



REVIEW ARTICLE

EXPLORING ANALYTICAL PATTERNS OF THE ARTERIAL PULSE

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ABSTRACT

Ayurveda has been practiced for thousands of years in India and the demand in the implementation of this form of alternative medicine is increasing because of accurate diagnosis and long term effect. The Ayurvedic doctor (*vaidya*) gets the health related information of the individual by placing the three fingertips (index, middle and ring) at the wrist. The procedure of pulse acquisition is subjective and differs not only from *vaidya* to *vaidya* but also depends on other physiological, pathological and environmental factors. These varying factors have made it difficult to correlate the subjective information with the laboratory controlled proof-based methodology used to quantize modern medicine. There are several attempts to standardize this Ayurvedic pulse-based methodology by using advanced instrumentation. The main aim of this review is to provide a summary of the feature extraction and pattern recognition techniques used for the Ayurvedic wrist-pulse based diagnostic techniques. Modifications in the pulse due to certain physiological and pathological conditions have also been described. These contents are mainly extracted from the published work from more than 50 journal and conference articles.

Keywords - Ayurveda, tridosha, pulse waveform, feature extraction, pulse rate variability.

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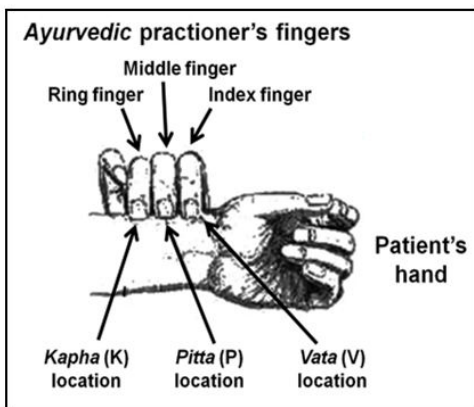
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1. INTRODUCTION

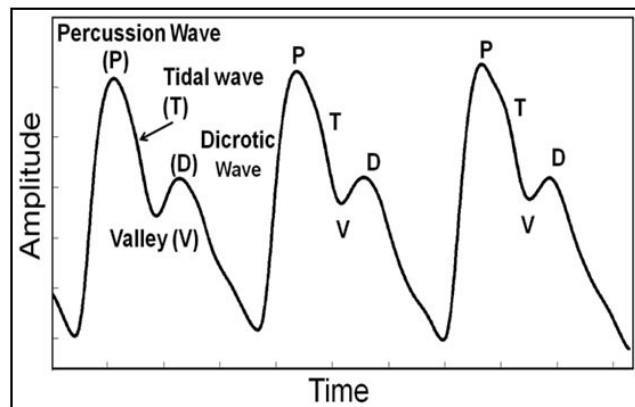
Alternate and traditional medicine (known as complementary and alternative medicine or CAM globally) has attained a lot of importance in recent years since approximately 70 % of the population prefer to use traditional medicine compared to modern medicine for treatment purposes.^[1-3]

Ayurveda considers three fundamental principles manifested from the *panchamahabhoota* called as the *tridoshas*. It considers any imbalance in the *tridoshas* as an indication for the onset of the detected through *Nadi Parisksha* as shown in Figure 1(a).^[2]

Figure 1. (a) The traditional methodology of pulse-based diagnosis. ^[2] (b) A general arterial pulse waveform having P-T-V-D nature.



(a)



(b)

The assessment of the arterial pulse is crucial in modern medicine as it acts as a preliminary diagnostic mechanism for heart rate and blood pressure parameters. Variations in pulse are considered as key diagnosis in heart conditions such as tachycardia, bradycardia, arrhythmia's etc. A typical pulse waveform consisting of three beats is shown in Figure 1(b). The pulse waveform is characterized by four regions – percussion wave (P), tidal wave (T), dicrotic notch (V) and dicrotic wave (D). Stoke volume, cardiac output, peripheral resistance, mean

arterial pressure and arterial stiffness are key factors governing the pulse waveform.^[4]

Lack of standardization of the diagnostic techniques, along with immediate relief provided by modern medicine, has resulted in reduced recognition for Ayurveda as a medicinal technique.^[5] From the literature, pulse wave analysis (PWA) a measure of arterial elastic properties and pulse wave velocity (PWV), a measure of arterial stiffness, have been widely used in clinical studies ^[6] as markers, as they are "non-invasive". The individual blocks of the instrumentation viz.

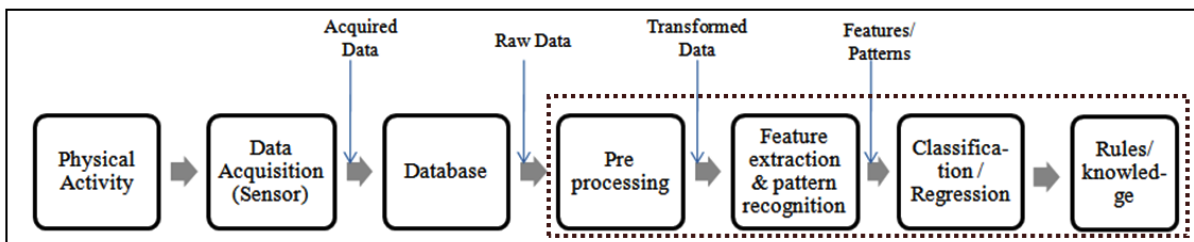
sensing, denoising, choice of method used for analysis, data compression and interpretation of the output data are influential components in pulse-based analysis and therefore must be reliable and accurate.

Flow of the paper

In this paper, only the radial pulse is considered. The paper is arranged in sections

based on the flow of a data mining procedure as shown in Figure 2, which is a process used to analyze huge amounts of data to extract relevant information, increase the efficiency and reduce the cost incurred for the particular application.

Figure 2. Typical data mining process for knowledge discovery. Note that only forward path is shown and feedback loops between blocks are not shown.



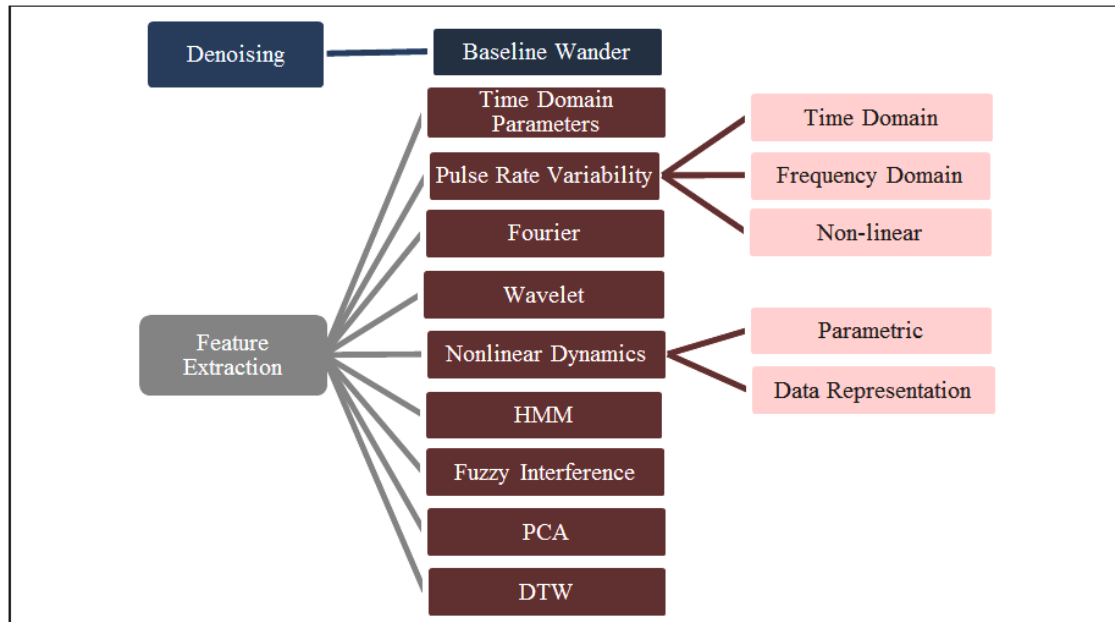
This paper contains the feature extraction techniques in Section 2, which highlight the typical features and help in pattern recognition of the procured radial pulse. Section 3 highlights changes in the pulse due to prevalence of certain conditions/disorders. Section 4 concludes this paper with a discussion and possible future work in this area.

2. DATA PREPARATION AND FEATURE EXTRACTION

In data acquisition of the pulse, raw data (output from the sensors) is saved in the form of time series or images along with personal and medical information of the subjects. The challenges in this conversion from enormous data to useful knowledge include insufficient data, corrupt data, missing data and outliers. Feature extraction is the process of transforming the data in raw format into a set

of numbers or patterns of other formats (generally usable for machine learning) and is applied to reduce redundancy in data or extract hidden patterns in the database. Time and frequency domain methods are the most commonly used methods for pulse-based analysis.^[7] The most significant feature extraction methods used for the pulse signals are summarized in Figure 3.

Figure 3. Overview of the methods used in the data preparation of pulse-based methodology.



2.1. Denoising

The pulse signals obtained from the data acquisition system consist of noise (motion artifact, unwanted variations due to respiration, power line hum, baseline wander etc.) which leads to corruption of data. If the noisy data is used in the analysis without any treatment, then the resulting interpretation and rules could be incorrect.

There are two main denoising techniques used viz. denoising the signal in original domain (time, space) and in transformed domain (Fourier, wavelet). Among these methods, denoising by wavelet transform and with thresholding coefficients is popularly used.^[8,9]

When a pulse signal is decomposed using

wavelet transform, frequency sub-bands are formed consisting of the details in the data set. Noise is present in these sub-bands and by assigning a particular threshold value, the noise is removed.^[10-11] The denoised signal of the noisy signal in Figure 4(a) is shown in Figure 4(b), where the noisy variation are completely removed keeping the main information.^[12]

2.1.1. Removal of Baseline Wander

Owing to the presence of noise or faulty connections, there is a shift in the signal from the base (generally x-axis) and it moves upwards or downwards instead of being in a straight line, causing a shift from the normal level (Figure 5).

Figure 4. (a) An example of noisy pulse signal. Note that P or V of the individual beats is not visible due to noise.^[12] (b) The denoised pulse signal obtained using the method of^[12].

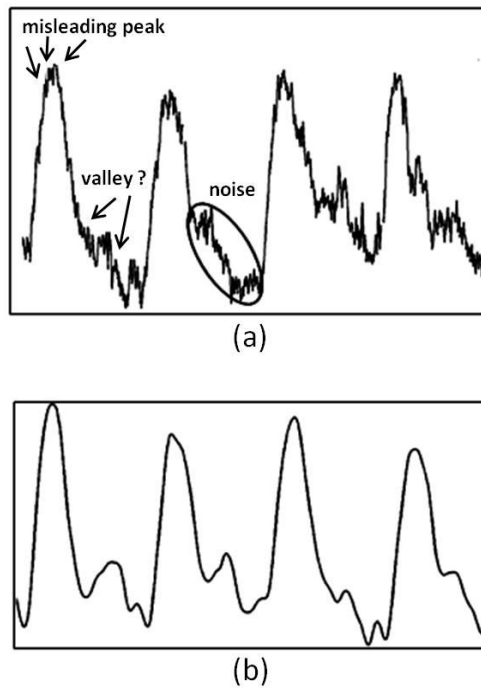
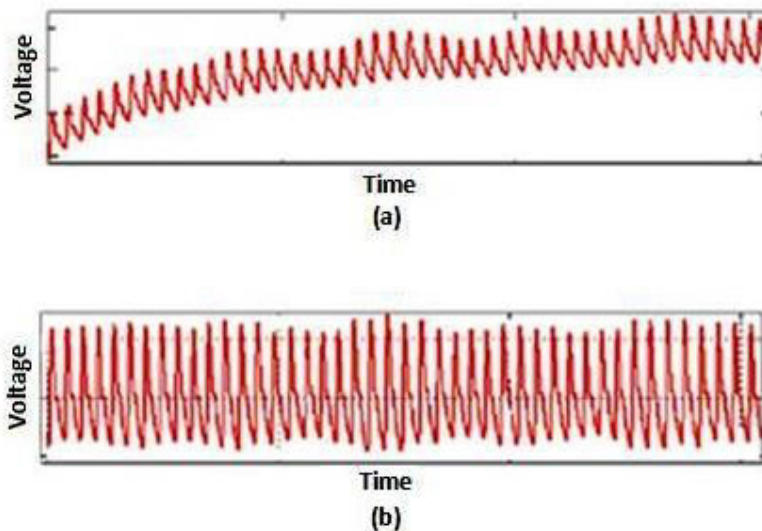


Figure 5. Baseline wander in a pulse signal. (a) Pulse signal before removal of baseline wander and (b) Pulse signal after removal of baseline wander. [17]



This change in the base level is termed as baseline wandering and is a common problem in biomedical signals. In pulse signals, baseline wandering occurs due to motion artifact and respiration.^[13] Attempts have been made to use high pass filters, FIR filters, Cubic Spline method and polynomial filtering for removal of baseline wander^[14,15] and Wavelet based

cascaded adaptive filter^[15] and empirical mode decomposition (EMD) for radial pulse.^[16, 17]

2.2. Feature Extraction Methods

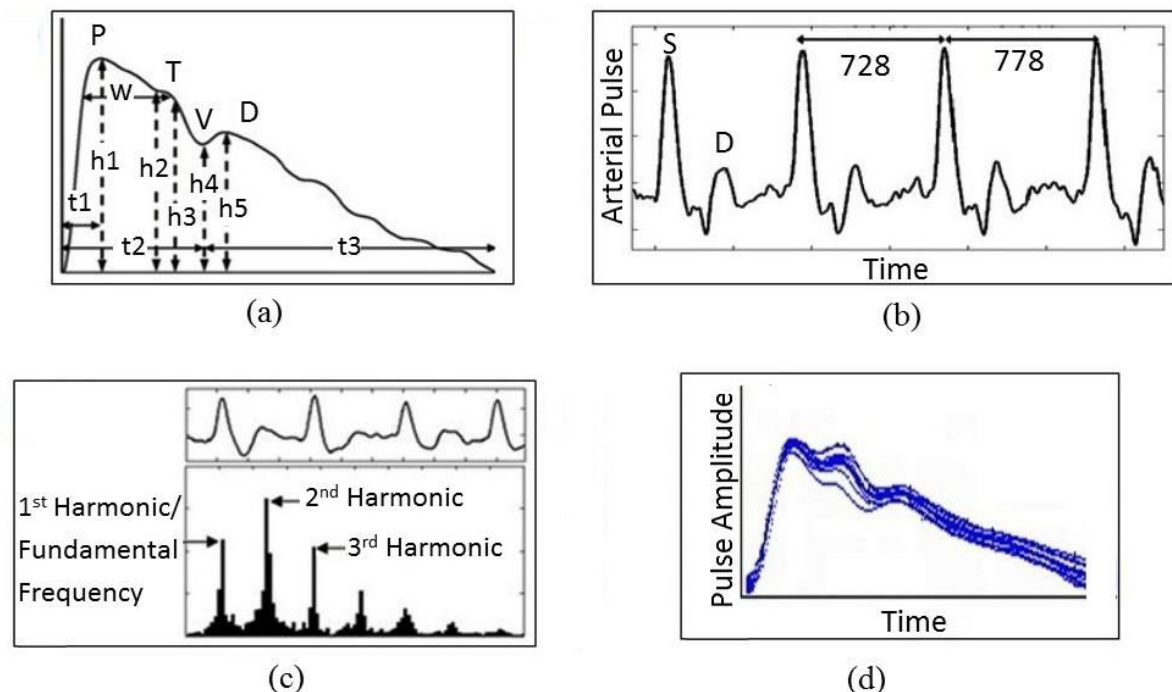
The denoised pulse signal is typically comprised of a P-T-V-D nature as shown in Figure 1(b). Machine learning of the signals in this format is not directly possible because of

the length of the signal in time series format. For building efficient rules, there is a need of transforming to numbers or patterns of different format with finite length. These methods are called feature extraction. Each method is useful in extracting or revealing different property of the pulse signal. The feature extraction methods can be individually used or combined for the machine learning step of Figure 2. In this section, we explain the feature extraction methods commonly used in pulse-based analysis.

2.2.1. Time Domain Parameters

Time domain analysis of the arterial pulse waveform is the illustration of variations of pulse waveform with respect to time.^[7] Over the past few years, time domain has been widely applied in the research for cardiovascular disorders and computation of the arterial pulse.^[7] Variations in peak-to-peak values of the pulse wave are pathologically and physiologically relevant and can be quantized using time domain parameters as shown in Figure 6(a).^[7,18]

Figure 6. Feature extraction techniques. (a) Typical arterial pulse pressure waveform in time domain.^[18] (b) Pulse rate variability observed in three beats.^[24] (c) Normal pulse waveform with its corresponding FFT.^[12] (d) Similar pulse signals obtained after using DTW.^[46]



The parameters h1, h2, h3, h4 and h5 are amplitude parameters at P, T, V, D sub-waves respectively. The parameters w, t1, t2 and t3 represent the width or duration of various portions of the wave.^[12, 18] These parameters

obtained are used to derive new parameters linking them to other physiological parameters (Example: depth through h1).^[7,19]

2.2.2. Pulse rate variability

Spontaneous variation in instantaneous heart rate of a person at rest is termed as heart rate variability (HRV). It is the time difference between two consecutive heart beats.^[20] HRV is efficient in early detection of autonomic neuropathy in diabetic and heart patients. Decrease in HRV is associated with decrease in autonomic activity, diabetic neuropathy and an indicator for sudden cardiac death or heart attack; thus directly affect the pulse.^[21] The more relaxed the heart, the more variable is the time interval.^[22,23]

Analysis of pulse rate variability (PRV) from the pulse wave signal is used as a potential substitute to HRV analysis. An example of variability in pulse signal is shown in Figure 6(b), where it can be observed that the difference between the consecutive peaks varies (728,778) in a nonlinear fashion.^[24] The recording of the pulse wave is simpler than the ECG as, in many cases, only a single pressure sensor is required. It is cost effective and is used in both hospitals and houses of patients. Generally, PPG (photoplethysmography) uses PRV to derive the arterial pulse interval (API) signals.^[25]

The analysis techniques PRV (derived from methods on HRV) can broadly be classified into time domain, frequency domain and non-linear methods. Time domain methods or parameters are associated with the overall

variability in pulse rate, an example being RMSSD associated with parasympathetic variability.^[26] More complicated calculations can be performed using statistical and geometrical methods pertaining to the applications.^[26,27] Frequency domain methods provide the information of power distribution as a function of the frequency which are classified as parametric and non-parametric methods. Parametric methods (e.g. auto regression) have smooth spectral components, simple post-processing and accurate estimation of PSD whereas non-parametric methods are simple and have a high processing speed.^[27] Depending on the duration, PRV consists of short (duration of 5 min) and long term (duration of 24 hours) analysis which calculate the total power, high frequency, low frequency and very low frequency. The ratio of low frequency to high frequency components is used to indicate the balance between sympathetic nervous system (SNS) and parasympathetic nervous system (PNS).^[27] Non-linear methods are determined by the various complicated interactions that are prevalent in the human body. Poincaré plot is the most commonly used non-linear method, in which the consecutive peak to peak differences are plotted on x and y axis; quantifying periodic processes, indicating short-term and long-term variability of the pulse signals.^[27]

2.2.3. Fourier Transform

Fourier transform is the mathematical transformation of time domain signals to frequency domain. It is a manner of representation of the signal/waveform illustrated by sine and cosine waves. Characteristically, as the wrist pulse is a low frequency signal, all the necessary information (e.g. vascular elasticity^[28]) is obtained in the first 10 harmonics. The fundamental frequency or first harmonic as observed in Figure 6(c) denotes the heart rate or pulse rate.^[12] When DFT was used, the dicrotic wave of the pulse was distinct but not the tidal wave^[28] signifying that application of DFT resulted in the feature extraction of few but not most properties of the arterial pulse.

2.2.4. Wavelet Transform

Wavelet transform is similar to Fourier transform with the difference being wavelet transform uses functions that are localized in both the real and Fourier space.^[29] Wavelet transform is suitable for non-stationary signals and since it is efficient in feature recognition, removal of signal noise and good computation of the amplitude variations, it is heavily utilized in pulse-based analysis. Wavelets are broadly classified as continuous and discrete wavelet transform (CWT & DWT). DWT is used for data compression and CWT for signal analysis.^[10] In pulse-based diagnosis, the deubechies mother wavelet (e.g. db4) is the

most commonly used.^[30,31] Wavelet transform combined with methods such as PCA, HMM have proven to give efficient results.^[32,33] For pseudo periodic signals such as pulse signal, techniques such as pitch synchronous wavelet transform (PSWT) has also been executed. PSWT consists of the samples incorporated into progression of variable lengths that signify a period of the signal. The dimension of the sample sequence depends on the aperiodicity of the signal and pitch variations.^[34]

2.2.5. Non-Linear Dynamics

The human body consists of complex mechanisms that govern the manner of functioning of the body. These regulatory systems give rise to the non-linear properties, which could be observed in the human pulse.^[24] When the output of the system varies randomly instead of linearly with the input, the system is termed as a non-linear system. Multifractal nature of the pulse has been studied in^[35] which concluded that multifractal nature was managed by the nervous system. Applications of non-linear dynamics for pulse-based analysis could throw light on evaluation of certain life-threatening conditions.^[24,27]

Low dimension attractor plots, D2 correlation dimension, Lyapunov exponents and Kolmogorov entropy are some of the techniques used for data representation or other quantitative exponents for this analysis. D2 correlation characterizes the distribution of

points of the attractor in the phase space. It has been successfully used in non-linear biological systems but is still to be tested for human data.^[36]

Lynapunov exponent is a measure characterising the rate of change of infinitesimally close trajectories. Kolmogorov entropy along with Lynapunov exponents is combined to form better networks than the feed-forward neural network for pulse-based analysis in TCM but it was also advised to have more clinical experience in diagnosis of the disease.^[37] Although the above methods have been very powerful in characterization of complex systems, attempts are being made to incorporate them in pulse diagnosis.^[27]

2.2.6. Other Methods

Other methods such as Hidden Markov Model (HMM), Fuzzy logic, principle component analysis (PCA) and dynamic time warping (DTW) are some of the techniques widely implemented in analyzing pulse-based diagnosis. HMM has been found useful in TCM when merged with other techniques such as AR model and db3 wavelet transform and was concluded that the joint algorithm got very good results and the diagnosis was quite accurate.^[38,39] The success of predicting the outcome for renal^[7,40] and vascular diseases has increased the prospect of using fuzzy logic technique in pulse-based analysis. PCA has been used in pulse-based diagnosis for TCM

and has been highly efficient (accuracy for symptom diagnosis was found to be 86%) and cost effective for pulse-based analysis.^[41,42,43] Widely used for speech and ECG pattern recognition, attempts have been made to incorporate DTW in wrist pulse signal analysis.^[44,45] DTW has been implemented for the wrist pulse signal in ^[46] (Figure 6(d)) for detection and elimination of the outlier pulse signal, giving accurate.

The process of denoising, removal of baseline wander, extracting features using several of the above mentioned methods in this section form the basis for knowledge discovery. It is therefore important for accurate analysis of the sensor-obtained pulse for prediction of the disease/illness.

3. Variations in Pulse Waveform

Numerous physiological (aging, menopause) and pathological (hypertension, diabetes mellitus, cardiovascular disorders, end stage renal disease etc.) conditions cause an increment in arterial stiffness; consequently altering the typical pulse contour.^[47] Changes such as movement, smoking, environmental or other disease conditions also vary the pulse waveform. Differences are observed in the carotid, radial and femoral pulse arterial waveform owing to the location of the pulse pressure point with respect to the heart. Pathogenic changes of an organ cause variations since it acts as a carrier to transmit

pathologic signals to the whole circulatory system.

Parameters such as blood viscosity, arterial stiffness, augmentation index (AI), compliance directly affect the pulse contour.^[48] These alterations are proportional to changes in the balanced state of the organs of the body. Pulse wave analysis is a non-invasive, cost efficient and simple methodology for observing changes in the human body. Gender, combined with factors for instance aging, showcases an immense diversity in the pulse waveform.^[49] The competence of the drugs could be obtained by the variations observed in the arterial pulse contour.^[50] Diet of an individual also contributes to changes in the pulse. The pulse waveform could be used to check the effects of foodstuffs on hot or cold constitution (depending on the *prakruti* and *vikruti*).^[51] The normal natures of the arterial pulse of *vata*, *pitta* and *kapha* have typical behavioural conditions that are characterised by the *gati*'s stated in section 2. Changes from this normal behaviour indicate the *dosha*; thus relating the pulse waveform to a particular disorder. The main motive of this section is to highlight the changes occurring in the pulse contour because of diseases or other conditions commonly prevalent among people today.

3.1. Effect of Cardiovascular disorders

High blood pressure (HBP/HTN) has contributed to about 12.8% of the total deaths internationally. Occurrence of HBP is 40% in adults above the age of 25 years as on 2008 (Reported by World Health Organization).^[52] HBP is the preliminary stage which leads to more severe cardiovascular disorders. Pulse wave analysis is a cheap, convenient and non-invasive method as a marker for cardiovascular disorders.^[53] The augmentation index obtained by the arterial pulse contour acts as an indicator for conditions such as arrhythmias, MI/heart block/attack, atherosclerosis, etc.^[54] Pulse wave velocity (PWV) was found higher in patients having hypertension, thus indicating it as a marker.^[55] Figure 7(a) shows the deviation of PWV in hypertensive and normotensive control group patients with hyperemia (surplus blood flow to tissues) of similar age groups.^[56]

Certain cardiac conditions can be distinguished in Ayurveda viz- *kaka* (crow) *gati* for aortic regurgitation, *mayura* (peacock) *gati* for arterial hypertension or high cholesterol, *ushtra* (camel) *gati* for aortic stenosis, *girija* (mountain) *gati* for heart block, *vishama* (irregular) *gati* for atrial fibrillation etc.^[2]

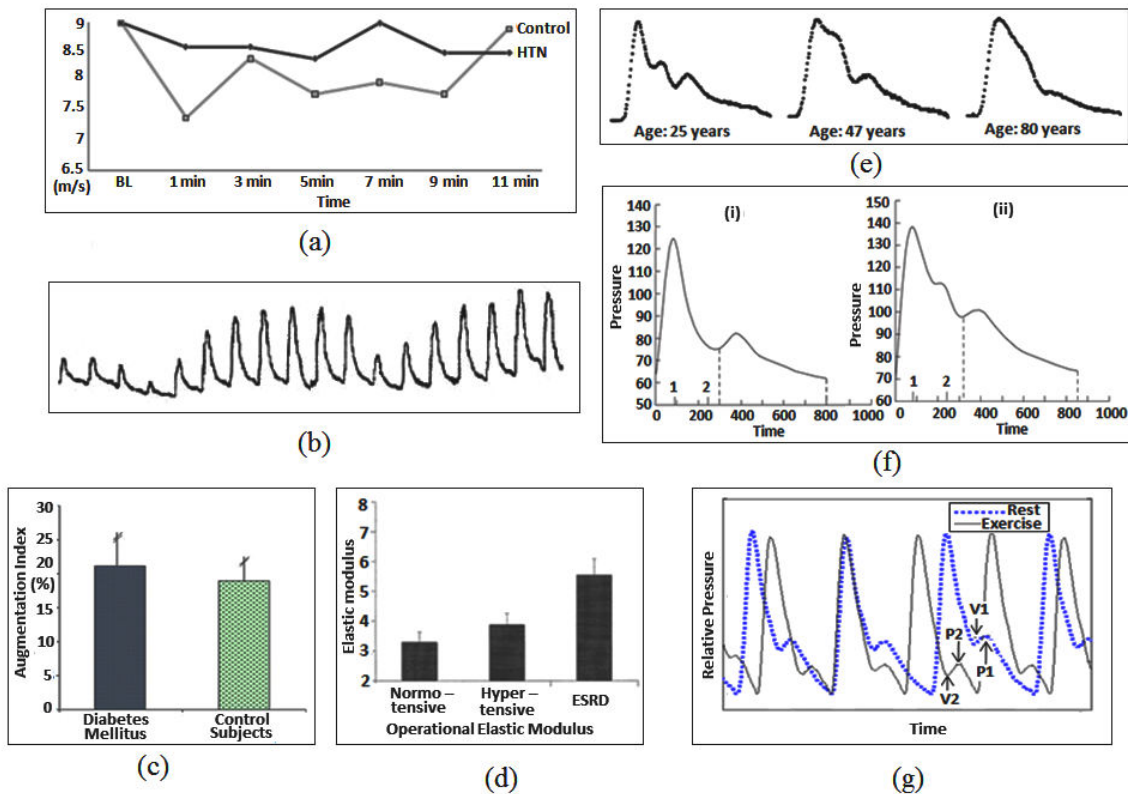
3.2. Effect of Respiratory Disorders

Changes occurring in the cardiac cycle because of variations in intermittent positive pressures

(caused by mechanical ventilation in the heart) could be decoded by the arterial pulse waveform. The alterations occur due to the variations in the alveolar pressure associated with the mechanical insufflations. The static and dynamic changes occurring in the respiratory wave causes corresponding changes in the arterial pulse as shown in Figure 7(b). It also corresponds to deviations in

the volume expansion and cardiac index correlating the arterial pulse to indices representing respiratory parameters.^[57,58] According to traditional literature, respiratory disorders (*swasaroga*) such as bronchial asthma can be represented by the *kapota* (pigeon) *gati*.^[2] Typically, the *kaphadosha* is responsible for respiratory related disorders.

Figure 7. Results (a) Effect on the carotid-radial PWV on patients with hypertension and control groups.^[56] (b) Effect of respiration on pulse.^[57] (c) Augmentation index (%) in patients having DM and control group.^[6] (d) Incremental elastic modulus of normotensive, hypertensive and ESRD patients.^[62] (e) Radial arterial waveforms of different age groups appear different.^[68] (f) Effects of passive smoking on radial pulse obtained at:(i) Baseline.(ii) 60 min after exposure to it.^[72] (g) Changes in pulse waveform of a graduate student at rest and after exercise.^[76]



3.3. Effect of Diabetes Mellitus (DM)

Diabetes mellitus (DM) is a chronic disease and has been projected that by 2030,

approximately 4.4% of the world's population would be suffering from it.^[59] According to the study in ^[47], PWV and pulse pressure in

diabetic patients was considerably higher than the non-diabetic patients. The increase in augmentation index (associated with several cardiovascular disorders), inferred that arterial stiffness was high in patients having type-2 diabetes compared to non-diabetic. Figure 7(c) shows a marked increase in AI in patients with DM compared to control subjects.^[6] Diabetes is demonstrated by the *kukkuta* (cock) *gati*^[2] and the prominent *dosha* for DM is generally *kapha*.

3.4. Effect of Renal Disorders

Numerous renal disorders are affected by arterial stiffness – changes which are observed in the arterial pulse waveform. Often death because of end stage renal disease (ESRD) is due to cardiovascular disorders.^[60] ESRD is an irreversible condition of kidney impairment which has dialysis or kidney transplant as the only solution to continue life.^[61] According to^[47], the changes of the arterial wall are independent of atherosclerosis as ESRD has been observed at the radial pulse level where atherosclerosis is considered absent. The Figure 7(d) shows the increase in elastic modulus, signifying that there is an increase in the arterial stiffness in patients having ESRD compared to normal or hypertensive patients.^[62] Renal failure in terms of Ayurvedic pulse is represented by *damaru* (drum) *gati*^[2] and prominence of *pittadosha* is typically responsible for it.

3.5. Effect of Cancer

Cancer is the uncontrolled growth of cells. There are at least 100 different types of cancer owing to the site of origin which are classified as malignant or non-malignant. Considerable amount of research has shown the direct correlation between heart/pulse rate and cancer occurrence.^[63] There was an association of resting pulse with the occurrences of cancer, most importantly among smokers.^[63] The radial arterial pulse parameters such as harmonic variation has been effective in the identification of stages of the cancer.^[64] According to ancient literature, people having cancer are said to have *kaphadosha* dominance.

3.6. Effect of Liver disorder

Liver disorder leads to serious complications such as cirrhosis. Arterial hypoxia affects liver transplant candidates.^[65] Pulse-based diagnosis is a useful marker in the identification of liver problems of the spleen meridian in TCM.^[66]

3.7. Effect of Increase in Age

Ageing has been established as one of the causes for modification of the compliance of the arterial vessel wall due to deposition of components such as calcium salts, fragments of elastin, etc.^[67] A correlation between aging and changes in the pulse waveform is shown in Figure 7(e). In^[68], oscillatory compliance C_2 (pulse contour analysis parameter for radial

artery wave)^[69] was dependent on age-related changes; making it a good marker. For men having hypertension (age group of 17-77 years), change in stroke volume altered the pulse waveform; however, an increase in age caused a decrease in the effects of stroke volume as a marker for cardiovascular diseases.^[70] Also, increase in age is found to be proportional to pulse amplitude, pulse wave velocity and arterial stiffness.^[71]

3.8. Effect of Smoking/ Cigar

Numerous cardiovascular diseases are the effect of acute or chronic smoking. Passive smoking is associated with atherosclerosis, coronary artery disease and stroke as shown in Figure 7(f).^[72] The vascular parameters were elevated than the normal values in case of smokers.^[73] Alteration of the arterial pulse waveform was prominent in long-term smokers compared to non-smoking subjects^[74], which influences the pulsatile function. Cigar smoking, which initially was considered as a safe alternative to cigarettes, increases the arterial stiffness and reflects in the arterial waveforms, thus, proving to be as hazardous.^[75] Any form of smoking (passive, acute, chronic) has a larger impact on the arterial pressure waveform in males in comparison to females.^[72]

3.9. Effects of Exercise and Other Motion Artifacts

The pulse contour varies greatly before and after exercise. In ^[76], three variations of the radial pulse contour were obtained before and after exercise viz. the incisure wave became very low, tidal and dicrotic wave were high, incisure and dicrotic wave became lower than the normal pulse contour (Figure 7(g)). To illustrate the effects of motion in the pulse wave contour, the pulse from various arterial points in the body was observed.^[77] The pulse contour obtained from the forehead had the least effect of movement of the subjects.

It can be observed from Section 3 that several physiological and psychological conditions make amendments in the arterial pulse, thus making it essential for betterment in its acquisition and knowledge discovery processes. Arterial stiffness acts as a very effective marker for numerous diseases and its alterations can be observed in the arterial pulse. Variation in the arterial pulse is a simple and rapid method for basic diagnosis. In the future, it can prove to be extremely beneficial and cost-effective.

4. DISCUSSION

Now-a-days, there is an enormous importance on quality of life and since Ayurveda treats the individual holistically, it is gaining importance.^[78] In Ayurveda, there are 3 *doshas*, 15 *subdoshas* and 7 *dhatu*s. Each of

these play an important role in maintaining the balanced condition of the mind. The *tridoshas* (*vata*, *pitta* and *kapha*) have dominance at different times of the day and also vary with the season. *Doshas* can be correlated to the *prahar* (each day is divided into 8 parts and each *dosha* is prominent in a cyclic order for a period of 3 hours). The *dhatu*s (tissue level) and the *subdoshas* are precise and can be correlated with disorders. Therefore, correlating the *dhatu*s, *subdoshas* and *doshas* with particular disorders and time could enhance the link with conventional medicine.

An efficient data acquisition system with appropriate sampling rate provides a perfect balance and proficient execution of the data for further analysis. For obtaining the features of the pulse waveform, Fourier transform was initially used which provided a prominent dicrotic wave but wavelets are more widely used in time-frequency analysis today. Combined with other methodologies (as seen in section 3 such as PCA, HMM), wavelet transform gives precise results for pattern recognition, leading to early diagnosis of disorders (arrhythmia patterns for CVD). Certain non-linear techniques such as Lyapunov exponent with other entropies in theory appear more accurate compared to other networks (artificial neural networks).

Exercise, smoking, age, motion artifacts, gender, drugs, etc. have an effect on parameters governing the arterial pulse (arterial stiffness, mean arterial pressure) which alter the contour. The deviation in the pulse waveform is evident at onset of the disease. The pulse waveform digresses very specifically for certain conditions such as diabetes, liver disorders, renal disorders, hypertension, cancer (few), etc. A change in the value of augmentation index is a very important marker for alterations in the arterial pulse contour. Research is also being carried out to check the changes in the arterial pulse contour at the time of surgery (orthopaedic liver transplantation^[79]).

The development of acquisition and analysis of ECG to its current advanced stage has taken over 300 years. With the experience of such developments of ECG and other biomedical signals, the advanced acquisition and analysis of the pulse signals may take lesser time.

4.1. Future Work

Due to a lack of standardization, there is a lot of uncertainty and skepticism regarding the Ayurvedic pulse and hence it essential to get a scientific recognition. Linking the pulse waveform in terms of Ayurveda and modern medicine would give this traditional medicine technique an international platform.

4.1.1. Validating Concepts

Research has been undertaken to find the origins and factors affecting the P-QRS-T waves of the electrocardiogram (ECG). Therefore, the understanding of the variation in one or many waves of the ECG makes it possible to diagnose and treat the heart conditions accordingly. As shown in Figure 1(b), a pulse beat is to be comprised of P-T-V-D subwaves. The exact origins of these subwaves are still unknown. Arduous research is required to find the origins and factors affecting the patterns of P-T-V-D, so that the pulse-based diagnosis could be automated for assistance similar to ECG.

Ayurveda considers that there may be changes in the pulse at different times of the day in different seasons i.e. the pulse is affected by the climatic and environmental changes.^[2] Advanced research would therefore be required to enable the quantization of these factors. A number of concepts such as three different signals obtained from the same artery are yet to be explained.

4.1.2. Establishing Standardization

Fuzzy logic is a computational method tolerant to sub-optimality and impreciseness (vagueness) and thus gives quick, simple and sufficiently good solutions. It would help to remove the limitation of inherent subjectiveness in the traditional treatment. A new database of pulse signals could be

prepared such that the same set of patients would go to a number of Ayurvedic practitioners and their diagnosis would be noted. It will consider the diagnosis of all the practitioners in respective proportions, and will provide the summarized output.

A well-sampled, large and open pulse database is needed, similar to Physionet^[80], with proper annotations to enable the scientists to find correlations. The open database will be useful for standardization, as reproducible and objectively comparable evaluations of different algorithms would be possible on the same data. It could thus prove beneficial in quantifiable improvements in the automated pulse-based analysis.

5. CONCLUSION

Exploring the various patterns and outcomes of the P-T-V-D waveform could help regulate the process of procurement and understanding of the Ayurvedic pulse. Comparing and correlating the Ayurvedic methods to that of modern medicine based on these P-T-V-D waveform variations could help validate this ancient science in today's times.

Summary of the signal processing and feature extraction techniques have been provided in Section 2. Computational methods such as fuzzy logic provide a good insight in predicting probable outcomes for pattern recognition. Several conditions affecting the arterial pulse (explained in Section 3) show that the pulse-

based system could prove to be a simple and efficient in detecting several life-threatening diseases.

Because of an increasing number of people using alternate medicine as a primary healthcare technique, it is essential to regulate the Ayurvedic teachings as per the norms of the scientific community for getting scientific recognition. Efforts are also made to include the complex circuitry involved to make the system compact and cost-effective for the Ayurvedic pulse-based diagnosis; thus making it easily available at affordable rates at hospitals.

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