Bridging Signal and Intelligence: A DSP-Driven EEG Feature Pipeline for Neural Network Seizure Detection

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Abstract

- **DSP-based EEG pipeline for seizure detection**
- **CHB-MIT dataset with notch & bandpass filters**
- **Extracted spectral & statistical EEG features**
- **Visualized raw vs. filtered & frequency spectra**
- **Features ready for ML seizure classification**

Introduction

- EEG is a **non-invasive** method to measure brain activity.
- Automated EEG-based **seizure detection** is a key biomedical DSP task.
- EEG's **non-stationary** nature demands **strong preprocessing & feature extraction.**
- DSP provides tools for **time–frequency** domain analysis (e.g., **convolution, DFT, filtering**).
- EEG data **(CHB-MIT**) is preprocessed, features extracted, and prepared for ML seizure classification.

Background: EEG and Seizure Activity

- EEG records brain's electrical signals via scalp electrodes.
- Typical EEG range: **0.5–70 Hz**, divided into standard bands:
  - **Δ (0.5–4 Hz)** – Deep sleep
  - **θ (4–8 Hz)** – Drowsiness/meditation
  - **α (8–13 Hz)** – Relaxed wakefulness
  - **β (13–30 Hz)** – Active focus
  - **γ (30–70 Hz)** – Cognitive processing
- **Seizures:** sudden, synchronized bursts of activity
  - visible as amplitude spikes & spectral power changes

Methodology: Data Acquisition

- Dataset: **CHB-MIT Scalp EEG Database** (pediatric epilepsy patients)
- Format: **EDF files** with multi-channel EEG recordings
- Loaded via ***mne.io.read_raw_edf()***
- Includes both **seizure** and **non-seizure** intervals

Methodology: Preprocessing Pipeline

- **Notch Filter (60 Hz):** remove power-line noise (IIR notch)
- **Bandpass FIR Filter (0.5–70 Hz):** isolate standard EEG range
- **Segmentation:** 10-s overlapping epochs for temporal analysis
- **Normalization:** z-score (zero mean, unit variance) for consistency

Methodology: DSP Operations

- **Correlation:** inter-channel Pearson correlation matrices
- **Convolution:** moving-average smoothing to reduce fluctuations
- **Spectral Analysis:** FFT + Welch PSD for frequency and band-power estimation

Methodology: Feature Extraction

- **Band Powers:** mean, std, median in δ, θ, α, β, γ bands
- **Statistical:** energy, variance, skewness, kurtosis
- **Spectral Entropy:** Shannon entropy of normalized PSD
- **Correlation Metrics:** mean, std, max of inter-channel correlations
- **Band Ratios:** e.g., α / β for cognitive state insight

Methodology: Implementation

- Tools: **Python 3.10**, MNE, SciPy, NumPy, pandas, Matplotlib
- Interactive workflow via **Jupyter Notebook**
- Features aggregated into *chb_features.csv*
- Repository: github.com/projectohid/4142-project

Results: Spectrogram Analysis (Normal vs. Seizure)

- **Normal EEG (Fig. 1) :** Broad spectral power (10–30 Hz, α & β bands)
- **Seizure EEG (Fig. 2) :** Dominant low-frequency power ($<$10 Hz, δ & θ)
- Confirms effective filtering and **distinct physiological vs. pathological patterns**

Results: Spectrogram Analysis (Normal vs. Seizure)

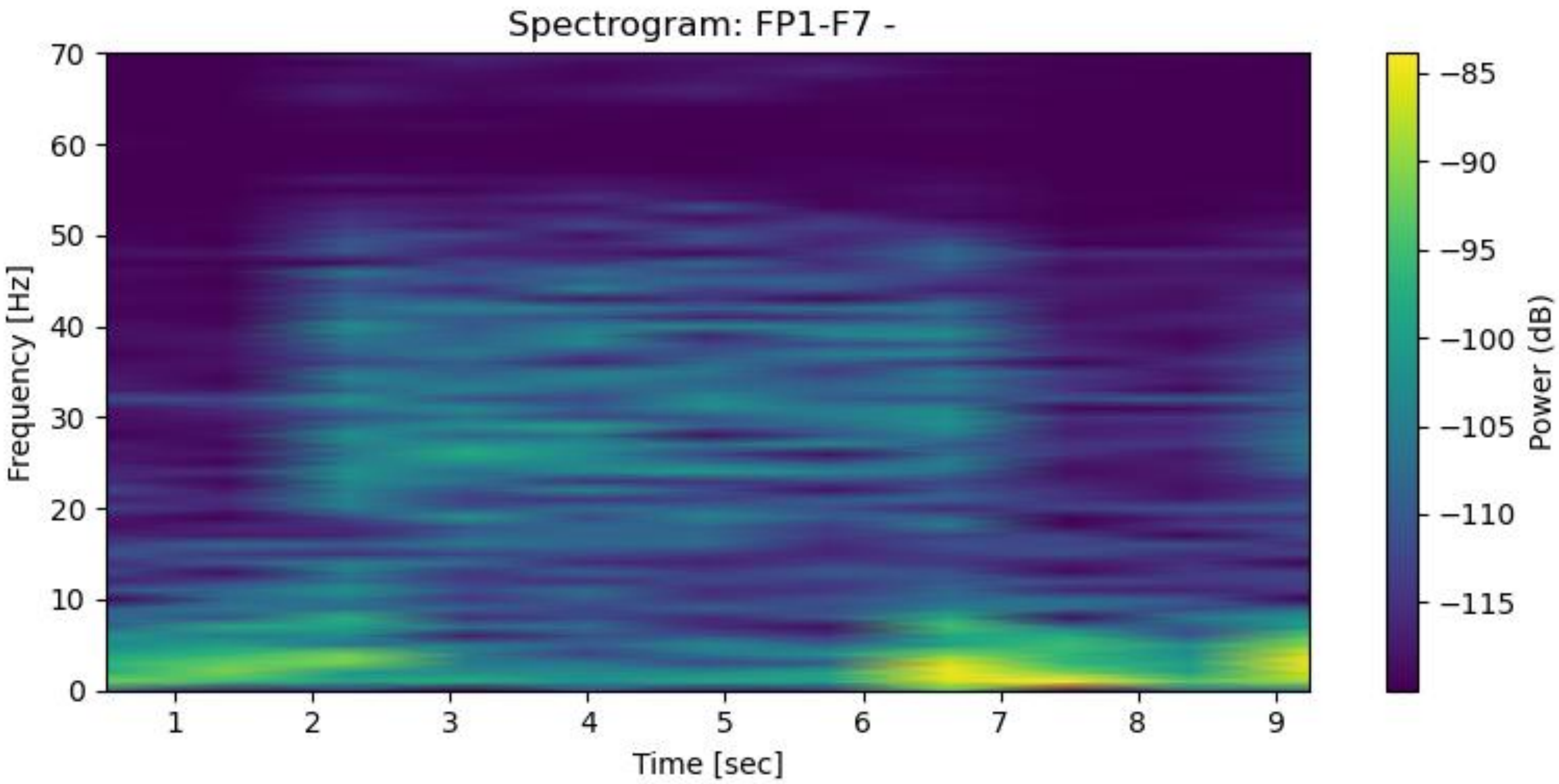

Fig. 1: Spectrogram for *Chb01_01.edf* (non-seizure).

Results: Spectrogram Analysis (Normal vs. Seizure)

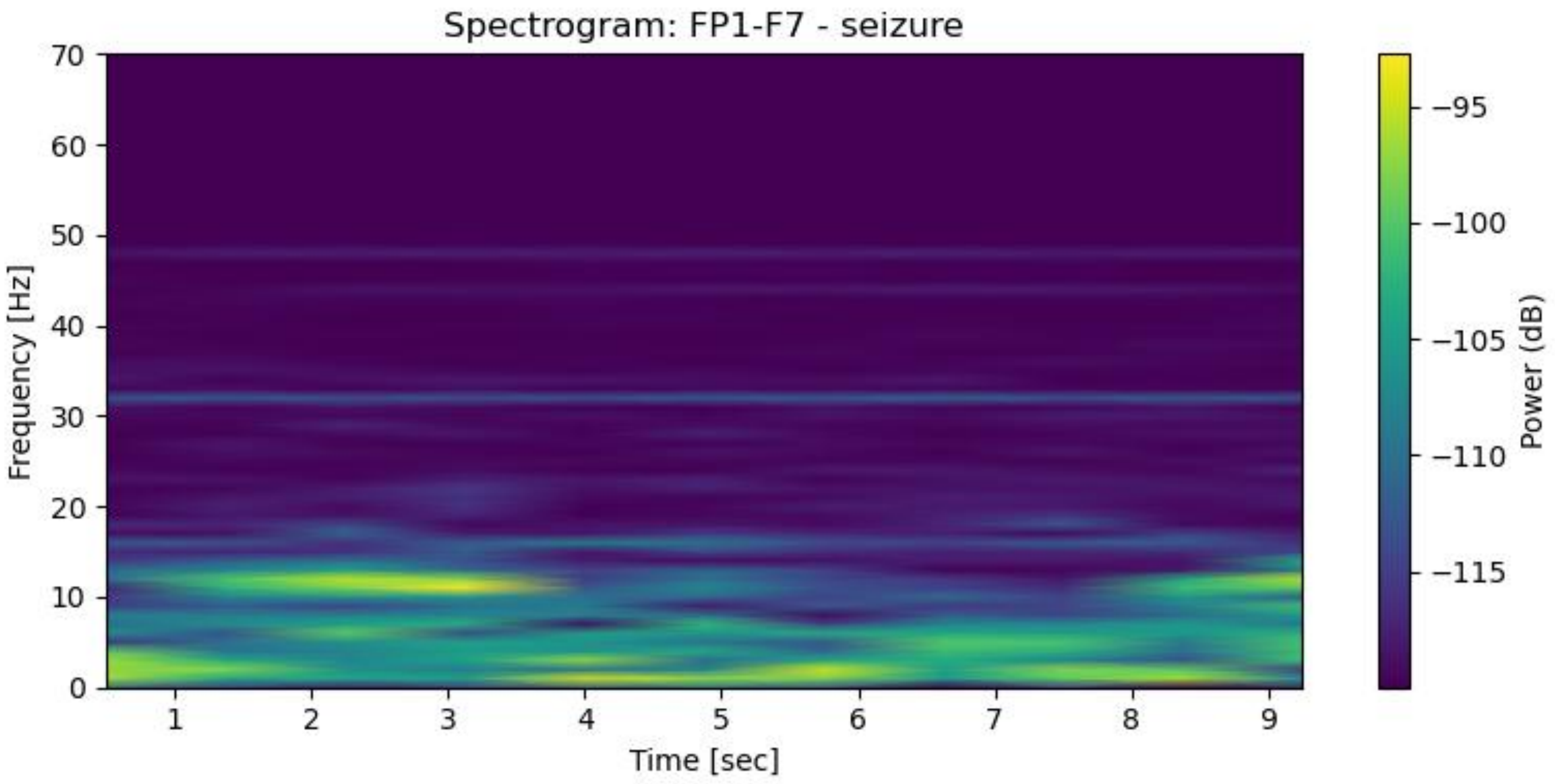

Fig. 2: Spectrogram for *Chb01_03.edf* (seizure).

Results: Raw Vs. Filtered Signal

- **Time-domain (Fig. 3):** Filtered signal smoother; reduced drift & 60 Hz noise
- **Frequency-domain (Fig. 3):** 60 Hz peak suppressed; spectrum confined to 0.5–70 Hz
- Verifies **notch + FIR bandpass filters** effectiveness

Results: Raw Vs. Filtered Signal

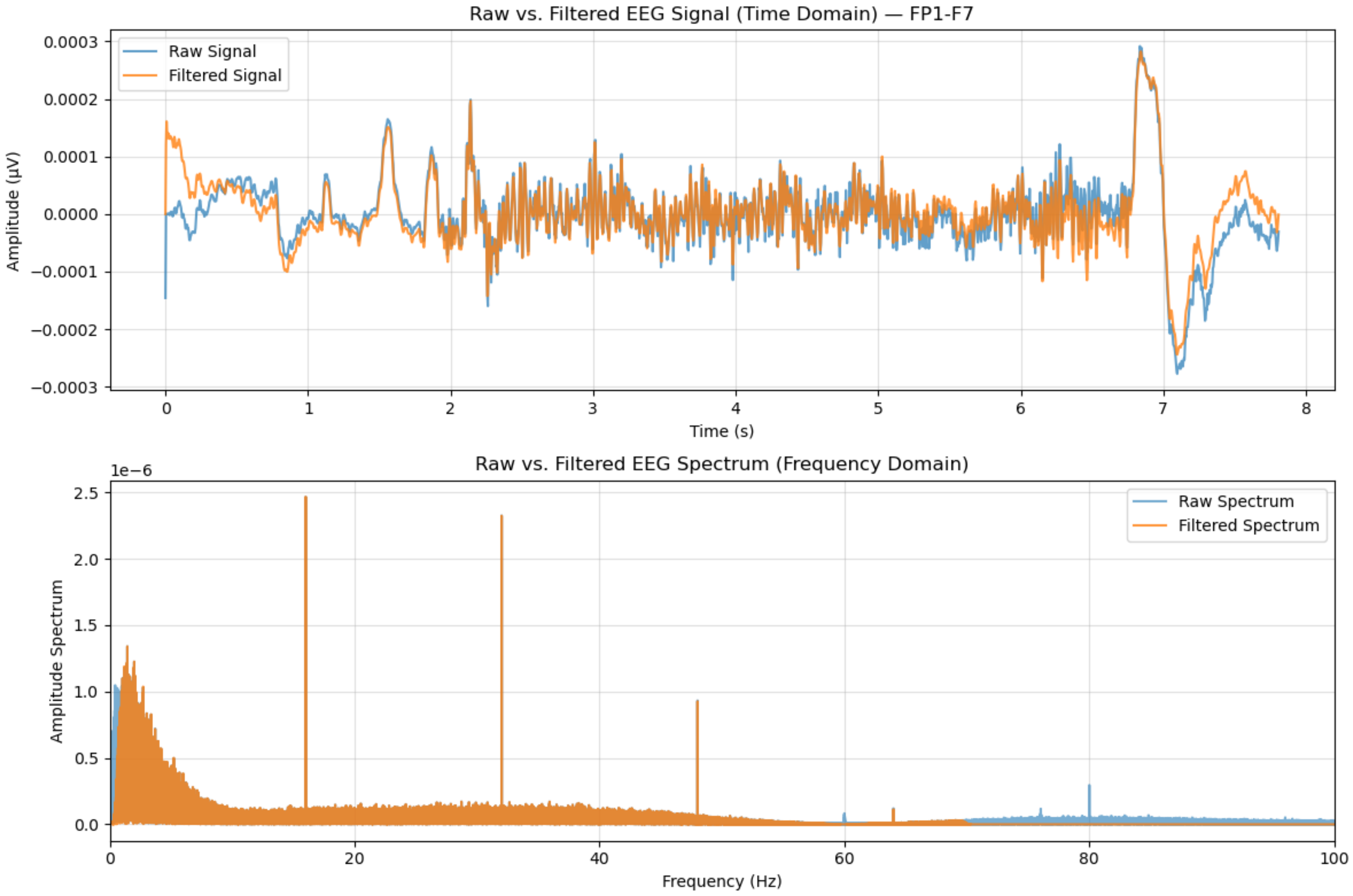

Fig. 3: Raw and filtered Signals and their Spectrums for *Chb01_01.edf* .

Results: EEG Band Power Distribution

- Power hierarchy:

  $$\Delta > \theta > \beta > \gamma > \alpha$$

- Low-frequency dominance → seizure or drowsy state indicator
- Confirms **spectral accuracy** of feature extraction

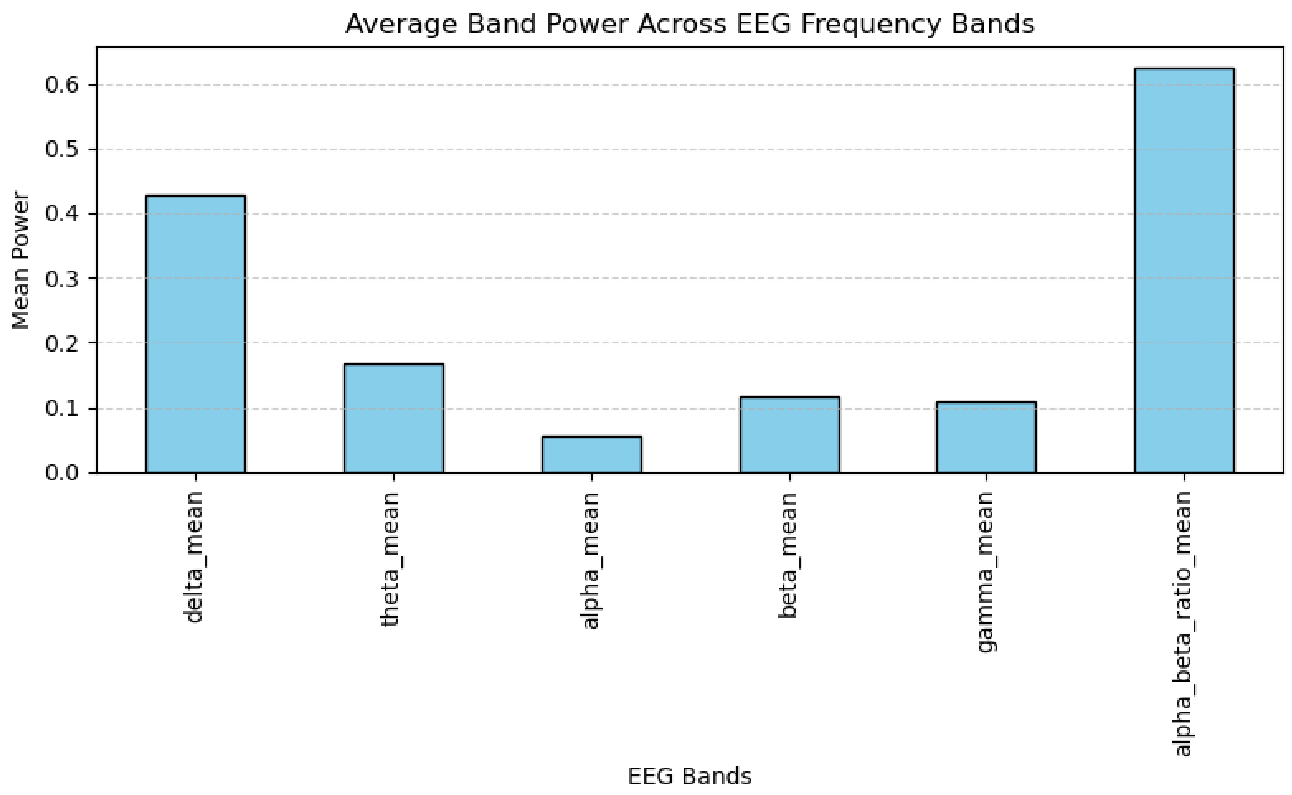

Fig. 4: Average Band Power Across EEG Frequency Bands for *Chb01_01.edf*.

Results: Time-Domain Statistical Features

- **High kurtosis:** sharp, transient seizure spikes
- **Low skewness:** symmetric yet with frequent outliers
- Confirms **impulsive, non-Gaussian EEG** patterns in seizures

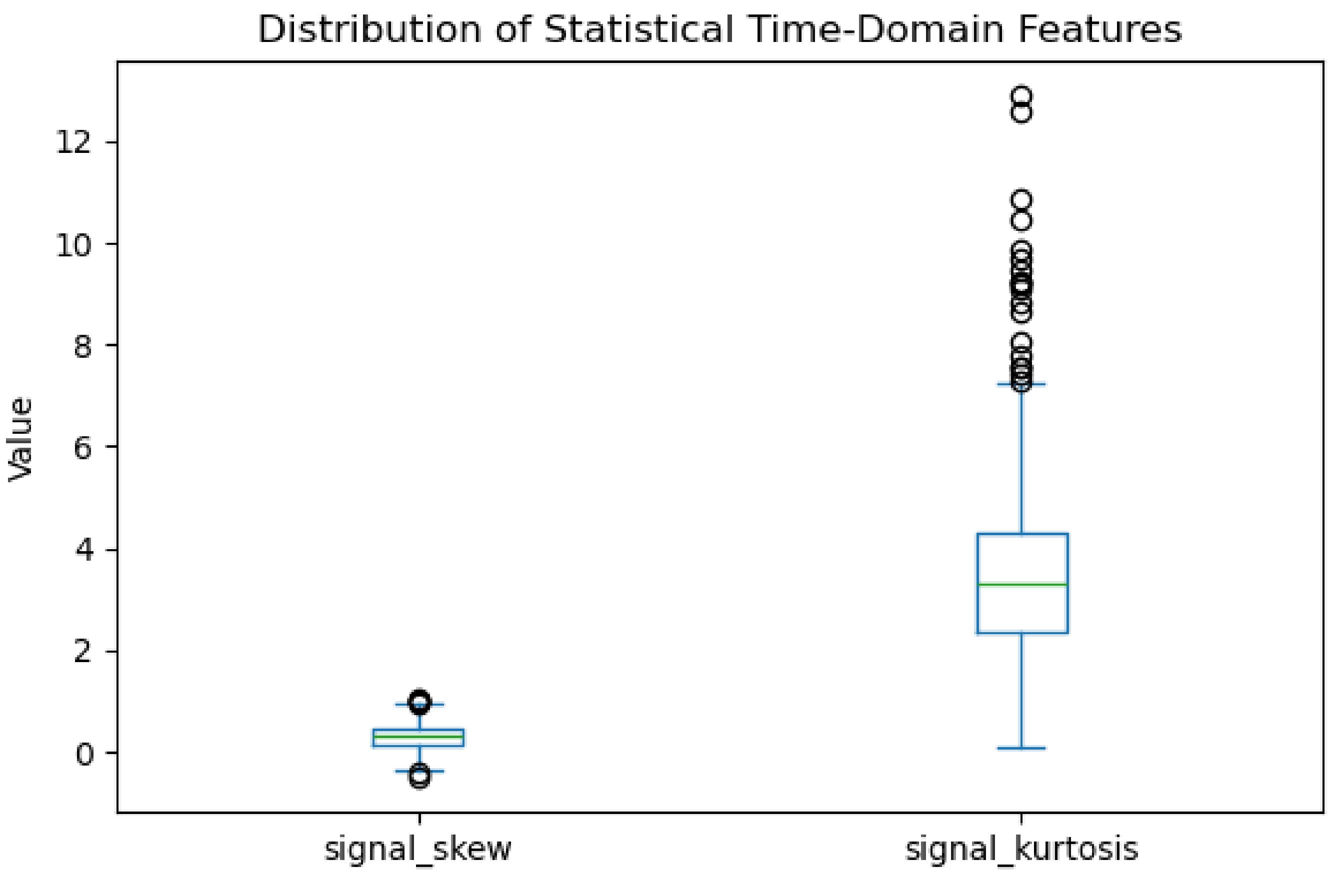

Fig. 5: Distribution of Statistical Time-Domain Features for *Chb01_01.edf* .

Results: Spectral Entropy vs. Delta Power

- **Negative correlation →** higher δ power = lower entropy
- Indicates **reduced complexity** during seizure activity
- Validates **entropy as nonlinear brain state marker**

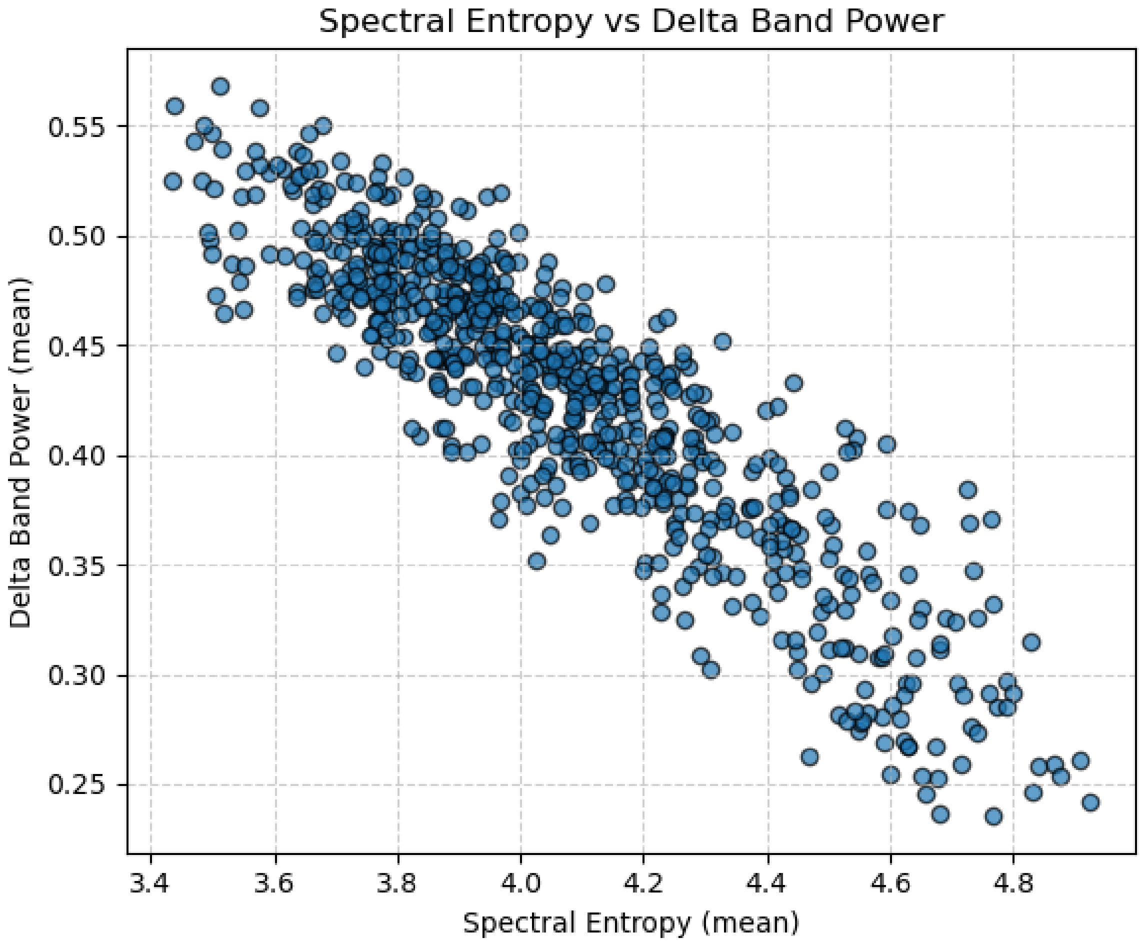

Fig. 6: Spectral Entropy vs. Delta Band Power for *Chb01_01.edf* .

Results: Inter-Channel Correlation

- **Max correlation ≈ 1.0:** strong cross-channel synchronization
- **Consistent** mean correlation = stable phase coupling
- Demonstrates **spatial coherence** in seizure EEG

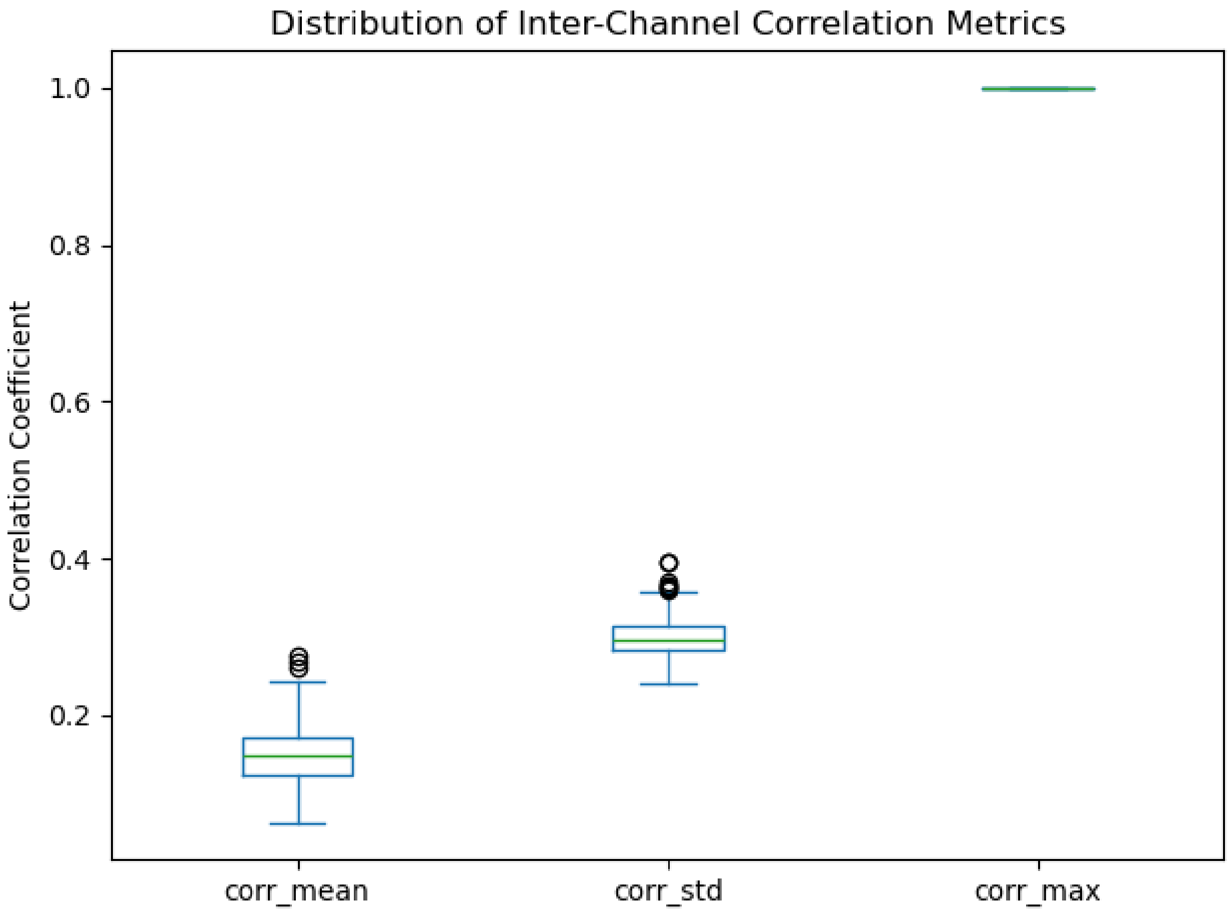

Fig. 7: Distribution of Inter-Channel Correlation Metrics for *Chb01_01.edf* .

Results: Feature Matrix & ML Readiness

Table I: Part of the extracted Feature Matrix for *Chb01_01.edf* .

	delta_mean	delta_std	delta_max	delta_median	theta_mean	theta_std	theta_max	theta_median	alpha_mean	alpha_std
0	0.439917	0.122878	0.680715	0.425868	0.134942	0.048450	0.229849	0.132495	0.046567	0.029513
1	0.491996	0.147472	0.753315	0.489125	0.157016	0.071678	0.355560	0.139707	0.052553	0.036122
2	0.375810	0.082527	0.485999	0.389008	0.155521	0.067377	0.320863	0.145871	0.055865	0.031640
3	0.328070	0.089442	0.475458	0.338504	0.164152	0.065626	0.293830	0.164945	0.056487	0.021148
4	0.467772	0.085527	0.657703	0.458547	0.173338	0.052196	0.284436	0.168564	0.054683	0.029469

5 rows × 34 columns

- Each 10 s epoch → **30+ DSP-based features**
- Seizure/non-seizure epochs clearly separable in feature space
- Confirms **pipeline suitability for neural network models**

Results: Summary

Domain	**Key Observation**	**DSP Technique**
Spectrograms	Low-frequency dominance	STFT / Spectrogram
Filtering	Removed 60 Hz & artifacts	Notch + FIR
Band Power	High δ, θ; low α, β, γ	FFT + PSD
Statistics	High kurtosis, low skewness	Time-domain
Entropy	−ve correlation with δ power	Entropy calc.
Correlation	Strong inter-channel sync	Pearson corr.
Feature Set	Clear seizure separation	DSP feature extraction

Discussion

- **Spectral Behavior**
  - Normal EEG: broad power (10–30 Hz, α–β bands)
  - Seizure EEG: strong low-freq. dominance (<10 Hz, δ–θ)
  - Confirms **shift from desynchronized → synchronized** neuronal activity
  - Filtering (notch + bandpass) effectively removed 60 Hz noise & drift while preserving core EEG content
- **Band Power Trends**
  - Hierarchy: **Δ > θ > β > γ > α**
  - High α/β ratio & reduced high-freq. power → decreased cortical processing during seizures

Discussion

- **Time-Domain Statistics**
  - **High kurtosis:** sharp epileptic transients
  - **Low skewness:** symmetric but heavy-tailed amplitude distribution
  - Indicates **impulsive, non-Gaussian** seizure morphology
- **Entropy & Complexity**
  - **Entropy ↓ as Δ-power ↑** → reduced signal complexity during seizures
  - Captures transition to **predictable, synchronized** brain dynamics
  - Entropy = nonlinear complement to power-based metrics

Discussion

- **Inter-Channel Correlation**
  - **High cross-channel correlation (≈1.0)** → strong spatial coherence
  - Reflects widespread cortical synchronization in seizure states
- **Integrated DSP Takeways**
  - **Filtering:** ensures clean, physiologically valid signals
  - **FFT / PSD:** reveal spectral composition
  - **Statistics + Entropy:** quantify morphology & complexity
  - **Correlation:** captures spatial coupling → Together, **classical DSP techniques uncover physiological + pathological EEG patterns**, producing interpretable features for intelligent seizure detection.

Conclusion

- DSP methods effectively applied for EEG seizure analysis.
- Filtering + spectral + statistical tools made EEG **interpretable**.
- **Key Points:**
  - **Preprocessing:** Notch & FIR filters removed noise, kept key signals.
  - **Spectral:** Clear normal–seizure separation (low-freq dominance).
  - **Stats:** High kurtosis, low entropy → synchronized seizure waves.
  - **Correlation:** Strong inter-channel coupling during seizures.
  - **Features:** Compact, ML-ready dataset for classification.
- **Takeaway:**

  → DSP bridges theory & application, enabling explainable EEG systems.

Future Work

- **Wavelet Filters:** Handle dynamic, non-stationary EEG noise.
- **ICA Cleaning:** Remove eye/muscle artifacts.
- **Deep Learning:** Train models on DSP-derived features.
- **Automation:** Streamline preprocessing & feature selection.

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Thank You

Any Questions?