Peak Detection and Pulse Analysis Using PPG Signals

Objective:

- **Develop a peak detection algorithm** to analyze pulse rate and pulse morphology from real PPG signals.
- **Extract features** related to Pulse Rate Variability (PRV) and Pulse Morphology for cardiovascular health assessment.

Theory:

Photoplethysmography (PPG) is an optical technique that measures blood volume changes in the microvascular bed of tissue. It uses light-emitting diodes (LEDs) and photodetectors to capture pulse waves, which correspond to heartbeats.

Key Features Extracted:

1. **Pulse Rate (PR)**: The number of pulses per minute, equivalent to heart rate.
2. **Pulse Rate Variability (PRV)**: Variation in time intervals between consecutive pulses, related to Heart Rate Variability (HRV).
3. **Pulse Morphology**: The shape and characteristics of the pulse waveform, including:
    - **Peak Amplitude**: Height of the peak, indicating blood volume.
    - **Peak Width**: Duration of each pulse.
    - **Dicrotic Notch**: A secondary dip in the waveform related to aortic valve closure.

Techniques Used:

1. **Adaptive Thresholding**: Dynamically adjusts the threshold for peak detection based on signal properties.

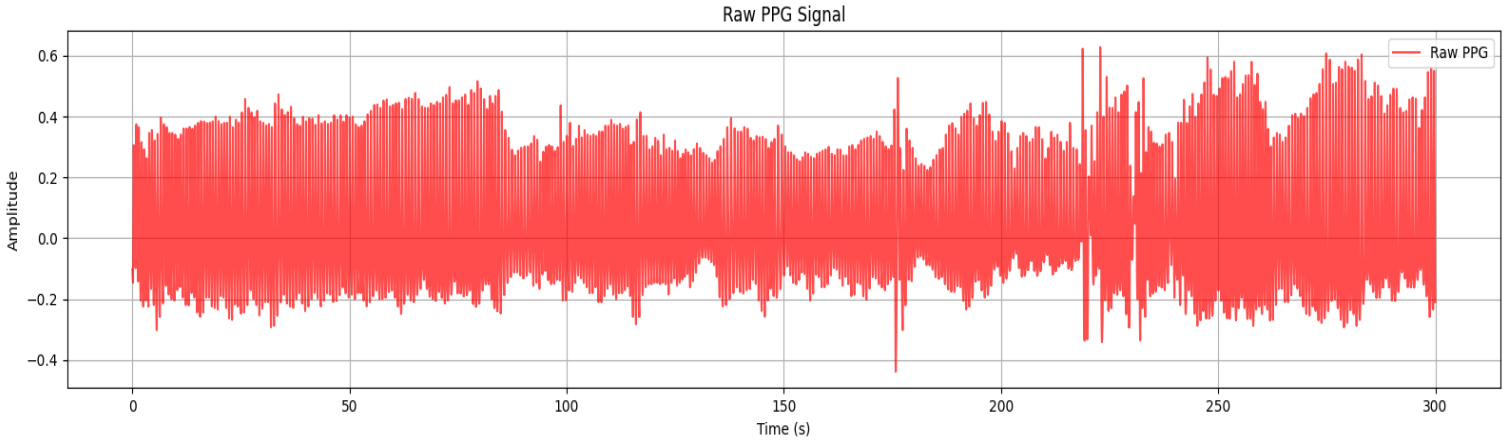
2. **Wavelet Transform**: Denoises and enhances peak detection accuracy.
3. **Signal Processing (SciPy)**: Used for filtering and detecting peaks.
4. **Visualization (Matplotlib)**: Visualizes waveforms and feature analysis.

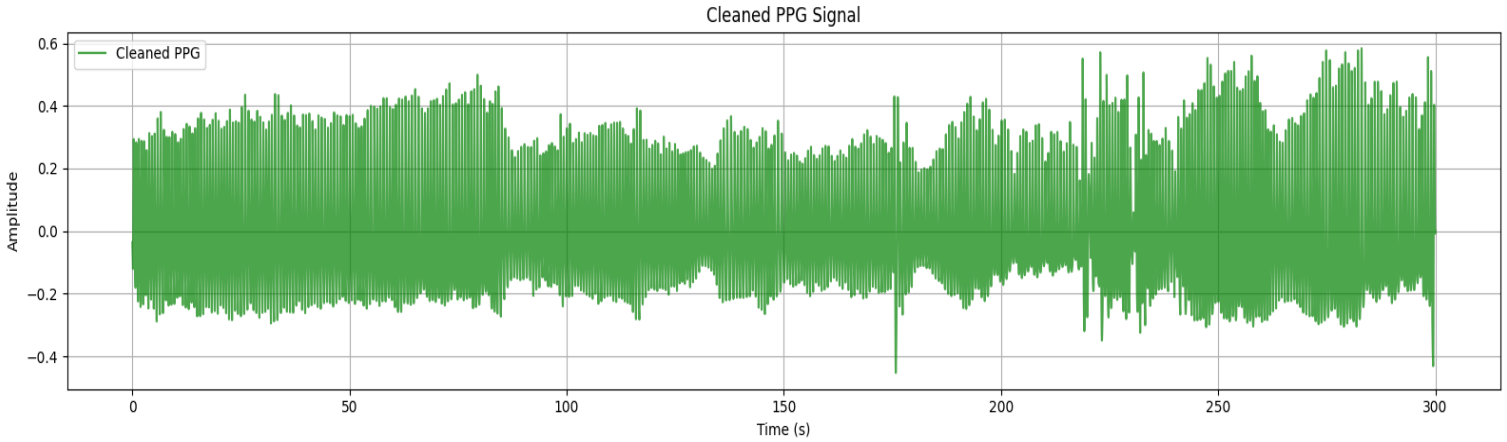
Data Processing Steps:

1. **Step 1: Load and Inspect Data**
    - Load PPG data from a CSV file.
    - Extract the relevant PPG column.
    - Visualize the raw data to understand noise and signal trends.
2. **Step 2: Signal Preprocessing**
    - Apply filtering to remove high-frequency noise and baseline drift.
    - Normalize the signal for consistent peak detection.
3. **Step 3: Peak Detection**
    - Use the find_peaks() function to locate peaks corresponding to heartbeats.
    - Adjust parameters like minimum peak height and minimum distance between peaks for optimal detection.
4. **Step 4: Pulse Analysis**
    - Calculate Pulse Rate (PR) in Beats Per Minute (BPM).
    - Compute Inter-Peak Intervals (IPI) for Pulse Rate Variability (PRV).
    - Analyze Pulse Morphology (e.g., amplitude, width).
5. **Step 5: Visualization**
    - Plot Raw vs. Cleaned PPG signals.
    - Mark detected peaks to validate the algorithm.
    - Visualize Pulse Rate Variability (PRV).

Code :

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from scipy import signal
import neurokit2 as nk

data = pd.read_csv('bio_resting_5min_100hz.csv')  # Load the CSV file
ppg_signal = data['PPG']  # Extract the PPG data from the 'PPG' column
fs = 100
time = np.arange(len(ppg_signal)) / fs

ppg_clean = nk.ppg_clean(ppg_signal, sampling_rate=fs)

#  Visualize Raw and Cleaned PPG Signals
plt.figure(figsize=(16, 8))

plt.subplot(2, 1, 1)
plt.plot(time, ppg_signal, color='red', alpha=0.7, label='Raw PPG')
plt.title("Raw PPG Signal")
plt.xlabel("Time (s)")
plt.ylabel("Amplitude")
plt.legend()
plt.grid(True)



plt.subplot(2, 1, 2)
plt.plot(time, ppg_clean, color='green', alpha=0.7, label='Cleaned PPG')
plt.title("Cleaned PPG Signal")
plt.xlabel("Time (s)")
plt.ylabel("Amplitude")
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()
```






```
#  Peak Detection in Cleaned PPG Signal
peaks, properties = signal.find_peaks(
    ppg_clean,
    distance=fs*0.5,
    height=np.mean(ppg_clean)*0.6
)

peak_count = len(peaks)
print(f"Total Peaks Detected: {peak_count}")
```

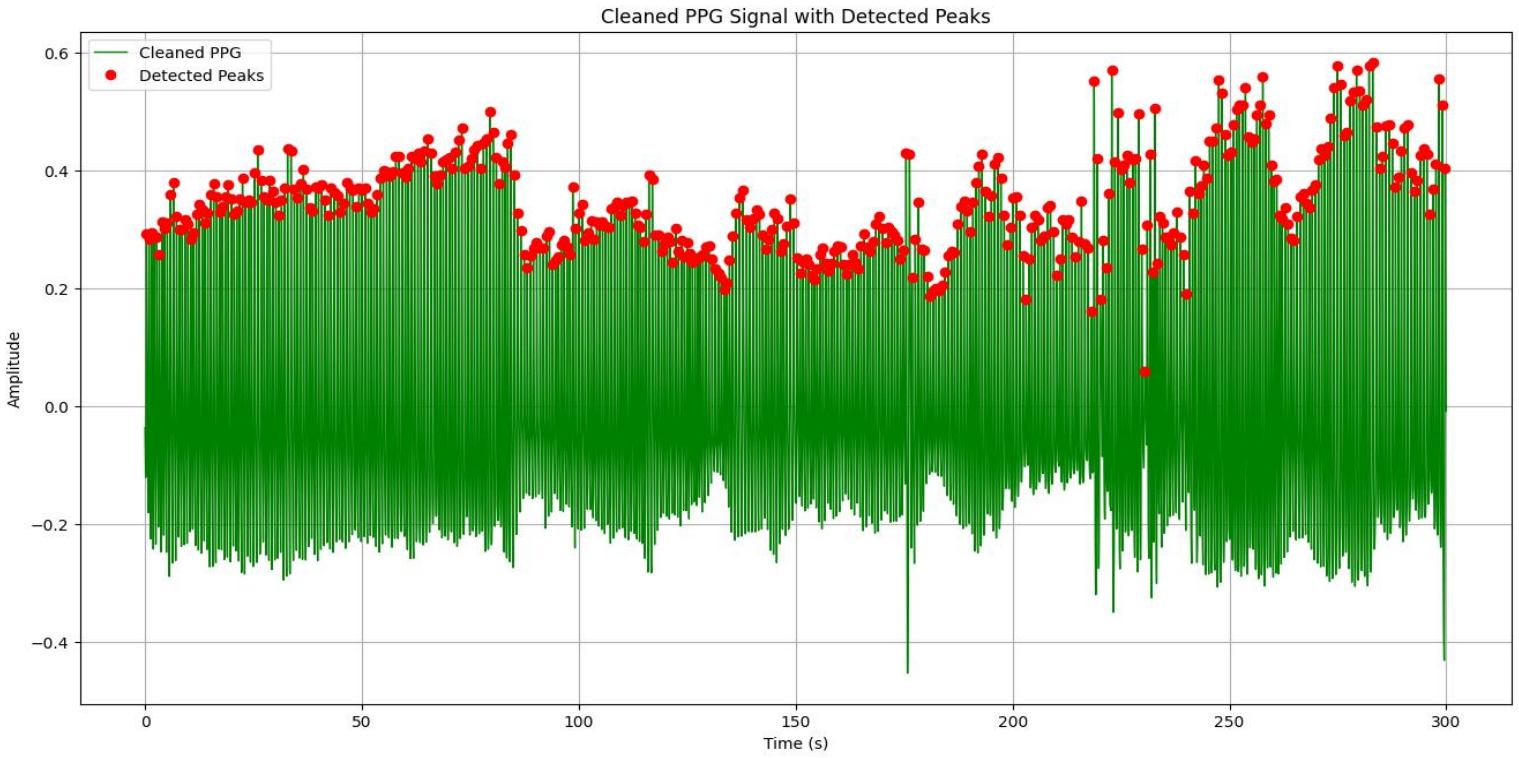
Total Peaks Detected: 432

```
#  Calculate Pulse Rate and PRV Metrics
if peak_count > 1:
     rr_intervals = np.diff(peaks) / fs
        pulse_rate = 60 / np.mean(rr_intervals)
    print(f"Pulse Rate: {pulse_rate:.2f} BPM")
```

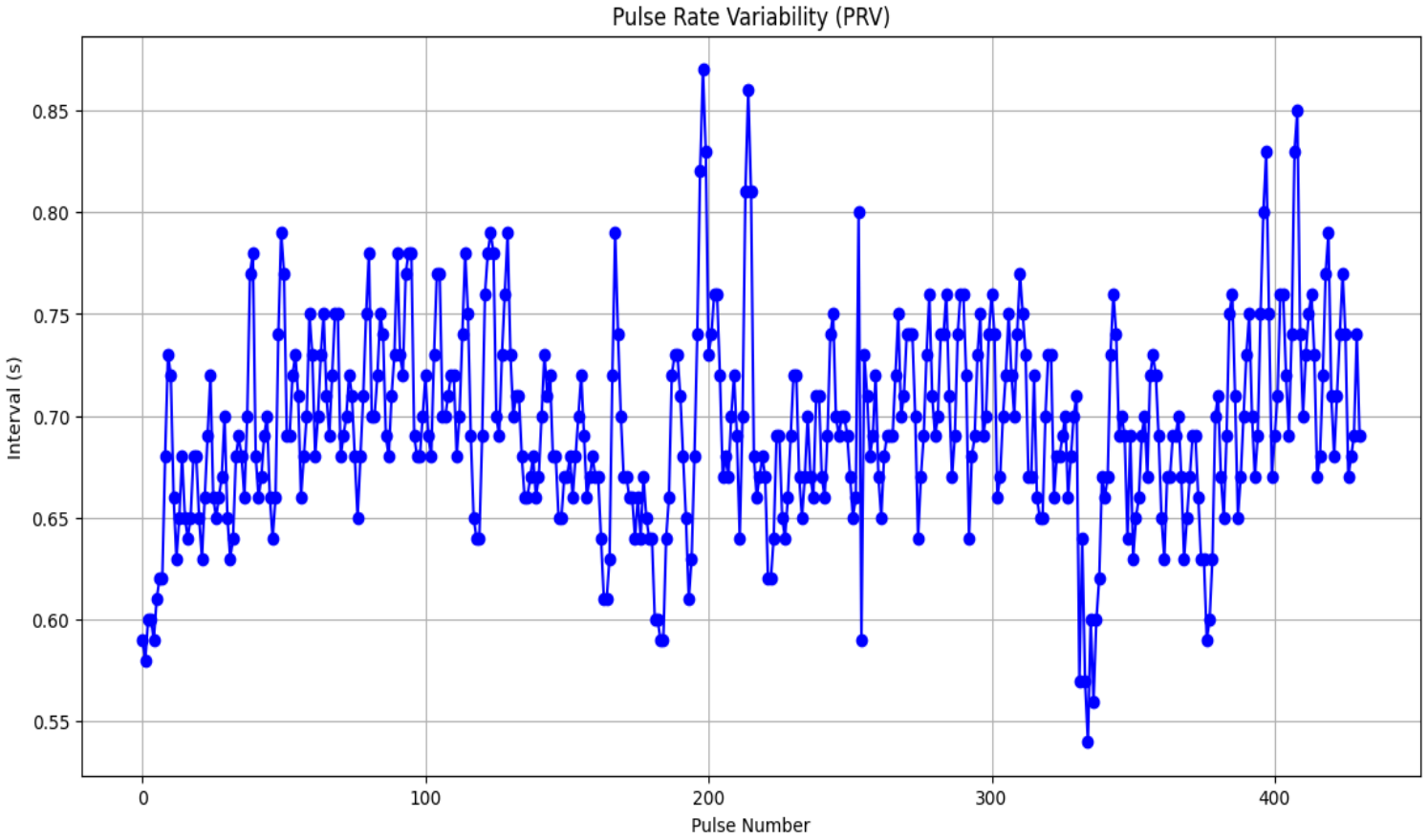
```
else:
    print("Insufficient peaks detected. Check signal quality or peak detection parameters.")
```

Pulse Rate: 86.37 BPM

```
#  Visualize Cleaned PPG with Detected Peaks
plt.figure(figsize=(16, 8))
plt.plot(time, ppg_clean, color='green', linewidth=1, label='Cleaned PPG')
plt.plot(time[peaks], ppg_clean[peaks], 'ro', label='Detected Peaks')  # Mark peaks
plt.title("Cleaned PPG Signal with Detected Peaks")
plt.xlabel("Time (s)")
plt.ylabel("Amplitude")
plt.legend()
plt.grid(True)
plt.show()
```



```
# Step 7: Pulse Rate Variability (PRV) Visualization
plt.figure(figsize=(14, 7))
plt.plot(rr_intervals, marker='o', linestyle='-', color='blue')
plt.title("Pulse Rate Variability (PRV)")
plt.xlabel("Pulse Number")
plt.ylabel("Interval (s)")
plt.grid(True)
plt.show()
```



Output Explanation:

1. **Raw vs. Cleaned PPG Signal**:
    - The raw signal shows noise and baseline drift.
    - The cleaned signal is smoother, with distinct peaks.
2. **Cleaned PPG with Detected Peaks**:
    - Red dots mark detected peaks corresponding to heartbeats.
    - Peaks are accurately aligned with pulse waves.
3. **Pulse Rate Variability (PRV)**:
    - The PRV graph shows variations in time between heartbeats.
    - This variability is used to assess cardiovascular health and stress levels.
4. **Console Outputs**:
    - Total Peaks Detected: Displays the number of detected heartbeats.
    - Pulse Rate: Shows the average heart rate in BPM.