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Feature Extraction of Wrist Pulse Signals using Gabor Spectrogram

Nidhi Garg and Nikita Babbar*

UIET, Panjab University, Chandigarh - 160014, Punjab, India; nidhi_garg@pu.ac.in, nikitababbar.16@gmail.com

Abstract

Background/Objectives: The practice of Ayurveda has been long followed in India which is based on the analysis of wrist pulse signal for diagnosing human health. The pulse signal is a non-stationary signal. A signal can be analyzed in either time domain, frequency domain or joint time-frequency domain. This paper highlights the need of joint time-frequency analysis for a non-stationary signal and provides an approach of analyzing wrist pulse signals in time-frequency domain using Gabor Spectrogram. **Methods/Statistical Analysis:** The work in this paper has been done using Virtual Instruments (VI's) in ®LabVIEW. In this paper, band pass filter and wavelet de-noising technique has been used for pre-processing of raw pulse signals. Segmentation and Normalization has been performed on the noise free pulse signals. For representing the pulse signals in t-f space, Gabor Spectrogram has been used. The Gabor Spectrogram is a time-frequency distribution technique that offers good time-frequency resolution and negligible cross term interference. The performance has been analyzed using a parameter Mean Square Error (MSE). **Findings:** Various features: Mean Instantaneous Frequency (MIF), Mean Instantaneous Bandwidth (MIB), Frequency Marginal Integral (FMI), Time Marginal Integral (TMI) and Group Delay (GD) have been extracted in t-f domain for pulse signals from healthy subjects and correlation has been performed. The extracted features for different healthy subjects show similarity in variation pattern even though the actual signals differ in time domain, illustrated through correlation, which marks a successful attempt towards the significance of time-frequency distribution for pulse signals. **Application/Improvement:** These features can prove very significant in health diagnosis of human beings.

Keywords: Feature Extraction, Gabor Spectrogram, Mean Instantaneous Frequency, Mean Instantaneous Bandwidth, Non-Stationary Signal, Time-Frequency Distribution, Wrist Pulse Signal

1. Introduction

The method of pulse diagnosis for examining human health is non-invasive and has been proved very effective from Indian Literature[1]. The ECG signal has also been used extensively for examining the health status of heart[2]. Compared with ECG signal, the pulse signal contains much more information as it travels a long way from heart and is influenced by other body organs thus revealing the health status of not just heart but other body organs too[3]. The pulse is generated as a result of heart beat and is based on the three elements of Tridosha theory — vata, pitta and kapha. These three elements together constitute a pulse signal and the health status of any subject is dependent on the constitution of these elements. In Ayurveda, the discrepancies in health state are represented by the proportions of these elements going out of the desired limits.

However, this approach is subjective in nature and the results are prone to differ as the examination is totally based on the skill of the practicing physician. The pulse is felt by the physician using three fingers and this makes the transfer of knowledge difficult as one can't see the variation of pulses, but only feel it. This gives rise to the need of a computerized approach for the analysis of wrist pulse signals.

The wrist pulse signal is a non-stationary signal. A non-stationary signal is represented by its changing

**Author for correspondence*

frequency with respect to time. Much work has been done on wrist pulse signal in timedomain[4,5] and frequency domain[6]. However, the time domain approach misses out on important information when analyzing a non-stationary signal. Also, sometimes the diastolic wave is very weak in time domain signal[6]. The time domain analysis does not accurately interpret the pathological changes. Moreover, the time varying spectral characteristics of the pulse signal cannot be obtained accurately with frequency distribution. A proper TFD (Time Frequency Distribution) technique can accurately interpret these conditions and may prove very beneficial for examining the wrist pulse signal.

In Figure 1, a non-stationary signal (A) and its reversed signal (B) are shown. The original non-stationary signal and the reversed signal have different variations with respect to time but the power spectrum obtained for both these signals are same making it difficult to distinguish between the two signals in frequency domain analysis. However, analyzing these signals in joint t-f space and obtaining their spectrograms clearly reveals the difference between original and reversed non-stationary signals. These concepts are equally suitable for any non-stationary signal.

The progress in the wrist pulse signal has been presented in[7]. The application of TFD approach has been seen in case of pregnant woman in[8]. The work done in[9-11] on ECG (Electrocardiogram) signals and in[12] on EEG (Electroencephalogram) signals depict that the time-frequency distributions have the ability to enhance and bring out the information from the transient nature of

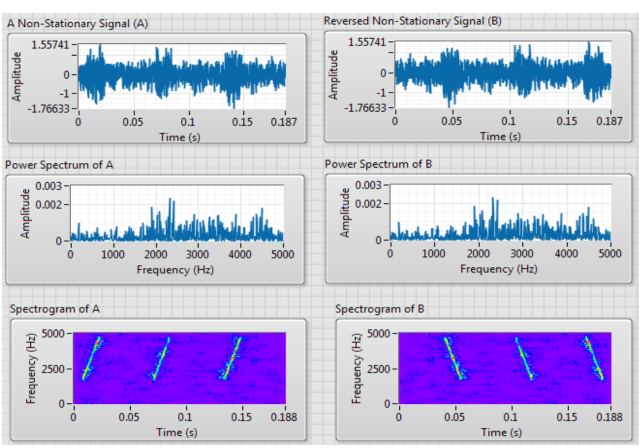

Figure 1. Power spectrum and spectrogram of a non-stationary and its reversed signal.

a non-stationary signal. Thus, due to the non-stationary nature of wrist pulse signals, the use of time-frequency distributions becomes ineluctable.

Therefore, the goal of this paper is to outline the basic concepts related to representing a wrist pulse (non-stationary) signal in time-frequency space using Gabor Spectrogram so that we can tell what frequencies appear when. ®LabVIEW has been used to store and process the wrist pulse signals using various Virtual Instruments (VIs). An attempt to extract various features from the t-f representation of the pulse signals has been made.

2. Signal Acquisition and Pre-processing

The physicians examine the wrist pulse by placing three fingers on the radial artery. They sense the pulse pressure wave using their fingers. Similarly, a sensor is needed to sense the pulse. A pressure sensor has been used to sense the pulse wave from radial artery. ®LabVIEW and Data Acquisition (DAQ) Card PCI-6251 have been used to acquire the data information from the pulse sensing device.

The wrist pulse signals have been collected from females in the age group of 20-25 years which constitute our database. This paper marks an attempt to show the importance of time-frequency domain in wrist pulse signals and therefore, initially the pulse signals from healthy subjects have been taken. These signals were stored as tdms files in computer. The collected signals are original and authentic. For each subject, the wrist pulse signals have been acquired from three channels i.e. vata, pitta and kapha which constitute as one pulse sample.

The signal gets contaminated due to the presence of noise and various artifacts such as:

- The breathing activity while collecting pulse signal causes baseline fluctuations in the signal.
- The high frequency components in the signal result from measuring and amplifying devices and are usually above 40 Hz.
- The low frequency noise results from movement, talking and also due to different emotions while collecting the pulse signal.
- The noise due to power line interference centered at 50Hz (in India) or 60 Hz (in USA).
- Noise from outside environment.

Thus, the collected raw signal must be processed to obtain useful information from it. Fig. 2 shows the framework of signal conditioning block used for pre-processing of raw pulse signals. The processing has been done using various Virtual Instruments in ®LabVIEW.

The acquired raw signal gets contaminated by various artifacts which need to be removed in order to obtain correct useful information. WA Detrend VI from ®LabVIEW has been used for correcting baseline drift. Then, after applying band pass filter, Wavelet De-noising was done.

The wrist pulse signal is a pseudo-periodic signal[13]. Therefore, after de-noising segmentation was done to present the pulse samples into a set of single period signals. The segmented pulse signals always have unequal lengths due to the variation of heart beat. Therefore, pulse normalization was done.

3. Gabor Transform

The Gabor Transform is a linear time-frequency transform. It computes the Gabor Coefficients for a given signal. The Gabor Expansion is the inverse of Gabor Transform which reconstructs the signal back into time domain. The characteristics of the non-stationary signal can become clear in time-frequency domain using Gabor Transform or Gabor Spectrogram which are not obvious in time or frequency domain alone.

$$G(\tau, f) = \int g(t).\, w(t-\tau).\, \exp(-j\omega t)\, dt \qquad (1)$$

Equation (1) gives the Gabor Transform $G(\tau, f)$ of the input time-varying signal $g(t)$ using windowing function $w(t-\tau)$ as the Gaussian window. The Gabor Transform is calculated by taking the Fourier Transform of the sampled input signal. The sampling is done using Gaussian Window. So, the sampling provides the time information for the signal and its Fourier Transform gives frequency information. Therefore, we get both time and frequency information together in one representation.

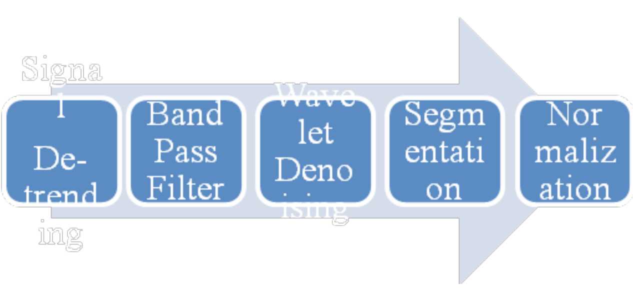

Figure 2. Signal pre-processing block diagram.

4. Results and Discussion

4.1 T-F Domain Pulse Features

Fig.3 shows the Spectrogram of wrist pulse signals of four subjects. Fig.4 - 8 illustrates the features extracted in joint t-f plane for these signals. These features denote the characteristics of pulse signal.

Spectrogram: It denotes the power of the pulse signal at a particular time and frequency. The signal power at different instant and frequency is represented by various color intensities in the spectrogram.

In the spectrogram, the output is shown by different colors denoting the intensity levels of output in order according to Violet, Indigo, Blue, Green, Yellow, Orange, and Red with red denoting the highest amplitude and violet denoting the least. Therefore, red portion in the spectrogram shows the output with highest amplitude, green and blue portions show negligible output.

- Mean Instantaneous Frequency (MIF): The parameter frequency is suitable to define stationary signals. For these signals, the term frequency can be estimated as number of oscillations or cycles per unit time. But for wrist pulse signal being a non-stationary signal, the term frequency becomes ambiguous due to the time varying nature of the signal[14] and such signals do not have a single frequency value. Therefore, instead of frequency, we use instantaneous frequency as a feature of wrist pulse signal. The instantaneous frequency (IF) defines the location of signal's spectral peak as it varies with time. In t-f plane, the energy of pulse signal is concentrated in frequency about the IF. Therefore, one approach is that IF can be estimated by peak detection in the spectrum of the signal. IF is also considered

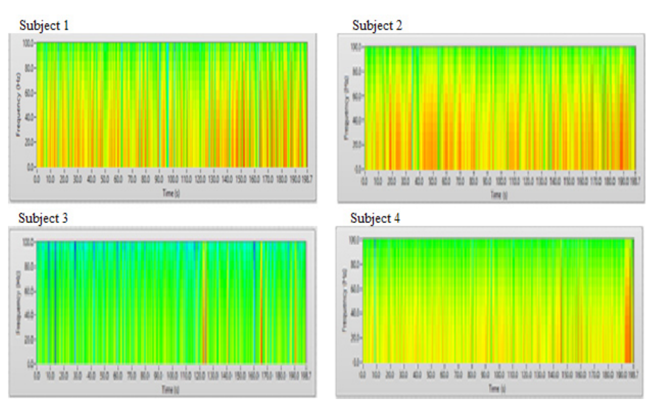

Figure 3. Gabor Spectrogram.

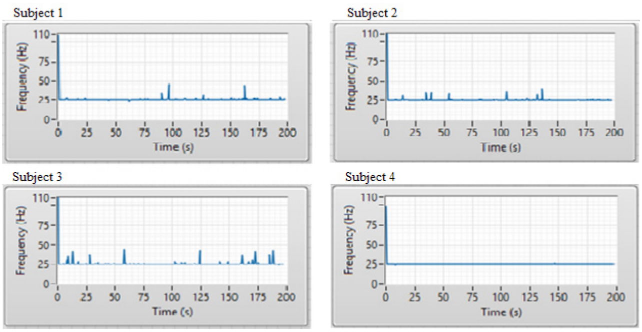

Figure 4. Mean Instantaneous Frequency.

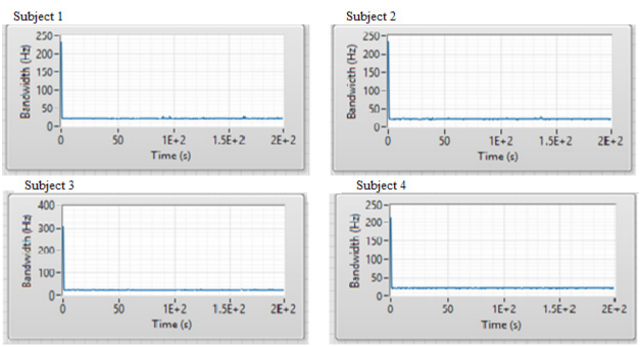

Figure 5. Mean Instantaneous Bandwidth.

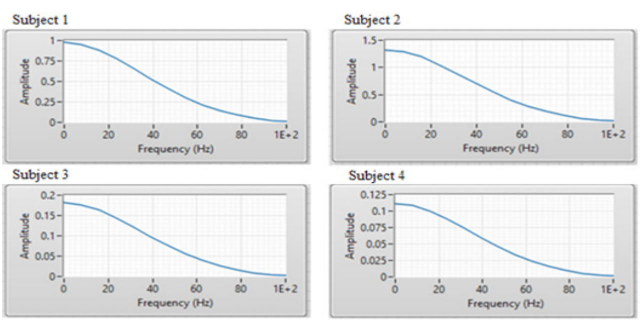

Figure 6. Frequency Marginal Integral.

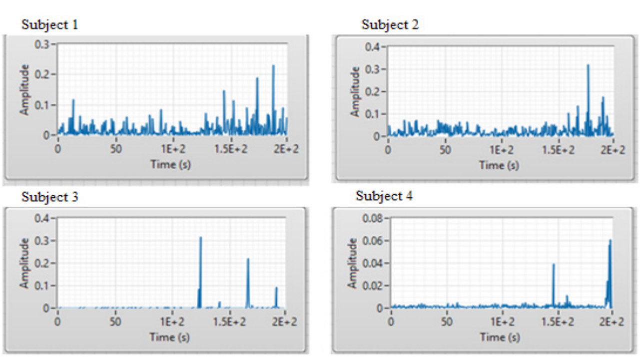

Figure 7. Time Marginal Integral.

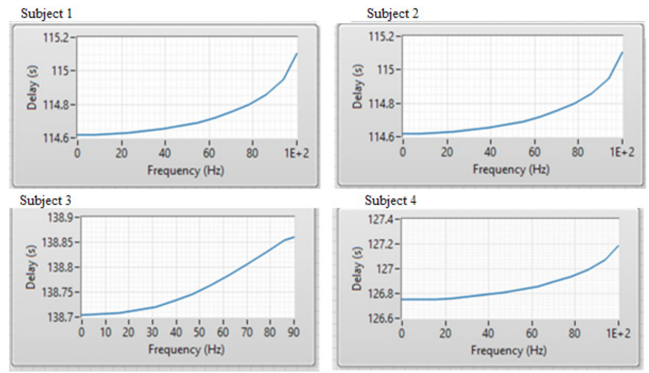

Figure 8. Group Delay.

to be the average of the frequencies present at a given time. And the Mean Instantaneous Frequency (MIF) reveals how the central frequency of the signal changes over time. The frequency variation for four subjects is shown in Fig.4 which is due to the non-stationary nature of pulse signals.

- Mean Instantaneous Bandwidth (MIB): Similar to frequency, the term bandwidth is fit to use only for stationary signals. The classical bandwidth definition can be interpreted as the spread of frequencies about the average. But, because there is no single fixed frequency value for a pulse signal, this definition becomes ambiguous. Therefore, we use the term instantaneous bandwidth for the pulse signal. The energy is concentrated in the spectrum about the IF giving rise to a spread of frequencies around it. This spread is called instantaneous bandwidth and the Mean Instantaneous Bandwidth (MIB) reveals how this instantaneous bandwidth of the signal changes over time. Fig. 5 shows the MIB for four subjects.
- Frequency Marginal Integral (FMI): We integrate the spectrogram of the pulse signal along time axis i.e. integrating each column of spectrogram.

$$FMI = \int_{-\infty}^{\infty} SP(t,\omega)dt \tag{2}$$

where SP denotes spectrogram of pulse signal as a function of time and frequency.

It is equivalent to the smoothed power spectrum of the pulse signal. The power spectrum reveals how the power of the signal changes with frequency. Therefore, frequency domain feature such as power spectrum of the signal can also be extracted using t-f analysis. Fig. 6 shows Frequency Marginal Integral pattern for four subjects. The values differ for different pulse signals but the pattern followed is same for all the subjects for frequency range up to 100 Hz.

- Time Marginal Integral (TMI): We integrate the spectrogram of the pulse signal along frequency axis i.e. integrating each row of spectrogram to obtain time marginal integral.

$$TMI = \int_{-\infty}^{\infty} SP(t,\omega)d\omega \quad (3)$$

where SP denotes spectrogram of pulse signal as a function of time and frequency. Fig. 7 shows Time Marginal Integral pattern for four subjects. It is equivalent to the smoothed instantaneous power of the pulse signal which reveals how the power of the signal changes over time. Therefore, time domain feature such as instantaneous power of the signal can also be extracted using t-f analysis.

- Group Delay (GD): It is a function of frequency. When a stationary signal is passed through a device such as an amplifier or a filter, all the frequency components of the signal are delayed by same amount of time. But wrist pulse signal being a non-stationary signal has multiple frequency components due to its time varying nature. Therefore, we get different delays for different frequency components at the output. Fig. 8 shows Group Delay pattern for four subjects up to 100 Hz frequency.
- Mean Square Error (MSE): The Mean Square Error between the original pulse signal fed to the Gabor Transform and the signal reconstructed after Gabor Expansion gives a measure of accuracy. The MSE has been calculated using (4).

$$MSE = \frac{1}{n}\sum_{i=0}^{n-1}(x_i - y_i)^2 \quad (4)$$

Where x_i is the original pulse signal and y_i is the reconstructed pulse signal from Gabor Expansion. The MSE for the pulse signals of 10 subjects is given in Table I.

4.2 Correlation

The linear correlation coefficients for pulse signals have been calculated based on features extracted from time-frequency distribution. The correlation coefficient value lies in the interval [-1,1]. The value 1 indicates complete positive correlation between the two signals and -1 indicates complete negative correlation. The value 0 represents no correlation. Table II represents the average correlationfor healthy pulse signals based on different features extracted.

Table 1. MSE for Wrist Pulse Signals

Wrist Pulse Signal	MSE
Subject 1	5.40E-14
Subject 2	7.80E-14
Subject 3	1.50E-14
Subject 4	6.40E-15
Subject 5	8.50E-15
Subject 6	7.40E-14
Subject 7	5.60E-15
Subject 8	2.30E-14
Subject 9	1.20E-14
Subject 10	8.30E-14
Average	3.60E-14

Table 2. MSE for Wrist Pulse Signals

Features	Average Correlation Coefficient
MIF	0.93988
MIB	0.99741
FMI	1
TMI	-0.0294
GD	0.98785
Spectrogram	0.95735

The Table 2 represents that even though the signals differ in time domain but their actual characteristics can become clear using features extracted from t-f domain. The low average value of correlation coefficient from Time Marginal Integral feature indicates that the pulse signals differ in time domain. But the rest of the values approach 1 indicating that the variation pattern for all the healthy signals considered are similar.

5. Conclusion

An approach for the analysis of wrist pulse signals using time-frequency distribution has been presented. Gabor Spectrogram has been used to analyze the wrist pulse signal in joint t-f space and various features have been extracted for healthy subjects. The Mean Square Error between original and reconstructed pulse signals has been calculated. Such low values clearly indicate the accuracy of t-f representation for pulse signals. The average value of correlation coefficient for pulse signals based on different features has been calculated indicating the similarity in pattern followed in t-f features.

6. Future Scope

In future, classification between healthy and unhealthy subjects can be done based on the extracted t-f features which will prove to be a significant tool in health analysis of human beings.

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