Vedic Pulse diagnosis System

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

by

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15BEC0146

Under the guidance of

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April, 2019

<u>DECLARATION</u>

I hereby declare that the project "**Vedic Pulse diagnosis system**" and associated thesis entitled "**Pulse diagnosis system for *Nadi Pariksha* using Parametric and Statistical analysis**" submitted by me, for the award of the degree of *Bachelor of Technology in Electronics and Communication Engineering* to VIT is a record of bonafide work carried out by me under the supervision of **Dr.Mythili Asaithambi**.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place : Vellore

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Signature of the Candidate

<u>CERTIFICATE</u>

This is to certify that the thesis entitled “Pulse diagnosis System for Nadi Pariksha using Parametric and statistical analysis” for the capstone project titled “Vedic pulse diagnosis system” submitted by **Amit Kadarmandalgi**, **School of Electronics Engineering**, VIT University, for the award of the degree of *Bachelor of Technology in Electronics and Communication engineering programme*, is a record of bonafide work carried out by him under my supervision during the period, 01. 12. 2018 to 30.04.2019, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfills the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place : Vellore

Date :

Signature of the Guide

Internal Examiner

External Examiner

Head of Department Dr. Thanikaiselvan V

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With regards,

Amit Kadarmandalgi

Executive Summary

Nadi Pariksha is a non-invasive pulse diagnosis method for assessing health of person in Ayurveda. The disease caused can be related to imbalance in any of three doshas i.e. vatha, pittha and kapha. 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 vatha, pittha and kapha respectively according previous research each point has a particular frequency of pulse which can be related to BPM (beats per minute). First a fundamental approach was given to the project by designing an Arduino based setup with the sensors to obtain BPM of each sensor and check if it deviates from the threshold value. In present research work the design and development of the pulse diagnosis system was carried out, in which Photoplethysmography (PPG) sensor was interfaced with Arduino was used to acquire wrist pulse signals from subjects in the form of data sets. Matlab software was used in signal processing after performing frequency domain analysis using power spectrum to design a filter and feature extraction was performed on these signals. Algorithms for three parameters were designed related to pulse sensors namely pulse wave velocity, augmentation index and reflectivity index. Data sets were created with the help of hundred volunteers. After performing statistical analysis on these data sets a standard signal was established.

Finally this experimental setup was used to diagnose patients with symptoms associated with imbalance in Tridosha to look for deviations from the standard vatha pittha kapha signal and these results were compared with theoretical results as per Ayurveda. Based on this research we came up with a conclusion with respect to the system designed.

Keywords— Vatha, Pittha, Kapha, dosha, Wrist pulse signal, peaks, *Photoplethysmography (PPG),* pulse wave velocity, argumentation index and reflectivity index

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List of Abbreviations

PWV	Pulse wave velocity
AI	Augmentation index
RI	Reflectivity index
PPG	Photo-plethysmographic
PTVD	Percussion tidal dicrotic valley
VPK	Vatha Pittha Kapha

Symbols and Notations

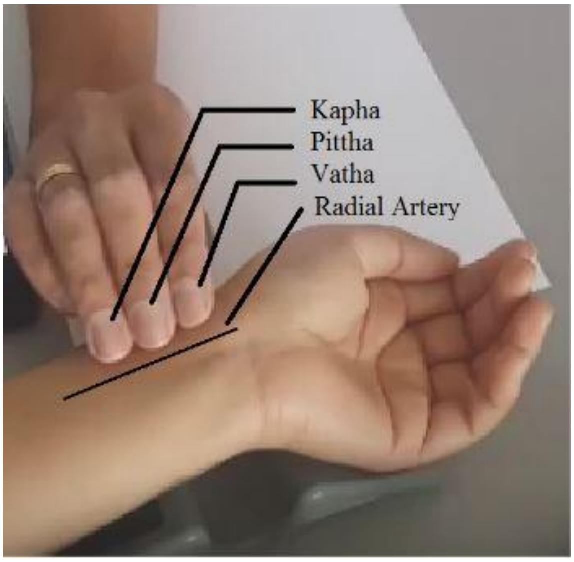
ε	**A parameter that controls the pass-band ripple**
ΩS	**Angular Frequency = 2*pi*f**
ΩP	**Cutoff frequency expressed as an angular value and is equal to $2\pi f_c$**
N	**Order of filter**
[ ]	**For numbering references**
( )	**For numbering formulas**

1. INTRODUCTION

1.1. OBJECTIVE

The significance of *Nadi Pariksha* is well understood and effectively used by Ayurveda practioners for assessing *Tridoshas* and various physiological and psychological states of the patient. The traditional texts *Sarangadhara Samhita*, *YogaRatnakara*, *Basavarajeeyam* and *Bhavaprakasha* have discussed the details of *Nadi Pariksha* in succinct set of *slokas*. Ayurveda has thousands of years of rich experience in *Nadi Pariksha* with strong literature support but is subjective in nature and the need for studying *nadi* with a scientific approach is well understood. Recently, pulse wave velocity has gained significant research interest as it is considered to be a strong indicator of cardiovascular disease; however, the relevance of pulse wave analysis to *Nadi Pariksha* has not been studied. In this review, traditional methods of *Nadi Pariksha* as defined in Ayurveda classics and the recent advances in pulse wave analysis are discussed. As per classical texts, qualities or properties of pulse such as pulse movement (*gati*), speed of the pulse (*vega*), stability of the pulse (*sthiratva*) and hardness of the artery (*kathinya*) play major role in *Nadi Pariksha* and in the current review these properties were analyzed and compared with the modern pulse parameters namely pulse wave velocity, pulse rate variability and arterial stiffness.

Hence the main objective of the project is to design a pulse diagnosis system and research on significance of pulse based analysis used in cardiovascular studies.



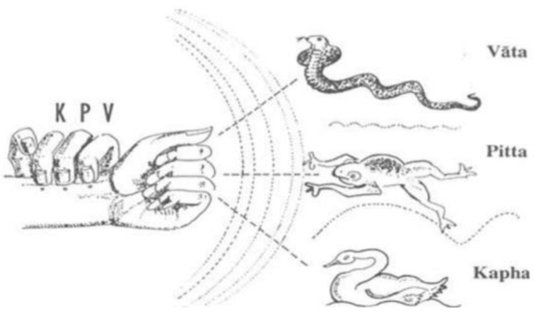


Fig 1.1. (a) ***Nadi Pariksha*** **(analyzing tri*dosha*)** **(b) Behavior of** ***Vatha, Pittha, Kapha*** **Pulse**

1.2. MOTIVATION

In Ayurveda, the health condition of a patient is determined by the dominant pulse among "Tridoshas" i.e. "Vatha", "Pittha", "Kapha" this practice of Nadi Pariksha has lost its significance and also there has been a reduction in number of physicians with this skill. Hence the objective of the project is to design an electronic system for pulse based health diagnosis used in traditional methods of *Ayurveda.*

The project focuses on product design for computer aided diagnosis which is done using arduino and sensors and it also focuses research done using Matlab by applying various signal processing techniques. Using this as a diagnostic tool we have carried out research by collecting data sets of healthy patients compared with patients with diseases like anxiety, body ache and common cold which are symptoms for vatha, pittha, kapha dosha respectively.

The main motivation for this project is to uplift traditional practices used in ancient Vedic system which has been proven globally yet we have become accustomed to western practices. The skill of "Nadi Pariksha" has been researched and published in various Chinese authors and yet we hesitate to adopt these methods.

Many research papers have already been published in this domain where each publisher has adopted different approach to system design with respect to choice of input sensor, software used and algorithms designed hence the approach involved in our project has been given most importance.

Hence the goal of the project is to Engineer and Design an electronic Pulse diagnosis system based on concept of '*Tridosha'* through advanced bio signal processing.

1.3. BACKGROUND

Ayurveda is one of the oldest literature which deals with diagnosis using signals obtained from three precise locations of radial artery, vatha, pittha and kapha which also played an important role in traditional Chinese medicine. The experienced Ayurvedic physicians used their skill to feel the patient's wrist to identify any imbalance of doshas (deviation in pulse) [1]. The research deals with design and development of an electronic computer aided diagnosis tool which uses methodology similar to traditional pulse-based method which requires a system for clean input signals, and extensive experiments for obtaining classification features which is referred to as its physiological properties [2]. Ayurvedic physicians 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. The index finger senses the vatha pulse, the middle finger senses the pittha pulse and the ring finger senses the kapha pulse. The different characteristics of the pulses have been indicated in Table 1 which is considered as our theoretical result. When dominance of any dosha or combination of doshas is observed, a disease is found through proper examination of pulse. It requires a lot of experience to learn pulse diagnosis technique so an acquisition device needs to be developed for novice practitioners.

TABLE 1.3.1. CHARACTERISTICS OF THE TRIDOSHA PULSES

Type of Pulse	**Type of Signal**	**Movement (Gati)**	**Disease associated with Dosha**
Vatha	Fast	Swan	Anxiety
Pittha	High Amplitude	Frog	Rashes and Body ache
Kapha	Slow	Snake	Cold

To develop pulse diagnosis acquisition systems, a lot of effort has been made worldwide.
A wrist pulse signal is produced by cardiac contraction and relaxation of heart and it is related to central aortic pressure waveform [3]. Pulse is felt at radial artery and the fluctuations are felt. Different types of sensors working on different principle have been used to measure the pressure exerted by blood in radial artery. In most recent papers sensor based on strain gauge with diaphragm movement was used and time series data acquired gave reproducible waveforms [4]. Portable prototype was made using sensor working on principle of Photoplethysmography and validation of the device performed using neural network [5]. A method was also proposed to measure heart rate variation, pulse propagation velocity and blood flow velocity using piezoelectric transducer array [6]. Apart from using the right sensor there also has been research done on software based analysis techniques such as Diagnosis of disease using wrist pulse signal classification algorithms based on pre meal and post meal analysis [7]. Spectral analysis of Tridosha signals and Comparative analysis of Butterworth and Bessel filter has been presented to identify cut off frequency of Tridosha using NI Labview data acquisition system [8]. Along with hardware implementations a lot of research

have been done in analysis of wrist pulse signal in time and frequency domain and pulse classifiers. Wrist pulse signal analysis have been performed involving power spectrum estimate of pulse signal for identifying the frequency of pulse in healthy and unhealthy subject [9,10]. Architecture designed using three main sensors and sub sensors as well as pressure adjustment module and classification with SVM classifier was an attractive development [3]. Replicating fingers of physician in pulse diagnosis is a big challenge, the proper design of hardware along with significant feature extraction and classification may lead to a non invasive device which can eliminate human error performed manually by Indian practitioners in the disease diagnosis. Considering all these references it is important to make sure to use simple hardware along with a compatible software in order to reduce complexity hence it was decided to design a system using PPG sensors with Arduino on matlab software. Hence the main aim of this research was to focus on parametric and statistical analysis.

2. PROJECT DESCRIPTION AND GOALS

Nadi Pariksha is a non-invasive pulse diagnosis method for assessing health of person in Ayurveda. The disease caused can be related to imbalance in any of three doshas i.e. vatha, pittha and kapha. 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 vatha, pittha and kapha respectively. The project can be categorized into product design and research. The product i.e. electronic system design which consists of Photoplethysmography (PPG) sensor interfaced with Arduino which was used to acquire wrist pulse signals from subjects in the form of data sets. Matlab software was used in signal processing after performing frequency domain analysis using power spectrum to design a filter and feature extraction was performed on these signals. Parametric analysis was completed by creating algorithms which are specifically related to pulse sensors namely pulse wave velocity, augmentation index and reflectivity index. For the research part, Data sets were created with the help of volunteers where samples of V P K signal was recorded along with features and parameters of each signal. After performing statistical analysis on these data sets a standard signal was established. Finally this experimental setup was used to diagnose patients with symptoms associated with imbalance in Tridosha to look for deviations from the standard vatha pittha kapha signal and these results were compared with theoretical results as per Ayurveda. Based on this research we came up with a conclusion with respect to the system designed.

The product designed should help a doctor visually distinguish the dominant pulse to understand patient’s condition. The research part includes experimenting affects of different signal processing techniques such as Fourier transform, filters, periodogram.etc. And applying parameters such as pulse wave velocity (PWV), augmentation index (AI) & reflectivity index (RI). After collecting the data sets for healthy people this standard signal can be used as a reference to check if there is deviation in Vatha, Pittha, and Kapha dosha in patients with anxiety, rashes, and common cold respectively. The research should help us in getting better results by comparing them to methods used in reference papers in similar line of work.

2.1. Photoplethysmography (PPG) sensor

Photoplethysmography is a simple optical technique used to detect volumetric changes in blood in peripheral circulation. The PPG sensor system consists of a light source and a detector, with light-emitting diodes (LEDs) commonly used as the light source, and Photo Diodes or Photo Transistors as the light detector. When light travels through biological tissues, it is absorbed by bones, skin pigments and both venous and arterial blood. Most changes in blood flow occur mainly in the arteries and arterioles, rather than the veins. They contain more blood volume during the systolic phase of the cardiac cycle than during the diastolic phase. The voltage signal from PPG is proportional to the quantity of blood flowing through the blood vessels. The changes in light intensity are associated with small variations in blood perfusion of the tissue and provide information on the cardiovascular system, in particular, the pulse rate. PPG is most effective when measured where the complexity of blood vessels is less and the thickness of the skin is relatively less.

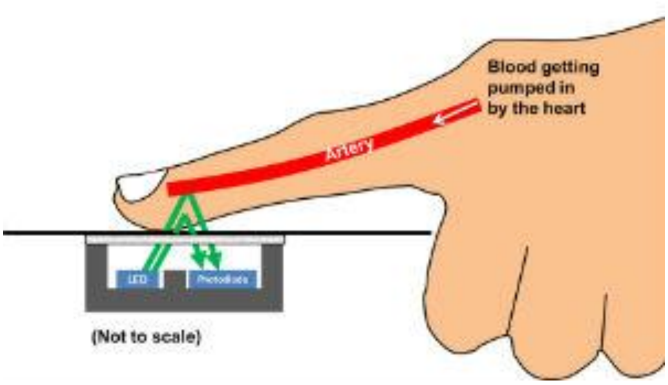


Fig 2.1. (a) Working of PPG sensor **(b) PPG sensor hardware**

2.2. Study of the signal

The Photoplethysmogram has a DC component and an AC component. The DC component is primarily due to the bulk absorption by the tissue and the average blood volume. The varying AC component is due to pulsatile pressure.

The appearance of the PPG pulse is commonly divided into two phases: the anacrotic phase is the rising edge of the pulse, whereas the catacrotic phase is the falling edge of the pulse. The first phase is primarily concerned with systole, and the second phase with diastole and wave reflections from the periphery. A dicrotic notch is usually seen in the catacrotic phase of subjects with healthy compliant arteries.

The different features observed in a typical PPG signal are:

- Systolic Amplitude:

The systolic amplitude (x) is an indicator of the pulsatile changes in blood volume caused by arterial blood flow around the measurement site. Systolic amplitude is proportional to blood stroke volume. The systolic peak is also known as percussion wave.

- Diastolic Peak:

The diastolic peak is due to the reflection of the wave from the arterial wall, which occurs during the diastolic period. This factor has a direct correlation with the thickness of the artery. The downslide in pulse is known as tidal wave.

- Dicrotic Notch:

The dip in the wave between the systolic and diastolic peaks is known as the dicrotic notch. The depth of the notch is a function of the healthiness of the artery. If the reflected wave returns too quickly, the depth of the notch can be almost negligible.

- Valley or Inflection Point:

The literal definition of inflection point is the point at which the concavity of a signal changes. Therefore, this is the point at which the first derivative of the signal is zero. It is an important feature as it also conveys information about the stiffness of arteries.

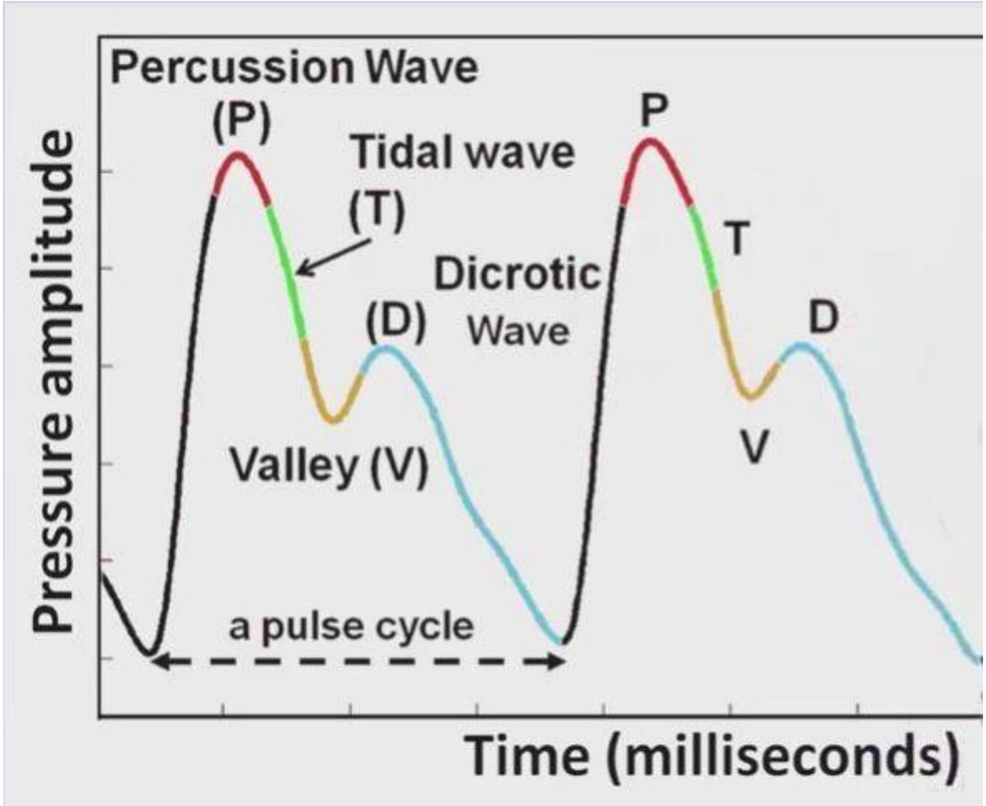


Fig 2.2. PTVD pattern in pulse sensor

2.3 Data Collection:

The data was collected over a period of 2 months. Close to 200 volunteers allowed for their PPG samples to be taken. The consent form, containing details about age, gender, diet, weight and patient ID, was filled by the volunteers prior to sample collection. The data collected was recorded in the form of excel sheet with columns v p k t columns representing voltage readings of vatha, pittha, kapha and time respectively. Around 500 readings of each sensor were measured within a minute. The initial plot along with pulse readings looked as follows.

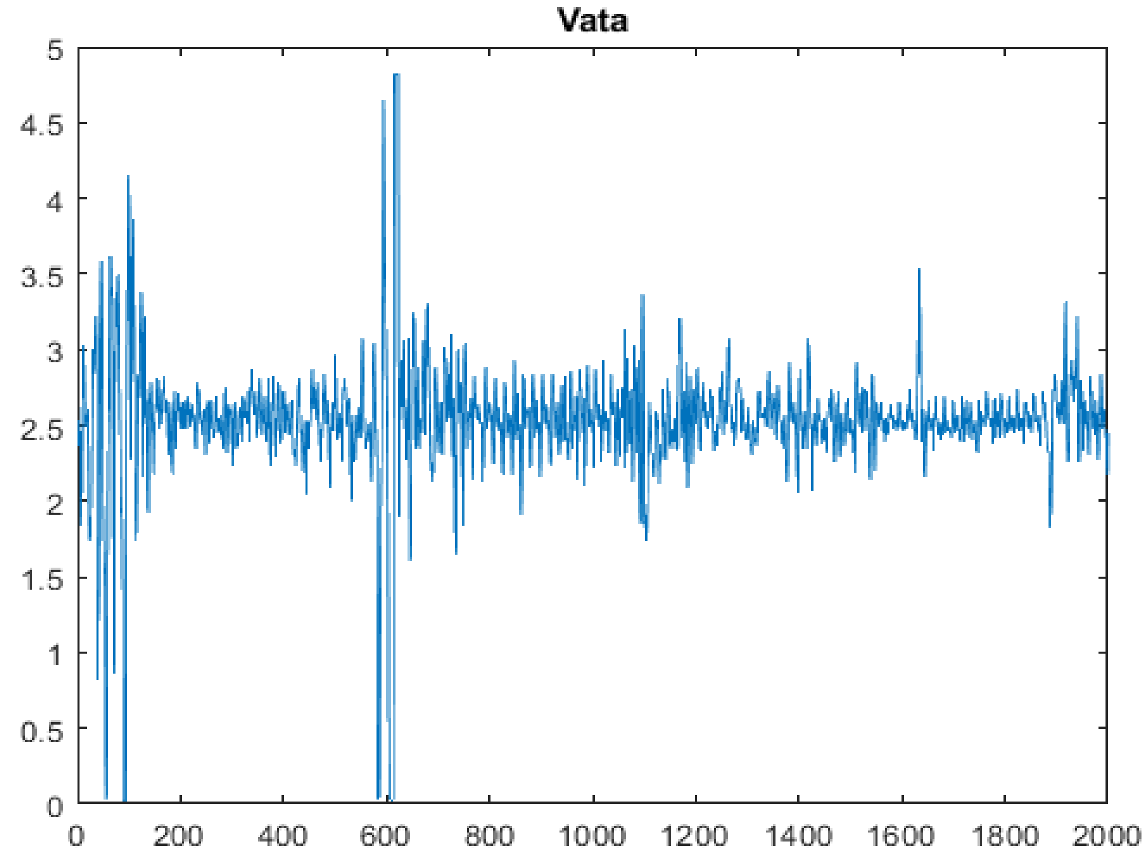


Fig 2.3.1.Raw Signal of Pulse sensors for Data acquisition

X axis- Number of Samples taken(2000)

Y axis- Voltage readings of each sample

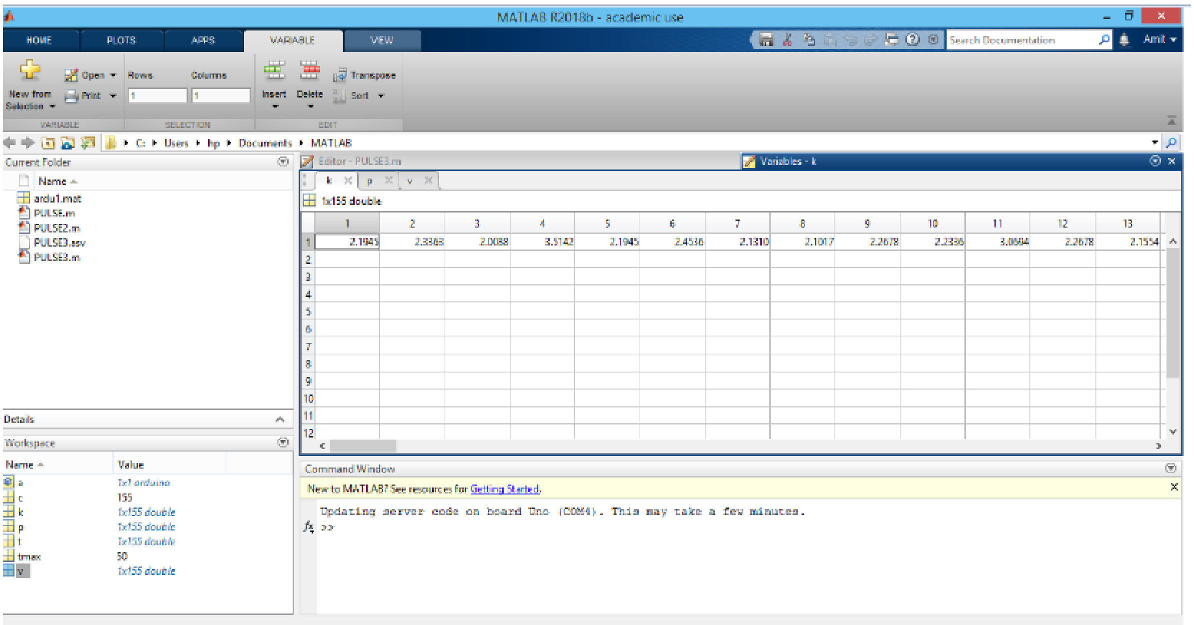
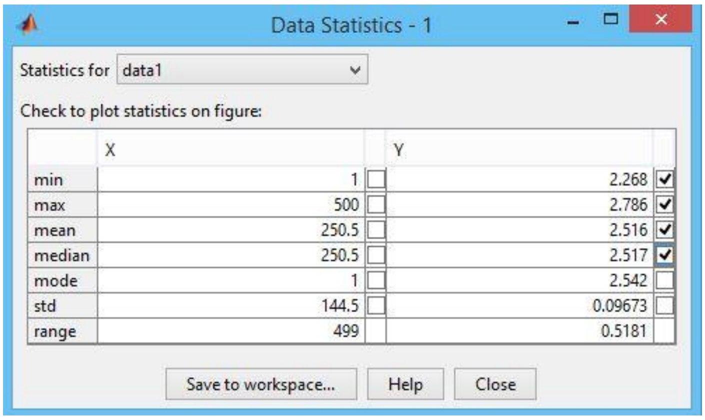


Fig 2.3.2. Analog voltage readings with respect to time



Data Statistics - 1

Statistics for data1

Check to plot statistics on figure:

	X		Y	
min	1	☐	2.268	☑
max	500	☐	2.786	☑
mean	250.5	☐	2.516	☑
median	250.5	☐	2.517	☑
mode	1	☐	2.542	☐
std	144.5	☐	0.09673	☐
range	499	☐	0.5181	

Save to workspace... Help Close

Fig 2.3.3. Statistical readings of signal

2.4. Signal Processing

The signals obtained from the PPG sensor are not readily useable in the parameter algorithms. The signals require a number of preprocessing steps. The first task in preprocessing is understanding the spectrum of the signal and its frequency content. In order to perform this study, a periodogram of the signal was plotted.

A periodogram calculates the significance of different frequencies in time-series data to identify any intrinsic periodic signals. It is similar to the Fourier Transform, but is optimized for unevenly time-sampled data, and for different shapes in periodic signals. The statistical significance of each frequency is computed based upon a series of algebraic operations that depend on the particular algorithm used and periodic signal shape assumed.

The periodogram of the PPG signal obtained was as follows

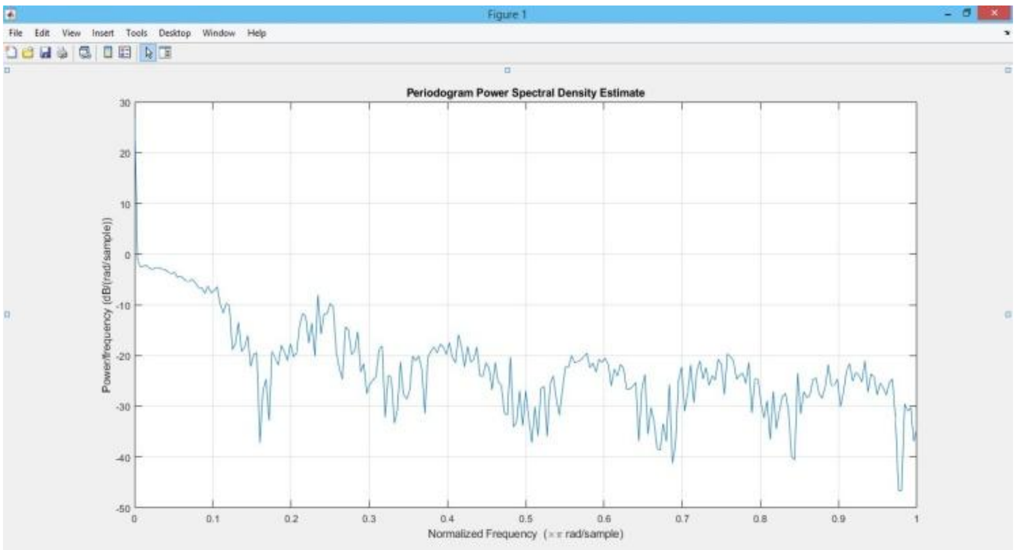


Fig. 2.4.1. Periodogram power spectral density of signal

X-axis : Normalized Frequency Y-axis: Power / Frequency

2.5. Filter Design

- From the periodogram it is clear that the information content is mainly in the 0 to 6 Hz band. Therefore, a low pass filter of cutoff frequency 6Hz is to be applied to the signal.
- The choices of filter were Moving Average Butterworth, Chebyshev and Elliptical Filters. Since the requirement is a simple noise removal filter, in time domain it can viewed as a Moving
- Average Filter, which has the response of a window filter in time domain. As impressive as it appeared in time domain, the Fourier Transform of the signal failed miserably as it was a sinc function, and the multiplication by sinc function would alter the signal irreparably.
- In case of Butterworth filter, although it had a flat pass-band response, it suffered the disadvantage of a very bad roll off even for high order of the filter.
- Elliptical would then be the next option considered. While it initially appeared as the right option, the filter complexity and the presence of ripples in both the pass and stop bands forced us to consider our final option, the Chebyshev filter.
- Although the Chebyshev filter has ripples in the pass band, the roll-off was much better than in the case of Butterworth filter. As a result, the filter used was a Chebyshev filter.
- Design of Filter:

The filter of choice is Chebyshev and the requirements are $\Omega P = 0 , \Omega S = \left(\frac{6}{200}\right) * 100$ and Pass-band ripple = 1 dB

ε, a parameter that controls the pass-band ripple is calculated as

$$\boldsymbol{\varepsilon = \sqrt{10^{\frac{Pass-band\ ripple\ in\ dB}{10}} - 1}} \qquad (1)$$

Also,

$$\boldsymbol{A = \sqrt{1 + \varepsilon^2 T^2 \frac{\Omega S}{\Omega P}}} \qquad (2)$$

Finally, the order of the filter is the smallest positive integer for which order thus calculated was 5.

$$N \geq \frac{\cosh^{-1}\sqrt{(A^2-1)/\varepsilon^2}}{\cosh^{-1}(\Omega S/\,\Omega P)} \tag{3}$$

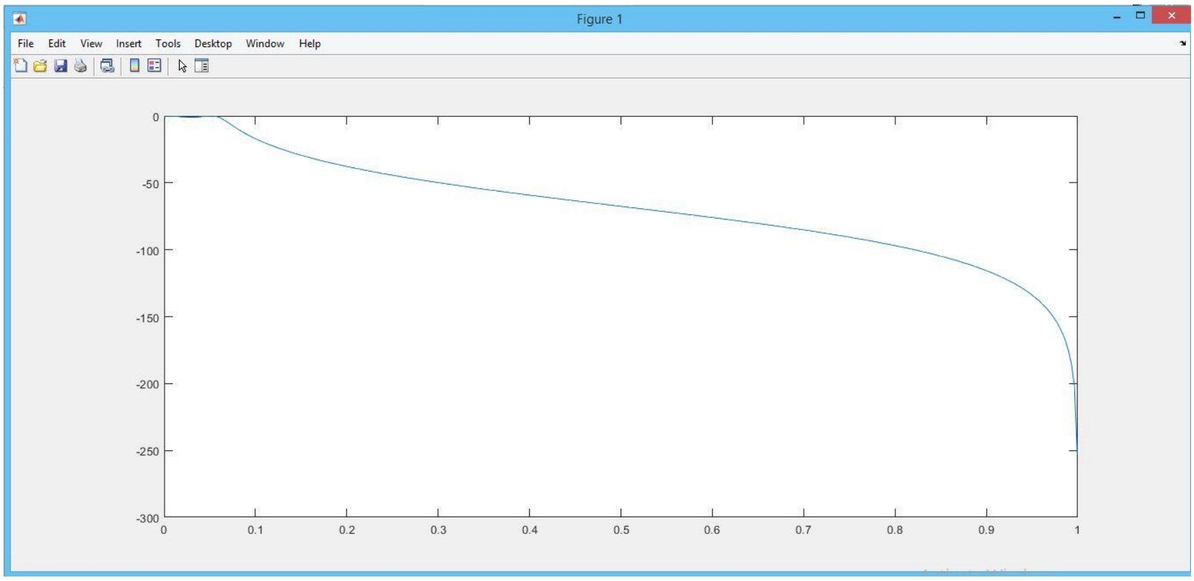


Fig 2.5.1. Butterworth filter design

2.6. Removal of constant offset

DC offset is a mean amplitude displacement from zero. In Audacity it can be seen as an offset of the recorded waveform away from the center zero point. DC offset is a potential source of clicks, distortion and loss of audio volume.

As implied by the periodogram, majority of the signal power lies in the 0Hz or DC component which does not contain any useful information. Therefore, the DC offset is removed.

An example for signals before and after removal of DC offset is as follows:

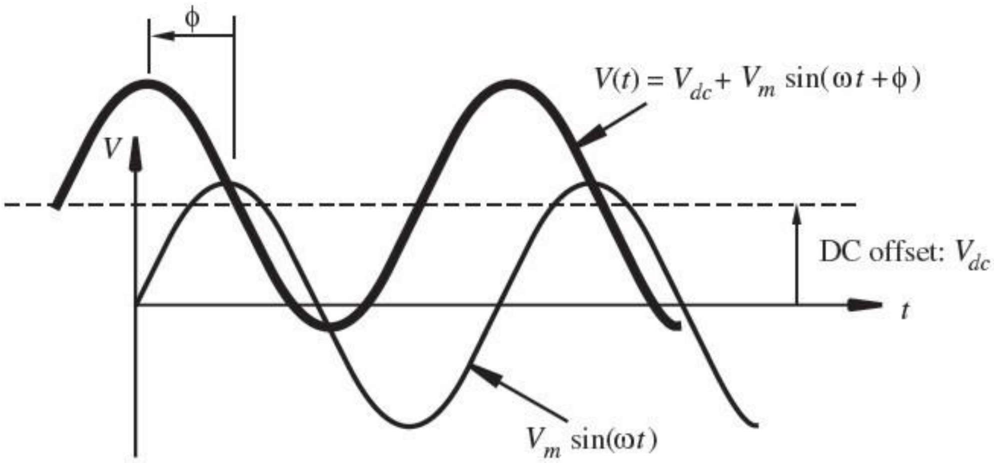


Fig 2.6.1. DC offset example

2.7.Downsampling

Downsampling (or sub sampling) is the process of reducing the sampling rate of a signal. This is usually done to reduce the data rate or the size of the data.

Given that the sampling rate is 2000 samples/second on arduino-matlab interface and that biomedical signals are maintained at a high sampling rate due to their unpredictability the signal is downsampled by a factor of 2.

An example for removing error in signal by downsampling is given as follows

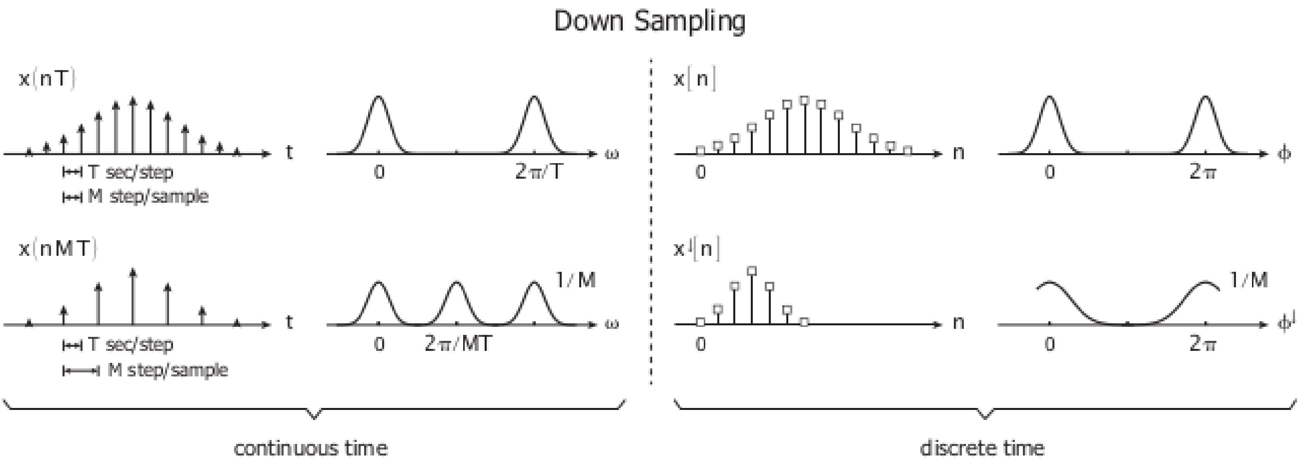


Fig 2.7.1. Downsampling of signal example

2.8. Feature Extraction

In this case finding the rising and falling peaks are the features of the signal which are further used in parametric analysis.

- Calculate the value of threshold. In case of peaks:

Threshold=mean(signal)+stddev(signal)

In case of troughs,

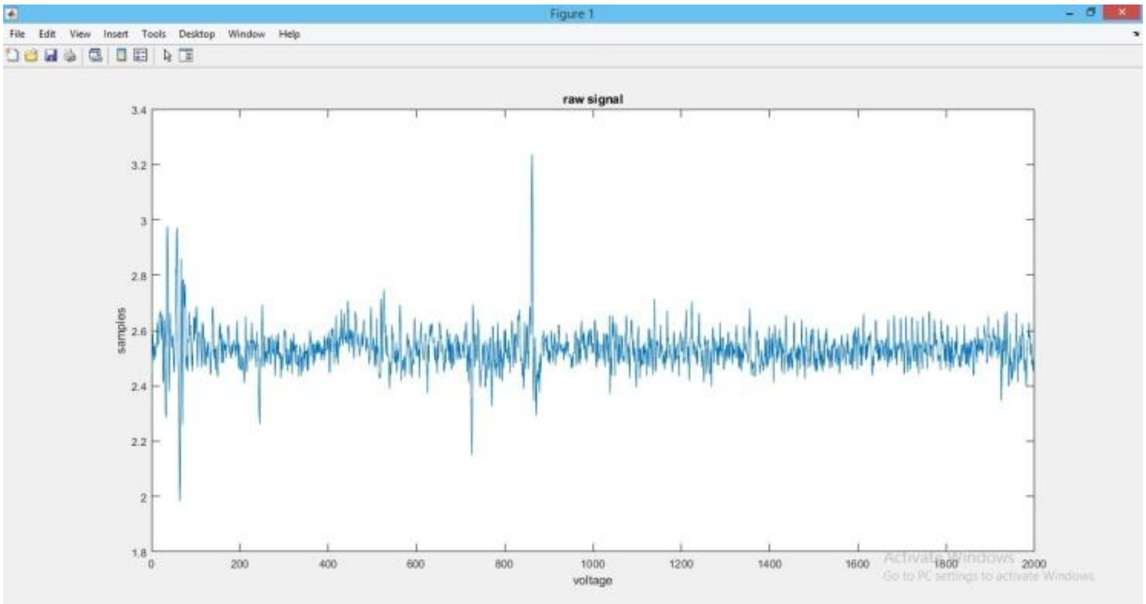
Threshold=mean(signal)-stddev(signal)

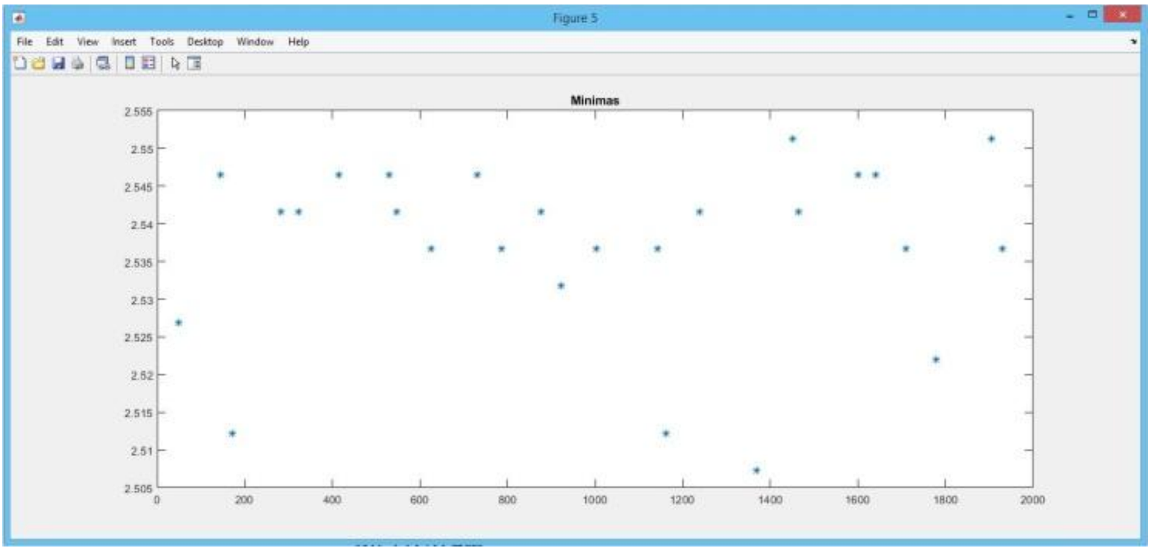
- Declare an array inv

$$inv = \begin{cases} 0, if\ signal(i) < thr \\ 1, if\ signal(i) > thr \end{cases} \qquad (4)$$

- Initiate two arrays r_peaks and f_peaks and fill them with rising and falling peaks respectively.
- This is done to calculate the number of peaks or troughs that can be found.

- In every set of data(ys) which is above the threshold encapsulated by the rising and falling edge, max(ys) in case of peaks and min(ys) in case of troughs, and the corresponding indices are stored in [peak_locs, peaks].
- Finally, the set of peaks [peak_locs, peaks] is checked for false peaks or nadirs. This is done by comparing every 70 samples in the vicinity of a peak or nadir. If the peak(or nadir) is a true peak (trough) then it is saved in [npeak_locs, npeaks]





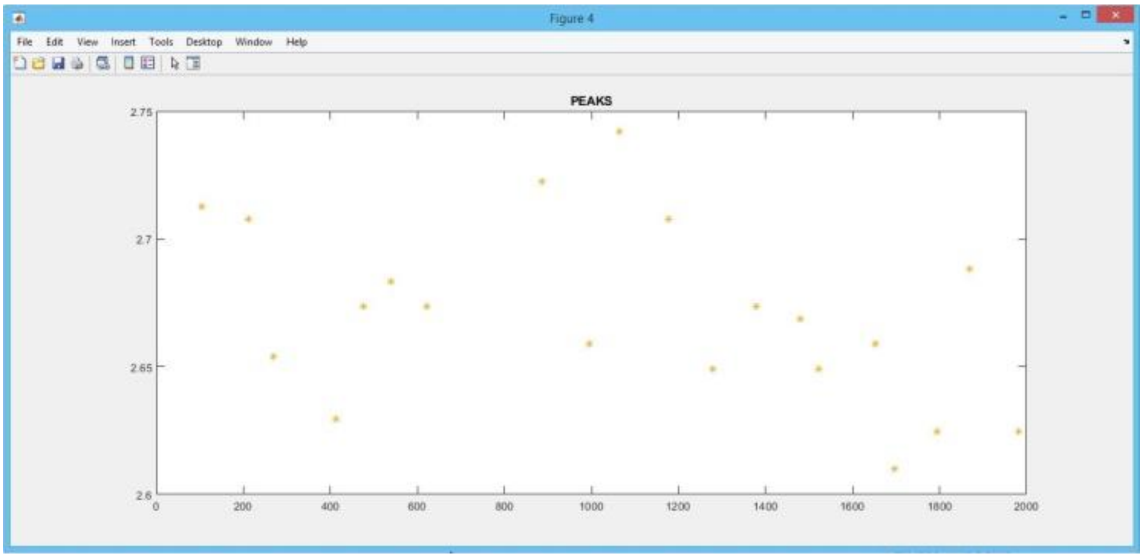


Fig. 2.8.1. Plotting minima and peaks of the signal

(a) Raw Signal

(b) Finding Minimas of Signal

(c) Finding Peaks of Signal

2.9.Parametric Analysis

2.9.1. Algorithm for PWV

As discussed, the value of PWV is given by

$$PWV = \frac{physical\ distance\ between\ the\ sensors}{PTT} m/s$$

Therefore, the calculation of PWV involves the following steps:

- The three signals of vatha, pittha and kapha are simultaneously obtained.
- The physical distance between the two sensors are noted which is nearly 1 cm.
- The systolic peaks of both signals are detected.
- The distance between the systolic peak in the wrist signal and the corresponding peak in the finger signal is stored in an array.

- The outliers in this array are removed, and the mean of this array is calculated and stored as mean value of PTT.
- PWV is calculated according to the formula.

2.9.2. Algorithm for AI

As discussed, the value of AI is given by

$$Augmentation\ Index(AI) = \frac{(Augmentation\ Pressure\ (AG))}{(Pulse\ Pressure\ (PP))}\%$$

Therefore, the calculation of AI involves the following steps:

- The two signals are simultaneously obtained.
- The signals are separated and the finger signal is retained.
- The signal is preprocessed for downsampling, dc offset removal and filtering.
- The inflection points are calculated as follows:

By definition, inflection points are those points where the concavity of the curve is reversed

The first differential of the signal is calculated and stored as an array

The troughs of this array are detected

The troughs of this array correspond to the points of inflection. The justification of this is as follows. When the curve changes concavity, the second differential is 0. This happens when the first differential is either a trough or maxima. It has been observed in PPG signals that the inflection points are the points of trough.

- The augmentation pressure is calculated as follows:

$$Augmentation\ Pressure\ (AP) = Systolic\ peak\ pressure - inflection\ point\ pressure$$

- The peaks and troughs of the PPG signal are detected for the calculation of Pulse Pressure
- Pulse Pressure is calculated as

$$Pulse\ Pressure = Systolic\ Pressure - Diastolic\ Pressure$$

- Finally, the Augmentation Index is calculated using the formula.

2.9.3. Algorithm for RI

The reflectivity index of a sample is given by

$$Reflectivity\ Index = \frac{Amplitude\ of\ Inflection\ Peak}{Systolic\ Pressure}\%$$

- The two signals are simultaneously obtained.
- The signals are separated and the finger signal is retained.
- The signal is preprocessed for downsampling, dc offset removal and filtering.
- The peaks of the signal are detected and the corresponding pressure is stored as the systolic pressure.
- Inflection points are found as the troughs of the first differential of the signal. The pressure corresponding to the inflection points are stored in an array of inflection peak amplitudes.
- The outliers of this array are removed, and the mean of the array is calculated and stored as the amplitude of inflection peak.
- Reflectivity index is then calculated using the formula.

2.10. Statistical analysis:

- Finding the average parameter table

The parameters of each data set were recorded such as the mean, Pulse wave velocity and augmentation index of each signal dataset created from 100 healthy people. The average of these hundred values was calculated and set as standard parameters.

- Finding the average signal of a healthy person

The dataset for 100 healthy people were collected such that each excel sheet had 500 samples under vatha pittha kapha columns clocked against time. Now using matlab code we were able to establish an average of these hindered signals giving a standard V P K signal which was saved the plot is shown in the figure.

- Comparative analysis

Based on this standard signal as reference we compared signals obtained from unhealthy patients we observed significant deviation from the pulse hence indicating an imbalance in *dosha*.

3 TECHNICAL SPECIFICATION

3.1. Sensor - Photoplethysmography (PPG sensor)

Photoplethysmography (PPG) is a simple optical technique used to detect volumetric changes in blood in peripheral circulation. The PPG sensor system consists of a light source and a detector, with light-emitting diodes (LEDs) commonly used as the light source, and Photo Diodes or Photo Transistors as the light detector. When light travels through biological tissues, it is absorbed by bones, skin pigments and both venous and arterial blood. Most changes in blood flow occur mainly in the arteries and arterioles, rather than the veins. The changes in light intensity are associated with small variations in blood perfusion of the tissue and provide information on the cardiovascular system, in particular, the pulse rate. PPG is most effective when measured where the complexity of blood vessels is less and the thickness of the skin is relatively less. In this case a reflectance type sensor was used to measure the pulse signal on vatha, pittha, kapha positions of wrist.

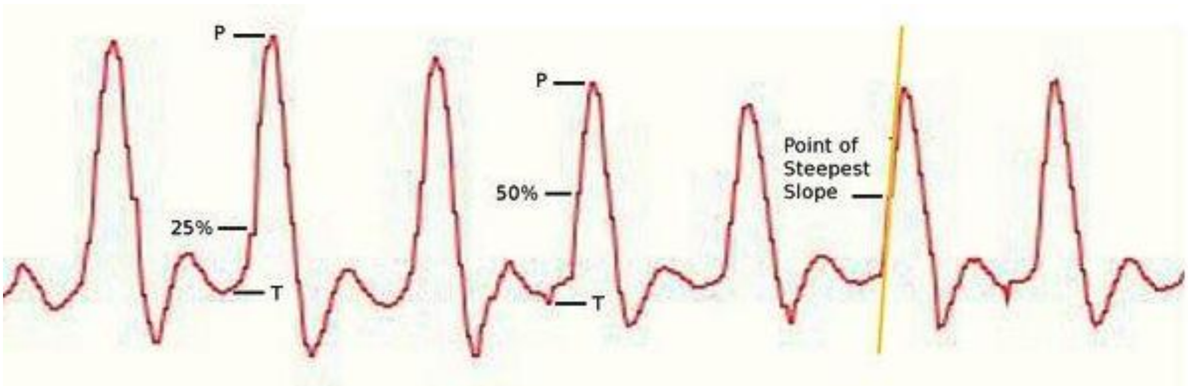


Fig 3.1.1. Signal pattern obtained from pulse sensor

The Pulse Sensor that we use is essentially a photoplethysmograph (PPG) which is a well known medical device used for non-invasive heart rate monitoring. PPGs measure blood-oxygen levels (SpO2), sometimes they don't. The heart pulse signal that comes out of a PPG is an analog fluctuation in voltage, and it has a predictable wave shape as shown in figure 3.1.1. The depiction of the pulse wave is called a Photoplethysmogram or PPG. Our latest hardware version, Pulse Sensor Amped, amplifies the raw signal of the previous Pulse Sensor, and normalizes the pulse wave around V/2 (midpoint in voltage). Pulse Sensor Amped responds to relative changes in light intensity. If the amount of light incident on the sensor remains constant, the signal value will remain at (or close to) 512 (midpoint of Arduino 10 bit ADC range). More light and the signal goes up. Less light, the opposite. The amount of light from the green LED that is reflected back to the sensor changes during each pulse. Our goal is to find successive moments of instantaneous heart beat and measure the time between, called the inter-beat interval (IBI). By following the predictable shape and pattern of the PPG wave, we are able to do just that.

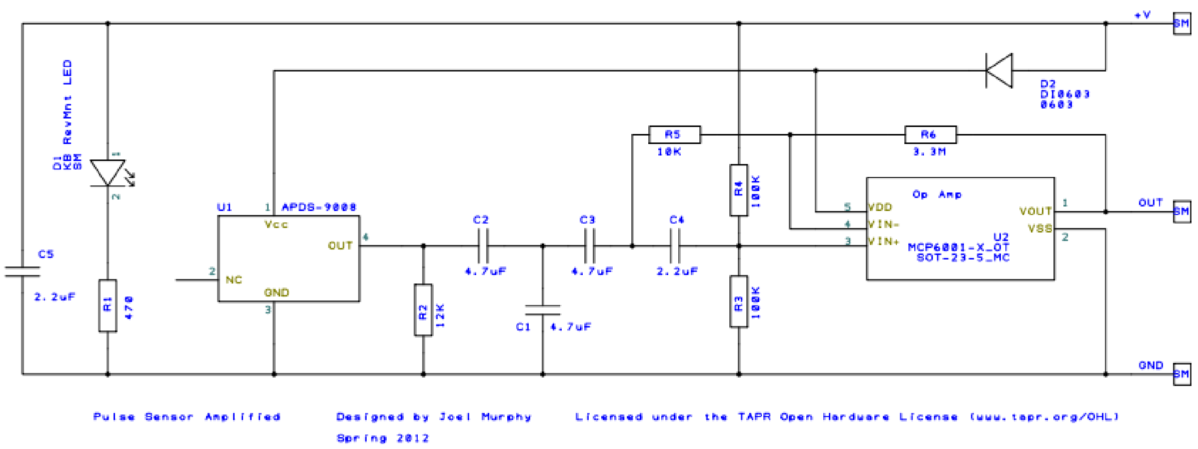


Fig 3.1.2 Circuit diagram of PPG sensor

3.2. Micro controller

The pulse sensor is placed at the right wrist position and is connected to Arduino micro controller which has voltage source of 5V and 45 mA current rating. This Arduino is interfaced with matlab which is coded to acquire pulse sensor data in the form of analog voltage reading values from 0-5 V. The code is modified accordingly to acquire samples at a particular rate which is clocked using a timer function.

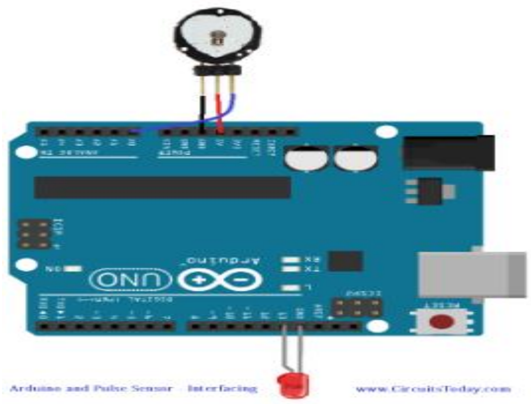


Fig 3.2. Arduino PPG interface

3.3 Software

The sensor is connected to Arduino micro controller which has voltage source of 5V and 45 mA current rating. This Arduino is interfaced with matlab which is coded to acquire pulse sensor data in the form of analog voltage reading values from 0-5 V. The code is modified accordingly to acquire samples at a particular rate which is clocked using a timer function.

MATLAB support package for Arduino lets you write MATLAB programs that read and write data to your Arduino and connected devices such as Adafruit motor shield, I2C, and SPI devices. Because MATLAB is a high-level interpreted language, programming with it is easier than with C/C++ and other compiled languages, and you can see results from I/O instructions immediately—without recompiling. MATLAB includes thousands of built-in math, engineering, and plotting functions that you can use to quickly analyze and visualize data collected from your Arduino.

Fig 3.3. Arduino Matlab serial interface

4 DESIGN APPROACH AND DETAILS .

4.1.Design Approach / Materials & Methods

The instrumentation setup is made using three pulse sensors at the right wrist positions to measure vatha, pittha, kapha pulse signals the data measured in the form of analog voltage readings from Arduino is plotted in matlab with respect to time to know we are getting the right dicrotic wave of a pulse signal.

Two Hundred (200) Subjects information was collected, consisting of 100 healthy and 100 unhealthy subjects for recording wrist pulse signal. The unhealthy subjects can be categorized in three based on imbalance in vatha, pittha, kapha. For imbalance in vatha dosha the most common symptoms are anxiety, body spasms, dry skin.etc. For Pittha dosha imbalance the most likely symptoms are acidity, rashes and anger. For kapha dosha imbalance is more of a common cold related symptoms. For the unhealthy persons data set, people with these symptoms were considered and the subject was requested to fill a consent form consisting basic information of the subject regarding the disease.

Data was obtained for about 5 min of each subject at sampling rate of 1000 Hz such that 500 samples of vatha, pittha and kapha pulses were collected simultaneously. A Matlab program was made to plot power spectrum. Filtering was performed in Matlab using low pass Butterworth filter of order 2. This is the signal processing stage where we try to remove noises.

The feature extraction stage involves obtaining rising and falling peaks of each pulse and using them to find parameters like pulse wave velocity, augmentation index and reflectivity index. After using all the collected data the statistical and parametric analysis were used to come up with a research conclusion.

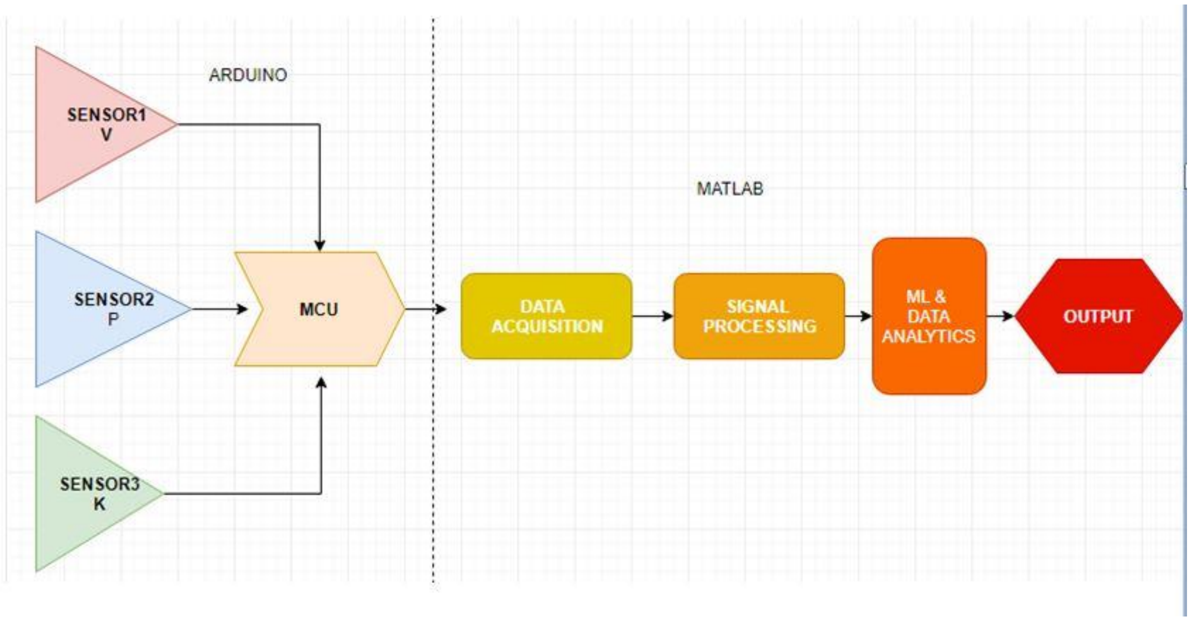


Fig 4.1.1. System design

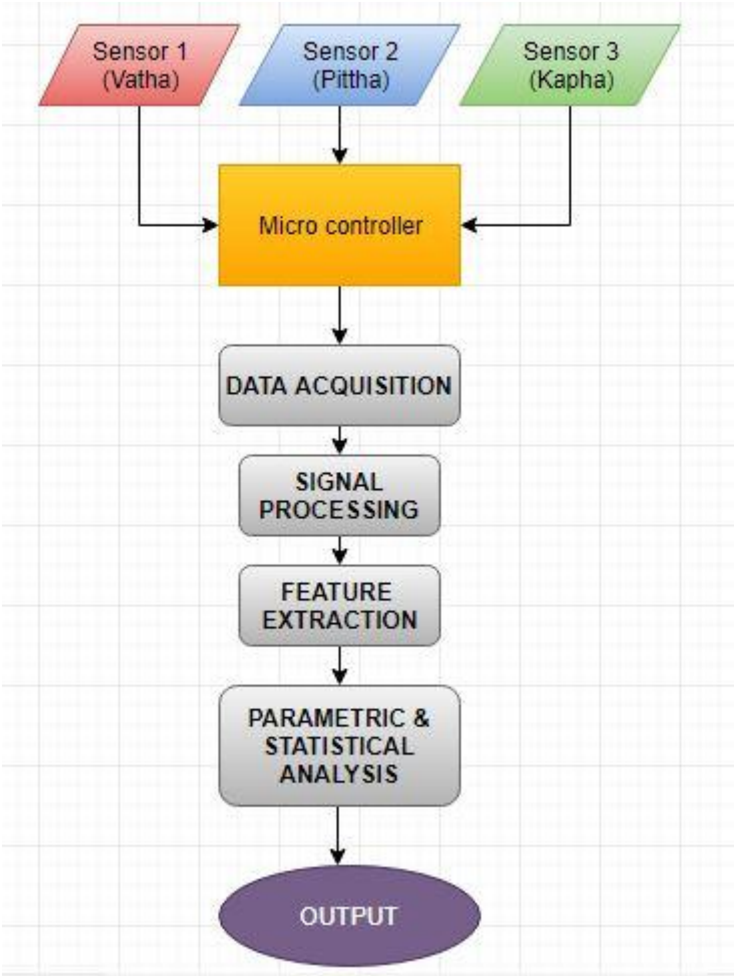


Fig 4.1.2. Methodology flow chart

4.2.Codes and Standards

- Arduino Uno
- Matlab 2018b
- Microsoft Excel
- Photoplethysmography sensor (PPG)·
- Serial communication between Arduino and Matlab
- ADC communication between Arduino and pulse sensor

4.3.Constraints, Alternatives and Tradeoffs

This can be explained considering various significant stages of system design and approaches given at different stages of project development phase:

- Initial System Design approach:

Authors classified the pulses on the basis of *Siddha theory* which states that the three pulses vary in amplitude in the ratios of 1:2:4 for *kapha, pittha,* and *vatha* respectively and the frequencies must be 80-95 beats/min for vatha pulse, 70-80 beats/min for pittha pulse and 50-60 beats/min for kapha pulse. Hence for intial prototype development stage only arduino interfaced with PPG sensors was used but later on many thesis working on this basis were considered non scientific hence in order to give a more scientific approach data acquisition using matlab had to be done.

- Choosing Sensors:

The choice of sensor is crucial as many researchers have tried to replace hands of a skilled Ayurvedic physician who consider the warmth, palpation and rate (gati) at which the pulse is moving hence sensors like diaphragm based pressure sensors, ECG sensors, temperature sensors and even microphones. But considering pulse based diagnosis being the key factor we chose Photoplethysmography sensor which has trade-offs like small hence can be placed to precision, easy to interface and works on light based principle which can be used to design other parameters.

- Matlab software:

After doing online survey we realized there were certain software were good at certain tasks such as NI-DAQ for data acquisition, python for designing algorithms, or even embedded C arduino for hardware interface but each had its cons whereas Matlab is a great tradeoff as I have been able to achieve all these in one software hence avoiding complications of jumping from one interface to another.

- Data acquisition setup:

Instead of using hardware software combination of Arduino matlab there were also other options such as NI- DAQ system or other micro controllers like beagle bone which would help in achieving a better signal at an adjusted data acquisition rate but the trade off being they were expensive and more important is the fact the learning aspect would have gone down due to usage of inbuilt libraries. Arduino has helped me keep the hardware simple and focus on the coding aspects of matlab which has helped me learn something new.

- Choice of Butterworth filter:

The choices of filter were Moving Average Butterworth, Chebyshev and Elliptical Filters. Since the requirement is a simple noise removal filter, in time domain it can viewed as a Moving Average Filter, which has the response of a window filter in time domain. As impressive as it appeared in time domain, the Fourier Transform of the signal failed miserably as it was a sinc function, and the multiplication by sinc function would alter the signal irreparably.

In case of Butterworth filter, although it had a flat pass-band response, it suffered the disadvantage of a very bad roll off even for high order of the filter.

Elliptical would then be the next option considered. While it initially appeared as the right option, the filter complexity and the presence of ripples in both the pass and stop bands forced us to consider our final option, the Chebyshev filter.

Although the Chebyshev filter has ripples in the passband, the roll-off was much better than in the case of Butterworth filter. As a result, the filter used was a Chebyshev filter.

- Analytics:

The key aspect of the project being what exactly is meant by Tridosha where the physician claims to an imbalance in one or more nadis(pulse) after referring many theoretical texts it was still unclear for how to detect this imbalance in the system. We stuck to our research ideas by relying on data sets to perform statistical analysis to come to a conclusion. This could be more tiring and not satisfactory for the amount of data collected but it is a good trade off for using complicated techniques which takes a lot of time to understand and code.

- Statistical analysis:

The theoretical goal of this project was to find an imbalance in one of the three pulses to which our approach was unique. A standard V P K signal has been plotted considering the average of data sets obtained from healthy patients this was used as a reference to diagnose patients with disease.

- Parametric analysis :

Pulse transition time and pulse wave velocity of three signals which has given an insight on significance of consideration of blood flow in unhealthy patients.

The reflectivity index which is the measure of reflected wave from PPG sensor has proven to be an important parameter to distinguish between the three doshas.

The augmentation index which deals with the blood volume also plays a significant role in case of unhealthy patients in different cases.

5. SCHEDULE, TASKS AND MILESTONES .

TABLE 5.1. WORKLOAD TIMELINE

Sno.	Month	Task
1	December	Literature survey and identification of problem
2	January	Hardware Implementation of base paper upto data acquisition
3	February	Applying various bio signal processing techniques and drafting a research paper based on the progress
4	March	Presenting research paper in IPACT19 conference and obtaining feedback in terms of further approach
5	April	Final review , project submission

6. PROJECT DEMONSTRATION

6.1. STAGE 1

At the first stage of the project was ideation and doing literature survey on it. In literature survey phase consisted of referring various texts of the practice *Nadi Pariksha* and considering existing research work in this domain. Based on this a simple system design was considered only using arduino and PPG sensor interface. An arduino code was designed to obtain BPM (beats per minute) from one sensor and further code was developed for three sensors. The main aim was to develop a code to check the threshold frequency of each dosha i.e. vatha, pittha, kapha which was referred to as 80-95 beats/min, 70-80 beats/min and 50-60 beats/min respectively.

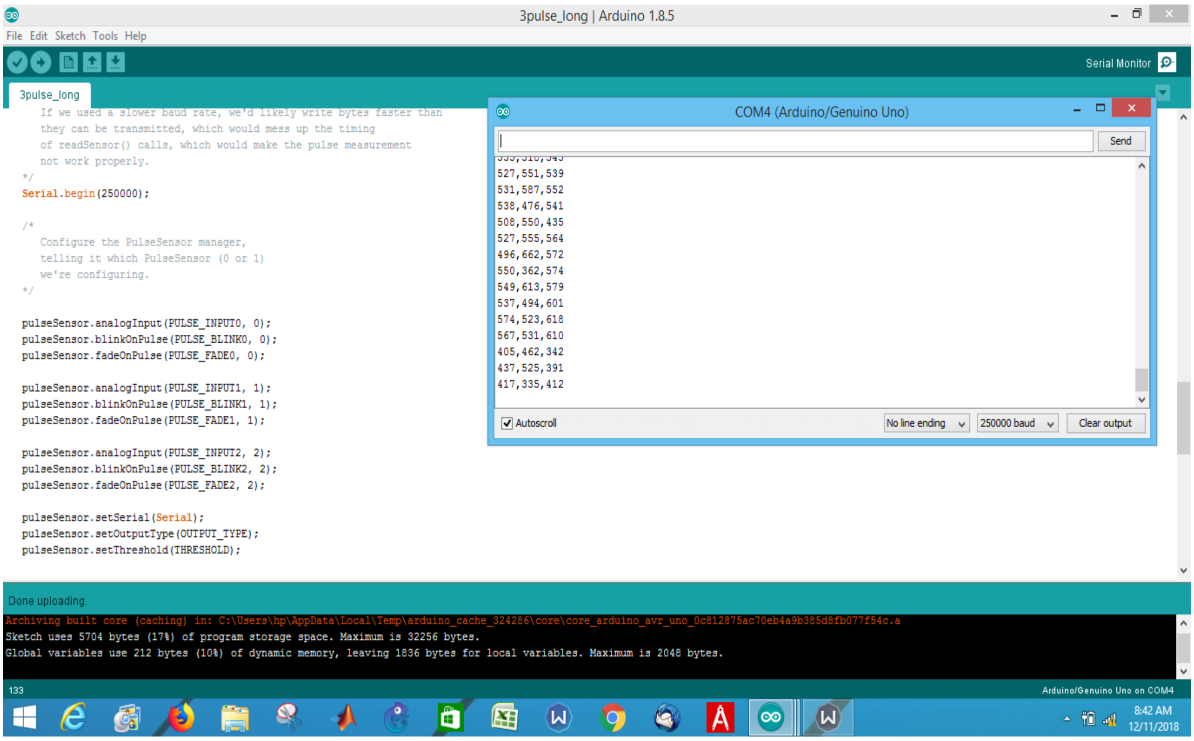


Fig. 6.1.1. Arduino interfaced with PPG sensor

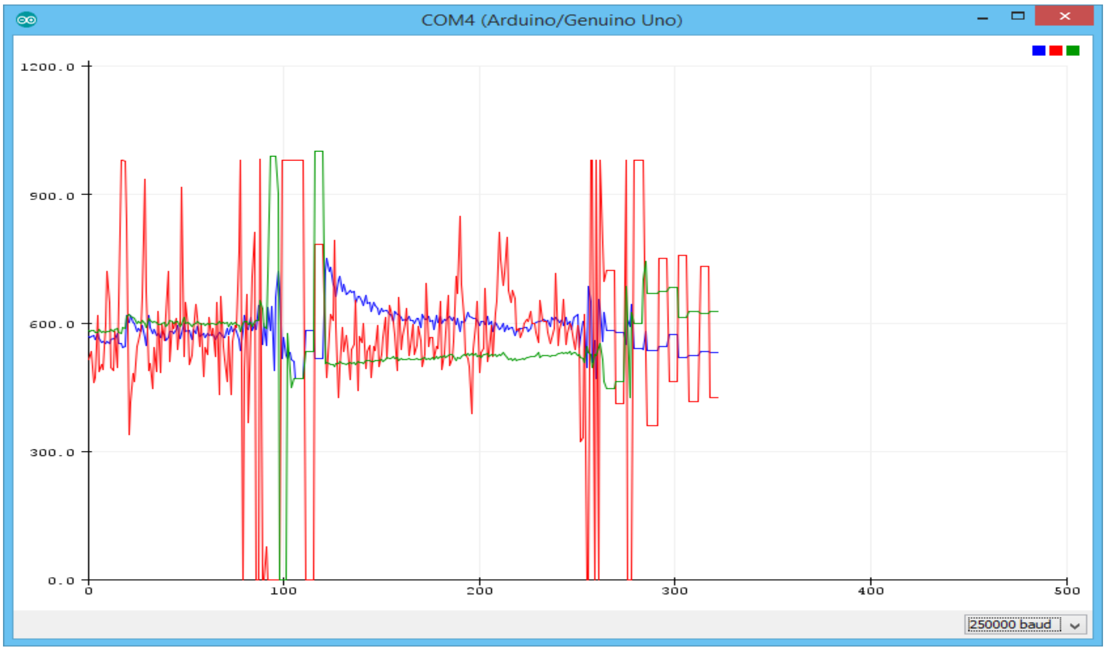


Fig 6.1.2. Arduino Serial plotter – VPK BPM plot

6.2. STAGE 2

After the prototype stage the system was now interfaced with Matlab software in order to dive deeper into understand the working of PPG sensor, to conduct research based on acquired data sets and to design our own methodologies to differ from the current research work in this domain. Hence this stage can be described as setting up a system for data acquisition. Matlab-Arduino interface was used where specific matlab functions were used to acquire analog voltage readings from sensor from arduino and plot three signals simultaneously on matlab. The data acquired was stored in excel form.

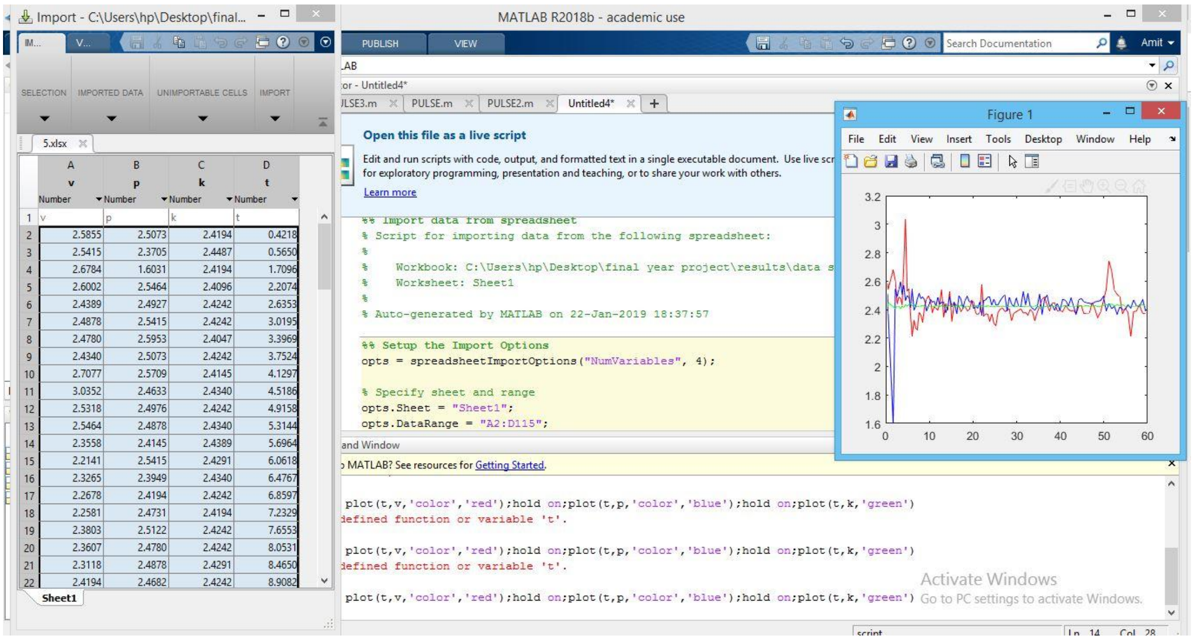


Fig. 6.2.1. Data acquisition using Matlab

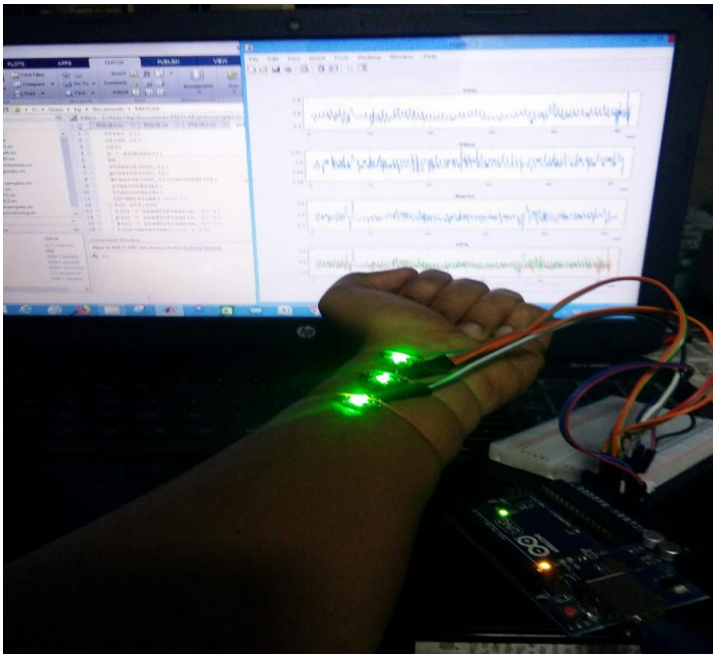


Fig 6.2.2. Experimental setup

At the initial attempts at this stage, two different algorithms:

- One where data is acquired based on restricted time duration such as 60 seconds. This method had a major drawback as there was no emphasis laid on sampling rate hence the signal acquired was poor.

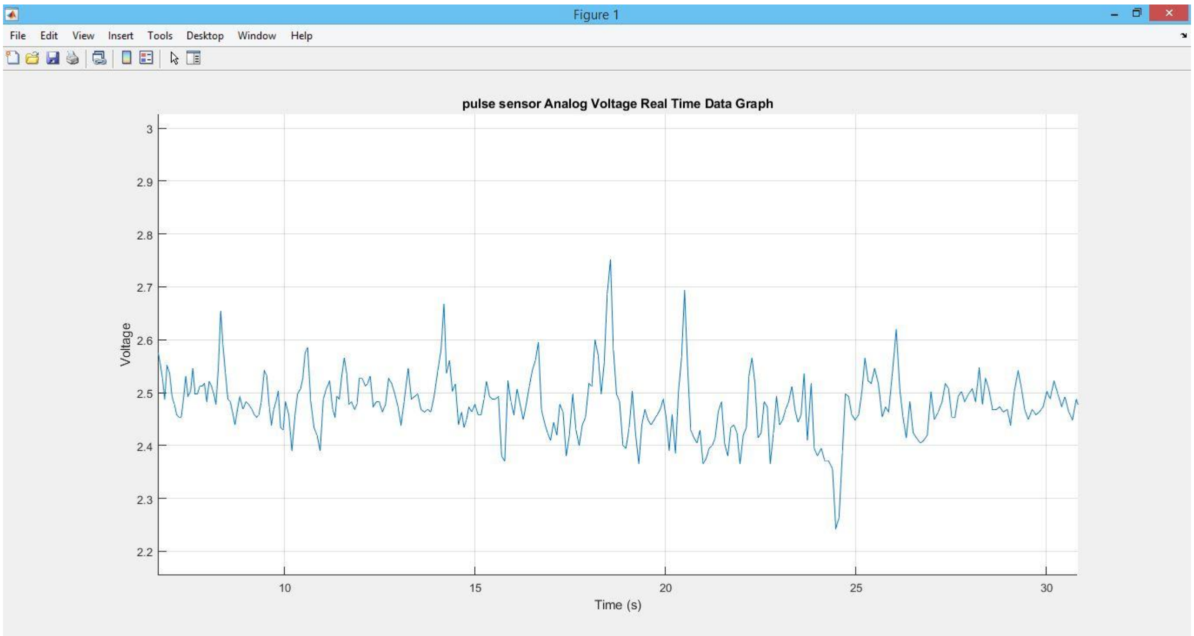


Fig 6.2.3. Voltage readings with respect to time

- At the second attempt this was improvised with data acquisition with emphasis laid on plotting sampling rate with respect to voltage.

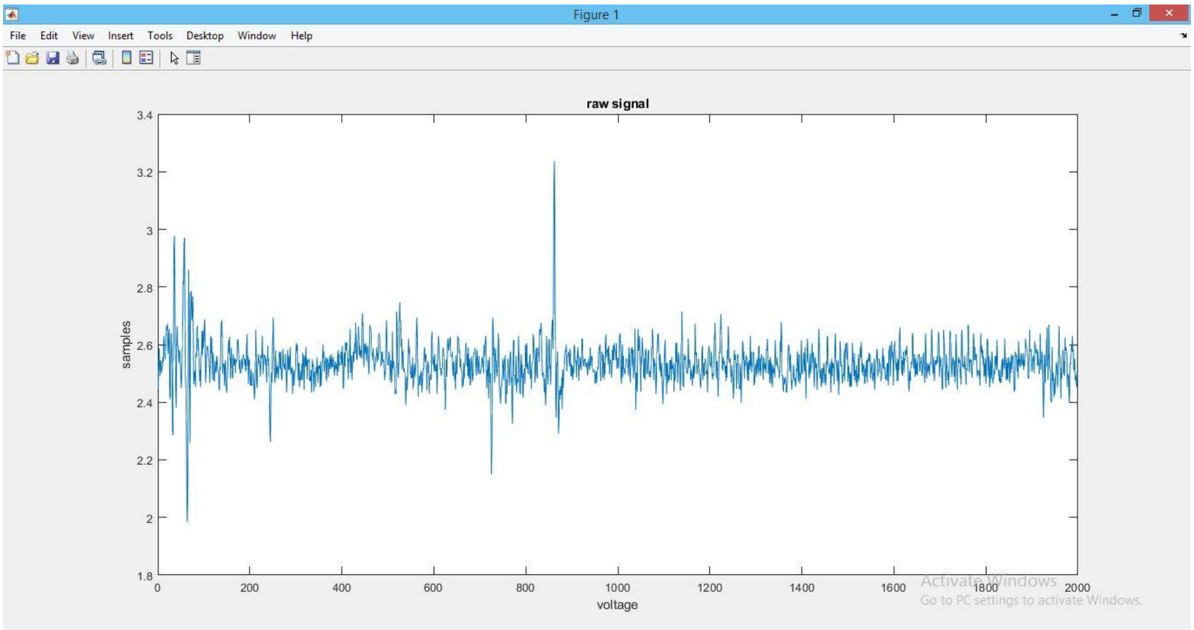


Fig 6.2.4. Voltage readings with respect to sampling rate

The signals obtained from three sensors for vatha, pittha, kapha is plotted simultaneously to depict a common VPK signal. The data acquired in the form of analog voltage with respect to time is stored in excel sheets in the form of vectors “v”, “p”, “k”. The code for data acquisition for 500 samples is given bellow:

```
clear all
close all
clc;
a = arduino();
v=zeros(500,1);

p=zeros(500,1);

k=zeros(500,1);

t=seconds(v);

t=seconds(p);

t=seconds(k);

t0=datetime('now');
for c=1:500
v(c) = readVoltage(a,'A0');
p(c) = readVoltage(a,'A1');
k(c) = readVoltage(a,'A2');
t(c)=datetime('now')-t0;
end
subplot(4,1,1)

plot(t,v);
```

```
title('Vata');
hold on
subplot(4,1,2)
plot(t,p);
title('Pitha');
hold on
subplot(4,1,3)
plot(t,k);
title('Kapha');
hold on
subplot(4,1,4)
plot(t,v,'color','red');
hold on
plot(t,p,'color','blue');
hold on
plot(t,k,'color','green');
title('VPK');
hold on
```

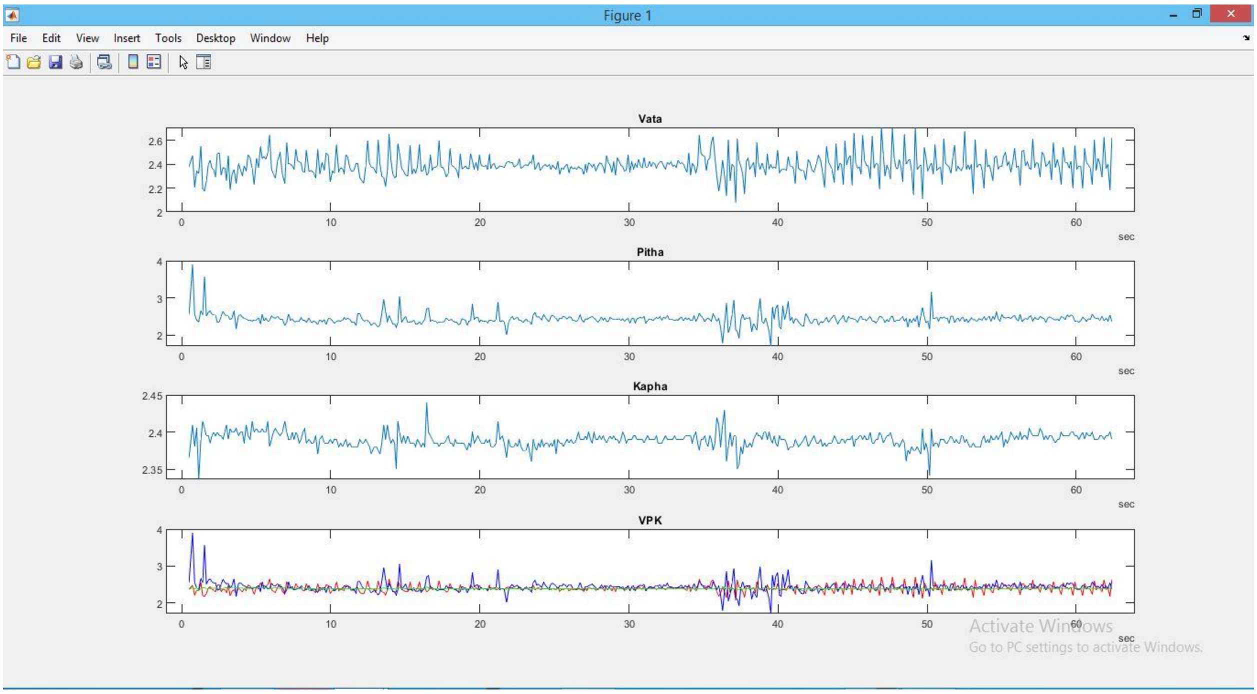


Fig. 6.2.5. Plotting V P K signal

6.3. STAGE 3:

This stage laid focus on pre processing of acquired signal to understand different types of noise coming from PPG sensors and removal of these errors. The approach given in this stage was as follows:

- Power Spectral density analysis.
- Removal of most common errors of PPG sensors such as DC offset and down sampling.
- Filter design to remove noise.

```
clear all
close all
clc;
a = arduino();
v=zeros(2000,1);

t=seconds(v);

t0=datetime('now');
for c=1:2000
v(c) = readVoltage(a,'A0');
t(c)=datetime('now')-t0;
end
figure(1)

plot(1:c,v);

title('Vata');
```

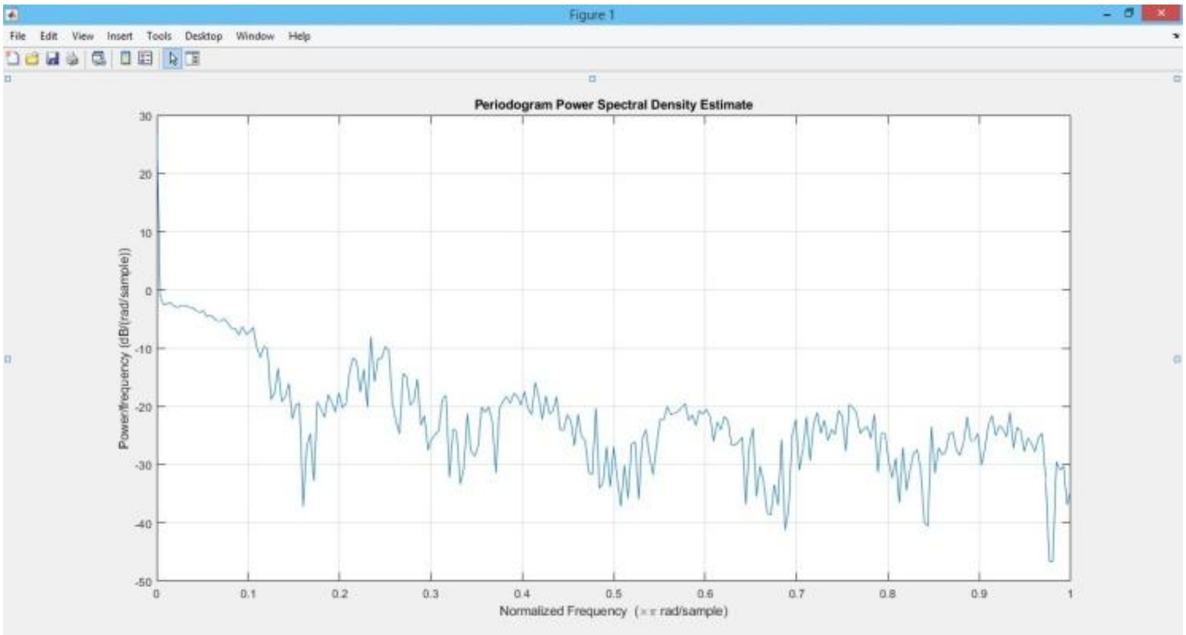


Fig 6.3.1. Power spectral density plot

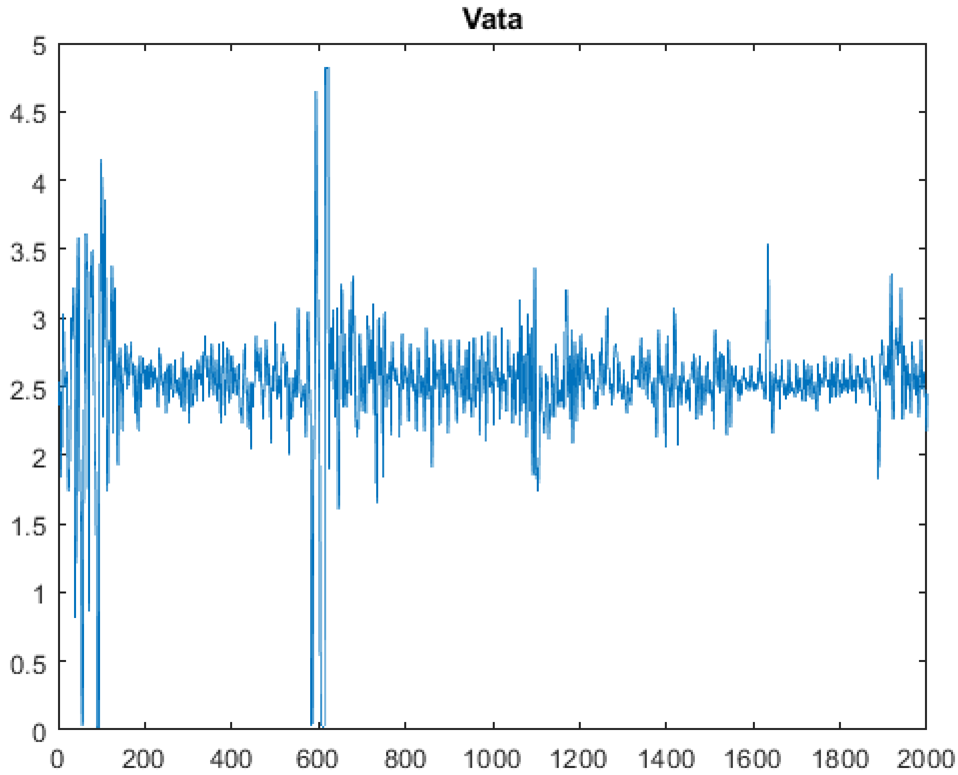


Fig 6.3.2. Raw signal

```
dss=downsample(v,2); %downsample by 4
figure(2)
subplot(2,1,1)
```

```
plot(1:c,v);
title('Signal before Downsampling');
subplot(2,1,2)
plot(1:length(dss),dss); title('Signal After Downsampling');

dssmin=dss-min(dss); %remove dc offset
figure(3)
subplot(2,1,1)
plot(1:length(dss),dss); title('Signal before Removal of DC    offset');
subplot(2,1,2)
plot(1:length(dssmin),dssmin); title('Signal After removal of DC offset');
```

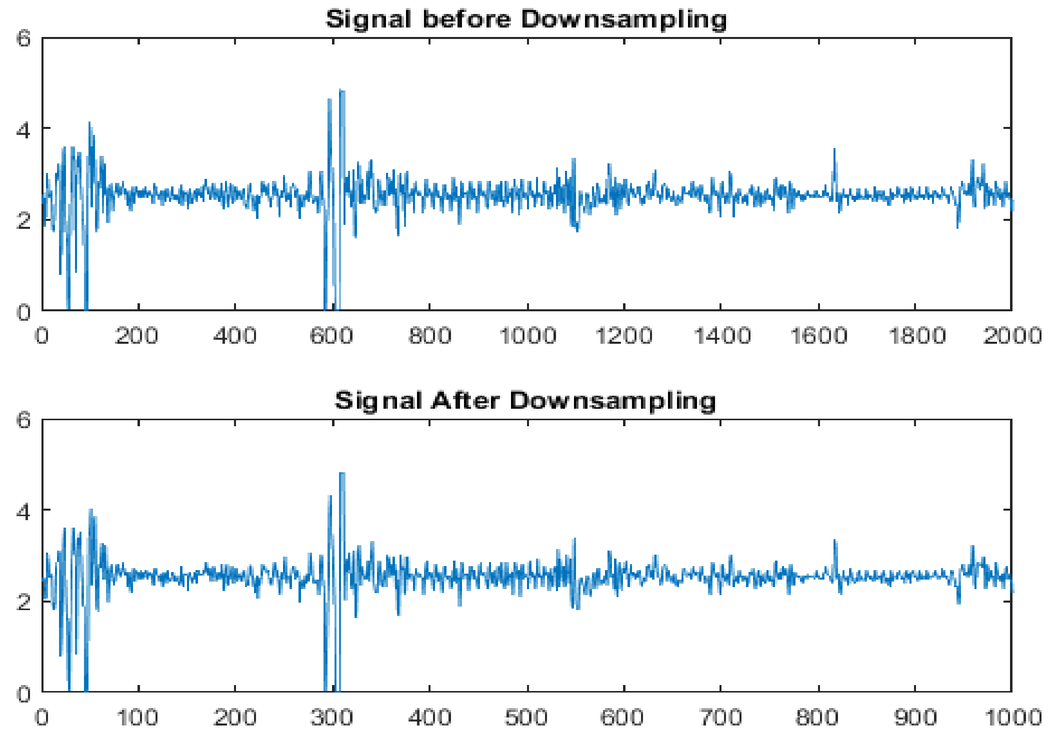


Fig. 6.3.3. Signal before and after Downsampling.

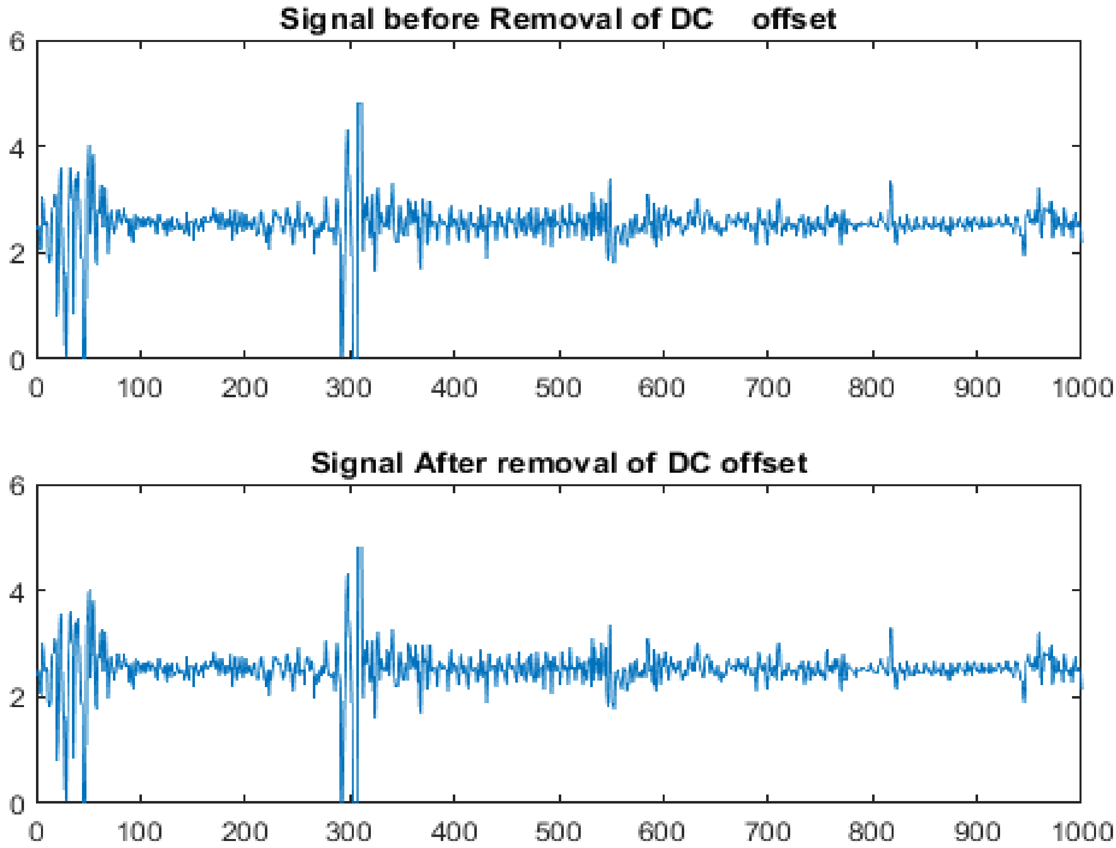


Fig. 6.3.4. Signal before and after removing DC offset.

```
N=3;R=1;

Wp=0.06;

[b,a]= cheby1(N,R,Wp,'low');
w = 0:0.01:pi;
[h,om] = freqz(b,a,w);
figure(4)
plot(om/pi,20*log10(abs(h)));
title('type 1 chebychev filter frequency response')
xlabel('W/W0 or om/pi')
ylabel('Gain(dB)')
yfil=filter(b,a,dssmin);
t=1:length(dssmin);
figure(5)
subplot(2,1,1)
plot(t,dssmin); title('Signal before Filtering');
subplot(2,1,2)
plot(t,yfil); title('Signal After Filtering');
```

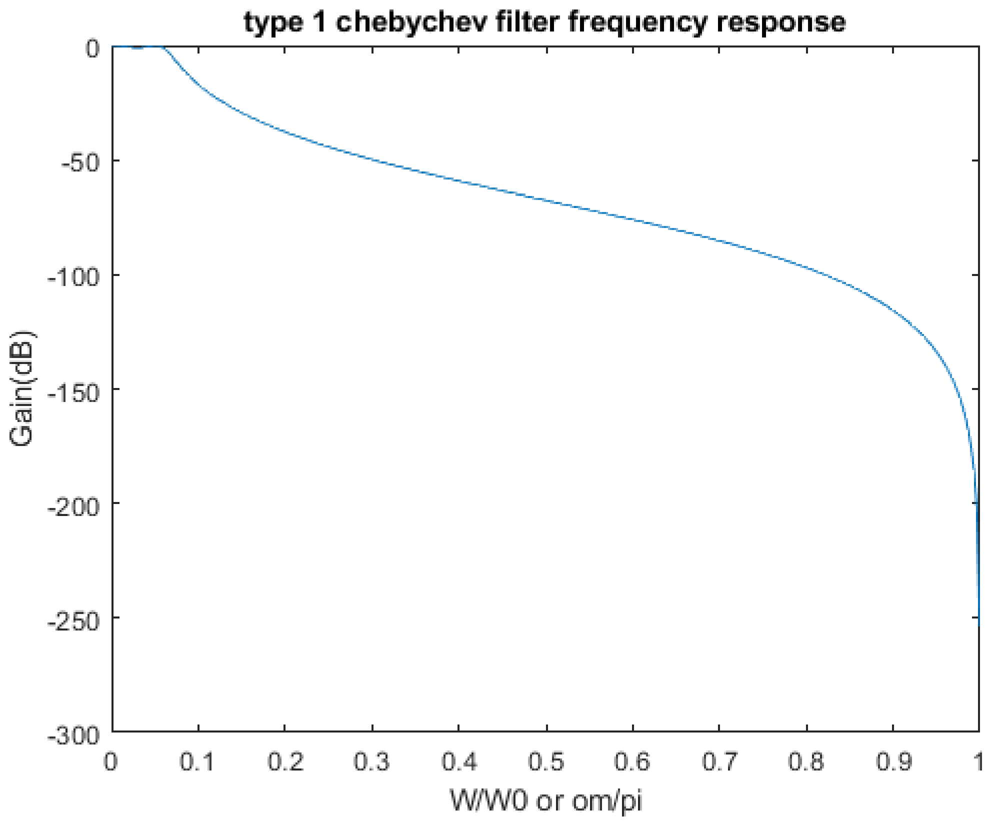


Fig.6.3.5. Low pass Butterworth filter

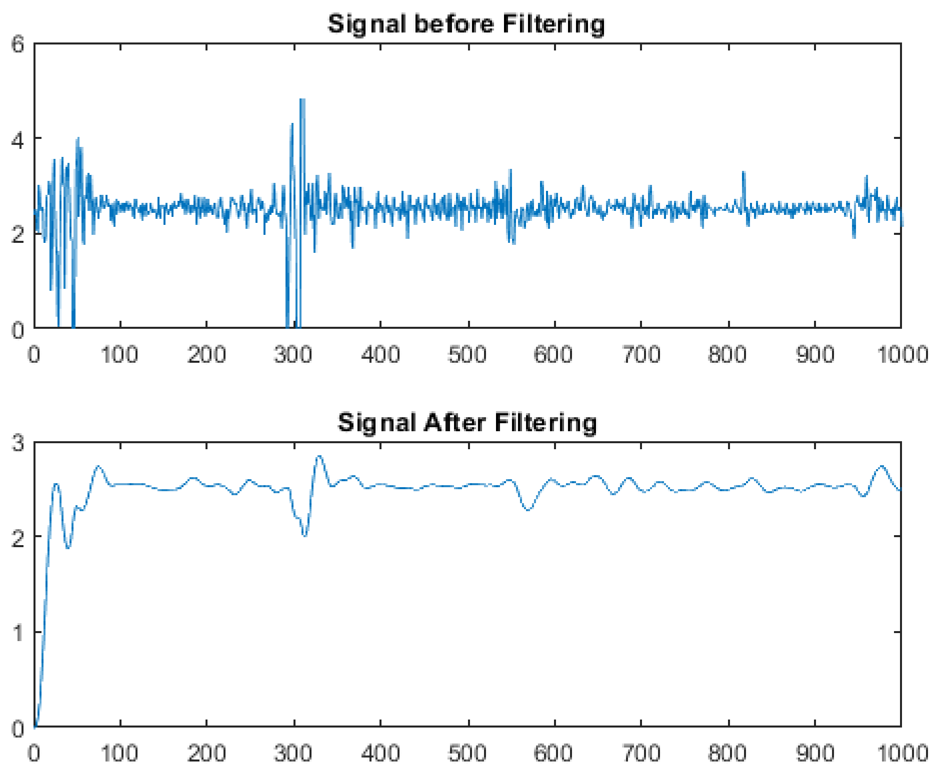


Fig.6.3.6. Signal before and after filtering

6.4. STAGE 4:

This stage laid emphasis on deriving a standard VPK signal obtained from data sets of healthy patients which needed the following steps:

- Feature extraction by designing algorithms for finding Maximas and Minimas.
- Parametric analysis using these features to design algorithms for deriving parameters related to PPG sensors which are AI, RI and PWV.
- Finding the average signal based on acquired data set.

6.4.1. Feature Extraction

Finding peaks code:

```
function [npeaks,npeak_locs]=findingpeaks(v)
m=mean(v)+std(v);
thr = m; %threshold value set at mean + standard deviation this should be m not m2
inds = (v > thr); %logical signal above threshold
r_peaks = []; %vector containg indices of rising edges in inds
% adding indices to r_peaks
for i = 2:(length(inds)-1)
    if inds(i-1)==0 && inds(i+1)==1 && inds(i)==1
        r_peaks = [r_peaks i];
    end
end
i = 0;
f_peaks = []; %vector containing indices of falling edges in inds
%adding values of f_peaks
for i = 2:(length(inds)-1)

    if inds(i-1)==1 && inds(i+1)==0 && inds(i)==1
        f_peaks = [f_peaks i];
    end
end
i = 0;
peak_locs = [];
peaks = [];
j = 0;
if r_peaks(1) < f_peaks(1) % if rising edge occurs before falling edge
    for j = 1:(min(length(f_peaks),length(r_peaks)))
        ys = v(r_peaks(j):f_peaks(j)); %vector of samples above threshold
        peak = max(ys);
        peaks = [peaks peak];
        pl1 = find(ys==peak) ;
        pl=pl1(1,1);
        peak_locs = [peak_locs (pl + r_peaks(j))];
    end

elseif r_peaks(1) > f_peaks(1) %if falling edge occurs before rising edge
    for j = 1:(min(length(f_peaks),length(r_peaks))-1)
        ys = v(r_peaks(j):f_peaks(j+1));
        peak = max(ys);
        peaks = [peaks peak];
        pl1 = find(ys==peak) ;
        pl=pl1(1,1);
        peak_locs = [peak_locs (pl + r_peaks(j))];
    end
```

```
end
npeak_locs = []; %vector containg peak locations (after removal of false peaks)
npeaks = []; %vector containg peak amplitudes (after removal of false peaks)
traversed2 = []; %vector holding values of traversed peaks

for k = 1:length(peak_locs)
    maxi = peaks(k);
    np = peak_locs(k) ;
    if ismember(k, traversed2) %skips a peak if it has already been traversed
        continue;
    else
      for p  = 1:70 %checks the next 70 samples for the presence of any peaks, if present,
compares amplitude to that of peak under consideration
        if ismember(peak_locs(k)+p , peak_locs)
            temp = find((peak_locs(k)+p) == peak_locs);
            if peaks(temp) > maxi %checks if encountered peak is greater than peak under
consideration
                maxi = peaks(temp);
                np = peak_locs(temp);
                traversed2 = [traversed2 temp];
            else
                traversed2 = [traversed2 temp];
            end
        end
      end
    end
    npeak_locs = [npeak_locs np];
    npeaks = [npeaks maxi];
end


hold on;
figure(4)
plot(npeak_locs, npeaks, '*');
```

Finding Minimas code:

```
function [npeak_locs, npeaks]=findingminimas(v)
m=mean(v);% -std(signal)/4;
thr = m; %threshold value set at mean - standard deviation
inds = (v < thr); %logical signal below threshold
r_peaks= []; %vector containg indices of rising edges in inds
% adding indices to r_peaks
for i = 2:(length(inds)-1)
    if inds(i-1)==0 && inds(i+1)==1 && inds(i)==1
        r_peaks = [r_peaks i];
    end
end
i = 0;
f_peaks = []; %vector containing indices of falling edges in inds
%adding values of f_peaks
for i = 2:(length(inds)-1)
    if inds(i-1)==1 && inds(i+1)==0 && inds(i)==1
        f_peaks = [f_peaks i];
    end
end
i = 0;
peak_locs = [];
peaks = [];
j = 0;
if r_peaks(1) < f_peaks(1) % if rising edge occurs before falling edge
    for j = 1:(min(length(f_peaks),length(r_peaks)))
        ys = v(r_peaks(j):f_peaks(j)); %vector of samples above threshold
        peak = min(ys);
        peaks = [peaks peak];
```

```
        pl1 = find(ys==peak) ;
        pl=pl1(1,1);
        peak_locs = [peak_locs (pl + r_peaks(j))];
    end
 elseif r_peaks(1) > f_peaks(1) %if falling edge occurs before rising edge
     for j = 1:(min(length(f_peaks),length(r_peaks))-1)
        ys = v(r_peaks(j):f_peaks(j+1));
        peak = min(ys);
        peaks = [peaks peak];
        pl1 = find(ys==peak) ;
        pl=pl1(1,1);
        peak_locs = [peak_locs (pl + r_peaks(j))];
     end
 end
 npeak_locs = []; %vector containg peak locations (after removal of false peaks)
 npeaks = []; %vector containg peak amplitudes (after removal of false peaks)
 traversed2 = []; %vector holding values of traversed peaks
 for k = 1:length(peak_locs)
    maxi = peaks(k);
    np = peak_locs(k) ;
    if ismember(k, traversed2) %skips a peak if it has already been traversed
        continue;
    else
      for p  = 1:70 %checks the next 70 samples for the presence of any peaks, if present,
compares amplitude to that of peak under consideration
      if ismember(peak_locs(k)+p , peak_locs)
          temp = find((peak_locs(k)+p) == peak_locs);
          if peaks(temp) > maxi %checks if encountered peak is greater than peak under
consideration
             maxi = peaks(temp);
             np = peak_locs(temp);
             traversed2 = [traversed2 temp];
          else
             traversed2 = [traversed2 temp];
          end
       end
     end
    end
    npeak_locs = [npeak_locs np];
    npeaks = [npeaks maxi];
 end

hold on;
figure(5)
plot(npeak_locs, npeaks, '*');
end
```

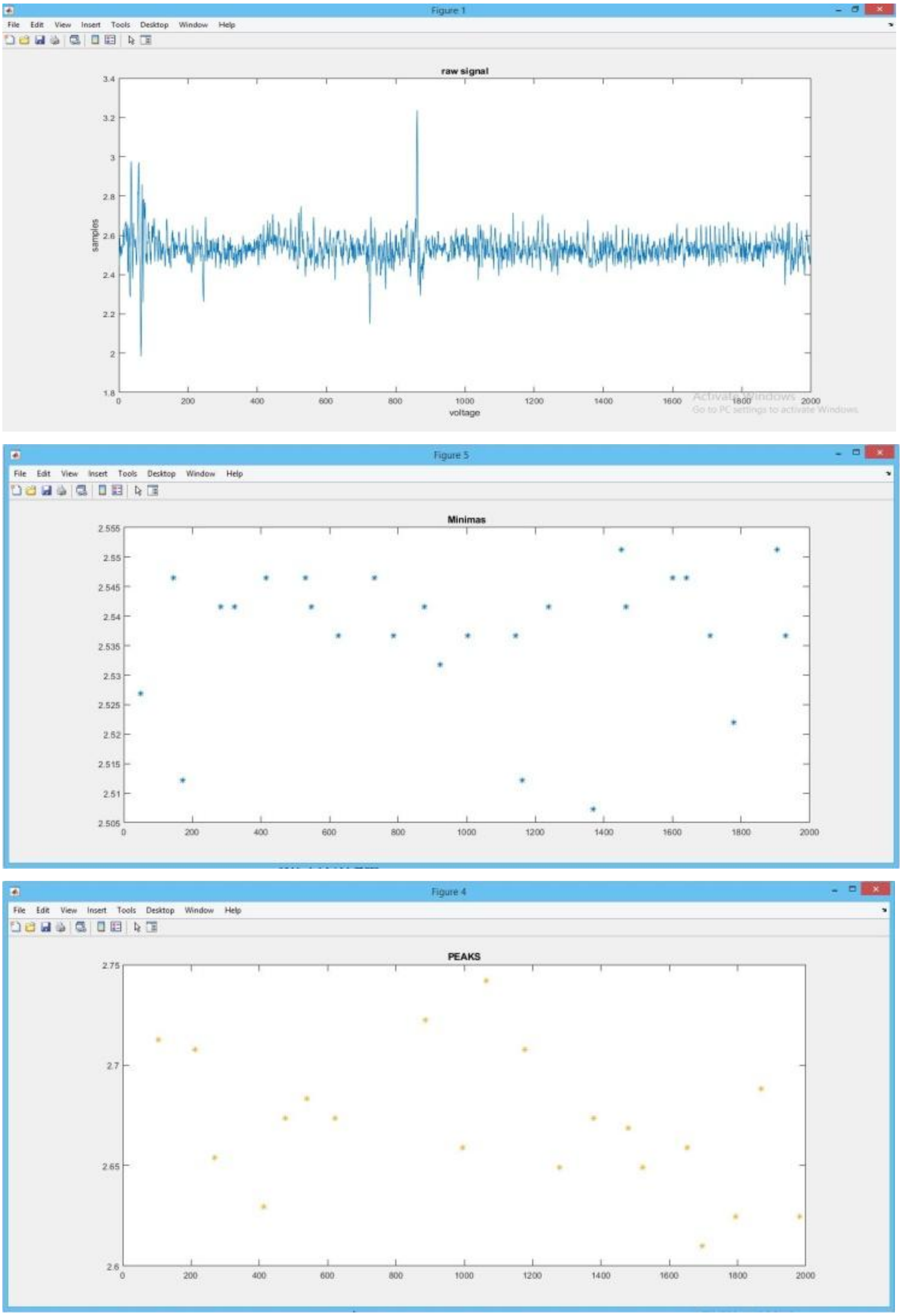


Fig. 6.4.1. Feature extraction - Plotting minima and peaks of the signal

(a) Raw Signal

(b) Finding Minimas of Signal

(c) Finding Peaks of Signal

6.4.2. PARAMETRIC ANALYSIS

After feature extraction algorithms were developed to obtain parameters related to PPG sensor which has been explained in project description.

Pulse Wave Velocity: rate at which pressure waves move down the vessel with respect to sensors at different positions.

Augmentation index: measure of systemic arterial stiffness derived from the ascending aortic pressure waveform.

Reflectivity index: measure of arterial stiffness based on reflected light from blood vessels during a pulse signal.

Code for Pulse wave velocity:

```
function [PWV,stdPWV]=codeforptt(v,p,k,distance)
[npeak_locs1,npeaks1]=findingpeaks(v);
[npeak_locs2,npeaks2]=findingpeaks(p);
[npeak_locs3,npeaks3]=findingpeaks(k);
  for j=1:(min([length(npeak_locs1) length(npeak_locs2) length(npeak_locs3)]))
                      npeak_locs_diff(j)=npeak_locs1(j)-npeak_locs2(j)-npeak_locs3(j);
end
      diff=abs(npeak_locs_diff);
     sum=0;
      count=0;
      newdiff=[];
      for k=1:length(diff)
        if (diff(k)>mean(diff)-1*std(diff) && diff(k)<mean(diff)+1*std(diff) && diff(k)~=0)
        sum=sum+diff(k);count=count+1;
        newdiff=[newdiff diff(k)];
        end
      end
      avg=sum/count;
      PWVinv=newdiff/(1000*distance);
      PWVarr=ones(length(PWVinv))/PWVinv;
      PWV=mean(PWVarr);
      stdPWV=std(PWVinv);
      stdPWV=1/stdPWV;
      disp('PWV is (in m/s) '); disp(PWV);
      disp(' Standard deviation of PWV is '); disp(stdPWV);
end
```

Code for Reflectivity index:

```
function [ri,stdri]=codeforRI(v)
[max1,max_locs1]=findingpeaks(v);
fd1=gradient(v);
[ip_locs1,ip1]=findingminimas(fd1);
for i=1:min(length(max_locs1),length(ip_locs1))
```

```
ri1(i)=v(ip_locs1(i))/v(max_locs1(i));
end
newri=[];
for i=1:length(ri1)
if (ri1(i)>mean(ri1)-1*std(ri1) && ri1(i)<mean(ri1)+1*std(ri1) && ri1(i)~=0)
newri=[newri ri1(i)];
    end
end
ri=mean(newri);
ri=ri*100;
stdri=std(newri)*100;
disp('reflective index for signal at ai0 is (in %) '); disp(ri);
disp('std devn of RI is');disp(stdri);
end
```

Code for Augmentation index:

```
function [AI,stdAI]=codeforAI(v)
            [max1,max_locs1]=findingpeaks(v);
            fd1=gradient(v);
            [ip_locs1,ip1]=findingminimas(fd1);
            [min_locs1,min1]=findingminimas(v);
     for i=1:min(length(max_locs1),length(ip_locs1))
            AG1(i)=v(max_locs1(i))-v(ip_locs1(i)); %augmentation pressure
     end
     for i=1:min(length(max_locs1),length(min_locs1))
  PP1(i)=v(max_locs1(i))-v(min_locs1(i)); %pulse pressure
     end
            AI1=AG1/(mean(PP1));
            avgAI=mean(AG1);
            AI=avgAI*100;
            stdAI=std(AI1)*100;
  disp('Augmentation index for signal at ai0 is(in %) '); disp(avgAI*100);
  disp('Std devn of AI is');disp(stdAI);
  end
```

6.5. STAGE 5

Final and most important stage of the research where the standard signal acquired from 100 healthy patients was compared with patients with symptoms associated with *Nadi Doshas* given as:

- *Vatha dosha* associated with anxiety and headaches.
- *Pittha dosha* associated with rashes and heat burns.
- *Kapha dosha* associated with common cold patients.

TABLE 6.5.1. AVERAGE SIGNAL CHARACTERISTICS

Average values	Vatha	Pittha	Kapha
Mean (V)	2.4908	2.4969	2.5354
Standard Deviation	0.0082	0.0241	0.0638
Pulse wave velocity	3.56E+04	9.98E+05	9.33E+05
Augmentation Index	0.9775	0.6517	0.201206
Reflectivity Index	99.6099	99.6094	91.0646

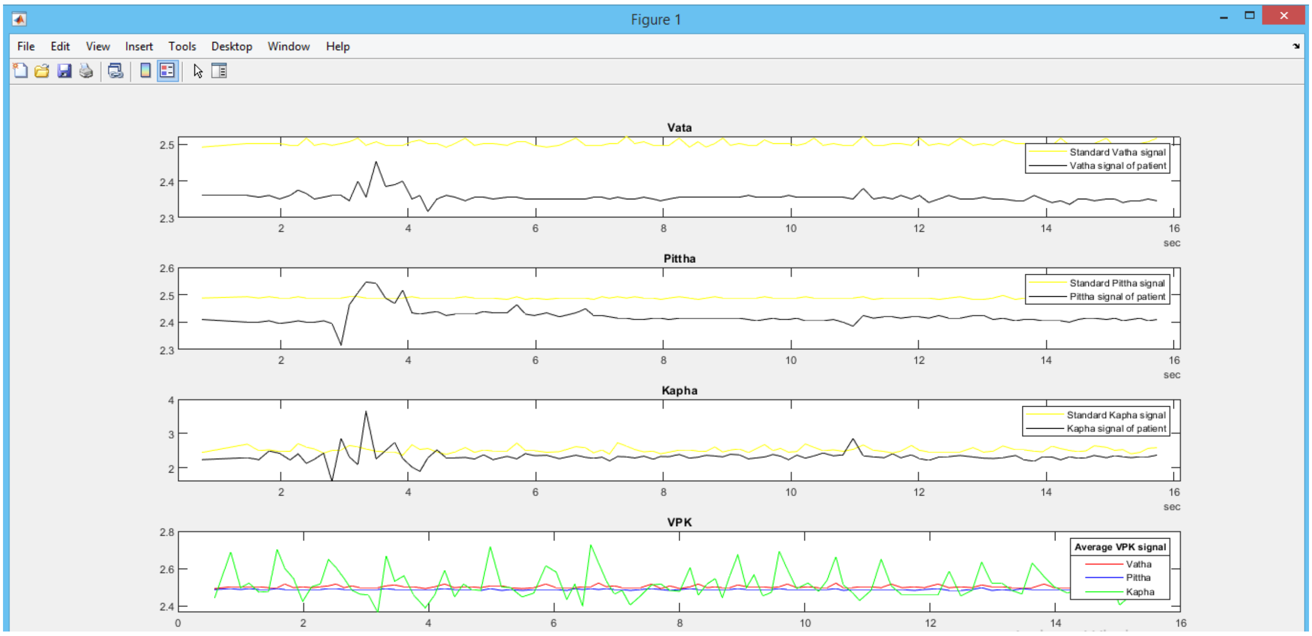


Fig. 6.5.1. Comparative analysis with respect to standard V P K signal from the above explanation this is a case of Vatha and Pittha imbalance.

Code for comparative analysis:

```
a = arduino();

V=zeros(100,1);

P=zeros(100,1);

K=zeros(100,1);

t1=seconds(V);

t1=seconds(P);
```

```
t1=seconds(K);

t0=datetime('now');
for c=1:100
V(c) = readVoltage(a,'A0');
P(c) = readVoltage(a,'A1');
K(c) = readVoltage(a,'A2');
t1(c)=datetime('now')-t0;
end
subplot(4,1,1)
plot(t1,v,'color','yellow');
hold on
plot(t1,V,'color','black');
title('Vata');
hold on
subplot(4,1,2)
plot(t1,p,'color','yellow');
hold on
plot(t1,P,'color','black');
title('Pittha');
hold on
subplot(4,1,3)
plot(t1,k,'color','yellow');
hold on
plot(t1,K,'color','black');
title('Kapha');
hold on
subplot(4,1,4)
plot(t,v,'color','red');
hold on
plot(t,p,'color','blue');
hold on
plot(t,k,'color','green');
title('VPK');
```

7. RESULT & DISCUSSION WITH COST ANALYSIS

The main aim of the project was to come up with a simple hardware design to minimize the instrumentation aspect and focus on possible software algorithms to assess the pulse signals. This goal has been achieved through this research work which relies on large data sets and statistical analysis. Hence a well defined methodology has been established to acquire data and process the data in order to work on analytics.

A standard V P K signal has been plotted considering the average of data sets obtained from healthy patients along with parameters and each of them have a significant role given as follows:

Pulse transition time and pulse wave velocity of three signals which has given an insight on significance of consideration of blood flow in unhealthy patients.

The reflectivity index which is the measure of reflected wave from PPG sensor has proven to be an important parameter to distinguish between the three doshas.

The augmentation index which deals with the blood volume also plays a significant role in case of unhealthy patients in different cases.

The prime focus of the research was to replace hands of a skilled vaidya but the parametric analysis has given more information to project other than vibrations, warmth or pressure felt by fingers.

There were significant deviations observed from the standard V P K signal when tested with diseased patients as expected from theoretical results. In order to categorize patients under vatha, pittha, kapha dosha, the tests were conducted on patients with specific dosha such as testing a cough and cold patient with the standard kapha(K) signal created from data set to check for deviations. In this case there could be other considerations such as presence of one or more doshas at the same time or other diseases which could have been bought into considerations but to avoid complication we have done this research considering the most fundamental facts in Ayurveda which can be cross verified from multiple authors. One of the key goals of the project was to minimize the cost of system design and focus more towards designing software algorithms and research.

TABLE 7.1. COST ANALYSIS

Component used	**Cost in INR (total 2000)**
Arduino Micro controller	400
Photoplethysmography sensor PPG(x3)	500x3=1500
Breadboard and wires	100

The system is designed keeping in mind the cost involved in making the product and the main object of the project was to make a cost effective design with focus towards software on algorithm design and analytics.

8. SUMMARY .

Nadi Pariksha is a great skill used in ancient Ayurveda which is slowly being forgotten and considered non scientific. Hence it is essential to carry out research focused on collecting large data sets with the right sensors to scientifically verify this skill. This project's research part not only attempts to achieve this to a great extent but also gives importance to product design part for using different algorithms and analytics to build a system for a computer aided health diagnosis.

Designing a Simple Hardware with focus on methodology involved in data acquisition, algorithm design and analytical techniques. A standard V P K signal has been plotted considering the average of data sets obtained from healthy patients along with parameters and each of them have a significant role. There were significant deviations observed from the standard V P K signal when tested with diseased patients as expected from theoretical results.

As far as scope of improvement following points will be considered.

Collecting larger data sets: As of now the data set has been collected from about 100 people and for a better research point of view there is a need for more volunteers.

Improving the product design: currently we are using rubber bands and gloves to hold sensors at the right position but for making it as a usable product the design needs to be improved.

Machine learning: the process of collecting data, finding average and comparative analysis was done manually but it will be very challenging to introduce machine learning to improve the device.

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APPENDIX A: ARDUINO DATA SHEET

Pin Description

Pin Category	**Pin Name**	**Details**
Power	Vin, 3.3V, 5V, GND	Vin: Input voltage to Arduino when using an external power source. 5V: Regulated power supply used to power microcontroller and other components on the board. 3.3V: 3.3V supply generated by on-board voltage regulator. Maximum current draw is 50mA. GND: ground pins.
Reset	Reset	Resets the microcontroller.
Analog Pins	A0 – A5	Used to provide analog input in the range of 0-5V
Input/Output Pins	Digital Pins 0 - 13	Can be used as input or output pins.
Serial	0(Rx), 1(Tx)	Used to receive and transmit TTL serial data.
External Interrupts	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.
SPI	10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Inbuilt LED	13	To turn on the inbuilt LED.
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide reference voltage for input voltage.

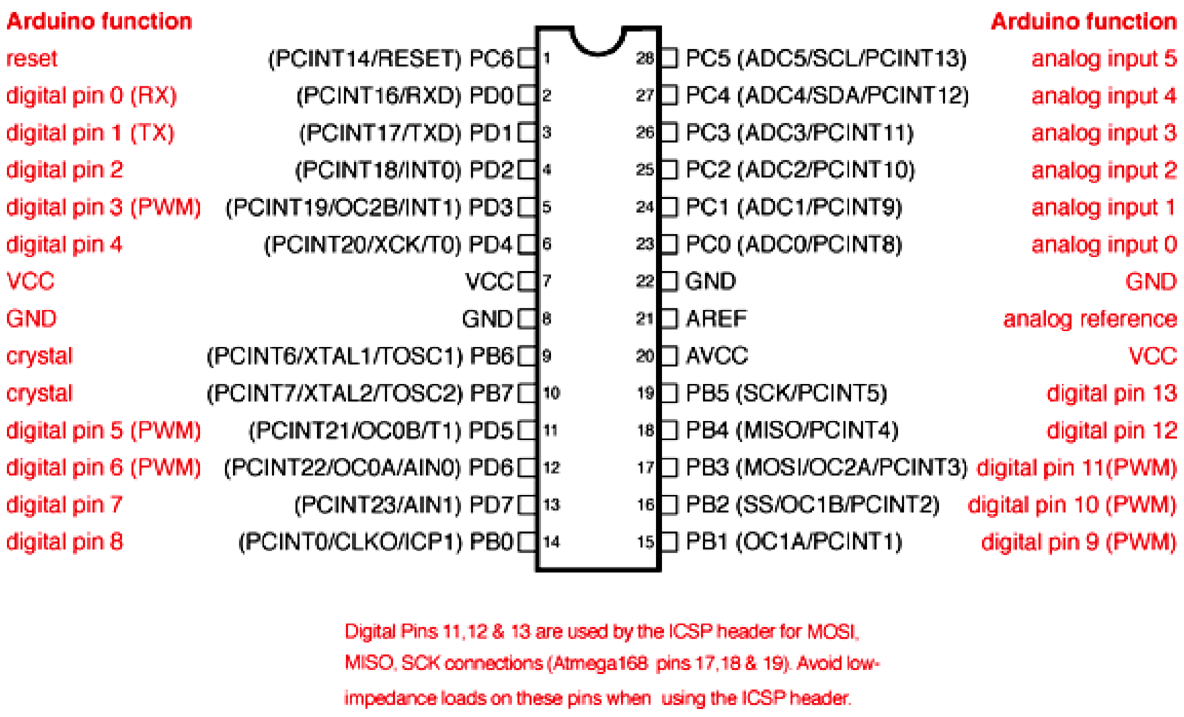
Arduino Uno Technical Specifications

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5V
Recommended Input Voltage	7-12V
Input Voltage Limits	6-20V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 Ma
Flash Memory	32 KB (0.5 KB is used for Bootloader)
SRAM	2 KB
EEPROM	1 KB

Frequency (Clock Speed)	16 MHz

Arduino Uno to ATmega328 Pin Mapping

When ATmega328 chip is used in place of Arduino Uno, or vice versa, the image below shows the pin mapping between the two.



APPENDIX B: MATLAB Product Description

Millions of engineers and scientists worldwide use MATLAB® to analyze and design the systems and products transforming our world. MATLAB is in automobile active safety systems, interplanetary spacecraft, health monitoring devices, smart power grids, and LTE cellular networks. It is used for machine learning, signal processing, image processing, computer vision, communications, computational finance, control design, robotics, and much more.

Math. Graphics. Programming.

The MATLAB platform is optimized for solving engineering and scientific problems. The matrix-based MATLAB language is the world’s most natural way to express computational mathematics. Built-in graphics make it easy to visualize and gain insights from data. A vast library of pre-built toolboxes lets you get started right away with algorithms essential to your domain. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

MATLAB helps you take your ideas beyond the desktop. You can run your analyses on larger data sets, and scale up to clusters and clouds. MATLAB code can be integrated with other languages, enabling you to deploy algorithms and applications within web, enterprise, and production systems.

Key Features

- High-level language for scientific and engineering computing
- Desktop environment tuned for iterative exploration, design, and problem-solving
- Graphics for visualizing data and tools for creating custom plots
- Apps for curve fitting, data classification, signal analysis, control system tuning, and many other tasks
- Add-on toolboxes for a wide range of engineering and scientific applications
- Tools for building applications with custom user interfaces
- Interfaces to C/C++, Java®, .NET, Python, SQL, Hadoop, and Microsoft® Excel®
- Royalty-free deployment options for sharing MATLAB programs with end users

APPENDIX C: PPG SENSOR DATASHEET

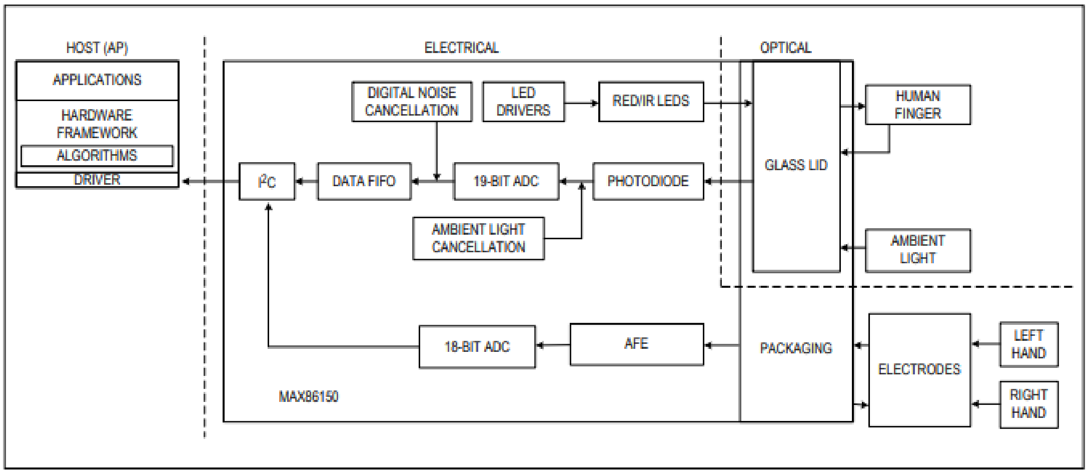
This sensor is a pulse sensor which is developed based on PPG (PhotoPlethysmoGraphy) techniques. This is a simple and low-cost optical technique that can be used to detect blood volume changing in the microvascular bed of tissues. It is relatively easy to detect the pulsatile component of the cardiac cycle according to this theory.
The sensor has two holes that you can use to attach to your belt. You can wrap on your finger, wrist, earlobe or other areas where it has contact with skin.

The heart sensor has two kinds of signal output mode: analog pulse mode and digital square wave mode. You can change its output mode using the dial switch. There are many user scenarios, including education, sport or maker/interactive projects!

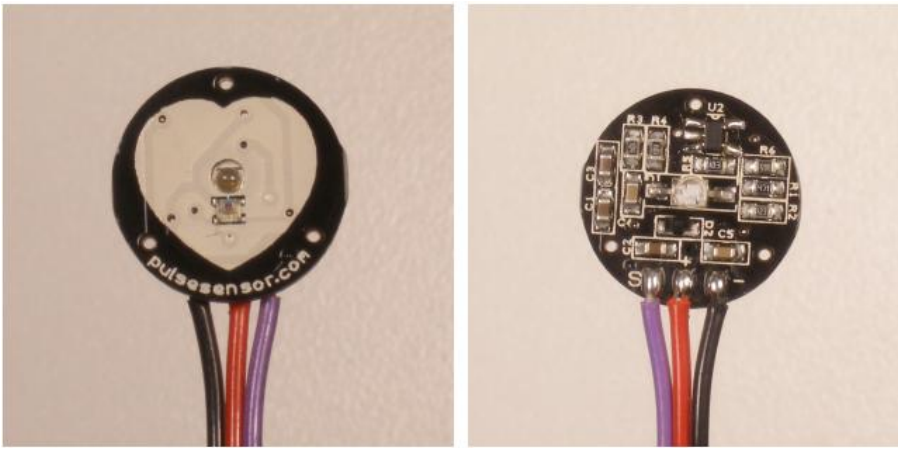
Specification

- Input Voltage (Vin): 3.3 - 6V (5V recommended)
- Output Voltage: 0 - Vin (Analog), 0/ Vin (Digital)
- Operating current: <10mA
- Dimension: 28 x 24(mm), 1.102" x 0.945"(in)
- Interface Type: PH2.0-3P

Simplified Block Diagram



PPG sensor front and back



APPENDIX D: IPACT 2019 CONFERENCE

The research paper titled "Pulse diagnosis System for *Nadi Pariksha* using parametric and statistical analysis" was presented in IPACT 19 conference held on 22nd and 23rd March.

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from VELLORE INSTITUTE TECHNOLOGY has participated / presented a paper titled

PULSE DIAGNOSIS SYSTEM FOR NADI PARIKSHA USING PARAMETRIC AND STATISTICAL ANALYSIS

in the 2nd IEEE International Conference on Innovations in Power and Advanced Computing Technologies, i-PACT2019 organized by School of Electrical Engineering, Vellore Institute of Technology, Vellore – 632014.

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