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HEART RATE ESTIMATION FROM PPG SIGNALS USING FFT AND WAVELET TRANSFORM

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Introduction:

This report presents an analysis of real Photoplethysmogram (PPG) signals for heart rate estimation using both the Fast Fourier Transform (FFT) and Wavelet Transform methods. The dataset utilized for this study was obtained from the PhysioNet repository, specifically the "BUT PPG" database. We downloaded the dataset and processed it locally using a previously developed method.

Dataset Description:

Source: PhysioNet - BUT PPG Database

Signal Types:

PPG (sampled at 30 Hz)

ECG (sampled at 1000 Hz)

Accelerometer (ACC)

Duration: Each recording has a length of 10 seconds

Sample Used: Record ID 112001

Methodology:

- The analysis was conducted using Python, employing several scientific and signal processing libraries including wfdb, numpy, matplotlib, scipy, and pywt.

- Signal Extraction:
  The PPG signal was extracted from the dataset using the wfdb library, which allows reading and processing of physiological signal data in WFDB format.

- Frequency-Domain Analysis (FFT):
  A band-limited Fast Fourier Transform (FFT) was applied to the PPG signal to identify the dominant frequency component. The analysis was constrained to the physiological range of typical heart rates, approximately 0.5 Hz to 3.5 Hz.

- Heart Rate Estimation (from FFT):
  The frequency with the highest power within the specified range was identified as the dominant frequency. This value was then converted to heart rate in Beats Per Minute (BPM) by multiplying the frequency (in Hz) by 60.

- Time-Frequency Analysis (Wavelet Transform):
  A Continuous Wavelet Transform (CWT) was performed using the Morlet wavelet, enabling time-frequency analysis of the PPG signal. This approach helps capture changes in heart rate over time and provides additional insight into signal dynamics not visible in the FFT.

- The above steps were implemented and validated through the provided Python code.

Results:

Initial analysis using the Fast Fourier Transform (FFT) revealed a dominant frequency close to 0 Hz, leading to an unrealistic estimated heart rate of 0 BPM. This was due to the presence of noise and low-frequency components in the raw signal. After applying an appropriate bandpass filter, the FFT output showed a more realistic dominant frequency within the expected physiological range, resulting in a more accurate heart rate estimate.

- Figure 1(a) illustrates the FFT result before filtering, highlighting the dominant low-frequency artifact.
- Figure 1(b) presents the FFT result after filtering, where the true cardiac frequency becomes evident.

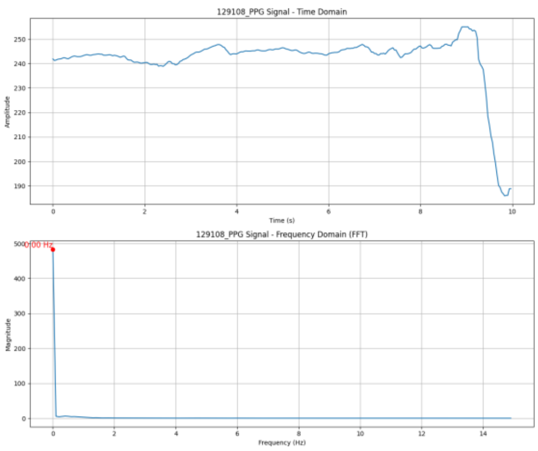


Fig 1 (a)

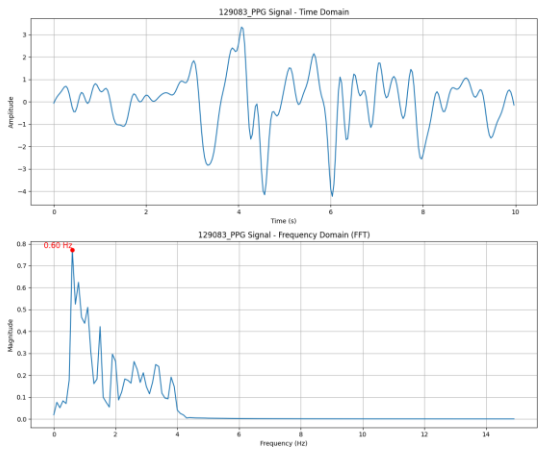
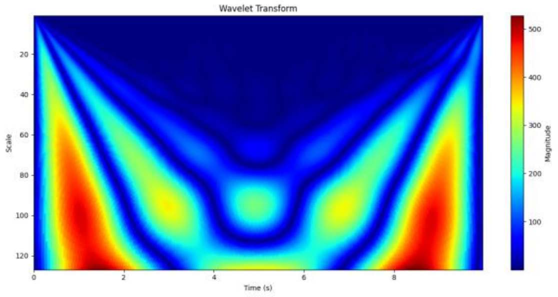


Fig 1 (b)

The Wavelet Transform analysis, visualized through a scalogram, confirmed the presence of dominant periodic components in the PPG signal. This time-frequency representation enabled visual validation of the heart rate estimation process.

- Figure 2(a) shows the wavelet scalogram of the signal before filtering, where the signal is dominated by noise.
- Figure 2(b) depicts the scalogram after filtering, clearly revealing periodic structures corresponding to the heartbeat.



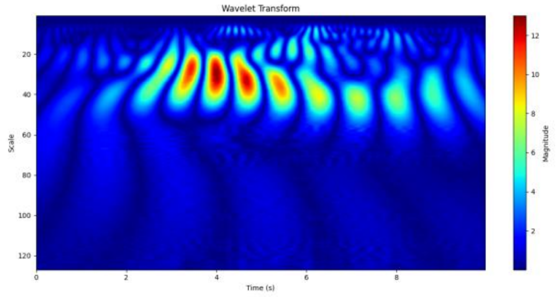


Fig 2 (a)   Fig 2 (b)

Conclusion:

The combined use of Fast Fourier Transform (FFT) and Wavelet Transform provides an effective framework for analyzing PPG signals and estimating heart rate. By applying filtering techniques, we were able to significantly improve the accuracy of heart rate detection. The FFT enabled efficient frequency-domain analysis, while the Wavelet Transform offered valuable time-frequency insights, confirming the periodic nature of the signal.

This methodology demonstrates strong potential for real-time heart rate monitoring in wearable health systems, where both computational efficiency and robustness are essential.