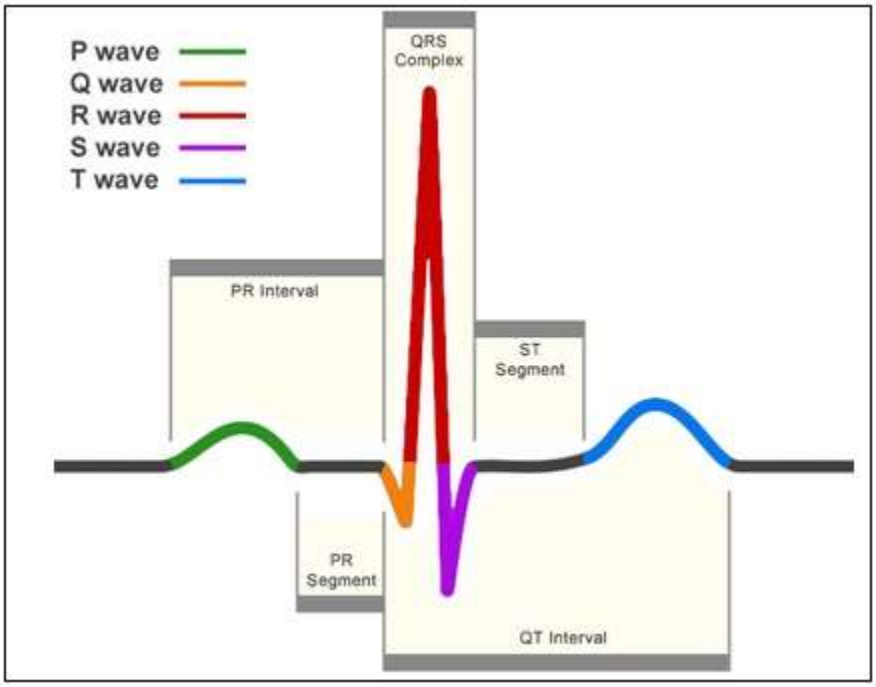

Fig. 2.3 Waves and intervals of ECG signal [12].

T-wave: The T-wave represents the relaxation of ventricles and continues for nearly 300 msec after the QRS-complex [16]. The position of the T-wave mainly depends on the heart rate. It becomes narrower and closer to the QRS-complex at high heart rate. The T-wave is smooth and possesses an amplitude in the range of 100–300 μV. Its frequency content is similar to that of the P-wave, with a higher low-frequency content than the P-wave.

PQ-interval: The PQ-interval reflects the time interval from the beginning of the atrial contraction to the beginning of the ventricular contraction [17]. The length of the PQ-interval only weakly depends on the heart rate.

QT-interval: The QT-interval is the time interval from the beginning of the ventricular systole to the completion of ventricular diastole. This interval generally depends on the heart rate, it becomes shorter at higher heart rates [18].

2.1.2. Basic instrumentation to record ECG Signal

Since the electrical activities in the heart precedes its mechanical activity, ECG signals are of high clinical importance [13]. The basic components comprising of an ECG signal acquisition system are discussed below-

2.1.3. Silver-Silver Chloride electrode

The electrodes used in recording of ECG signal comprises of a metal, generally silver, and a salt of the metal, typically silver chloride [19]. Also some form of electrode paste or jelly is applied in between the electrode and the skin.

2.1.4. Equivalent circuit of the electrode-skin interface

The electrode-skin interface behaves as non-polarizable that suggests that the main component of the impedance is resistive. The electrochemical processes occurring at the electrode-electrolyte interface is accounted for by adding a parallel resistance. The two layer of charges of opposite sign suggests the presence of a capacitance (Fig. 2.4).

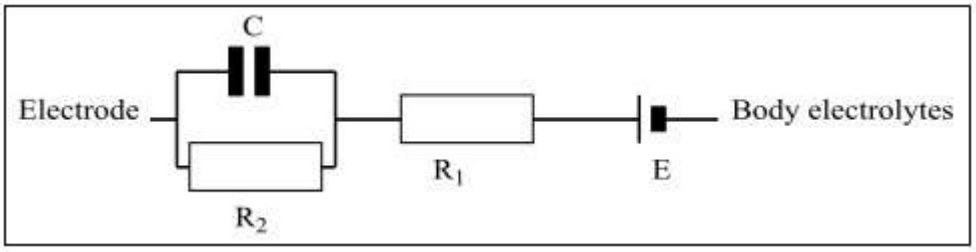

Fig. 2.4 Equivalent circuit of electrode-electrolyte interface [20].

2.1.5. Instrumentation Amplifier

The amplitude of ECG signal varies from the microvolt to the millivolt range. Because of this small amplitude range, the ECG signals measured demands amplification, in order to have a better interpretation. The amplifiers must possess a high common mode rejection ratio to avoid large offset signals. Most of the bio-potential amplifiers are differential amplifiers. Differential amplifiers are used to ensure that the noise from the inputs are not amplified thus resulting in a better integrity signal. Differential amplifiers possessing such features are difficult to obtain. Therefore, the combinations of differential amplifiers are utilized to build what is known as an instrumentation amplifier [21]. A basic three-op-amp instrumentation amplifier has been represented in Fig. 2.5.

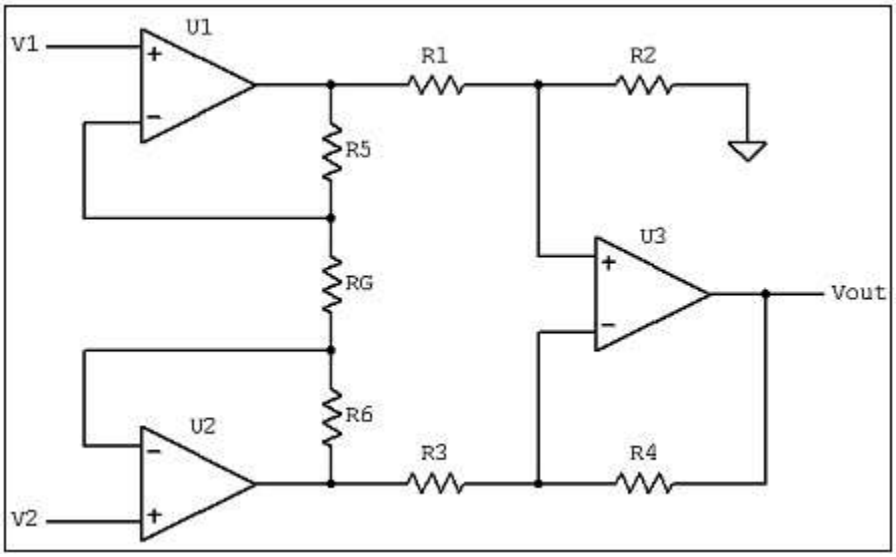

Fig. 2.5 Basic instrumentation amplifier [20].

The instrumentation amplifier comprises of two stages which help in making it to match the features of an ideal bio-potential amplifier. The first stage is called the input stage of the amplifier which is followed by the gain stage. Fig. 2.6 shows the breakdown of the instrumentation amplifier in to the two stages.

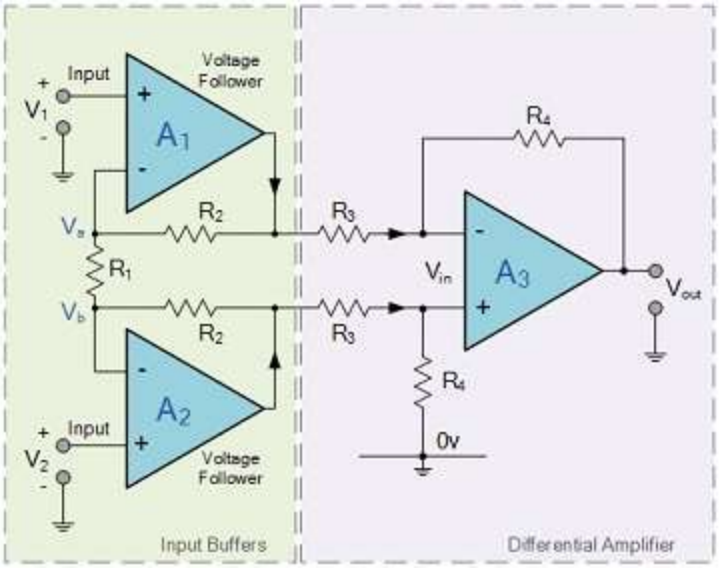

Fig. 2.6 Stages of the of the instrumentation amplifier [22].

Texas Instruments (TI) provides such an instrumentation amplifier for use in the medical instruments. Fig. 2.7 shows the schematic of TI's most commonly used instrumentation amplifier known as INA128P. This single chip allows the user adjust the gain flexibly while also decreasing circuit design error.

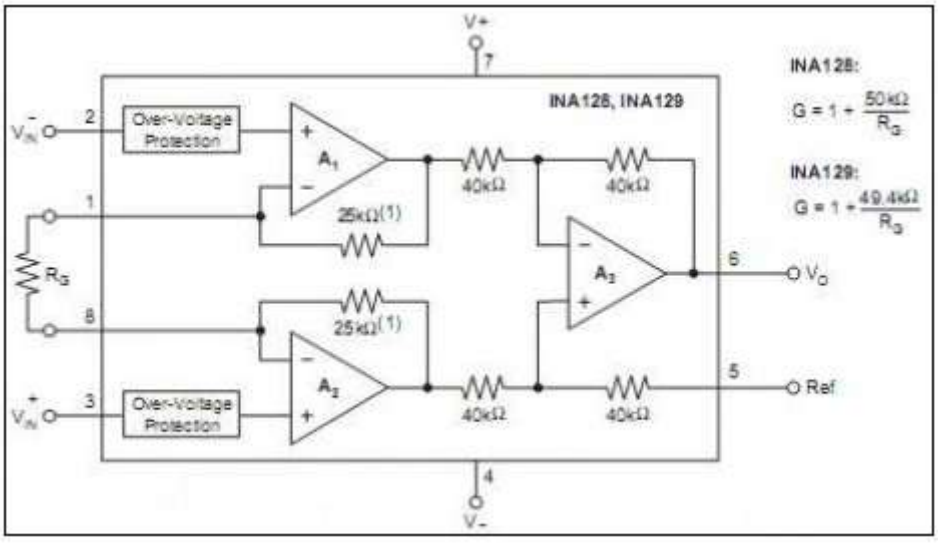

Fig. 2.7 Schematic of INA128 [23].

2.1.6. Filtering

The ECG signals are subject to many different types of noise internally and externally [24]. Fig. 2.8 shows the different types of artifacts that the ECG signals generally experience.

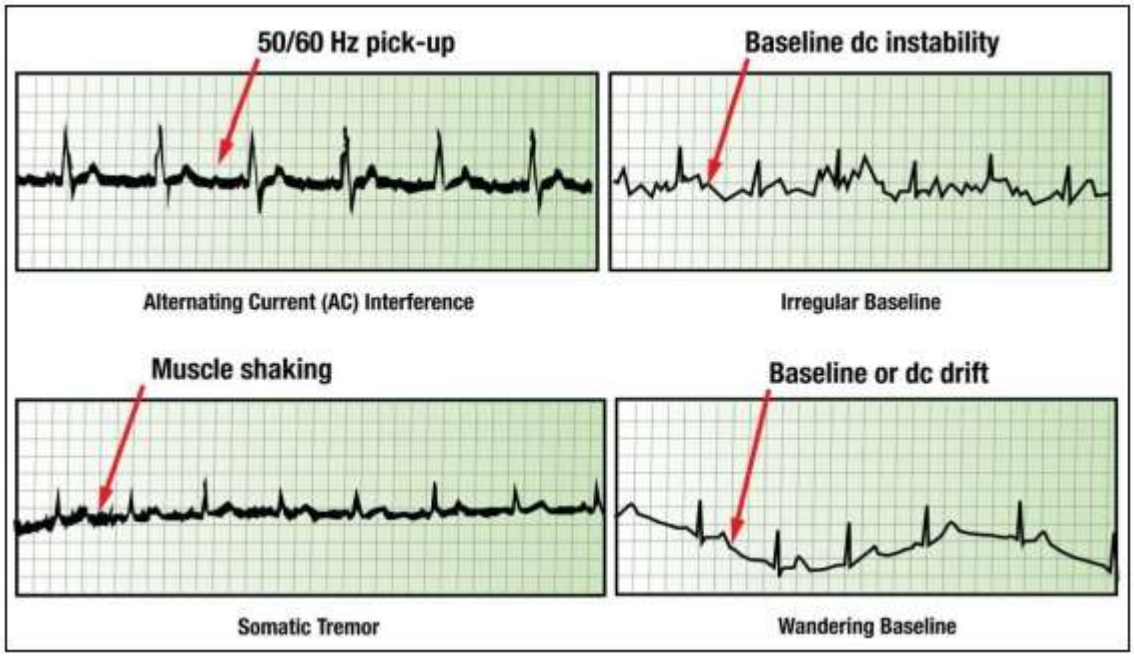

Fig. 2.8 ECG artifacts [12].

These artifacts can be removed by digital means as well as through analog circuits. For example, the analog band stop filter shown in Fig. 2.9 can be used to modulate 60 Hz noise from power lines based on what resistor, capacitor, and inductor values are chosen.

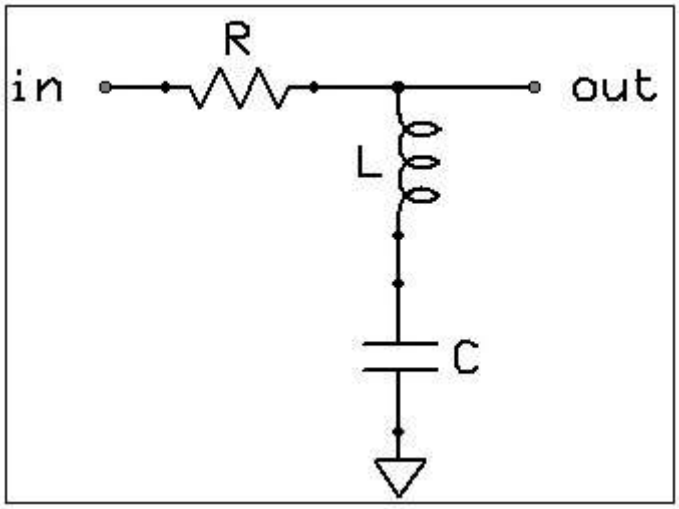

Fig. 2.9 Second order band stop filter [25].

Digitally, softwares such as LabVIEW and Matlab etc. allow implementation of filters with the help of the Fast Fourier Transforms (FFTs). For example, an FFT can extract the ECG and muscle shaking frequency components. From that, one can design a filter to obtain only the ECG signal frequency components of the signal.

2.1.7. Right Leg Drive Circuit

The motivation behind the use of the right leg drive circuit is to minimize the interference from the amplifier [26]. The right leg drive circuit results in the inversion and amplification of the average common mode signal back into the patient's right leg as represented in Fig. 2.10. This activity cancels 50 Hz noise from AC power supply and creates a cleaner ECG output signal. The higher gain that can be achieved in the feedback loop of the right leg drive circuit also improves the common mode rejection ratio. Canceling of the noise/interference in this manner reduces the attenuation required from the common mode rejection of the instrumentation amplifier.

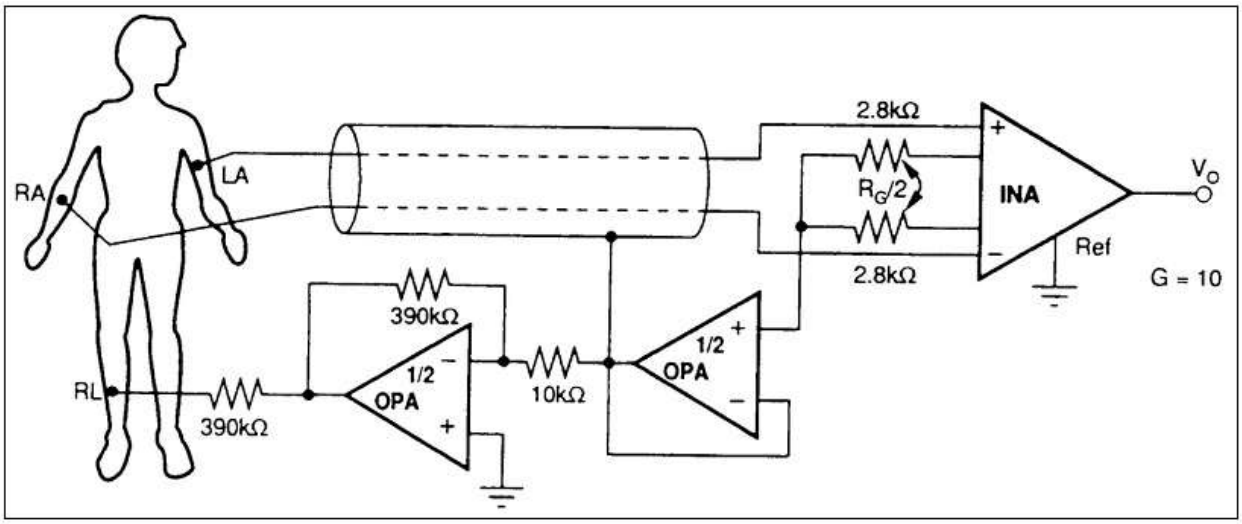

Fig. 2.10 ECG Amplifier with Right Leg Drive Circuit [27].

2.2. Principle of phonocardiography

The technique of listening to the sounds produced by the various organs and vessels of the body is regarded as auscultation [28]. The areas at which these sounds are heard better are known as the auscultation area. The graphical representation of the sounds associated with the pumping action of the heart is called as phonocardiogram. These sounds are produced by the vibrations produced in the blood inside the heart by the sudden closure of valves, movement of the heart wall, closure of walls, turbulence and leakage of the blood flow.

2.2.1. Heart sounds

First heart sound (Lub):

The first heart sound is produced due to the closure of the mitral and tricuspid valves which allow the passage of blood from atria into the ventricles i.e. it occur at the end of the atrial systole and at beginning of the ventricular systole. It occurs nearly 0.05 second after the beginning of the QRS complex and just before ventricular contraction. It is usually longer in duration, lower in frequency

(30 – 45 Hz) and greater in intensity as compared to the second heart sound. Its duration is about 50 to 100 msec. The auscultation area is at the apex of the mid pericardium.

Second Heart Sound (Dub):

The second heart sound occurs at the end of the ventricular contraction due to the closure of the semilunar valves (aortic and pulmonary aortic valves) present in the arteries leading out of the ventricles. It starts 0.03-0.05 second after the end of the T wave. It has frequency components in the range of 50 – 70 Hz. Its duration is 25 to 50 msec. It is best heard in the aortic and pulmonary areas.

Third heart sound:

The third heart sound occurs due to surcease of the ventricular filling. It is generally obtained in case of children and the patients suffering from left ventricular failure, because of the rapid inflow of blood from the atria into the ventricles. The accumulated blood from atria and veins causes the distention and vibration of ventricles. Its frequency is below 30 Hz and the duration is 0.1 to 0.2 sec. It starts 0.12 – 0.18 seconds after the beginning of the second heart sound. The auscultation area is at the apex and left lateral position after lifting the legs.

Fourth heart sound/ atrial heart sound:

The fourth heart sound is produced due to the contraction of the atria. It is generally not audible because of the low amplitude and frequency of vibration. It starts just before the onset of the first heart sound. It occurs 0.12-0.18 second after the beginning of the P wave. Its duration is 0.03 to 0.06 second and frequency is in the range of 10-50 Hz (Fig. 2.11).

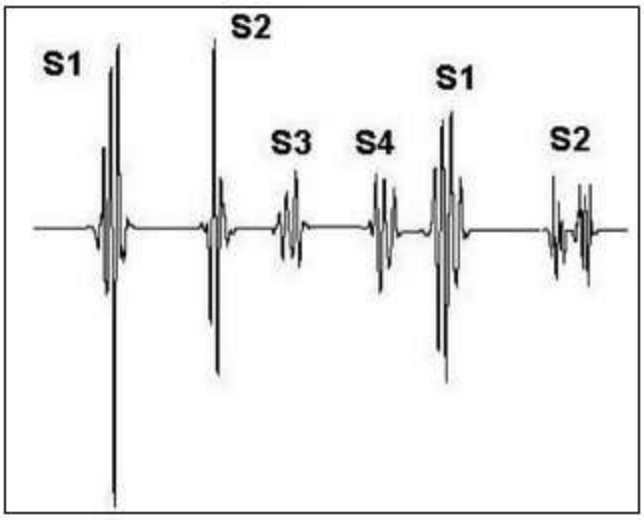

Fig. 2.11 Heart sounds [6].

The third and fourth heart sounds are also known as the diastolic sounds and are normally audible in the children, but are not heard in case of a healthy adult. The Fig. 2.12 shows the time relationships between the first and second heart sounds with respect to ECG.

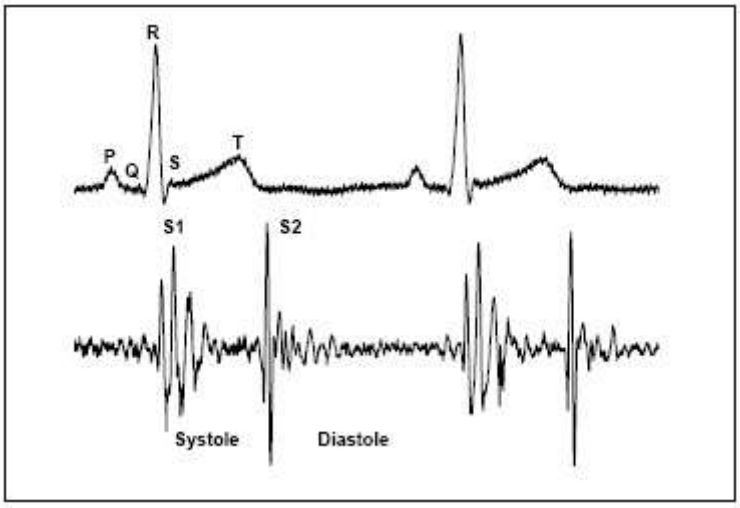

Fig. 2.12 Time relationships between the heart sounds with respect to ECG [29].

2.2.2. Acoustical Stethoscope

A stethoscope is the main device used for listening to the heart sounds. (stethos is a Greek word which means ‘chest’ and skopein is another Greek word which means ‘to examine’). Stethoscope is a simple instrument that carries the sound energy from the chest of the patient to the ear of the physician via a column of air [30]. It has two earpieces connected to a common bell or chest piece (Fig. 2.13). It has low fidelity and no amplification.

Fig. 2.13 Acoustical Stethoscope [31].

2.2.3. Electronic stethoscope

The electronic stethoscope is an improvement of the acoustical stethoscope which comprises of a microphone, an amplifier and a head set [32]. It can detect very weak and high frequency heart sounds. It is generally not used.

2.2.4. The Phonocardiogram (PCG) Equipment

The Phonocardiogram equipment/Phonocardiography is an instrument that is used for obtaining the waveforms of the heart sounds [33]. It mainly comprises of a transducer (microphone), an

amplifier circuit, a filter circuit and a display module. The microphone used in the Phonocardiogram equipment may be either a piezoelectric crystal microphone or a condenser microphone, or a moving coil microphone having frequency response in the range of 5 Hz to above 1000 Hz which converts the heart sounds into electrical signals. The electrical signals from the microphone are amplified by an amplifier. The amplifier should have similar response characteristics.

2.3. Human Body Temperature

The human body temperature is a way of representing the ability of the human body to produce or get rid of heat. The body maintains its temperature within a narrow, safe range in spite of the large variations in temperature outside the body. When the surrounding environment is very hot, the blood vessels of the skin expand to bring the excess heat to skin surface. As a result, sweating occurs and evaporation of the sweat helps to cool the body. Different parts of the body have different temperatures. The body temperature of a healthy individual changes during the day by nearly 0.5 ^{o}C. The body temperature is generally lower in the morning and higher in the afternoon and evening due to the changes in the needs and activities of the body [34].

2.3.1. Measurement of Human Body Temperature

Body temperature is one of the vital signs that should be monitored to assure a safe and effective health. The body surface temperature measurement can be done by various types of medical grade temperature sensors [35]. Generally, negative temperature coefficient (NTC) thermistors are the best suited sensors for measurement of human body temperature (Fig. 2.14).

2.3.2. NTC Thermistor

NTC thermistors can provide adequate accuracy and sensitivity in the body temperature range. Also, NTC thermistors are the perfect choices of temperature sensors for disposable medical applications [36].

Fig. 2.14 NTC Thermistor 103 [37].

Key Characteristics of NTC Thermistors

- Defined sensitivity to temperature
- Sensitivity to electrical power input
- Sensitivity to changes in thermal conductivity

Main Applications of NTC Thermistors

- Temperature measurement and control
- Temperature compression

- Surge suppression
- Power measurement
- Fluid level-flow detection

Chapter III

Materials and methods

3.1. Materials

- Instrumentation amplifier (INA128P)
- operational amplifier (UA741CP)
- Data Acquisition System (NI USB 6009)
- Disposable Electrodes (BPL, India)
- Multisim (Version 13.0, National Instruments, USA)
- Ultiboard (Version 13.0, National Instruments, USA)
- Student Stethoscope
- NTC Thermistor 103 (10KΩ)
- Passive components (resistors, capacitors and electret microphone)

3.2. Methods

3.2.1. Designing of ECG Amplifier

For developing an ECG amplifier, a commercially available instrumentation amplifier INA128P (Texas Instruments, Singapore) was utilized. The theoretical gain of the amplifier was set to 2500 V/V. The output of the instrumentation amplifier was filtered using an integrator whose output was connected to pin no. 5 of the instrumentation amplifier, in order to remove any dc offset generated by the instrumentation amplifier. The resistor connected between Pin no. 1 and 8 of the INA128P is known as gain resistor. In this case, two 10 Ω resistances connected in series to each other form the gain resistance of the instrumentation amplifier. Through the junction of the resistances (10 Ω), a signal was passed to a buffer. The output of the buffer was passed into an integrator with a gain of 20 V/V and a cut-off frequency of 15.92 Hz. The output of this integrator was used as the reference signal. The buffer and integrator combination is popularly known as the

right leg drive circuit. The right leg drive circuit helps in the reduction of common mode noise and provides safety to the patient, in case a dangerously high voltage is applied, by isolating the patient from the ground. The output of the INA128P was passed through a 2nd order low pass filter having a cut-off frequency of 160 Hz so as to band limit the signal. The schematic diagram of ECG signal amplifier has been shown in Fig. 3.1.

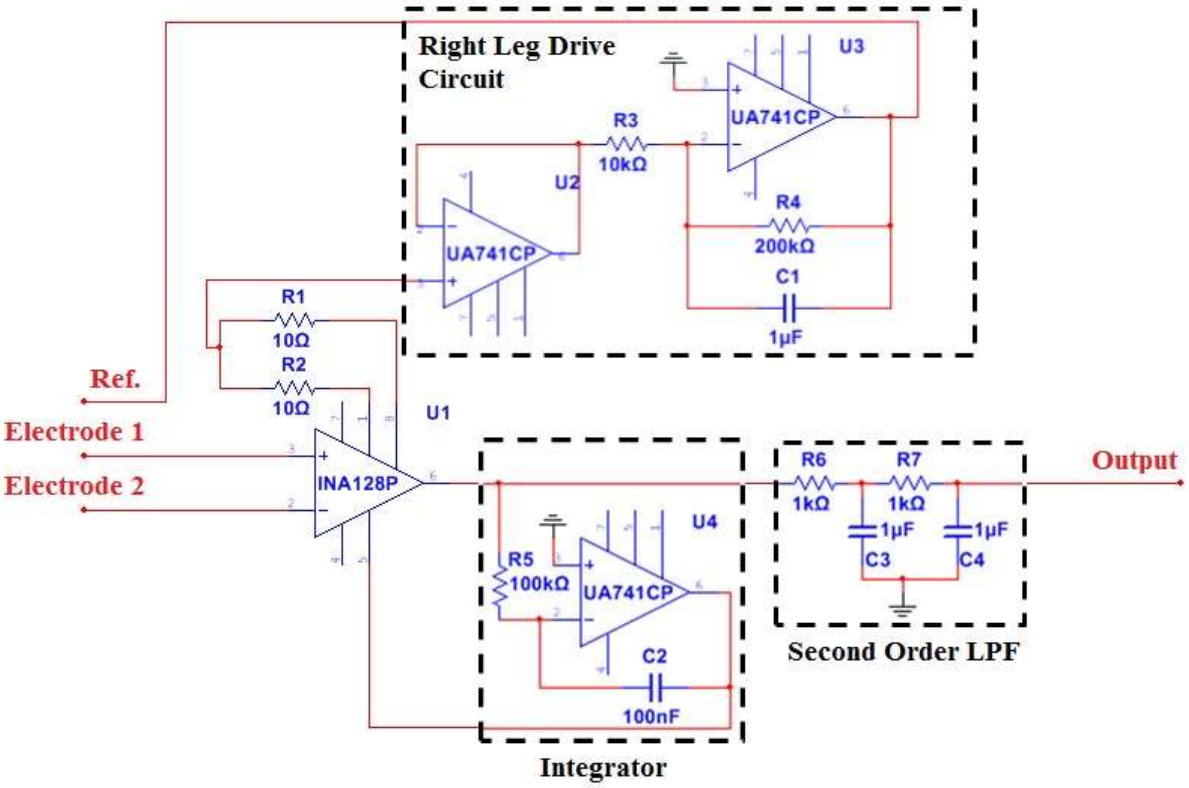

Fig. 3.1 Schematic diagram of ECG signal amplifier

3.2.2. Designing of PCB Amplifier

An electret microphone was incorporated within the rubber tubing that is connected with the chest piece of the stethoscope so as to sense the sound waves generated because of the activity of the heart. The output of the electret microphone was provided to a non-inverting amplifier possessing a gain of 45. The output of the amplifier was then passed through a band pass filter having higher

cut-off frequency of 160 Hz and lower cut-off frequency of 1.59 Hz. The output signal of the band pass filter was again subjected to amplification in two consecutive stages using inverting amplifiers, each having individual gain of 101 V/V. The schematic diagram has been shown in Fig. 3.2.

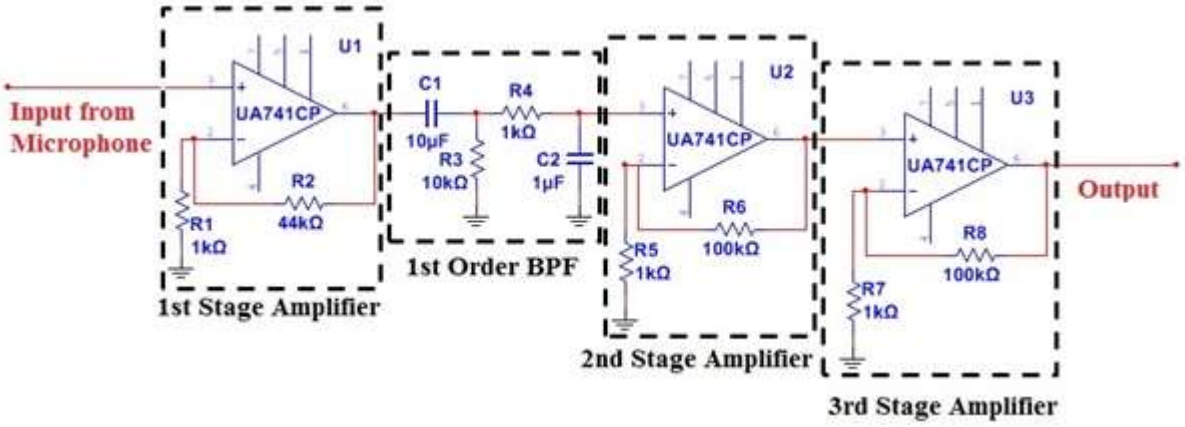

Fig. 3.2 Schematic diagram of the PCG amplifier

3.2.3. Designing of Temperature Signal Conditioning Circuit

A negative temperature coefficient (NTC) thermistor having a resistance of 10KΩ was used for body temperature measurement. A voltage divider circuit was formed using the thermistor and a 10KΩ resistance. Power was provided to the voltage divider circuit using a controlled 5V supply, obtained from the 5V terminal of the NI USB 6009. The output was taken from the junction point of the thermistor and the 10KΩ resistor. The schematic diagram of the temperature signal conditioning circuit is represented in Fig. 3.3.

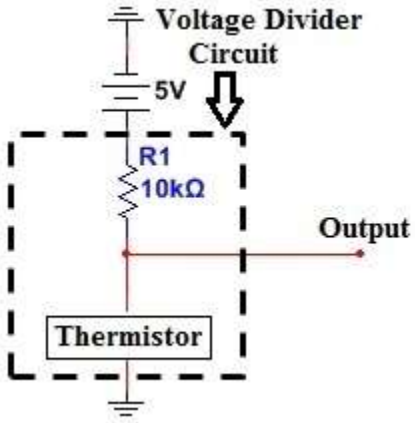

Fig. 3.3 Schematic diagram of the temperature signal conditioning circuit

3.2.4. Designing of PCB

A Printed Circuit Board (PCB) layout was designed using the software Ultiboard (Version 13.0, National Instruments, USA) that combines all the above mentioned circuits. After designing the layout, a PCB was developed using a copper cladded board. The fabrication was achieved by carbon transfer-copper etching method using Ferric Chloride ($FeCl_3$) solution.

3.2.4. Signal Acquisition and Processing

The output signals from the ECG, PCG and temperature sensors were provided in to a laptop using NI USB 6009 (National Instruments, USA) data acquisition system. LabVIEW (Version 13.0, National Instruments, USA) was used for designing a program in order to analyze and store the signals. The device was tested to check its functionality in continuously acquiring the signals.

Chapter IV

Results and Discussion

4.1. Designing of ECG Amplifier

An ECG signal amplifier circuit was designed that provides a theoretical gain of 2500 V/V and simultaneously acts as a low pass filter of f_c = 160Hz. The output of ECG signal amplifier was given to analog input pin AI0 of the data acquisition system NI USB 6009 (National Instruments, USA) which acts as an interface between the ECG amplifier and LabVIEW 2013. NI USB 6009 data acquisition system is a 8 channel, 10k sample multifunction I/O device. In order to observe the output on the computer screen, a LabVIEW program was developed in the block diagram panel of LabVIEW 2013 as shown below as Fig. 4.1.

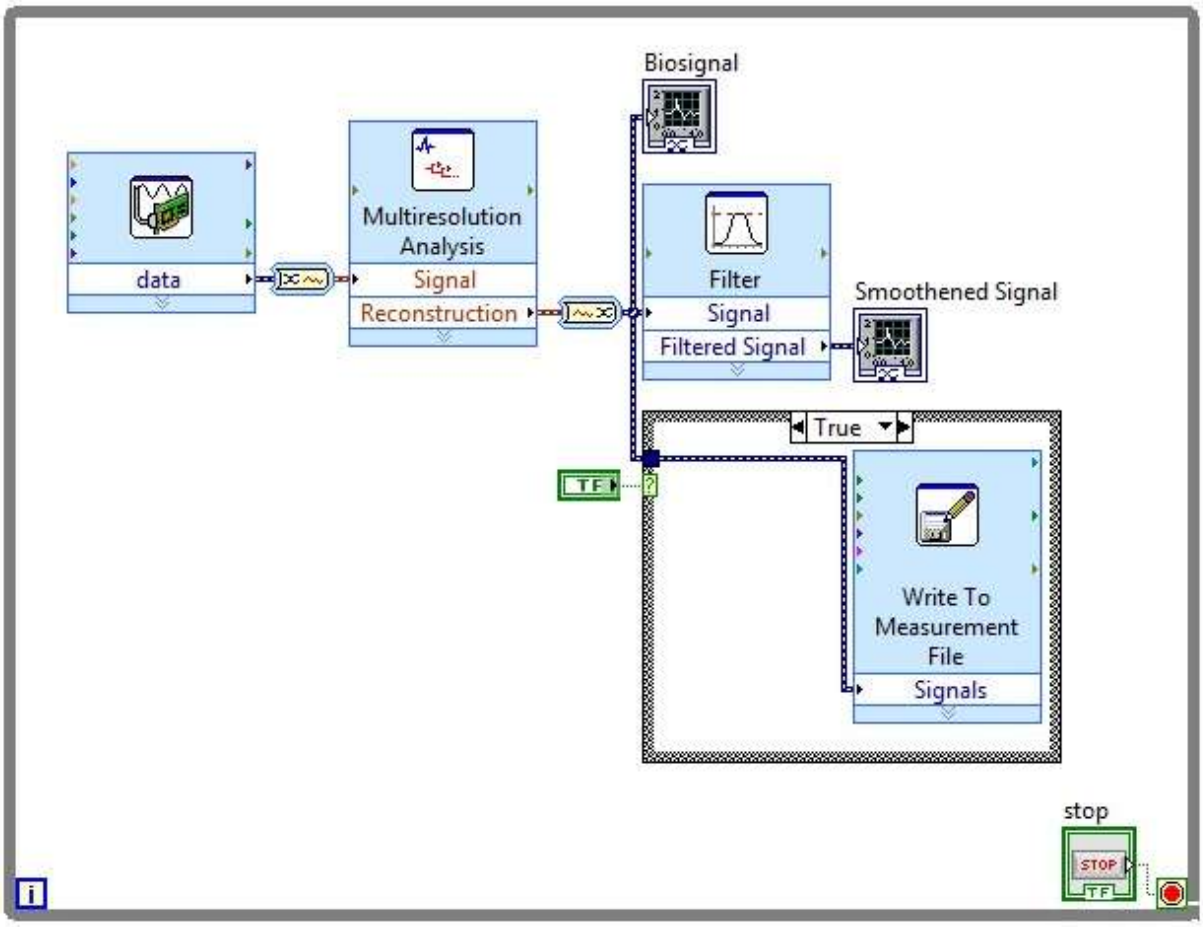

Fig. 4.1 LabVIEW program for ECG signal acquisition

In the LabVIEW program, “Multiresolution Analysis” palette was used for better reconstruction of the ECG signal. Filtering of the reconstructed signal was done for better visualization of the individual waves of the ECG signal. “Write to measurement” palette of LabVIEW facilitated the recording of the signal. The output waveforms observed on LabVIEW front panel has been shown in Fig. 4.2 below.

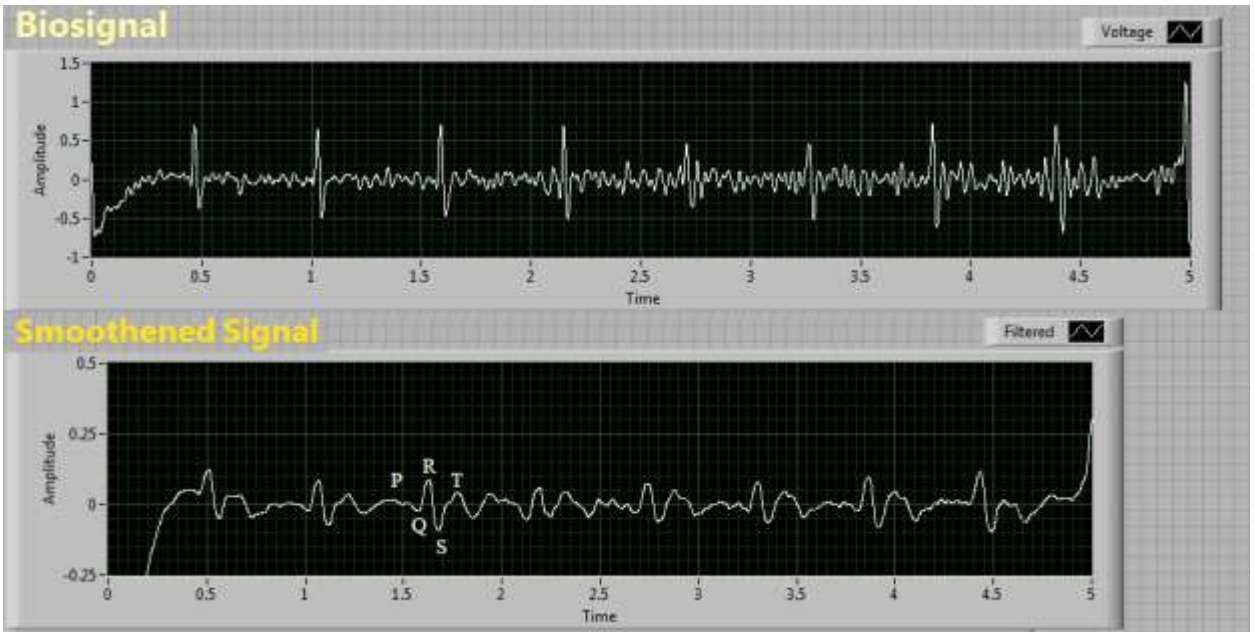

Fig. 4.2 Output waveforms observed on LabVIEW front panel

4.2. Designing of PCG Amplifier

A commercially available electret microphone was utilized as the sensor for the acquisition of the PCG signal. One leg of the electret microphone was connected with the input terminal of a non-inverting amplifier that possesses a theoretical gain of 45 V/V. The second leg of the electret microphone was connected to ground. The output of the non-inverting amplifier was filtered using a band pass filter having lower and upper cut-off frequencies of 1.59 Hz and 160 Hz. The band pass filter was provided to remove the presence of any dc frequency, which could have saturated

the output at the end stage of the amplifier, and to band limit the signal (although the PCG signal has frequency components in between 10 Hz and 500 Hz).

The reason behind band-limiting the frequency components of the signal to 160 Hz were to minimize the interference due to external environment and sound generated due to the movement of the body parts. As per the literature, the frequency ranges of the first heart sound (S1), second heart sound (S2), third heart sound (S3) and forth heart sound (S4) lie in the range of 30-45 Hz, 50-70 Hz, less than 30 Hz and 10-50 Hz, respectively. After filtration using the band-pass filter, the output signal was subjected to further amplification in two consecutive amplifier stages, each having a gain of 101 V/V. This resulted in the total theoretical gain of 459045 V/V for the circuit. The output of PCG signal amplifier was given to analog input pin AI0 of the data acquisition system NI USB 6009 (National Instruments, USA) which acts as an interface between the PCG amplifier and LabVIEW 2013. NI USB 6009 data acquisition system is a 8 channel, 10k sample multifunction I/O device. In order to observe the output on the computer screen, a LabVIEW program was developed in the block diagram panel of LabVIEW 2013 as shown below as Fig. 4.3.

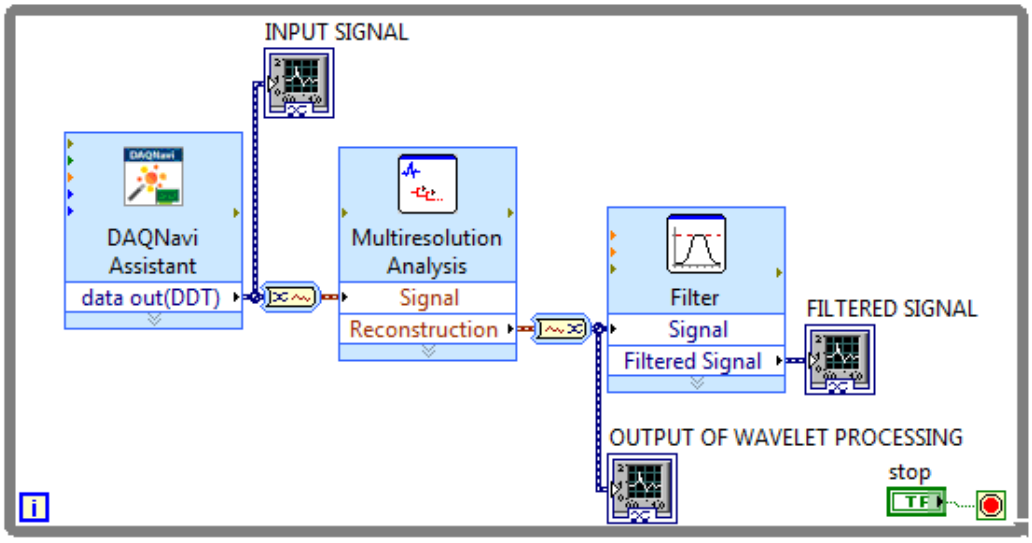

Fig. 4.3 LabVIEW program for PCG signal acquisition

In the LabVIEW program, “Multiresolution Analysis” palette was used for better reconstruction of the PCG signal. Further, band-pas filtering of the reconstructed signal was done for better visualization of the first and second heart sounds of the PCG signal. The output waveforms observed on LabVIEW front panel has been shown in Fig. 4.4 below.

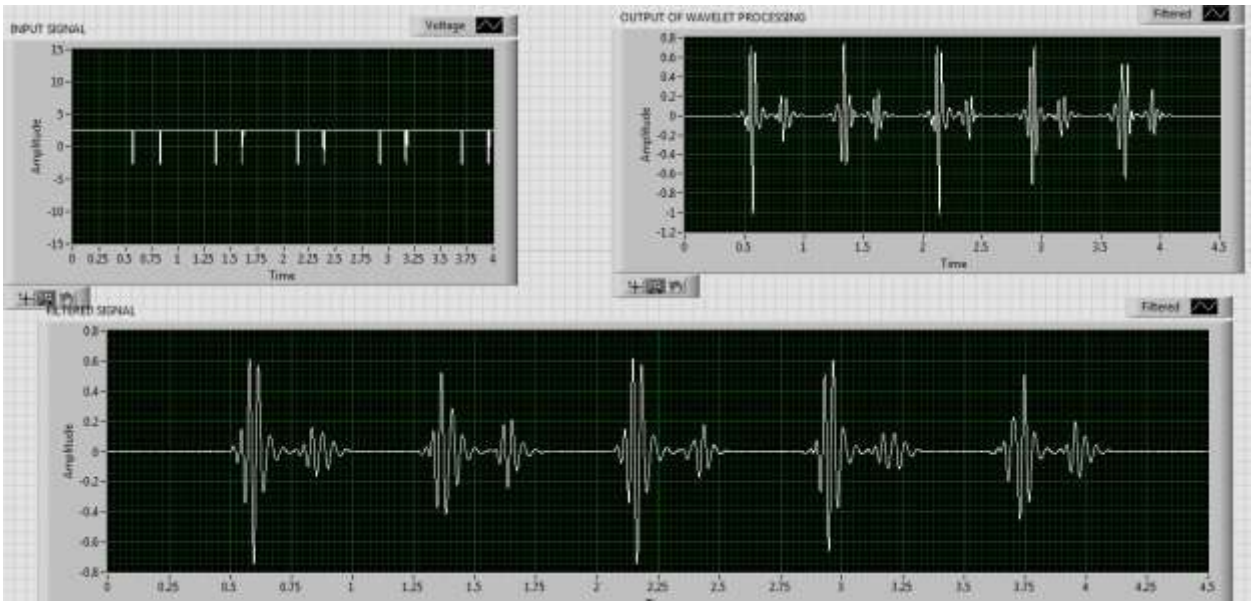

Fig. 4.4 Output waveforms observed on LabVIEW front panel

The PCG signal was acquired by putting the chest piece of the stethoscope on the chest of a volunteer.

4.3. Designing of Temperature Signal Conditioning Circuit

A 10K Ω NTC type thermistor was utilized as the temperature measuring sensor for measuring of the body temperature. The calibration of the NTC sensor is an essential step while developing any temperature monitoring system. NTC type thermistor has non-linear relationship between temperature and thermistor resistance. In order to provide the exact relationship between temperature and thermistor resistance, various models have been proposed. In our study, the β-factor model and Steinhart-Hart model have been utilized for the above mentioned purpose. The

coefficients of the mathematical models (β-factor model and Steinhart-Hart model) were calculated using the prescribed procedure. The thermistor was put within a temperature controlled cabinet (VIGITAL Hot Air Oven, ADARSH, India), where the temperature was set either to 25 ^{o}C or 50 ^{o}C (Table. 1). The corresponding resistance values of the thermistors were noted down. The β-factor of the thermistor was calculated as per the Equation (1).

$$\beta = \frac{T1 \times T2}{T1 - T2} \times Ln\left(\frac{R1}{R2}\right) \quad (1)$$

Where:

$R1$ = thermistor resistance (Ω) at temp $T1$ (K)

$R2$ = thermistor resistance (Ω) at temp $T2$ (K)

β = beta, the material constant

$$\frac{1}{T} = a + b(LnR) + C(LnR)^3 \quad (2)$$

Where:

T = temperature in Kelvins (K = ˚C + 273.15)

a, b and c are equation constants

R = resistance in Ω at temperature T

The calculated β-factor has been given in Table. 2. The coefficients of Steinhart-Hart model (Equation (2)), which is regarded as a better model than the β-factor model were also calculated. In order to calculate the coefficients of Steinhart-Hart model, the resistance of the thermistor at three different temperature values which are at least 10 ^{o}C apart should be utilized. Therefore, the coefficients (Table. 2) were calculated by measuring the resistance of thermistor at 30^{o}C, 40^{o}C and

50ºC (Table. 1). After calculating the coefficients of the different models, the corresponding working equations were formulated. The working equations of the β-factor model and Steinhart-Hart model have been represented in Equations (3) and (4) respectively.

$$T = \frac{3929.07 \times T_0}{3929.07 + T_0 Ln\left(\frac{R}{R_0}\right)} \quad (3)$$

Where:

T = temperature in Kelvins (K = ˚C + 273.15)

T_0= reference temperature (K)

R_0 = thermistor resistance (Ω) at temp T_0 (K)

$$\frac{1}{T} = 1.130584 \times 10^{-3} + 2.338360 \times 10^{-4}(LnR) + 8.924245 \times 10^{-8}(LnR)^3 \quad (4)$$

Where:

T = temperature in Kelvins (K = ˚C + 273.15)

R = resistance in Ω at temperature T

Table. 1 Resistance of Thermistor at different temperatures

Temperature (K)	Resistance of Thermistor (Ohms)
298	10012.6
303	8056.60
313	5326.03
323	3602.01

Table. 2 Parameters of different Thermistor models

Model	Parameter	Value
β-factor	β-factor	3929.07 K
Steinhart-Hart	A	1.130584×10^{-3}
	B	2.338360×10^{-4}
	C	8.924245×10^{-8}

Thereafter, these equations were utilized for calculating the temperature of the environment in the temperature range of 10°C to 50°C. The calculated temperature was compared with a commercially available digital thermometer (MAXTECH, India). The percentage errors at different temperature, between the measured temperature using the digital thermometer and the calculated temperature from the thermistor based device were determined. It was observed that, the percentage error was least when the temperature was calculated using Steinhart-Hart model. Hence, in this study we used Equations (4) for calculating the body temperature. Thereafter, the body surface temperature of a volunteer was measured which has been shown in Fig. 4.5.

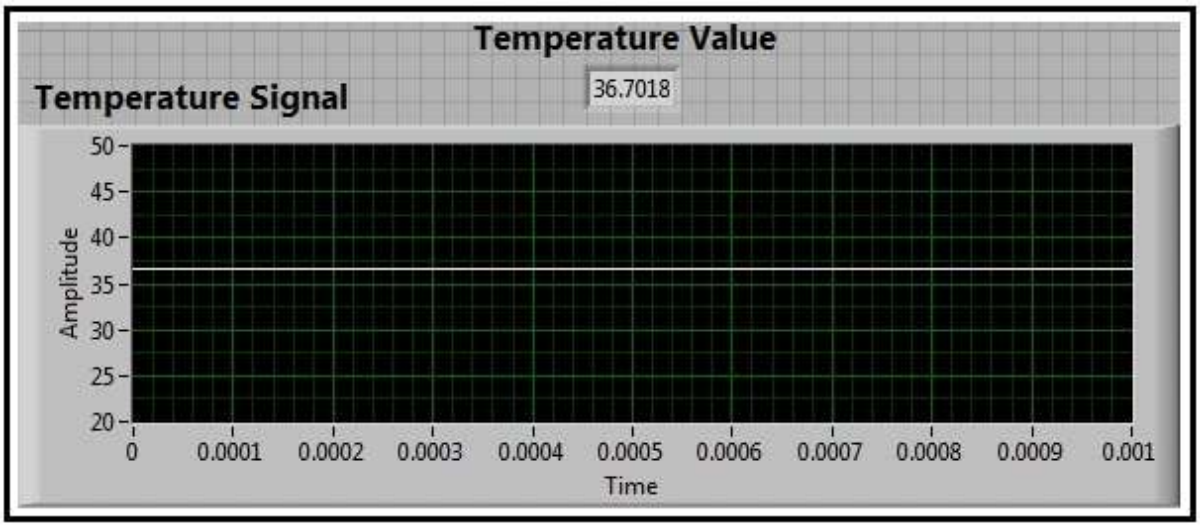

Fig. 4.5 Body surface temperature signal of a volunteer

4.4. PCB Designing

After successfully developing the ECG, PCG, and body surface temperature monitoring systems, a PCB design layout was developed using the Ultiboard (Version 13.0, National Instruments, USA) for simultaneous acquisition of the ECG, PCG, and body surface temperature signals. The 3D view of the ECG-PCG-body surface temperature measurement system has been shown in Fig. 4.6. A properly cleaned copper cladded board was taken. The imprint of the PCB layout was transferred on to the copper cladded board through the use of an electric iron. Then, the exposed copper was subjected to etching using ferric chloride ($FeCl_3$) solution. This resulted in the removal of the exposed copper present on the copper cladded board. Then the copper cladded board was washed using steel scrub in running water for removing the carbon deposited over the designed PCB layout. Holes were drilled in the PCB board using a drill bid of 1mm for inserting the components at designated locations. The components were finally soldered on the PCB. The outputs of the ECG, PCG and body surface temperature sensors were connected to the AI0, AI1 and AI2 analog input ports of the NI USB 6009 data acquisition device. The ICs were powered using a ±9 V power supply designed using Nickel Metal Hydride (NiMH) +9V batteries. 5V power supply to the voltage divider circuit of the temperature signal conditioning circuit was provided from the 5V output pin of the NI USB 6009. The USB 6009 was connected to a laptop that was working in the battery mode, so as to feed the sensed signals to the laptop. A provision was made in the LabVIEW front panel program using "write to measurement" palette in order to store sensor data in a text file. Fig. 4.7 represents the sensor data acquired simultaneously from ECG, PCG and body surface temperature measurement units using the developed PCB. The developed device was

able to acquire signals simultaneously from the ECG, PCG, and body surface temperature sensors with adequate accuracy to be useful for medical purposes.

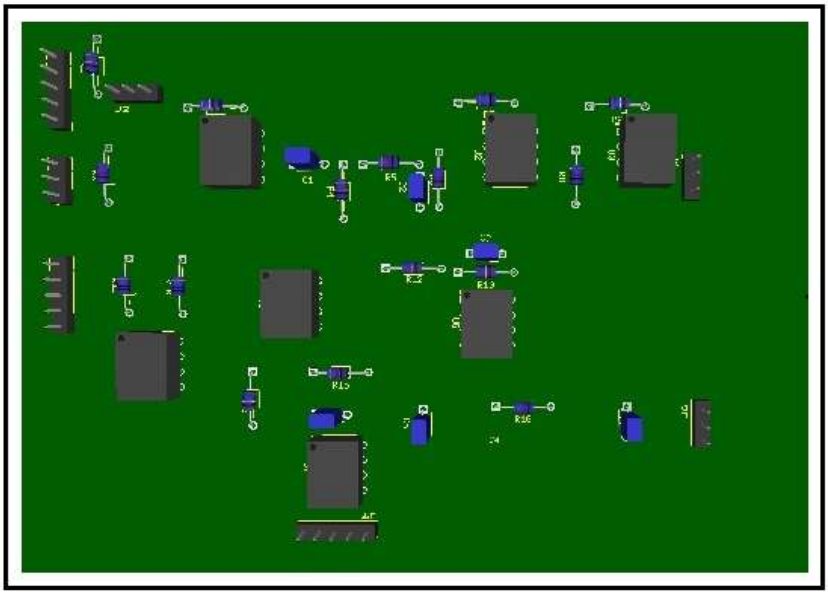

Fig. 4.6 3D view of the ECG-PCG-Body surface temperature measurement unit

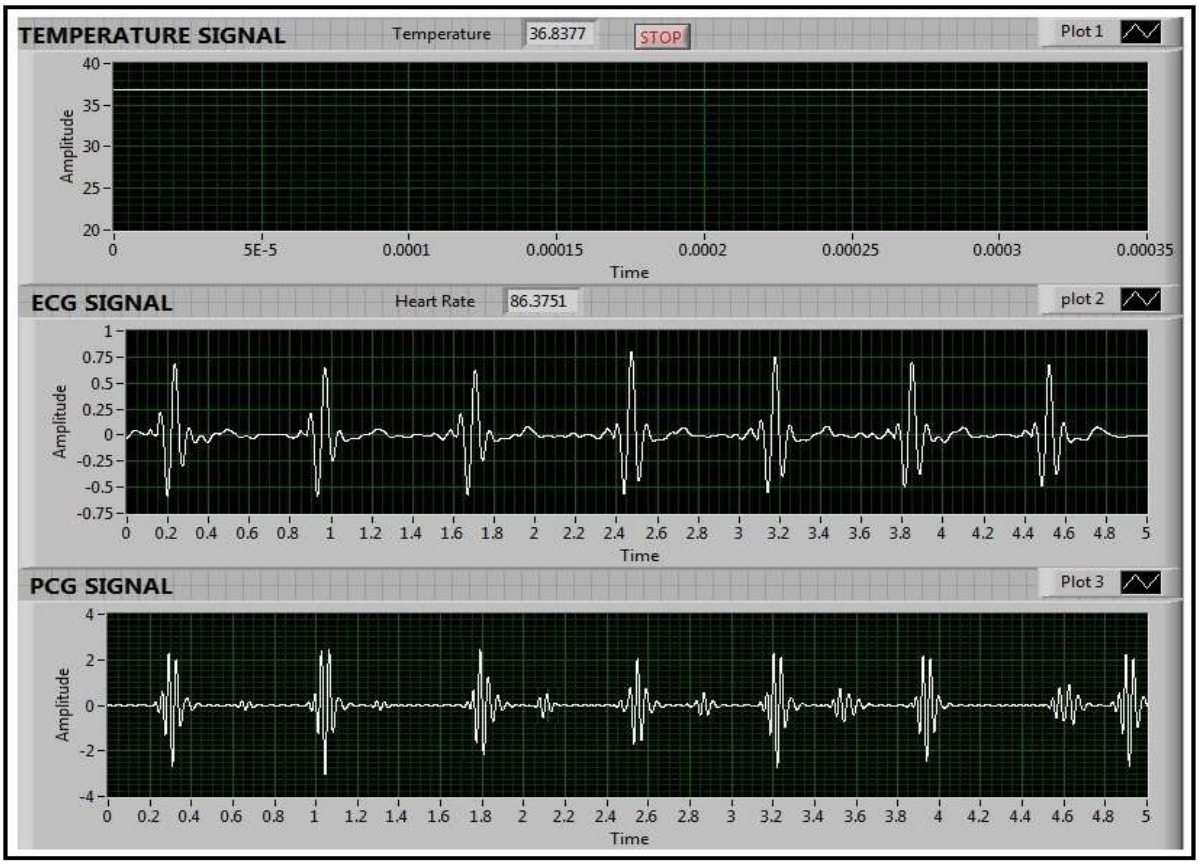

Fig. 4.7 Output of the ECG-PCG-Body surface temperature measurement system

Chapter V

Conclusion

5. Conclusion

In the current study, the development of a simultaneous ECG, PCG and body surface temperature monitoring system has been done successfully. Now a days, there is a necessity to develop ambulatory devices that can be useful for monitoring the cardiovascular conditions staying at home. The demand for ambulatory devices is on rise because of the increase in the occurrence of the cardiovascular diseases across the globe. Early detection of the cardiovascular diseases can provide help to the physicians to rehabilitate the pathological conditions only through medicines. The developed device can be utilized in remote locations for collecting the vital signs of a patient, which can be sent to the physician who is present at a distant location. The device is easy to handle.

6. References

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