Time-Frequency Analysis of Non-Stationary Electrocardiogram Signals Using Hilbert- Huang Transform

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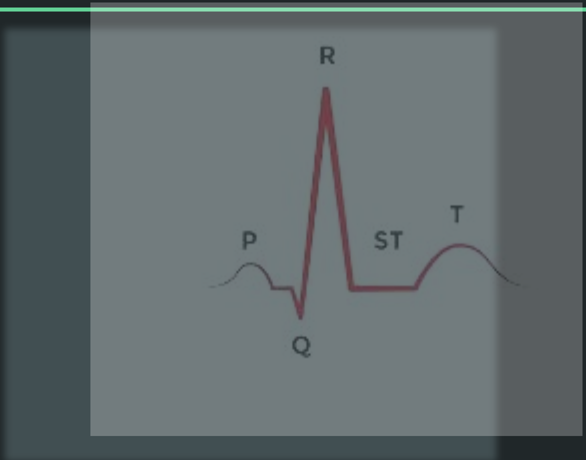
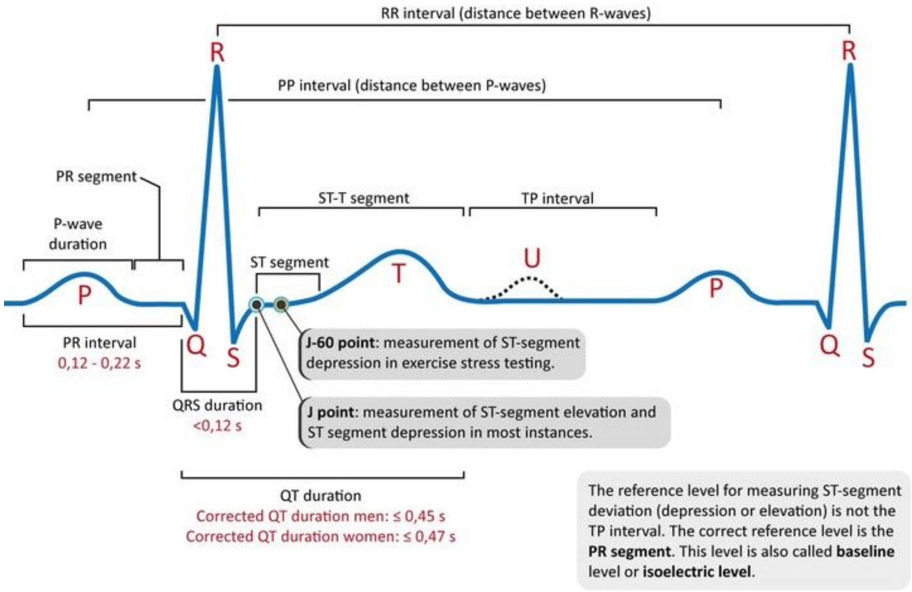
Link to Video :

https://youtu.be/lmFovET44GA
https://drive.google.com/file/d/19uSq_1pVRHbbPGz4FWLAUgkYyTI-xtSv/view?usp=sharing



Electrocardiogram (ECG)

- Electrocardiogram signal - non stationary (interfered with muscle potentials or noise or other frequencies)
- Potential Difference between two electrodes v/s time
- P wave
    - Contraction of Atria
- QRS complex
    - Contraction of Ventricles
- T wave
    - Repolarization of Ventricles
- U wave
    - Exact significance not known
    - An extension of repolarization



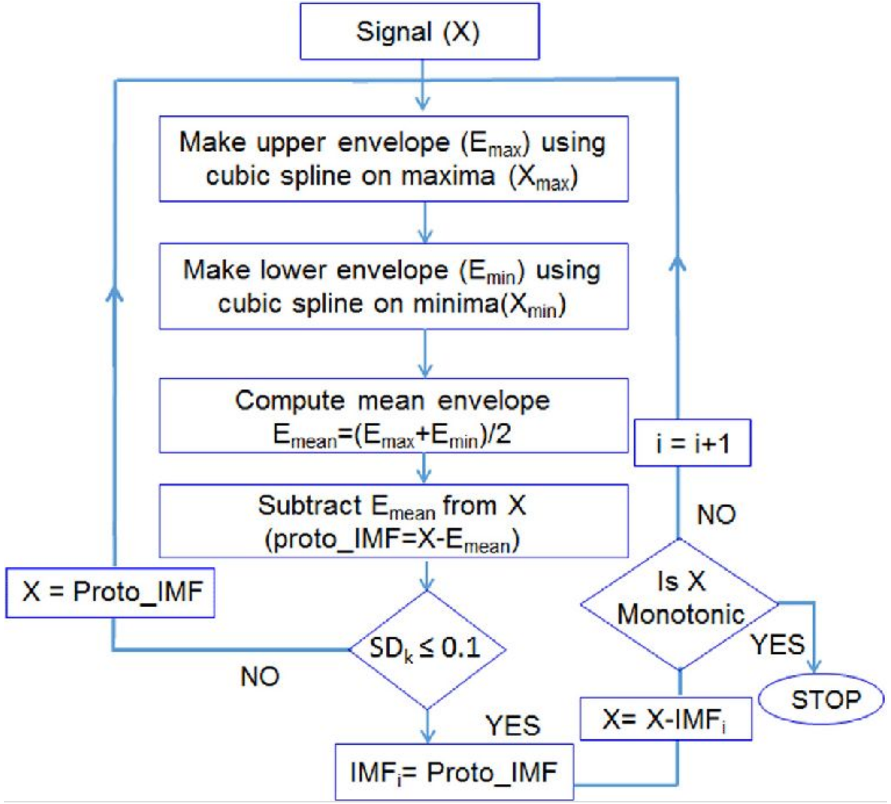
Why Time Frequency Analysis for ECG?

- The heart signals are non-stationary and might have abrupt changes in the time domain.
- To know more accurately about the condition of the patient the shift toward frequency domain has been proposed.
- Non-stationarity effects the variations in the frequency domain.
- Proposed methods - therefore require time-frequency analysis.

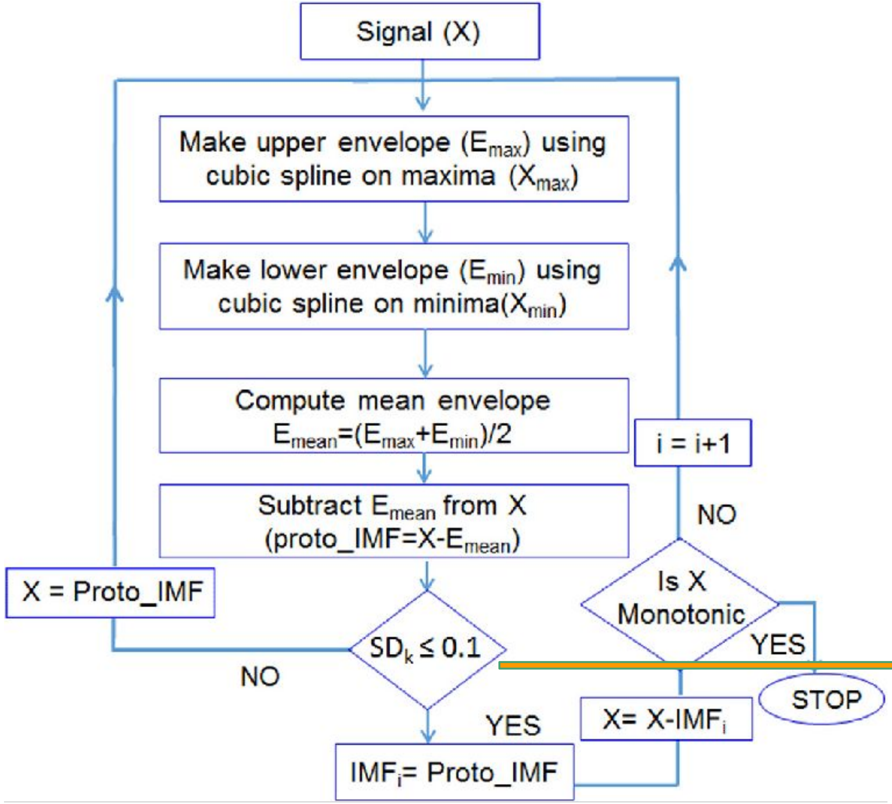
Considered Methods

- STFT
- Wavelet Transform
- Wigner Ville
- HHT - main focus

Constructing EMF’s (HHT)



Constructing EMF's (HHT)



$$SD_k = \sum_{t=0}^{T}\left[\frac{\left|(h_{1(k-1)}(t) - h_{1k}(t))\right|^2}{h_{1(k-1)}^2(t)}\right]$$

Empirical Mode Decomposition (EMD)

```
while ~ismonotonic(x)
   x1 = x;
   sd = Inf;
   while (sd > 0.1) | ~isimf(x1)
      s1 = getspline(x1);
      s2 = -getspline(-x1);
      x2 = x1-(s1+s2)/2;
      sd = sum((x1-x2).^2)/sum(x1.^2);
      x1 = x2;
   end

   imf{end+1} = x1;
   x          = x-x1;
end
imf{end+1} = x;
```

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Stoppage Criteria:
Squared difference sd is smaller than predetermined threshold, sifting process will be stopped.

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```

Stoppage Criteria:
Squared difference sd is smaller than predetermined threshold, sifting process will be stopped.

Append to imf list:
Add to imf list if the condition for imf is satisfied.

Hilbert Transform

For xi ϵ {x1,x2,...xn} xi is an IMF

zi(t)=xi(t)+jH{xi(t)} where H{} is hilbert transform

ai(t)=amplitude(zi(t))

θi(t)=phase(zi(t))

inst_energy(i,t)=|ai(t)|^2

inst_frequency(i,t)=diff(θi(t))

end

$$X(t) = \sum_{j=1}^{n} a_j(t) \exp\left(\mathrm{i} \int \omega_j(t)\,\mathrm{d}t\right).$$

$$R_j(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{r_j(t)}{t-\tau} d\tau = H(t)$$

$R_j(t)$ - is the Hilbert spectral analysis

r_j (t)- is the empirical mode of the signal,

$$a_j(t) = \sqrt{r_j(t)^2 + R_j(t)^2}$$

$$\theta(t) = \arctan\left(\frac{R_j(t)}{r_j(t)}\right); \ \omega = \frac{d\theta}{dt}$$

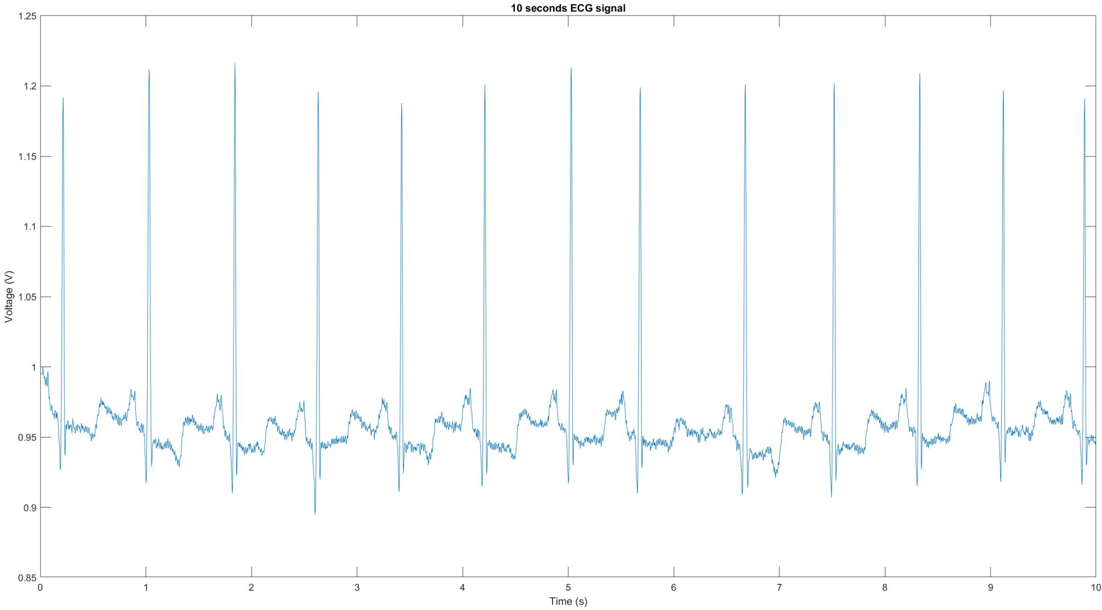
frequency-time spectrum of the ECG signal

$$H_j(\omega, t) = \sum_{j=1}^{n} a_j e^{q\int \omega(t)dt}$$

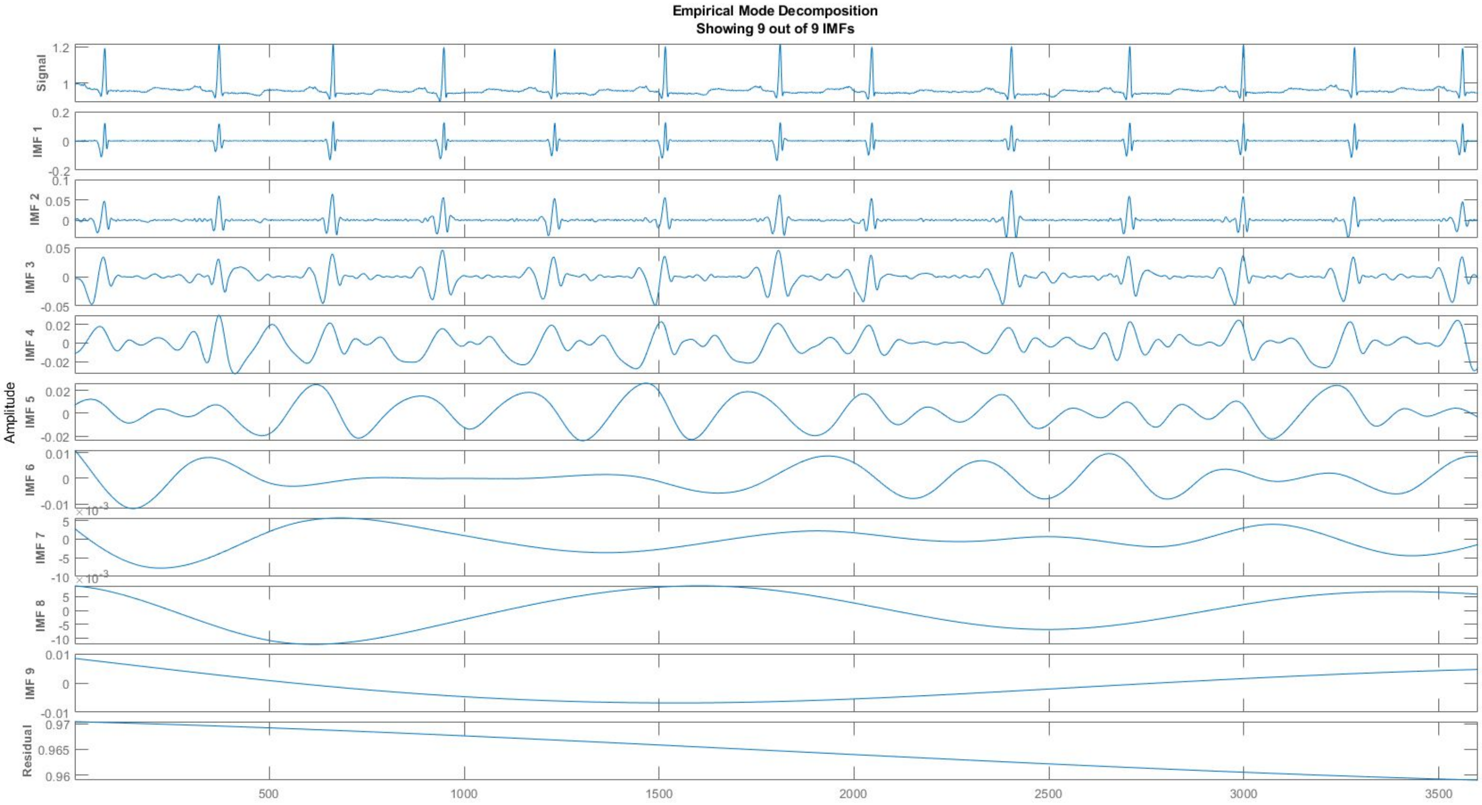
Results

Dataset

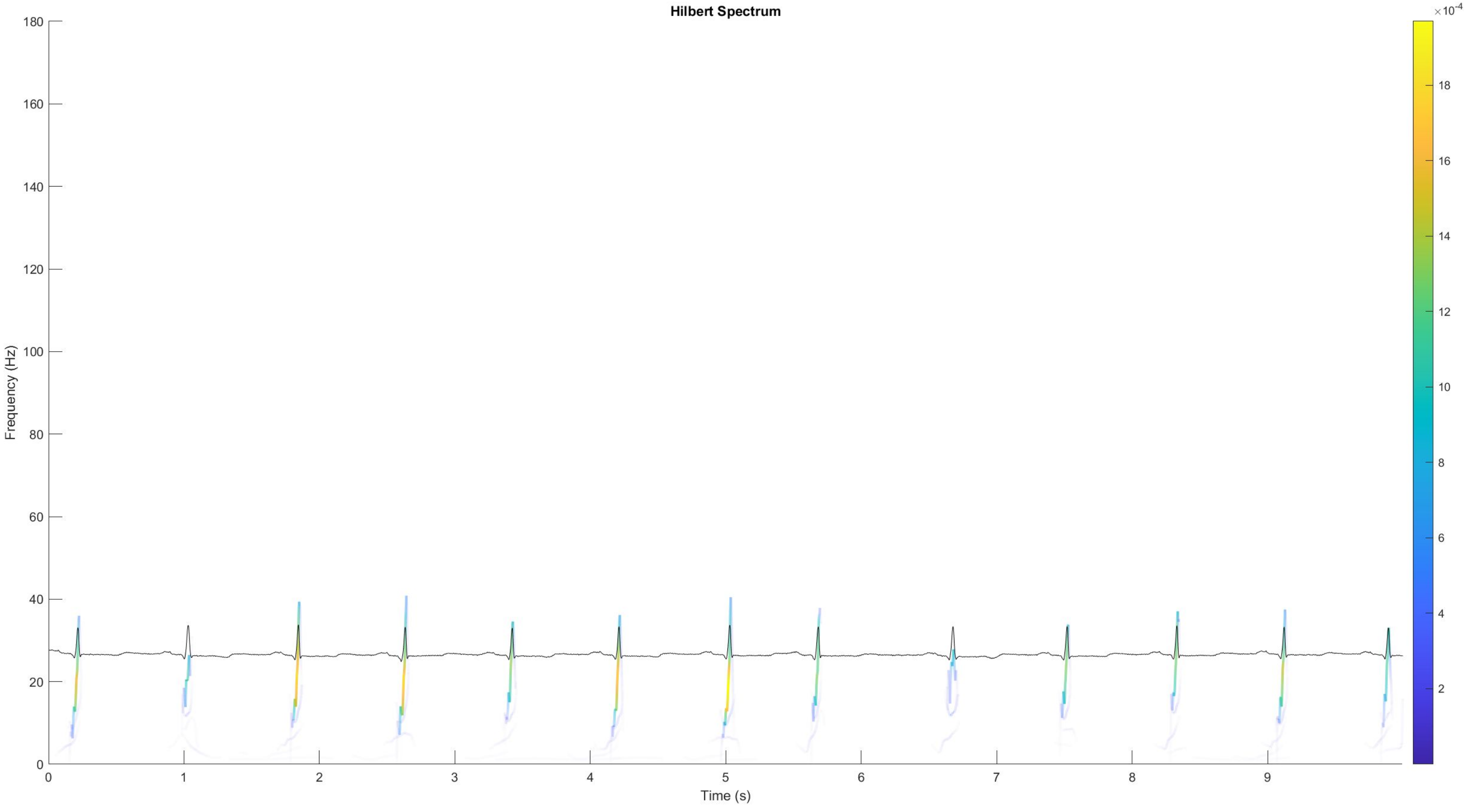
- The database to be used is MIT-BIH Arrhythmia Database- https://www.physionet.org/content/mitdb/1.0.0/
- 48 half-hour excerpts of two-channel ambulatory ECG recordings, obtained from 47 subjects
- Digitized at 360 samples per second per channel with 11-bit resolution over a 10 mV range.
- Available in “*.dat” format



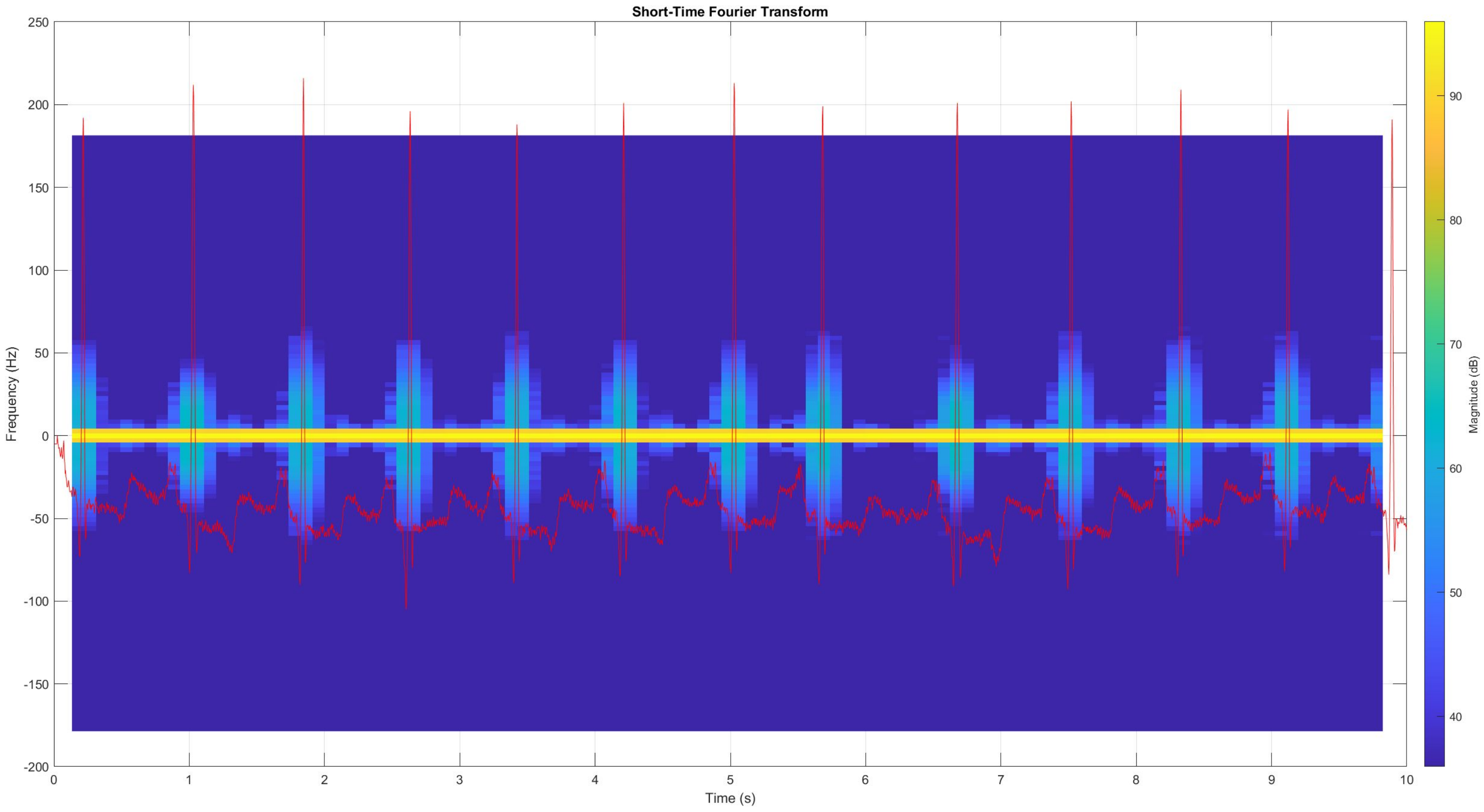
EMD Step - IMFs



HHT Spectrum

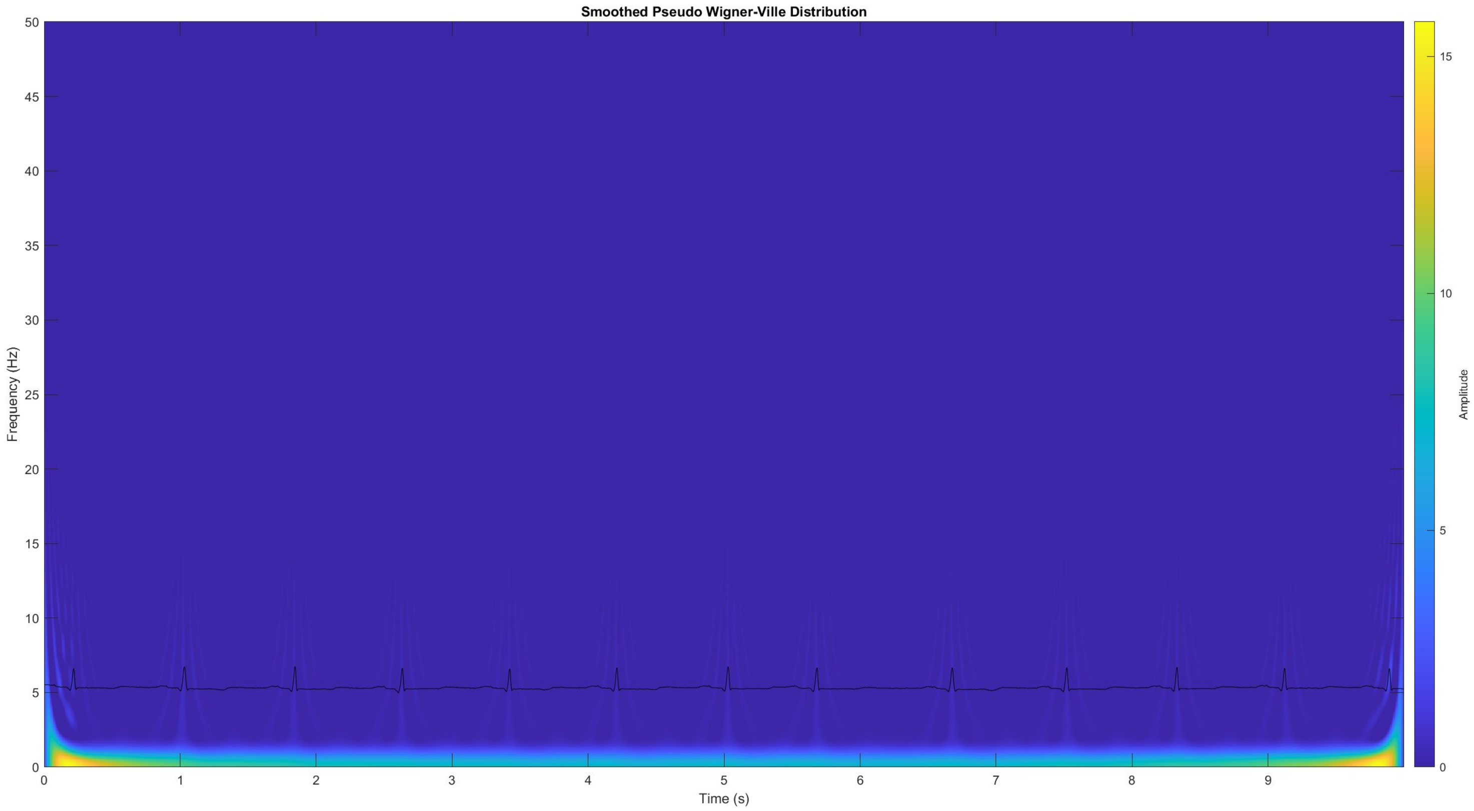


STFT



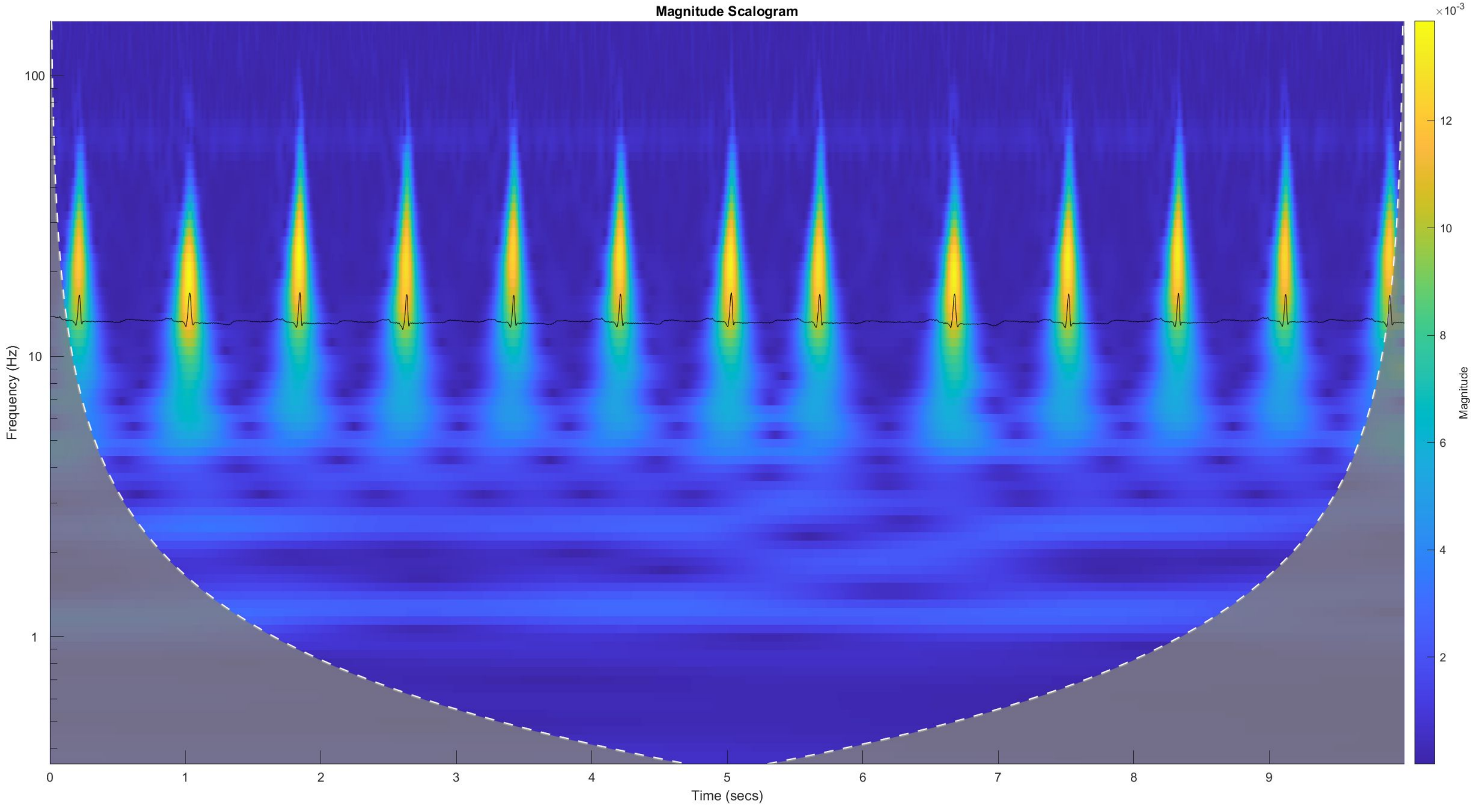
Short-Time Fourier Transform
Frequency (Hz)
Time (s)
Magnitude (dB)
250
200
150
100
50
0
-50
-100
-150
-200
0
1
2
3
4
5
6
7
8
9
10
90
80
70
60
50
40

Pseudo WVD



Smoothed Pseudo Wigner-Ville Distribution
Frequency (Hz)
50
45
40
35
30
25
20
15
10
5
0
Time (s)
0
1
2
3
4
5
6
7
8
9
Amplitude
15
10
5
0

Continuous Wavelet Transform



Conclusion

- HHT has been shown to exactly identity the QRS peak in the Time frequency domain.
- The Wigner Ville and STFT seem good enough approaches, none could have a excellent results due to a fine frequency resolution requires a large window which will, on the other hand, violate the stationary conditions.
- Choice of the analyzing window is problematic, and is the ECG is a very low frequency signal.
- For wavelet, a important point is the selection of threshold, scaling and the type of wavelet for different types of arrhythmia conditions.
- On the other hand, HHT is almost a non-parametric approach for the TF analysis for the ECG signal.

To be followed by:

- Comparison with different interpolation techniques for HHT
- Comparison using earlier stoppage criteria for HHT

References

- Chin-Feng Lin, and Jin-De Zhu ,HHT-Based Time-Frequency Analysis Method for Biomedical Signal Applications, Recent Advances in Circuits, Systems, Signal and Telecommunications.
- Cervantes et. al., Frequency, time-frequency and wavelet analysis of ECG signal, 2006 Multiconference on Electronics and Photonics.
- Bhargav Lenka, Time-frequency analysis of non-stationary electrocardiogram signals using Hilbert-Huang Transform, 2015 International Conference on Communications and Signal Processing (ICCSP).