Pulse diagnosis System for Nadi Pariksha using parametric and statistical analysis

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***Abstract*— 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. 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

I. Introduction

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.

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TABLE I. CHARACTERISTIS 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.

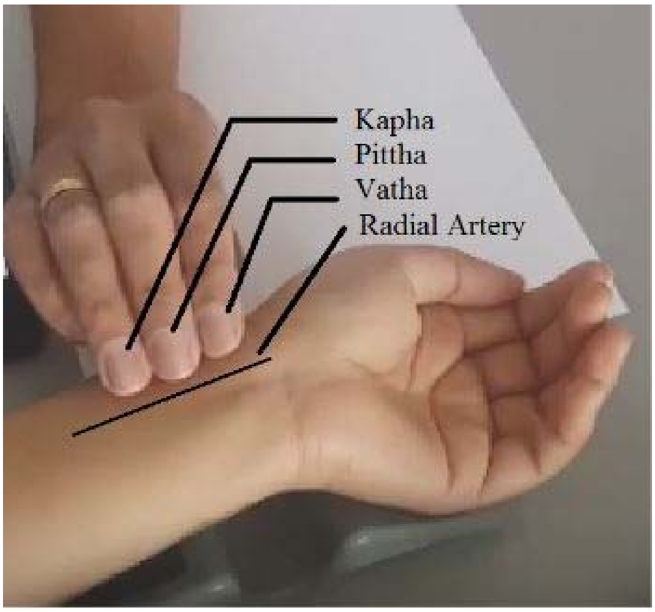

Fig. 1. Nadi Pariksha Vatha Pittha Kapha pulse diagnosis positions

II. System Design

A. 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.

B. 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.

C. 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.

Fig. 2. Hardware Setup using Arduino and Matlab

III. Methodology

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 categoriesd 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.

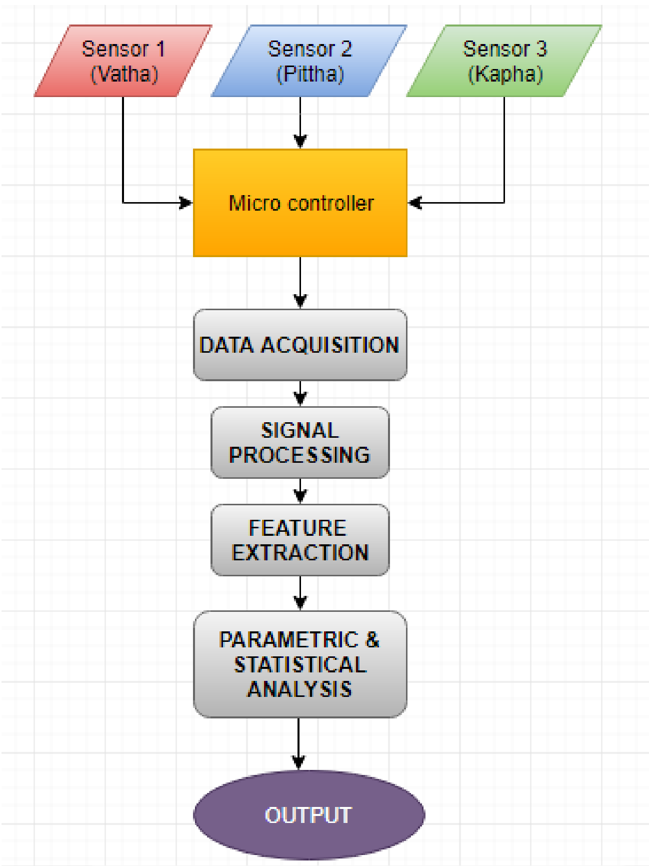

Fig. 3. Methodology Flow Chart

IV. 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.

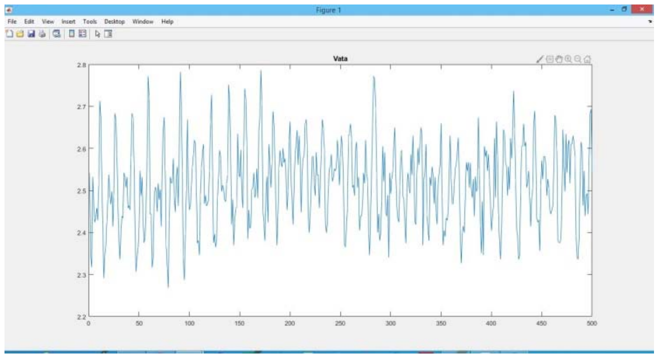

Fig. 4. Raw Signal of Pulse sensors for Data acquisition
X axis- Number of Samples taken(2000)
Y axis- Voltage readings of each sample

V. SIGNAL PROCESSING

A. Preprocessing

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

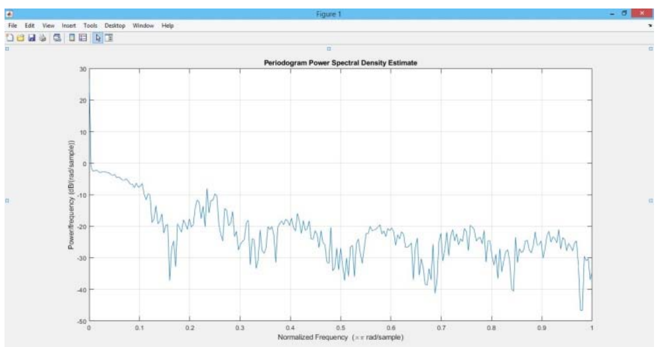

Fig. 5. Periodogram power spectral density of signal
X-axis : Normalized Frequency Y-axis: Power / Frequency

B. 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

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

Also,

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

Finally, the order of the filter is the smallest positive integer for which

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

The order thus calculated was 5. The frequency response of the filter is as shown

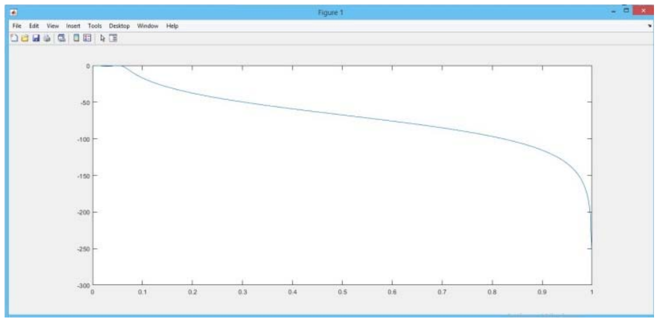

Fig. 6. Output of Low pass Filter
X axis- Normalized Frequency Y axis- Amplitude in dB

C. Removal of constant offset

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.
The signals before and after removal of DC offset are as follows:

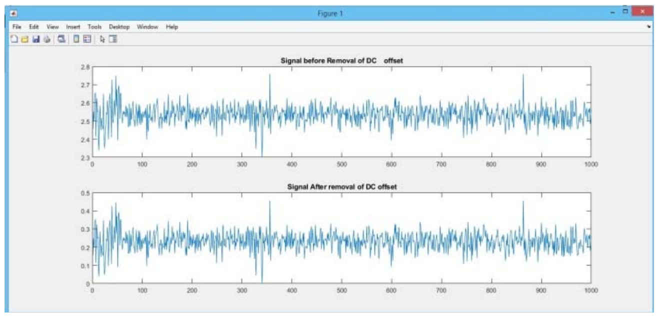

Fig. 7. Signal before and after removing DC offset.

VI. 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]

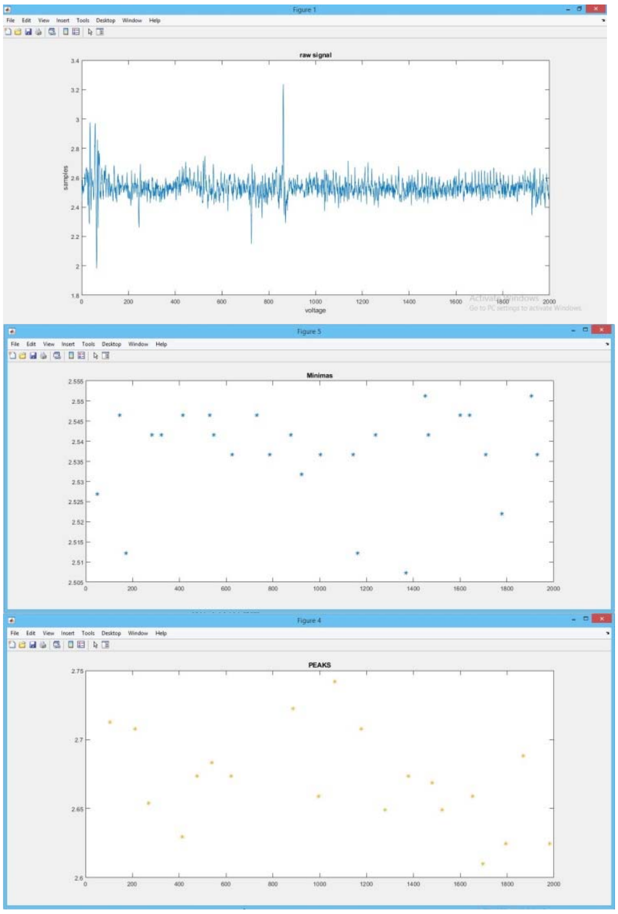

Fig. 8. Plotting minima and peaks of the signal

(a) Raw Signal

(b) Finding Minimas of Signal

(c) Finding Peaks of Signal

VII. Parametric Analysis

A. 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.

B. 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:

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

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

3) The troughs of this array are detected

4) 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.

C. 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.

VIII. STATISTICAL ANALYSIS

A. Finding the average parameter table

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

TABLE II. AVERAGE VALUES OF DATASET

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

B. Finding the average signal of a health person

The dataset for 100 healthy people were collected such that each excel sheet had 500 samples under vatha pitha kapha columns colcked against time. Now using matlab code we were able to establish an average of these hundered signals giving a standard V P K signal which was saved the plot is shown in the figure. Based on this standard signal as reference we comared signals obtained from unhealthy patients we observed significant deviation from the pulse hence indicating an imbalance in dosha.

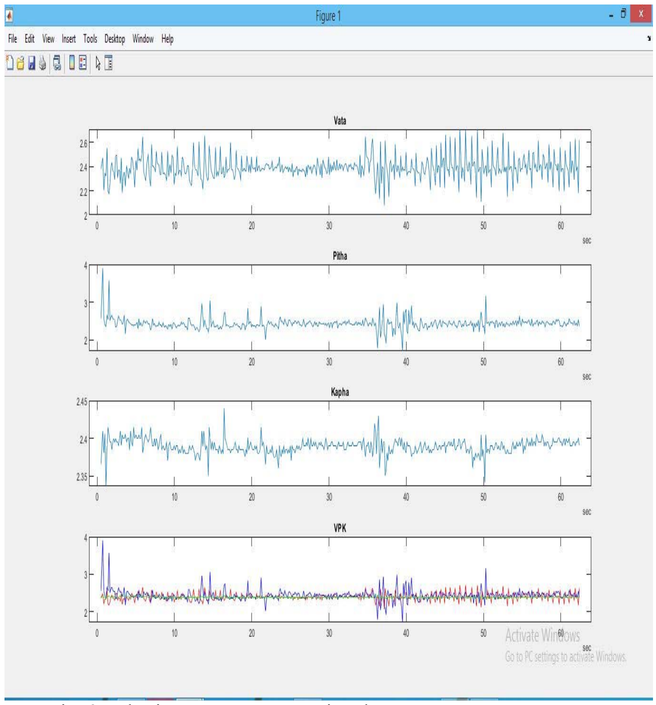

Fig. 9. Plotting average V P K signal

IX. RESULTS AND DISCUSSION

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:

1) 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.

2) 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.

3) 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 theoritical 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.

X. CONCLUSION

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 paper not only attempts to achieve this to a great extent but also gives importance to different algorithms and analytics to build a system for a computer aided health diagnosis. Most of the results obtained satisfied the theoretical results.

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