Computers in Biology and Medicine 39 (2009) 1145–1152

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Adaptive threshold method for the peak detection of photoplethysmographic waveform

Hang Sik Shin, Chungkeun Lee, Myoungho Lee *

Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 29 August 2009
Accepted 8 October 2009

Keywords:
Photoplethysmography (PPG)
Peak detection
Adaptive threshold
Frequency analysis
Respiratory noise

ABSTRACT

Photoplethysmography (PPG)-based temporal analyses have been widely used as a useful analytical method in physiological and cardiovascular diagnosis. Most of temporal approaches of PPG are based on detected peak points, peak and foot of PPG. The aim of presented study is the development of improved peak detection algorithm of PPG waveform. The present study demonstrates a promising approach to overcome respiration effect and to detect PPG peak. More extensive investigation is necessary to adapt for the cardiovascular diseases, whose PPG morphology has different form.

1. Introduction

Nowadays, photoplethysmography (PPG) is widely used in cardiovascular and hemodynamic analysis [1]. PPG measures blood volume changes at a peripheral artery such as finger, toe, ear and forehead, and measured waveform has a little difference according to where it measured [2–4]. Though the different waveform is measured by measuring site, PPG waveform has a bottom or foot (V_{min}) and top or peak (V_{max}) points in common. V_{min} represents minimum blood volume changes which corresponds beginning of ventricular contraction and blood ejection, on the other hands V_{max} describes the maximum blood volume changes which means the end of blood ejection. PPG is generated by blood pressure and flow; however, it is an arbitrary unit signal because PPG is easily affected by environmental conditions not only sensor fitting method, but also skin condition, skin depth, race, humidity and circumference brightness. From these characteristics, it is hard to analyze using PPG amplitude, and PPG analysis has mainly carried out with a timing analysis and amplitude variability.

The most of PPG applications have been intensively studied with temporal analysis such as pulse transit time (PTT) and pulse wave velocity (PWV). PTT and PWV mean the time taken and the speed, respectively, in the arterial pulse pressure wave to travel from the aortic valve to a peripheral site. PTT and PWV are widely used for physiological estimations such as arterial stiffness [5,6], left ventricular ejection time (LVET) [7], left ventricular pre-ejection period (LVPEP) [8,9] and blood pressure [10,11]. With the development of temporal analysis based PPG applications, peak detection methods of PPG have become not special but very important issue in PPG temporal analysis because most of temporal analysis depend on peak position.

PPG has a lesser sophisticated morphology than other physiological signals and this also means peak detection of PPG relatively easy because there are few specific points. However, PPG could have an enormous baseline drift and wondering followed by physiological condition and movement, moreover it frequently happens. It was demonstrated that PPG contains fluctuation caused by respiratory and sympathetic activity [12], even arousal changes such as drowsiness causes PPG baseline wandering or drift. These artifacts could be explained with the three major interferences of PPG, motion artifact, respiration effect and low perfusion. Motion artifact generally induces baseline drift; however, it also could be a reason of amplifier saturation which makes waveform loss. Respiration changes not only heart rhythm but also thoracic pressure. Rhythmic change followed by respiration is already known as respiratory sinus arrhythmia [13], and thoracic pressure also could have an effect on physical heart activity [14]. Therefore, PPG naturally contains a respiratory component, and it is reflected on the baseline and signal amplitude. With the low perfusion, which means weak blood flow of arterial blood to a capillary bed, these artifacts should be defined and removed for better detection.

Most of previous researches were performed with maximum or minimum values detection of PPG waveform in classifying V_{max} and V_{min} by detecting local maxima or minima detection method (LCM) [15,16]. It is general acceptance that PPG is composed with incident wave and reflected wave [17–25]. Considering on respiration effect, the changes of reflected wave should be

* Corresponding author. Tel.: +82 2 2123 4946; fax: +82 2 312 2770.
E-mail addresses: glority@yonsei.ac.kr, micon78@yonsei.ac.kr, mhlee@yonsei.ac.kr (M. Lee).

0010-4825/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compbiomed.2009.10.006

investigated. The amplitude and velocity of reflected wave could be varied by respiratory activity, and it causes rapid changes of PPG waveform [26]. It was demonstrated that the reflected wave velocity becomes faster by increasing of age and vessel stiffness [21,27], and it was appeared in PPG [28,29]. In other words, we should discriminate the maximum position of incident wave from reflected wave disturbances for more precise analysis. These changes could be a reason of miss-detection of V_{max} which closely related to reflected wave. LCM method is hard to apply for rapid changes of PPG waveform and different heart rate, and it also contains time delay from its specific window-size. Since PPG is frequently analyzed with ECG, in most cases, PPG peak detection has depended on ECG-gated method. However, these attempts are hard to use in the clinical application as well as it is increasing to use PPG as a single reference such as respiration and heart rate estimation [30].

The aim of the present study is summarized signal conditioning of PPG waveform and detection of V_{max} and V_{min} of PPG waveform. Frequency analysis based filtering was used for signal conditioning, and adaptive threshold (ADT) method was developed for peak point detection. ADT method was able to detect both V_{max} and V_{min} and evaluated by clinical experiment.

2. Methods

2.1. Subject

Eighteen young and healthy subjects (11 male and seven female, mean ages of 24.1 years, range 17–30 years, mean BMI of 23.2, range 18.5–30.1) were participated in experiment. The subjects were normotensive (mean systolic/diastolic blood of $118/70 \pm 6.3/5.6$mmHg, range 100/63–140/8mmHg), and had no known cardiovascular, neurological or respiratory disease. Prior to the experiment, the subjects were requested to provide information about their physical condition. Physical information such as height and weight are also measured for demographical research and summarized in Table 1. Every experiment was performed in a typical sports medicine laboratory at an ambient room temperature from 11 am to 6 pm. Drinking and smoking were prohibited during 24 and 2 h before experiment, respectively.

Table 1
Demographic data for the subjects in this study.

Subject (male/female)	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	SBP[a] (mmHg)	DBP[b] (mmHg)	HR (bpm)[c]
1 (M)	29	185	103	30.1	124 ± 5.7	70 ± 6.8	69.70 ± 7.23
2 (M)	30	172	81	27.6	139 ± 4.8	81 ± 4.9	82.80 ± 6.94
3 (M)	29	178	68	21.4	127 ± 13.7	73 ± 6.5	78.10 ± 2.22
4 (M)	28	175	78	25.3	122 ± 9.4	71 ± 2.2	61.95 ± 9.05
5 (M)	26	175	63	20.6	110 ± 3.5	66 ± 2.4	69.02 ± 3.26
6 (F)	26	161	57	22.2	100 ± 1.9	63 ± 2.0	57.04 ± 0.78
7 (F)	23	162	56	21.2	101 ± 3.7	67 ± 5.3	64.87 ± 4.07
8 (F)	21	161	60	23.1	107 ± 4.6	65 ± 3.4	79.73 ± 1.80
9 (M)	29	177	71	22.6	126 ± 10.7	72 ± 8.1	65.65 ± 3.29
10 (M)	24	171	68	23.1	135 ± 7.7	72 ± 7.4	68.82 ± 3.78
11 (M)	17	171	65	22.2	131 ± 8.4	67 ± 8.9	71.60 ± 2.97
12 (F)	22	159	47	18.5	103 ± 6.6	68 ± 4.7	78.98 ± 1.07
13 (M)	25	174	77	25.7	119 ± 9.3	72 ± 5.7	69.21 ± 1.74
14 (F)	22	163	55	20.5	107 ± 3.1	74 ± 5.6	80.14 ± 6.39
15 (M)	18	175	83	26.9	134 ± 9.1	75 ± 6.8	63.70 ± 5.16
16 (M)	23	172	71	24.2	140 ± 9.1	77 ± 12.5	56.46 ± 4.22
17 (F)	19	164	63	23.6	110 ± 2.9	69 ± 5.1	57.60 ± 5.30
18 (F)	21	160	60	23.6	120 ± 4.5	75 ± 5.7	61.49 ± 3.67
Male	25.3 ± 4.5	175 ± 4.1	75 ± 11.2	24.5 ± 2.9	128 ± 8.3	72 ± 6.6	68.36 ± 8.20
(range)	(17–30)	(171–185)	(63–103)	(20.6–30.1)	(109–140)	(66–80)	(56.46–82.80)
Female	22 ± 2.2	161 ± 1.6	57 ± 1.9	21.8 ± 1.9	105 ± 3.7	68 ± 4.4	69.53 ± 11.08
(range)	(19–26)	(159–164)	(47–63)	(18.5–23.6)	(100–119)	(63–75)	(57.07–80.14)
Mean $\pm$ SD	24.1 ± 3.8	169 ± 7.7	67 ± 13.2	23.2 ± 2.9	118 ± 6.3	70 ± 5.6	68.77 ± 9.20
(range)	(17–30)	(159–185)	(46–103)	(18.5–30.1)	(100–140)	(63–80)	(56.46–82.80)

[a] Systolic blood pressure.
[b] Diastolic blood pressure.
[c] Heart rate (beat per minute).