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Monitoring Arterial Pulse Waves with Optical Pulse Sensor to Detect the Effect of Aging and Gender

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ABSTRACT: Wrist pulse signal is known to examine the health status of a person. Feature extraction methods are used to extract the time and frequency, linear and non linear features of wrist pulse signal. There is need for integration of the features for pulse diagnosis and classification because of heterogeneous nature of pulse signal which contains the complementary information. In Pulse Examination, palpation of adjoining three points of radial artery is sensed with the help of index, middle and ring finger giving the sensation of energies or doshas in terms of Vata, Pitta and Kapha which are collectively known as bio-elements or Tridosha. This study is intended to analyze the effect of age and gender on the wrist pulse. Data was collected gender wise and age wise with the help of optical pulse sensor interfaced with ATMEGA328 microcontroller. Three different groups of age was considered viz young subjects (18 to 30 years old), middle age subjects (more than 30 to 55 years old) and old age subjects (above 55 years old) for feature extraction. For gender wise analysis, the pulse rate and extracted features are found high for female subjects than male subjects. Dominance of Kapha for young subjects, Pitta for middle age subjects and Vata for old age subjects are observed in age wise analysis of wrist pulse. Wrist pulse signal is used to diagnose the disease. This research work can help the clinicians in better diagnoses considering the effect of gender and age on the wrist pulse signal.

Keywords: Age, ATMEGA328 microcontroller, Gender, Optical Pulse Sensor, Pulse Examination, Wrist Pulse.

I. INTRODUCTION

Wrist pulse analysis is always of great importance for the researchers as the wrist pulse contains rich pathological and physiological information. In traditional Indian Medicine, for thousands of years the practitioners use the fingers to feel the palpation of the wrist pulse to measure the pulse signal and examine the health status of the person. Modern medicine studies show that pulse signal can be used for cardiovascular disease detection. These days many sensors are used to obtain the pulse signal as the traditional pulse diagnosis suffers from several limitations.

Ayurveda, popularly known as healing science comprises of three important factors as Medicinal herbs or plants, Indian medical science and Pulse Examination or Nadi Parikshan [1]. Ayurveda fills the gaps in the modern medical science, thus people are turning towards Indian culture and trying to adapt this in day-to-day life. Many health care monitoring systems and research projects are available which are based on Ayurveda. Pulse Examination at the radial artery gets influenced by the physiological activities in the body. Many parameters are taken into consideration for pulse diagnosis such as rhythm, rapidity and size of the pulse. Fig. 1 shows the standard waveform of the pulse acquired from radial artery.

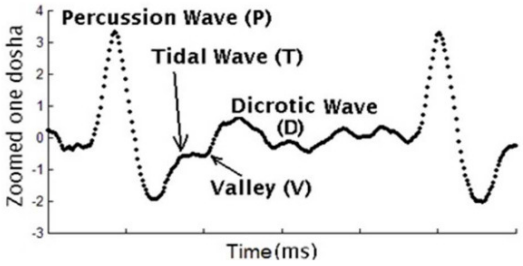

Fig. 1. Standard Pulse Waveform [2].

The pulse wave consists of the combination of the forward and reflected wave. During the systolic phase, the pulse travels away from the heart and it is reflected back towards the heart at the time of diastolic phase.

Manual diagnosis of the pulse rate with the index, middle and ring finger, needs concentration and state of mind of the physician at the time of diagnosis. Overall heart health and fitness level are checked with the pulse rate. The pulse rate can be observed at different positions of human body as back of the knees, groin, neck, top or inner side of the foot, wrist [3]. The Table 1 lists the pulse rate for various age groups.

Table 1: Pulse Rate for various age groups [3].

New born (0–3 months old)	Infants (3 – 6 months old)	Infants (6–12 months old)	children (1–10 years)	Children over 10 years & adults, including seniors	Well-trained adult athletes
99-149	89–119	79-119	69-129	59–99	39–59

According to Ayurveda, basic elements of the human body or the energies are referred as Vata, Pitta and Kapha according to the Three-Dosha Theory. The Fig. 2 below shows the location of the fingers for Pulse Examination and associated energies.

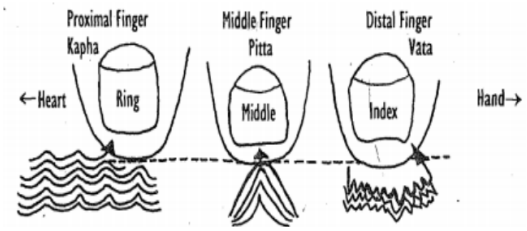

Fig. 2. Location of fingers for Pulse Examination [4].

Vata, Pitta and Kapha energies are present in every individual. Physical and emotional state of the individual are strongly dependent on the dominance of the bio-elements. These bio-elements can also occur in combination i.e Vata-Pitta Dosha, Pitta-Kapha Dosha, Vata-Kapha Dosha, Vata-Pitta-Kapha Dosha [5]. Correct pulse reading helps to observe the dominant energy. Position of the hand plays an important role in sensing the wrist pulse. The experience and the skill of the practitioner are important as well. This Fig. 3 shows the correct position for wrist pulse examination.

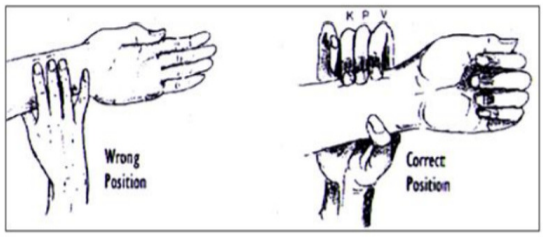

Fig. 3. Correct Wrist pulse Examination Position [4].

Vata is associated with the movement of the energy, Pitta signifies the metabolism in humans while Kapha is related to the structure of the human body and the lubrication. Root cause of the disease is usually the excess or deficiency of Vata, Pitta and Kapha bio-elements according to the Ayurveda [6]. Vata, Pitta and Kapha have different characteristics from each other. Some of the Vata, Pitta and Kapha characteristics are listed in Table 2.

Table 2: Vata, Pitta, Kapha Characteristics [4].

	Vata	Pitta	Kapha
Characteristics	Light, feeble, fast, thin, disappears on pressure	Forceful, high amplitude, strong, lifts up the palpating fingers	Slow, thick, deep, broad, wavy, regular
Location	Index Finger	Middle Finger	Ring Finger
Movement	Like a cobra	Like a frog	Like a swimming swan
Temperature	Cold	Hot	Cool or Warm
Pulse Rate	80-95	70-80	50-60

Nowadays the pulse extraction is possible with the help of sensors. With these we can easily identify the diseases. There are systems developed in past to quantify the signals such as EMG, ECG, EEG etc to obtain some meaningful results [7]. But in the area of pulse waveform, not much work has been done. Recently this field is accelerating *towards progress*.

Gouri *et al.,* (2016) presented the design of portable device for Nadi Parikshan [8]. A standard database of simulated signals with known diseases were stored. Basically here the simulation of the data was being done. This simulated pulse signal contains the noise due to position of sensors and other factors also. So this noise was removed using suitable filters. In this paper the simulated waves were being given after applying various filter techniques. Block Diagram is shown below in Fig. 4.

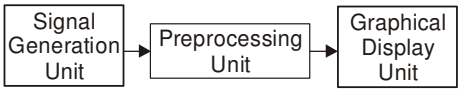

Fig. 4. Various units of Device [8].

Vata signal waveform was found to be linear first then the amplitude increased and subsequently decreased reaching to linear stage again. The extracted Pitta signal gradually increased, reaching to the maximum slope and then started decreasing and comes out to be linear till it started increasing again. Kapha waveform was considered as a reverse sawtooth waveform. The increasing line and decreasing line had different slope values. Roopini *et al.,* (2015) presented a Nadi Parikshan Yantra for Pulse Examination [9]. Pulse Features were extracted with the help of the optical pulse sensor. As there is an increase interest in examining the arterial pulse, various sensors can be used to extract the features. Shete and Kakade (2012) proposes a Nadi Parikshan system using three piezoelectric sensors On the basis of amplitude, the collected pulse data was being analyzed [10]. This variation in pulse waveform gives an idea of dominant Dosha. The amplitude varies according to the pressure applied. As the pressure increases, the amplitude follows the same pattern. But after reaching the maximum value, it starts decreasing. This could be related to systolic and diastolic energies also. The design of the instrument is shown in Fig. 5.

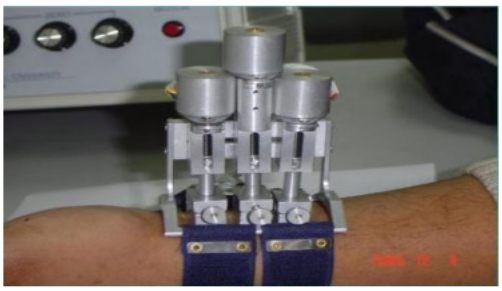

Fig. 5. Instrument to capture pulse [10].

Various sensors are available these days to extract the waveform of the pulse e.g. pulse sensor, pressure sensor, photoelectric sensor. Although pressure sensor is more prone to external interference and noise, leads to more pressure variation and hence the amplitude varies.

In this research work, the effect of age and gender on the wrist pulse signals i.e Vata, Pitta and Kapha is taken into consideration which can prove useful for better prediction of the disease and checking the emotional and physical status of an individual.

II. METHODOLOGY

Here in this research, for data acquisition the pulse sensor is being interfaced with the microcontroller. The sensed Vata, Pitta and Kapha signals are pre-processed with the help of Butterworth filter in the MATLAB. Some of the necessary features are extracted with the help of filtered Vata, Pitta and Kapha waveform. Fig. 6 below shows the methodology schematics.

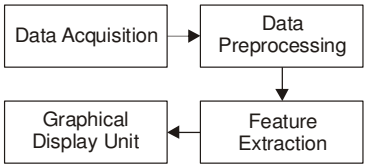

Fig. 6. Schematics Representation of Methodology.

A. Data Acquisition

The data is acquired gender wise and age wise for this study. For the male the Pulse Examination is done on the right hand while for female it is performed on left hand because nerve plexus is different in males and females [11]. Different age groups are considered viz (18 to 30 years old), (more than 30 to 55 years old), (above 55 years old). The pulse sensor is interfaced with the Arduino ATMEGA328 to sense the Vata, Pitta and Kapha energies. The Fig. 7 below shows the Data Acquisition technique.

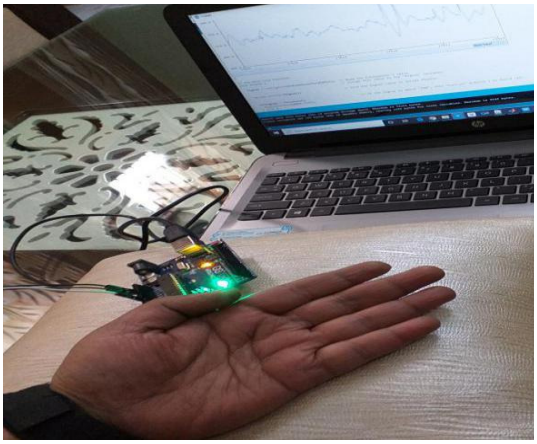

Fig. 7. Data Acquisition.

Pulse Sensor and Arduino: For acquiring the Vata, Pitta and Kapha waveform, the Pulse Sensor is used in this research work. This sensor follows the principle of Photoplethysmography [12] and mainly consists of two components: Light Emitting Diode (LED) and the detector or Photodiode. LED emits the light when the sensor is placed on the radial artery. This emitted light is absorbed by the blood in small amount while the rest is reflected back which is detected by the detector or photodiode embedded on the pulse sensor. This sensor is interfaced with the arduino to obtain the bio-elements or tridosha waveform. The pulse sensor and arduino uno are shown below in Fig. 8 and 9 respectively.

The pulse sensor is interfaced with the analog pins present in the Arduino Uno. Analog-to Digital converter of the Arduino Uno converts the pulse sensor output to digital form as the sensed output is in analog form. The acquired Vata, Pitta and Kapha signals are the difference between the incident and the reflected light at the three distinct and precised locations of the radial artery.

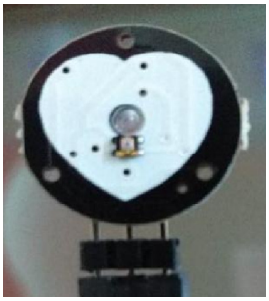

Fig. 8. Pulse Sensor.

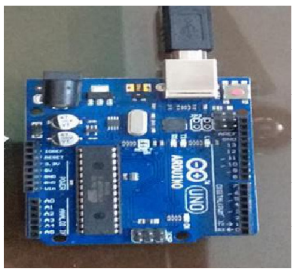

Fig. 9. Arduino Uno.

B. Data Preprocessing

For preprocessing of the digitized Pulse Signal, the Lowpass Butterworth filter with cut off frequency 200 Hz is designed in the MATLAB. No ripples are there in frequency response of the Butterworth filter [13]. This preprocessing of the signal is needed as the acquired signal is contaminated due to interaction with skin and muscles.

C. Feature Extraction

Features are extracted from the filtered Vata, Pitta and Kapha waveform in MATLAB. Vata, Pitta and Kapha Rate, Spectral Entropy [14], Approximate Entropy [15], Sample Entropy [16], Augmentation Index [17, 19], Maximum Amplitude value and statistical features are calculated which distinguish the subjects gender wise and age wise.

D. Graphical Display Unit

The Vata, Pitta and Kapha filtered signals are obtained on MATLAB GUI to observe the differences in waveform visually. The Fig. 10 shows the processed Vata, Pitta and Kapha waveform.

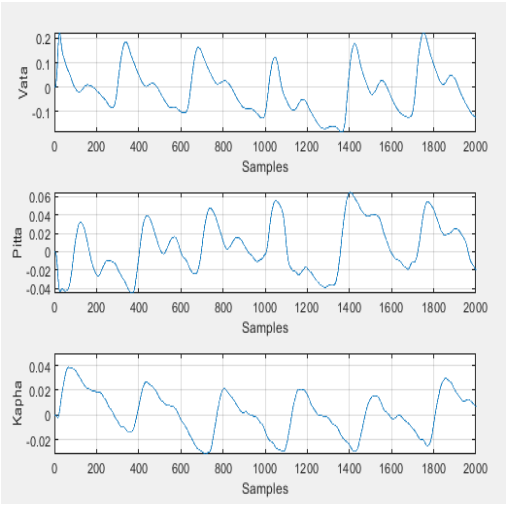

Fig. 10. Processed Vata, Pitta and Kapha Waveform.

III. RESULTS AND DISCUSSION

The data samples are acquired for different age groups. Data is collected for 27 subjects. Feature are extracted using these processed and filtered samples. To study the differences between the Vata, Pitta and Kapha signal of Male and Female, the subjects of same age group are considered. The weight and height of the subjects are also considered at the time of data collection as the pulse rate also depends on the height of the person [4]. The approximate entropy, sample entropy, spectral entropy, Maximum amplitude, Vata Rate, Pitta Rate, Kapha Rate and mean Pulse Frequency of female are found to be greater than the male. The Table 3 lists some of the extracted features.

Table 3: Extracted Features for Male and Female.

	Male			Female		
Parameters	**Vata**	**Pitta**	**Kapha**	**Vata**	**Pitta**	**Kapha**
Approximate Entropy	0.0433	0.0490	0.0479	0.0621	0.0632	0.0574
Sample Entropy	0.0318	0.036	0.0428	0.05182	0.0529	0.05158
Spectral Entropy	0.4942	0.497	0.4936	0.5023	0.5024	0.4986
Maximum Amplitude	0.1377	0.324	0.0814	0.1636	0.3358	0.1607
Mean Pulse Frequency	0.1791	0.1875	0.169	0.2725	0.2641	0.2666
Pulse Rate	72	67.87	68.98	81.05	79.005	80.83

The Fig. 11 below shows the comparison of extracted features gender wise. Here ApEn refers to approximate Entropy, SampEn is Sample Entropy, SpecEn is Spectral Entropy, Max Amp is maximum amplitude of bio-element, Freq refers to mean pulse frequency.

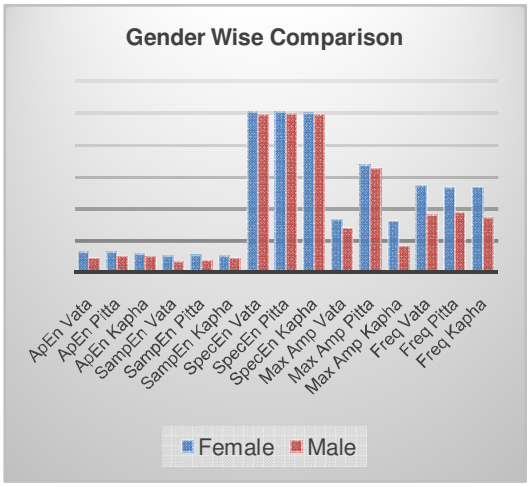

Fig. 11. Gender wise Vata, Pitta, Kapha Features Comparison.

The processed Vata, Pitta and Kapha waveform for the male and female are shown in Fig. 12-17 below. Here the amplitude of Female Vata, Pitta and Kapha waveform is higher than the Male bio-elements waveform.

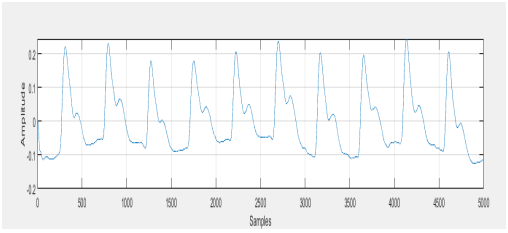

Fig. 12. Male Vata Signal.

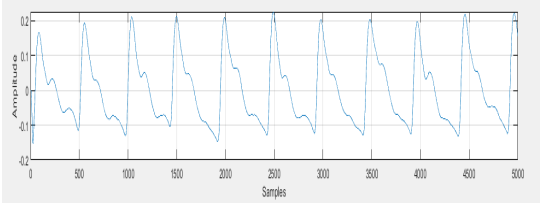

Fig. 13. Male Pitta Signal.

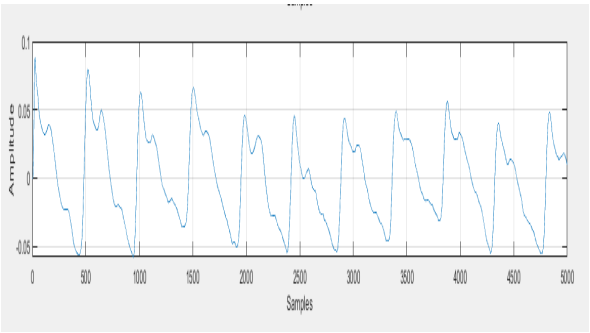

Fig. 14. Male Kapha Signal.

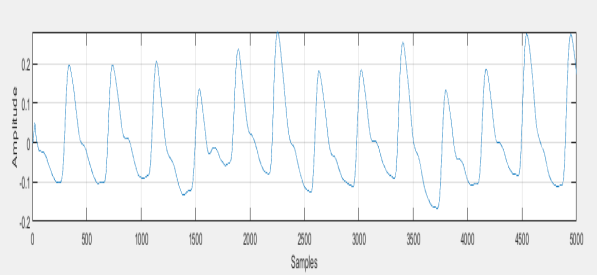

Fig. 15. Female Vata Signal.

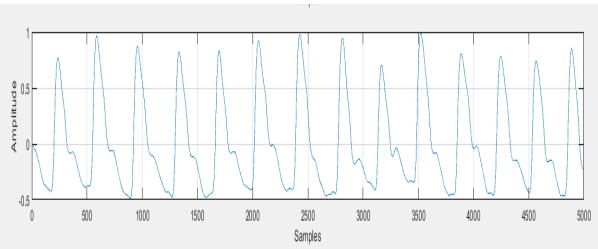

Fig. 16. Female Pitta Signal.

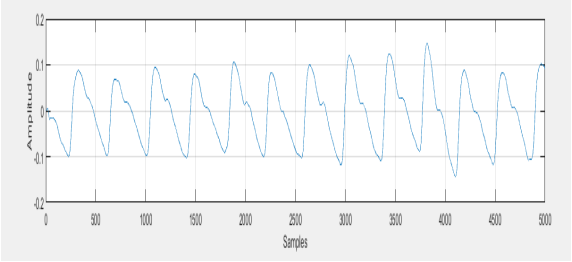

Fig. 17. Female Kapha Signal.

Aging is associated with the increase in disease processes and decline in cardioprotective system [20]. To study the effect of aging on Vata, Pitta and Kapha signals, time domain and frequency domain parameters are considered to extract the features. Three class of age group are considered viz young class (18 to 30 years old), middle age class (more than 30 to 55 years old) and old age class (above 55 years old).

High value of Approximate Entropy is found in young subjects than middle age class followed by old age class. Similar trend is observed for Sample Entropy values. Augmentation Index of Vata, Pitta and Kapha is found high in old age subjects which indicates the arterial stiffness increases with the age [21]. Mean Pulse frequency of Wrist Arterial Waves is observed high in young and middle age subjects than old age subjects. Standard Deviation of Vata, Pitta, Kapha rate is more for old age group people. The Kapha Rate is found high in young group, Pitta Rate is more for middle age group and high Vata Rate is observed in old age group. As the arteries stiffness is closely related with the dominance of Vata energy and this bio-element or dosha is more prevalent in old age people. Table 4 below lists the extracted features.

The Fig. 18 below shows the comparison of extracted features age wise. Here ApEn refers to approximate Entropy, SampEn is Sample Entropy, AI is Augmentation Index, Freq refers to mean pulse frequency.

Table 4: Age wise Extracted Features.

	Young Subjects			Middle Age Subjects			Old Age Subjects		
Parameters	**Vata**	**Pitta**	**Kapha**	**Vata**	**Pitta**	**Kapha**	**Vata**	**Pitta**	**Kapha**
Approximate Entropy	0.2265	0.1979	0.1854	0.1958	0.1748	0.1653	0.1143	0.096	0.1481
Sample Entropy	0.1881	0.1756	0.1556	0.1516	0.1341	0.1330	0.0896	0.0809	0.0968
Augmentation Index	0.9575	0.9664	0.9622	0.9509	0.9543	0.9603	0.9592	0.9666	0.9835
Mean Pulse Frequency	1.652	1.264	1.784	1.49	1.46	1.752	1.224	0.736	1.564
Pulse Rate	84.26	85.84	91.05	81.18	87.43	83.84	96.28	76.62	77.42

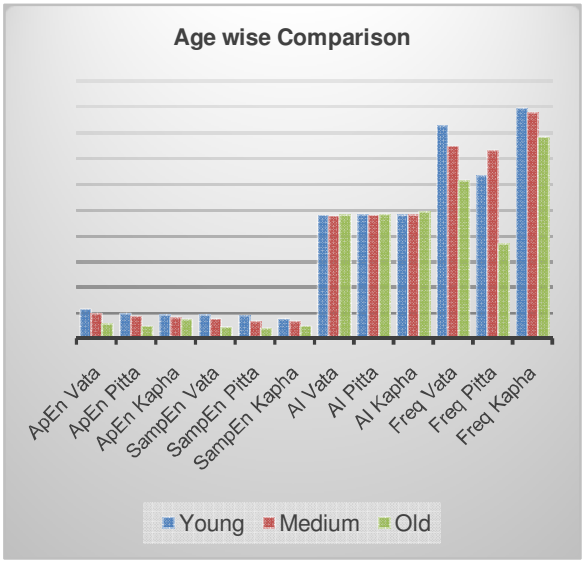

Fig. 18. Age wise Vata, Pitta, Kapha Features Comparison.

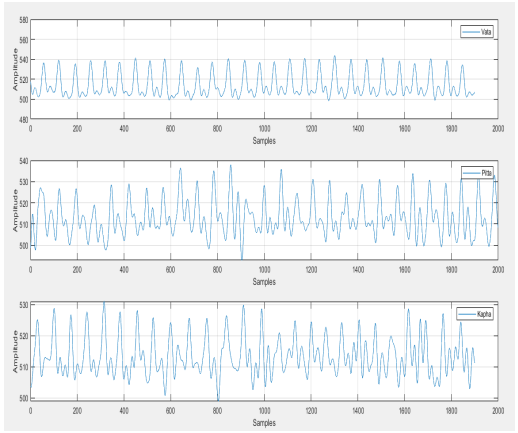

Fig. 19. Vata, Pitta and Kapha Waveform for Young Subject.

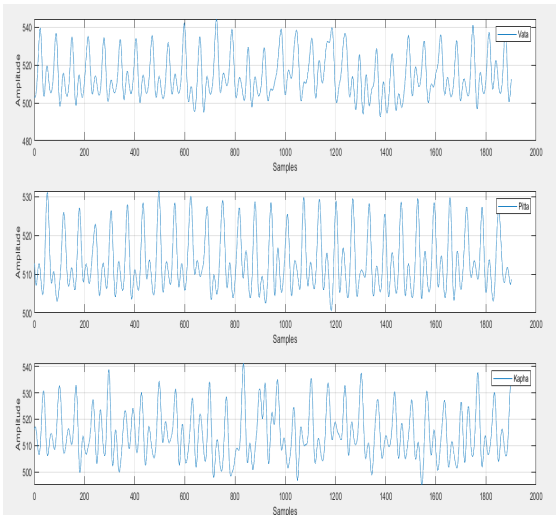

Fig. 20. Vata, Pitta and Kapha Waveform for Middle Age Subject.

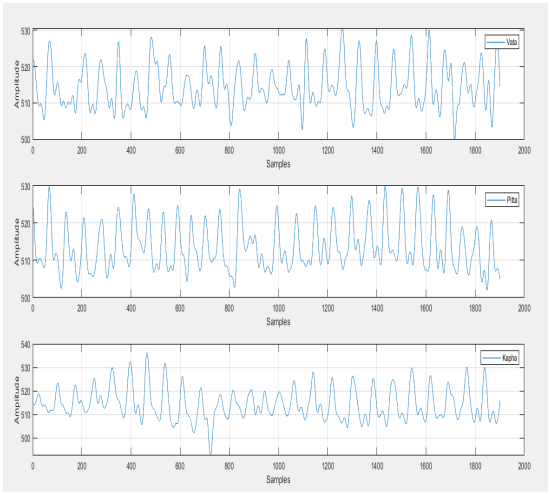

Fig. 21. Vata, Pitta and Kapha Waveform for Old Age Subject.

The acquired waveform of wrist pulse signals are filtered in MATLAB to remove the contamination [22]. The Fig. 19-21 below shows the acquired Vata, Pitta and Kapha waveform for the young, middle age and old age subjects respectively. Here the dicrotic waves and percussion waves are more prominent in young age group and least in old age group [2].

IV. CONCLUSION

The study of effect of gender and age on the Vata, Pitta and Kapha signal is carried out with the Pulse Sensor. This sensor is interfaced with the Arduino Uno to obtain the real-time data. This acquired data is filtered using Lowpass Butterworth Filter. Some of the features are extracted to observe the effect of aging and variations of Bio-elements or Tridosha gender wise. The preprocessing of signal and feature extraction is done in MATLAB software package version R2018a. The extracted features can provide an effective means for Pulse Examination. For the gender wise effect, the female Vata, Pitta and Kapha Rate is more than the male bio-element Rate. Also the Approximate Entropy, Sample Entropy, Spectral Entropy, Pulse Frequency, Maximum Pulse Amplitude are high for female than male. In age wise study, different energies are found to be dominant at different age groups. As for the young subjects (18 to 30 years), the Kapha energy is dominant and Approximate Entropy, Sample Entropy, Mean Pulse Frequency are higher than other age groups. For middle age subjects (above 30 to 55 years), the Pitta energy is dominant. For the old age group (above 55 years), the Vata energy is dominant and the Augmentation Index, standard deviation in tridosha waveform are higher than other groups. This clearly indicates the more stiffness in arteries in old age group. The Fig. 22 below shows the effect of gender and age on Vata, Pitta and Kapha Rate. This research work can help the doctors in better diagnoses of the disease related to the age and gender of the person using the pulse signal.

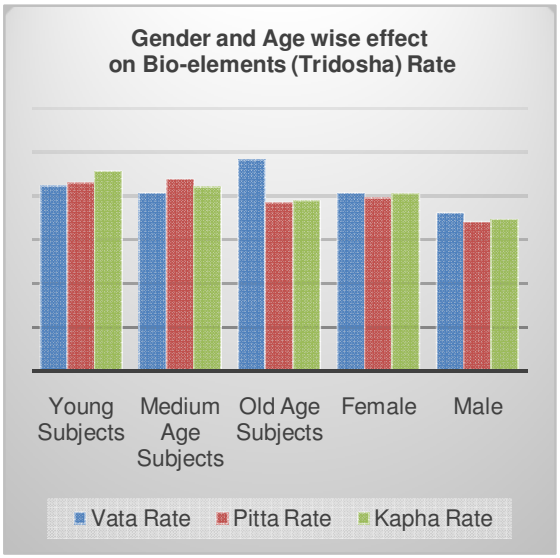

Fig. 22. Gender and Aging effect on Vata, Pitta and Kapha Rate.

V. FUTURE SCOPE

The current study has the potential to offer inputs for those interested in finding the effect of aging and gender on other physiological signals. Also, this work can be used for finding out the early detection and prediction parameters for various disease as wrist pulse signal serves as indicator for the health status of an individual.

Conflict of Interest. The authors confirm that there are no known conflicts of interest associated with this publication of this paper.

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