A PULSE BASED SENSOR FOR DISEASE DIAGNOSIS

A Dissertation submitted in fulfillment of the requirements for the Degree

of

MASTER OF ENGINEERING

in

Electronic Instrumentation & Control Engineering

Submitted by

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2016

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CERTIFICATE

Certified that the dissertation entitled, **"A Pulse Based Sensor for Disease Diagnosis"**, which is being submitted by **Krittika Goyal** in fulfillment of the requirements for the award of the **Masters of Engineering in Electronic Instrumentation & Control Engineering** to **Thapar University, Patiala,** is a bona-fide record of the candidate's own work carried out by her under my supervision and guidance. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree.

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I hereby certify that the work which is being presented in the project entitled **"A Pulse Based Sensor for Disease Diagnosis"**, by **Krittika Goyal** (**801451015**) in partial fulfilment of requirements for the award of degree of Masters of Engineering in Electronics Instrumentation and Control Engineering submitted in the Department of Electrical and Instrumentation Engineering at THAPAR UNIVERSITY, PATIALA is an authentic record of my own work carried out under the supervision of Dr. Ravinder Agarwal, Professor. In case of any plagiarism or copyright violation, I will be solely responsible for it.

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ACKNOWLEDGEMENT

I express my deep sense of gratitude towards Dr. Ravinder Agarwal, Head, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala.

I would like to express my thanks and indebtedness to my esteemed and worthy supervisor Dr. Ravinder Agarwal, Professor**,** Department of Electrical and Instrumentation Engineering, Thapar University, Patiala for his effective supervision, deep involvement and continuous motivation throughout this research work.

I would like to thank my P.G. coordinator of M.E. (EIC), Mr. Nirbhowjap Singh, Assistant Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala for his encouragement and inspirations.

I am immensely grateful to Dr. N.K. Sharma, Professor and Dr. B.P. Kaushik, Professor, Government Ayurvedic College and Hospital, Patiala for providing useful information to carryout this research work. I feel immense pleasure in expressing my regard, sincere appreciation and deep sense of gratitude to Ph.D. Scholars Mr. Rohit Gupta and Mr. Piyush Samant for providing moral support and help with their valuable suggestion throughout the research work.

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NOMENCLATURE

Main symbols and notations used in this study are listed below. Sometimes a symbol may have alternate meaning but in such a case; the context is sufficient to avoid confusion.

FSR	Force Sensitive Resistor
NI	National Instruments
DAQ	Data Acquisition
LCD	Liquid Crystal Display
HRV	Heart Rate Variability
MSO	Mixed Scope Oscilloscope
ADC	Analog to Digital Convertor
DAC	Digital to Analog Convertor
BER	Band Energy Ratio
SVM	Support Vector Machine
LR	Logistic Regression

ABSTRACT

According to Ayurveda, the root cause of the disease is imbalance of three doshas i.e. vat, pit and kaph. These doshas are the primary disease causing agents in the human body. The doshas derive from the five elements. *Vat* is composed of Space and Air, *Pit* of Fire and Water, and *Kaph* of Earth and Water. The health status of the person is examined by ayurvedic physician by feeling palpation from three fingers (index, middle and ring) placed on the radial artery for vat, pit and kaph, respectively. Examination of the pulse (Nadi Parikshan) requires a lot of experience in pulse reading. It depends upon the perception of the practitioner, hence there is a need to develop pulse diagnosis system to obtain accurate diagnosis of disease. Present work focuses on the design and development of the pulse diagnosis system, in which sensor MPXM2053D sensor from FREESCALE was used to sense the pulse signals from 21 subjects. Thereafter, the signal conditioning circuit was designed using instrumentation amplifier and amplified signal was displayed and analyzed on MSO. Real time monitoring was performed using myRIO DAQ card in LabVIEW. Further, filtering of pulse signal was performed and band energy ratio features was extracted. Classifier was used to classify healthy and unhealthy person and results were obtained with good accuracy.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The word Ayurveda is a combination of two Sanskrit terms ‘Ayur’ and ‘Veda’. Ayur means life and Veda means science. Hence, Ayurveda refers to the science of life. Ayurvedic knowledge originated in India more than 5,000 years ago and is oftentimes recognized as the “Mother of all healing” [1]. The main aim of Ayurveda is to preserve the health of a healthy person and restore the health of sick one. It advises the practice of those principles which are good for life and abstinence from those which are harmful. It believes that health is happiness while the disease is unhappiness.

Ayurveda emphasizes on the maintenance of health through balance of body and mind. Many factors, both internal and external disturb this balance and thus result in an unbalanced state of body and mind. These factors comprise of both emotional and physical stress, such as diet, weather and seasons. The causes of imbalance can be eliminated by understanding these factors affecting the imbalance. Imbalance is a disorder and disease is referred to as the cause of this disorder.

1.2 Tridosha Doctrine

According to Ayurveda, there are three primary life forces in the body, also known as biological humors. These are called in Sanskrit as “Vat,” “Pit” and “Kaph”. Figure 1.1 shows these three biological humors. Vat corresponds to elements of air, pit refers to the elements of fire and Kaph corresponds to elements of water [2]. The Ayurvedic term used for humor is dosha. Dosha means which causes things to decay or spoil. Hence, the three biological humors are known as tridosha. The imbalance of these doshas causes disease. These are the three major principles for good mental health as described by Ayurveda, which regulate the functions of the body and mind. In order to learn balancing of mind and body one must need to know that how vat, pit and kaph work together.

1.2.1 Vat

Vat is the biological air humour. Sometimes it is also known as wind. It is composed of space (ether) and air, which means it moves things. The air is dry, light, cool and posses motion. It is responsible for movement. It also governs mental balance and orientation. The functions include breathing, muscle movement and blinking. In balanced state vat promotes creativity and flexibility and it promotes anxiety, fear when it gets imbalanced. Symptoms of vat imbalance are thirst, pain in the whole body, roughness of skin, contraction of skin [3].

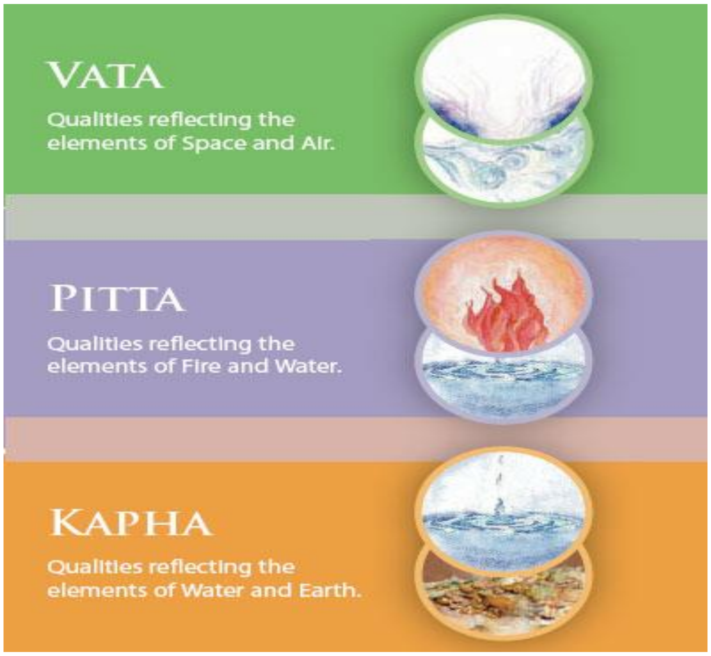

Figure 1.1: The three biological humors

1.2.2 Pit

Pit is the biological fire humor. Sometimes it is also known as bile. It is composed of fire and water, which digest things. Fire is wet, fiery, hot and fetid, responsible for chemical and metabolic transformations. It also governs mental digestion and capacity to understand things. The functions include digestion, assimilation and absorption**.** When pit is in balanced state it promotes capacity to understand things as they are that is intelligence and promotes anger, jealousy when it gets imbalanced.

1.2.3 Kaph

Kaph is the biological water humor. Sometimes it is also known as phlegm. It is composed of water and earth, which hold things together. Water is wet, cold, heavy and dull, responsible to provide structure to the body. It moisturizes the skin and also maintains immunity. It moistens food and if it is imbalanced then it produces loss of appetite, firmness of the limbs.

1.3 Pulse Diagnosis

Pulse diagnosis means an examination of pulse. In Ayurveda it is known as Nadi Parikshan. It is a non invasive technique. Examination of the pulse as a diagnostic tool was recognized by Indian physicians in twelfth century A.D. [3]. Sarangadhara Sanhita, an authentic book of Ayurveda states that the pulse at the wrist signifies the presence of life. The physician should recognize health and ill health of person from the activities of the pulse at wrist [4]. Tridosha govern the function of the entire body, Ayurvedic physician use the pulse to determine heart rate as well as feel the patterns of vibration that represent the status of the body and mind at a specific time. Ayurvedic practitioner places three fingers 2 cm up the wrist with index finger placed near the thumb on radial artery corresponding to each of the three doshas as shown in figure 1.2. The index finger senses the vat pulse, the middle finger senses the pit pulse and the ring finger senses the kaph pulse.

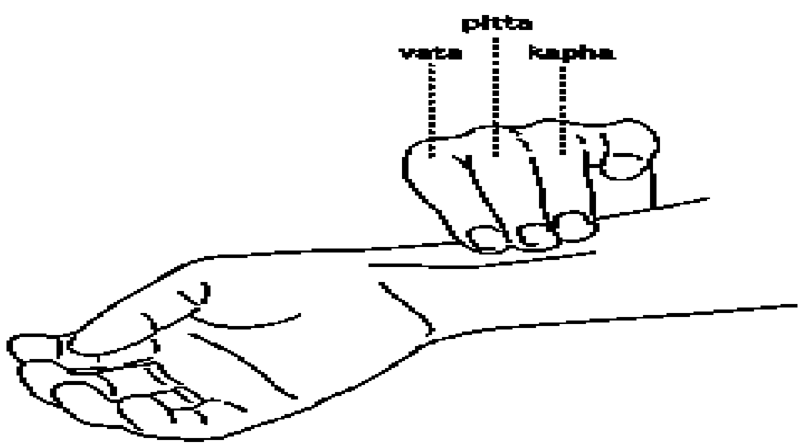

Figure 1.2 Standard positions to obtain a pulse

During the sensing of vat, pit and kaph, physician observe the rate, volume, wall of artery and rhythm of pulse as shown in Table 1. In this way the physician identifies the features of the pulse. In order to understand the basic nature of pulses, they were compared with the gait of different animals as shown in figure 1.3. During the increase of vat the movement of pulse resembles the movement of a snake. During the increase of the pit it resembles the movement of the frog and during increase of kaph it resembles the movement of a swan. When dominance of any dosha or combination of doshas is observed disease is found through proper examination of pulse.

Table 1.1 Characteristics of pulses

	VAT	PIT	KAPH
Location	Index Finger	Middle Finger	Ring Finger
Movement	Spiral	Jumping	Symmetrical
Speed	Irregular	Fast	Slow
Volume	Low	Full	Full

Figure 1.3 Comparison of pulse to gait of different animals

1.4 Dissertation Organization

Chapter I introduces the basis of research and understanding of concepts on which research is based. It briefly describes the three biological humors and technique of pulse diagnosis.

Chapter II introduces important researches which have been done in this area. It gives a brief idea about important references, methodology used and the results of that particular research. Gaps in the study and objectives of the present study have been discussed. Also, an architecture is proposed to carry out present research work.

Chapter III gives a brief idea about the material and methods used to develop the complete acquisition system along with calibration and configuration of components and component description are basic points which are explained.

Chapter IV deals with result and discussion part of the thesis.

Chapter V gives the idea of conclusion and future scope of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Vat, Pit and Kaph are the three basic elements present in the human body. These are often known as dosha. The imbalance of the three doshas causes disease. From pulse signal the quality of the three doshas can be studied. The work has been done to study the characteristics of pulses to know about health status of person.

2.2 Previous works: Technological aspects

Aniruddha Joshi *et al.* [5] designed Nadi Tarangini for obtaining pulses. The system Nadi Tarangini contained a strain gauge based sensor having the diaphragm at its center, followed by a transmitter cum amplifier and by digitizer for quantification of analog signals. Dimensions of strain gauge sensor used were of order of 1×1 cm. The diaphragm at the center was deformed by the pressure exerted by an artery and thus the system was found to capture pulse waveforms as a time series data. Reproducibilty of collected waveform was checked as pulse waveform of single health person was recorded at different times for five consecutive days. It was found that waveforms obtained were reproducible and matched with literature waveforms.

A.E Kalange *et al.* [6] proposed a three point radial pulse acquisition system for the collection of pulse signals. To capture the data, three similar data acquisition channels were used at three pulse points vat, pit and kaph, respectively. Simultaneous measurement of radial pulse at three points was to be measured so a combination of three pressure sensors with the same characteristics were arranged on a module. The sensor used was of diameter is 10 mm and sensors were placed at a distance of 6 mm between them. Sensors were further connected to three channels for acquisition of data. Reseaech work was carried out by using single sensor which operated on ultrasonic frequency and pressure to be applied was determined. Pulse signal was studied in time and frequency domain. t test for statistical comparison was performed and it was found that doshas can be differentiated based on test.

M.Sharmila Begum *et al.* [7] designed a system named Nadi Tarangini. The system comprised of three sensors in a similar manner as compared to three fingers of a physician. Spring system was attached to the sensors. Type of sensor used was based on piezo film. The developed system was tested upon around 200 students. Thereafter, raw signal obtained was filtered, amplified and read by a software application and graphs were plotted with respect to time. Waveforms obtained were found to be reproducible and were compared in case of different type of diseases. Further, it needs to be expanded to diagnose different types of diseases like cancer.

A.E Kalange *et al.* [8] proposed a system in which a transducer based on piezoelectric properties was used for detecting the human pulse. Piezoelectric sensor was used as no power supply was required and also it was capable of detecting dynamic pressure. Sensor was placed upon wrist and data obtained was further processed using signal conditioning circuit. Signal conditioning circuit comprised of buffer amplifier, low pass filter and notch filter to remove noise. Pressure on the wrist was maintained through sphygmomanometer cuff. Pulse waveforms were recorded on a digital storage oscilloscope. It was found that three doshas had different frequencies.

Roopini N *et al.* [9] developed a portable prototype of nadi prakshan yantra. Sensors used were based upon the principle of photoplethysmography. Optical sensors were used to acquire signal from the wrist. Acquired signal for further processing was given to microcontroller ATMEGA328. Appropriate selection was done in order of Butterworth filter to remove noise. Signal conditioning was performed using LabVIEW software. Data was acquired and collected from around 100 subjects and features such as amplitude, mean, frequency were calculated. Also, data was tested and validation by using neural network.

Mahendra Kumar *et al.* [10] developed an electro-mechanical system, namely 'Nadi Yantra.' Piezoelectric based pressure sensors were used to capture the signals from the radial artery at the wrist. The raw signal obtained was filtered, amplified and transferred to the PC. Biopac 150 system was used for data acquisition. Waveforms obtained were found to match with present literature waveforms. Waveforms were found reproducible and hence the system achieved stability. Signal processing techniques such as power spectral analysis and bandpower were applied to observe features of three signals. An experiment was carried out on 5 subjects and signals were captured before and after lunch. It was found that the amplitude of vat rises before lunch and falls post lunch while the amplitude of pit and kaph rises post lunch. Further, for processing of pressure signals, wavelet based techniques were used for the identification of percussion peaks.

Sajana K. Mathew *et al.* [11] developed a hardware in which pulse signals were acquired using sensor based on piezoelectric property. Single sensor was used and placed at radial artery. The pulses were obtained and processing was carried out with an embedded system. For proper acquisition of signal MPLAB software was utilized. Further, using MATLAB, calculation of mean factor was performed with respect to age and the heart beat of the subject was read from a pulse oximeter. An experiment was performed on 5 subjects of different age groups and found that mean value increases as age increases. It was found that the people of the same type of age group had similar mean value. The system needs to be extended to three sensors for better results.

Akshita Baisware *et al.* [12] proposed design using technology based on virtual instrumentation. For wrist pulse acquisition sensor used was Force Sensitive Resistor (FSR). In FSR when pressure is applied it changes resistance which further causes a change in voltage. Single FSR was used to sense pressure, which was further followed by acquisition through NI DAQ card. Force / pressure was converted to a voltage and a plot of voltage was obtained in LabVIEW on front panel. Signal conditioning was performed in LabVIEW using filters of suitable order and amplifiers. Data was collected from single pulse point, thus for effective and accurate results it needs to be expanded to three sensors.

Bhaskar Thakker *et al.* [13] designed a pulse acquisition system for wrist using sensor based on piezoresistive principle. In this system, pulse acquisition was performed using three piezoresistive type of sensors. A circuit for signal conditioning was designed using an instrumentation amplifier to amplify the weak wrist pulse signal followed by removal of unwanted frequencies using a low pass filter. For the digitization of signals, microcontroller was used and for real time monitoring data were displayed on LCD. In order to observe signals in better way touch interface was included for better access. For processing of the signals in offline mode recording was performed on the memory card. The waveforms obtained were compared with waveforms present in literature and were found to have good match.

Xingsheng Che *et al.* [14] proposed a method for calculation of the power spectrum of wrist pulse signals. Data was acquired using a pressure sensor for more than 3 minutes. The algorithm for calculating the power spectrum was established. Since the waveform was periodic, waveform interception was calculated in order to determine one sample of wrist pulse. Then the sample was normalized before calculation of the power spectrum. Every time, amplitude normalization was performed. The power spectrum was calculated for smooth and taut pulse. It was found that the major concentration of energy in case of smooth pulse was within 10 Hz whereas in case of taut pulse, it was within 5 Hz. A study was carried out by relating diseases and shapes of waveforms with different frequency ranges.

N ArunKumar *et al.* [15] suggested a method for distinguishing between healthy and unhealthy person on the basis of approximate entropy. Initially the pulse signals were acquired using suitable sensor and processed using wavelet denoising algorithm. D9 as a wavelet function was applied since it is similar to pulse signal. Approximate entropy as a measure for calculating the repeatedness of the waveform was calculated for healthy and unhealthy subjects. In case of healthy subjects it was greater than 0.25 and in case of unhealthy it was less than 0.1771. Unhealthy subjects with diabetes type were tested using this technique.

Megha Sareen *et al.* [16] designed a system named Nadi Yantra to acquire pulse signals in which piezoelectric type of pressure sensors were used. Information was gathered and processed using wavelet decomposition technique. Fourier transform of the signal was plotted and it was found that most of the frequency lies in 0-10 Hz band. Further, percussion peaks were detected and features were extracted in order to compute heart rate variability. Time domain as well as frequency domain analysis was carried out. In time domain analysis features such as mean, standard deviation were calculated. Frequency domain analysis was carried out to know the portion in which frequency lies. It was inferred that peak detection for calculating HRV can be used as a diagnostic tool.

Bhaskar Thakkar *et al.* [17] proposed methodology for calculating the power spectrum. Power spectrum was used as a diagnostic tool to distinguish between healthy and unhealthy person. A study was carried out on unhealthy people suffering from gastrointestinal disorders. Wrist pulse signals were obtained and were processed. They had baseline wander which was removed using wavelet transform. Then further wrist signals were processed in the frequency domain. Band energy ratio was applied to identify band in order to distinguish between healthy and unhealthy person. Frequency of abnormal group was found between 4 to 10 Hz. In order to ensure that the test performed was correct, receiver operating characteristics were analyzed in which sensitivity, specificity and accuracy were calculated.

Peng Wang *et al.* [18] designed an architecture which contained three semiconductor strain gauge main sensors and subsensors. Also, designed a module for pressure adjustment for the positioning of three main sensors on the radial artery. The signal conditioning circuit was made of amplifier and filter. Signals were acquired and graphical user interface was designed through which pressure applied could be controlled on sensors. Data from healthy and diabetic subjects was collected and sample entropy was calculated. System was tested for both single and three channel. It was found that accuracy of three channels is more in comparison to the single channel system.

Kruti Parikh *et al.* [19] proposed a method for calculating wrist pulse signals. Data was acquired using a board from ST Microelectronics. Pulse signals of healthy and unhealthy subjects were calculated. Feature extraction was done using a feature band energy ratio. Different band was chosen and it was found that frequency of pulse signal in healthy and unhealthy subject variability in the band from 4 to 10 Hz. Then a linear and quadratic classifier was used to classify them into healthy and unhealthy subjects. For reliability of features K cross validation approach was applied.

2.3 Gaps in the study

Limitations of Current wrist pulse Acquisition Systems

Available wrist pulse acquisition systems are either single channel or three channels. The pulse acquisition system is made as to replicate the three fingers of a physician but there are some problems unresolved in creating the system. Problems such as acquisition of different pulses under different pressures and positioning of sensors at accurate positions to acquire signal is a challenge. Most of the designed hardware involves costly circuitry. Designing of three channel wrist pulse acquisition systems is still in the process of investigation. Creating an improved device that can overcome these obstacles is essential for this research work.

2.4 Objectives

The study proposes to fulfil following objectives:

a. Design and implementation of a non invasive device which can eliminate human error performed manually by Indian practitioners in the disease diagnosis

b. Sensing of wrist pulse signal with the help of piezoresistive sensor

c. Observing the real time waveform on a monitor which provides information about the diagnosis

d. Testing of system for different subjects to check whether healthy or unhealthy

2.5. Proposed architecture

The proposed architecture for the present research is shown in figure 2.1. In the first phase of the research work, suitable sensor was selected for sensing pulse. Different type of pulse sensors have been used in past research work, *e.g.*, strain gauge based sensors have been used by Annirudha *et al* [5], Bhaskar *et al* [13]. Piezoelectric sensor made up of different materials like polydivenyl fluoride and lead zirconate titanate or working upon the principle of ultrasonic frequency have been used by Sharmila *et al* [7], Mahendra *et al* [10], Sajana et al [11], AE Kalange [8], A.E. Kalange [6] respectively. Optical sensor has been used by Roopini *et al* [9]. Also force sensitive resistor have been used by Akshita *et al* [12]. Every sensor working on different principles has its own advantages and disadvantages. Therefore, MPXM2053D based on piezoresitive principle was selected for sensing wrist pulse signal. Since the wrist pulse signal is mV signal so it was amplified using instrumentation amplifier. Obtained signal was observed on Mixed Signal Oscilloscope. Also signal can be recorded and saved in excel sheets and processed.

In the second phase, acquisition and real time monitoring was performed using myRIO DAQ card and data was collected from healthy and unhealthy subjects.

In the third phase, obtained data was imported to Matlab for further processing. Filtering was performed using a Butterworth filter of suitable order and feature extraction was carried out. Classifier was used for classifying person healthy or unhealthy.

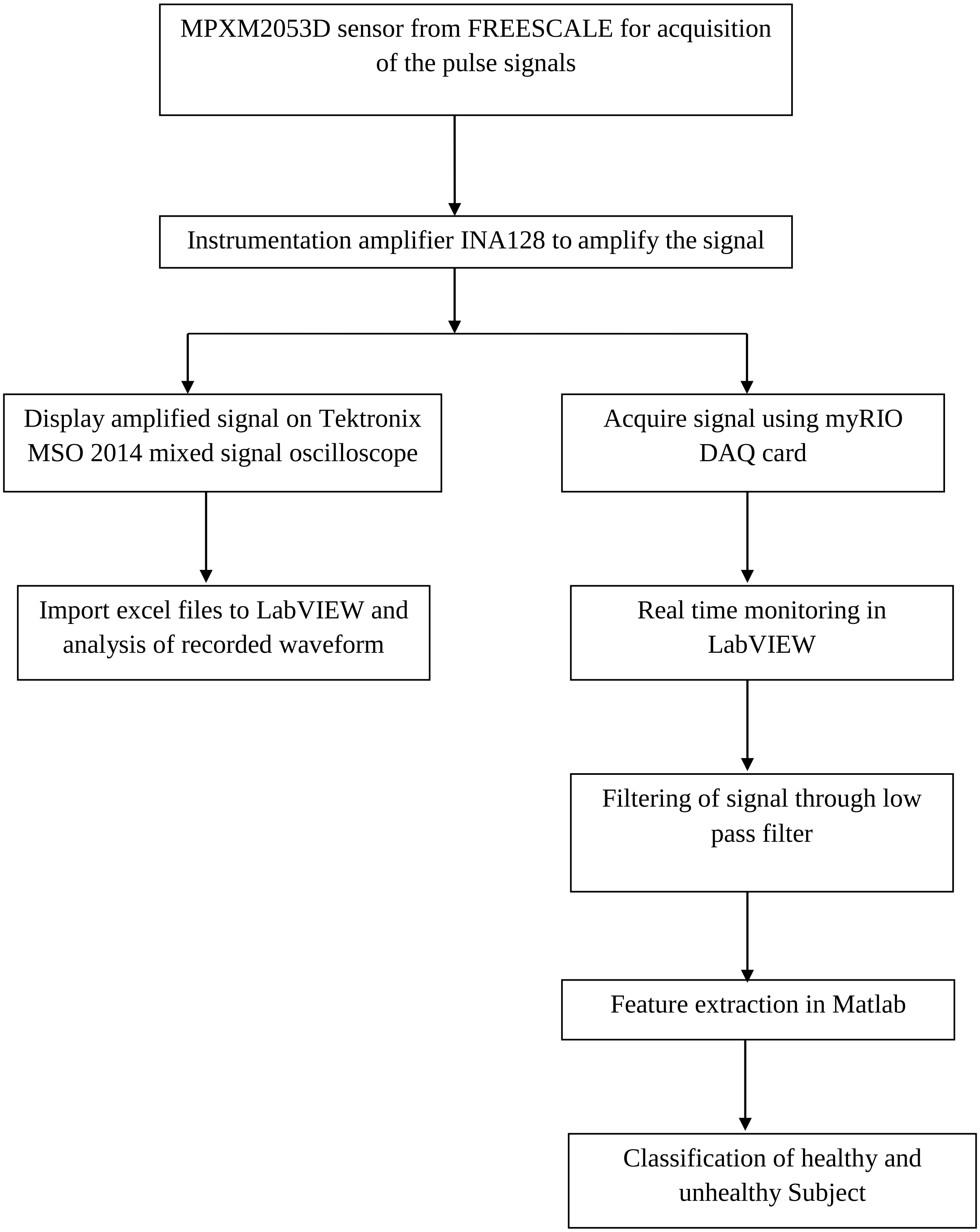

Figure 2.1 Proposed architecture

CHAPTER 3: MATERIAL AND METHODS

3.1. Introduction

Wrist pulse signal was acquired by using piezoresistive sensor, followed by amplification of the signal using instrumentation amplifier because it is a low frequency signal. After amplification of signal it was given to acquisition device. It was captured by DAQ device and observed on the monitor. Signal conditioning of the signal was done to have clear signals. Features useful in diagnosis were extracted from the signal.

3.2 Wrist Pulse Sensor

A wrist pulse signal is produced by cardiac contraction and relaxation of heart as shown in figure 3.1. It is related to central aortic pressure waveform [18]. Pulse is felt at radial artery and the fluctuations are felt.

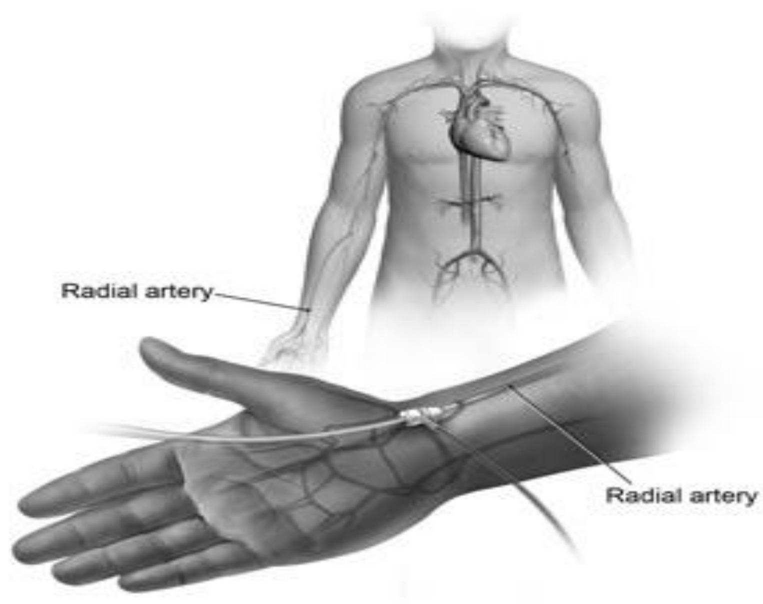

Figure 3.1 Pulse at radial artery

Wrist pulse is a pressure signal, so a pressure sensor is used to acquire a pulse signal. There are number of pressure sensors available with a different principle, *e.g.* piezoelectric and strain gauge based sensors. Both the sensors can be used for human pulse detection but both have different advantages and disadvantages.

Both strain gauge and piezoelectric meet the requirement but in present research piezoresistive pressure sensor was used because piezoelectric sensor requires shielding. Also, piezoresistive sensors provide both static and dynamic response. Hence, piezoresistive sensor from FREESCALE of suitable size and sensitive to variation in pressures was used.

3.2.1 Piezoresistive sensor (MPXM2053D)

MPXM2053D is a piezoresistive principle based silicon pressure sensor. It has the dimensions of of 9.1 mm ×7 mm with pin description as shown in figure 3.2. Dimensions of the sensor are suitable as they are similar to that of surface area covered by a finger tip.

Figure 3.2 MPXM2053D from FREESCALE [20]

It provides a linear voltage and output corresponding to the pressure. The sensor consists of a diaphragm at center and thin film resistor network. It provides a wide range for measurement i.e., 0 to 50 kPa or 0 to 375 mm of Hg. It is highly suitable for biomedical applications since systolic blood pressure ranges from 140 mm of Hg to 190 mm of Hg and diastolic pressure ranges from 90 mm of Hg to 100 mm of Hg. It provides a differential output voltage corresponding to the applied differential pressure. Its output voltage increases as pressure increases relative to the other side in differential sensor [20].

A. Specifications

a. Pressure range: 0-50 kPa

b. Supply voltage: 10-16 Vdc

c. Supply current < 16m Adc

d. Offset: 1 mV

e. Sensitivity: 0.8mV/kPa

f. Operating temperature: -40 to 125 ^{0}C

B. Theoretical Differential Pressure versus Ouput Voltage

Table 3.1 Calibration of sensor [20]

Applied Differential Pressure (kPa)	**Output Voltage (mV)**
0	0.8
12.5	10
25	20
37.5	30
50	40

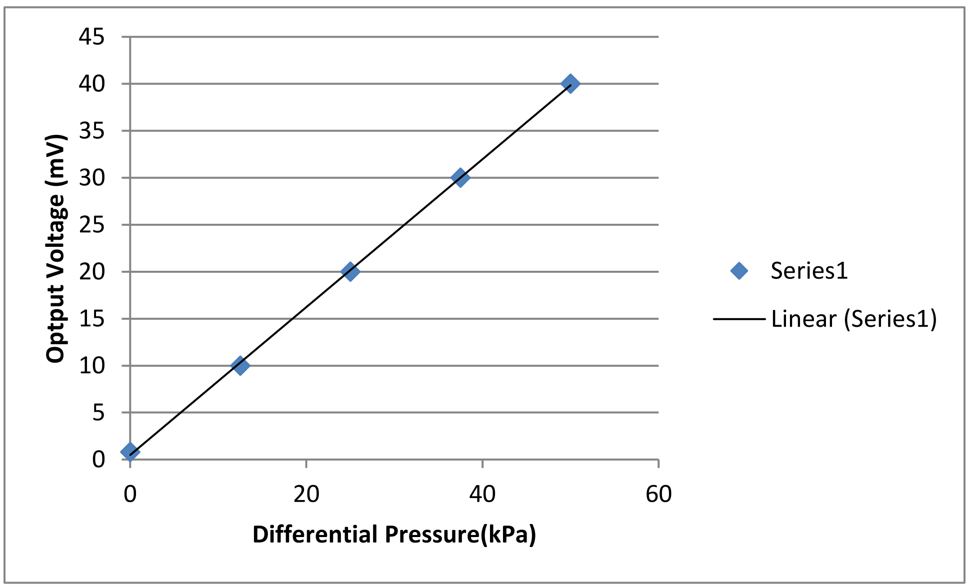

Figure 3.3 Graph of calibration of sensor [20]

Hence, it provides high linearity and sensitivity.

3.3 Instrumentation Amplifier

MPXM2053D sensor provides differential output voltage. Sensor provides differential output in mV which needs to be amplified to give as an input to acquisition device. Instrumentation amplifier was used to amplify the differential output of the sensor, which does not require input impedance matching [21]. In research work, instrumentation amplifier INA128 was used as shown in figure 3.4. It has high common mode rejection ratio, which helps in removing common mode signal that is noise. It provides high bandwidth even at high gain.

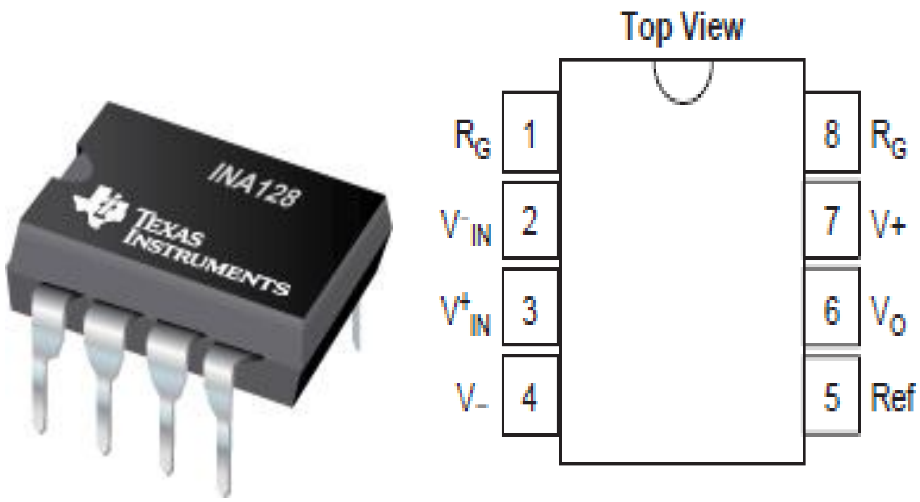

Figure 3.4 INA128 along with pin configuration

A) Features

a. Low input bias current: 5nA

b. Supply voltage: 2.25V -18V

c. Quiescent current: 700μA

d. Low offset voltage: 50μV

e. Operating temperature: -40 to 125 ^{0}C

f. Low drift: 0.5 μV/^{0}C

g. High common mode rejection ratio: 120 dB minimum

h. Slew rate: 4V/ µsec at gain of 10.

B) Pin Description

Table 3.2 Pin description of INA128 [22]

Pin no.	Name	Description
5	REF	This is an input pin known as reference which is connected to ground
1,8	R_G	Gain Setting pin, to set gain greater than 1, place resistor of suitable value
4	V-	Negative supply
7	V+	Positive supply
2	V_{IN-}	Inverting input
3	V_{IN+}	Non inverting input
6	V_0	Output

3.3.1 Simulation and Circuit Designing

Simulation was performed using Multisim software as shown in figure 3.5. Function generator was given as an input to operational amplifier. The output of operational amplifier was observed on an oscilloscope. The pin configuration of INA128 and AD620 is similar so AD620 was available in multisim and thus used for simulation.

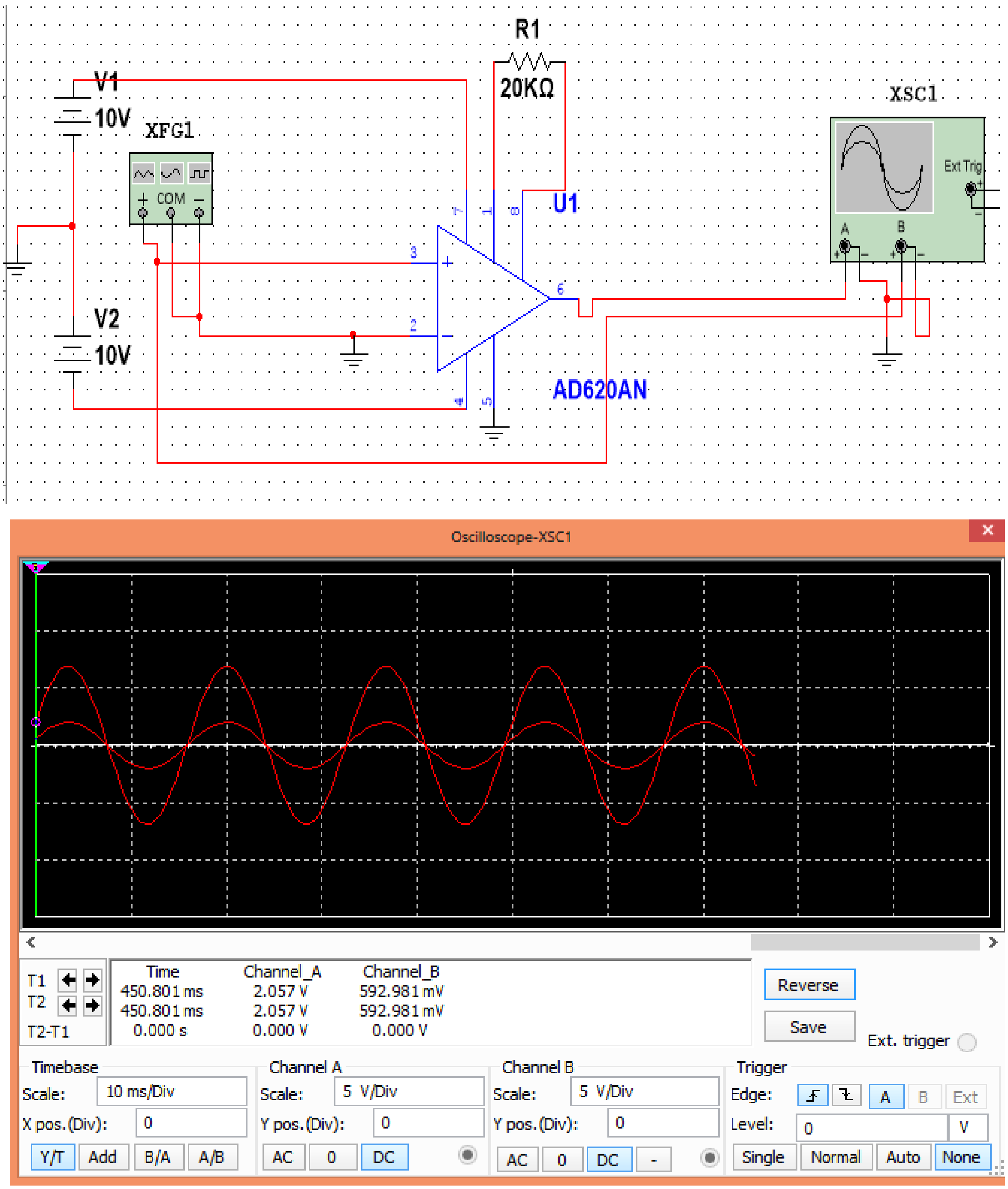

Figure 3.5 Simulation using Multisim

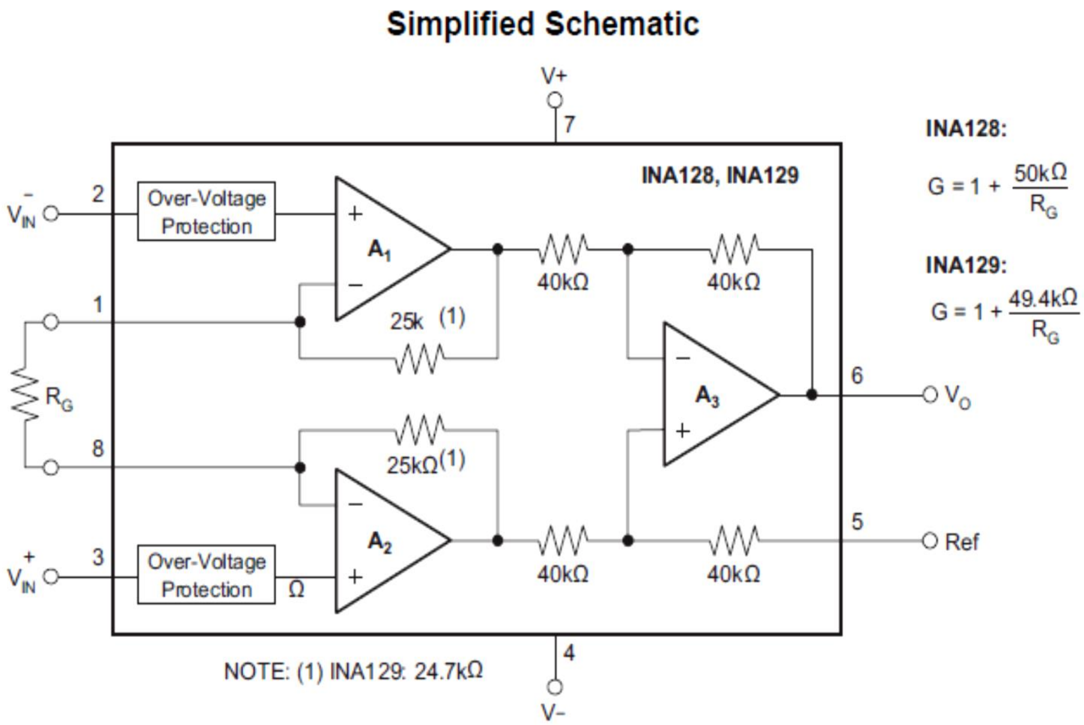

Figure 3.6 Schematic circuit diagram of INA128 [22]

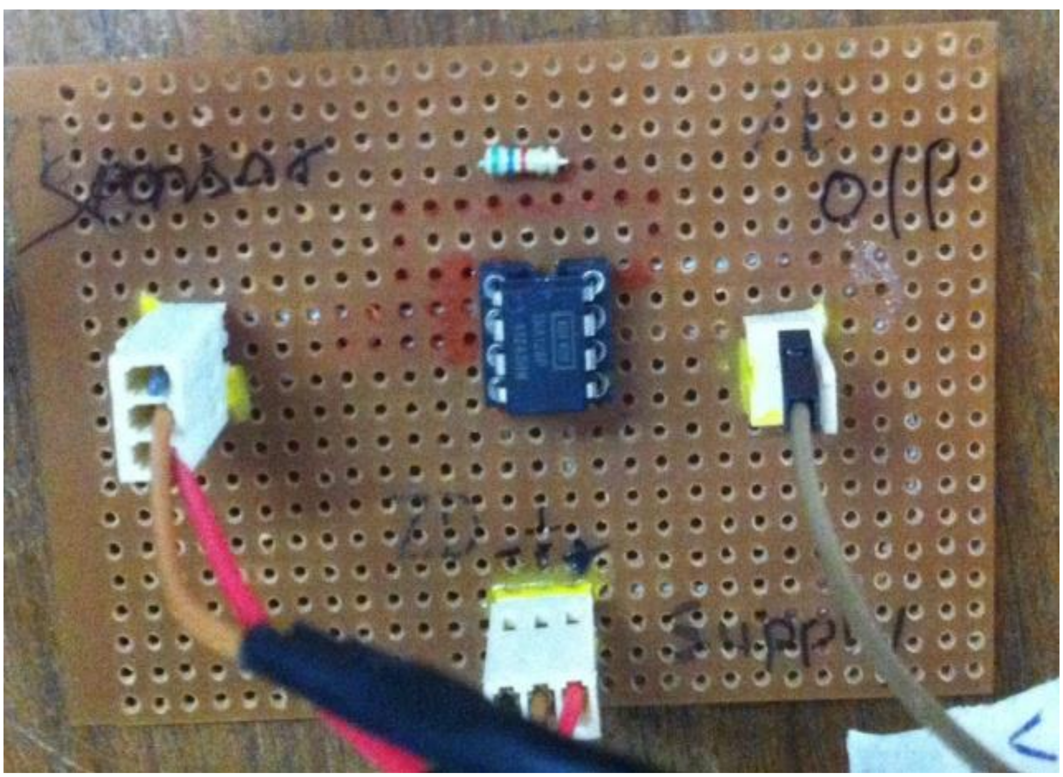

Figure 3.7 Connections of INA128 on hardware

3.3.2 Testing and Calibration

The circuit was tested and INA128 was calibrated using a function generator to generate input signal and thus implemented on hardware. The output was observed on Mixed scope oscilloscope. Calibration of instrumentation amplifier was performed to calibrate and achieve correct output. Minimum signal available using inbuilt function generator in MSO was 10 mv. To perform calibration of INA128 different values of gain were set according to a formula provided in the datasheet.

$$Gain = 1 + \frac{50K\Omega}{R_F}$$

Table 3.3 Calibration of INA128

Gain (Value of resistor, R_F)	Input signal (mv)	Output signal (V)
1 (NC)	10	0.01
	20	0.02
	50	0.05
	100	0.1
	200	0.2
10 (5k ohm)	10	0.1
	20	0.2
	50	0.5
	100	1
	200	2
50 (1k ohm)	10	0.5
	20	1
	30	1.5
	40	2
	50	2.5
100 (500 ohm)	10	1
	20	2
	30	3
	40	4
	50	5

3.4 Data Acquisition System

In the present research work myRIO data acquisition system was used. A DAQ device is essentially an analog to digital convertor. Signal acquired was very low in amplitude and full of common mode noise so the myRIO DAQ card was found suitable choice for this work as it provides differential mode of operation.

3.4.1 myRIO DAQ Card

The NI myRIO device is as shown in figure 3.8. It consists of analog inputs, analog outputs, digital inputs and digital output. It can be connected to a computer through USB cable or either by Wi-Fi and Bluetooth. The hardware overview has been discussed in detail [23].

Figure 3.8 myRIO DAQ card

A) Hardware Overview

a. It has an inbuilt three axis accelerometer.

b. 3 different input/output connectors

c. USB and WiFi

d. Audio input/output

e. 4 LEDS

f. 1 Push button

B) Connector Pinout A and B

This device consists of two identical sets of signals. In hardware they are named as connector A and connector B respectively as shown in figure 3.9.

Figure 3.9 Connector pinout A and B

a. +5V: +5V power output, which is referenced by DGND.

b. AI<0...3>: 4 Analog input channels which are referenced by AGND.

c. AO<0...3>: 4 Analog output channels which are referenced by AGND.

d. DIO<0...15>:16 Digital input/output channels with 3.3V output which are referenced by DGND.

e. AGND: Reference for analog input and analog output.

f. DGND: Reference for digital signals, +3.3V and +5V power supply.

g. +3.3V: +3.3V power output, which is referenced by DGND.

C) Connector Pinout C

In hardware it is named as connector C as shown in figure 3.10.

Figure3.10 Connector pinout C

a. +15V/-15V: +5V power output, which is referenced by AGND.

b. AI0+/AI0-: Differential analog input for channel 0 which is referenced by AGND

c. AI1+/AI1-: Differential analog input for channel 1 which is referenced by AGND

d. AO<0...1>: 2 Single ended Analog output channels which are referenced by AGND.

e. DGND: Reference for digital signals, and +5V power supply.

f. +5V: +5V power output, which is referenced by DGND.

D) Analog Input Channel

NI myRIO device has many analog input channels present on connector A, connector B as well as connector C. All the analog inputs are further multiplexed to one Analog to Digital Convertor (ADC) that performs sampling of all channels as shown in figure 3.11. Four single ended analog inputs of connector A as well as of connector B can be used to generate signals up to 5 V, whereas connector C has 2 channels which are differential analog input channels that can be used to generate up to +10 V signals.

E) Analog Output Channel

NI myRIO device has many analog output channels present on connectors A, connector B as well as connector C. All the digital outputs are further multiplexed to one Digital to Analog Convertor (DAC) that performs the updation of all channels simultaneously as shown in figure 3.12. Two analog outputs of connector A as well as of connector B can be used to generate signals up to 5 V, whereas connector C has 2 channels which are analog output channels that can be used to generate up to +10 V signals.

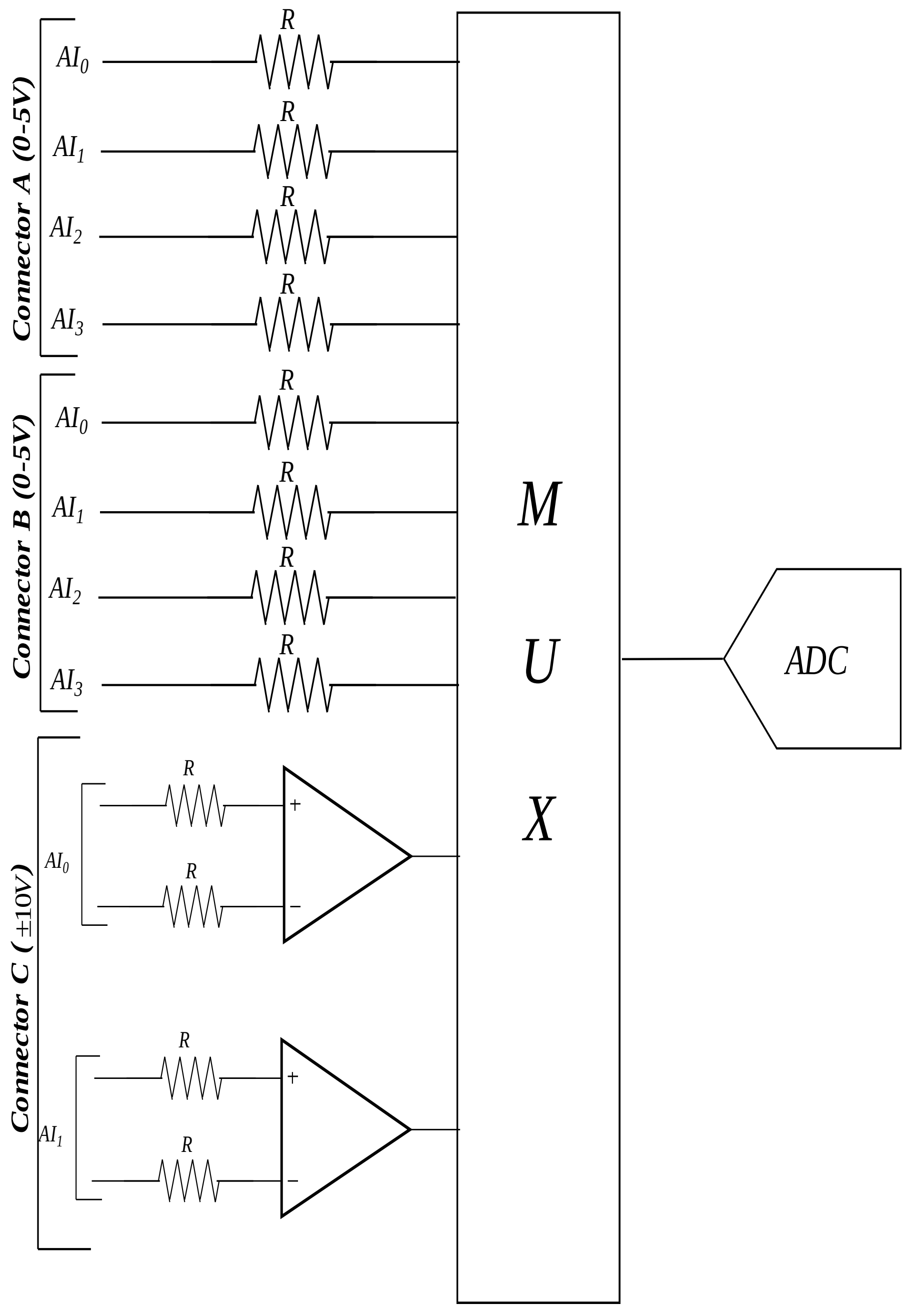

Figure 3.11 Circuit diagram of analog input channel

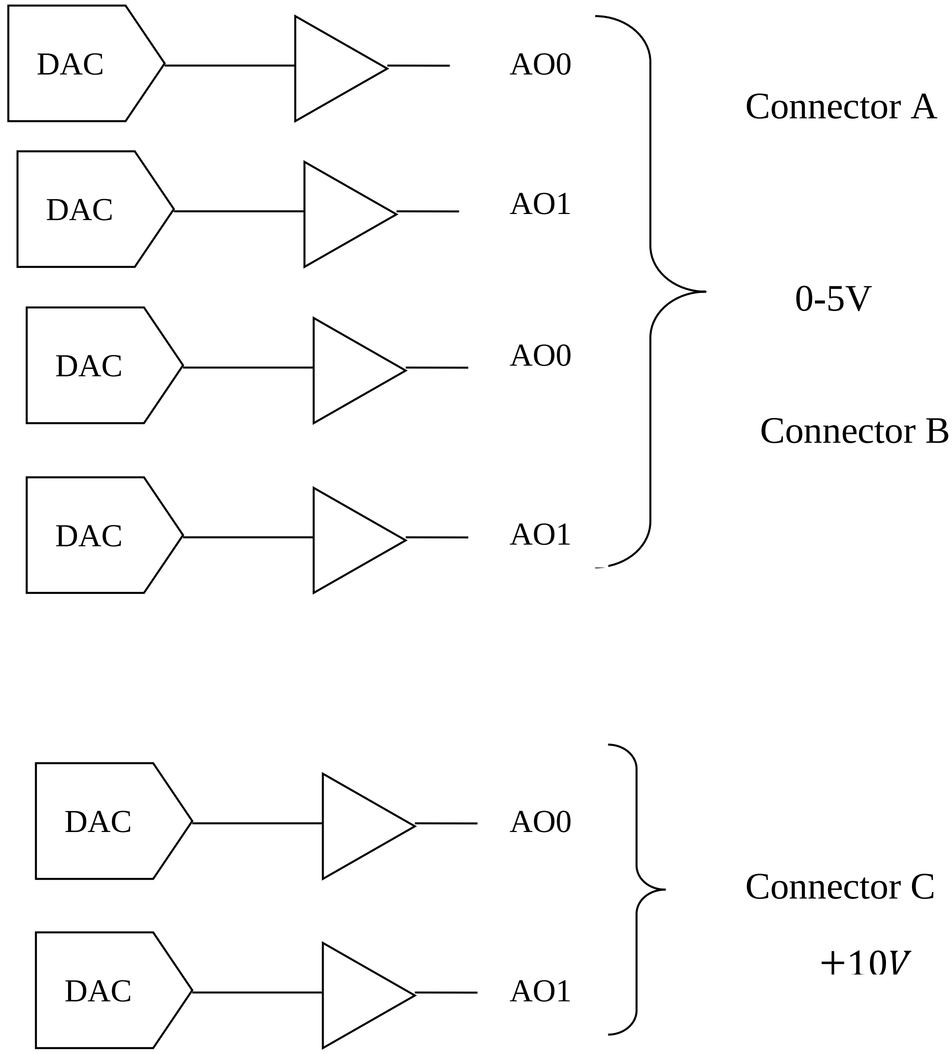

Figure 3.12 Circuit diagram of analog output channel

F) Start of myRIO

The hardware required for myRIO device is adapter, USB cable and myRIO Card as shown in figure 3.13. Softwares required to operate myRIO device are LabVIEW, LabVIEW Real time module, LabVIEW myRIO toolkit.

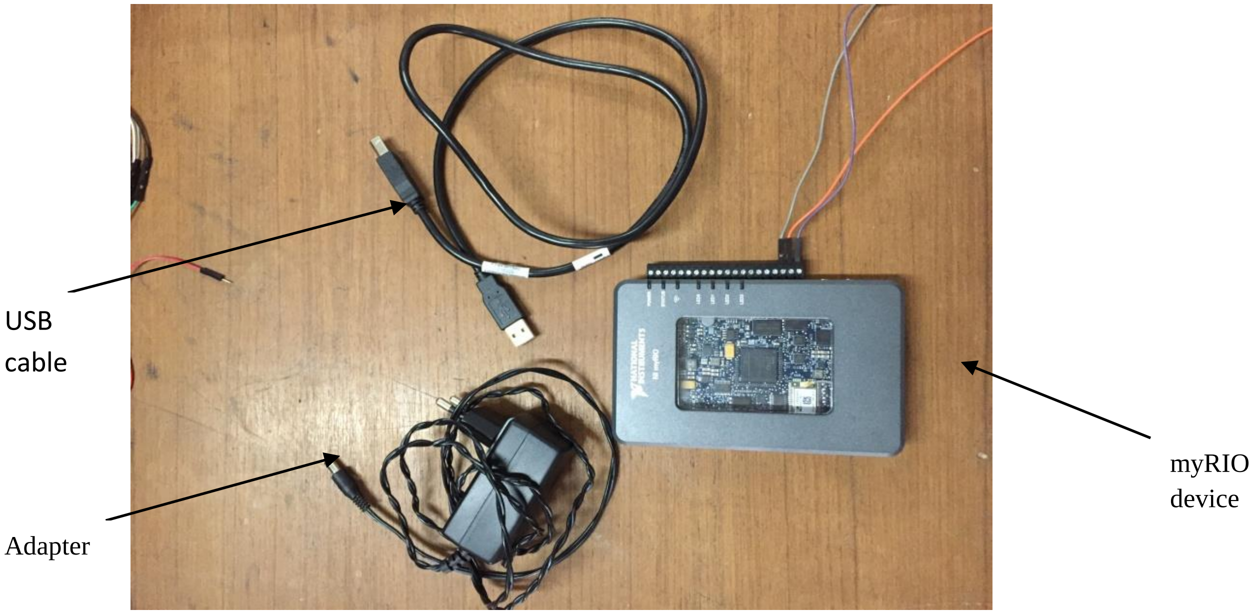

Figure 3.13 myRIO device with USB cable and adapter

Procedure:

a) Install the software LabVIEW, LabVIEW Real time module, LabVIEW myRIO toolkit.

b) Connect myRIO device to adaptor.

c) Initially plug in the USB cable of myRIO to the USB port of computer.

d) When the device is plugged in a pop window arises as shown in figure 5.14.

e) Go to LabVIEW 2014, is selected and new project in VI is configured as shown in figure 3.15.

f) Code is built accordingly and executed.

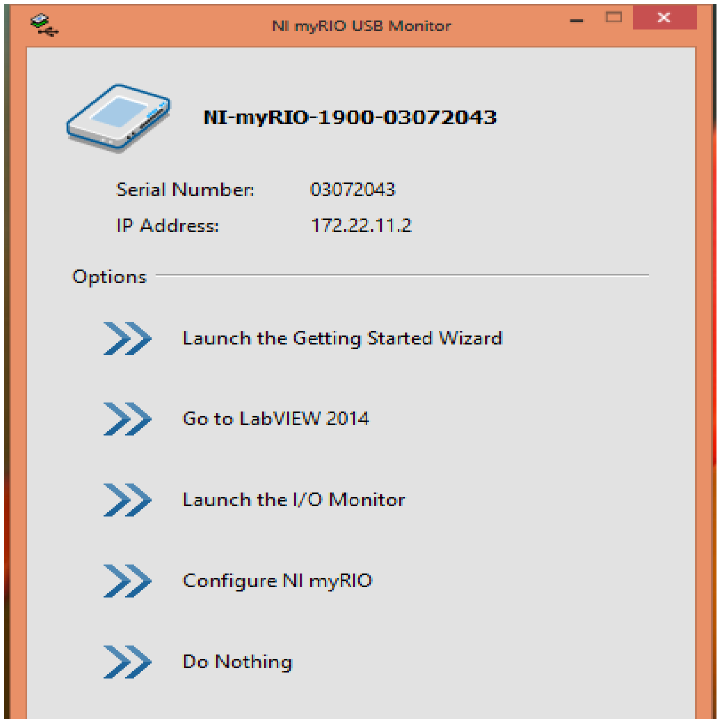

Figure 3.14 Pop window

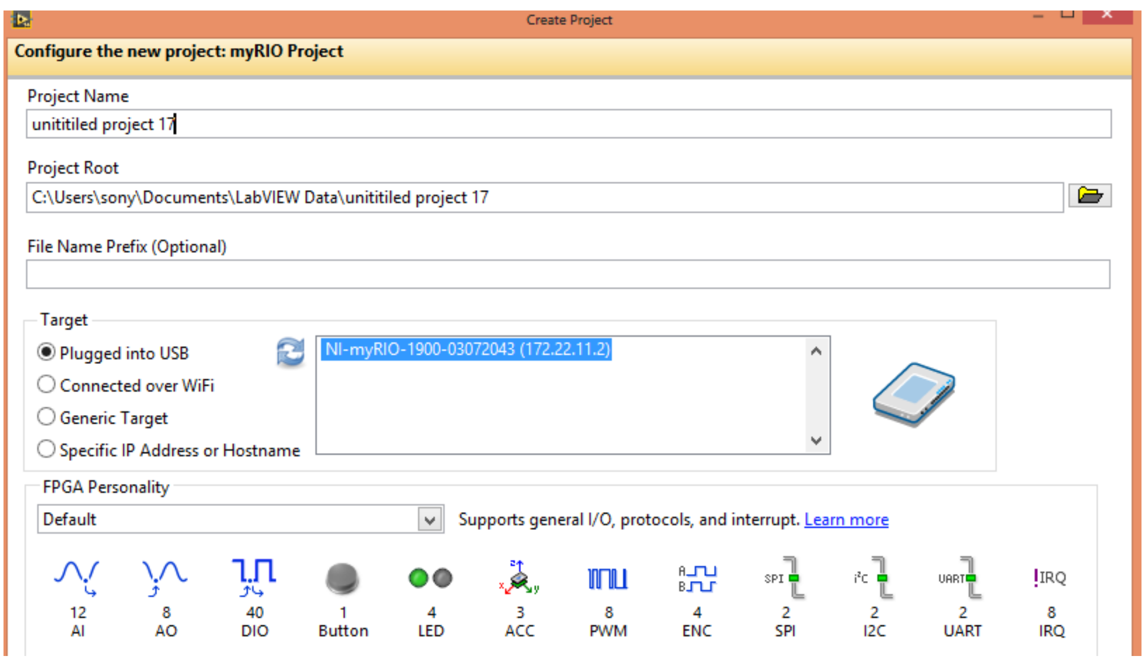

Figure 3.15 Configuration of myRIO

3.4.2 Single Channel

In the present research work single channel wrist pulse acquisition system was designed. In this system single piezoresistive sensor was used to sense wrist pulse signal which was amplified using instrumentation amplifier and collected through myRIO DAQ card. The connections are as shown in Circuit diagram in figure 3.16.

A) Circuit Diagram

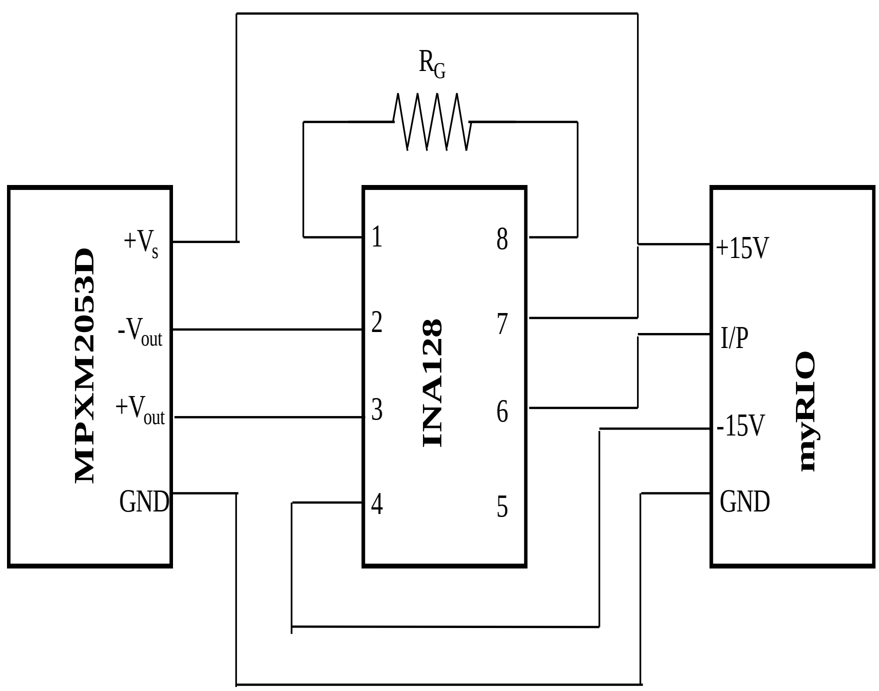

Figure 3.16 Circuit diagram of single channel system.

B) MPXM2053D Sensor

MPXM2053D was available in form of a surface mounted device. After proper soldering/connection it was connected to dual in line package devices. The sensor produced differential output, which was given to inverting and non inverting pins of the instrumentation amplifier as input. Ground and positive power supply were provided with the myRIO DAQ card.

PIN 4: -Vout

PIN 3: Vs

PIN 2: +Vout

PIN 1: Ground

Figure 3.17 Soldered SMD sensor

C) Power supply

MPXM2053D sensor required power supply of the order of 10 to 16 V and instrumentation amplifier required power supply of the order of 2.5 to 18 V. Also, the sensor and instrumentation amplifier required three terminal power supply that is positive, negative and ground. Initially, power supply with three terminals was designed but there was a problem of discharging of batteries with time and maximum power supplied was that of 9 V at which sensor did not work properly. Hence, this power was extracted from the myRIO DAQ card as it is capable of providing +15 V, -15 V and ground as shown in figure 5.18. Power supply of +15 V to the third pin of the sensor was given from connector C of myRIO device and power supply of +15V, -15V and ground to INA128 was also given from connector C of the device.

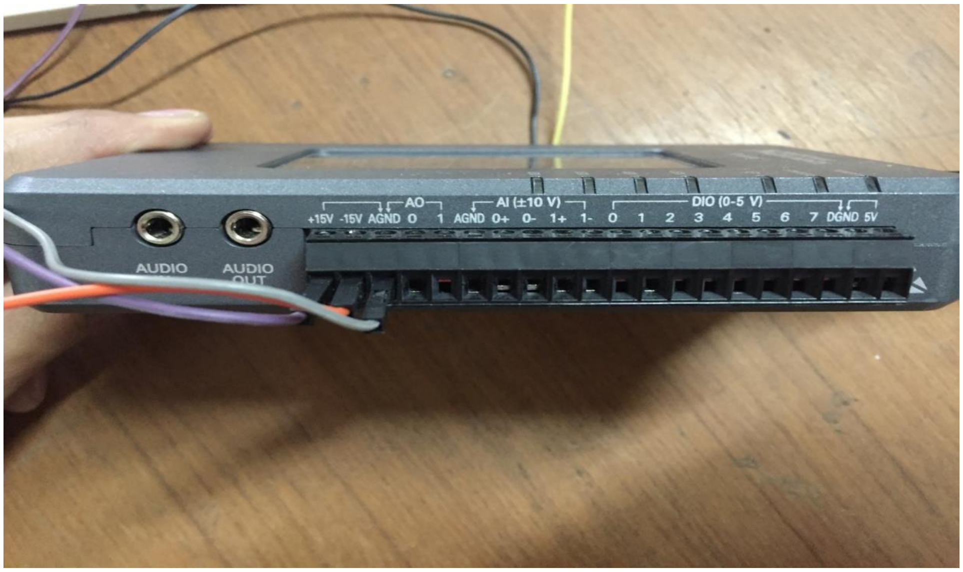

Figure 3.18 Power supply extracted from myRIO

D) INA128 Instrumentation amplifier

INA128 converted and amplified the differential input to output, which was given to myRIO DAQ card. Input was given to INA128 device from the sensor and power supply. Output was connected to pin number 3 of connector A of DAQ device. Value of the gain resistor was decided according to formula as mentioned in the datasheet. Value of gain resistor was kept at 500 **Ω** because desired gain was 100 times the signal.

$$Gain = 1 + \frac{50K\Omega}{R_F}$$

Here, R_F is 500 Ω, So Gain is equal to 100.

E) Working of Circuit

The sensor was placed in suitable position i.e., 2 cm up the wrist to sense waveform. To hold the sensor in its position a wrist band was used to apply a suitable amount of pressure so that diaphragm of the sensor was in contact with radial artery at the wrist and the pressure or vibration of blood flow could be sensed.

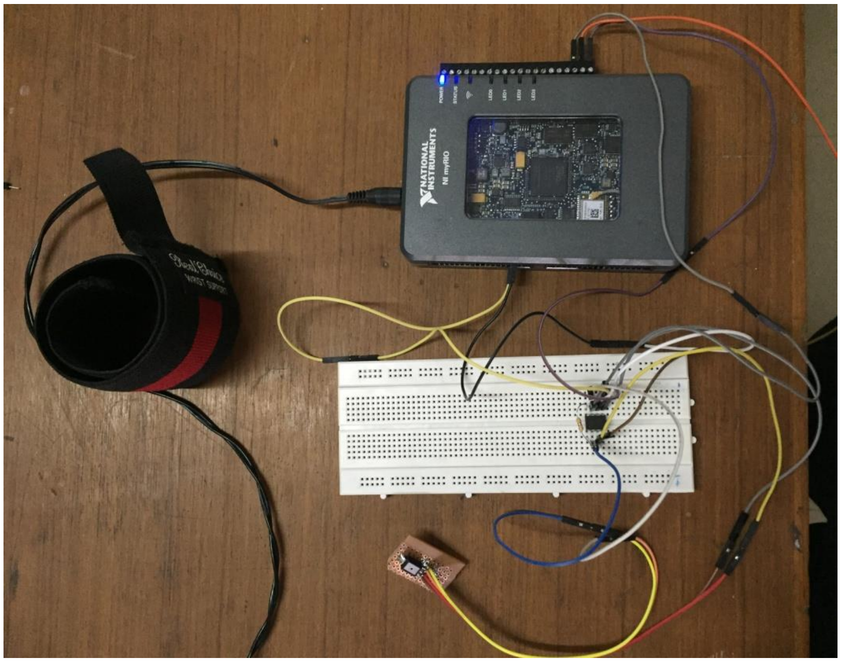

Figure 3.19 Experimental setup of hardware

3.4.3 Real Time Monitoring

Real time monitoring refers to a process in which functions are performed on data in real time and can be visualized with the help of bar charts and graphs.

A) Acquisition of Signals

Proper connections were made and addressed properly in software to perform interfacing of device with a computer. LabVIEW consists of block diagrams and front panel. The front panel refers to the the graphical user interface, whereas the block diagram refers to the virtual design of the circuit diagram. Circuit was designed on block diagram side and output in form of waveform chart or waveform graph was observed. DAQ device was used as shown in figure 5.20. All the steps for setting the parameters are shown below in figure 5.21, 5.22, 5.23, respectively.

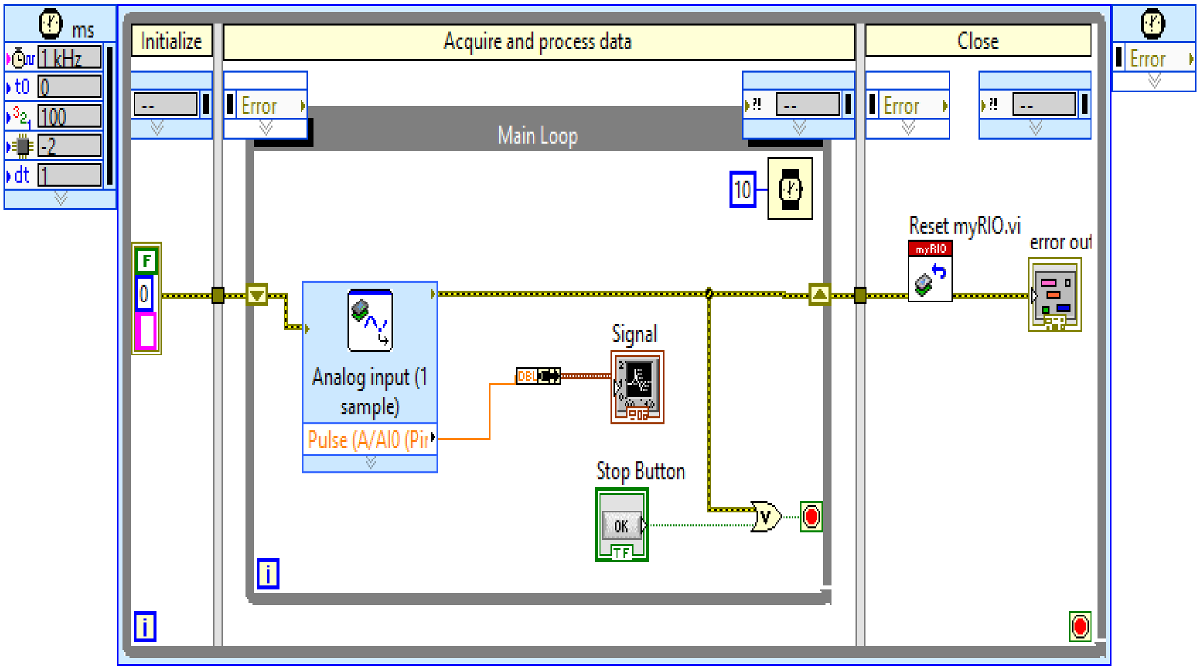

Figure 3.20 Block diagram of interfacing DAQ device

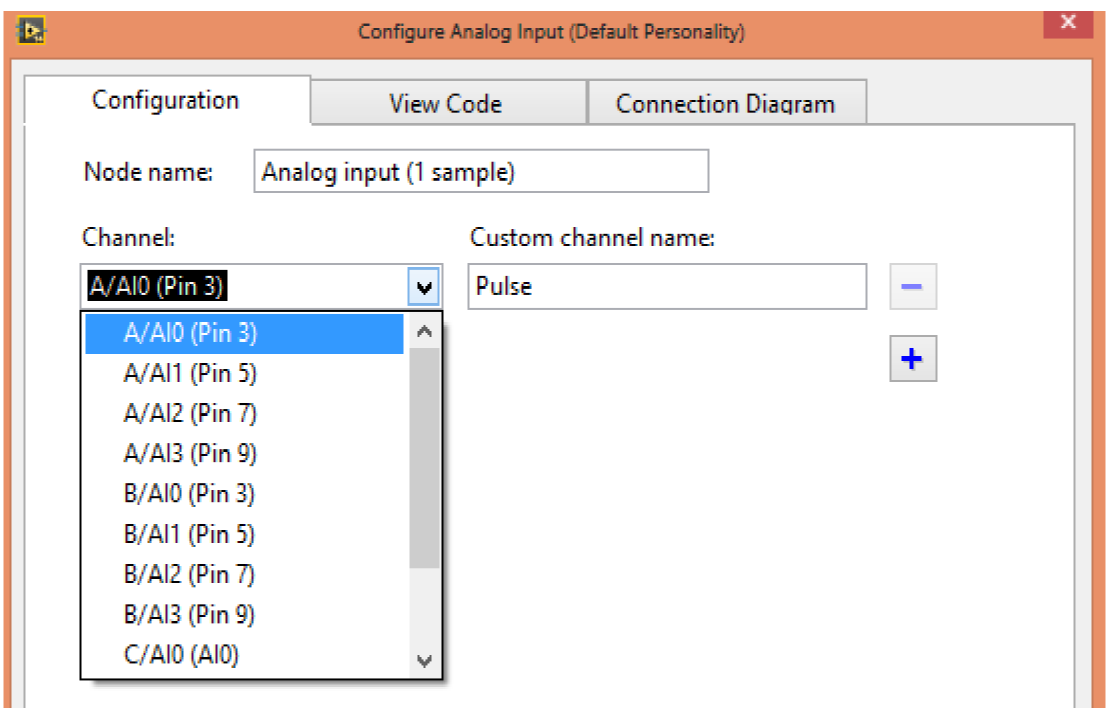

Figure 3.21 Selection of analog input from connector port

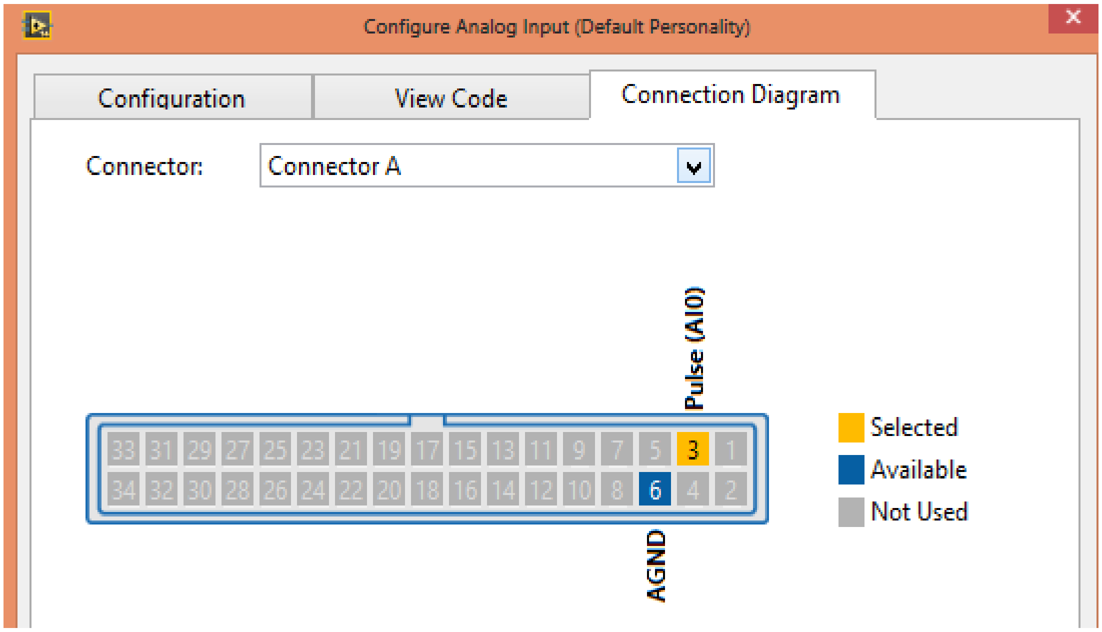

Figure 3.22 Connection diagram of selected analog input

B) Sampling Rate

Sampling rate refers to the speed or frequency at which data was collected by using a timed loop as shown in figure 5.18. Data was collected at the rate of 1000 Hz. In 1 sec 1000 samples were collected or in 1 min 60000 samples. The capturing of the data was set according to either number of samples or sampling rate:

a) Amount of information captured was adjusted by changing sampling rate. For instance, initial sampling frequency was 1000 Hz, it was required to capture data for 4 seconds, so sampling frequency was set at 50 Hz and 200 samples were recorded.

b) Amount of information captured was adjusted by changing the number of samples. For instance, initial sampling frequency was 1000 Hz, it was required to capture data for 4 seconds at 1000 Hz, so samples were adjusted to 4000.

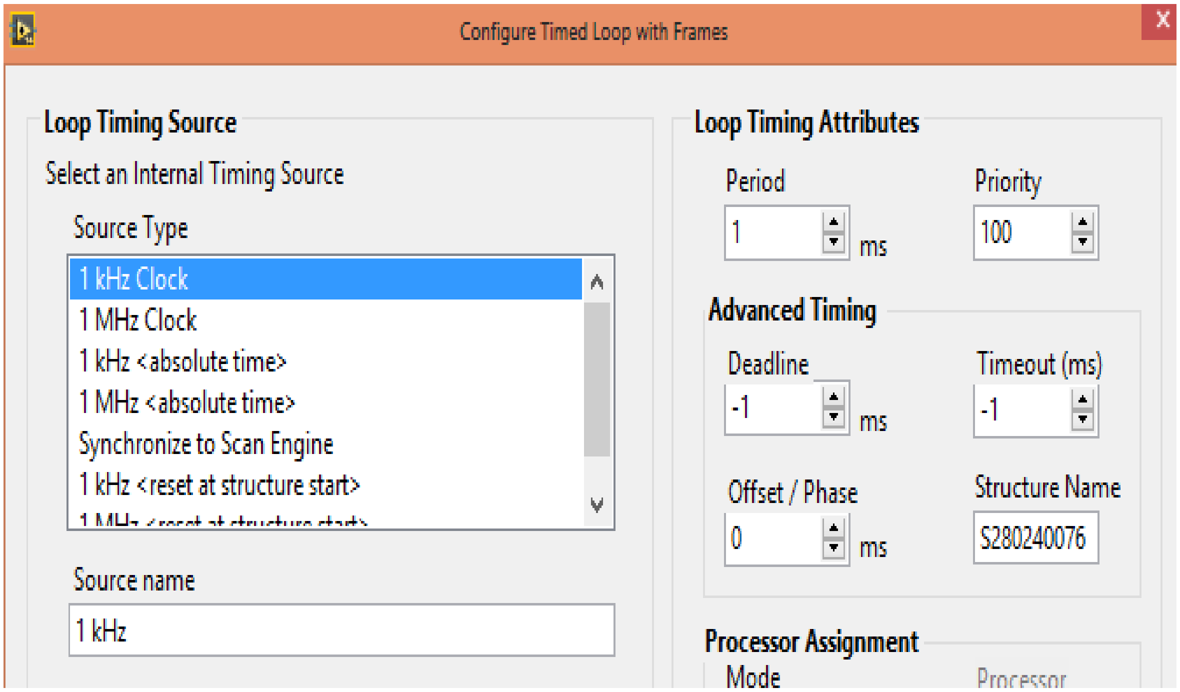

Figure 3.23 Configuration of sampling rate

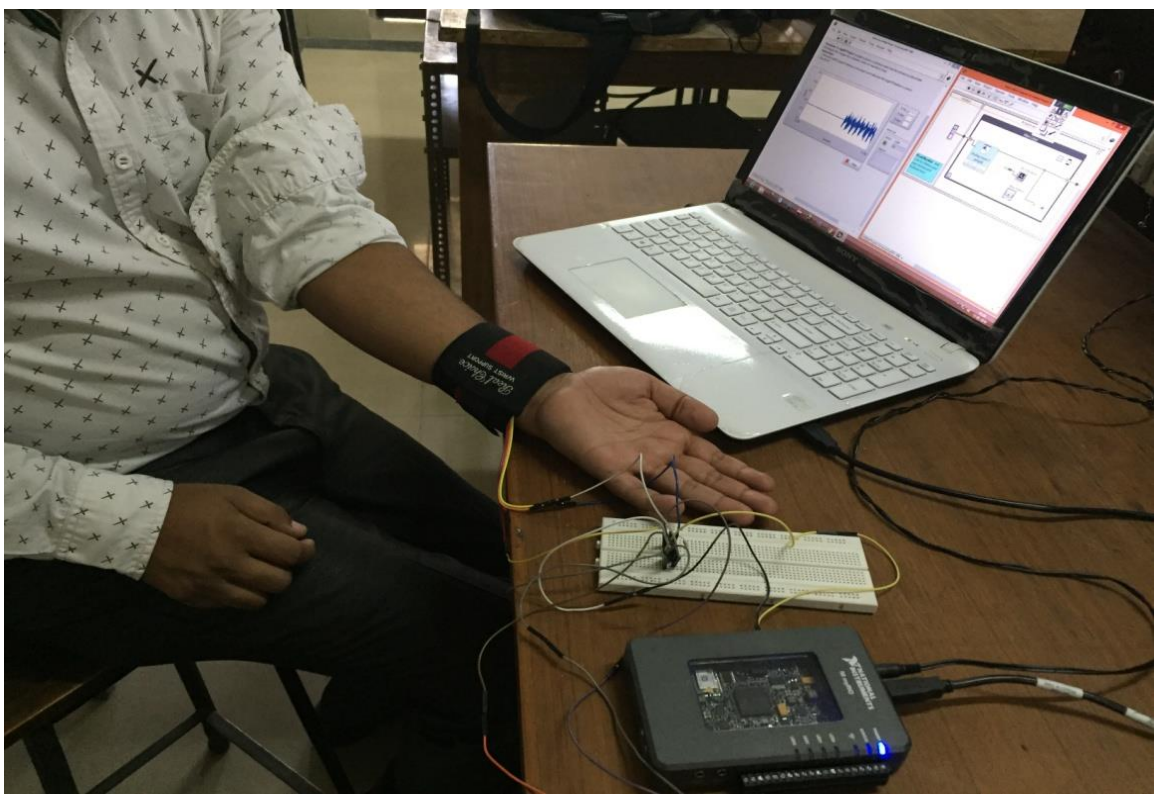

Figure 3.24. Experimental setup for acquiring a pulse signal

3.5 Processing of Data

Subsequently the data was compiled from a number of subjects, processing was performed on the raw signal in order to make a clear signal.

The steps followed for processing of data and feature extraction:

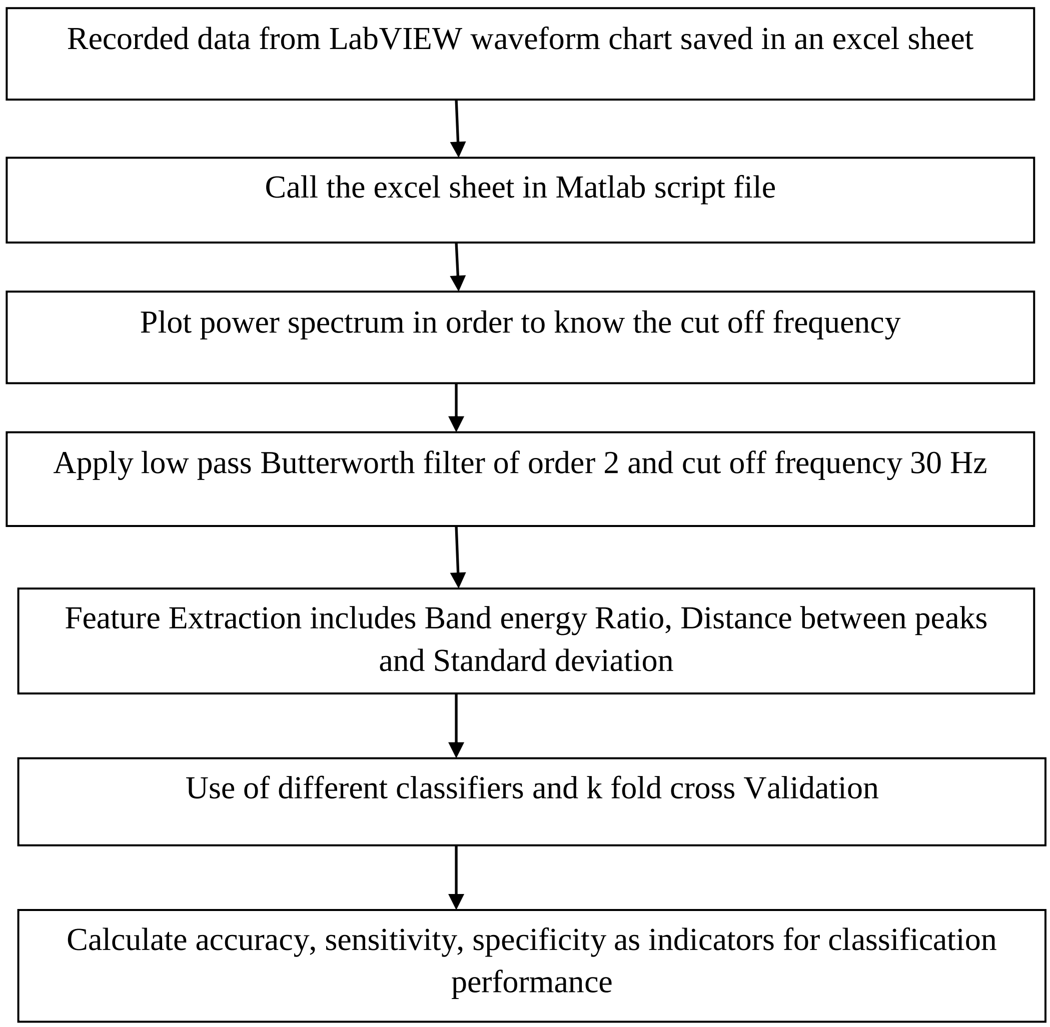

Figure 3.25. Steps for processing of data

3.5.1 Pre-processing Techniques

A) Power Spectrum

The power spectrum of time series refers to the distribution of power into frequency components composing that signal [24]. To know the frequency components of wrist pulse signal, the signal was converted from time domain to frequency domain. The power spectrum was plotted in Matlab.

B) Low pass Butterworth Filter

Filtering was performed on the raw signal obtained in LabVIEW. Filtering was carried out using low pass Butterworth filter of order 2. Cut off frequency of low pass filter was decided by observing the power spectrum. It was found that wrist pulse signal is a low frequency signal and has a frequency below 30 Hz [18]. Cut off frequency was kept at 30 Hz.

3.5.2 Feature Extraction

Feature extraction was performed by calculating various features such as band energy ratio and distance between peaks.

A) Band Energy Ratio

Band energy ratio was used as a feature to determine the energy distribution in the range of 0-30Hz. Band energy ratio refers to percentage energy in the particular band divided by total energy within that band [19]. It can be determined by using the following formula:

$$\text{BER (n)} = \frac{E_n}{E_T} * 100$$

where, BER (n) is the band energy ratio of nth band in percentage,m n is band of frequency E_n is energy present in nth band and E_T is the total energy in 0-30 Hz. A signal of 30 Hz total frequency range was divided into ten bands of 3 Hz each. Then, total 10 bands were obtained. In each band of frequency, BER was calculated and plotted in a bar graph.

B) Distance between Peaks

Distance between peaks of filtered signal was calculated by using peak detector and assigning threshold value for finding major peaks.

C) Standard Deviation

Standard deviation is defined as a measure of the dispersion of a set of data from its mean value [25]. Standard deviation of data containing the distance between peaks from their average was calculated.

3.5.3 Classifier

Classification refers to the identification to which class does the new observation belongs to. Also, classifier is the algorithm that helps in identification of the classification process. In the present study two classes are healthy and unhealthy and different classifiers were used to identify subjects belonging to two classes. Classification was done by using various classifiers such as support vector machine (SVM) [27] and logistic regression (LR) [28]. To check the reliability of classifier accuracy, sensitivity, specificity were determined. These parameters were calculated to indicate performance of the classifier. They are described as follows:

Confusion Matrix: It refers to a table that is used to describe the performance of classifier given by

$$\begin{bmatrix} T_p & F_n \\ F_p & T_n \end{bmatrix}$$

A) Accuracy: Accuracy refers to the number of correct predictions made divided by the total number of predictions made [26].

$$\%\text{age Accuracy} = \frac{T_p+T_n}{T_p+T_n+F_p+F_n} * 100$$

B) Sensitivity: Sensitivity refers to the fraction of positives that are actually identified as such. It is the true positive rate of test [26].

$$\%\text{age Sensitivity} = \frac{T_p}{T_p+F_n} * 100$$

C) Specificity: Sensitivity refers to the fraction of negatives that are actually identified. It is the true negative rate of test [26].

$$\%\text{age Sensitivity} = \frac{T_n}{T_n+F_p} * 100$$

where, T_P is True positive, T_n is True negative, F_p is False positive and F_n is False negative.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

Wrist pulse signal was acquired using designed wrist pulse acquisition system. Waveform of the pulse signal was obtained as desired and found a good match with the literature waveform [13]. Experimental setup followed by results obtained have been discussed.

4.2. Results

21 Subjects information was collected, consisting of 14 healthy and 7 unhealthy subjects. The subject was requested to fill a consent form as shown in appendix-A consisting basic information of the subject. Thereafter, the subject was made to relax and seated with his or her elbow in resting position. Data was collected at the same time between 7 am to 9 am for all subjects. Data was obtained for more than 5 min of each subject. Data was acquired, processed and feature extraction performed. Frequency of pulse signal in different bands was observed. Based on the frequency obtained in bands subjects were classified as healthy and unhealthy. Accuracy, sensitivity and specificity were found to indicate performance of the classifier.

The wrist pulse signal was acquired using DAQ device in LabVIEW and graphical user interface made to observe and perform real time monitoring as shown in figure 4.1.

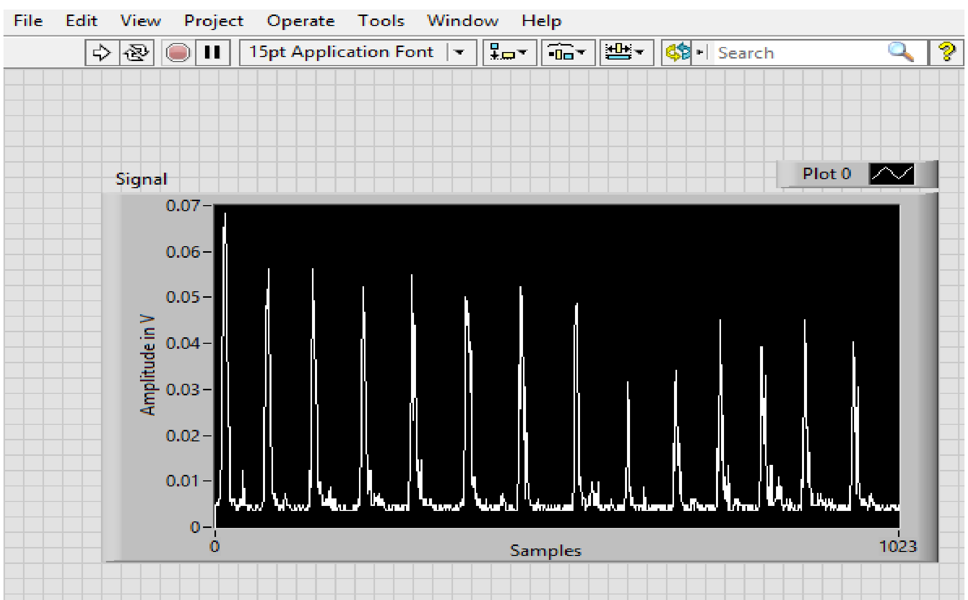

Figure 4.1 Real time monitoring with GUI

4.2.1 Raw Signal

Raw Signal of healthy and unhealthy subject is shown in figure 4.2 and 4.3 respectively. Waveforms obtained were noisy, so in order to know the difference, filtering was performed.

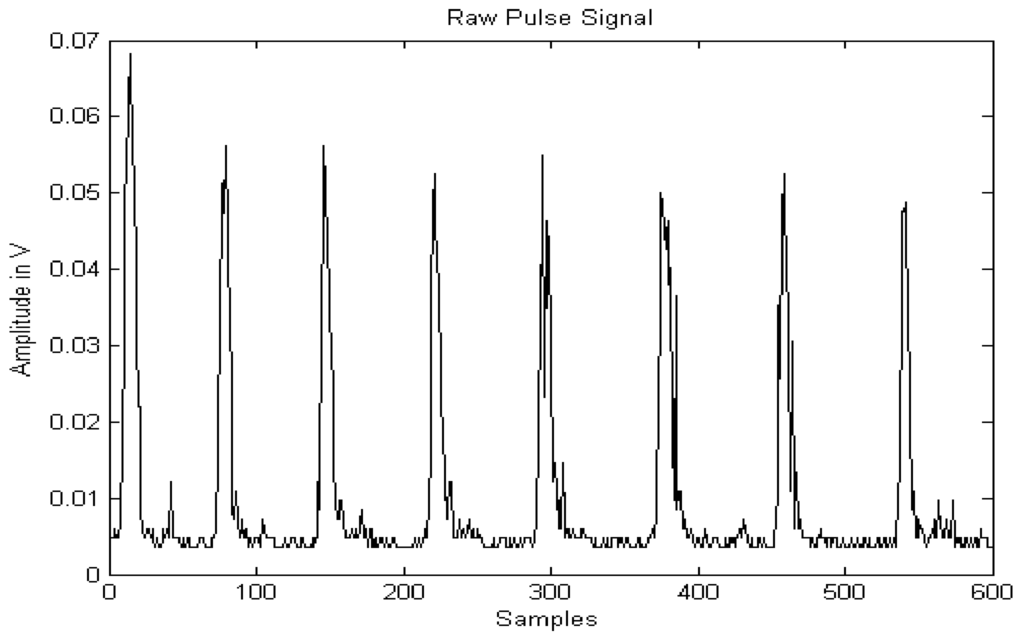

Figure 4.2 Raw signal of healthy subject

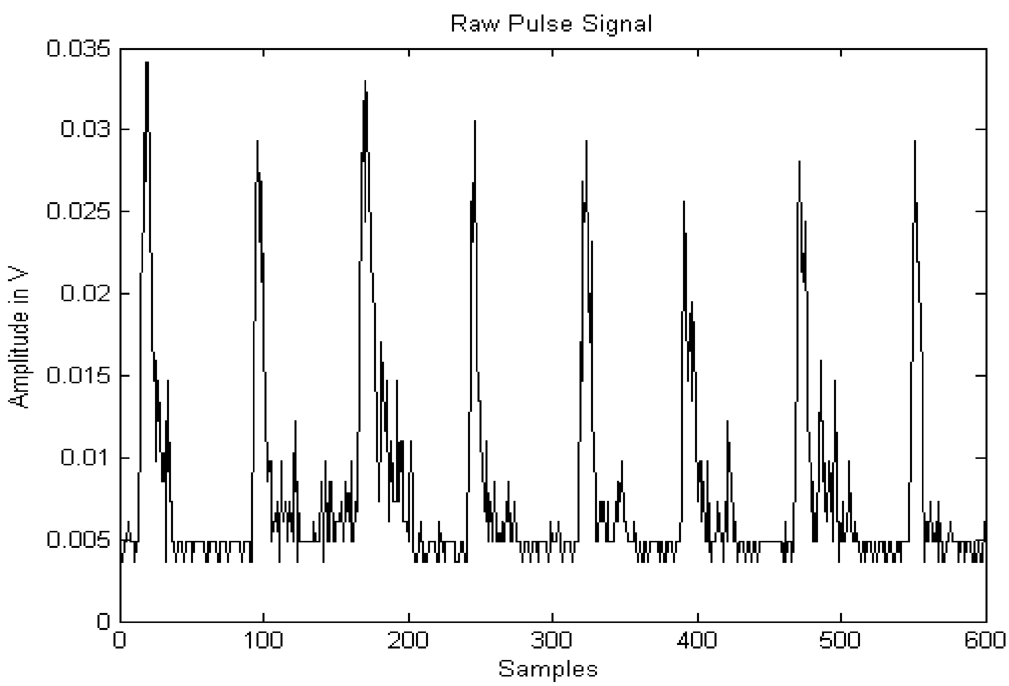

Figure 4.3 Raw signal of unhealthy subject

4.2.2 Filtered Signal

Filtered Waveforms of healthy and unhealthy subject are shown in figure 4.4 and figure 4.5 respectively. These were obtained by using a low pass Butterworth filter of order 2. It was observed that the waveform of unhealthy subject was little undistorted and broadened as compared to the waveform of healthy subjects.

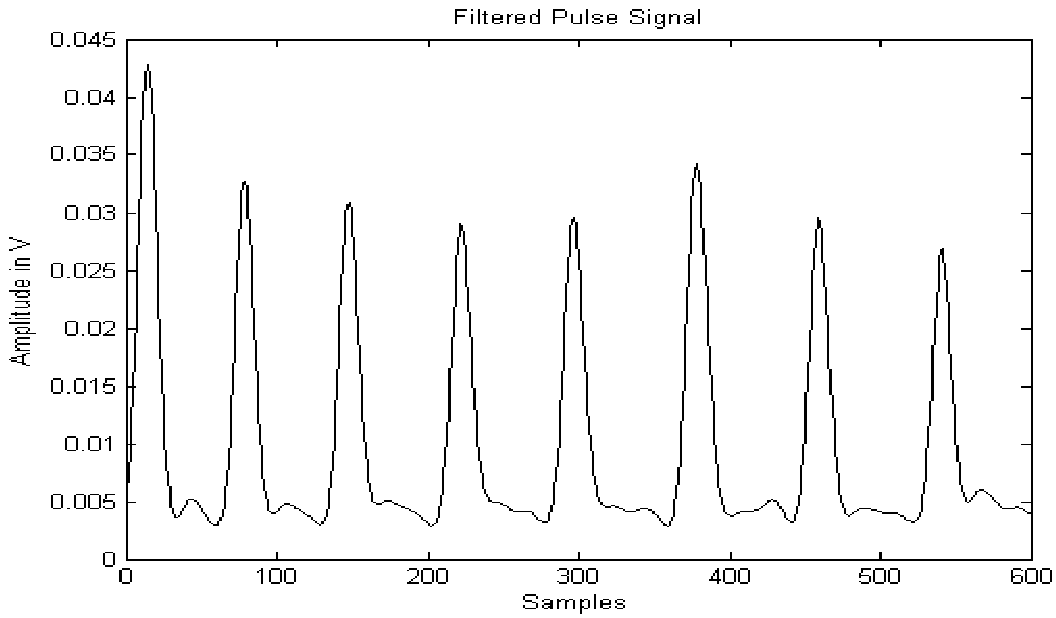

Figure 4.4 Filtered signal of healthy subject

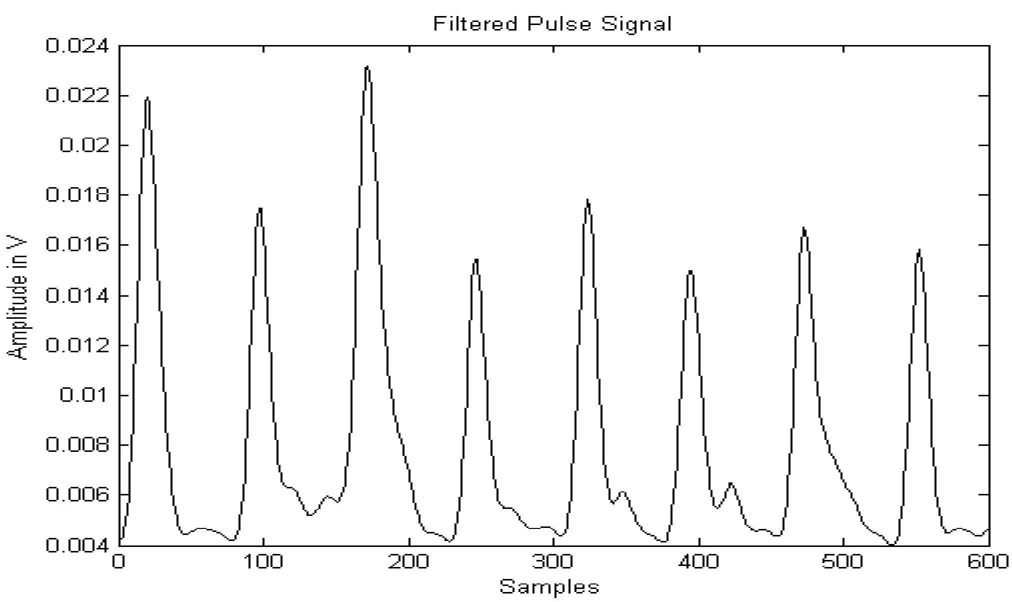

Figure 4.5 Filtered signal of unhealthy subject

4.2.3 Power Spectrum

Power spectrum provided information that all the frequency components were contained in 1 Hz to 30 Hz as shown in figure 4.6.

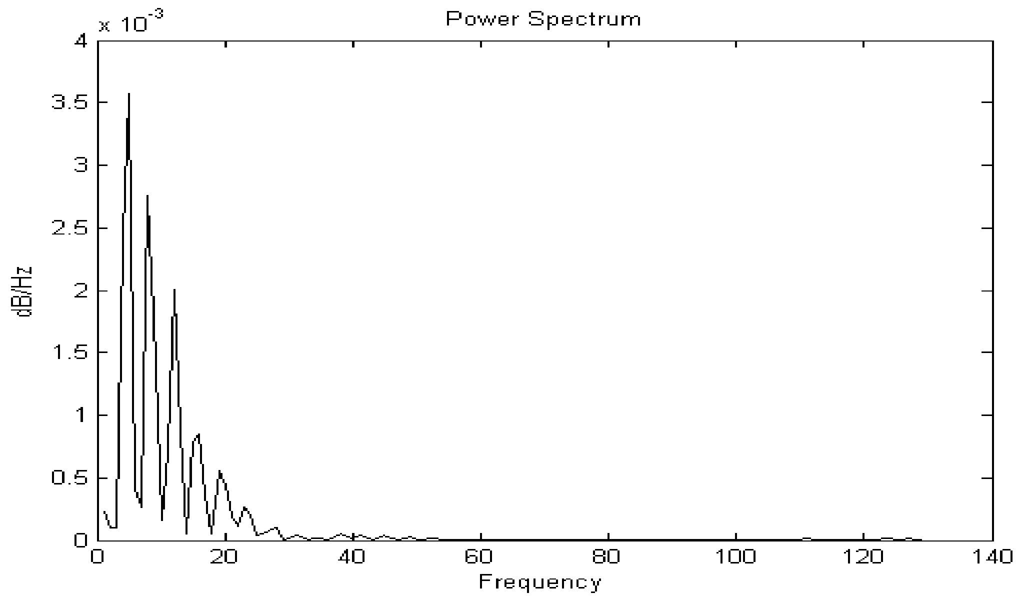

Figure 4.6 Power spectrum of wrist pulse signal

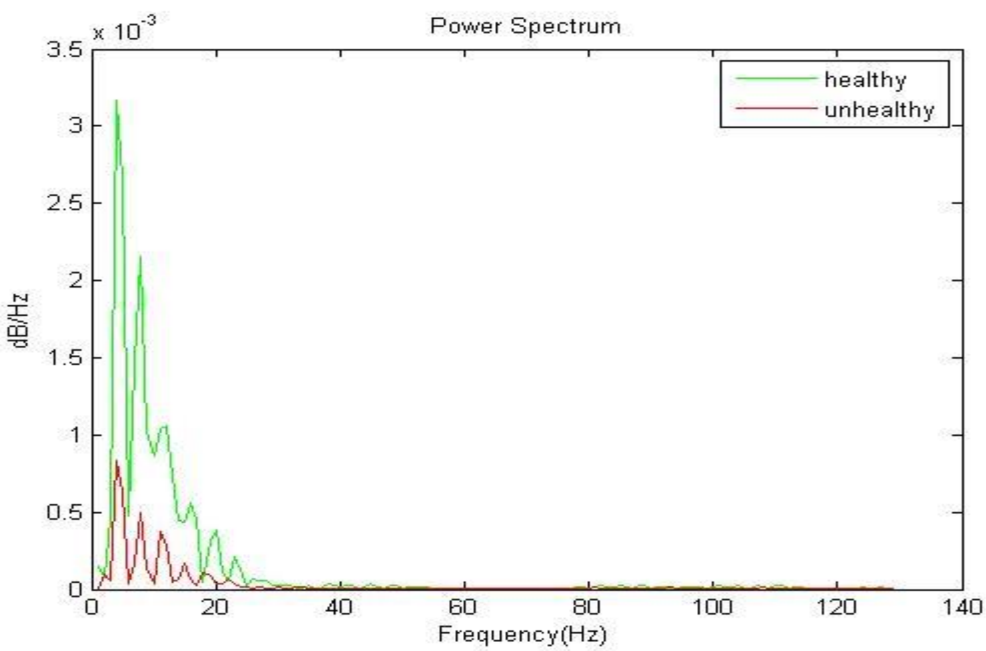

Figure 4.7 Comparison between power spectrum of healthy and unhealthy subject

4.2.4 Feature Extraction

Features such as Band Energy Ratio, distance between peaks were extracted as shown below:

4.2.4.1 Band Energy Ratio

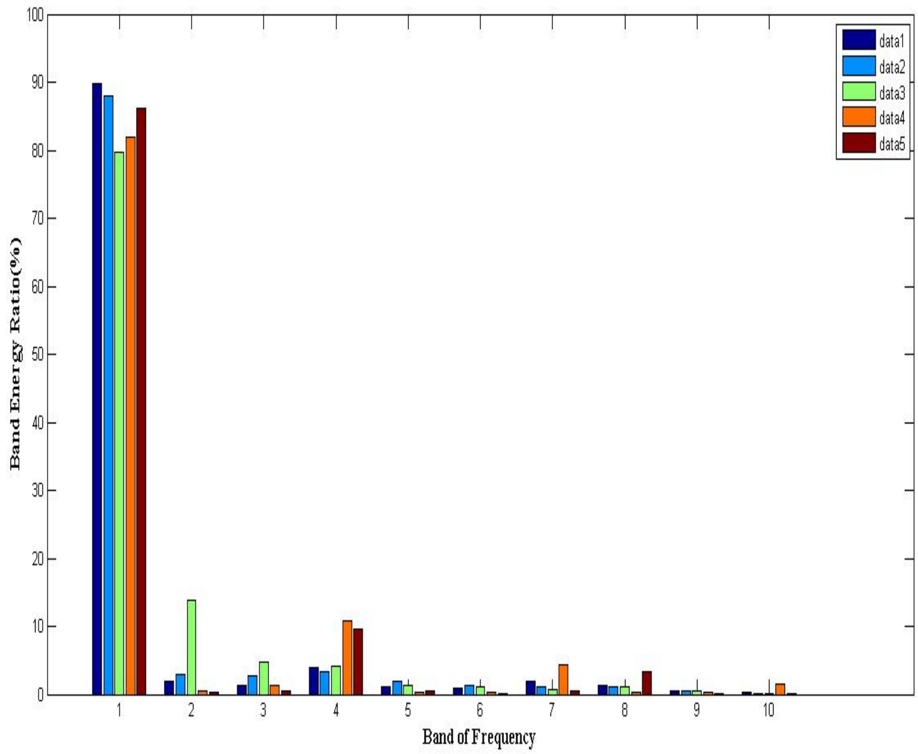

Figure 4.8 Comparison between BER of healthy and unhealthy subject

Band energy ratio of wrist pulse signal was calculated in different bands of frequencies. Total frequency of 30 Hz was observed from power spectrum and then divided into 10 equal parts of 3 Hz each. A band of 3 Hz of frequency was formed and band energy ratio in that particular band was calculated. It was observed that the maximum amount of energy lies between 0-3 Hz. Band energy ratio of healthy and unhealthy person was found different in band 2, 3, 4, i.e., between frequency 3 Hz to 12Hz.

4.2.4.2 Distance between Peaks

Distance between major peaks was found and standard deviation was calculated. The distance between all the major peaks in signal for a fixed number of samples and average was found (figure 4.9). Values calculated for all the subjects are presented in tabular form in table 4.1.

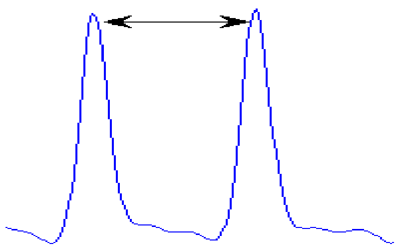

Figure 4.9 Distance between 2 major peaks of pulse signal

Table 4.1 Features of subjects

Subject	Distance between Peaks(samples)	Standard Deviation
1	75	2.82
2	75	3
3	42.3	9.1
4	82	3.16
5	31	7.09
6	33.66	2.87
7	32.8	3.83
8	25.11	8.4
9	38.2	5.12
10	32.8	3.83
11	78.7	2.87
12	26.15	7.33
13	31.2	7.9
14	73	2.44
15	67.8	5.06
16	75.5	3.2
17	44	9.8

18	69.1	1.9
19	78.3	1.52
20	72	1.41
21	35.3	6.16

4.2.5 Classifier

Classification was performed using classifier SVM and LR with 5 fold cross validation. Feature vector was formed by considering features in different sets as follows:

SET1: BER (0-9 Hz)

SET2: BER (0-30 Hz)

SET3: BER (9-30 Hz)

SET4: BER and distance between peaks

SET5: BER and standard deviation

SET6: BER, distance between peaks and standard deviation

Performance of both the classifiers was evaluated as shown in table 6.2 and table 6.3.

Table 4.2 Performance of support vector machine

	CONFUSION MATRIX	ACCURACY	SENSITIVITY	SPECIFICITY
SET 1	$\begin{bmatrix} 26 & 0 \\ 14 & 2 \end{bmatrix}$	66.67	100	12.5
SET 2	$\begin{bmatrix} 26 & 0 \\ 9 & 7 \end{bmatrix}$	78.5	100	43.75
SET 3	$\begin{bmatrix} 26 & 0 \\ 11 & 5 \end{bmatrix}$	73.8	100	31.25
SET 4	$\begin{bmatrix} 24 & 2 \\ 8 & 8 \end{bmatrix}$	76.19	92.3	50
SET 5	$\begin{bmatrix} 26 & 0 \\ 10 & 6 \end{bmatrix}$	76.19	100	37.5
SET 6	$\begin{bmatrix} 25 & 1 \\ 8 & 8 \end{bmatrix}$	78.5	96.15	50

It was found that

- Accuracy of SET 3 was more than that of set1,which means important information are contained in SET 3.
- Accuracy of SET 2 was more than that of SET1 and SET 3, which means the entire band from 0 - 30 Hz should be considered.
- Accuracy of SET 6 was greater than that of SET 4 and SET 5, so all the features calculated should be considered for good accuracy.
- Sensitivity refers to fraction of subjects with disease that are correctly classified as positive by the test and was found to be high in present work
- Specificity refers to fraction of subjects without disease that are correctly classified as negative by the test [27]

Table 4.3 Performance of logistic regression

	Confusion Matrix	**Accuracy**	**Sensitivity**	**Specificity**
SET 1	$\begin{bmatrix} 22 & 4 \\ 7 & 9 \end{bmatrix}$	73.8	84.6	56.25
SET 2	$\begin{bmatrix} 24 & 2 \\ 4 & 12 \end{bmatrix}$	85.71	92.3	75
SET 3	$\begin{bmatrix} 24 & 2 \\ 4 & 12 \end{bmatrix}$	85.71	92.3	75
SET 4	$\begin{bmatrix} 26 & 0 \\ 2 & 14 \end{bmatrix}$	95.2	100	87.5
SET 5	$\begin{bmatrix} 24 & 2 \\ 2 & 14 \end{bmatrix}$	90.47	92.3	87.5
SET 6	$\begin{bmatrix} 26 & 0 \\ 2 & 14 \end{bmatrix}$	95.2	100	87.5

Similar results were found in case of logistic regression. However, accuracy of LR was found to be better than that of SVM as shown in figure 4.10.

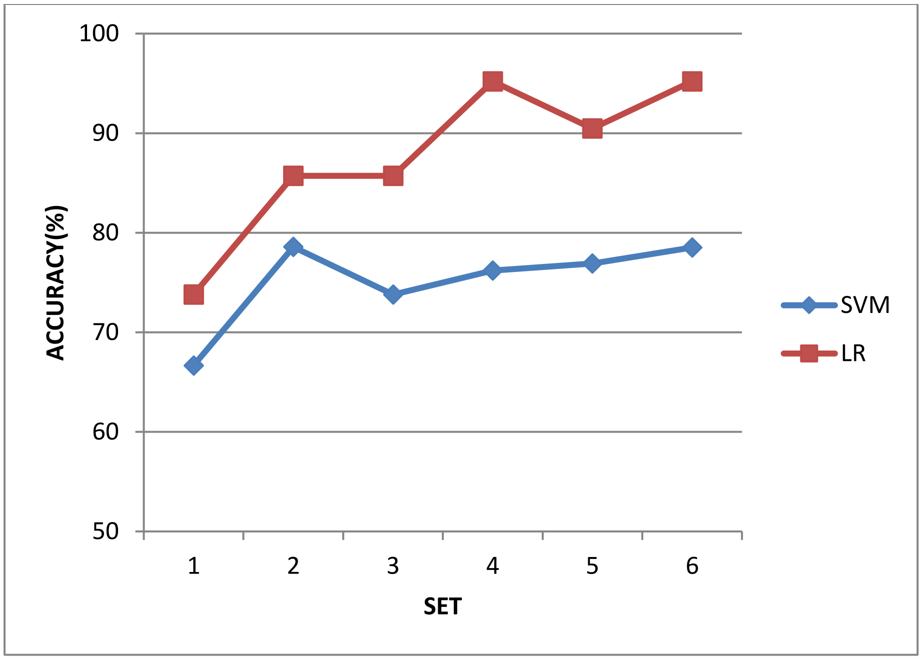

Figure 4.10 Comparison of classifiers

4.3. Discussion

The system designed using piezoresitive sensor MPXM2053D, acquired wrist pulse signal. Wrist pulse sensor sensed the fluctuations and vibrations in blood and sensed the pressure exerted on its diaphragm. DAQ card myRIO, acquired the signal at a fixed sampling rate and performed the acquisition of wrist pulse signal with mimimal circuity [10] [13].

Here, non invasive diagnosis for disease was used on 21 subjects including 14 healthy and 7 unhealthy. Initially, raw waveform was recorded by wrist pulse acquisition system for both healthy and unhealthy subject as shown in figure 4.2 and 4.3. The noisy raw waveform was filtered by using low pass Butterworth filter (of order 2) with cut off frequency of 30 Hz, to obtain clean waveforms. Thereafter, the waveforms were matched with the literature waveforms, reported by Thakker *et. al*. [13]. The waveform obtained from unhealthy subject was found to be distorted and broadened as compared to waveform of healthy subject as shown in figure 4.5. Compared with those reported by Thakker *et.al.* [17], similar type of distortion in the waveform of unhealthy subject was achieved.

Power spectrum was plotted to know the frequency components contained in wrist pulse signal. The frequency of signal was found between 0 - 30 Hz. The wrist pulse signal is a low frequency signal which carries information between 0 – 30 Hz. The power spectrum of both healthy and unhealthy subject was found different beyond 5 Hz, as energy contained in signal of unhealthy subject was greater than healthy subject.Thus, power spectrum can be used as an important tool to distinguish between healthy and unhealthy subject.

Frequency domain analysis was carried out with power spectrum and the features such as band energy ratio were extracted to know the percentage of energy in particular frequency band and wrist pule signal contained frequency till 30 Hz so the whole available frequency spectrum was divided into bands of 3 Hz each. 10 bands were formed of different ranges of 3 Hz each and it was found that the energy in 0 - 3 Hz was more than 80 percent in both healthy and unhealthy subject. For unhealthy subject, in bands 3 - 6 Hz, 6 - 9 Hz and 9 -12 Hz it was greater than from that of healthy subject. The major proportion of energy of wrist pulse signal lies from 0 - 3 Hz in both healthy and unhealthy subject and percentage of energy varies from band of 3 - 12 Hz. Distance between peaks and standard deviation of the waveform obtained was calculated to know the distance between consecutive peaks.

The features extracted were used to classify the person as healthy or unhealthy with the help of classifier. Since the classification to be performed contained 2 classes, so support vector machine and logistic regression were chosen for this purpose. Feature vector was given as an input to both the classifiers. Feature vector was prepared by using 12 features of band energy ratio, distance between peak and standard deviation. For classifier feature, vector was formed by using different combination of features in different sets. 6 SETs were formed in which SET 1 was formed by considering band energy ratio from 0 - 9 Hz. In SET 2, band energy ratio from 0 - 30 Hz was considered. In SET 3, band energy ratio from 9 - 30 Hz was considered, In SET 4, band energy ratio and distance between peaks were considered. In SET 5, band energy ratio and standard deviation were considered. In SET 6, band energy ratio, distance between peaks and standard deviation were considered.

Accuracy, sensitivity and specificity of all the sets were calculated with help of two classifiers SVM AND LR with K fold cross validation. In the present research work, for validation of extracted features the value of K was chosen 5. In 5 fold cross validation subsamples were formed and 4 subsamples were used for training and 1 sub sample for testing. It was repeated 5 times and subsample was used once as testing or training and the average was determined.

Average accuracy of the classifiers was calculated and confusion matrix was generated. It was found that accuracy of SET 3 was more than that of SET 1, which means important information is contained in SET 3. Accuracy of SET 2 was more than that of SET 1 and SET 3, which means the entire band from 0 - 30 Hz should be considered. It was found that accuracy was highest for SET 6 in which all the features were considered, as compared to other sets as shown in table 4.2 and 4.3. Sensitivity and specificity were also calculated from confusion matrix that predicted subject as true positive and true negative. A comapartive study was performed between SVM nad LR.

In case of SVM, accuracy for different sets was achieved, for SET 1 (66.67%), SET 2 (78.5%), SET 3 (73.8%), SET 4 (76.19%), SET 5 (76.19%), SET 6 (78.5%). Whereas in case of LR accuracy for different sets was achieved, for SET 1 (73.8%), SET 2 (85.71%), SET 3 (85.71%), SET 4 (95.2%), SET 5 (90.47%), SET 6 (95.2%). The accuracy achieved with LR was higher than SVM. Sensitivity achieved in case of SET6 in SVM was 96.15% and 100% in LR, which means that unhealthy subject were truely classified as having disease. Specificity in case of SET 6 achieved in SVM was 50% and 87.5% in LR, which means that unhealthy subject were truely classified as not having disease.

In the system designed using single channel acquisition system accuracy achieved with LR classifier using 5 fold cross validation was 95.2%, sensitivity achieved was 100%, specificity achieved was 87.5%. Compared with those reported in [18], higher value of classification accuracy was achieved. SVM classified the person as healthy or unhealthy with accuracy (78.5%), sensitivity (96.15%) and specificity (50%). Thus Logistic regression as compared to SVM can be used as a simple and better classifier to classify between healthy and unhealthy with high accuracy, sensitivity ans specificity.

CHAPTER 5: CONCLUSION AND FUTURE ASPECTS

5.1. Introduction

Wrist pulse acquisition system was designed in the present research work and hence wrist pulse signal was acquired successfully. Analysis was carried out with the experimental setup developed. Conclusion of the results obtained have been discussed below.

5.2. Conclusion

The present research work demonstrated diagnose of healthy and unhealthy subjects based on non invasive method of pulse diagnosis with the help of wrist pulse acquisition system. Piezoresistive sensor, MPXM2053D gave the satisfactory pulse waveform and provided wrist pulse signal. Band energy ratio provided information about energy of signal in 0 - 30 Hz band. It indicates that maximum energy lies in 0 - 3 Hz band and range of 3 - 12 Hz to distinguish between healthy and unhealthy subject. Classifer was applied on different sets of features and it gave highest accuracy in SET 6 which indicates that band energy ratio, distance between peak and standard deviation contain useful information and should be used to distinguish between healthy and unhealthy subject. A comparative study using two types of classifiers, SVM and LR was performed. SVM classified the person as healthy or unhealthy with accuracy (78.5%), sensitivity (96.15%) and specificity (50%). In case of LR, classification was performed with accuracy (95.2%), sensitivity (100%) and specificity (87.5%). Hence the developed system can be used for pulse diagnosis with simplified, mimimal circuitry, high accuracy, sensitivity and specificity.

5.3. Future Aspects

In the proposed hardware, single channel wrist pulse acquisition system was implemented. The same design can be extended to three channel wrist pulse acquisition system to provide more accuracy. More work needs to be done to determine hold pressure that is back pressure of piezoresistive sensor. Also, positioning of the sensors in use of three sensors is a big challenge which needs to be worked upon in more simplified manner.

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PUBLICATIONS

Conference

1. Krittika Goyal, Piyush Samant and Ravinder Agarwal, **“**Piezoresistive based wrist pulse Acquisition System”, *9th International Conference on Advances in Metrology* (AdMet - 2016), Feb 24-26, 2016, National Physical Laboratory, New Delhi.

Journal

1. Krittika Goyal, Ravinder Agarwal, “Pulse Based Sensor Design for Wrist Pulse Signal Analysis and Health Diagnosis”, *Journal of Medical and Biological Engineering* - *Springer* (Commumnicated- June 2016).

APPENDIX - A

BASIC INFORMATION OF A SUBJECT

NAME	
AGE	
GENDER	
WEIGHT	
HEIGHT	
BLOOD PRESSURE	
SLEEP TAKEN	
PRE LUNCH	
POST LUNCH	
ANY ACUTE DISEASE	
ANY CHRONIC DISEASE	

OBSERVATIONS	**Tick**		**Tick**		**Tick**	
Weight change		Trouble gaining		Can gain but lose quickly		Gains weight easily, hard to lose
Skin type		Thin, dry		Smooth, combination skin		Thick, oily,
Hair		Dry, brittle, scarce, gets knotted		Straight, oily, prone to hair loss		Thick, curly, oily, wavy, luxuriant
Nails		Dry, rough, easily broken		Sharp, flexible, long, reddish tint		Thick, smooth, shiny surface
Lip		Dry, cracked		Often inflamed		Smooth, large
Appetite		Irregular in frequency and magnitude		Strong, cannot skip meals		Steady, regular, skips meals
Taste preference		Sweet, sour, salty		Sweet, bitter, astringent		Bitter, pungent, astringent
Thirst		Variable		Need water regularly		Sparse need for water
Digestion		Irregular		Quick		Slow
When there is indigestion		Tendency to constipation, forms gas		Causes burning, heart burn, reflux		Forms mucous

Physical activity		Always active		Moderate		Slow, measured
Mental activity		Always active		Moderate		Calm
Personality		Vivacious, talkative, social, outgoing		Likes to be in control, intense, ambitious		Reserved, laid back, concerned
Emotional response when stressed		Anxiety, fear		Anger, jealousy		Greedy, possessive, withdrawn
Memory		Good short term, quick to forget		Medium but accurate		Slow to remember but then sustained
Sleep		Short, broken up		moderate and sound		Deep and long
Dreams		Multiple and quick, fearful		Fiery, often about conflicts		Slow, romantic
Speech		Rapid, hither thither		precise, articulate		Slow, monotonous

I have read the contents of this consent form and have been encouraged to ask questions. I have received answers to my question. I agree to participate in this study.

Signature:
Date: