www.jmss.mui.ac.ir

A Novel Method for Pulsometry Based on Traditional Iranian Medicine

Farzane Yousefipoor, Vahidreza Nafisi[1]

Department of Electrical and Computer Engineering, Tarbiat Modares University, [1]Department of Electrical and Information Technology, Iranian Research Organization for Science and Technology, Tehran, Iran

Submission: 01-08-2015 Accepted: 05-10-2015

ABSTRACT

Arterial pulse measurement is one of the most important methods for evaluation of healthy conditions. In traditional Iranian medicine (TIM), physician may detect radial pulse by holding four fingers on the patient's wrist. By using this method, under standard condition, the detected pulses are subjective and erroneous, in case of weak and/or abnormal pulses, the ambiguity of diagnosis may rise. In this paper, we present an equipment which is designed and implemented for automation of traditional pulse detection method. By this novel system, the developed noninvasive diagnostic method and database based on the TIM are way forward to apply traditional medicine and diagnose patients with present technology. The accuracy for period measuring is 76% and systolic peak is 72%.

Key words: *Automation, Heart Rate, Pulse, Wrist, Fingers, Cardiovascular Physiological Phenomena, Traditional Iranian Medicine*

INTRODUCTION

Every ventricular contraction pumps blood to aorta. This results in expansion in aorta and spreads as a wave in arteries. The pulse wave may be palpate in any place that allows an artery to be compressed against a bone. This palpation that leads to the movement of arteries walls is named as pulse. Pulse (or the count of arterial pulse per minute) is equivalent to measuring the heart rate. In adults, normal pulse rates at rest times are between 60 and 100 (in beats per minute [bpm]). The pulse characteristics and rhythm is a diagnostic symptom in tachycardia, bradycardia, arrhythmia, and other cardiovascular diseases.

One of the common palpable sites for pulse measurement is radial artery. This pulse includes important information about people's health. It is good to mention the history of using pulse measurement in old medicine. Traditional Chinese pulse diagnosis (TCPD) in traditional Chinese medicine has been clinically valuable for more than 2000 years. Chinese physicians usually use three fingertips to feel the pulse fluctuation at three positions, named "cun" "guan," and "chi," respectively. They apply different pressures independently on a patient's wrist over the radial artery, named "fu," "zhong," and "chen" to feel and acquire the wrist-pulse pattern and then judge the health condition of the patient according to their professional skills.[1] It is known as "Three Positions and Nine pulse-Takings." In this paper, the device is localized for Iranian people and based on traditional Iranian medicine (TIM). It is one of the novelties of this design.

Based on TIM, Avicenna was a prominent physician of the late 900s and early1000s who systematized medicine in Islamic Iran. All his books and papers on medicine except for "Nabz" (Pulse), "Anatomy," and "Judiyeh" were in Arabic. His "Canon in medicine" gave medicine a shot in the arm. It was used for centuries as a major medical reference in the world, particularly in Europe. His books are some of the best references for pulse measuring.

The rationale for pulse analysis is based on the fact that blood travels with different rates in different organs, resulting in different patterns that allow characterization of the health condition of a particular organ.[2] Thus, through the vessels

Address for correspondence:
Farzane Yousefipoor, Department of Electrical and Computer Engineering, Tarbiat Modares University, Tehran, Iran.
E-mail: f.yousefipoor@gmail.com

How to cite this article: Yousefipoor F, Nafisi V. A Novel Method for Pulsometry Based on Traditional Iranian Medicine. J Med Sign Sense 2015;5:230-7.

some visceral states and diseases can be identified by means of wrist-pulse diagnosis. Retrospective clinical studies on pulse analysis of patients with severe liver problems,[3] septic problems,[4] and arteriosclerosis[5] showed that the condition of organs can indeed be reflected in wrist-pulse patterns, completely.

It is desirable to improve healthcare by introducing a wider use of TIM. However, wrist-pulse assessment is a matter of technical skill and subjective experience. The accuracy depends upon the individual's persistent practice and quality of sensitive awareness. Wrist-pulse diagnosis is difficult to understand. Objective measuring equipment, automatic wrist-pulse waveform acquisition, and intelligent analysis would, therefore, enable an integration of traditional diagnosis knowledge and skills with modern technology, which may extend the use of such device.

The quality of the wrist-pulse signal can be influenced by the kinds of unavoidable interferences and noises, which arise from breathing, speaking, muscular vibration, and limb trembling during wrist-pulse retrieval. It is necessary to design a moderate and accurate taking pressure method for the wrist-pulse retrieval. Measurement and control of the taking pressure is accomplished, but the stability and accuracy of this method do not yet satisfy the clinical requirements.

Previous projects in TCPD research appearing worldwide in China, Japan, India, Korea, Germany, Canada, and the US have focused on wrist-pulse retrieval, pulse-wave pattern recognition, and pathological diagnosis. Apparatuses and systems have been demonstrated with the same interests as our method.[6]

The PPG waveform comprises a pulsatile ("AC") physiological waveform attributed to cardiac synchronous changes in the blood volume with each heartbeat, and is superimposed on a slowly varying ("DC") baseline with various lower frequency components attributed to respiration, sympathetic nervous system activity, and thermoregulation.[7] These characteristics are also site-dependent.[8] The AC and DC components of the PPG signal can be extracted with suitable filtering and amplification and subsequently used for pulse wave analysis.

In this paper, we introduce a new device that can measure the pulse rate, based on TIM. Since the traditional methods are as strong as before, designing a system that can measure pulse automatically and independently of physician, seems necessary. In pervious diagnoses, it was probable that the physician cannot determine the correct position of wrist-pulse, while it was so important in some diseases such as arrhythmia. On the other hand, in traditional method, exact diagnosis was not approachable. In this study, a device has made that is independent of physician and it is more accurate in pulse diagnosis than human. The sample and low-cost sample device, with limited usage, has made by Nafisi and Sakhavi in 2012.[9] In this design, 7 sensors are considered that can help the best diagnosis.

METHODS

In this study, a robotic finger has been developed which can work as a real finger for pulse measurements. For this purpose, we need some special sensors. We used optical sensors and put them at the end of the robotic finger, which were placed on the skin. Light intensity scattered from the given source by the tissue and a suitable photo-detector collected them. This sensors have infrared wavelengths and used for measuring blood volume changes. They are suitable for pulse measurement purposes, because of the absorption of blood vessel hemoglobin and oxy-hemoglobin in these wavelengths.

The pressure of pulse wave is measured with capacitor microphones. The size of these microphones is small and would be appropriate for mounting on the robotic finger.

To make sure that the finger is in complete touch with the wrist of subjects, force sensitive resistance (FSR) sensor is used. FSR sensor measures the applied force on the skin. It can measure the maximum pressure that results the best pulse diagnosis. The amount of applied pressure is important because of making reliable data. Not enough pressure may lead to noisy data, especially for photodetectors.

The combination of these three parts, lead to a robotic finger that can measure radial pulse as well as a pulse oximeter. Figure 1 shows a normal pulse waveform.

Figure 2 shows the infrared sensor waveform.

The overall system has four fingers that can simulate physician's fingers. These fingers have been controlled with stepper motors. At the end of hardware processing, collected data are transmitted to PC. The transmission device is a serial port which is named "advantec 7402." Then, received data in PC have been analyzed with Matlab

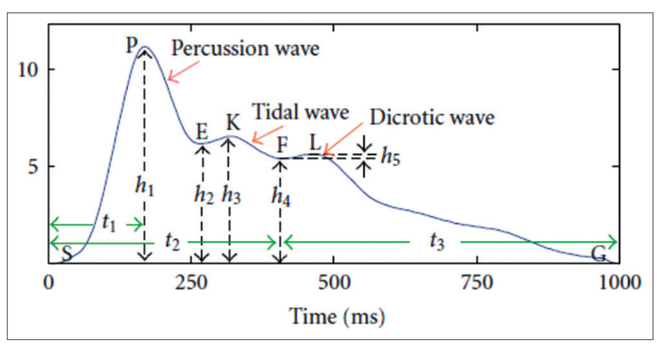

Figure 1: Ideal waveform of pulse

2012.[10] Some important features were extracted from signal and the cure pulse plotted for users.

Infrared Transmitter-Receiver

There are some key factors that can affect the amount of light received by the photodetector: Blood volume, blood vessel wall movements, and the orientation of red blood cells.[11] An increase in blood volume resulted in more absorption and this lead to more light attenuation.

The sensor used for this purpose is CNY70. It is a reflective sensor that includes an infrared emitter and phototransistor in a leaded package which blocks visible light.[12,13] Blood volume in capillary bed of tissue changes in systole and diastole phases, then light intensity varies, as a result, the pulse would be made and it's alternation would be seen in oscilloscope.

Force Sensor

During pulse measurement, an appropriate pressure is needed. In this case, the pressure is one of the important parameters in pulse analysis, and effects on pulse quality signal-to-noise ratio (SNR). However, the wrist-pulse signal has small amplitude and low SNR and some internal interference such as breathing, speaking, and muscle vibration, disturbed it. It is a challenge to retrieve high-quality, clinically relevant wrist-pulse data under the unavoidable external interference. Therefore, a wrist-pulse signal conditioning circuit and a robust external taking pressure control algorithm are designed to overcome low SNR.[13]

A good solution for pressure measurement is FSR. Embedding an FSR sensor for every robotic finger is a perfect solution. As said before, we have 4 robotic fingers. Force sensitive resistors, or FSRs, are robust polymer thick film devices that exhibit a decrease in resistance with an increase in force applied to the surface of the sensor.[14] This force sensitivity is optimized for use in human touch control of electronic devices such as automotive electronics, medical systems, and in industrial and robotics applications.

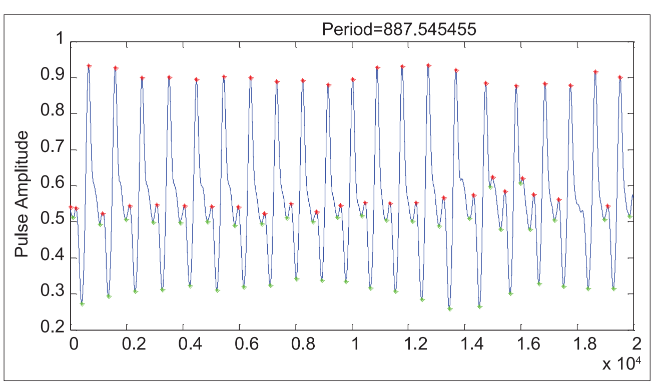

Figure 2: Waveform of infrared sensor

Capacitor Microphone

This sensor measures wrist pulse changes, in another way. In fact, usage of capacitor is measuring the stroke of the pulse.

Analog to Digital Converter

We need to convert analog signals into digital values which are suitable for digital hardware. It is, therefore, required to define an adequate sampling rate. This value is 100 samples per second in our method. Whole data in every experiment transmitted and saved to MATLAB software in PC using this analog to digital converter device ("advantec 7402").

Mechanical Part

A stepper motor is embedded to control the position of the robot's finger on the subject's wrist. Every step resolution should be as small as appropriate pressure accuracy. Figure 3 shows this mechanism. This part is an automatic version of physician's control on his fingers in traditional medicine. The physician would adjust his finger pressure proportional to subject's sex, age, etc. The motor can move up or down the finger, in every step.

MATLAB Software

As mentioned above, data are transferred to PC using serial port. Figure 4 shows the software flowchart in this study.

Figure 2 shows a part of processed and plotted signals using MATLAB. In addition, determination of time-domain parameters of pulse signals is done in MATLAB.

Based on the definition, the parameter h1 is the amplitude of percussion wave, reflecting the ejection function of the left ventricle and the resilience of the main artery. The parameter T_1 represents the left ventricular ejection time. The parameters are computed based on the characteristic points, of which, S is the onset of percussion wave, P is the peak of percussion wave, E is the onset of tidal wave, K is the peak of tidal wave, F is the onset of dicrotic wave, and L is the peak of dicrotic wave [Figure 1].[9]

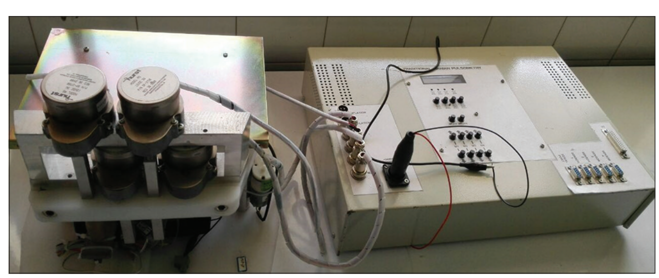

Figure 3: Mechanical part of device

To remove the effect of fake points on the signal, we should consider a threshold value. This value is related to maximum and minimum of waveform amplitude. Values which are greater than half of difference between maximum and minimum of amplitude, are considered as an accurate peak.

Feature Extraction

Heart rate

Heart rate is the distance between every two peaks in pulse signal. Moreover, it is the speed of the heartbeat measured by the number of poundings of the heart per unit of time - typically bpm.

Systolic amplitude (peak point of primary wave)

Absolute maximum in each cycle of waveform is named systolic peak. The period of ventricular contraction of the cardiac cycle is called systole. In addition, this period is one of the important features for pulse. In this paper, this feature is considered.

Dicrotic notch amplitude

Dicrotic notch is third local maximum in pulse signal. It is a sign of heart valves response to blood volume pumped. It is a small, downward deflection observed on the down stroke of an arterial pressure waveform. It represents closure of the aortic or pulmonic valve at the onset of ventricular diastole. The local minimum between two peaks in pulse waveform shows dicrotic notch.

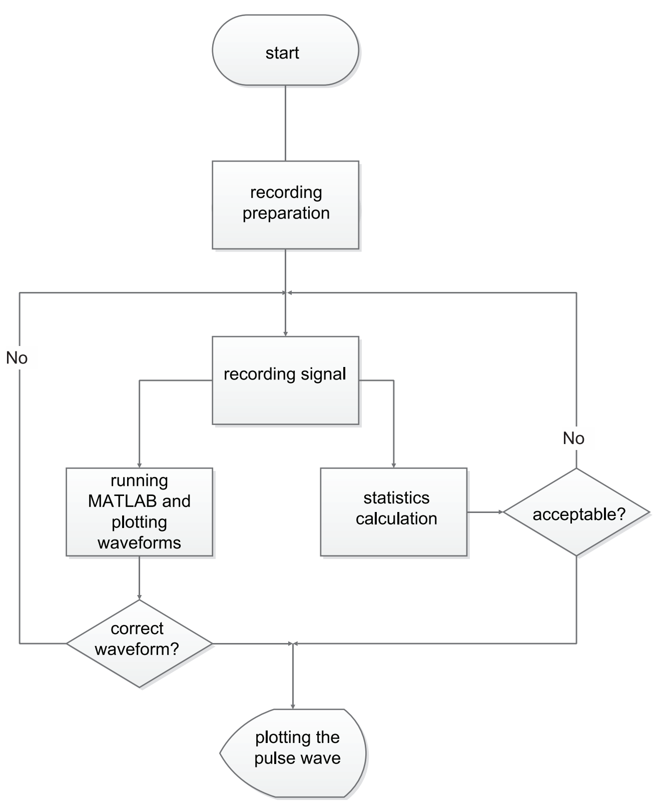

Figure 4: The plan block diagram

As you move further out, in perfect circumstances, when measured in the aorta, this notch is very sharp and it actually does represent the closing of the aortic valve.

As mentioned below, the dicrotic notch position varies with the position of the arterial line.

A suspiciously low dicrotic notch could mean very poor vascular resistance, for example, in a situation such as severe septic shock. In addition, there is an increase in human age influence vascular resistance, so the appearance of dicrotic notch is not clear.

Diastolic amplitude (peak point of secondary wave)

There are two peaks in normal pulse waveform. As said, first one is systolic peak and the second is named diastolic peak. This peak represents the ejection of blood behind the heart valve.

Area of pulse

Area under pulse waveform is a criterion that shows the power of pulse and is a traditional feature in waveform analyzing.

Vessels resistance

Vessels resistance refers to the resistance that must be overcome to push blood through the circulatory system and create flow. It's resultant of ratio between systole to diastole amplitude. Figure 5 shows the mentioned feature on the pulse waveform.

In Figure 5, a, b, c, and d points are the onset of pulse period, systolic peak, dicrotic notch, and diastolic peak, respectively.

RESULTS

Repeatability, Reproducibility and Accuracy

The device experiments In these experiments, several times to prove its r epeatability and reproducibility. 5 steps on the right hand of 5 subjects for 1 min are studied. Reproducibility surveyed for all data was collected from each subject. Table 1 [Figure 6] shows the result of repeatability.

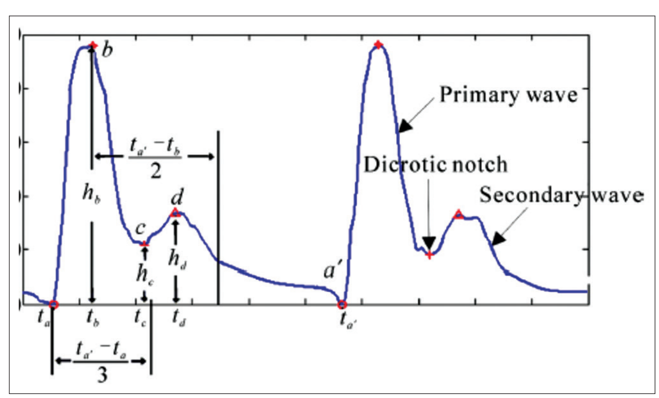

Figure 5: An illustration of important feature (points) in pulse

Figure 5 shows more focused repeatability. This graph is just plotted for T_1 parameter [Eq. 1].

$$T_1 = t_b - t_a \quad (1)$$

The accuracy was surveyed using 5 subjects' data. The results were compared with data collection of pulse oximeter for every same subject. The pulse oximeter model was Dolphin medical co. (OEM 701). Table 2 [Figure 7] shows the accuracy of the device.

The pulse is calculated using Eq. 2 (also T_1, replacing period with T_1):

$$\text{number of pulse beats (per minutes)} = \frac{60 \times 1250}{\text{Period}} \quad (2)$$

Where period values are depicted in Table 1, and the sample rate is 1250 samples per second.

Figure 8 shows repeatability results for 25 data, just for period. Every column shows a comparison between period value computed within our device and pulse oximeter.

The correlation between two signals, in pulse oximeter and pulsometer device was calculated too. The average value of correlation coefficient was 0.8.

Analysis of reproducibility was performed using statistical test such as *t*-test and Bland-Altman (BA). BA plots were used to detect agreement and bias. The graph shows the average of two measures on the horizontal axis (i.e., x-axis) and the difference between two values on the ordinate (i.e., y-axis). BA plots showed an absence of bias in measures of repeatability and of reproducibility. The averages observed for the repeatability and reproducibility are not significantly different from 0. The limits of agreement are expressed as averages of the differences ±1.96 standard deviation (SD)[11] [Figures 8].

The results in Table 2, applying *t*-test, show that there are no significant differences between every pair of these means.

Table 3 [Figure 9] shows the accuracy for 5 analyzed data for 5 subjects.

In previous section, we checked repeatability, reproducibility, and accuracy of the heart rate. This section describes the result of statistical test for other features. Tables 4 and 5 [Figures 10 and 11] show repeatability, reproducibility, and accuracy for these features. In Table 4, every feature for one subject in 5 repetitions is shown. In Table 5, the analyzed data from our device were compared to pulse oximeter data, as mentioned before.

The results show that these features are repeatable [Table 4], and Table 5 demonstrates that these features are accurate.

Table 1: Comparing repeatability for every subjects

T_1	Period	h_b
331.1	1009.4	320.6
393.6	919.5	253.2
358.5	1063	277.7
278.4	1091.5	354.6
234.2	955.7	299.7
Mean: 319.2±63.5	Mean: 1013.8±78.41	Mean: 301.15±39.01
Range: 234.2-393.6	Range: 955.7-1063.0	Range: 253.2-354.6

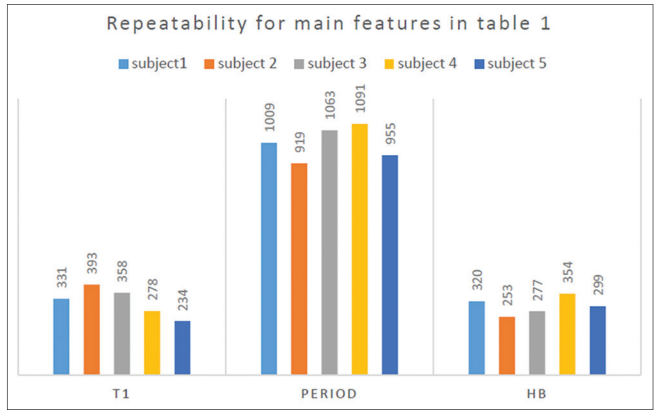

Figure 6: Repeatability for T1, hb, and period. Consider that these features have different ranges. There are 5 subjects that have repeatable data

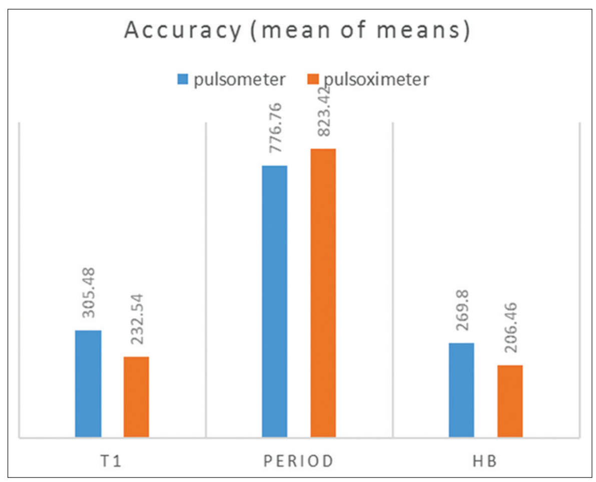

Figure 7: Accuracy for data in Table 2. Shown values are mean of means of data. Consider that these features have different ranges

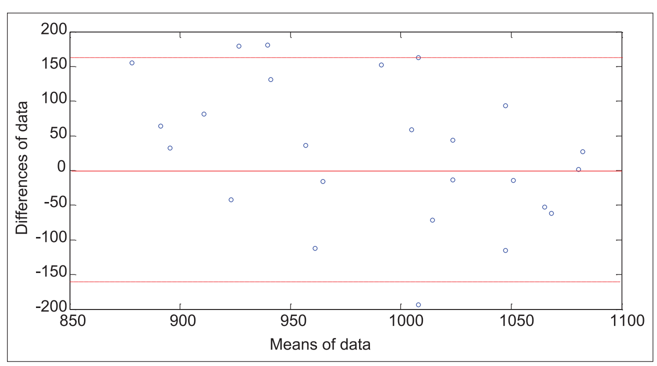

Figure 8: Bland-Altman analysis of the reproducibility under different experimental conditions

Figure 12 shows the reproducibility using BA algorithm. The diagram for all features is something like this that makes sure the data are reproducible.

Since the data are in the limits of agreement (averages of the differences ±1.96 SD), the result of data recording is reproducible and it confirms the functionality of device.

CONCLUSION

In this study, we define a multi-sensors pulsometry system that works based on TIM. The aim of this study was increasing the reproducibility and pulse analyzing in TIM. Used sensors are photodetector (infrared) and capacitor microphones that are used for blood volume and pressure changes measurement in the artery, respectively. After signal recording with robotic finger, the data are transferred to the PC using ADC hardware. MATLAB software analyzed the data. Some special features such as T_1 and H1 are extracted from processed signal. The experiments repeated for 12 subjects, 5 times repetitions and 1 min duration. Reproducibility, repeatability, and accuracy were calculated. The device had enough sensors to be sure about accuracy and precision of pulse information. In addition, the pressure was controllable by stepper motors. Some important features, such as systolic amplitude, dicrotic

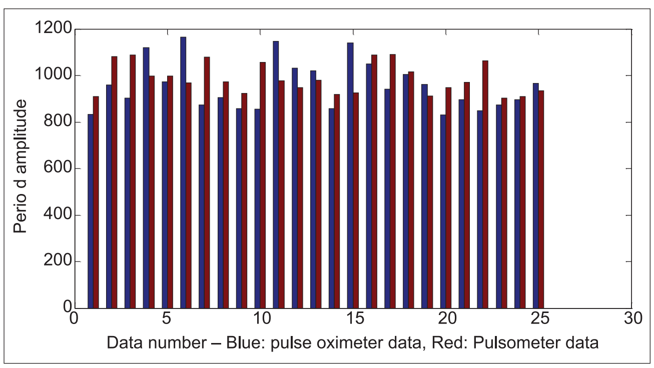

Figure 9: Accuracy in 25 data – period

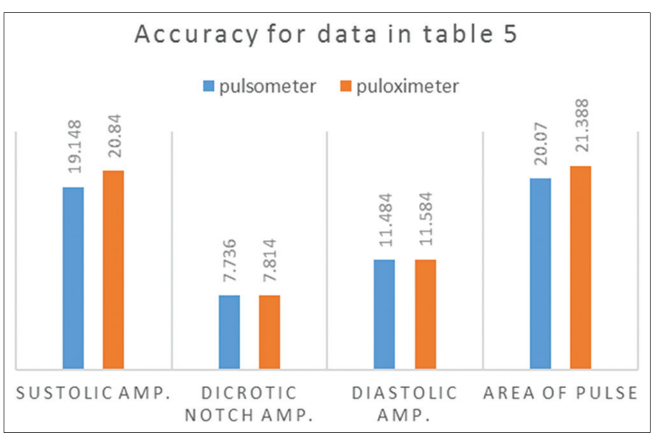

Figure 11: Accuracy for features in Table 5. Consider that these features have different ranges

Table 2: Repeatability and accuracy in 5 subjects (means of data)

T_I mean (pulse oximeter)	T_I mean	Period mean (pulse oximeter)	Period mean	h_b mean (pulse oximeter)	h_b mean
238.7	441.9	976.3	1071.9	250.1	386.8
275.9	318.1	1053.1	865	263.5	284.7
304.9	367.1	1089	999.3	248.7	217.3
333.6	294.8	937.4	1162.1	385.8	314.4
343.2	400.3	998.7	947.6	270	460.2

Table 3: Repeatability and accuracy in 5 subjects (SD of data)

T_I SD	Error percentage	Period SD	Error percentage	h_b SD	Error percentage
62	25	68	24	47	49
117	43	73	33	33	5
76	8	69	26	16	50
51	38	68	24	39	23
103	25	55	~0	22	30 s

SD – Standard deviation

Table 4: Repeatability for 5 features in 5 repeats for one subject

Systolic amplitude	Dicrotic notch amplitude	Diastolic amplitude	Area of pulse	Vessels resistance
22.23	7.36	10.16	21.29	3.02
21.72	8.64	13.48	18.14	2.51
15.34	8.00	12.83	19.51	1.91
18.11	10.93	10.63	22.23	1.65
16.94	7.06	13.47	25.39	2.39

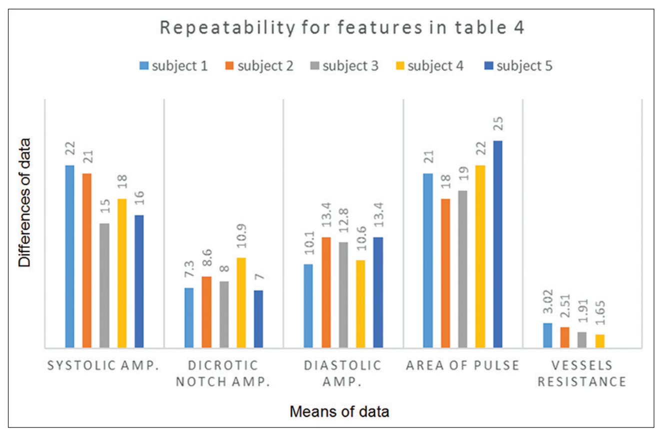

Figure 10: Repeatability for features in Table 4. Consider that these features have different ranges

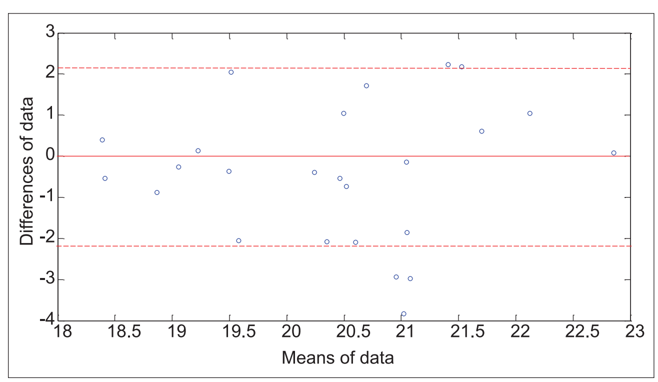

Figure 12: Reproducibility for systolic amplitude (Bland-Altman analysis)

Table 5: Accuracy for 5 features in 5 subjects (the values are averaged)

Systolic amplitude	Dicrotic notch amplitude	Diastolic amplitude	Area of pulse	Pulse oximeter			
				Systolic amplitude	Dicrotic notch amplitude	Diastolic amplitude	Area of pulse
19.67	6.42	13.13	19.24	18.48	7.47	10.87	22.07
21.29	7.16	10.06	19.48	19.39	6.10	12.85	22.52
16.98	8.90	11.11	18.05	20.73	8.57	12.78	18.63
19.37	8.51	12.32	20.73	22.78	7.96	10.42	22.56
18.43	7.69	10.80	22.85	22.82	8.97	11.00	21.16

notch amplitude, diastolic amplitude, area of pulse, and vessels resistance are also measured and reproducibility, repeatability, and accuracy were determined for them. The result of device test can confirm that it is accurate and the data recording process is reliable. Therefore, the device can be used in clinic as a utility and help the physician in better diagnosis.

One of the limitations of this device is that it is not portable. In addition, the sensors are not exactly coincident with the physician's finger sensors.

The improvement of this device and making a full electromechanical device are the future plans of our research team.

Acknowledgment

We thank Ms. Mina Shahabi for assistance with special techniques and comments that greatly improved the manuscript.

Financial Support and Sponsorship

Nil.

Conflicts of Interest

There are no conflicts of interest.

REFERENCES

1. Michard F, Boussat S, Chemla D, Anguel N, Mercat A, Lecarpentier Y. Relation between respiratory changes in arterial pulse pressure and fluid responsiveness in septic patients with acute circulatory failure. Am J Respir Crit Care Med 2000;162:134-8.
2. Xia C, Rui L, Runi L. Wrist Pulse Feature Variability Analysis Via Spectral Decomposition. In Bioinformatics and Biomedical Engineering, 2009. ICBBE 2009. 3rd International Conference on IEEE; 2009.
3. Sareen M, Sareen M. Nadi Yantra: A Robust System Design to Capture the Signals from the Radial Artery for Non-invasive Diagnosis. In Bioinformatics and Biomedical Engineering, 2008. ICBBE 2008. The 2nd International Conference on IEEE; 2008.
4. Yoon YZ, Lee MH, Soh KS. Pulse type classification by varying contact pressure. IEEE Eng Med Biol Mag 2000;19:106-10.
5. Xu L, Zhang D, Wang K, Li N, Wang X. Baseline wander correction in pulse waveforms using wavelet-based cascaded adaptive filter. Comput Biol Med 2007;37:716-31.
6. Tyan CC, Liu SH, Chen JY, Chen JJ, Liang WM. A novel noninvasive measurement technique for analyzing the pressure pulse waveform of the radial artery. IEEE Trans Biomed Eng 2008;55:288-97.
7. Gong J, Shilong Lu, Rui Wang, Li Cui PDhms: "Pulse Diagnosis via Wearable Healthcare Sensor Network". In Communications (ICC), 2011 IEEE International Conference on IEEE; 2011.
8. Fu S, Lai S. A system for pulse measurement and analysis of Chinese medicine. in Engineering in Medicine and Biology Society, Images of the Twenty-first Century., Proceedings of the Annual International Conference of the IEEE Engineering in IEEE; 1989.
9. Pei-Yong Z, Hui-Yan W, A framework for automatic time-domain characteristic parameters extraction of human pulse signals. EURASIP J Adv Signal Process 2008. p. 55.
10. Allen J. Photoplethysmography and its application in clinical physiological measurement. Physiol Meas 2007;28:R1-39.
11. Greco A, Ragucci M, Liuzzi R, Gargiulo S, Gramanzini M, Coda AR, *et al*. Repeatability, reproducibility and standardisation of a laser Doppler imaging technique for the evaluation of normal mouse hindlimb perfusion. Sensors (Basel) 2012;13:500-15.
12. Nafisi V, Sakhavi S. Today Technology for Yesterday Experiment: Design of a Device for Analyzing Pulse Based on Traditional Medicine. 4th Conference on Electronic Health, 2000, Mashahd.
13. Nafisi VR, Firoozmand M. Desing of a Pulsometer for Using in Traditional Medicine. Tehran: Iranian Research Organization for Science and Technology (IROST); 2013. p. 90.
14. MATLAB and Statistics Toolbox Release. Natick, Massachusetts, United States: The MathWorks, Inc.; 2012a.

BIOGRAPHIES

Farzane Yousefipoor received the B.Sc and M.Sc. degrees in Biomedical engineering respectively from Amirkabir University of technology in 2012 and Tarbiat Modares University in 2015. Her research interests include biological Signal Processing, Bioinstrumentation and Cognitive Science.

E-mail: f.yousefipoor@gmail.com

Vahidreza Nafisi received the B.Sc degree in electrical engineering from the Isfahan university of technology, Isfahan, Iran in 1985. He received his MSc and PhD degrees in Biomedical engineering from Amirkabir university of technology respectively in 1995 and 2005. His research interests include biological signal/image processing and bioinstrumentation.

E-mail: vrnafisi@yahoo.com