International Journal of Community Medicine and Public Health
Manjunatha YC et al. Int J Community Med Public Health. 2023 Nov;10(11):4512-4519
http://www.ijcmph.com
pISSN 2394-6032 | eISSN 2394-6040

DOI: https://dx.doi.org/10.18203/2394-6040.ijcmph20233503

Review Article

Nadifit: a novel single position pulse based diagnostic system

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Received: 31 August 2023
Accepted: 03 October 2023

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ABSTRACT

Both traditional Chinese medicine (TCM) and traditional ayurvedic medicine (TAM) rely on a system of radial pulse diagnostics to assess a patient's health. The doctor or practitioner should place all three fingers on the patient's wrist and feel the styloid processes to detect any changes in the radial pulse. However, finding medical professionals skilled in pulse diagnosis or nadipariksha is becoming increasingly challenging in the current and upcoming generation. One technological approach that could solve this issue once and for all would be to transform objective pulse diagnosis into a subjective process. To automate this procedure, however, three separate sensors must be constructed for three positions in order to capture pulse at varying pulse pressures, which increases the hardware complexity for consumer use. To simplify the process and ensure a correct diagnosis, this study presents an effort to create the smart portable system Nadifit, which takes a single pulse reading from the patient. A single pulse is all that's needed to identify distinctive organ patterns, which can then be analyzed to provide insight into potential health issues. Analogue signals are quantified with the help of a microphone, a transmitter, and a 32-bit microprocessor. The data is acquired with a precision of 10 bits and virtually no electronic or contaminating noise outside of the system. The computer receives the collected pulse signal and does time and frequency domain analysis of the Nadi patterns, shapes, and width to determine the presence of the three ayurveda doshas (Vata, pitta, and kapha) as well as Chinese organ patterns (such as Qi stagnation, yin deficiency, yang excess, etc.). The experimental results demonstrate the effectiveness of the suggested system in identifying dosha, making it highly tailored to the individual patient's health issue. It is also demonstrated that the pulse waveform demonstrates the desired fluctuations in relation to patient age, pressure applied to the sensing element and full vs. empty stomach. Comparisons of stiffness across age groups are also performed. Practitioners, vaidhyas, and medical professionals are used to verify the system's accuracy. Hence, we believe a larger segment of the general public will be able to make use of our technology.

Keywords: Nadifit, Single position pulse measurement, TCM, Ayurveda, Pulse waveform

INTRODUCTION

Traditional Chinese medicine (TCM) evolve from the practices and experiences of ancient Chinese people as they sought to treat a wide range of illnesses. The four methods of diagnosis utilized in TCM are visual inspection, hearing and smelling examination, questioning, and palpation of the pulse.[1] Taking and feeling a patient's pulse is the most recognizable and crucial diagnostic tool. A pulse is the beating sound heard in the arteries caused by the heart's pumping action. TCM and ayurveda both refer to the rate, intensity, and depth of the pulse as a "pulse condition." Figure 1 depicts the vata, pitta, and kapha pulse zones of the radial artery in the wrist, also known as Cun, Guan and Chi. Just below the styloid process on the radius bone is the Guan, one finger in front of the Guan is the Cun, and one finger behind the Guan is the Chi.[2] The condition of the pulse and its pattern in the body indicates the dynamic role and health of the many organs in the human body.[3] For instance, the state of the heart and small intestine are represented by Cun on the left, whereas the state of the large intestine and lungs are represented by Cun on the right, and so on.[4] TCM practitioners use three fingers to locate Cun, Guan, and Chi in the wrist radial artery, adjust the intensity of the finger compression, and read the patient's pulse. Results from taking the patient's pulse and the other three diagnostic methods are used by TCM practitioners to make diagnoses and formulate treatment plans. The practice of taking a person's pulse as become increasingly common in recent years due to the fact that it is painless and does not require any invasive procedures. Despite its widespread use, pulse diagnosis has major shortcomings. To begin, a finger's assessment of a pulse is highly subjective and prone to error.[5] Second, it's challenging to pass on the knowledge of how to take a pulse, even if it does demand a lot of manpower and resources. Therefore, numerous academic institutions and specialists have investigated the subjectivity of obtaining a pulse.[6] The research often entails the collecting, analysis, and classification of pulse signals.

Instruments for monitoring pulse rate are the subject of serious study. The created device's primary capabilities are the simulation of TCM pulse diagnosis modes and the acquisition of crucial data for classifying pulses. Pulse measurements can be taken in one of two ways. Firstly, the traditional method "Three positions and nine indicators" (TPNI) idea involves taking your pulse in three different locations, and secondly, you can take your pulse in a single location (usually Guan). In the first method, practitioners of TCM place their index, middle, and ring fingers on Cun, Guan, and Chi, respectively, and apply mild (Fu), medium (Zhong), and hard pressure (Chen) to each area. As a result, the diagnosis process involves detecting a pulse at three different pressure levels, yielding a total of nine symptoms and twenty-eight pulse patterns. This makes system automation more complicated (both software and hardware design) and also leads to data quantification problem to derive five elements (Panchabhutas) or yin-yang from the pulse. The second method is single position which is simple and less complicated involves taking pulse only at one position usually Guan position (Pitta position in ayurveda). Pulse amplitudes of wrist pulse are different under different position and pulse-taking pressures. The pulse-taking pressure and position under which the amplitude of pulse is at maximum is called the best pulse-taking pressure. Pulse waveforms can show the quantity, shape, and strength of the pulse, while optimal pressure, position, and the trend of pulse amplitude with pulse-taking pressure can be used to evaluate the depth of the pulse. The final output of the device should include the pressure at which the pulse was taken and the pulse waveform, and it should be calibrated to meet the needs of diagnostic procedures in TCM as well as the ayurveda. Therefore, the creation of the pulse measurement device should involve sensor choice, pressurization, position adjustment, general mechanical construction, and the circuit design.

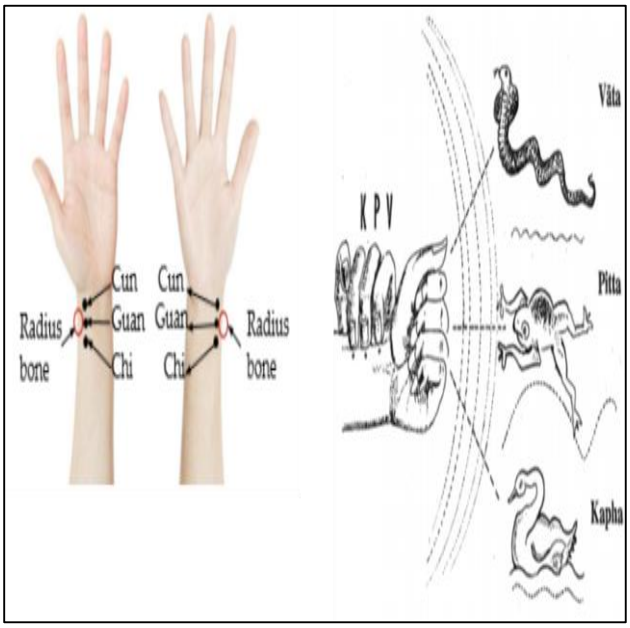

Figure 1: Three pulse regions of the radial artery in the wrist both TCM and ayurveda.

Many researchers and research institutes have conducted studies on pulse measuring devices in recent years. Most research employ piezo sensors or optical sensors as sensors. TCM practitioners typically take the pulse with their fingertips. The pressure produced by the fingers and the force of the pulse beat are important elements in determining the kind of pulse. However, optical sensors used in pulse measuring equipment monitor the change in blood flow in the artery, which differs from TCM in measurement methodology. The pulse diagrams produced by the two measuring techniques differ in substance. As a result, the optical sensor measurement data must be transformed and understood before being compared to the TCM theory. Much investigation is needed to determine the link between the two measurement outcomes. The use of optical sensors for measuring is indirect. Furthermore, most current research utilizing optical sensors without a pressurization structure makes it hard to imitate TCM physicians' measuring approach and acquire pulse-taking pressure.[2,7-10] As a result of the measurement principal difference and the lack of pulse information, the use of optical sensors in the development of pulse measuring devices is limited. Furthermore, piezo sensors failed to catch deep and slow pulse signals, making it difficult to detect minute changes in the pulse pattern using these sensors. An acoustic sensor is used for pulse collection in the proposed system to deal with these problems and reduce the likelihood of data loss. The method uses a single microphone sensor with exceptional sensitivity to record a single pulse for analysis.

An armrest unit, ultra sound microphone sensor, resonance media, signal acquisition circuit, signal processing software, microcontroller unit (MCU), Bluetooth low energy (BLE) module, battery, and other components are proposed in this study as part of a clinical wrist pulse measurement system to aid vaidhyas/doctors/practitioners. The fingertip sensor is used to mimic a manual pulse reading with minimal effort. In order to find the optimal pressure and location for taking a pulse, the sensor can be placed in a variety of pressure zones, as illustrated in Figure 2 A. It can detect and record pulses from a specific location. Maximum pulse amplitude is obtained by manually pressurizing and positioning the device.

LITERATURE SURVEY

Pulse diagnosis in TCM and nadiparikshsa in ayurveda have a rich history dating back thousands of years and serve as a foundation for differentiating TCM symptoms and prescribing and treating patients accordingly.[11] Taking a patient's pulse is a most mysterious process in TCM and ayurveda. The doctors' middle finger is first laid on the head of the radius, then followed by the index and ring fingers, the thumb rests upon the dorsum of the carpus. TCM's Cun, Guan, and Chi pulses, as well as ayurveda's vata, pitta, and kapha pulses, are felt in the radial artery of the index, middle, and ring fingers, respectively.

The traditional pulse theory represented Qi (the most essential substance to constitute the human body and sustain its life activity) stagnation and blood stasis, body fluid deficiency, essence and blood deficiency, whereas in modern pulse, unsmooth pulse represents inflammatory lesions, vascular sclerosis, plaque formation, etc.[12,13] In contemporary pulse theory, each level comprises unique physiological and pathological data. An irregular pulse at a particular level of the radial artery may be a sign of illness in a particular organ or tissue. Theoretically, the position of the irregular pulse can be used to determine the location and type of sickness.

Nowadays, researchers are increasingly using computerized methods to study TCM and ayurveda, which bridges the gap between modern and traditional medicine.[14] Changes in the waveform of your radial artery may reveal some of your body's inner workings.[15] Researchers are increasingly turning to computerized, objective analysis of sensor-collected pulse waves to assist them diagnose a wide range of disorders.[16-19] The entire procedure can be broken down into three distinct phases. First, obtain a wrist reading by means of a variety of electrical sensors. Second, an algorithm to extract those patterns is developed. Third, the subjects are checked using the algorithm or feature. Such as the work of Zhang et al.[16] The pressure sensor and photoelectric sensor pulse signals underwent three types of processing: stacked sparse auto encoder, wavelet scattering, and graph convolutional neural network. The researchers next developed a graph-based multi-channel feature fusion method for disease diagnosis, which they tested on diabetes, renal disease, and hyperlipidemia. According to Wang et al, the two components of continuous pulse waves-periodic and non-periodic-are important for clinical diagnosis.[17] As a result, they separated the two parts independently, combined them with the formula, and set up a diagnostic model. The model was then used to diagnose diabetes and pregnancy, where it showed considerable improvements in sensitivity, specificity, and accuracy. In the author combined a pressure sensor and a photoelectric sensor and employed them in a three-stage experiment, with pressure serving as the primary sensor and photoelectric as an ancillary one.[18] The first thing that was done was to examine the differences between the pulse waves recorded in Cun, Guan, and Chi using each individual sensor and the combined sensor. Part two involved contrasting the effects of Cun, Guan, and Chi pulse fusion with those of the fusion on its own. Third, using people with diabetes as test objects, the accuracy of this sensor was compared to that of other sensors and determined to be 93.07%. Using pressure sensors to capture the wrist pulses of healthy persons and lung cancer patients, the researchers identified 26 features in a single pulse cycle as a basis for discriminating between the two groups.[19] This method is based on the Jin's pulse theory, an important method of current pulse diagnostics. To separate the de-noised data into discrete time intervals, they created the Iterative Slide Window technique and discovered that the cubic support vector machine's recognition performance was enhanced by the usage of bagged trees classifiers. Exploration teams have developed acoustic-based pulse detecting systems in addition to pressure or photoelectric sensors.[20] The findings suggested a novel approach to the objective investigation of TCM pulse diagnosis, as the device's gathered pulse waveforms were found to be equally accurate regardless of the pulse pressure. Recent research has also demonstrated that heart sound measures and other acoustic signals from the radial artery can represent physiological characteristics of important organs.[21,22]

Thus, the waveforms detected in the wrist did not represent a pressure or photoelectric signal in absolute terms.[20] Moreover, stratification of pulse is rarely used in modern works.

In this work, we will discuss the feasibility of using acoustics for pulse diagnosis. The technology employs a single, highly sensitive microphone sensor to collect and analyze pulse data from a single location. In addition, the literature provides context for data collection at three depths. We have developed a new method whereby a single location for taking a pulse is sufficient for predicting the patterns of various internal organs. The organ patterns can be studied to make diagnoses. We've developed a novel method for gathering acoustic pulses. Pulse waves were captured and stored using high-quality MATLAB software before being analyzed using time-domain and frequency-domain techniques. To further verify the efficacy of the suggested method, a database of 600 subjects was considered, which included healthy people, people with chronic diseases, and people with acute illnesses.

SYSTEM ARCHITECTURE AND VALIDATION

As can be seen in Figure 2 A, proposed system consists of a fingertip holder and sensor holder and an armrest box. The fingertip holder is made out of rubber 8400 (2.5 MPa tensile strength). As can be seen in Figure 2 B, the sensor holder has been specifically built to provide the desired radial pulse pattern. It uses a condenser microphone as the pulse variation sensing element. To measure a signal, the microphone is pushed on the pulse measuring point through a tube-like structure designed to create resonance effect. The armrest box measures 300mm by 100 mm by 130 mm. Total weight of combined fingertip sensor and the armrest box is less than 500 g. The weight of fingertip sensor is less than 10 g, it contains a finger holding clip and sensor cap for easy capturing nadi signal. Sensor can be easily located to different regions with different pressures to find best pulse-taking pressure and position. I00t supports single position pulse acquisition mode. To get max pulse amplitude for analysis, manual pressurization and placement are required. Battery circuits, bluetooth low energy (BLE), and micro-controller (MCU) module are all housed in armrest box. Wireless communication board is hardwired to MCU.

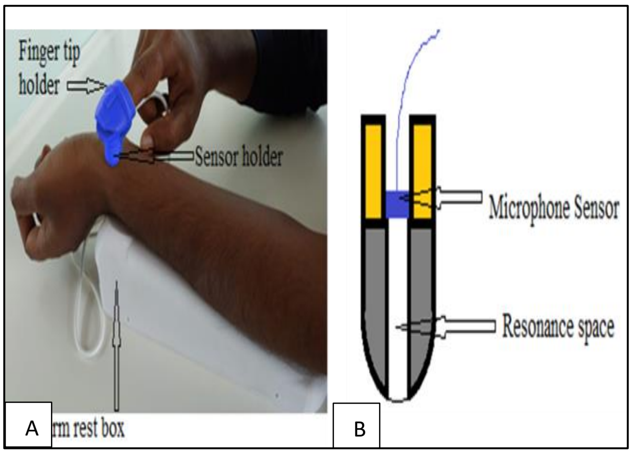

Figure 2 (A and B): Pulse capturing at single position using proposed system. Proposed custom sensor holder for pulse acquisition

Signal acquisition and processing

As can be seen in Figure 3 A, Nadifit gadget uses its sensor, filtering circuitry, and a computer to acquire and process pulse signal. System's microcontroller (MCU), analog-to-digital (A/D) converter, timer, and other components are all based on ARM7LPC2148. Microcontroller uses 5 V power supply. A/D converter has resolution of 10 bits. This pulse sensor operates on a 3.3 V power supply and has a sensitivity of -46 dB (electret condenser microphone). Microphone produces a signal on the millivolt scale. This complicates the microcontroller's ability to notice fluctuations in sensor output. A bias and amplifier circuit, depicted in Figure 3 B, developed and constructed to solve this problem.

Microphone's normal operating range was 2V, while its maximum voltage rating was 10V. The microcontroller unit (MCU) supplied 5V, thus the voltage was divided by two identical 1k resistors to reach the 2.5 V required to bias the microphone. A capacitor was connected to the microphone's output in order to filter out DC offset.

The employed capacitor was big enough to avoid filtering out the necessary low frequencies. The equivalent output impedance of the sensor is about 400 ohms when two 1 k resistors are connected in parallel with the microphone's output. Most of the low frequencies of relevance are suppressed by a simple high pass filter created using a 10 uF capacitor and a cutoff frequency of roughly 40 Hz.

In order to amplify AC-coupled signal, it was connected to operational amplifier's positive input (Vin+). Vin+ line of op-amp was biased to 2.5 V so that biggest positive and negative swings from microphone output could be captured by micro-controller ADC, which measures voltages between 0 and 5 V. To accomplish this biasing, 2nd voltage divider circuit was built out of pair of 20 k resistors, to prevent changing equivalent output impedance from previous stage, these resistors' values set to be bigger than resistors in prior voltage divider.

As shown in Figure 4 radial pulse is taken from a single location (often Guan) on the wrist, and software uses pattern to determine which doshas and panchabhutas are present. Using 10-bit ADC onboard LPC2148 MCU and a Bluetooth connection to a personal computer, we can digitize analogue signal produced by pressure detecting element. For a set amount of time, data is sampled at 100 Hz (much more frequency than required by the Nyquist criterion). MATLAB (math works, USA) is used for data collecting and control of the digitization process. The smallest change in the signal that can be detected is entirely dependent on the resolution of the ADC.

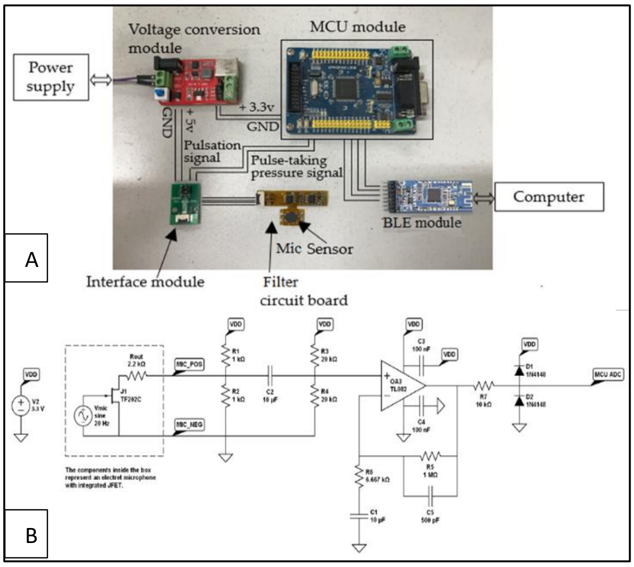

Figure 3 (A and B): Pulse acquisition and processing unit. Sensor data filtering and amplification circuitry.

DISCUSSIONS

Experiment with single-position measurement

In ayurveda, the nadi is sensed by the Ayurvedic practitioners at three different positions (Vata, Pitta and Kapha) on the wrist with varying pressure. At different applied pressures, different amplitudes, energies etc. are sensed which are then correlated with the body conditions. Furthermore, in TCM, the three pulse points (Cun, Guan, and Chi) were only classified as floating or sinking dependent on the amount of force needed to find them.[23] We followed similar methodology of applying varying pressure using our system but only at one position (Pitta in ayurveda and Guan in TCM). Pulse signals recorded by our sensor at three different locations in accordance with TCM and Ayurvedic principles are depicted in Figure 5. The optimum place to take a pulse is at the Gaun/Pitta location on the wrist, where the amplitude is maximum (marked as red) compared to other places (marked as blue). Further, it is observed that pattern is same in all the three signals except the change in amplitude. Our Nadifit software prefers the single signal (Gaun/Pitta position) having highest amplitude and performs pattern analysis using machine learning algorithms in order to identify three doshas (in ayurveda) and panchabhutas (in TCM).

Nadifit implements strong feature extraction techniques followed by machine learning models depend not only on clinician's experience but also on the quality of the acquired pulse. Feature extraction involves extracting variable features like amplitude, energies, variance, standard deviation, angles, entropies, velocities both on time-domain as well as in frequency domain. Such variability patterns can also be seen in the signals captured by Nadifit.

Figure 6 shows the cross-correlation between two pulse signals captured at single best pulse-taking position of both hands. It is observed that both hand patterns are almost same with slight difference and these cross-correlation features could also reveal some information about body conditions.

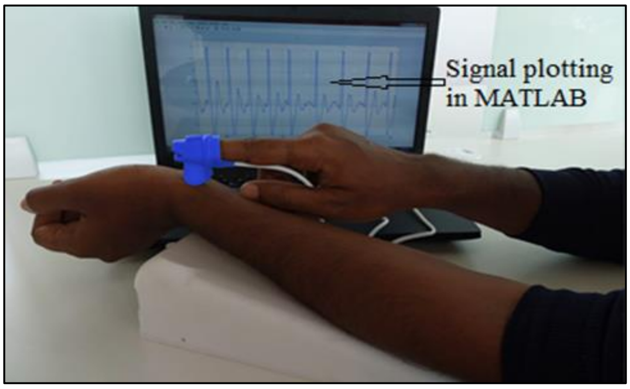

Figure 4: Real time pulse acquisition and analysis using MATLAB.

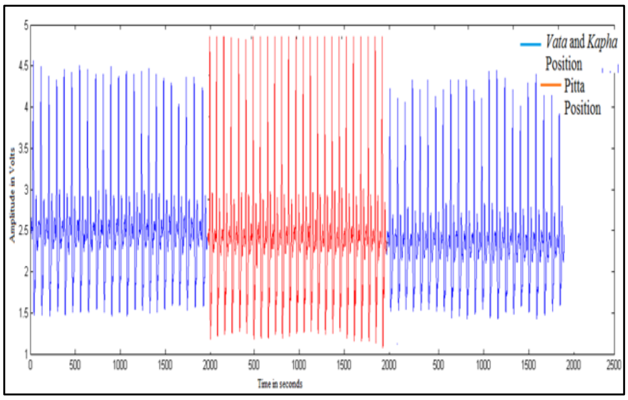

Figure 5: Pulse signals captured from our sensor at 3 different positions as in principles of TCM and ayurveda.

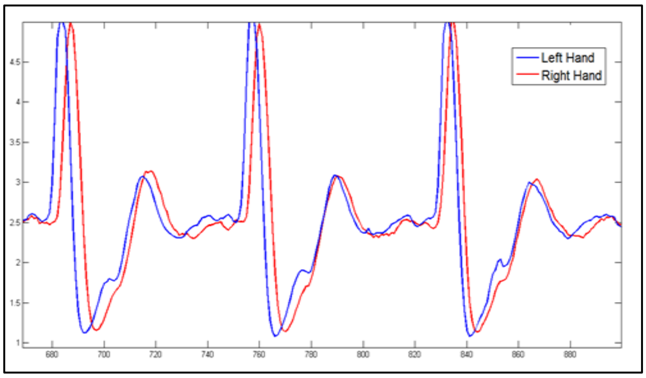

Figure 6: Pulse signals captured at single best position on both hands.

Disease diagnosis using single-position measurement

There are more than a hundred distinct nadi signals stated in Ayurveda and TCM, making diagnosis based on these patterns extremely difficult. Additionally, change in the patient's emotional and physiological status are reflected in their nadi patterns. With the help of artificial intelligence and pattern recognition Nadifit has made an attempt to derive tridoshas and five elements (panchabhutas) from a single pulse through which any patient can be diagnosed and treated.

The nadi is captured at single position (as mentioned earlier) and data analysis is performed to identify the root cause of the disease. Further discussion on disease diagnosis using Nadifit will be discussed in further research publications.

Validation of the system

Pulse parameters

The PPG-acquired digital volume pulse (DVP) is a combination of both incident and reflected waves. The diastolic peak occurs during the diastolic phase and is caused by the reflected wave. The overall route length of the pressure wave (from the artery's origin to its reflection point and back to its origin) and the individual's height determine the time difference between the systolic and diastolic peaks. The stiffness index (SI) is the ratio of a person's height to the time difference between their systolic and diastolic blood pressure peaks, whereas the reflection index is the inverse of this relationship.[24]

The pulse data acquired by Nadifit is a continuous wave and Figure 7 corresponds to single pulse wave isolated from stream of pulse waves.

The stiffness indices are computes as follows:[25] Stiffness index (SI)=height of the person/(T4-T1), Reflection index (RI)=diastolic peak/systolic peak (P4/P1) and fullness Index (FI)=(P3/P1).

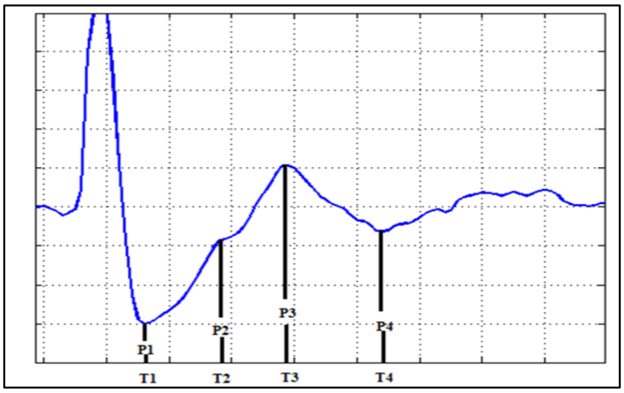

Figure 7: A pulse wave obtained with Nadifit that illustrates the different radial pulse peaks and times. P1=pulse amplitude at systolic peak; P2=pulse amplitude at inflection point; P3=pulse amplitude at dichrotic notch; P4=pulse amplitude at diastolic peak; from the beginning of the systolic phase, time periods T1, T2, T3, and T4 are monitored. T1 denotes the systolic peak time; T2 the inflection point time; T3 the dichrotic notch time; and T4 the diastolic peak time.

Variation of SI and RI with respect to different age groups

The proposed system's viability is tested on participants of varying ages treated by well-respected TCM and *Ayurvedic* doctors. The group comprises of 40 healthy individuals younger than 25, 55 individuals between the ages of 25 and 50, and 33 individuals older than 50 with chronic conditions. It has been determined that pulse signals "below 25" are noticeably quicker and more rapid. The 25-50 age range is rather steady, while the 65+ range is more prone to fluctuations and noise. Age-related differences in pulse rhythms are depicted in Figure 8 A. As can be seen, both the pulse rate and force diminish and the patterns change with age.

Table 1 displays the results of an age-adjusted analysis of the means of SI and RI for pulse signals collected at a single point. The SI and RI values of people who have different dosha predominance have been found to vary significantly. The SI of people who are predominantly pitta is the highest among the three dosha types. It also demonstrates that a single, optimally-taken pulse may detect and predict an individual's arterial stiffness.

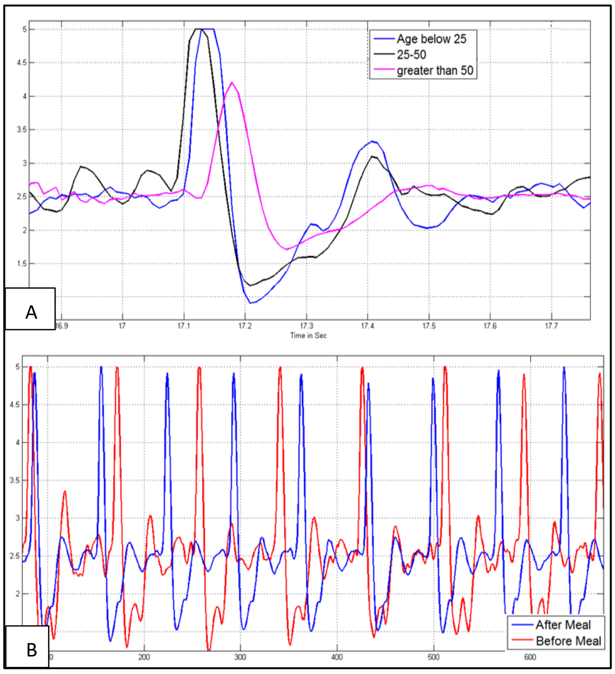

Figure 8 (A and B): Variation of pulse patterns with respect to age groups and variation of pulse patterns before and after meal.

Table 1: The means of SI and RI for pulse signal captured at single position.

Age groups (In years)	Parameters	Pulse captured at single position		
		VATA dominant	**PITTA dominant**	**KAPHA dominant**
Age below 25	SI (m/s)	4.9464±0.434	9.1667±2.032	6.3462±2.281
	RI	2.1944±1.056	1.7309±1.356	1.6707±1.1875
Height (cm)	Ht (cm)	168.12±10.43	165.56±12.55	162.46±1.8783
Age 25-50	SI (m/s)	5.154±1.145	8.787±2.897	5.688±2.5566
	RI	2.453±1.245	1.956±1.988	1.61±1.154
Height (cm)	Ht (cm)	167.87±11.75	164.56±11.46	163.77±1.733
Age greater 50	SI (m/s)	5.2676±0.897	10.343±2.454	7.265±2.544
	RI	2.1944±1.056	1.856±1.5434	1.5933±1.066
Height (cm)	Ht (cm)	166.76±10.067	167.99±13.99	167.44±12.556

Table 2: Means of FI values for pulse signal captured at single position, where n=number of participants.

Age groups (In years)	Parameters	Pulse captured at single position	
		Before meal	**After meal**
Trial 1, (n=8)	FI	1.7996±0.654	2.1597±1.056
Trial 2, (n=10)	FI	1.6574±0.5871	1.9897±0.876
Trial 3, (n=6)	FI	1.7076±0.435	1.9109±0.912

Variation of FI with respect to full and empty stomach

In addition, as shown in Figure 8 B, we conduct an experiment in which we take a person's pulse both before (on an empty stomach) and after they have eaten. Overall pulse amplitude was considerably higher after a meal, making it simple to distinguish between pre- and post-meal states. After eating, there was more activity in the stomach and a higher rate of blood flow. Consistent with increased strength, the pulse was also longer and wider.

Table 2 displays the average FI values obtained from multiple experiments where pulse signals were recorded from the same location. In each test, participants' pulses are taken both before and after they eat. The FI parameter is found to fluctuate noticeably between when the stomach is full and when it is empty. It has been demonstrated that the levels of stomach fire (jataragni) can be determined for disease diagnosis through the use of single pulse analysis and the FI parameter.

CONCLUSION

The purpose of this research is to aid vaidhyas, doctors, and practitioners by proposing the Nadifit clinical wrist pulse measurement system.

This system consists of a combined armrest unit, ultra sound microphone sensor, resonance media, signal acquisition circuit, signal processing software, a microcontroller unit (MCU), Bluetooth low energy (BLE) module, battery, and other components. Resembling the manual pulse reading, the sensor tip can be simply connected to the end of a finger. In order to determine the optimal pressure and position for taking a pulse reading, the sensor can be moved to various regions on the wrist radial position. The mode can acquire pulses from a single location. Maximum pulse amplitude for analysis requires manual pressurizing and placement. The device utilizes a sensor containing an acoustic microphone to record the pulse from a single position (the Guan in TCM and the pitta in ayurveda). Our time-series pulse waveforms have significantly more detail than those of previously disclosed systems. Our waveforms were shown to be fully formed and reproducible. Consistent with prior research and TCM literature, we also showed variations in response to pressure, age, and stomach empty and fullness. There is also an examination of stiffness in terms of age groupings. Based on this, we believe that our system can be used by a larger number of lay persons. We are currently collaborating with TCM doctors and ayurvedic vaidhyas to evaluate Nadifit's diagnosis accuracy. Rigorous machine learning algorithms could be applied on these waveforms to classify them into major types of nadi's defined in TCM literature.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

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Cite this article as: Manjunatha YC, Raghu B, Pavan KYC. Nadifit: a novel single position pulse based diagnostic system. Int J Community Med Public Health 2023;10:4512-9.