2 DESIGN OF A PULSE SENSOR FOR SIDDHA BASED DISEASE DIAGNOSIS

M. Manivannan* **and Mahesh Shankara**†

Faculty of Biomedical Engineering, Indian Institute of Technology Madras, IIT Madras, Chennai, Tel: +91 044 22576500. E-mail: mani@iitm.ac.in

†*System Engineer, IBM Bangalore, IBM, EGL 'C' Block, Bangalore. Tel: +91 080 41927090. E-mail: maheshan@in.ibm.com*

The roots of diagnostic techniques in Indian medical systems lie in the three radial pulses. Pulse reading is essentially a haptics technique in which the experts use various palpation techniques in order to mine the hidden physiological signals. In this paper we present the design principles we used and the design and analysis of a pressure pulse sensor using PVDF material for acquiring the three pulses from the radial artery. Sensitivity analysis of the design is also presented. The sensors are firmly held at each of the three radial points and by varying the pressure on the sensor head the recordings were done on 10 healthy subjects who had no history of cardiovascular disease. The shapes of the pulses were analyzed using frequency domain analysis and accordingly classified the subjects as vata, pitta, and kapha body type. Further we can also find that the pulses are varying over time from morning, afternoon, to evening. Establishing that the three pulses provide information about the psychic characteristics is difficult and it requires long term comprehensive, comparative research into both modern medicine and Indian medicine.

Keywords: Haptics, PVDF, Sensors, Vata, Pitta, Kapha.

1. INTRODUCTION

Developing a universal tool for diagnosing almost all kinds of diseases is an ambitious task for every biomedical engineering researcher. According to Siddha which is considered as one of the world's oldest medical systems and local to south India *Pulse diagnosis* is such a tool. It was developed and practiced widely not only in India, but also in other parts of the world like China, Egypt, and Greece. There has been a mention in the papyrus of ancient Egyptian medicine about the pulse diagnosis.

Where physicians in the West use the pulse to determine heart rate, their Siddha counterparts feel the patterns of vibration that represent the metabolic processes going on in the body at a specific time. They locate three different pulses in single radial artery on each wrist, corresponding to each of the three *doshas*. The index finger senses the *vata* pulse; the middle finger, the *pitta* pulse; and the ring finger, the *kapha* pulse. The adept practitioner can also locate other pulses that are combinations of the main three as well as subdivisions of those pulses. Altogether, the skilled pulse-reader can detect as many as 32 different pulse qualities. What the rhythm and vibrating movement of these distinct pulses tell the examiner is the condition of other systems beyond those related to the cardiovascular system. The experienced physician can read, through the pulses, the strength and vitality of each internal organ, and even is reputed to be able to diagnose diseases like asthma and diabetes. Pulse diagnosis is explained scientifically by its proponents as each dosha having different *tactile vibratory qualities* in the radial artery (or, the vibrations in the wrist artery have a different feel to each finger). It is the presence and location of these tactile qualities (with such names as the *snake pulse*, the *frog pulse*, or the *swan pulse*) that alert the physician to the nature of the imbalance that is responsible for the patient's condition.

In this paper we present haptic design principles we used in designing a high sensitive pressure sensor for acquiring the three pulses from the radial artery.

1.1. Pulse Diagnosis

The three principal pulses are felt in the wrist region along the radial artery.[1] The place for feeling the pulse is on the lateral aspect of the right forearm, 2 cm up from the wrist. The index, middle, and ring fingers are used to feel the three pulses in their respective order as shown in Figure 1. Pressure of varying levels is applied with each finger on the artery in order. Application of pressure is repeated as many times as needed for diagnosing the disease. Based on the dominant pulse among the three and the direction in which the pulse motion is felt, a trained practitioner identifies over 350 different disease conditions. The study of the relationship between these pulse patterns is the key to identification of the ailment.[2] Healthy human subjects have the three pulse amplitudes in the ratio of 4:2:1 respectively. However, this ratio is believed to follow seasonal variations and changes with parameters such as time of the day, temperature and humidity of the skin. The right arm of male subjects and left arm of female subjects is used to read the pulse.

As shown in Table 1, the three pulses could be differentiated using eight parameters namely location, rate, rhythm, force, gait, tension and volume, temperature, and vessel wall.

1.2. Haptic Design Principles

Here we restrict our discussion to active touch where both sensory and motor system work together for acquiring more information about the environment (real or virtual, near or tele). Two different view points exists in designing haptics sensors or actuators: cognition and perception. While the cognitive view point considers all the dimensions of cognition such as intuition, learnability, motivation, consistency, and others, the perceptive view point considers all the dimensions of perception (specifically, of somoto-motor system) such as bandwidth, amplitude, resolution (temporal, spatial, and spectral), velocity of motion, adaptation, masking, Range of Motion (ROM), Just Noticeable Differences (JND), and others.

We focus our discussion only on the perceptive dimensions of the design specifically to human finger pads, as the pulse reader acquires signal only through the finger pads. Also, we consider only the tactile and kinaesthetic aspects of the pulse reading, the temperature and pain are not considered in the design.

Psychophysics involved in designing typical haptics devices is available in various haptics literatures.[13] Here we discuss the psychophysical parameters related to the eight parameters that a pulse reader typically acquire as listed in Table 1.

The location of the three fingers: index, middle, and ring finger do not alter the tactile psychophysical aspects of measurements. All the three fingers have very similar two-point discrimination (TPD), and vibration perception threshold (VPT).

The frequency of the different pulse is related to the temporal resolution of the fingers. While the table lists only the fundamental frequency, the pulse readers use higher order harmonics of the signal. With the 1 kHz temporal resolution restrictions of the human finger pad, upto the third harmonics can only be felt in the finger pad. Our JND of frequency resolution is about 10% which can easily resolve the three pulses in to different categories.

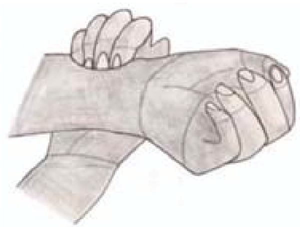

Figure 1. The process of Pulse Diagnosis.

Table 1. Characteristics of Pulses.

	1st Pulse	2nd Pulse	3rd Pulse
Location	Index	Middle	Ring
Frequency	80–95	70–80	50–60
Regularity	Irregular	Regular	Regular
Amplitude	Low+	High+ + +	Moderate++
Gait	Quick and leaps like a frog	Prominent, strong, high amplitude, like snake	Deep, slow, broad, like elephant
Tension and Volume	Low	High	Moderate
Temperature	Cold	Hot	Warm to cool
Vessel wall	Rough, hard	Elastic, flexible	Soft thickening

Regularity of the pulse is more related to the cognitive aspect of the pulse reading. Similarly the gait attribute of the pulse. Two point discrimination (TPD) will determine the direction of movement of the pulse features from beat to beat.

The amplitude of the pulse, though qualitative, is related to the absolute detection threshold of our finger pad; it can detect 20 μm at static, 10 μm at 10 Hz, and 0.1 μm at 250 Hz. At 50 Hz fundamental frequency of the slower pulse, finger pad can detect an amplitude of 1 μm. At higher frequencies, it can detect smaller amplitudes.

The tension and volume of the pulse indicates essentially the blood pressure and the stroke volume of the circulation. The stiffness measurement involves both the sensory and motor system together.

The weber ratio for temperature measurement is 2%. It is shown in the literature that the temperature affects the TPD.

The quality of vessel wall is again sensory-motor system parameter. The JND of compliance measurement in case of the deformable surface is about 3%. Therefore, a small change in the tension can easily be detected.

1.3. Design of PVDF Based Pulse Sensor

Photo-plethysmography (PPG) for cardiovascular pulse detection to measure the optical power variation due to absorption or scattering when the amount of blood in the measurement volume varies is widely used.[3] However, IR sensors do not measure the pressure directly. Recently piezoelectric sensors have been used for measuring pulse pressure directly where the mechanical stimulus generated by the pressure pulse in converted to an electrical signal for further signal processing. Sorvoja *et al.*[4] and Ruha *et al.*,[5] describe utilization of new pressure sensitive materials like electromechanical film (EFMi) and polyvinylidene fluoride (PVDF) in sensors for pulse detection in the radial artery. Dupuis *et al.*[6] describe use of a strain gauge differential pressure sensor in a measurement system, where a low pressure cuff was wrapped around the wrist and then the pressure modulation in the cuff caused by the pressure pulse was measured with strain gauges. Gagnadre *et al.*,[7] describe the use of fiber optic sensors to detect heart rate. A multimode optical fiber was placed between two aluminum plates. The force generated by the pressure pulse caused variation in the modal distribution in the fiber and the pulse is detected using a photodetector.

Our sensor is designed using a piezoelectric polymer known as PVDF (polyvinylidene fluoride). PVDF is a highly non-reactive and pure thermoplastic fluoropolymer. Polyvinylidene fluoride is a long chain semicrystalline polymer of the repeat unil (CH2–CF2). The monomer, vinylidene fluoride, CH2=CF2, has a large dipole moment, about $7.56 \times 10–30$ Cm. The monomer units polymerize in an orderly fashion to produce greater than 90 percent had-to-tail configuration; i.e. –CH2–CF2–CH2–CF2–. Thus, the polymer exhibits an unusually high net dipole moment.

The properties of PVDF, including piezoelectricity, are highly influenced by the degree and type of crystalline structure. Therefore it is important to consider piezo film as a dynamic material that develops an electrical charge proportional to the change in mechanical stress, in our case pulse pressure.

It does not operate in a static condition because of the rapid decay of the induced charge. The time constant is determined by the film's dielectric constant and internal resistance, as well as by the impedance of connected circuits. Among many constant characterising the material, we considered the coupling constant K, piezoelectric Strain Constant d, piezoelectric Stress Constant g, and Piezoelectric Hydrostatic Constant dh.

The length of the PVDF required for our sensor was decided based on the following:

- The diameter of radial artery and the sheath above it. The radial artery diameter varies from 2 mm–4 mm and including sheath it will come up to 3 mm–5 mm.
- The length should be more or twice the (diameter + sheath) and hence it is (5 × 2) mm that is 10 mm.
- The length should be less than the distance between the two tendons (that is the Abductor pollicis longus and Extensores pollicis longus) between which the artery passes. This varies from person to person from 10 mm to 20 mm and hence the length was restricted to 14 mm.
- The breadth of the PVDF was designed based on the placement of sensor since the sensor is placed at three points on the wrist where we acquire the three pulses are at a distance of 7 mm center to center the breadth should be restricted to 5 mm.

The handle for holding the PVDF material was made using Plexiglas in a simply supported beam arrangement as shown in Figure 2.

1.3.1. Sensitivity analysis for the sensor

The sensor is modeled as a simply supported beam as shown in Figure 3a for the purpose of sensitivity analysis. Here P is the load applied on the PVDF at the center, which is the pressure (either the systolic or the diastolic pressure) acting over the area of the artery. To simply the analysis, we considered only the half of the PVDF as shown in Figure 3b.

Tensile Stress $\sigma_t = P\ \mathrm{Sin}\theta / b \times t_p$. The relation between the stress and the resultant electric field generated on the polymer can be written as $\epsilon = -(\sigma_t \times g_{31}) - (\sigma_b \times g_{32})_{+\beta D'}$ where g_{31} and g_{32} are PVDF material constants. The electric displacement D' is independent of the coordinate direction x3 and so are the strains. This is justified by the thinness of the PVDF film. Hence the voltage across the

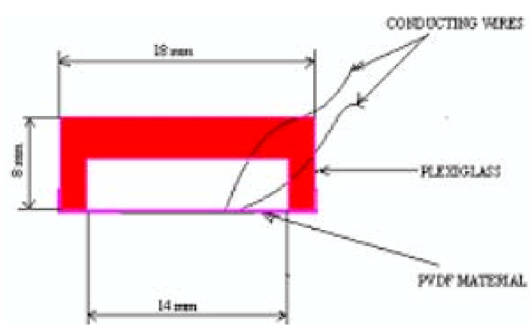

Figure 2. Design of our Pulse sensor.

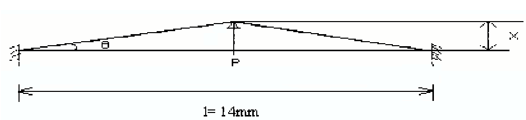

Figure 3a. Model of our sensor for sensitivity analysis.

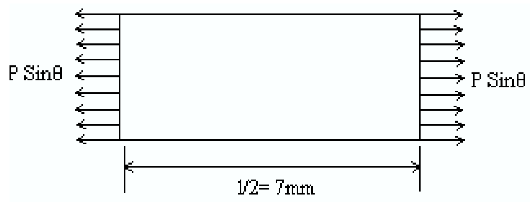

Figure 3b. Half of the above model to simplify our analysis.

electrode can be obtained by a simple integration of the electric field equation $\epsilon = e/t_p$ where e is the voltage across the electrode and t_p is the film thickness. Therefore

$$e/t_p = -(\sigma_t \times g_{31}) - (\sigma_b \times g_{32})_{+\beta D'}$$

Rearranging the above equation we get $D' = e/_{\beta}t_p + (\sigma_t \times g_{31})/_{\beta} + (\sigma_b \times g_{32})/_{\beta}$

D' In the above equation can also be written in terms of electric charge q as dq/dA, generated in the electrodes substituting for D' and integrated over the surface area of the polymer which gives the total charge $q = (e/_{\beta}t_p + (\sigma_t \times g_{31})/_{\beta} + (\sigma_b \times g_{32})/_{\beta}) \times A$

$$\text{where } A = \text{area of the film which is electroded } = l/2 \times b$$

To get the voltage across the polymer open circuit conditions are established by setting the charge equal to zero and solving for open- circuit voltage that is generated by the bending of the PVDF $e/t_p = -(\sigma_t \times g_{31}) \times A - (\sigma_b \times g_{32}) \times A$

$$e = -(P\ \mathrm{Sin}\theta/a)g_{31} \times t_p \times A - (P\ \mathrm{Sin}\theta/a)(1+\nu)g_{32} \times t_p \times A$$

where $a = b \times t_p$ Hence

$$e = -(P\ \mathrm{Sin}\theta/b)\{g_{31+}(1+\nu) \times g_{32}\} \times A$$

Since g_{32} is very small the equation can be written as

$$e = -(P\ \mathrm{Sin}\theta/b) \times g_{31} \times A$$

Therefore sensitivity is given as

$$M_0 = e/P = (\mathrm{Sin}\theta/b) \times g_{31} \times A$$

Considering that θ does not exceed 45 degrees, sensitivity is 2.1×10^{-3}.

1.4. Our Pulse Measuring System

We have designed a signal conditioning unit to improve the quality of the signals such as signal scaling, amplification, linearization, filtering, and common-mode rejection, generated by the PVDF sensor before they are converted in to digital signals by the data acquisition card interfacing the computer. The signal conditioning unit consists of charge amplifier, voltage amplifier, and a low pass filter.

2. METHODOLOGY

The sensor system required for picking up the radial pulses from the wrist was initially tested with signals from the function generator and found to be showing the same shape of pulse as any other pulse system such as Photoplethysmography (PPG). PVDF sensor are attached to the wrist at three different places as identified by siddha experts and the vata, pitta, and kapha pulses are recorded as shown in the Figure 4. The sensors are firmly held at each point using a tape. By varying the pressure on the sensor head at that point recordings were done on 10 healthy subjects in the age group of around 20–30 years with a mean age of around 25 years, who had no history of cardiovascular disease. The recording was done three times a day for each subject to see the variation of three pulses during morning, afternoon

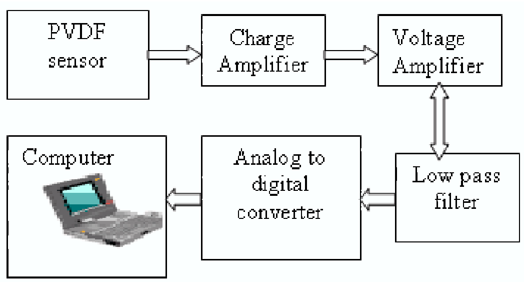

Figure 4. Basic block diagram of the pulse sensor system.

and evening. All the subjects were asked to fill up a questionnaire regarding their daily routine activities and lifestyles which will indicate their body type and combination of doshas as per the siddha concept.

The signal was acquired at 250 Hz and the three pulses were recorded one after other from all the pulse points and then analysis was done.

We followed the following procedure for recording and data acquisition:

1. The subjects were made to relax for 10 min before taking the readings.
2. The subjects were asked to sit on a chair comfortably and stretch his left arm forward approximately at the heart level for placing the sensor.
3. The PVDF sensor was first placed over the radial artery where we recorded the vata pulse that is the sensor was placed below the radial styloid as shown in the figure. The radial styloid is the protruding wrist bone on the thumb side of the hand of the pulse recipient.
4. Then the second pulse and the third pulse were recorded by placing the sensors at the second and the third pulse points respectively which are next to the first pulse point. All the three pulses were recorded at the same smapling frequency 250 Hz.
5. The recording was done three times a day for each subject at the same ambient room temperature during recording 22–24°C.

3. RESULTS AND DISCUSSION

The shapes of the pulses were varying across subjects and there was also variation in amplitude and frequency among the three pulses within subjects. According to the siddha theory and principles the three pulses vary in amplitude in the ratios of 1:2:4 for kapha, pitta, and vata respectively and the frequencies must be 80–95 beats/min for vata pulse, 70–80 beats/min for pitta pulse and 50–60 beats/min for kapha pulse. According to the amplitude and the frequency of the three pulses we classified the subjects as vata, pitta and kapha type if either the amplitude or frequency deviates from that of the prescribed for normal subjects. The frequency analysis of a subject's pulses are shown in Figure 5. It could be inferred from the data that the vata pulse rate is less than the normal range that is 80–90 beats/min where as the pitta and the kapha pulse is with in the normal range. This indicates that the person may have less vata constituents. Further we can also find that the pulses are varying over time that is during morning, afternoon and evening even though there is variation in the pulse rate of the three pulses we can see that pitta pulse is always maintaining higher rate than the other two pulses.

From the amplitude data as shown in Figure 6 of the same subject, it could be inferred that the ratio of vata, pitta, and kapha pulses are in the ratios 1:0.6:0.4 respectively. This indicates that that the person is having more pitta and kapha constituents.

The scores of the subject in the standard Ayurvedic questionnaire is vata-62, pitta-70, and kapha-67. This also indicates that the person is having less vata and more pitta constituents. The amplitude and frequency analysis was done for all the 10 subjects and is shown in Table 2.

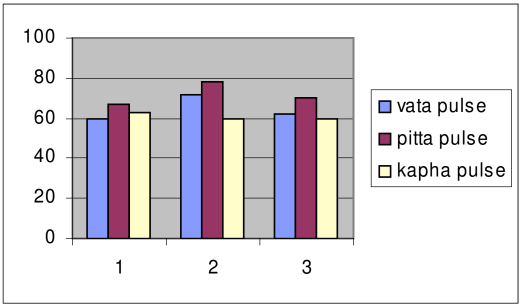

Figure 5. The variation of the pulse rate for the three pulses during morning, afternoon and evening of a typical subject.

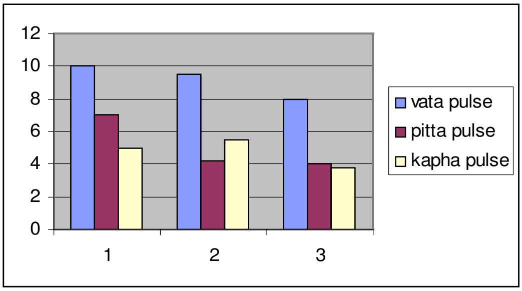

Figure 6. The variation of the pulse amplitude for the three pulses during morning, afternoon and evening of a typical subject.

Table 2. Comparison of constitution determination from three experiments. (a) Frequency analysis (b) amplitude analysis, and (c) questionnaire. L-Low, N-Normal, H–High.

	Pulse rate analysis			Amplitude analysis			Analysis done using questionnaires			Constitution
Subjects	Vata	Pitta	Kapha	Vata	Pitta	Kapha	Vata	Pitta	Kapha	Conclusion
1	L	N	H	N	N	H	62	67	70	Kapha with less Vata
2	N	N	H	N	N	H	72	65	78	Kapha
3	L	N	N	N	L	H	68	62	72	Kapha less Pitta
4	L	N	H	N	L	H	74	65	78	Kapha with less Vata
5	N	N	H	N	H	H	69	78	73	Pitta-Kappa
6	L	L	N	N	N	N	69	64	71	Kapha with Less vata and pitta
7	L	N	N	L	H	H	62	70	67	Pitta with less Vata
8	N	N	H	N	L	H	67	65	77	Kapha with less Pitta

4. CONCLUSION AND FUTURE WORKS

We have designed and implemented a system for acquiring the radial pulses from the wrist using PVDF. This system could be used as an important diagnostic tool for various clinical applications. We collected the three pulse data from the radial artery from 10 subjects at different time that is during morning, afternoon and evening.

Information regarding the Siddha or Ayurveda body type of the subjects is obtained with the help of the questionnaires and compared the result with our analysis. It is interesting to note that body type classification done by both methods coincides. If this is not a coincidence, then this raises an important question that how the pulse waveform, which represents specific properties of circulatory system, can reveal fundamental information about subjects personality characteristics? This question is not obviously easy to test as it requires long term comprehensive, comparative research in to both modern medicine and Indian medicine systems. The present work is only a preliminary work in this direction and towards understanding fundamental principles behind our Indian medical systems.

There are several questions which are unanswered at this juncture. Existence of the three pulses itself is a mystery; from a single radial artery, how three different pulses with different characteristics as explained in the Table 1 could exist. The above question requires research in subtle anatomy and fluid dynamics. In the present work the pulses were not acquired simultaneously. A cuff could be used to fix all the three sensors on the wrist and can be used for getting the pulses simultaneously which can give reliable results.

This work can be extended to an algorithm that estimates the relative levels of the three doshas from the three pulses and to predict the diseases. Three pulses can be analysed for different pathological cases such as diabetes, heart disease, respiratory problem and others.

ACKNOWLEDGMENTS

This paper reports work funded by the Applied Mechanics Department, Indian Institute of Technology Madras, (Presented materials, ideas and results reflects the views of the authors, and do not necessary reflects the views of the Indian Institute of Technology Madras.)

REFERENCES

[1] Sarvadeva Upadhyaya (1986). Nadi Vijnaana, First Edition, Vedic Life Sciences Pvt. Ltd.
[2] Vasant D. Lad (2005). Secrets of the Pulse: The ancient Art of Ayurvedic Pulse Diagnosis, Motilal Banarsidass.
[3] Herztman (1937). Photoelectric Plethysmography of the fingers and toes in man, *Proceedings of the Society for Experimental Biology and Medicine*, 37, 1622–1637.
[4] Sorvoja, H. *et al.* (1998). Licentiate Thesis, University of Oulu (in Finnish).
[5] Ruha *et al.* (1996). in *Proceedings of Biosignal*, 1, 198–200.
[6] Dupuis & Eugene (2000). in *IEEE Transaction on Instrumentation & Measurement*, 49, 498–502.
[7] Gagnadre *et al.* (1998). in *Electronic Letters*, 32, 1991–1993.
[8] Kazuo Kodama, Hitoshi Ishiyama and Hiroshi Kasaha (1992). Visualisation and quantitative analysis of the pulse diagnosis in Ayurveda, Tokyo Denki University.
[9] Young-Zoon Yoon, Myeong-Hwa Lee and Kwang-Sub Soh (2000). Pulse type classification by varying contact pressure, *IEEE Engineering in Medicine and Biology*, 106–110.
[10] Shantanu Sur and Ghatak, S. K. An Inexpensive Arterial Pressure Wave Sensor and its application in different physiological condition, School of Medical Sc & Technology, Dept of Physics and Meteorology, Indian Institute of Technology, Kharagpur.
[11] Elizabeth O. Y. Lau and Allen T. Chwang, Fellow, ASCE Relationship between Wrist-pulse Characteristics and Body Conditions, *Department of Mechanical Engineering*, The University of Hong Kong.