Friedrich-Alexander-Universität
Technische Fakultät

Automatic Detection of Parkinson's Disease Using Gait Signals and State Space Models/Mamba

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Agenda

Subheadline möglich. Gegebenenfalls löschen.

Motivation & Background

Motivation and Background

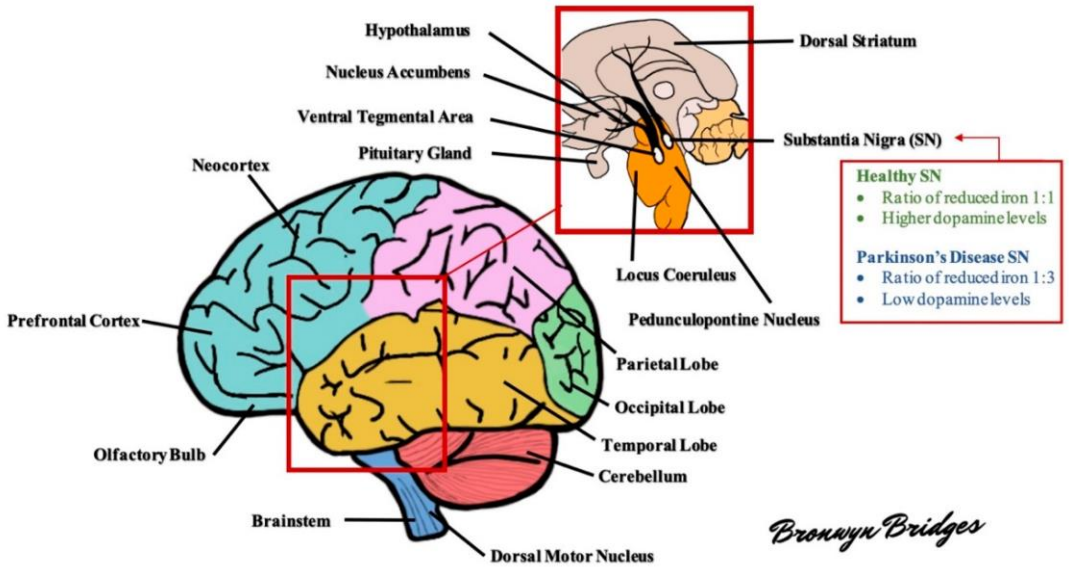


Image source: *Bronwyn Bridges et al. (2020), Molecules, MDPI, https://doi.org/10.3390/molecules25194382*

- ✓ Parkinson's Disease (PD) affects gait rhythm and symmetry.
- ✓ Ground reaction forces (VGRF) from walking can capture these motor abnormalities.
- ✓ Early gait-based detection enables timely clinical intervention.
- ✓ This project establishes a *feature-level baseline* before applying Mamba/State Space Models.

Dataset Description & Demographics

Dataset Overview-1

Group	Subjects	Mean Age (±SD	Male	Female
Control	72	63.7 ± 8.7	40	32
PD	93	66.3 ± 9.5	58	35

Figure: Participant demographics distribution by group, age, and gender.

- ✓ Total of **165 subjects** analyzed (72 Controls, 93 PD patients).
- ✓ **Mean age:** PD group is slightly older (66.3 ± 9.5 years) than Controls (63.7 ± 8.7 years).
- ✓ **Gender balance:** Both groups have comparable male, female ratios, ensuring unbiased comparisons.
- ✓ **Relevance:** These demographic similarities support reliable baseline feature and gait analysis.

Dataset Overview-1

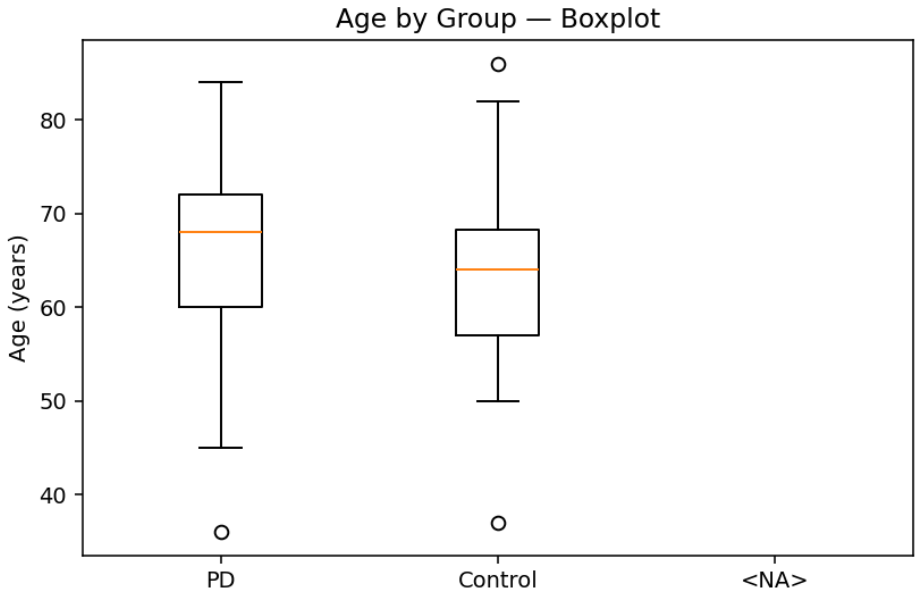


Figure: Age distribution by group

- ✓ **Dataset:** 306 subjects (≈ 214 PD + 92 Controls
- ✓ **Signal type:** Vertical Ground Reaction Force (VGRF) from both feet
- ✓ **Sampling rate:** 100 Hz (10 ms intervals)
- ✓ **Observation:** PD group shows higher median age, but similar variability
- ✓ **Relevance:** Ensures demographic comparability before model training

Dataset Overview-2

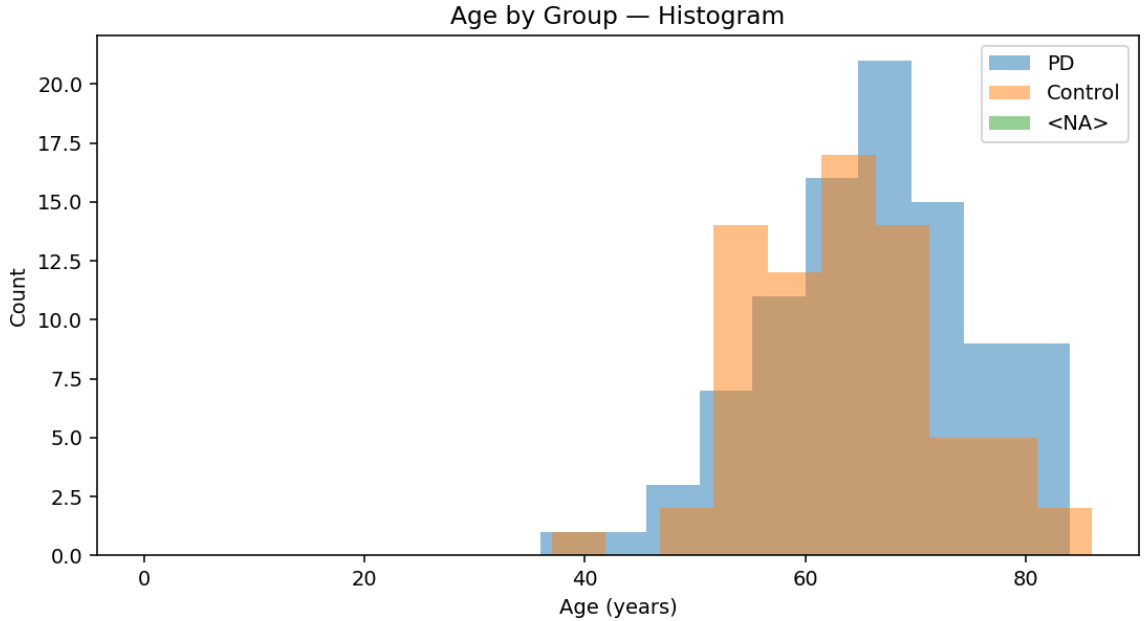


Figure: Age distribution histogram

- ✓ Visualizes age distribution across PD and Control subjects.
- ✓ PD participants show a higher frequency in the 65–80 year range.
- ✓ Both groups have comparable spread, supporting balanced dataset demographics.

Dataset Overview-3

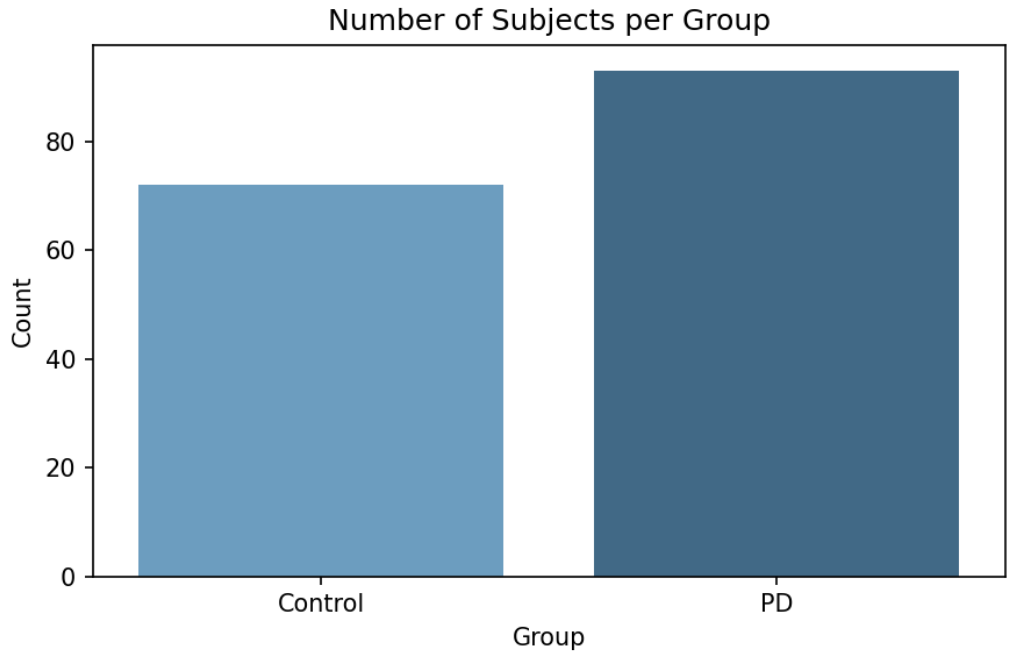


Figure: Subject distribution across PD and Control groups

- ✓ Visualizes participant count per group.
- ✓ ~70 Control and ~90 PD subjects included in analysis.
- ✓ Slightly higher PD count, ensuring adequate representation for both classes.
- ✓ Balanced group size supports fair model training and comparison.

Example Signals

Example VGRF Signals-1

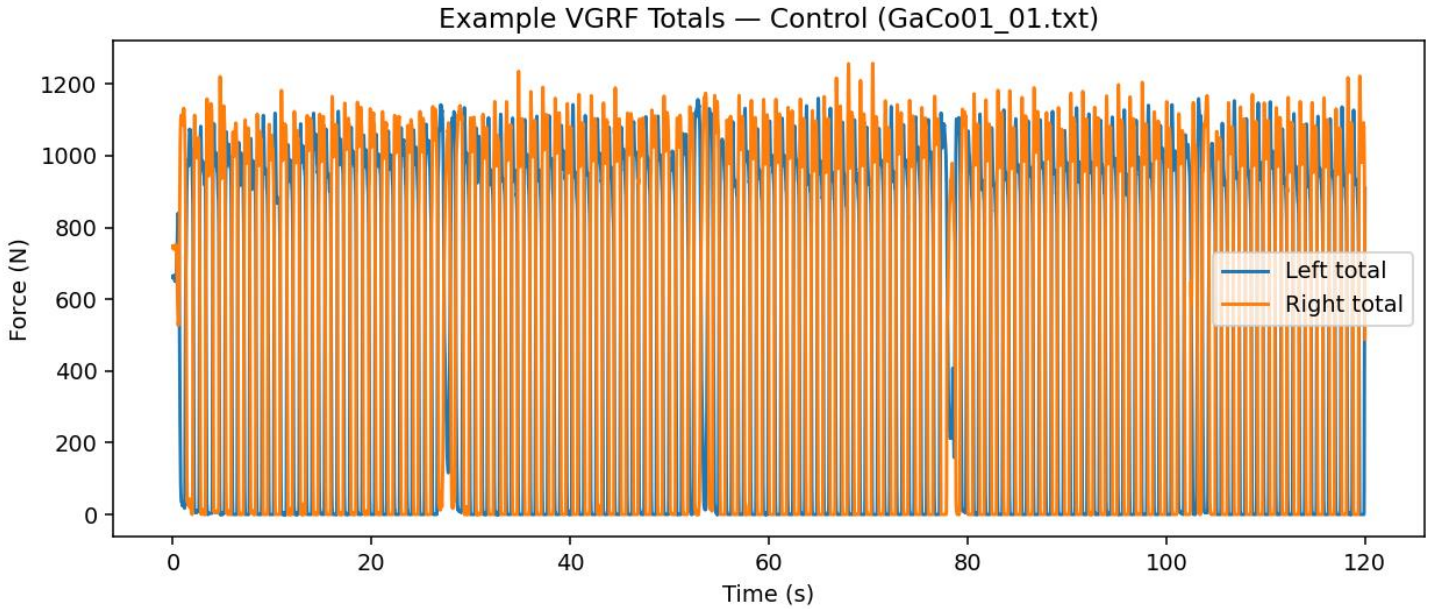


Figure: Control subject VGRF pattern

- ✓ Shows periodic Vertical Ground Reaction Force (VGRF) signals for a healthy control.
- ✓ Left and right foot curves overlap closely, indicating rhythmic and stable gait.
- ✓ Demonstrates the normal force distribution pattern used as baseline for PD comparison.
- ✓ Dataset collected using **force plates** measuring **Vertical Ground Reaction Force (VGRF)** at **100 Hz** sampling rate.
- ✓ Each subject walks over the plate; sensors record **force (N)** exerted by the **left and right foot**.
- ✓ Force curves capture gait rhythm, symmetry, and balance — which differ between **(PD)** and **Control** groups.
- ✓ Example signals show reduced amplitude and irregular rhythm for PD.

Example VGRF Signals-2

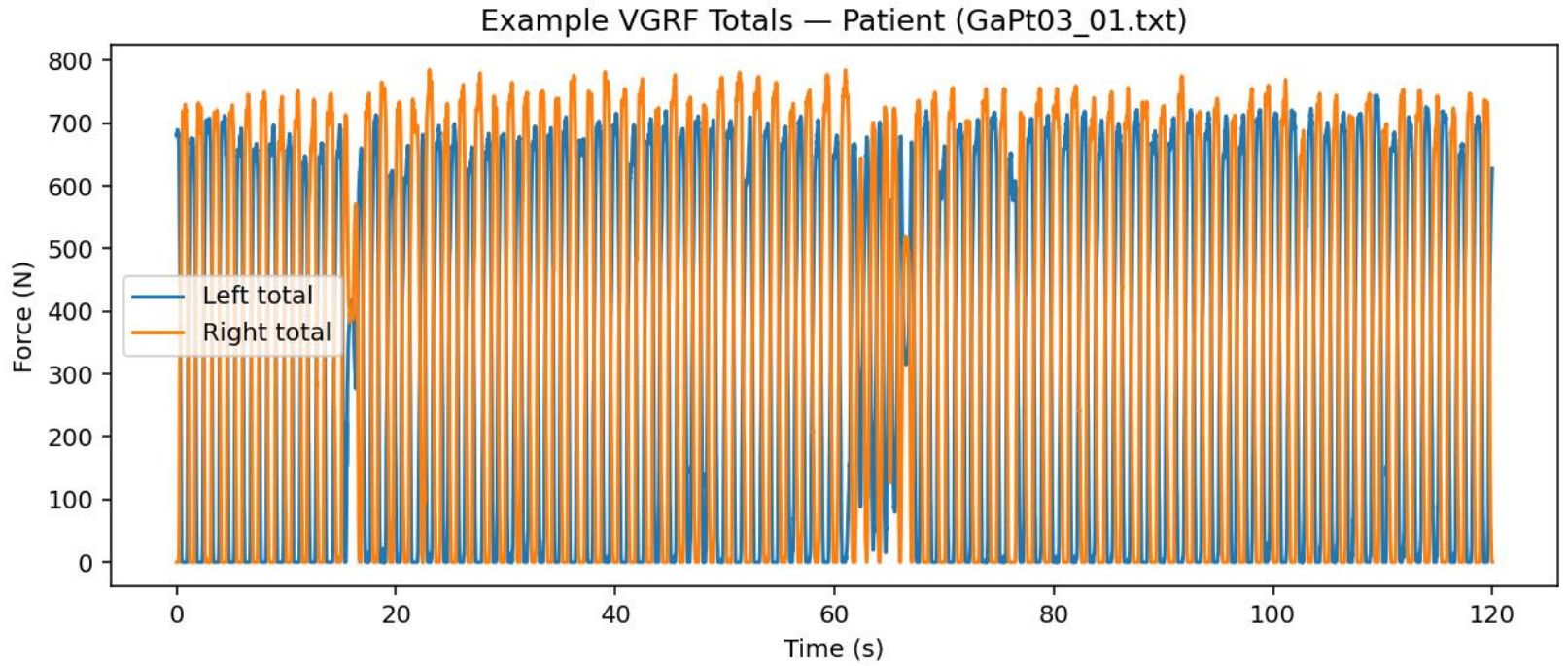


Figure: PD subject VGRF pattern

- ✓ Displays Vertical Ground Reaction Force (VGRF) for a Parkinson's patient.
- ✓ Left and right foot signals show irregular amplitude and timing differences.
- ✓ Indicates gait asymmetry and instability, typical of PD-related motor impairment.

Feature Extraction Approach

Feature Extraction with TSFresh

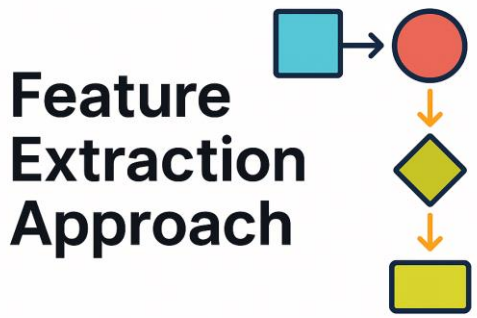


Figure: TSFresh-based feature extraction workflow

Image source: *Bronwyn Bridges et al. (2020), Molecules, MDPI, https://doi.org/10.3390/molecules25194382*

- ✓ Raw VGRF time series are transformed into **statistical features** using **TSFresh**.
- ✓ Features summarize time-domain properties:
  → *mean, standard deviation, skewness, kurtosis, energy, RMS, zero-crossings, etc..*
- ✓ Extraction performed using a **30 ms window** with **15 ms overlap**.
- ✓ Each feature represents a short segment of the gait signal.
- ✓ Result: ~56 features per subject per foot after aggregation.

Feature Combination Strategy

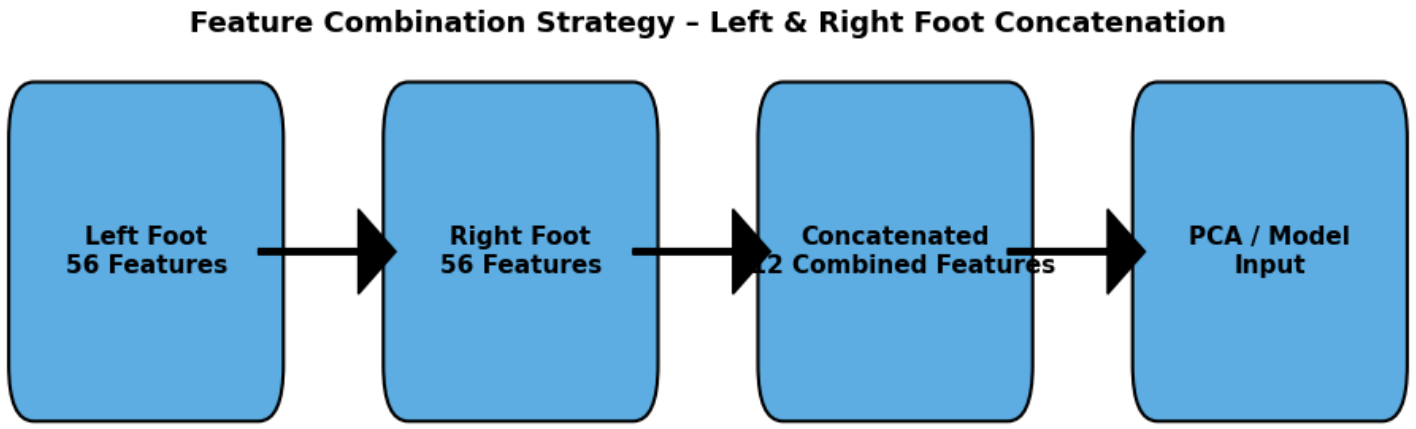


Figure: Feature Combination Strategy

- ✓ Each subject has two independent feature sets:
  → Left foot features (56 columns)
  → Right foot features (56 columns)
- ✓ To analyze inter-foot coordination:
  → Concatenated horizontally → 112 combined features (**LR vector**).
  Two approaches tested:
- ❑ **Concatenation:** merge L + R feature vectors.
- ❑ **Averaging:** compute mean of corresponding left/right features.
- ✓ Combined feature set improves PD detection by capturing gait asymmetry.

Feature Analysis (Variance & Correlation)

Feature–UPDRS Correlation Analysis

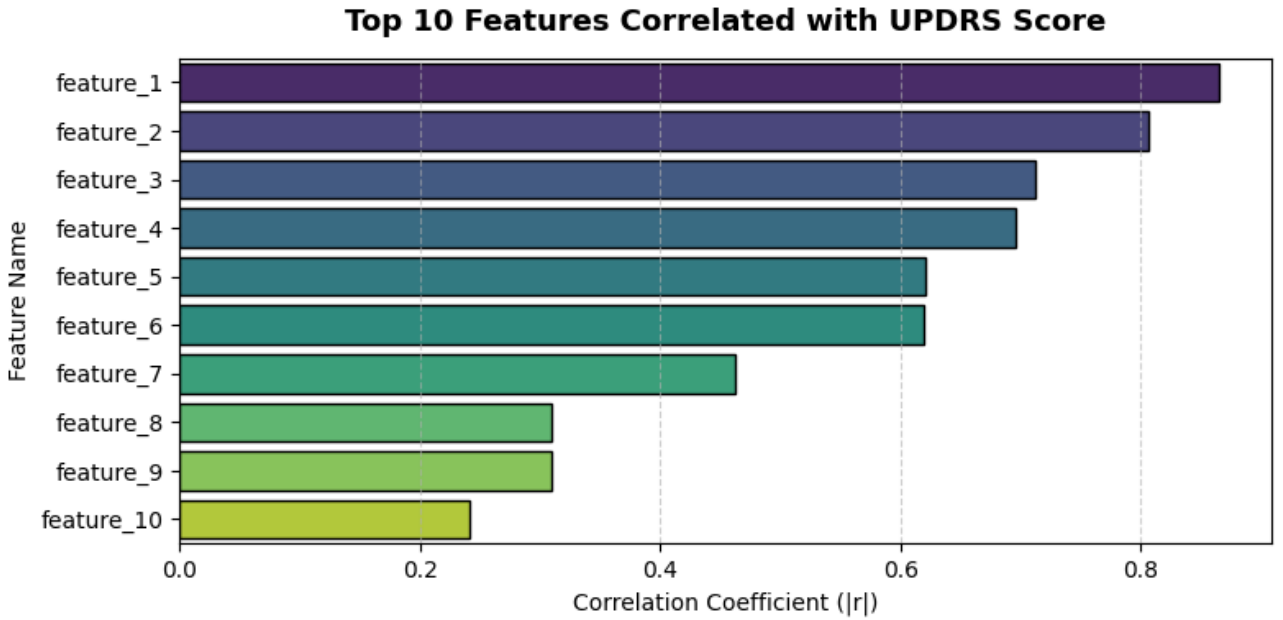


Figure: Feature–UPDRS Correlation Analysis

- ✓ Correlation computed between each extracted feature and UPDRS score.
- ✓ High correlation indicates stronger predictive power for disease stage.
- ✓ UPDRS (Unified Parkinson's Disease Rating Scale) measures PD severity (higher = worse).
- ✓ Visualization methods:
  → **Heatmap** of feature–UPDRS correlation.
  → **Bar plot** of top correlated features.
- ✓ Helps identify the most informative gait parameters (e.g., variability, symmetry).

Feature Variance and Correlation Analysis-1

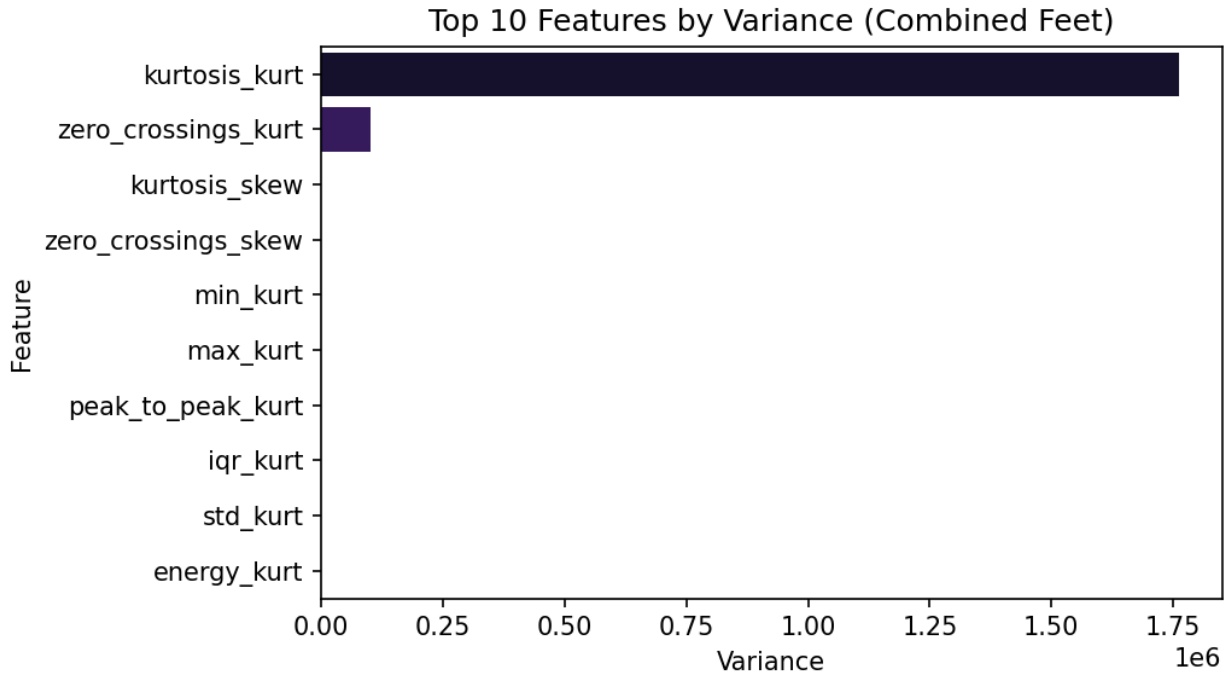


Figure: Top 10 high-variance features (combined feet)

- ✓ Displays the most variable TSFresh features from combined left–right foot data.
- ✓ *Kurtosis_kurt* shows the largest variance, suggesting strong sensitivity to gait irregularities.
- ✓ Variance ranking helps identify the most discriminative features for PD vs. Control.
- ✓ These top features are later used for dimensionality reduction via PCA.

Feature Variance and Correlation Analysis-2

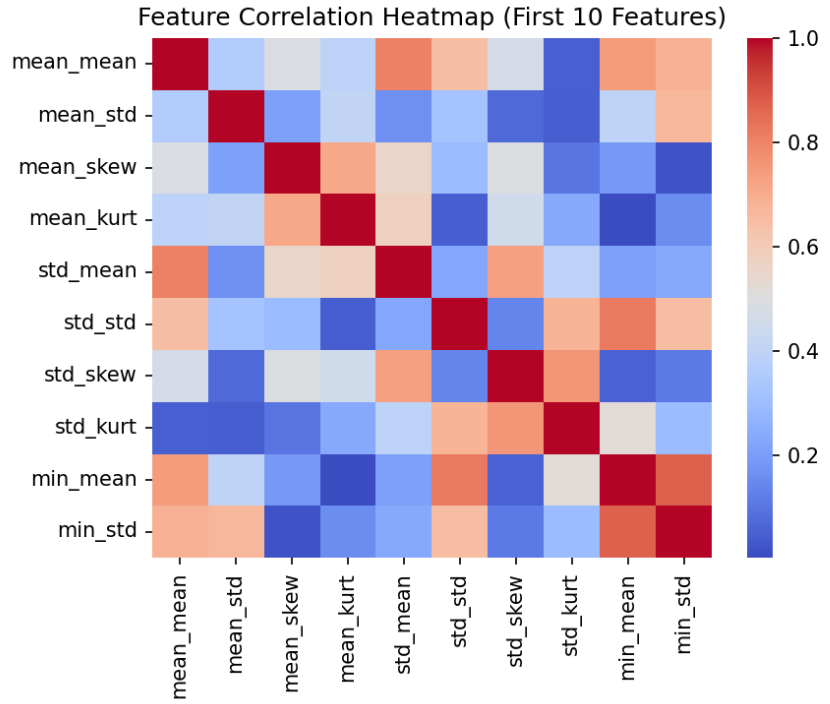
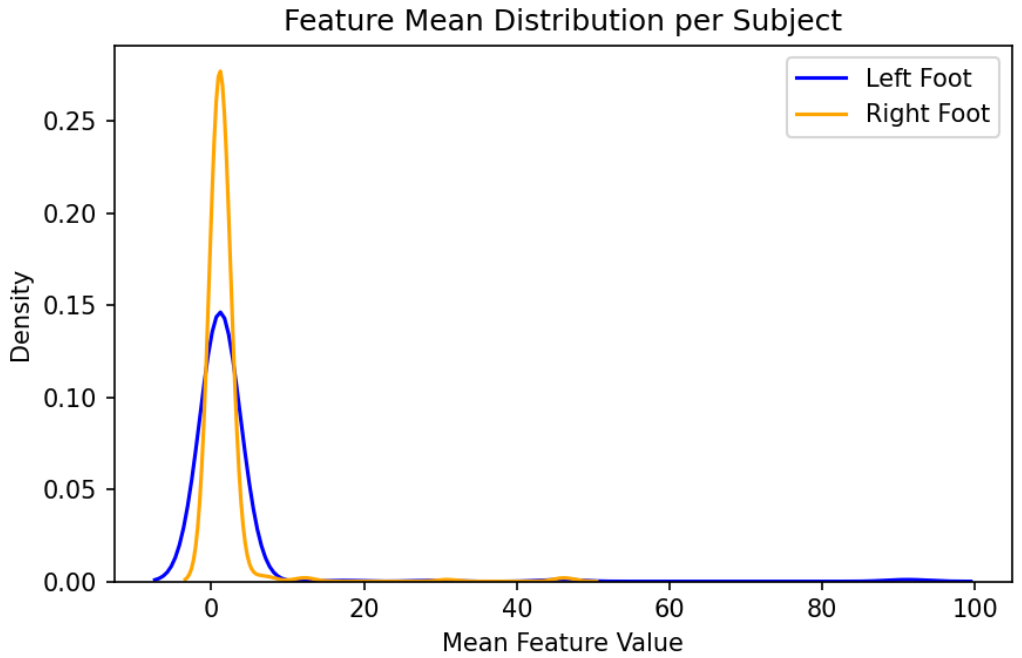


Figure: Correlation among top 10 features

- ✓ Displays correlation between the first 10 extracted TSFresh features.
- ✓ Moderate correlations observed between mean and standard deviation metrics.
- ✓ High feature redundancy is visible, justifying the use of PCA for dimensionality reduction.
- ✓ Ensures that strongly correlated features are compactly represented for efficient analysis.

Bilateral Feature Distribution

Left vs Right Foot Feature Distribution



Feature mean distribution across left and right feet

- ✓ Compares mean feature distributions between left and right foot signals.
- ✓ Both feet show a similar overall distribution, confirming consistent gait capture.
- ✓ Slight right-foot dominance may indicate asymmetric force behavior in PD patients.
- ✓ Confirms that extracted features are balanced across sides before PCA analysis.

Dimensionality Reduction (Right Foot)

PCA Visualization – Right Foot Features

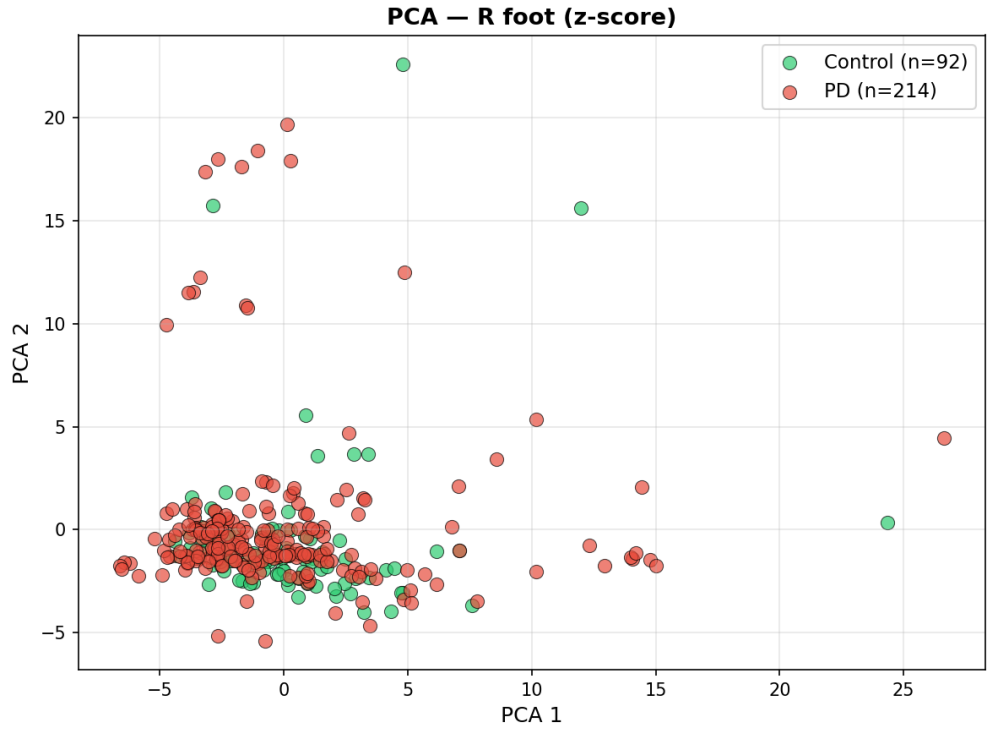


Figure: PCA projection for right-foot features

- ✓ PCA reduced 56-dimensional right-foot features to 2 principal components.
- ✓ Partial class separation is observed between PD (red) and Control (green) subjects.
- ✓ The right-foot dynamics reveal stronger gait irregularities in PD participants.
- ✓ Highlights that right-foot features may be more sensitive indicators of motor asymmetry.

Dimensionality Reduction (Left Foot)

PCA Visualization – Left Foot Features

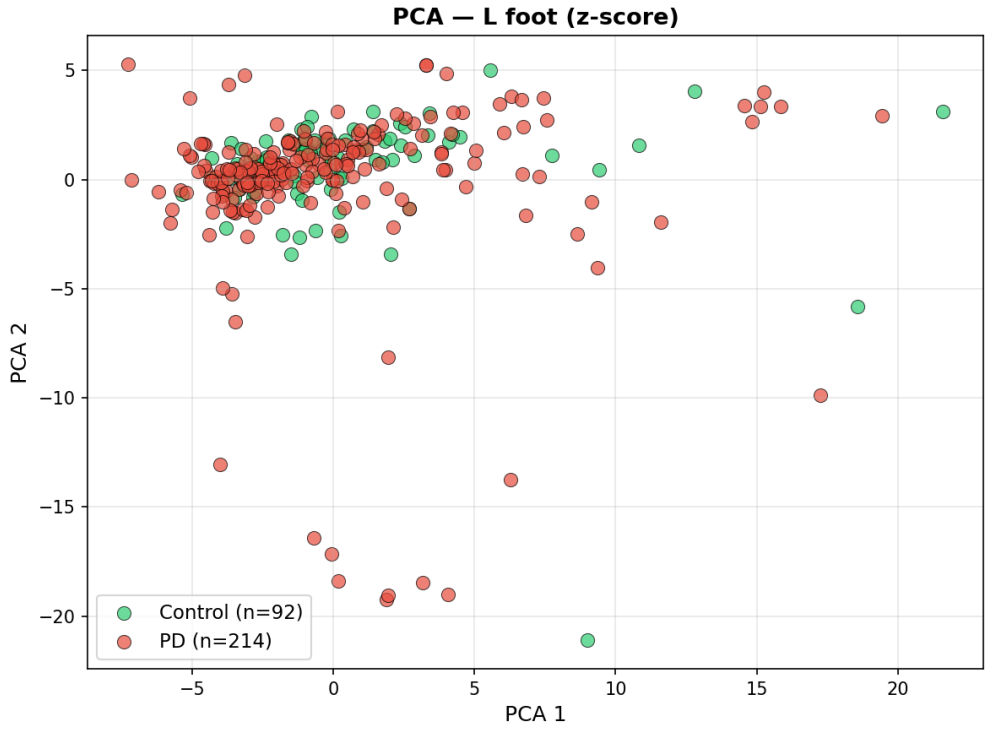


Figure: PCA projection for left-foot features

- ✓ PCA reduced 56 left-foot features to 2 principal components for visualization.
- ✓ Control (green) and PD (red) subjects show overlapping clusters with mild separation.
- ✓ Left-foot data appears slightly more compact, indicating consistent stride rhythm.
- ✓ Suggests that PD-related asymmetry is less pronounced on the left side compared to the right.

Dimensionality Reduction (Combined Feet)

PCA Visualization – Combined Left & Right Features

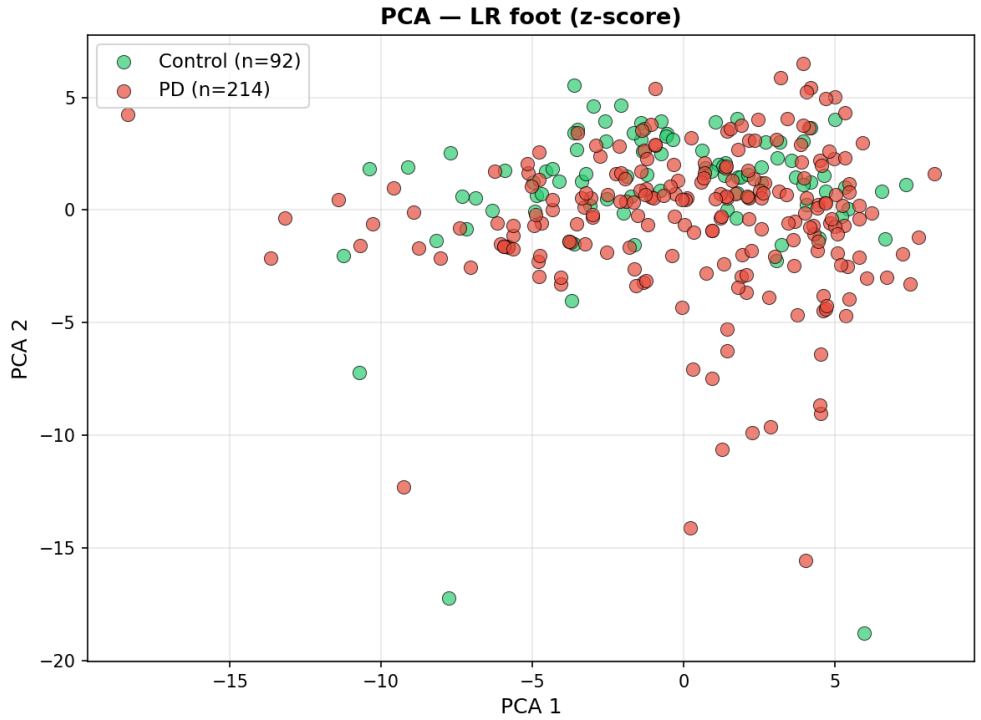
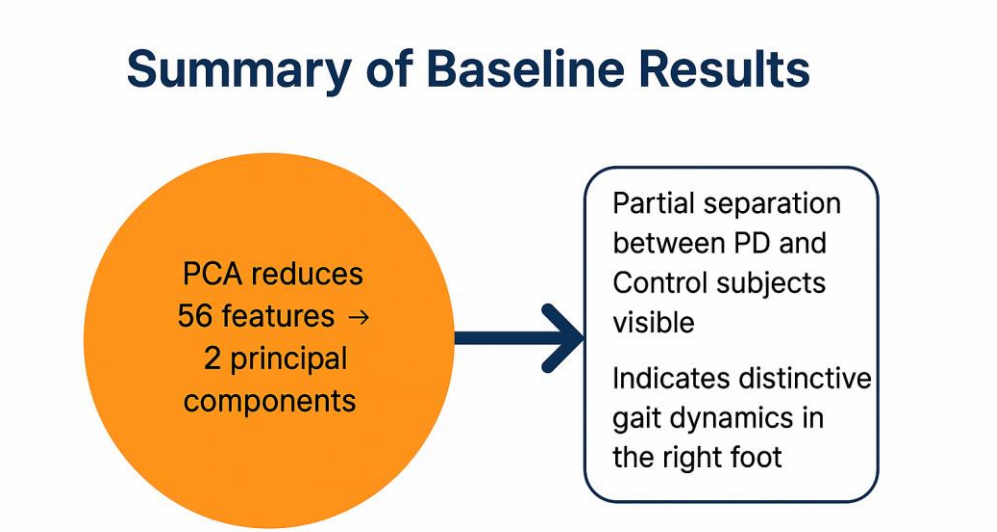


Figure: PCA projection for combined left & right foot features

- ✓ Combines left and right foot features to analyze overall gait symmetry.
- ✓ PCA reveals partially separable clusters between PD and Control participants.
- ✓ Integration of both feet provides richer movement representation and balance cues.
- ✓ This combined feature space will guide future Mamba-based classification modeling.

Results Summary

Summary of Baseline Results



- ✓ **306 subjects** analyzed (≈ 214 PD + 92 Controls).
- ✓ Extracted **56 TSFresh features** per subject using 30 ms windows with 15 ms steps.
- ✓ Applied **Z-score normalization** followed by **PCA** for dimensionality reduction.
- ✓ PCA revealed **partial separation** between PD and Control groups, indicating feature sensitivity to gait asymmetry.
- ✓ **Right foot** features showed stronger differentiation patterns, suggesting higher diagnostic relevance.
- ✓ These results establish a **reliable feature-level baseline** for upcoming **Mamba/State Space Model integration**.

Discussion & Next Steps

Discussion & Future Direction

- ✓ The PCA results indicate **partial separability** between PD and Control subjects, confirming the discriminative potential of extracted gait features.
- ✓ Variability within PD samples suggests **heterogeneous motor impairment patterns**, aligning with clinical findings.
- ✓ The **baseline feature analysis** successfully demonstrates measurable differences in gait dynamics, validating the preprocessing and feature engineering pipeline.
- ✓ Future work will focus on implementing **State Space Models (SSM) and Mamba architectures** to capture **temporal dependencies** in gait signals.
- ✓ These models aim to enhance **classification accuracy** and provide **interpretable, real-time Parkinson's detection** capabilities.

Q & A

Thank you