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Nadi Tarangini: A Pulse Based Diagnostic System

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***Abstract*— *Ayurveda* is a traditional medicine and natural healing system in India. *Nadi-Nidan* (pulse-based diagnosis) is a prominent method in *Ayurveda*, and is known to dictate all the salient features of a human body. In this paper, we provide details of our procedure for obtaining the complete spectrum of the *nadi* pulses as a time series. The system *Nadi Tarangini*[1] contains a diaphragm element equipped with strain gauge, a transmitter cum amplifier, and a digitizer for quantifying analog signal. The system acquires the data with 16-bit accuracy with practically no external electronic or interfering noise.**

Prior systems for obtaining the *nadi* pulses have been few and far between, when compared to systems such as ECG. The waveforms obtained with our system have been compared with these other similar equipment developed earlier, and is shown to contain more details. The pulse waveform is also shown to have the desirable variations with respect to age of patients, and the pressure applied at the sensing element. The system is being evaluated by *Ayurvedic* practitioners as a computer-aided diagnostic tool.

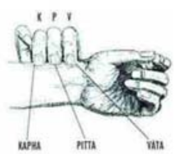
***Index Terms*— *Ayurveda*, pulse waveform, varying pressure.**

I. Introduction

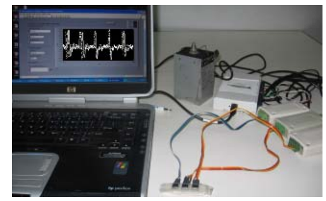
In the non-invasive Indian traditional system of *Ayurveda* it is believed that the function of entire human body is governed by three humors: *vata*, *pitta*, and *kapha*, called as *Tridosha*. The standard position to obtain *Tridosha* is through a "pulse waveform" obtained on a wrist with the index, middle and the ring fingers respectively [1] as shown in Fig .1(a). The *nadi* resembles the ECG which has been explored the most in the recent studies. The convenient, inexpensive, painless, and noninvasive pulse-based diagnosis (PBD) extracts the imbalances of *Tridosha*, which in turn identifies the presence and location of disorders in a patient's body [1].

The following points were considered while developing our system named *Nadi Tarangini*:

- One challenge in *Nadi-Nidan* is the skill of "feeling" the pulse, obtained by the master physician is too difficult when practiced by the novice. Due to this difficulty, many people still take it as a mystery. Thus, it would be useful to introduce *Ayurveda* through the waveform patterns & visualization of modern medicine.
- It would also be useful to extend the convenience, and the state of the art of diagnosis by applying machine learning algorithms on these waveforms to classify various types of *nadi*s in *Ayurvedic* literature [2].



(a) Standard position to obtain pulse



(b) Our set-up

Fig. 1. Pulse-based diagnosis methodology.

We describe an easy-to-use system that captures the arterial pulse as a time series data. We have checked the important properties of our collected pulse waveforms, such as reproducibility, completeness, variations with age & pressure applied, and so on. These observations were found to be consistent with the literature and, we believe, can be used quantitatively for identifying different types of *nadi*s.

The rest of our paper is as follows. After exploring previously developed methods in Section II, we describe our system in Section III. We compare our waveforms with previous methodologies, describe variations with respect to applied pressure and age in section IV and then we conclude with some final remarks.

II. Prior Work

A number of nonlinear methods have been developed for long to quantify the dynamics of physiological signals such as ECG, EEG, etc and have achieved some meaningful results. But the acquisition of pulse waveform is sporadic, not very trivial to obtain. We mention few of the recent pulse waveform acquisition methodologies here, which are mainly in Traditional Chinese Medicine (TCM).

The earliest work dates back to the1950s, when quantification of beat-to-beat changes in stroke volume was done using arterial catheter-manometer system [3], involving simultaneous recording of arterial pressure from multiple sites in the arterial tree. More recently, there has been a renewed interest in examining the arterial pulse. An arterial tonometer sensor array (model N-500, Nellcor Inc) [4], a wrist-watch-like structure with PSS-02KAF pressure sensors (Kyowa Electronic Instrument Co. Ltd. Japan) [5], a commercial grade photoplethysmograph transducer (Biopac Systems Inc., CA, USA) [6], a HMX pulse sensor (Shanghai Medical Instrument Company) [7], a pulse sensor with a strain cantilever beam transducer [8] are few of the recent methodologies used to acquire pulse data. Other interesting methodologies include an optical sensor setup consisting of infrared LED

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[1]*Tarangini* stands for cascaded waves

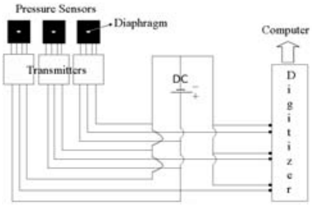


Fig. 2. Line diagram of *Nadi Tarangini*.

& three photodiodes [9], a condenser microphone with pre- and main amplifiers and Bessel filters [10].

III. Our System

In this section, we describe the salient features of *Nadi Tarangini*. The *nadi* pulses are sensed by the fingertip, which actually measure the pressure exerted by the artery. These pulsations are very minute in pressure units and therefore their acquisition is very challenging.

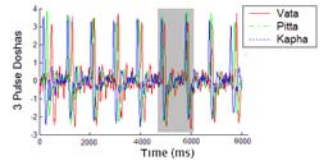
For this, initial experiments were carried out using a '1 PSI' pressure sensor from 'Sensym Products'; but were found to be inadequate for capturing the intricacies of the pulse. Hence, we have currently adopted 'Millivolt Output Medium Pressure Sensor' [Mouser Electronics, Inc.] with tiny diaphragm at the center, and having '0–4 inch H2O' pressure range.

As shown in Fig. 2, a set of three such pressure transducers is mounted on the wrist to sense three location pulses, namely *vata*, *pitta* and *kapha* [2]. The electrical signal proportional to the pressure experienced, in differential mode, by the pressure sensing element is then digitized using the 16-bit multifunction data acquisition card NI USB-6210 (National Instruments, TX, USA), having an interface with the personal computer. The data is captured at a sampling rate of 500 Hz (which is sufficiently higher than the Nyquist criteria) for a predetermined length of time. We use the data acquisition software LabVIEW (National Instruments, TX, USA), which controls the digitization as well. The minimum change in the signal, which can be measured, depends solely on the resolution of the digitizer.

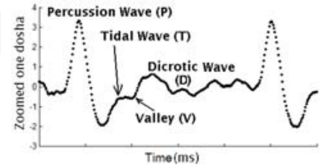
Sensor. Our strain gauge transducer is approximately of dimension $1cm \times 1cm$. It consists of a flexible diaphragm at the center (as shown in Fig. 2), which is a force-gathering element that gets deformed by arterial pressure waves. A Wheatstone bridge circuit consisting of three constant resistors and a variable resistor transforms the strain into a proportional electrical signal. In addition, the sensor utilizes a micromachined, stress concentration enhanced structure to provide a very linear output to measured pressure.

Transmitter. The transmitter is a standard industrial amplifier with 4–20 mA output, which linearizes and conditions the signal. While connecting to 16-bit digitizer, the 4-20mA is converted to 2–10 V through a resistor (500 ohm). It also provides the zero and span adjustments. The zero adjustment is calibrated to adjust the zero, such that at zero pressure (atmospheric pressure), the output is 4 mA. The span adjusts the degree of amplification for output of the signal.

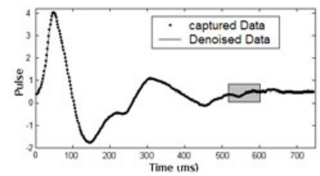
The data obtained in this way is usually corrupted because of implicit and explicit electronic and electrical noise, but the



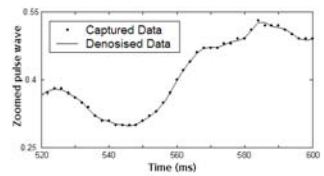
(a) Three doshas of a patient. *Pitta dosha* in the gray portion is zoomed in (b).



(b) Time-domain features in a pulse. The dotted style gives an idea of the number of points per pulse cycle.



(c) Denoising using wavelets.



(d) Zoomed version of (c).

Fig. 3. A sample pulse waveform in our database.

noise level obtained in our developed system is negligible, after proper shielding.

IV. Discussion

In this section, we analyze the waveforms obtained from *Nadi Tarangini*. Sample waveforms from the left hand of a patient using our system, as described in Section III are shown in the Fig. 3.

The three different colors in Fig. 3(a) represents the data obtained from the three different pressure transducers for *vata*, *pitta* and *kapha dosha*s respectively. The zoomed waveform in Fig. 3 (b) gives an idea of the number of points per pulse cycle (sampling frequency 500Hz) and also that it contains details in the form of secondary peaks. Though the pulse form is clean, we use wavelet denoising to remove the extreme high frequency component (Fig. 3(c)). The solid line (pulse after denoising) almost follows the dotted line (pulse captured from sensor). Fig. 3(d) depicts the denoised signal at better resolution.

A pulse waveform is usually composed of important time-domain features: percussion wave (P), tidal wave (T), valley (V) and dicrotic wave (D), as shown in Fig. 3(b). These wave-parts should be present in a standard pulse waveform with definite amplitude and time duration to indicate proper functioning of the heart and other body organs. These collected pulse waveforms are rich in harmonics and appear superior as compared to previously developed systems.

A. Comparison with earlier systems.

Fig. 4 shows few of the pulse waveforms from earlier works. These waves are of different patients, of different age groups, using various techniques and are of different resolutions. The subfigures from (a) through (o) are from [3], [11], [12], [4], [13], [14], [15], [16], [17], [18], [19], [20], [21], [8], [22] respectively. We observe that there has not been substantial improvement in the pulse waveforms from 1950s to the current methodologies in a form that permits diagnosis.

Feature extraction followed by machine learning methods depend not only on clinician's experience but also on the

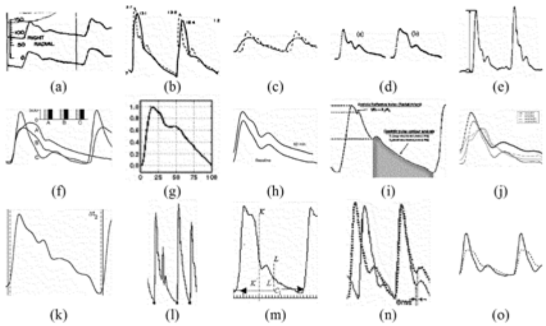


Fig. 4. Pulses as presented in selected earlier works, arranged in ascending published date.

quality of the pulse waveforms. We now provide some of our *normalized* pulses from various patients with different disorders, and age groups for the *vata dosha* in Fig. 5. It can be observed that there are distinctly observable patterns in each of the six pulses. For example, a healthy pulse has a main peak and 2 secondary peaks with regular behavior, whereas a fever pulse is very irregular in nature. Further, various other disorders are also reflected in the pulse waveforms as shown. We can observe variations in amplitudes, the rising & falling slopes, systolic & diastolic energies, velocities, and so on. Machine learning algorithms can be applied on these waveforms to distinguish major types of *nadis* defined in *Ayurveda* [1].

We find there is a strong temporal inter-beat similarity or correlation between successive beats. Heart rate variability (and now variability in pulse) more appropriately emphasizes the fact that it is the variations or the intervals between consecutive beats that is sometimes more important than the heart/pulse rate or the average values. Variability in various time-domain, frequency domain morphology-based features; such as amplitude, energies, angles, entropies, velocities have been explored [23], [8]. Such variability patterns can also be seen in the pulses captured by *Nadi Tarangini*.

Fig. 6 displays cross-correlation between two *doshas* (*vata* and *pitta*) of left hand, and one *dosha* (*vata*) of both the hands of a patient. The phase between them can be determined using the phase difference between the corresponding harmonics of the FFT. These cross-correlation features could also reveal some information about body conditions.

B. Important Properties of Pulse Waveform.

The complex pulse signals should be able to provide reproducibility, accuracy and precision. For our system, we checked the reproducibility and completeness as follows:

- In order to check the reproducibility, pulse waveforms of a single healthy person were recorded at different times from 10.30am to 5pm for five consecutive days with the same settings. It was observed that the Approximate Entropy (ApEn) of the waveforms, and the number of data points per pulse cycle remained (almost) constant for the same timings for the 5 days. There were some slight changes in the pulse shape, as the *nadi* is also sensitive to the mental status, stresses, thoughts, and so on.

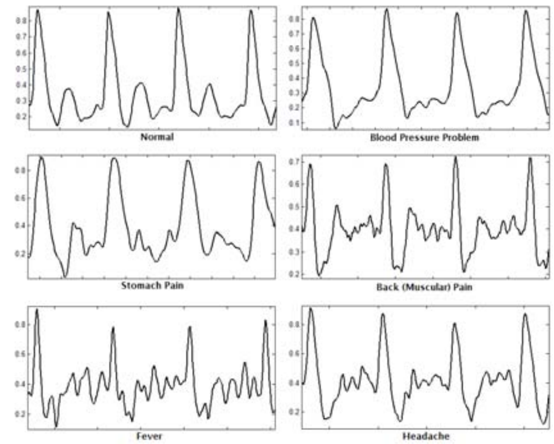


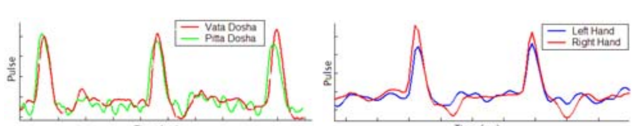
Fig. 5. Pulse waveforms using our methodology on patients with various disorders. Only one of the three acquired waveforms have been given for each type.

- In order to check the completeness of the acquired time series, *nadi* was acquired with the same sensor but of a digitizer having an accuracy of 8-bit, 12-bit and 16-bit for same set of patients. The details captured by 8-bit digitizer were less as compared to the 12-bit. As there was no significant new information from 12-bit to 16-bit upgradation, we claim that all the details have been captured. In all the further experiments a digitizer having accuracy of 16-bit is used.

C. Varying Pressure

In *Ayurveda*, the *nadi* is sensed by the *Ayurvedic* practitioners at the wrist with varying pressure. At different applied pressures, different amplitudes, energies etc. are sensed which are then correlated with the body conditions. Further, traditionally in TCM, the pulse has been classified simply as floating or sinking, according to whether the force exerted to detect the pulse is small or large [13]. We followed similar methodology of applying varying pressure using our system, and were able to confirm the desired behavior as shown in Fig. 7.

As the contact pressure of the sensor over the pulse point increases, the amplitude of the pulse signal first increases, reaching a maximum, and then decreases. After a particular threshold value, the pulse dies. All these observations are consistent with the *Ayurvedic* literature [1],[2]. At each pressure, the pulse gives different insights about the body. However at this point, we consider this finding to be only a appropriate observation which necessitates further investigation with much larger population samples.



(a) Two doshas of left hand (b) vata dosha of two hands

Fig. 6. Cross-correlation in pulse waveforms.

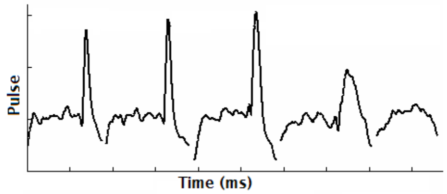
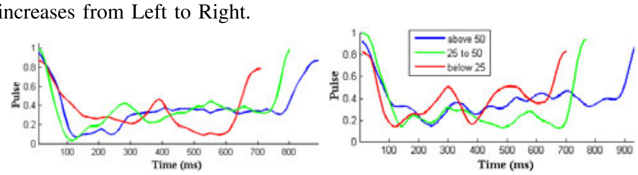


Fig. 7. The changes observed in the pulse waveform as the applied pressure increases from Left to Right.



(a) Left Hand (b) Right Hand

Fig. 8. Comparison in a pulse cycle for various age groups.

D. Variations with Age.

We now describe the changes in the pulse waveforms for 31 patients in our database depending upon their age. They are classified in age groups 'below 25', '25–50' and 'above 50'. We observed that the 'below 25' pulses are more dominant in secondary peaks. '25–50' group is relatively stable, while older pulses are irregular in nature. We have given samples of healthy *nadi* of 3 groups in Fig. 8 of both the hands. As can be seen, the pulse duration increases (rate decreases) as the age increases and also the patterns are different. Again, these observations are consistent with [4], [15]; the changes are indicative of an age-dependent reduction in large artery (capacitive) compliance and in small artery (oscillatory or reflective) compliance.

However, we consider all above findings to be only a preliminary suggestion to investigate further with much larger dataset. While applying machine learning algorithms on pulse dataset for identifying pulse type, we need to consider all the above dimensions, i.e. age, pressure applied, disorder and many more given in the literature.

V. Conclusion

Modern pressure sensors can reflect the "feeling" information used in the Indian system of *Ayurveda*, or in Traditional Chinese Medicine (TCM). We have adopted pressure sensing based methodology and the recent developments in instrumentation technologies in designing a high quality pulse acquisition system. Our pulse waveforms, in the form of time series, has high details, as compared to earlier reported systems. We showed that our waveforms are reproducible and complete. We also showed variations with respect to applied pressure and age groups which are consistent with *Ayurvedic* literature and prior work.

Based on this, we believe that our system can be used by a larger number of lay persons. We are currently evaluating, with the help of *Ayurvedic* practitioners the use of *Nadi Tarangini* for diagnostic purposes. Rigorous machine learning algorithms could be applied on these waveforms to classify them into major types of *nadi*s defined in *Ayurvedic* literature.

VI. Acknowledgments

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