Perform the complete time-domain/frequency-domain analysis of the data

Objectives:

- The primary objective of this study is to perform a detailed analysis of the Gait Phase Database to extract meaningful insights into the biomechanical changes and adaptations that occur in human gait at different walking speeds.

Sub-Objectives:

Time-Domain Analysis:

- Characterize the temporal dynamics of gait cycles, including the durations of various gait sub-phases like stance, loading response, mid stance, terminal stance, pre-swing, and swing.
- Analyze the variation in ground reaction forces through the gait cycle.
- Determine the synchronization and phase relationships between different markers placed on the foot.

Frequency-Domain Analysis:

- Perform Fourier analysis to identify predominant frequencies in the marker trajectories and ground reaction forces.
- Assess how these frequencies vary with walking speed and between individuals.
- Explore the presence of harmonic components and their relevance to gait stability and efficiency.

Description of Dataset:

- **Objective**: The study aimed to analyze how different phases of walking (like stance, swing, etc.) change with walking speed, using detailed measurements from an infrared system and a special treadmill.
- **Activities**: Participants walked on a treadmill at 12 different speeds (ranging from 0.6 to 1.7 meters per second), with the speed order randomized to reduce fatigue.
- **Participants**: The study included 21 healthy adults (10 men and 11 women, average age around 24 years), but one participant was excluded due to incomplete data.
- **System Setup**: Data was collected using markers on the shoes and force plates. Markers' positions were tracked at 200 Hz, and ground reaction forces at 1000 Hz. The data was processed to correct any drifts and filtered to remove noise.
- **Data Format**: The collected data was stored in comma-separated files, with separate files for each subject and speed. The data included both marker positions and ground reaction forces, organized in a specific column order. Overstep events were also recorded in separate files

Literature Review:

1. **Problem Addressed:** Investigating if muscle synergy features from EMG signals enhance gait phase classification accuracy over traditional methods.
2. **Methodology Used:** Utilizing NNMF to identify muscle synergies and four machine learning algorithms for gait phase classification with EMG data from eight healthy individuals.
3. **Final Outcomes:** Muscle synergy features showed superior accuracy in gait phase classification, supporting their potential for improved neuromuscular analysis during locomotion.
4. **Gaps Identified:** Further exploration needed on muscle synergy applications in pathological gait and broader populations; consideration of integration with other sensor modalities for enhanced detection.

Introduction:

- The Gait Phase Database offers a unique opportunity to analyze human walking dynamics across a spectrum of speeds using high-resolution biomechanical measurements.
- The comprehensive dataset includes three-dimensional (3D) marker positions and ground reaction forces collected from 21 healthy subjects. These measurements were captured while subjects walked on an instrumented split-belt treadmill across a range of speeds.
- Such datasets are crucial for understanding the biomechanics of walking, with applications ranging from clinical diagnostics to enhancing athletic performance and designing assistive technologies.

What is Time domain and Frequency domain analysis?

Time Domain Analysis

- Time domain analysis involves studying a signal as it varies over time. In this domain, the signal is typically represented as a function of time, $x(t)$ where t indicates time.
- The main focus in time domain analysis is on the changes and patterns of the signal's amplitude as they occur over time. This includes observing how the signal behaves, its amplitude at different times, and its overall shape and structure during the observation period.

Frequency Domain Analysis

- Frequency domain analysis involves examining a signal in terms of its constituent frequencies. This is typically done using mathematical transformations such as the Fourier Transform, which converts the time-domain signal $x(t)$ into its frequency-domain representation $X(f)$, where f stands for frequency.
- The frequency domain analysis reveals what frequencies are present in the signal and their respective amplitudes. This helps in understanding the signal's frequency content—essentially, how much of the signal is made up by different frequency components.

Time-Domain Features:

- Time-domain features used in gait analysis or other biomechanical time series data include:
- **Mean**: The average value of the data points in the time series, which provides a measure of the central tendency.
- **Median**: The median gives a robust measure of the central tendency of the data, which is less affected by outliers and skewed data than the mean. This is particularly useful in biomechanics, where extreme values (outliers) can be due to measurement errors or anomalous movements that do not reflect typical gait behavior.
- **Standard Deviation**: Measures the amount of variation or dispersion in the dataset, which can indicate the stability or consistency of the movement.
- **Variance**: The square of the standard deviation, another measure of dispersion in the dataset.
- **Range**: The difference between the maximum and minimum values in the dataset, providing a sense of the total amplitude of the signal.

Time-Domain Features(cont..)

- **Maximum**: The peak value in the dataset, which could be important for identifying peak forces or positions.
- **Minimum**: The lowest value in the dataset, similarly useful for understanding the dynamics of the motion.
- **Zero-crossing Rate**: The rate at which the signal changes from positive to negative or back. This can be useful in analyzing the frequency content of a signal in the time domain and may relate to the cadence in gait analysis.
- **Signal Magnitude Area (SMA)**: An aggregate measure of the magnitude of the signal over time, often used in activity recognition to gauge the intensity of movement.
- **Root Mean Square (RMS)**: Represents the square root of the average of the squares of the values. It provides a measure of the magnitude of a varying quantity and can be useful for assessing the power of the signal.

Frequency-Domain Features:

- **FFT Coefficients**: These are the results from the Fast Fourier Transform applied to the time-series data, which convert the signal from the time domain to the frequency domain. In gait analysis, these coefficients can help identify dominant movement patterns or rhythms within the gait cycle.
- **Fundamental Frequency**: This is the frequency at which the largest peak in the Fourier transform occurs. In terms of gait, this could correspond to the most prominent periodic movement frequency, such as the cadence of steps.
- **Low Frequency Band Energy:** Energy in specific frequency bands can be crucial in identifying characteristics of gait dynamics. Low frequency band energy (1-10 Hz) might be associated with the overall gait cycle dynamics.

Frequency-Domain Features(cont..)

- **High Frequency Band Energy**: High frequency band energy (10-50 Hz) might reflect finer, more rapid movements or adjustments, possibly relating to corrections in balance or foot placement.
- **Spectral Rolloff**: This measure gives the frequency below which a specified percentage of the total spectral energy (typically 85%) is contained. It can be used to differentiate between walking speeds or identify when significant changes occur within the gait cycle, such as transitioning from stance to swing.

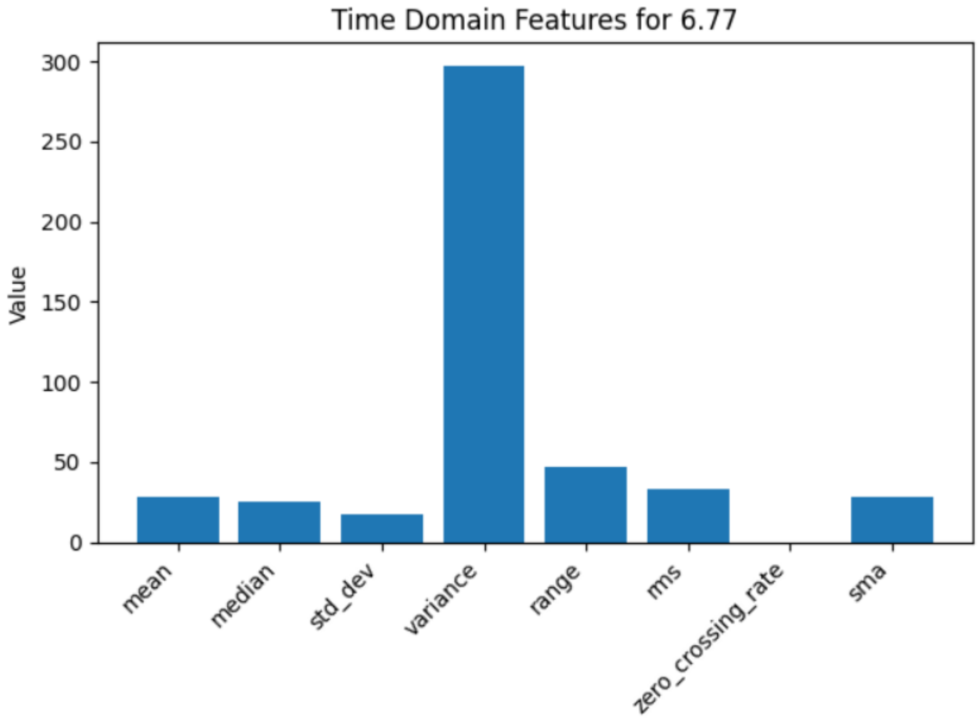
Results and Analysis:

For the data GP2_1.2_oversteps.csv

```
Please enter the path to the CSV file: /content/GP2_1.2_oversteps.csv
     6.77
0   7.825
1  19.515
2  31.070
3  54.440
```

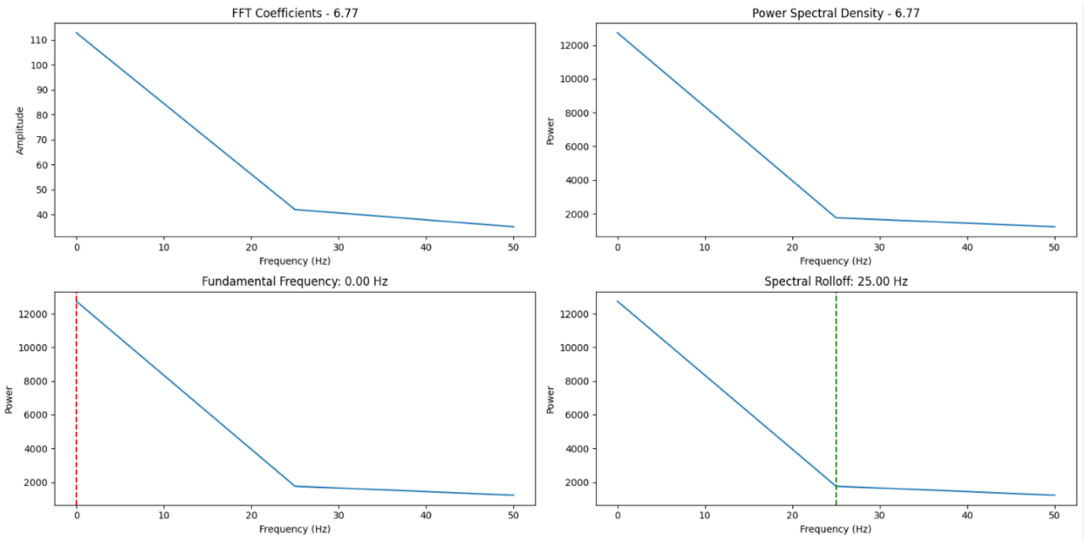
Values of Time Domain Analysis Features:

```
Enter the CSV file path: /content/GP2_1.2_oversteps.csv

Time Domain Analysis for 6.77:
mean: 28.2125
median: 25.2925
std_dev: 17.2289
variance: 296.8359
range: 46.6150
rms: 33.0572
zero_crossing_rate: 0.0000
sma: 28.2125
<ipython-input-4-1e7729dcbf08>:42: UserWarning: FixedFormatter
  ax.set_xticklabels(feature_names, rotation=45, ha='right')
```



Values of Frequency Domain Analysis Features:

```
Please enter the CSV file path: /content/GP2_1.2_oversteps.csv

Frequency Domain Analysis for 6.77:
fft_coefficients: Array of 3 elements
power_spectral_density: Array of 3 elements
fundamental_frequency: 0.0000
low_freq_band_energy: 0.0000
high_freq_band_energy: 2989.2892
spectral_centroid: 6.7069
spectral_rolloff: 25.0000
spectral_entropy: 0.8874
```



Conclusion:

- The time domain analysis features provided valuable insights into the temporal characteristics of the EMG signals, revealing patterns related to muscle activation and relaxation during gait. These features offer a fundamental understanding of muscle behavior throughout the gait cycle.
- The frequency domain analysis features offered deeper insights into the spectral properties of the EMG signals, unveiling frequency-specific information about muscle activation patterns. These features enable a more detailed examination of muscle activity dynamics and frequency modulation during locomotion.

THANK YOU