# Wavelet Power Spectrum Analysis for PVC Discrimination

N. Uchaipichat, C. Thanawattano, and A. Buakhamsri

*Abstract*— **Premature ventricular contraction (PVC) is a type of heart arrhythmias that occurs a contraction of ventricles before normal ECG rhythm. This paper presents a technique for PVC screening. Wavelet power spectrum analysis was applied to extract some characteristic features form ECG beats. The database used in this study is MIT-BIH arrhythmia database. The discriminant analysis with Mahalanobis distance was used as classifier to discriminate between sinus group and PVC group. The classification with combined features achieved the best performance with sensitivity of 81.99±1.07% and specificity of 90.38±0.64%.**

*Index Terms*— **Arrhythmias, Electrocardiogram, Premature ventricular contraction, Wavelet transform**

## I. Introduction

CURRENTLY, the number of deaths due to heart disease has increased steadily. Arrhythmias are a major cause of death among patients with heart disease. Electrocardiogram (ECG) is an important physical signal in the diagnosis of people with heart disorders. In each cycle of normal heart, structure of the ECG consists of P wave, QRS Complex, T wave, and U wave. This morphological information of ECG can be used to diagnose disorders of the heart in different areas; for example unusual shape of the P wave is seen to indicate malfunction of the atrium. Premature ventricular contraction (PVC) also known as ventricular premature contraction is a type of heart arrhythmia which is often caused from disorder of ventricle. PVC can be found in healthy people of all ages but it is common in patients with hypertension and myocardial dysfunction. The QRS complex of PVC is wider than normal and sometimes there is no P wave. In screening and detection of PVC has been continuously developed with various methods. In 1997 Wieben O. and colleague applied decision-tree algorithm and fuzzy rule-based classifier to develop PVC screening [1]. In 2005 Chiu C.C. and colleague presented method to detect PVC and APC using a correlation coefficient of the signal [2]. In 2007 Chen S.W. proposed a new method for detecting PVC using nonlinear trimmed moving averaging [3]. In 2009 Talbi M.L. and Charef A. studied pattern of the QRS power spectrum in the Bode diagram by determining the characteristics of the QRS power spectrum in the frequency range 3-8 Hz and 15-19 Hz for screening PVC [4]. This paper presents a new method for screening PVC using wavelet transform for ECG analysis. In the screening method, discriminant analysis was used to distinguish between a normal ECG and PVC. The data used in this study are MIT-BIH arrhythmia database, which is available in *Physionet*.

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N. Uchaipichat is with Faculty of Engineering, Thammasat University, Pathumthani, 12120 Thailand. (e-mail: unopadol@engr.tu.ac.th).

C. Thanawattano is with National Electronics and Computer Technology Center, Pathumthani, 12120 Thailand. (e-mail: chusak.thanawattano@nectec.or.th).

A. Buakhamsri is with Cardiology Unit & Thammasat Heart Center Faculty of Medicine, Thammasat University, Bangkok, Thailand.

## II. Methodology

### A. Wavelet Transform

The wavelet transform is a signal processing method has been widely popular such as engineering, economics, and medicine [5]. The advantage of wavelet transform is the ability to analyze both time and frequency domains which is the limitation of Fourier transform. The wavelet transform of continuous-time signal can be computed from (1).

$$T(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \psi^{*}\left(\frac{t-b}{a}\right) f(t)\,dt \qquad (1)$$

where $\psi^*(t)$ is the complex conjugate of the analyzing wavelet used in the computation and, in this application, $f(t)$ is ECG signal. Parameter $a$ and $b$ in (1) presents scale and time position of wavelet in respectively. The wavelet scale $a$ can be converted into frequency of wavelet with relation between the characteristic frequency and scale as presented in (2)

$$f = \frac{f_c}{a} \qquad (2)$$

where $f_c$ is the passband center of the mother wavelet. The energy density surface called scalogram can be defined as (3).

$$E(f,b) = \left|T(f,b)\right|^2 \qquad (3)$$

### B. Study Data

Premature ventricular contraction (PVC) is a type of heart arrhythmias that occurs a contraction of ventricles before normal ECG rhythm. The ECG waveform of PVC has wider QRS complex than normal waveform and no P wave appears. The examples of PVC beats are illustrated in Fig. 1.


Fig. 1 Example of PVC beats [6]

In this study the MIT-BIH arrhythmia database was used as experimental data which contains 48 subjects [6]. The ECG traces were recorded at sampling frequency of 360 Hz and with 11-bit resolution over a 10 mV range. The data was divided into two groups: sinus rhythm (N) and PVC based annotation data in the database. The studied data consists of 774,980 sinus beats and 7,141 PVC beats. Each studied beat has a length of 0.75 second measured from 0.20 second prior to R wave to 0.55 second after R wave. Fig. 2 shows averaging signals of sinus rhythm and PVC that the R wave is no visible in PVC wave and QRS duration is wider than sinus beat. Moreover the irregular pattern of ECG rhythm is noticeable in PVC.

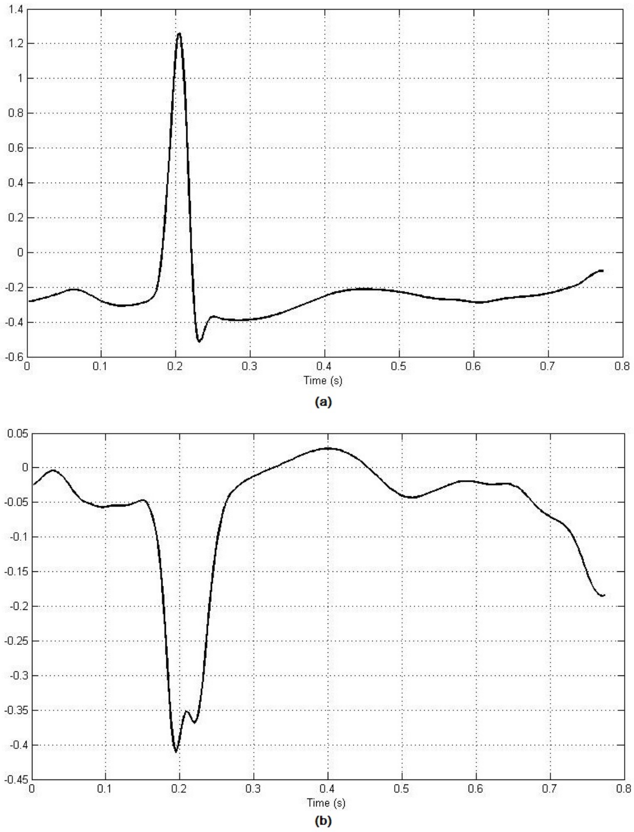


Fig. 2 Averaging ECG signals:

(a) Sinus and (b) PVC

### *C. Feature Extraction and Classification*

In the feature extraction, the ECG beats obtained from previous stage were processed with wavelet transform. The mother wavelet used in this study is Morlet wavelet. Fig. 3 and 4 illustrate examples of wavelet scalogram for sinus beat and PVC beat, respectively.

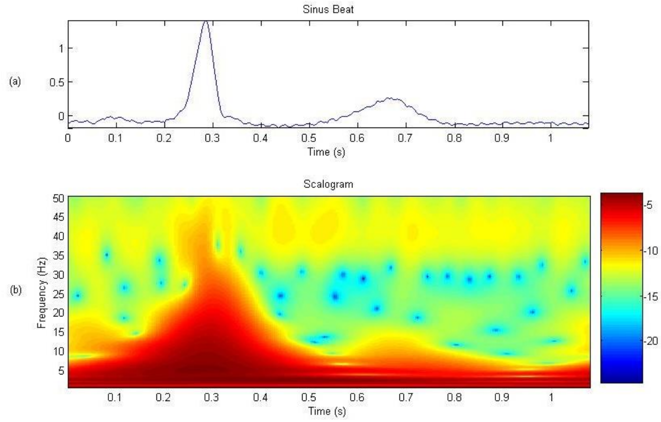


Fig. 3 Wavelet transform of sinus beat

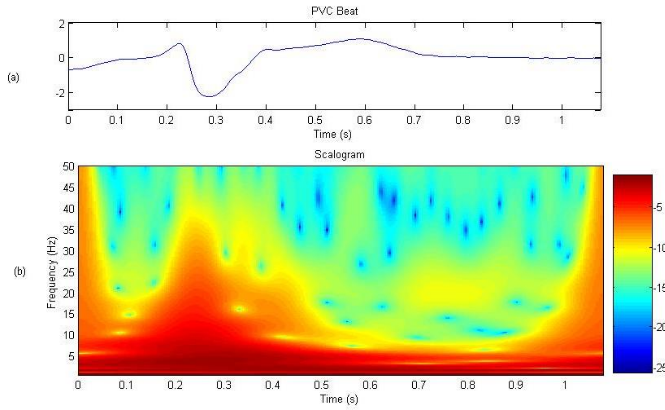


Fig. 4 Wavelet transform of PVC beat

Then, the wavelet power spectrum density of each ECG can be computed from its wavelet scalogram as defined in (4).

$$E(f) \;=\; \int E(f,\tau)d\tau \qquad (4)$$

Fig. 5 displays the wavelet spectra of sinus beat (represented with solid line) and PVC beat (represented with dotted line).

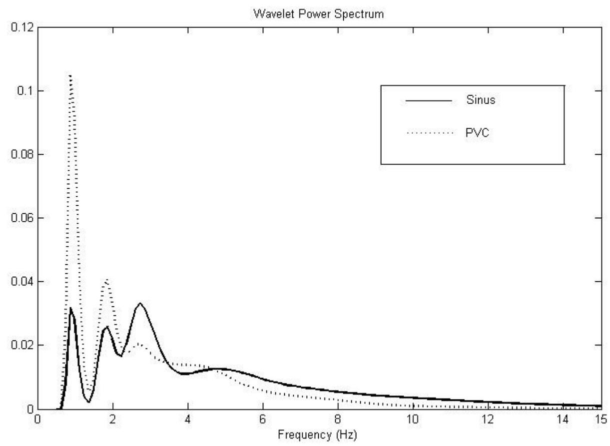


Fig. 5 Wavelet power spectrum density

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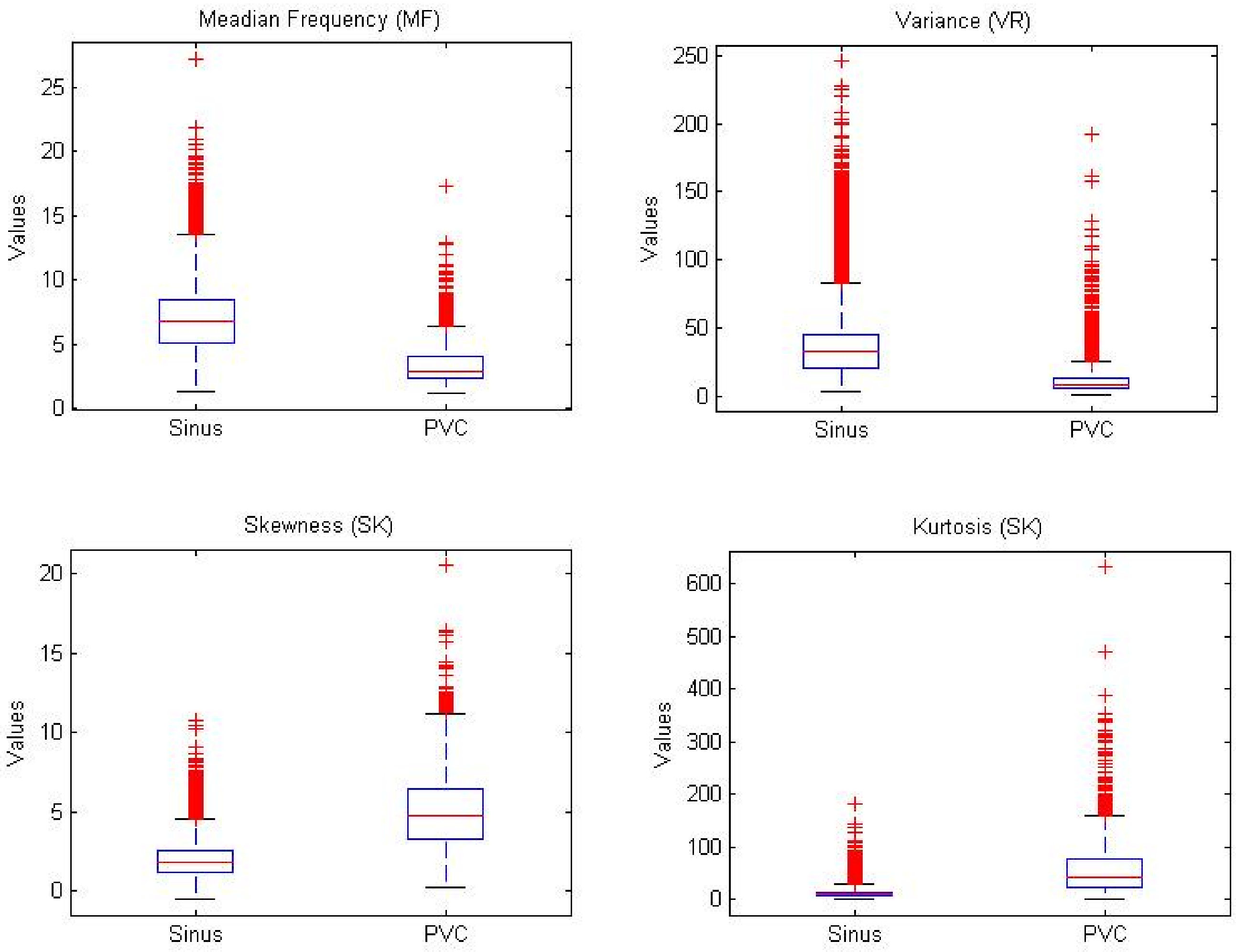


Fig. 6 Boxplots of studied features

Several characteristic features were extracted from wavelet spectrum density including mean frequency (MF), variance (VR), skewness (SK), and kurtosis (KT).

The discriminant analysis was employed in classification method in order to distinguish between a normal and PVC groups. The Mahalanobis distance was used as discriminant function to classify classes. The K-folding cross validation was applied in classification training and test in order to confirm the reliability of classifier. The performance index of classification was measured from sensitivity and specificity values.

## III. Experimental Results

Regarding to methodology stated in previous section, the main component of wavelet power spectrum for PVC is concentrated in the frequency range of 0 to 2 Hz. The distribution of PVC's spectrum is more compact compared to sinus beat. In contrast to the power spectrum of sinus rhythm is distributed over various frequencies. The distribution of all studied features can be presented in Fig 6. In addition to the statistical information of each feature is presented in Table I. As the results it can be seen that the distribution of all features are significantly different between sinus group and PVC group. Considering to the MF feature, it is found that the sinus rhythms have mostly higher frequencies than PVC rhythms. The variance of wavelet spectrum in sinus group is greater than PVC group that can be implied that the wavelet spectrum of sinus beat is boarder that PVC spectrum.

TABLE I
Distribution and Statistical Results

| | Sinus | PVC | P value |
|---|---|---|---|
| Median Frequency (MF) | 6.96±2.19 | 3.34±1.33 | < 0.001 |
| Variance (VR) | 36.24±21.4 | 10.72±9.55 | < 0.001 |
| Skewness (SK) | 2.05±1.03 | 4.97±2.09 | < 0.001 |
| Kurtosis (KT) | 11.47±9.45 | 55.09±41.7 | < 0.001 |

Table II presents classifying results using discriminant analysis with Mahalanobis distance. The studied data were equally separated for training set and test set in crossing validation technique. Regarding to experimental results, the combination of all features achieved the best performance with sensitivity of 81.99±1.07% and specificity of 90.38±0.64%.

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TABLE II
CLASSIFICATION RESULTS

| Studied Feature | Sensitivity | Specificity |
|---|---|---|
| MF | 83.43±0.25% | 83.87±0.08% |
| VR | 87.50±0.83% | 79.33±1.20% |
| SK | 79.85±0.12% | 84.76±0.02% |
| KT | 81.46±0.67% | 87.39±0.12% |
| MF-VR-SK-KT | 81.99±1.07% | 90.38±0.64% |

## IV. DISCUSSION AND CONCLUSION

This study proposes a technique to screening PVC from ECG trace. The studied features were extracted from wavelet power density in sinus and PVC beats. In classification stage the discriminant analysis with Mahalanobis distance was used in this study. As the results, it is found that all studied features including MF, VR, SK, and KT are separately in data distribution analysis. The classifying with combined features gave the best performance at sensitivity of 81.99±1.07% and specificity of 90.38±0.64%.

Recently, wavelet transform is widely used in medical signal analysis. From previous works by authors, the wavelet transform were employed in several studies associated with ECG analysis such as prediction of defibrillation outcome [7], ventricular fibrillation detection [8], prediction of ventricular arrhythmias [9], and prediction of sleep apnea [10]. In this study, the wavelet transform also gave promising results in PVC screening. The preliminary results in this paper shows wavelet power spectrum based- PVC discrimination are comparable with Fourier transform [4]. In future study, authors suggest that the temporal analysis in wavelet scalogram should be applied for feature extraction.

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