33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

A Pulse Wave Simulator for Palpation in the Oriental Medicine

Ki Young Shin, Seung Oh Jin, Su Hyun Youn, Su Bin Joo, Yo Han Jo, Oh Kyung Kwon and Young Huh

Abstract*—Pulse diagnosis, which is one of methods of diagnosis, is an important factor in oriental medicine. However, a problem in diagnosis with the pulse is that there is no objective standard. Therefore, the practitioners pass on the skill and students learn about pulse diagnosis as a method that depends on speech. In this study, the electronic pulse wave reproduction apparatus, which is an objective and accurate means for measuring the pulse, was developed. The previous model reproduced the pulse wave in one part of the point, but it was made by using three pairs of voice coil motors (VCM) in order to similarly express the three parts of the pulse: Cun, Guan and Chi. To evaluate this system, the output of the pulse wave was confirmed in order to reproduce the pulse wave with these settings. Consequently, the targets for slow pulse and rapid pulse have a 7 ms standard deviation, which is within the error tolerance. A voltage value of H_1, utilized to verify vacuous pulse and the replete pulse, has a standard deviation range of 4.7-5.4 mV. This system, which is similar to a person's pulse diagnosis, can be used to educate others in pulse diagnosis both quantitatively and scientifically.

I. INTRODUCTION

IN western medicine, people are diagnosed through physical checkups and testing equipment. However, in oriental medicine, doctors diagnose according to their senses and the patient's symptoms[1, 2]. There are four methods used in the oriental diagnosis process: interrogation, visual inspection, auditory and olfactory observation, and palpation[2].

The method of diagnosis for pulse taking and palpation is to feel one's pulse and examine a part of the body such as the abdomen to obtain data[2, 3]. These diagnostic methods have been integral parts of oriental medicine. While it has fought the same diseases since ancient times, it is the product of experience through repetition and practice[2].

Manuscript received April 15, 2011. This work was supported by grant from the Ministry of Knowledge Economy, Republic of Korea (Grant No. 10028436).

K. Y. Shin is with the Korea Electrotechnology Research Institute, Ansan, Korea (e-mail: kyshin79@gmail.com).

S. O. Jin is with the Korea Electrotechnology Research Institute, Ansan, Korea (e-mail: sojin@keri.re.kr).

S. H. Youn is with the Sungkyunkwan University, Suwon, Korea (e-mail: younsh00@skku.edm).

S. B. Joo is with the Sungkyunkwan University, Suwon, Korea (e-mail: 1001subin@paran.com).

J. H. Jo is with the FT Global inc., Siheung, Korea (e-mail: sanjing2@empas.com).

O. K. Kwon is with the FT Global inc., Siheung, Korea (e-mail: ok0461@nate.com).

Y. Huh is with the Korea Electrotechnology Research Institute, Ansan, Korea (corresponding author to provide phone: +82-31-8040-4150; fax:+82-31-8040-4109; e-mail: yhuh@keri.re.kr).

The term pulse diagnosis is defined as judging and diagnosing a patient's physical condition based on their heart rate[4]. It analyzes the altered pulse of a patient who has a disease based on a healthy person's moderate pulse. The practitioners pass on the skill to students, who learn that it is a method that depends on speech and personal experience. It is the most important elements of diagnosis in oriental medicine[2, 3, 4].

Although a pulse wave has a complex nature, it acts according to a rule. Therefore, developing an analytical ability to judge your own thinking subjectively and independently allows you to make an accurate diagnosis[2].

However, a problem in diagnosis with the pulse is not only that there is no objective standard, but that it could result in misdiagnosis due to a doctor's condition, prejudice and judgment. Because the heart rate changes based on the environment, it is difficult to objectively diagnose the pulse wave of the human body[2, 3]. Therefore, it is necessary to have standard equipment that allows for the development of an objective standard for pulse analysis by oriental students and doctors.

Hence, the electronic pulse wave reproduction apparatus, which is an objective and accurate means for measuring the pulse, was developed. It is important that the device simulating the pulse accurately reproduces the pulse wave. The former device that beats a pulse only beats one part of the whole[7]. However, taking the pulse is generally composed of three parts. The right middle finger, called Guan, is located in the nearest radial artery from the belly of the skeleton which is located near the styloid process of the fibula. The index finger and ring finger, called Cun and Chi respectively, are located next to Guan[2]. All three parts of the device to be able to reproduce the pulse wave, Cun, Guan and Chi, were developed.

Cun, Guan and Chi can each be controlled separately and the reproduction of the pulse wave was proved to be within the margin of error tolerance at the feature point of the outside interface. This occurred when reproducing a moderate pulse wave, slow and rapid pulses, and for vacuous and replete pulses.

II. SYSTEM DESCRIPTION

A. The materialization of reproducing the pulse wave

Shown in Fig. 1 is one of the diagnosis methods in oriental medicine. The location of the radial artery is given in order to measure the pulse wave, since the skin is thin and the artery is on the surface layer.

The general method of pulse diagnosis is to feel the pulse with fingers whose locations are divided into three parts of pressure, Cun, Guan and Chi. Each of their characteristics can help understood the condition of patients.

In this study, the electronic pulse wave reproduction apparatus was developed to act like a moderate pulse wave in three parts, Cun, Guan and Chi, and in the following modes: slow pulse, rapid pulse, vacuous pulse and replete pulse.

Fig. 1. Location and Method of Pulse Diagnosis

B. The composition of pulse wave reproduction

As shown in Fig. 2, it requires a large system to reproduce the pulse wave through a part of the radial artery.

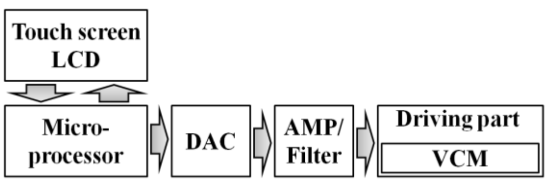

Fig. 2. System Composition for a Pulse Wave Reproduction Device

The system gives time and amplitude information to express the characteristic of the pulse wave by touch screen. It consists of an LCD to display settings, a microprocessor to form the pulse wave using the input data, a digital-to-analog converter (DAC) and an amplification/filter to change the calculated pulse wave into an analog signal. Voice coil motors (VCM, LVCM-013-013-02, Moticont, USA) reproduce the pulse wave, and the device control contains a linear motor.

As shown in Fig. 3, the pulse wave reproduction device uses a VCM. The VCM controls the Cun, Guan and Chi separately, so the generated pulse is closer to an actual pulse.

C. The method of reproducing the pulse wave

To reproduce a pulse wave, a user enters a total of 11 feature points at the User Interface (UI): T_1 toT_5, T_{end}, and H_1 to H_5. The entered feature points add dots through interpolation. Digital dots are converted into wavy analog through the DAC. After that, the analog signal is amplified to reproduce the pulse wave in a range that's easier to use.

The microprocessor controls the period of the pulse wave based on the speed of the pulse and the electric current depending on whether it is a vacuous pulse or a replete pulse.

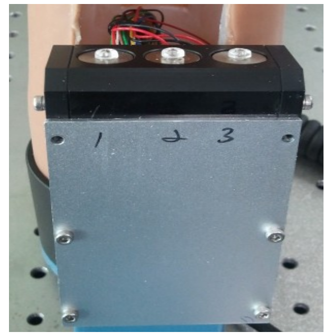
Fig. 3. A Motor for the Device Control

III. Experiment

A. Components of the system

The system that reproduces the pulse wave is shown in Fig. 4. Three of the VCM include the artificial arm for operating, the touch-screen for the UI, and the produced pulse wave. The pulse wave which is already restored can be selected, or a new pulse wave can be entered by entering new feature points.

A Data Acquisition (DAQ) board (USB-6218, National Instruments, USA), which has been widely used for measurement, was used to measure data at 2000 samples per second.


Fig. 4. A System the Reproduces the Pulse Wave

B. Method of measurement

In order to evaluate the properties for the pulse wave reproduction system, it measures the output analog signal. That is, it reproduces the pulse wave according to the entered feature points, such as in Fig. 5, and compares the output pulse wave.

To measure the output pulse wave, the DAQ board is used. Through Labview programming, the real time wave signal is measured and the feature points are sampled. The algorithm that samples and records time (T) and voltage (H) values chooses feature points as the points where the differential changes in the measured signal.

In this study, the method to evaluate the developed system accurately compares the difference between the T and H values at the sampled feature points and the entered values.

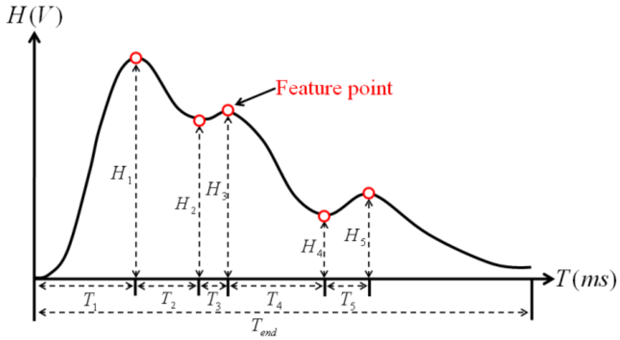

Fig. 5. Feature Points of the Pulse Wave

IV. Result & Discussion

In order to estimate the developed electronic pulse reappearance system, setups corresponding to moderate pulse, slow pulse, rapid pulse, vacuous pulse and replete pulse are input, and 100 waves for each pulse are acquired. Specific points for each pulse wave are acquired from the mean data of 100 waves. Mean difference, standard deviation, and signal power are also calculated to use in the electronic pulse reappearance system assessment.

In general, comparing a moderate pulse to a slow pulse and a rapid pulse is possible by differentiable tempos of pulse waves, fast and slow. The time to finish a period of the pulse is the decisive factor to compare speed. From the time taken in one cycle, short means an increase of pulse speed per minute, and long means a decrease in pulse speed. Pulse wave strength is key in distinguishing vacuous pulse and replete pulse from moderate pulse. In this case, the highest value of voltage is a factor which can be used to compare strong and weak signals.

TABLE I
Input Data for the Feature Point

	Slow pulse (ms)	Moderate pulse (ms)	Rapid pulse (ms)
T_1	97	69	47
T_2	47	34	23
T_3	77	55	37
T_4	96	69	47
T_5	47	34	23
T_{end}	1200	857	600

Slow and rapid pulse estimation starts with setting fixed voltage values that match H_1 to H_5. Table I shows voltage values T_1 to T_5 and T_{end}. T_{end} is the time taken for one cycle, and can be applied to BPM calculation. The range of a healthy man's pulse is 60-90 BPM, where less than 60 BPM means slow pulse and more than 90 BPM means rapid pulse.

Table II gives measured T values. Comparison of initial inputs and measured outputs gives verification to the reappearance pulse wave. The Mean difference for T_1 to T_5 ranges from 0.11-13.16 ms, with a standard deviation range of 1.400-6.911 ms. T_{end}, which can be a prime factor to determine the speed of the pulse, has a mean difference of 0.25-5.33 ms and a standard deviation of 1.97-5.33. In addition, the % Error spans 0.03-0.52 %, which is low. The results above shows a 70 BPM moderate pulse, a 50 BPM slow pulse, and a 100 BPM in rapid pulse, which are equal to the result of input T_{end}. The % Error values from T_1 to T_5 should be accepted as accurate, but the actual data in cases with a high % Error is not used.

TABLE II
Results of Measuring the Pulse

		Slow pulse (ms)	Moderate pulse (ms)	Rapid pulse (ms)
T_1	Avg.	99.37	68.89	47.15
	M.D.	2.37	0.11	0.15
	S.D.	4.67	2.91	1.69
	%Error	2.44%	0.16%	0.32%
T_2	Avg.	54.18	35.77	24.03
	M.D.	7.18	1.77	1.03
	S.D.	4.58	2.95	1.40
	%Error	15.28%	5.21%	4.48%
T_3	Avg.	76.04	49.82	34.59
	M.D.	0.96	5.17	2.41
	S.D.	4.57	3.68	2.36
	%Error	1.25%	9.42%	6.51%
T_4	Avg.	97.33	67.47	46.24
	M.D.	1.35	1.53	0.75
	S.D.	3.54	2.98	2.47
	%Error	1.39%	2.22%	1.62
T_5	Avg.	60.16	38.52	27.01
	M.D.	13.16	4.52	4.01
	S.D.	6.91	4.50	3.08
	%Error	60.16	38.52	27.01
T_{end}	Avg.	1206.20	857.25	599.65
	M.D.	6.20	0.25	0.35
	S.D.	5.33	3.75	1.97
	%Error	0.52%	0.03%	0.06%

The strength of the pulse wave in the cases of vacuous pulse and replete pulse are controlled by regulating the strength of the motors which correspond to Cun, Guan and Chi to +2 or -2 at the pulse wave reappearance system, and the resultants are compared. The inputted H_1 for vacuous pulse and replete pulse are in Table III.

TABLE III
Input Data for the Feature Point

	Vacuous pulse (Volts)	Moderate Pulse (Volts)	Replete pulse (Volts)
H_1	3.6	4	4.4

To compare pulse waves, the highest value at a specific point, and signal power as in equation (1) are compared. Measured values present in volt.

$$P_f = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} \left(\left| f(t) \right|\right)^2 dt \quad (1)$$

Measured values from input data are shown in Fig. 6. Results like this are from different voltage values, time specific points for different pulse waves, and changes in pulse strength at vacuous pulse and replete pulse levels.

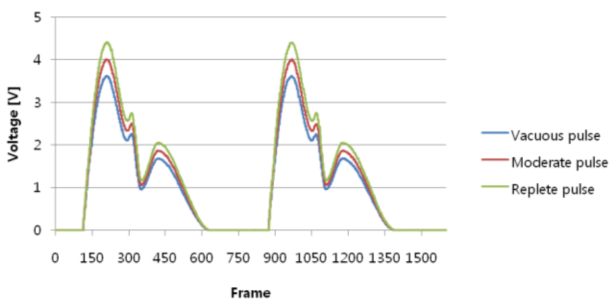

Fig. 6. A Graph Obtained from the Measured Data

In Table IV below, H_1 is the highest specific point value from each specific point in the form of a voltage value. Through the H_1 value, the change in mean values is given, which is used to confirm the difference between real and rearranged, vacuous pulses, and replete pulses. Standard deviation calculated is in the low range, 4.7-5.4 mV. Moreover, in a way to estimate signal power, equation (1) is proposed, and comparing results shows a difference in strength between moderate pulse, vacuous pulse, and replete pulse.

TABLE IV
Results of Measuring the Pulse

		Vacuous pulse (volt)	Moderate Pulse (volt)	Replete pulse (volt)
H_1	Avg.	3.61	4.01	4.41
	M.D.	0.0125	0.0159	0.0102
	S.D.	0.0047	0.0054	0.0054
	%Error	0.35%	0.39%	0.23%
Signal power		2.43	2.99	3.60

On the whole, specific points of T_1 to T_5, and T_{end} which related to slow pulse and rapid pulse gives 7 ms of standard deviation, within error tolerance. Volt value of H_1, utilized to verify vacuous pulse, and replete pulse, shows range of 0.0047-0.0054 V standard deviation, which indicates that there is “little in change.” Each measured values allows comparing pulse waves, and from this, rearranged pulse waves appear in the allowable error range.

V. Conclusion

Pulse diagnosis, which can classify a patient's disease information, is a way of diagnosis that oriental doctors use to examine subjects with their fingers on three parts of the radial artery: Cun, Guan, and Chi. The existing pulse diagnosis method can only be instructed by one's conjecture or opinion because pulse diagnosis only depends on the sense of the oriental doctor’s diagnosis. The reason for this stems from the lack of existing products to communicate between educator and trainee[4]. Therefore, objective information, quantification and reliability, are needed for the sake of learning pulse diagnosis.

In order to develop objective reproduction apparatus, equipment that can reproduce input data with low error is needed. The reproduction device made through this study showed a mean difference of 0.11-13.16 ms for T_1 to T_5 with 1.400-6.911 ms of standard deviation. T_{end}, which is a prime factor in determining the speed of pulse, has a mean difference of 0.25-5.33 ms and 1.97-5.33 ms standard deviation in the cases of slow/rapid pulse. Through the H_1 values, change in mean values is given, which is used to confirm the difference between real and rearranged, vacuous pulses, and replete pulses. Standard deviation calculated was in the low range of 4.7-5.4 mV.

On the whole, each measured value allowed comparing pulse waves, and from this, rearranged pulse waves appear in the allowable error range.

Randomized three pulses of Cun, Guan, and Chi can be reproduced with three pairs of motors, and many pulse waves can also be reproduced by utilizing these data. Furthermore, the developed pulse wave reproduction system was able to reproduce different pulse waves for patients of different age groups [6].

Henceforth, various comments about pulse waves from many oriental doctors will be collected and applied to the system developed in this study. If the device can materialize similar pulse waves of real humans, this apparatus can be used as an instructional indicator for the clinicians who would like to acquire a sense for pulse diagnosis.

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