An Ultra-Band Study of Pulse Rate Variability for Homecare by Using Instantaneous Pulse Rate Variability

Po-Hsun Huang
Institute of Computer Science and Engineering,
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: sdk58927@gmail.com

Chia-Chi Chang
A-Neuron Electronic Corporation
Institute of Biomedical Engineering,
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: ccchang.cs@gmail.com

Tzu-Chien Hsiao
Department of Computer Science, Institute of Biomedical Engineering, Biomedical Electronics Translational Research Center
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: labview@cs.nctu.edu.tw

***Abstract*—Most of human body regulation is controlled by the autonomic nervous system (ANS). The activities of ANS influence the human health, therefore, how to observe the proper activity of ANS in time is important. Heart rate variability (HRV) is generally a common and widely non-invasive used method for indicating the activities of ANS. However, electrocardiography (ECG) used for HRV analysis is not suitable for homecare. Pulse rate variability (PRV) of photoplethysmography (PPG) is a surrogate method for HRV of ECG. Furthermore, PPG is easier and more convenient to use at home. Whether using HRV or PRV, there still remains some limitations because of the timescale which causes the frequency domain analysis restricted to only 0.5 Hz. For breaking the limitations, a novel method instantaneous pulse rate variability (iPRV) was proposed. The previous study had shown the difference between fever patients and normal people by using iPRV analysis. Nevertheless, it did not compare the result of iPRV to the conventional method. The aim of this study is to examine that iPRV can not only indicate the activities of ANS as PRV but provide more information. The result of this study shows the conventional indexes have no significant difference between PRV and iPRV. But the modified indexes including the very high frequency band (VHF) computed by PRV are different to the one computed by iPRV. The power of VHF is much greater in iPRV than PRV. This band as an indicator may contain more information about the body regulation. In this study, using iPRV as a method in homecare has more efficiency.**

Keywords-Pulse rate variability (PRV); Empirical mode decomposition (EMD); Instantaneous PRV (iPRV).

I. INTRODUCTION

There are various mechanisms for regulating the human body. Many of them are dominated by the autonomic nervous system (ANS). The ANS contains sympathetic (SNS) and parasympathetic (PNS). The balance between SNS and PNS is important to maintain health of human. It influences the health when the activities of ANS are not stable [1].

Heart rate variability (HRV) is generally a common and widely non-invasive used method for indicating the activities of ANS [2]. Electrocardiography (ECG) signal is acquired to calculate the beat-to-beat interval (RRI) for HRV analysis (Fig 1(a)). But, ECG measurement is too inconvenient to use in the home. It is not suitable for homecare.

Compared to ECG, photoplethysmography (PPG) is easier and more convenient to use in the home [3]. It is called pulse rate variability (PRV) if applying the PPG signal instead of ECG to calculate the peak-to-peak interval (PPI) for HRV analysis (Fig 1(b)). Though the ECG signal and PPG signal have the difference because of the pulse transition time (PTT) between RRI and PPI, many studies have determined that PRV can act as a surrogate of HRV during some conditions [4].

Nevertheless, the timescale of RRI and PPI have a limitation. It causes the frequency band of HRV or PRV spectrum analysis to be restricted to about only 0.5 Hz [5].

For breaking the limitation, instantaneous pulse rate variability (iPRV) was proposed [6]. iPRV adopted PRV technique and applied the frequency range extension method based on Hilbert-Huang transform (HHT) [7]. HHT can deal with the non-stationary and nonlinear data by the pre-process, called empirical mode decomposition (EMD). However, the intermittency phenomenon, which called mode mixing

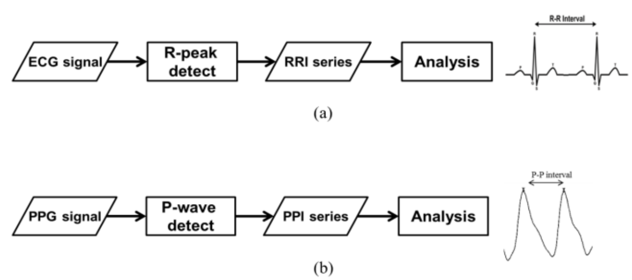

Figure 1. The procedure of (a) HRV and RRI, (b) PRV and PPI.

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problem is involved in EMD. The noise-assisted method called ensemble EMD (EEMD) was proposed to solve this problem [8].

The previous study had compared the difference between the fever patients and normal people by iPRV spectrum analysis [9]. The aim of this study is to compare the iPRV spectrum result of the previous study [9] to PRV result to examine iPRV is useful and reliable for observing the activities of ANS. Besides this, the iPRV has more information in embedded in higher frequency band than PRV.

II. MATERIA AND METHOD

A. Subjects and data collection

The experiment was carried out in Yo-Yo Clinic, Kaohsiung, Taiwan. The body temperature was measured by ear thermometer (Radiant TH889, Radiant Innovation Inc.) and the signal was acquired by PPG (Nonin 8500, Nonin Medical Inc.) with 200 Hz sampling rate.

30 subjects were recruited in this study. 15 subjects whose body temperature are higher than 37.9 ℃ serve as fever group, others serve as normal group. All subjects were measured the body temperature before acquiring the PPG signal. The subjects were required to rest quietly in supine position when the PPG signal acquiring for 10 minutes. This experiment was approved by the institutional review board of the National Chiao Tung University. Informed consent was obtained from all subjects before the experiment.

B. PRV procedure

The procedure PRV is shown in Fig 2. First, finding out the peaks in each pulse cycle. Second, calculating the PPI series by the interval between each peak and interpolating to 200 samples per second. Last, transforming the PPI series to power spectrum by fast Fourier transform (FFT) and calculating the power of each band.

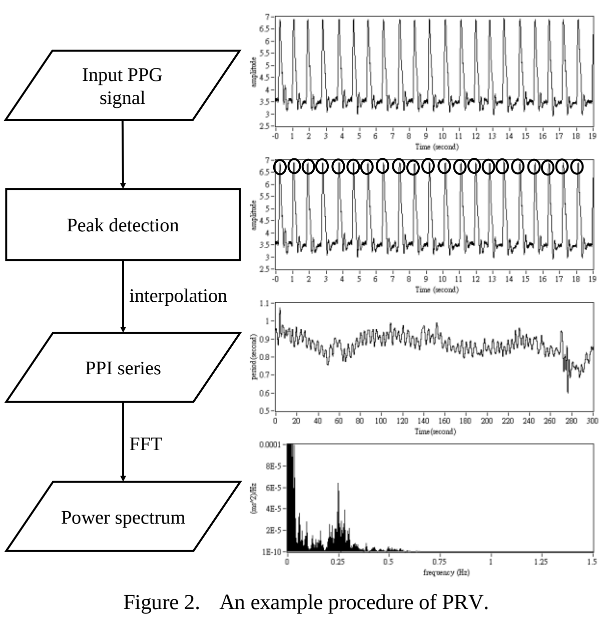

Figure 2. An example procedure of PRV.

C. iPRV procedure

There are many steps of the iPRV procedure [6]. First, it uses EMD to decompose the PPG signal to many intrinsic mode functions (IMFs) [7]. The algorithm of EMD is shown in Fig 3. However, because of the mode mixing problem involve in the EMD, the EEMD was used in this study. The procedure of EEMD is shown in Fig 4. [8]. After decomposition, one of the IMFs which was sinusoid-like is considered as the heartbeats component. This IMF is used for calculating the instantaneous frequency (IF) by normalized direct quadrature (NDQ) [10]. The procedure of NDQ is shown in Fig 5. The iPRV uses the inversion of IF called iPeriod to calculate the power spectrum by FFT. The whole procedure of iPRV is shown in Fig 6. The spectral analysis programs in this study

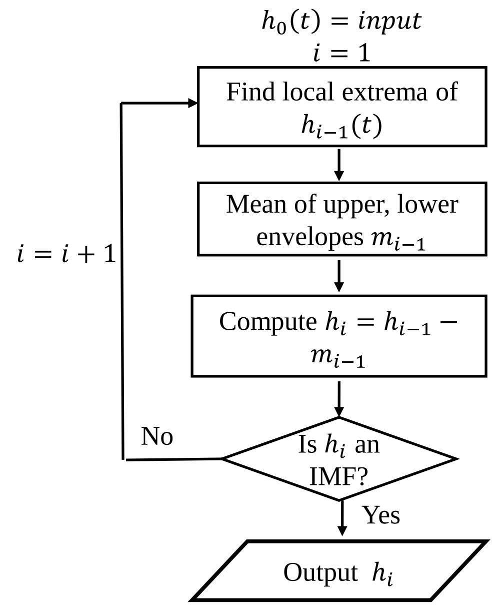

Figure 3. The algorithm of EMD.

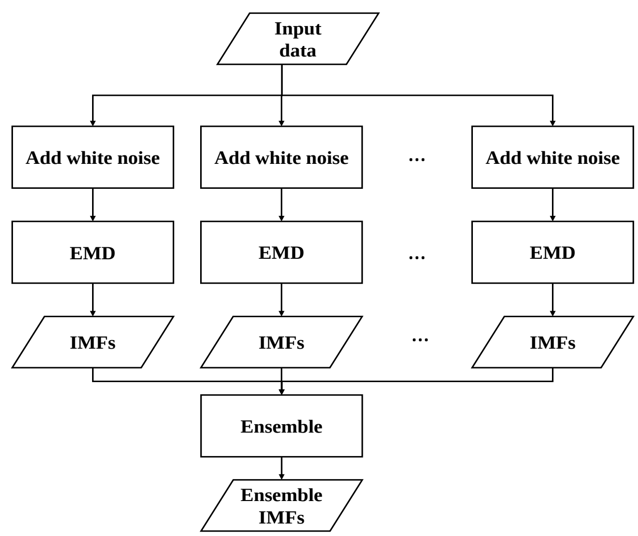

Figure 4. The algorithm of EEMD

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were developed by using a commercial software platform (LabVIEW version 2013, National Instruments Corp., Austin, USA).

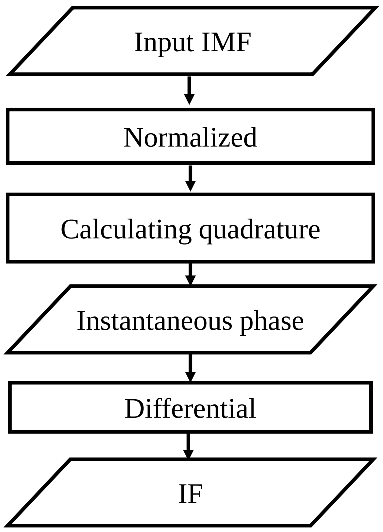

Figure 5. Calculate IF by NDQ.

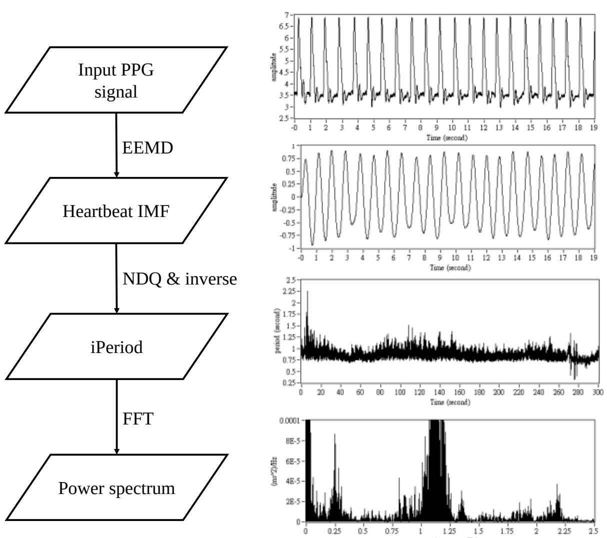

Figure 6. The procedure of iPRV.

D. Iindex calculating

The standard of bandwidth of low frequency band (LF) is between 0.04 Hz and 0.15 Hz and high frequency band (HF) is between 0.15 Hz and 0.4 Hz [11]. The conventional indexes of normalized power (nLF and nHF) and LF-HF ratio are calculated as follows.

$$nLF = 100\% * (LF / (LF + HF)), \quad (1)$$

$$nHF = 100\% * (HF / (LF + HF)), \text{ and} \quad (2)$$

$$\text{LF-HF ratio} = 100\% * (LF / HF). \quad (3)$$

For calculating including very high frequency band (VHF), we assume the bandwidth of VHF is from 0.4 Hz to 0.5 Hz in PRV and 0.4 Hz to 0.9 Hz in iPRV. The modified indexes are calculated as follows.

$$nLF^a = 100\% * (LF / (LF + HF + VHF)), \quad (4)$$

$$nHF^a = 100\% * (HF / (LF + HF + VHF)), \text{ and} \quad (5)$$

$$nVHF = 100\% * (VHF / (LF + HF + VHF)). \quad (6)$$

Each abbreviation, LF, HF and VHF in equations presents the power of each frequency band.

E. Statistic analysis

Homogeneity test was used to test the distribution of each index calculated by PRV and iPRV is homogeneity or not before independent t-test. Independent t-test was used to compare the significant difference between each index calculated by PRV and iPRV. *P* value of <0.05 was considered significant. All statistical analysis was performed by using commercial statistics software (IBM SPSS statistics, version 22.0.0.0, IBM corp., New York, USA).

III. RESULT

The comparison result between PRV and iPRV is shown in Table 1.

TABLE 1. THE COMPARISION BETWEEN PRV AND IPRV

group	**Normal group**		**Fever group**	
method	***PRV***	***iPRV***	***PRV***	***iPRV***
nLF	49.6±16.6*	46.5±16.4*	67.2±12.4	62.5±12.8
nHF	50.4±16.6*	53.5±16.4*	32.8±12.4	37.5±12.8
LF-HF ratio	128.8±112.6*	109.9±86.9*	263.6±187.0	207.5±136.2
nLF^a	42.8±15.8*#	26.4±10.9	56.7±11.9#	32.5±11.7
nHF^a	43.9±16.6*#	30.5±11.5*	27.5±10.1#	18.8± 7.4
nVHF	13.2±10.2#	43.1±10.4	15.8±6.8#	48.7±13.6

[1] * means p-value <0.05 compared with Fever group, # means p-value<0.05 compared with iPRV

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There is no significant difference in nLF and nHF between PRV and iPRV. If calculating including VHF, each index in PRV is significantly different to the one in iPRV whether in normal group or fever group. However, each index whether computed including VHF or not, they have the same trend in PRV and iPRV. For example, comparing to normal group, nLF increased in fever group whether calculated by PRV or iPRV. Nevertheless, the value of nVHF is much larger in iPRV than PRV, we discuss it in the next section.

IV. Discussion

The conventional indexes, nLF, nHF and LF-HF ratio, calculating by HRV usually present the activities of ANS [2][11]. The PRV can be used as an alternative measurement of the HRV [4]. So, nLF, nHF and LF-HF ratio are useful for indicating the activities of ANS by PRV. Besides this, the result of this study also shows the value of nLF, nHF and LF-HF ratio calculated by iPRV are no significant difference to PRV. Therefore, nLF, nHF and LF-HF ratio calculated by iPRV can also indicate the activities of ANS. For modified indexes in this study, because of the narrow bandwidth of VHF in PRV, nLF^a and nHF^a are similar to the conventional indexes. Otherwise, the power of VHF is much larger in iPRV. VHF band may contain more information about not only activity of ANS but more body regulation.

Some studies have assumed that VHF has the possible meaning of cardiac output or peripheral circulation [6][12][13]. Another study also shows the VHF band has potential to evaluate fluid responsiveness [14]. In addition, the previous study had compared the difference between normal people and fever patient and discussed the relationship between some thermoregulation and each index [9]. However, it still needs more experiments to examine the meaning of VHF.

V. Conclusion

This study has shown the reliability of the conventional indexes in iPRV. Moreover, the ultra-band, VHF, computed by iPRV contains more information about the body regulation for monitor. iPRV uses the convenient and easy measurement for signal acquiring, but provide more information than PRV. iPRV has a potential to be a better monitor of health status for homecare.

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