International Journal of the Physical Sciences Vol. 7(32), pp. 5224-5229, 23 August, 2012
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.1136
ISSN 1992 - 1950 ©2012 Academic Journals

Full Length Research Paper

Myocardial ischemia diagnosis by pulse wave derived form factor analysis

Kang-Ming Chang[1,2]*, Shing-Hong Liu[3] and Chu-Chang Tyan[3]

[1]Department of Photonics and Communication Engineering, Asia University, 500, Lioufeng Rd., Wufeng, Taichung 41354, Taiwan.
[2]Graduate Institute of Clinical Medical Science, China Medical University, Taichung, Taiwan.
[3]Department of Computer Science and Information Engineering, Chaoyang University of Technology, Taichung, Taiwan.

Accepted 21 August, 2012

Pulse wave analysis with computerized diagnosis was used for myocardial ischemia patients. Novel feature derived from form factor of pulse signal was investigated. Form factor is estimated from variance of pulse signal waveform. Pulse waves were measured using newly developed three-axis sphygmography. Three groups participated in this study: 16 patients diagnosed with myocardial ischemia (positive), 19 healthy subjects (control) and 28 subjects exhibiting myocardial ischemia-like symptoms (negative). Form factor distribution and pulse wave variations of the three groups were calculated. Six form factor values derived from both hands' acupoints on Cun, Guan, and Chi were calculated. Data showed that there were significant statistical differences between myocardial ischemia patients and healthy subjects with respect to form factor, especially for Cun and Guan points (p<0.01). The negative group showed similar results to the myocardial ischemia patients. This study showed that form factor will be potential feature for pulse signal. It can be applied for the early screen of myocardial ischemia candidates by form factor features.

Key words: Form factor, myocardial ischemia, pulse wave analysis.

INTRODUCTION

Traditional Chinese medicine utilizes four major techniques for diagnosing illnesses: observation of the patient's face; assessment of the patient's odor, verbal discourse investigating the patient's state of health and measurement of the patient's pulse wave variation, technique which incorporates pulse wave analysis (PWA) (Xue et al., 2010). This type of analysis allows for identification of various conditions based on pulse wave patterns and pulse strength (Lu et al., 1999). There are three standard pulse measurement positions defined as Cun, Guan, and Chi (Figure 1). In performing PWA traditionally, the practitioner places a middle finger at the Guan position, a forefinger at the Cun position, and a ring finger at the Chi position.

Currently, descriptions of typical pulse patterns are often abstract and difficult to communicate with other expert and for beginners. A medical student learning the technique generally learns a specific PWA method from an experienced practitioner, who gives detailed verbal instructions which are highly case-oriented. However, this approach is ambiguous, as there is not a standardized method for describing pulse signal patterns; and as a result different practitioners may recognize and describe different pulse waves. This subsequently leads to inconsistent diagnoses for the same condition, potentially leading to different and possibly inappropriate treatments.

In recent years, scientific research investigating

*Corresponding author. E-mail: changkm@asia.edu.tw. Tel: 886-4-23323456 EXT 20003. Fax: 886-4-23316699.

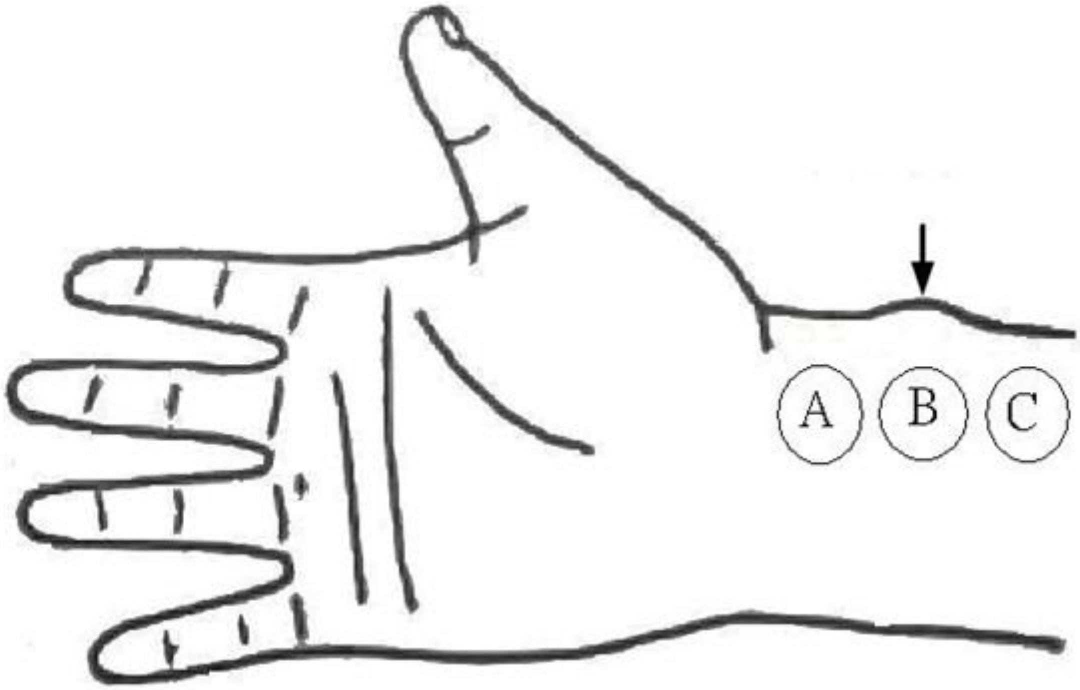

Figure 1. Pulse measurement positions. Traditional chinese medicine defines the standard pulse measurement positions as: Cun (A), Guan (B), Chi (C). Guan is at the pulse radius on the wrist (marked by the arrow).

Chinese medicine has grown in popularity with PWA being one of the more popular fields (Lu et al., 1999; Lu et al., 1996). There are several approaches to PWA research. One of them is to replace the traditional method of diagnosis, using instruments that measure the pulse waves electronically instead of physical contact, which is highly subjective. The measured pulse waves can then be recorded and displayed using a computer, allowing for further automatic pulse signal analysis.

In PWA analysis, harmonics, a frequency domain feature, which are based on the spectrum of pulse signals, are the standard features used for diagnosis (Hsu et al., 2006; Wang et al., 1998). In this study, a novel approach, form factor (FF) was employed. Form factor is a time domain feature which is derived from the ratio of signal standard deviation. FF is also used in signal analysis of various biomedical signals, such as vibroarthrographic (VAG) signals (Rangayyan and Wu, 2008) and ECG (Rangayyan, 2002). To the best of our knowledge, applying FF to pulse analysis has not been previously investigated in any other works. Additionally, this study employed novel three-axis sphygmography to measure pulse waveforms. It includes a two-axis mechanism and a standard positioning procedure for detecting the optimal measurement site and accurate pulse waveform measurement.

This study investigates the potential application of PWA analysis on the diagnosis of myocardial ischemia.

Myocardial ischemia results from oxygen deprivation of the heart muscle, and is accompanied by inadequate removal of metabolites due to reduced blood flow and perfusion. Myocardial ischemia patients may often suffer chest pains. A conventional diagnosis of myocardial ischemia utilizes an ECG treadmill test. The test exhibits a horizontal or lower slope of ST depression for myocardial ischemia patients, in comparison to results from a healthy individual. Previous studies showed that the exercise and physical exertion involved in ECG examinations may lead to chest pains in the patients, whilst only having a diagnostic accuracy of 70% or less (Baer, 2007). To avoid the painful treadmill ECG test, we would like to develop a rapid diagnosis approach. In this study, three-axis sphygmography is used to measure pulse waves for study of myocardial ischemia which are then compared to results obtained using a conventional ECG test.

METHODS

Hardware: Pulse wave measurement

A three-axis pulse measurement system with a modified sensor was used. The system allowed for simultaneous measurement of pulse waveforms (using a pressure transducer) and analog-to-digital

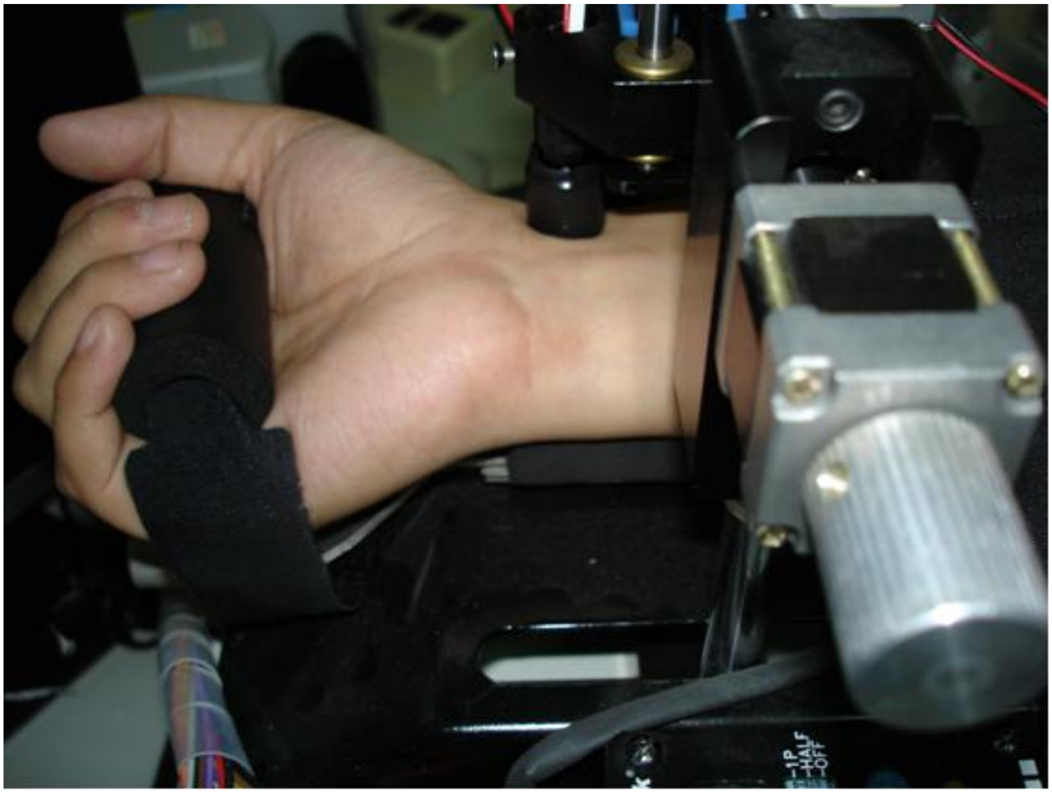

Figure 2. Pulse measurement using three-axis sphygmography.

conversion (using a strain gauge). The waveform signals were recorded using a digital analog acquiring card (National Instrument PCI 6014, with bandwidth 0.1~40 Hz) with LabView software for data retrieval and manipulation. The pressure-sensor gain and the strain-gauge gain were 100 and 1000 respectively. The sampling frequency was 500 Hz. The pressure sensor was calibrated using a mercury-column pressure gauge.

During measurement of the pulse waveforms, each subject was asked to sit on a height-adjustable chair. The subject's arm was situated on a table at the height of the subject's heart-level. The palm was pointed upwards with the wrist supported on a cushion. Results from subject's left wrists in three specific positions was measured (Figure 2). Each pulse was recorded for three seconds.

Experimental design

This study was approved by the institutional review board of the Chinese Medical University Hospital. Written consent was obtained from all subjects. All subjects were asked to stop smoking and refrain from alcohol consumption. Furthermore, consumption of stimulants (e.g. coffee and tea), as well as other stimulatory medications, was prohibited during the 24 h leading up to the experiment. Information regarding subjects in the positive, negative and control groups is listed in Table 1. The positive group consisted of subjects diagnosed (using ECG treadmill test) with myocardial ischemia; subjects in the control group were healthy individuals without myocardial ischemia; subjects in the negative group had chest pains similar to those experienced by myocardial ischemia patients, but their exercise ECG test showed no myocardial ischemia. The three groups were examined and diagnosed both by medical doctors (Western medicine) and traditional Chinese medicine doctors.

Data analysis: Form factors and statistics

For a given signal x[n], the first and second derivative of x[n] is denoted as $x_1[n]$ and $x_2[n]$ respectively. The variance of x[n] is denoted as σx, and the variance of $x_1[n]$ is denoted as σx_1. FF is defined in the following equation:

$$FF = \frac{\sigma x \times \sigma x_2}{(\sigma x_1)^2} \quad (1)$$

FF of a sinusoidal wave is unity; while FF value of other waveforms is increasing according to signal variations.

Each subject had six FF values, which were estimated from the pulse signal, chosen from the pulse's first major positive peak to 1.8 s later. Thus, the pulse waveform was similar between subjects, reducing the FF bias due to different pulse patterns. The three FF values were named LFF1, LFF2, LFF3 (L denotes left hand, and the numbers 1, 2, and 3 denote pulse measurements at the positions of Cun, Guan, and Chi respectively. For example, LFF1 is FF measured on the left hand at the Cun position). Differences between each of the three groups were established using a Student's *t* test for FF values. A comparison of the baseline characteristics among the three groups was estimated by ANOVA analysis. Comparisons were based on results from the same hand and the same pulse measurement position.

Table 1. Subject information list.

	Positive group (n=16)	Negative group (n=28)	Control group (n=19)
Male	11	18	9
Female	5	10	10
Age: Average (std)	58.9 (11.59)	54.2 (9.1)	63.9 (13.73)

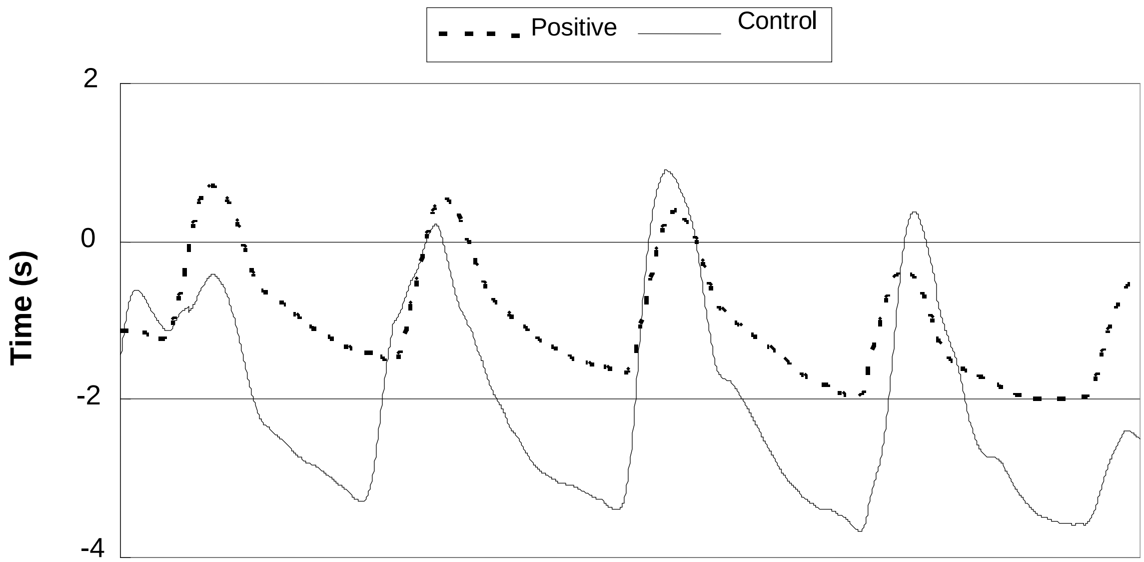

Figure 3. A typical pulse signal from the positive (dash line) and control groups (solid line). X-axis has a recording duration of three seconds.

RESULTS

Standard pulse signals contain one major peak and two subsequent minor peaks within one complete period. Figure 3 illustrates the typical pulse wave of myocardial ischemia patients (positive group) and healthy subjects (control group). Minor peaks of myocardial ischemia patients were more insignificant than those of the normal group.

Table 2 lists the mean FF values for the three groups and corresponding *t*-test values. From the results in Table 2, it was evident that the control group had higher FF values than those of the other two groups. Table 2 also shows that both the positive and negative groups had significant statistical differences in comparison with the control group, especially for LFF1 and LFF2 ($p<0.01$). But there was no statistical difference between positive and negative groups. ANOVA analysis showed that there was different of baseline characteristics among the three groups for all three features.

Figure 4 is a two dimensional diagram illustrating the distributions of LFF1 and LFF2 pairs for all subjects. Figure 4 demonstrates that the control group had higher LFF1 and LFF2 values, indicated by the dense distribution in the upper-right region, while FF pairs of the positive group were distributed around the origin.

DISCUSSION

In this study, data regarding myocardial ischemia was gathered using traditional Chinese medicine and was confirmed by conventional medical doctors (Western medicine). This study was also the first application of FF to PWA and showed significant differences between the positive and control groups. Peaks of the two minor pulses in the positive group were weaker than those of control subjects; therefore the pulse signal variation of the positive group was lower, resulting in lower FF values than the control group (Table 2 and Figure 3). The negative group also had a similar waveform (and therefore similar FF values) to the positive group. Negative and positive group subjects all suffered from chest pain, although patients in the negative group did not have myocardial ischemia according to ECG test. Further examination of these patients would be required

Table 2. FF values of the six pulse signals for the three groups, and corresponding statistical ANOVA results among three groups. T-test result of each groups are also listed.

Feature	Group	FF mean (std)	ANOVA	Positive vs. Control	Control vs. Negative	Positive vs. Negative
	Positive	12.56 (3.77)				
LFF1	Control	20.66 (6.40)	3.8E-6***	6.0E-5***	6.1E-5***	0.238
	Negative	14.01 (3.91)				
	Positive	14.08 (3.77)				
LFF2	Control	19.84 (7.40)	1.9E-5***	0.0062**	2.6E-5***	0.0688
	Negative	11.40 (4.95)				
	Positive	15.85 (3.39)				
LFF3	Control	19.42 (6.10)	0.0022**	0.0374*	0.0014**	0.184
	Negative	13.97 (4.89)				

* Denotes p<0.05; ** denotes p<0.01; *** denotes p<0.001.

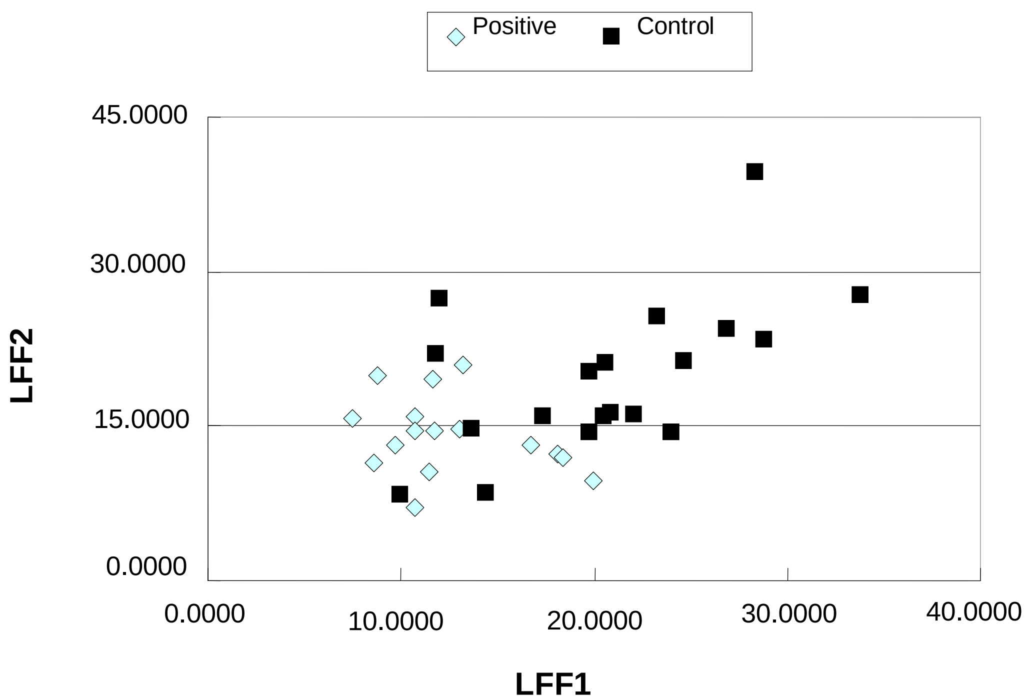

Figure 4. Illustration of feature distribution diagram with LFF1 and LFF2 pairs of positive and control subjects.

according to our results. One of the questions to be investigated is whether or not chest pain sufferers would have similar pulse wave patterns. Additional data would be necessary to further investigate this aspect of PWA with respect to myocardial ischemia.

In this study, the pulse signal was measured at 1.8 s, with total recording duration of each pulse signal being 3 s. In order to eliminate a possible FF bias due to different pulse wave variations, we chose the pulse signal from the beginning of the first major peak as a starting point with the same duration of 1.8 s. A 1.8 s duration was sufficient to achieve a complete pulse wave period and ensure similar pulse patterns were available for comparison.

In Table 2, *t*-test results indicated that there were significant differences between the positive/ control group, and the negative/control group, as indicated by the low p values. This result is consistent with the data shown in Table 2. For example, LFF1, LFF2 and LFF3 were all statistically different between the positive and control groups. This phenomenon was also observed between the negative and control groups. For PWA using only one hand, the left hand was a better choice than right hand.

Figure 4 indicates that approximately three or four control group subjects had low FF values which overlapped with FF values of the positive group. Although these subjects were considered healthy, they may actually have had other illnesses other than myocardial ischemia, which would have manifested themselves as PWA variations different to those of the control group. In other words, different diseases may have similar pulse waveforms to those of myocardial ischemia, resulting in similar FF values. This hypothesis needs further investigation; however present study is insufficient to further pursue this question.

Traditional time-domain pulse features were estimated either from the absolute and relative height of peaks, or time differences between major and minor peaks. FF only takes the whole pulse signal variance ratio, ignoring the minor pulse pattern variations between peaks. In some cases, there were slight visual differences in the pulse waves, but with similar FF values. This is also an advantage of FF as it only considers the whole pulse variance. FF can be useful for screening normal and even seriously ill patients using their FF of pulse signals.

Although the sample group sizes in this study were relatively small (16 positive group subjects, 28 negative group subjects and 19 control group subjects), there was sufficient data to demonstrate the significance of the pulse signals measured using the FF. In this study, we determined FF to be a low cost, highly sensitive addition to the test for diagnosing myocardial ischemia by PWA. Overall, FF appears to be a good candidate for use in PWA when diagnosing a well documented disease. PWA is thus a more powerful diagnostic tool when using the FF features with overall advantages in rapid and non-invasive measurement. In the future, more pulse wave signals of various diseases can be thoroughly analyzed and characterized by FF distributions.

Conclusion

In conclusion, FF was used in conjunction with PWA and was an efficient and highly complementary addition to the technique. This study applied FF for the diagnosis of myocardial ischemia using pulse signals, and showed a statistically significant difference between myocardial ischemia patients and control group subjects. Results from this study suggest that traditional Chinese medicine may have new potential applications, specifically as an accurate screening tool utilizing non-invasive and real-time measurement of pulse waves.

ACKNOWLEDGEMENTS

This study was supported by the National Science Council of Taiwan (Grant number NSC 100-2221-E-468-004-) and Asia University (Grant number asia100-cmu-1).

REFERENCES

Baer FM (2007). Stress-ECG is adequate to detect myocardial ischemia: when are additional diagnostic tests needed? Dtsch. Med. Wochenschr. 132(39):2026-2030.

Hsu TL, Chao PT, Hsiu H, Wang WK, Li SP, Wang YY (2006). Organ-specific ligation-induced changes in harmonic components of the pulse spectrum and regional vasoconstrictor selectivity in Wistar rats. Exp. Physiol. 91(1):163-170.

Lu WA, Cheng CH, Lin Wang YY, Wang WK (1996). Pulse spectrum analysis of hospital patient with possible liver problem. Am. J. Chin. Med. 24(3-4):315-320.

Lu WA, Wang YY, Wang WK (1999). Pulse analysis of patients with severe liver problems. Studying pulse spectrums to determine the effects on other organs. IEEE Eng. Med .Biol. Mag. 18(1):73-75.

Rangayyan RM (2002). Biomedical Signal Analysis─A Case Study Approach, Wiley-IEEE Press, New York, NY, USA.

Rangayyan RM, Wu YF (2008). Screening of knee-joint vibroarthrographic signals using statistical parameters and radial basis functions. Med. Biol. Eng. Comput. 46(3):223-232.

Wang WK, Hsu TL, Wang YY (1998). Liu-wei-dihuang: a study by pulse analysis. Am. J. Chin. Med. 26(1):73-82.

Xue CC, Zhang AL, Greenwood KM, Lin V, Story DF (2010). Traditional Chinese medicine: an update on clinical evidence. J. Altern. Complement. 16(3):301-312.