MLPR

Parkinsons Detection On-the-fly using Wearables

BY: TRUSHA MAHESHWARI, RHEA SINGH, DEVAM AGARWAL

GROUP 33


10:37
Current
64 BPM
64 BPM, 1m ago


10:09
Past 7 Days
T W T F S S M
Respiratory Rate
14.6 BrPM
Within Typical Range


Results
10:09
Blood Oxygen
98%
Done
You can view Blood Oxygen measurements in the Health app on


Cancel
10:09
7
Keep Washing
Done
10:09
Well
Done

With smartwatches already so seamlessly integrated in our lives , can we use this piece of technology to detect a life-altering disease early on?

Parkinsons Disease

- A **progressive neurodegenerative disorder** primarily affecting movement.
- The hallmark symptoms: **bradykinesia** (slowness of movement), resting tremor, muscle rigidity, with postural instability often developing in later stages.
- Cause: remains **unknown**, but both **genetic** and **environmental** factors play roles.

Parkinson's Disease: pathogenesis and clinical aspects. (2018). In Codon Publications eBooks. https://doi.org/10.15586/codonpublications.parkinsonsdisease.2018

Current Diagnosis Methods

- Clinical Examination & Medical History – Neurologists assess symptoms like tremors, rigidity, and bradykinesia using criteria like **MDS Clinical Diagnostic Criteria.**
- Imaging Techniques – **DaTscan (SPECT), MRI, and PET** scans help differentiate PD from other movement disorders.
- Levodopa Challenge Test – Improvement in symptoms after taking Levodopa suggests Parkinson's.
- Motor & Non-Motor Assessments – Includes **UPDRS scale,** gait analysis, handwriting tests, and olfactory tests (loss of smell).

Parkinson's Disease: pathogenesis and clinical aspects. (2018). In Codon Publications eBooks. https://doi.org/10.15586/codonpublications.parkinsonsdisease.2018

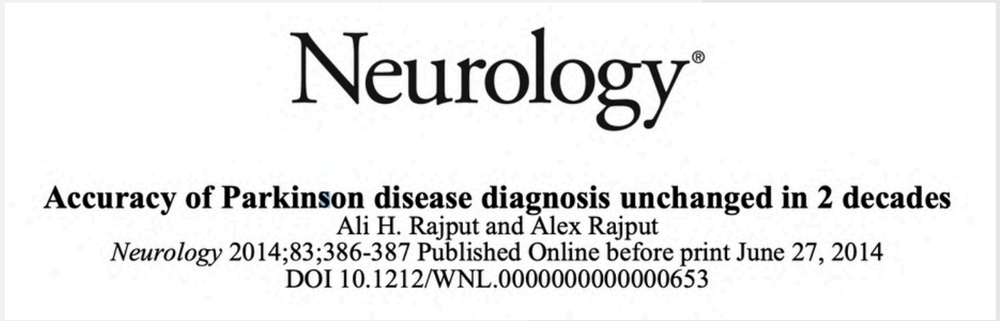
Limitations

- All methods right now are detecting via clinical advancements, and more medically induced methods
  - **Limited Accessibility:** Techniques like DaTscan, MRI, and PET are expensive, not widely available, and impractical for routine screening.
  - **Late Diagnosis:** Clinical symptoms often appear after significant brain degeneration, delaying early intervention.
  - **Lack of Continuous Monitoring:** Traditional methods miss daily symptom fluctuations and early subtle changes, especially in non-motor symptoms.

Parkinson's Disease: pathogenesis and clinical aspects. (2018). In Codon Publications eBooks. https://doi.org/10.15586/codonpublications.parkinsonsdisease.2018

Literature Review

American Academy Of Neurology



Neurology®

Accuracy of Parkinson disease diagnosis unchanged in 2 decades

Ali H. Rajput and Alex Rajput

Neurology 2014;83;386-387 Published Online before print June 27, 2014

DOI 10.1212/WNL.0000000000000653

- **Diagnostic Accuracy:** An accuracy rate of 77% indicates that approximately **one in four PD diagnoses may be incorrect**.
- The study highlights that neurologists often rely heavily on clinical skills due to **limited diagnostic tools in movement disorders**. This reliance can contribute to diagnostic inaccuracies.
- The **lack of improvement in diagnostic accuracy over two decades** suggests that advancements in diagnostic methodologies or technologies have been minimal, pointing to a need for better diagnostic approaches.

Challenges in the diagnosis of Parkinson's disease

Eduardo Tolosa, Alicia Garrido, Sonja W Scholz, Werner Poewe**

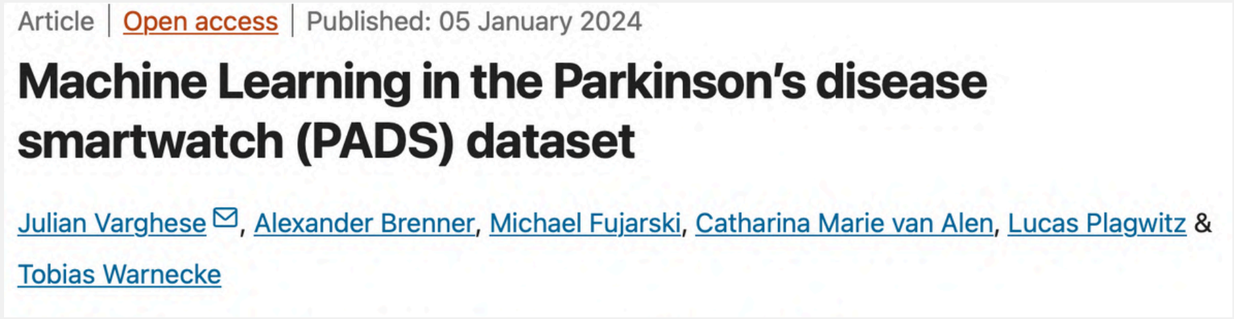
Hospital Clinic of Barcelona, University of Barcelona

Lancet Neurol 2021; 20: 385–97

*Joint senior authors

Parkinson's Disease and Movement Disorders Unit, Neurology Service, Hospital Clínic de Barcelona, Barcelona, Spain (Prof E Tolosa PhD, A Garrido MD)**; Centro de Investigación Biomédica en Red Sobre Enfermedades Neurodegenerativas (CIBERNED), Hospital Clínic, IDIBAPS, Universitat de Barcelona, Barcelona, Spain** (Prof E Tolosa, A Garrido)**;**

- Despite numerous advancements, early-stage Parkinson's remains difficult to diagnose due to symptom **overlap with other neurodegenerative disorders.**
- While imaging (e.g., PET, DaTscan) and biomarkers are promising, they **lack universal accessibility** and standardization, making them impractical for widespread use.



- **Computational Expensive:**

High due to multi-source data processing, feature extraction, deep learning complexity, and cross-validation for distinguishing similar disorders.

- **Accuracy**:

The model achieved **91.16% accuracy for PD vs. healthy controls** and **72.42% for PD vs. differential diagnoses**, highlighting challenges in distinguishing similar disorders.

- **Deployment:**

The current model is unsuitable for deployment on smartwatches due to its high computational cost.

Drawbacks of the current methodology

1. **Feature Selection Methodology**
   - Features are selected **manually**
   - Then this **limited set** is fed into deep learning models.
   - Causes the **loss of potentially important information** due to hand-picked features as model extracts from less data .

2. **High Computation Cost**
   - Tests multiple models on different feature sets and **reports the best performing model.**
   - **Unnecessarily heavy** as all models need to be simultaneously run.

Problem Statement

Can we develop a machine learning model for the **early prediction** of **Parkinson's disease** using **movement sensor data** and self-reported **questionnaire** responses?

Datasets

Movement/Motor Dataset:

- Accelerometer
- Gyroscope

Questionnaire Dataset:

- Subjective Self-Reported Symptom responses

Patient Dataaset:

- Condition, Age, Gender, etc.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{
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  "subject_id": "001",
  "study_id": "PADS",
  "id": "Non-motor Symptoms",
  "questionnaire_name": "NMS",
  "item": [
    {
      "link_id": "01",
      "text": "Dribbling of saliva during the daytime",
      "answer": false
    },
    {
      "link_id": "02",
      "text": "Loss or change in your ability to taste or smell",
      "answer": false
    },
...
```

```
{
  "resource_type": "patient",
  "id": "001",
  "study_id": "PADS",
  "condition": "Healthy",
  "disease_comment": "-",
  "age_at_diagnosis": 56,
  "age": 56,
  "height": 173,
  "weight": 78,
  "gender": "male",
  "handedness": "right",
  "appearance_in_kinship": true,
  "appearance_in_first_grade_kinship": true,
  "effect_of_alcohol_on_tremor": "Unknown"
}
```

```
{
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  "subject_id": "001",
  "study_id": "PADS",
  "device_id": "Apple Watch Series 4",
  "id": "Neurological Assessment",
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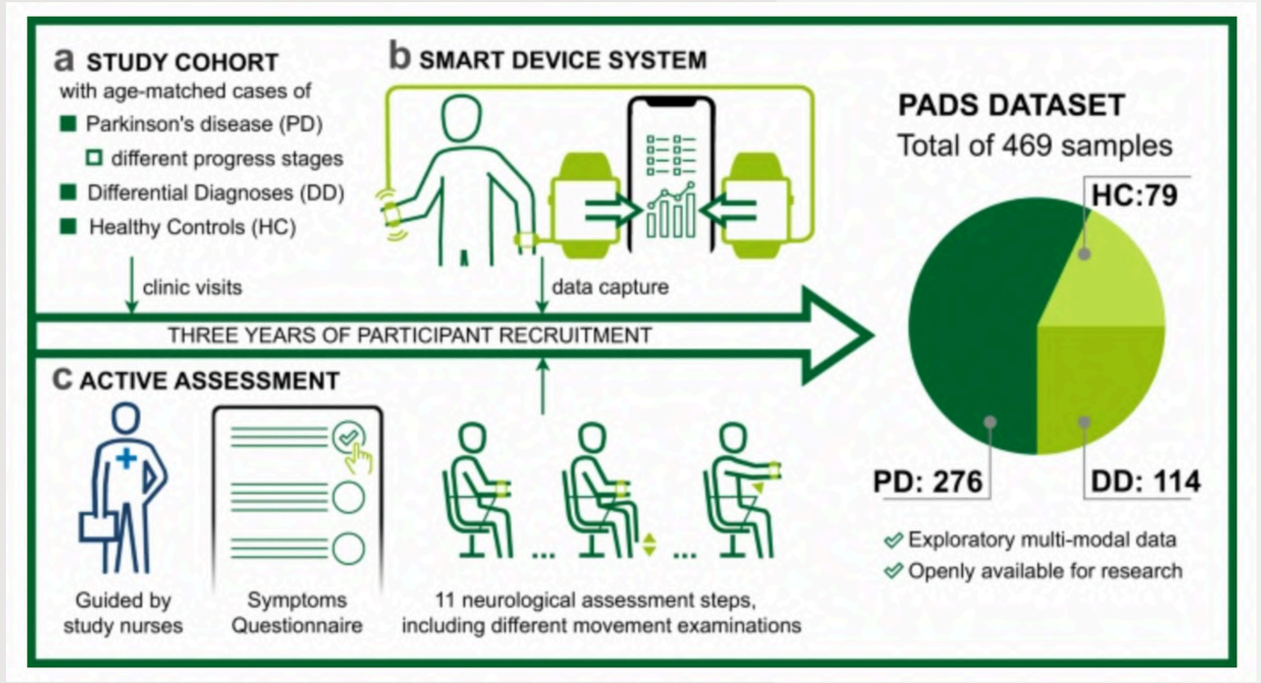
  "sampling_rate": 100,
  "data_type": "float",
  "bits": 32,
  "session": [
    {
      "record_name": "Relaxed",
      "rows": 2048,
      "records": [
        {
          "device_location": "LeftWrist",
          "channels": [
            "Accelerometer_X",
            "Accelerometer_Y",
            "Accelerometer_Z",
            "Gyroscope_X",
            "Gyroscope_Y",
            "Gyroscope_Z"
          ],
          "units": [
            "g",
            "g",
            "g",
            "rad/s",
            "rad/s",
            "rad/s"
          ],
```


Varghese, J., Brenner, A., Fujarski, M., Van Alen, C. M., Plagwitz, L., & Warnecke, T. (2024). Machine Learning in the Parkinson's disease smartwatch (PADS) dataset. Npj Parkinson S Disease, 10(1). https://doi.org/10.1038/s41531-023-00625-7

Data Collection

This data is sourced via :

- 3-year cross-sectional study at a large tertiary care hospital
- A **multi-modal smartphone app** integrated **electronic questionnaires** and **smartwatch measures** during an interactive assessment designed by neurologists to provoke subtle changes in movement pathologies.
- 5000 clinical assessment steps from **504 participants, including PD, DD, and healthy controls (HC).**



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Preprocessing

Multimodal Data

pads-parkinsons-disease-smartwatch-dataset-1.0.0

Name	Date Modified	Size	Kind
scripts	Today at 4:15 AM	--	Folder
preprocessed	08-Mar-2025 at 10:38 PM	--	Folder
questionnaire	07-Mar-2025 at 4:15 PM	--	Folder
patients	07-Mar-2025 at 4:15 PM	--	Folder
movement	07-Mar-2025 at 4:15 PM	--	Folder
SHA256SUMS.txt	26-Mar-2024 at 2:25 AM	1.4 MB	Plain Text
LICENSE.txt	19-Mar-2024 at 11:47 PM	Zero bytes	Plain Text

timeseries

Name	Date M
001_CrossArms_LeftWrist.txt	12-Ma
001_CrossArms_RightWrist.txt	12-Ma
001_DrinkGlas_LeftWrist.txt	12-Ma
001_DrinkGlas_RightWrist.txt	12-Ma
001_Entrainment_LeftWrist.txt	12-Ma
001_Entrainment_RightWrist.txt	12-Ma
001_HoldWeight_LeftWrist.txt	12-Ma
001_HoldWeight_RightWrist.txt	12-Ma
001_LiftHold_LeftWrist.txt	12-Ma
001_LiftHold_RightWrist.txt	12-Ma
001_PointFinger_LeftWrist.txt	12-Ma

questionnaire

questionnaire_response_001.json	questionnaire_response_002.json	questionnaire_response_003.json	questionnaire_response_004.json	questionnaire_response_005.json	questionnaire_response_006.json	questionnaire_response_007.json
questionnaire_response_011.json	questionnaire_response_012.json	questionnaire_response_013.json	questionnaire_response_014.json	questionnaire_response_015.json	questionnaire_response_016.json	questionnaire_response_017.json
questionnaire_response_021.json	questionnaire_response_022.json	questionnaire_response_023.json	questionnaire_response_024.json	questionnaire_response_025.json	questionnaire_response_026.json	questionnaire_response_027.json
questionnaire_response_031.json	questionnaire_response_032.json	questionnaire_response_033.json	questionnaire_response_034.json	questionnaire_response_035.json	questionnaire_response_036.json	questionnaire_response_037.json

patients

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patient_002.json	15-Feb-2024 at 11:44 AM	458 bytes	JSON
patient_003.json	15-Feb-2024 at 11:44 AM	363 bytes	JSON
patient_004.json	15-Feb-2024 at 11:44 AM	391 bytes	JSON
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patient_018.json	15-Feb-2024 at 11:44 AM	402 bytes	JSON
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patient_020.json	15-Feb-2024 at 11:44 AM	377 bytes	JSON
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patient_025.json	15-Feb-2024 at 11:44 AM	394 bytes	JSON
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patient_030.json	15-Feb-2024 at 11:44 AM	389 bytes	JSON
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observation_028.json	12-Mar-2024 at 9:41 AM	13 KB	JSON
observation_029.json	12-Mar-2024 at 9:41 AM	13 KB	JSON

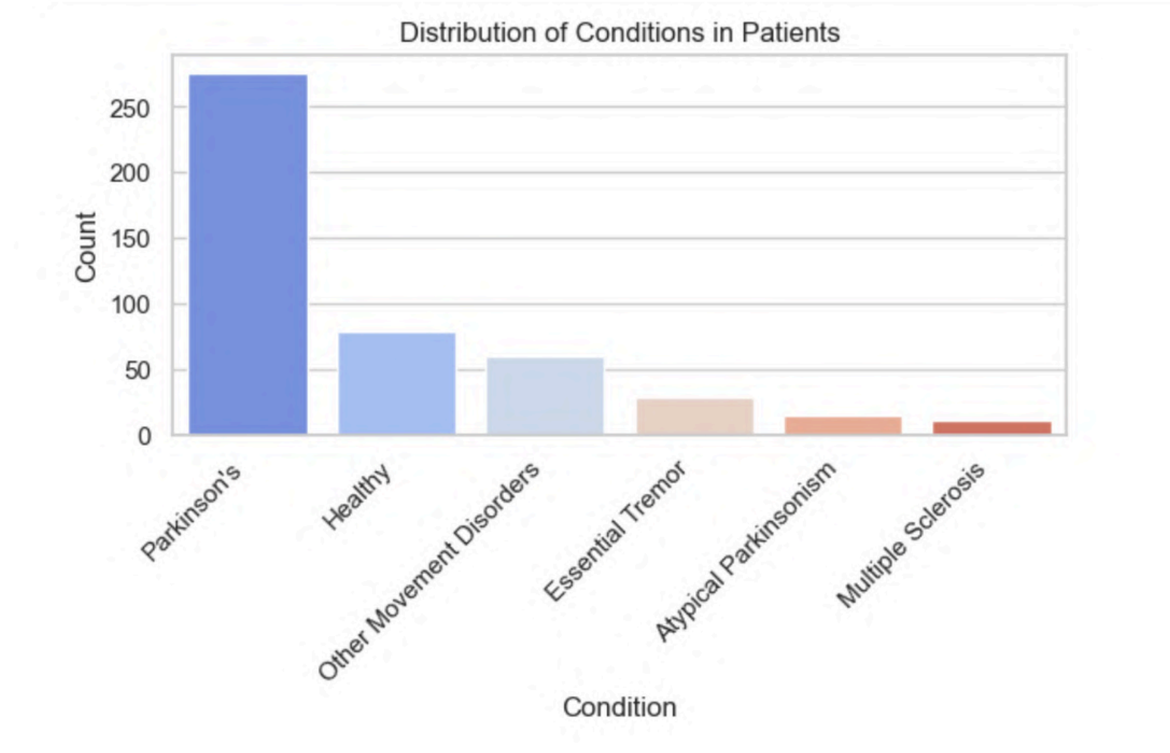
Integrating Multiple Datasets

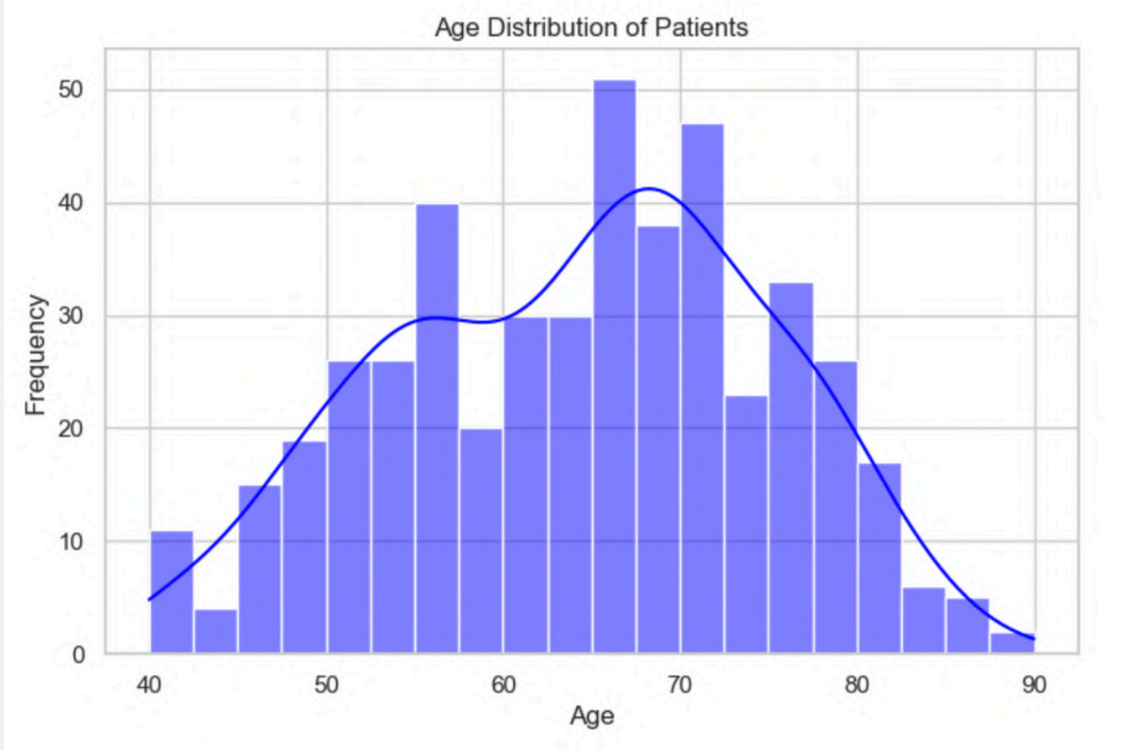
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	resource_typ	id	study_id	condition	disease_com	age_at_diagn	age	height	weight	gender	handedness	appearance_	appearance_	effect_of_alcohol
2	patient	36	PADS	Multiple Scle	Multiple Scle	24	40	183	75	male	right	TRUE	TRUE	No effect
3	patient	54	PADS	Healthy	-	40	40	183	88	female	right	TRUE	TRUE	No effect
4	patient	193	PADS	Healthy	-	40	40	183	78	male	right	FALSE	FALSE	Unknown
5	patient	308	PADS	Healthy	-	40	40	183	88	female	right	TRUE	TRUE	No effect
6	patient	77	PADS	Other Moven	Dystonial tre	37	41	170	60	female	right	FALSE		No effect
7	patient	178	PADS	Other Moven	SWEDD	0	41	174	66	female	left	TRUE	TRUE	No effect
8	patient	250	PADS	Healthy	-	42	42	168	68	female	right	FALSE	FALSE	Unknown
9	patient	276	PADS	Other Moven	ET DD functic	14	42	178	62	female	right	TRUE	FALSE	Unknown
10	patient	307	PADS	Parkinson's	IPS with dyst	37	42	193	90	male	right	FALSE		Unknown
11	patient	367	PADS	Other Moven	IPS tremordo	38	42	174	72	female	left	TRUE	TRUE	No effect
12	patient	444	PADS	Healthy	-	42	42	170	62	female	right	FALSE		No effect
13	patient	176	PADS	Other Moven	Bacterial Me	0	43	168	110	female	right	FALSE	FALSE	No effect
14	patient	438	PADS	Multiple Scle	MS type Bali,	30	43	173	85	male	right	FALSE	FALSE	Improvement
15	patient	287	PADS	Other Moven	Adult multifo	43	44	167	68	female	left	FALSE		Unknown
16	patient	408	PADS	Healthy	-	44	44	167	50	female	right	FALSE	FALSE	Unknown
17	patient	3	PADS	Healthy	-	45	45	170	78	female	right	FALSE		Unknown
18	patient	50	PADS	Other Moven	-	37	45	174	56	female	right	FALSE		Unknown
19	patient	445	PADS	Essential Tre	-	45	45	165	53	female	right	FALSE		Improvement
20	patient	449	PADS	Healthy	-	45	45	194	109	male	right	TRUE	TRUE	No effect
21	patient	71	PADS	Parkinson's	IPS tremordo	33	46	184	110	male	right	FALSE		Unknown
22	patient	86	PADS	Parkinson's	IPS hypokinet	40	46	163	69	female	right	TRUE	FALSE	Unknown
23	patient	111	PADS	Other Moven	Tremor of unk	42	46	163	76	female	right	FALSE		Worsening
24	patient	162	PADS	Parkinson's	IPS akinetic-r	35	46	168	69	female	right	FALSE		Unknown
25	patient	268	PADS	Parkinson's	Segmental dy	43	46	183	97	female	right	FALSE		No effect
26	patient	9	PADS	Parkinson's	IPS mixed typ	35	47	184	85	male	left	FALSE		Unknown
27	patient	65	PADS	Parkinson's	IPS mixed typ	32	47	175	70	male	right	FALSE		No effect
28	patient	305	PADS	Parkinson's	Starting IPS t	47	47	196	110	male	right	FALSE		No effect
29	patient	380	PADS	Parkinson's	IPS hypokinet	47	47	179	76	male	right	FALSE		Unknown
30	patient	412	PADS	Parkinson's	IPS hypokinet	43	47	158	54	female	right	FALSE		Worsening
31	patient	451	PADS	Other Moven	Unknown Tre	42	47	162	76	female	right	FALSE		Improvement
32	patient	29	PADS	Parkinson's	IPS, THS	33	48	175	70	male	right	FALSE		No effect
33	patient	121	PADS	Healthy	-	48	48	172	73	female	right	TRUE	TRUE	Unknown
34	patient	134	PADS	Healthy	-	48	48	184	90	male	right	FALSE	FALSE	Unknown
35	patient	201	PADS	Parkinson's	IPS mixed typ	46	48	159	57	female	right	FALSE		No effect

DATASETS

- clean-questionnaire-data
  - clean_questionnaire_data.csv
- formatted-questionnaire-data
  - Questionnaire_Data_with_ID.csv
  - pd_dd_formatted.csv
  - pd_hc_formatted.csv
- movement2
  - movement
- patient-labels2
  - patient_labels.csv
- pd-dd-hc
  - pd_dd.csv
  - pd_hc.csv

Data Spread


Distribution of Conditions in Patients
Count
250
200
150
100
50
0
Parkinson's
Healthy
Other Movement Disorders
Essential Tremor
Atypical Parkinsonism
Multiple Sclerosis
Condition


Age Distribution of Patients
Frequency
50
40
30
20
10
0
40
50
60
70
80
90
Age

Smartwatch Data (Time Series Data)

001_LiftHold_RightWrist.txt

```
0.0000000000,-0.0147468289,0.0315866508,-0.0289480109,-0.0015876302,0.0097835213,0.0193514172
0.0100480318,-0.0089029511,0.0372068919,-0.0278404374,-0.0048806285,0.0193599816,0.0278514270
0.0200489759,-0.0040525040,0.0310502257,-0.0265596528,-0.0285215117,0.0362140648,0.0406074375
0.0300369263,-0.0021101676,0.0326233394,-0.0251935143,-0.0308836531,0.0595494136,0.0427452214
0.0402200222,0.0008163608,0.0341879912,-0.0235961098,-0.0321496688,0.0797050148,0.0438184738
0.0505290031,0.0086413184,0.0376937129,-0.0198715348,-0.0258635432,0.0914388970,0.0448845401
0.0603309870,0.0106166163,0.0392142422,-0.0150572676,-0.0131524885,0.1011277512,0.0491330810
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0.0907980204,-0.0079430779,0.0896889642,-0.0316563249,0.1310431212,0.0909014121,0.0777605250
0.1007310152,-0.0167893618,0.1012628451,-0.0402459502,0.1812209934,0.0904093236,0.0979224592
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0.1810319424,-0.0701495260,0.0967280939,-0.0706378818,0.1523934603,0.1031937599,0.3071095645
0.1911200285,-0.0718862861,0.1020642892,-0.0769465566,0.1875778139,0.1078976989,0.3304625452
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008_LiftHold_RightWrist.txt

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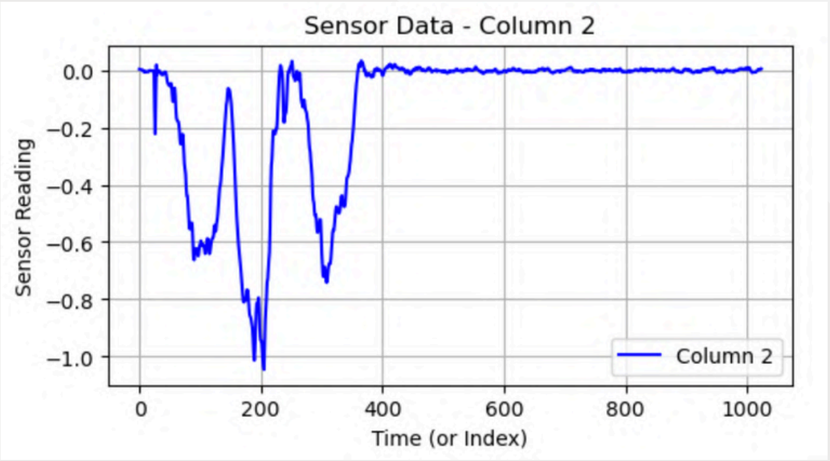
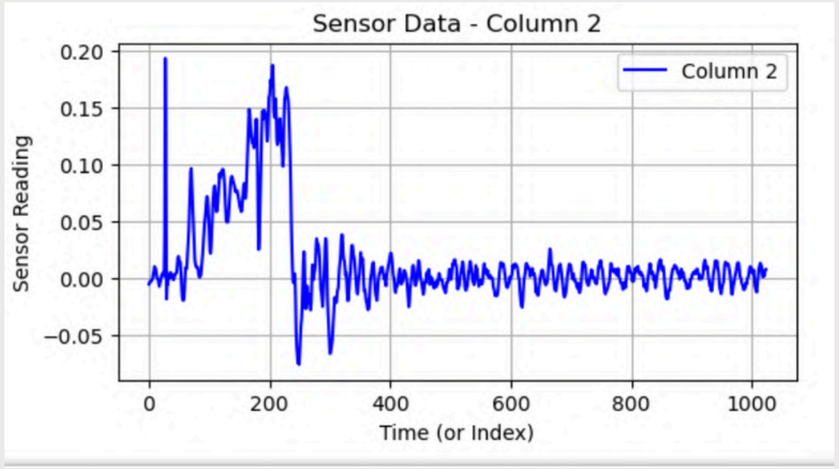
Accelerometer

x-axis

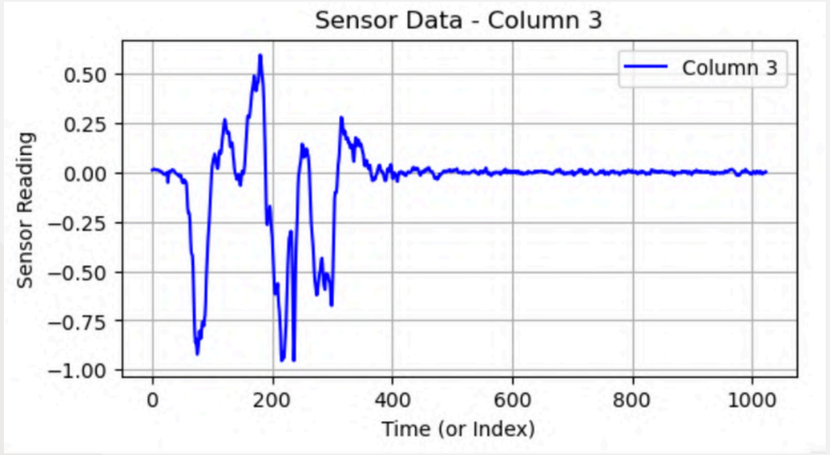


HC



PD

y-axis



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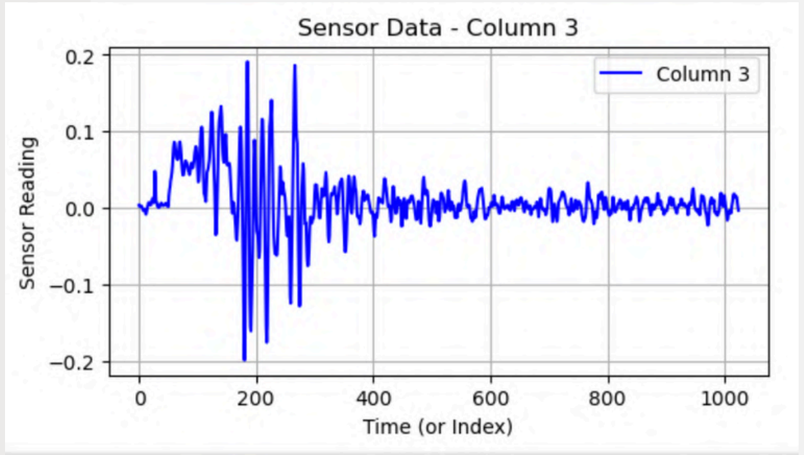
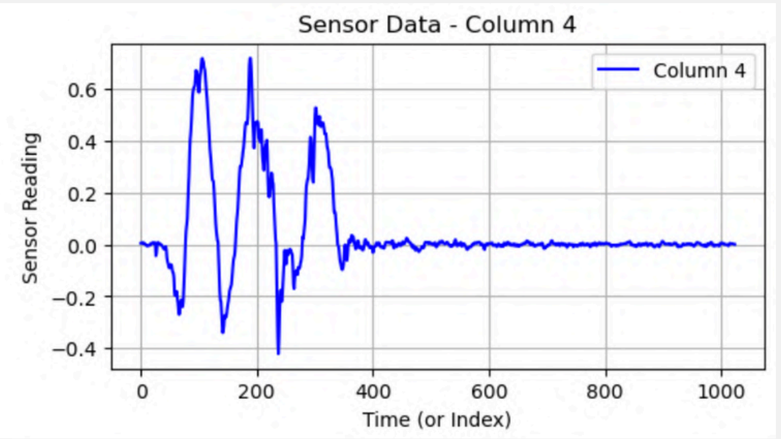


PD

z-axis



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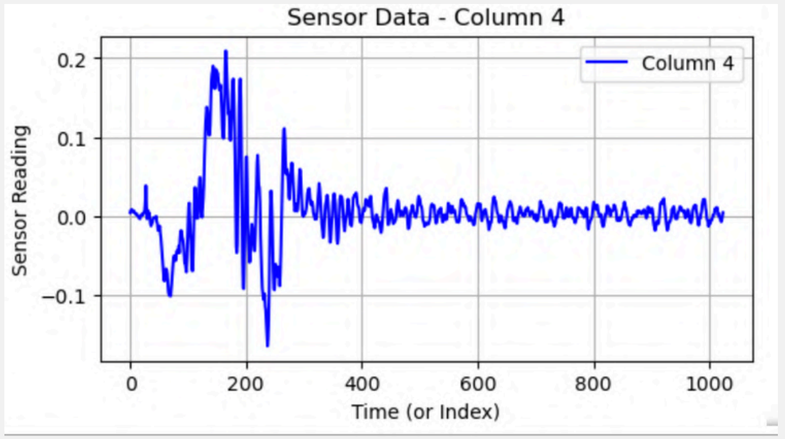
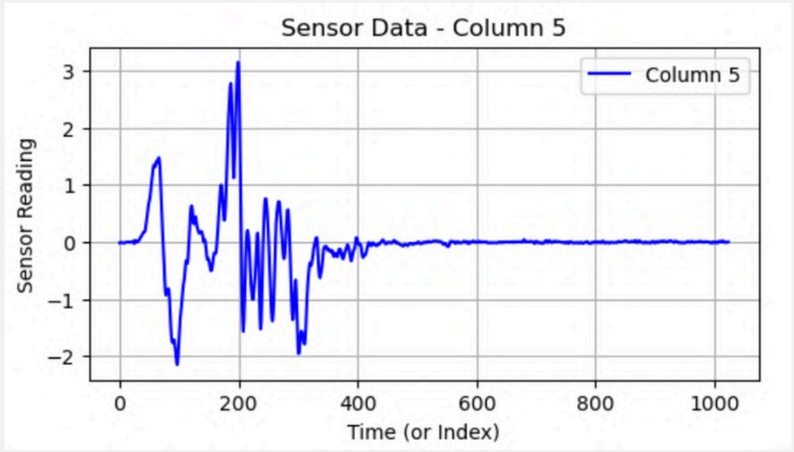


PD

Gyroscope

x-axis



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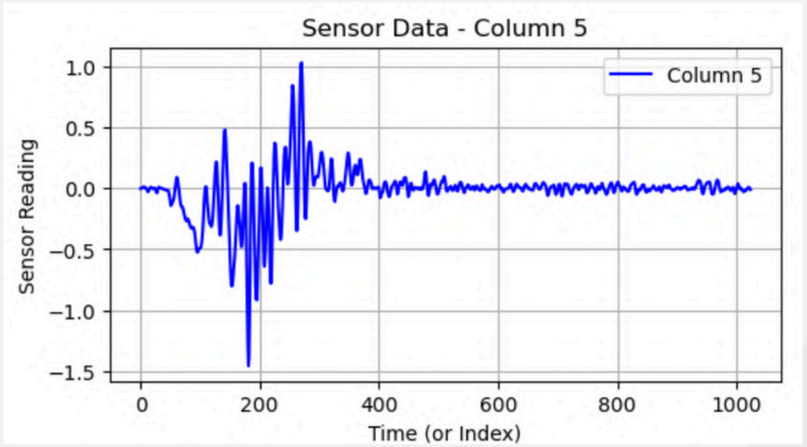
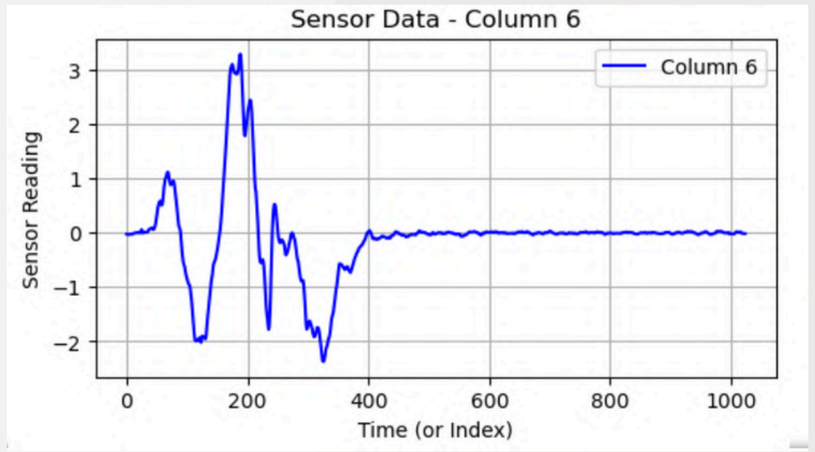


PD

y-axis



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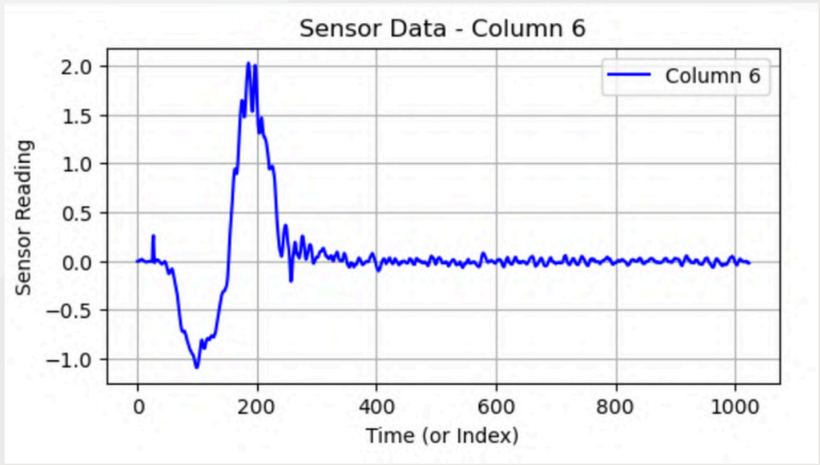
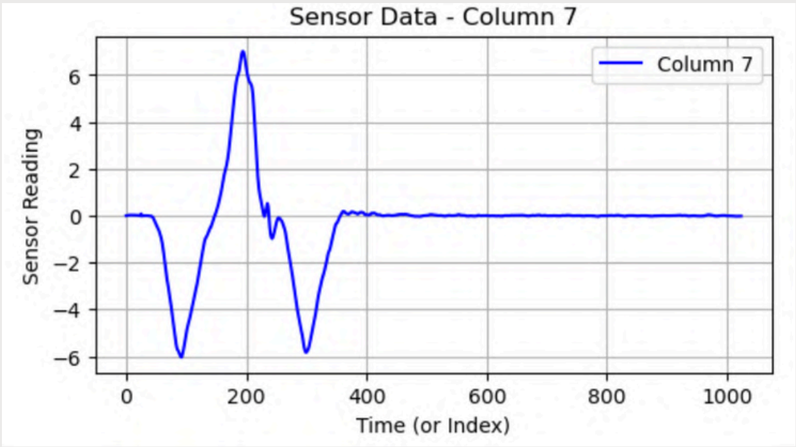


PD

z-axis



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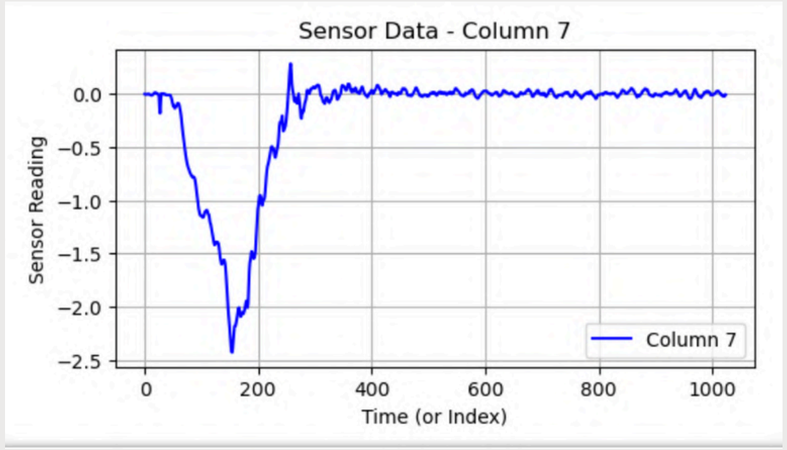
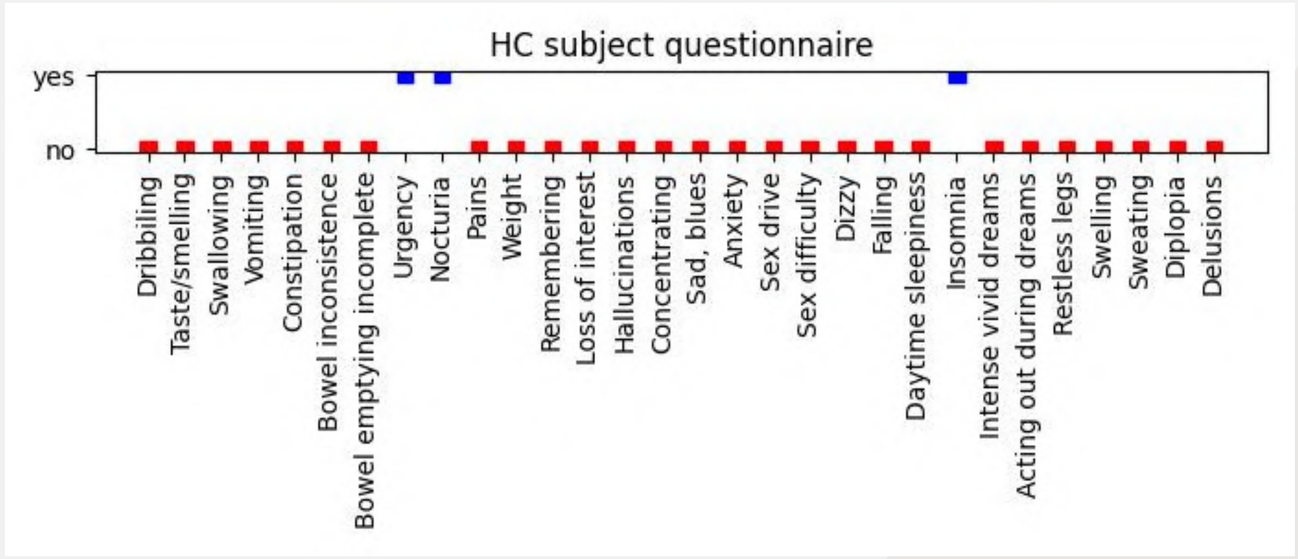
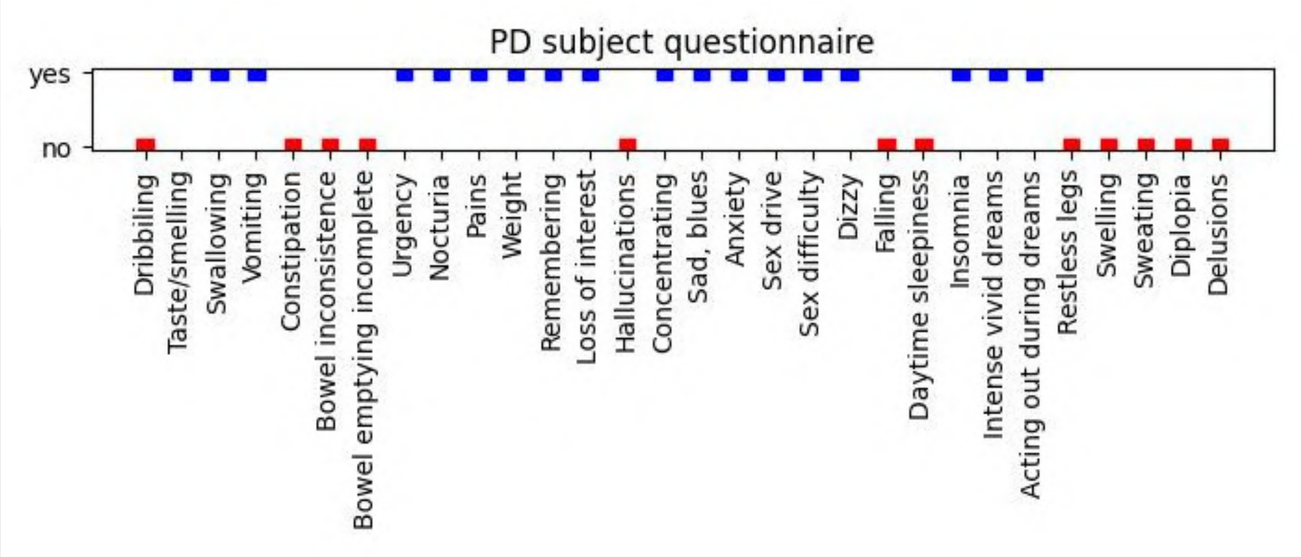


PD

Questionnaire





ML Methodology

Motor Model - What Didn’t Work

Attempted: Omni-Scale CNN

Reason:

- Inspired by **XceptionTime**; expected good performance on multimodal signals.
- Why Omni-Scale: **Computationally light**, good for small devices (smartwatches).

What we tried:

- **Hyperparameter tuning** (grid search on learning rate, neurons, depthwise separable conv).

Outcome:

- **Accuracy plateaued** early (~mid 60s%).
- Adding layers didn’t help which meant convolutions not learning useful features.

Learning:

- Non-Convolutional models may work better for time-series motor features.

```
Cross-validation results:
Average accuracy: 0.6610
Average precision: 0.6617
Average recall: 0.8655
Average f1: 0.7484
Average auc: 0.7010
```

Questionnaire Model - What Worked

Baseline: Feedforward Neural Network

Achieved:

- Training accuracy: **84%**
- Test accuracy: **80%**
- No signs of overfitting.

Simple model **worked well** → stuck with it for fusion.

	precision	recall	f1-score	support
0.0	0.75	0.69	0.72	35
1.0	0.82	0.86	0.84	59
accuracy			0.80	94
macro avg	0.79	0.78	0.78	94
weighted avg	0.80	0.80	0.80	94

Training Set Evaluation:

	precision	recall	f1-score	support
0.0	0.81	0.81	0.81	158
1.0	0.86	0.86	0.86	217
accuracy			0.84	375
macro avg	0.83	0.83	0.83	375
weighted avg	0.84	0.84	0.84	375

Moving to a Fusion Model

Fusion

Concatenated raw features → fed to basic random forest.

Result:

- Accuracy: late 60s

Improvement:

Feature Engineering

Extracted features from motor data:

Statistical: Mean, std, min, max, RMS, skewness, kurtosis, FFT energy

Wavelet: Mean, std, energy across levels (PyWavelets)

Cross-channel: Correlation and phase differences

Combined with questionnaire responses.

Feature Extraction Approach

Architecture

- **ParkinsonClassifier** (MLP): Motor features
- **QuestionnaireNN** (MLP): Questionnaire
- FusionModel: Concatenates both

Performance:

- PD vs HC: **81.69%**
- PD vs DD: **74.36%**
- Close to the results in the literature review using only simple, interpretable models

```
Test Set Metrics:
Accuracy: 0.8169
Precision: 0.8088
Recall: 1.0000
F1: 0.8943
Auc: 0.9852
```

PD vs HC

```
Test Set Metrics:
Accuracy: 0.7436
Precision: 0.7397
Recall: 0.9818
F1: 0.8438
Auc: 0.8664
```

PD vs DD

Final Fusion Model Architecture

Model Architecture:

- Input: Extracted motor features
- 3 hidden layers → BatchNorm + ReLU + Dropout
- QuestionnaireNN (Questionnaire MLP):

- Input: Scaled questionnaire features
- 2 hidden layers → ReLU + Dropout

FusionModel:

- Concatenates both branches
- Final FC layers → Sigmoid output

Training Setup:

- Early stopping
- 5-fold stratified cross-validation
- Train/test split = 80/20

Results:

- Accuracy (PD vs DD): ~98.72%
- Accuracy (PD vs HC): ~100%
- Robust generalization across validation & test splits

```
Best validation metrics: {'acc': 1.0, 'prec': 1.0, 'rec': 1.0, 'f1': 1.0, 'auc': 1.0}

Evaluating best model on test set...

Test Set Metrics:
Accuracy: 0.9872
Precision: 0.9821
Recall: 1.0000
F1: 0.9910
Auc: 1.0000
```

PD vs DD

```
Best model was from fold 1 with validation loss 0.0013
Best validation metrics: {'acc': 1.0, 'prec': 1.0, 'rec': 1.0, 'f1': 1.0, 'auc': 1.0}

Evaluating best model on test set...

Test Set Metrics:
Accuracy: 1.0000
Precision: 1.0000
Recall: 1.0000
F1: 1.0000
Auc: 1.0000
```

PD vs HC

```
Best validation metrics: {'acc': 1.0, 'prec': 1.0, 'rec': 1.0, 'f1': 1.0, 'auc': 1.0}

Evaluating best model on test set...

Test Set Metrics:
Accuracy: 0.9872
Precision: 0.9821
Recall: 1.0000
F1: 0.9910
Auc: 1.0000
```

PD vs DD

```
Best validation metrics: {'acc': 1.0, 'prec': 1.0, 'rec': 1.0, 'f1': 1.0, 'auc': 1.0}

Evaluating best model on test set...

Test Set Metrics:
Accuracy: 1.0000
Precision: 1.0000
Recall: 1.0000
F1: 1.0000
Auc: 1.0000
```

PD vs HC

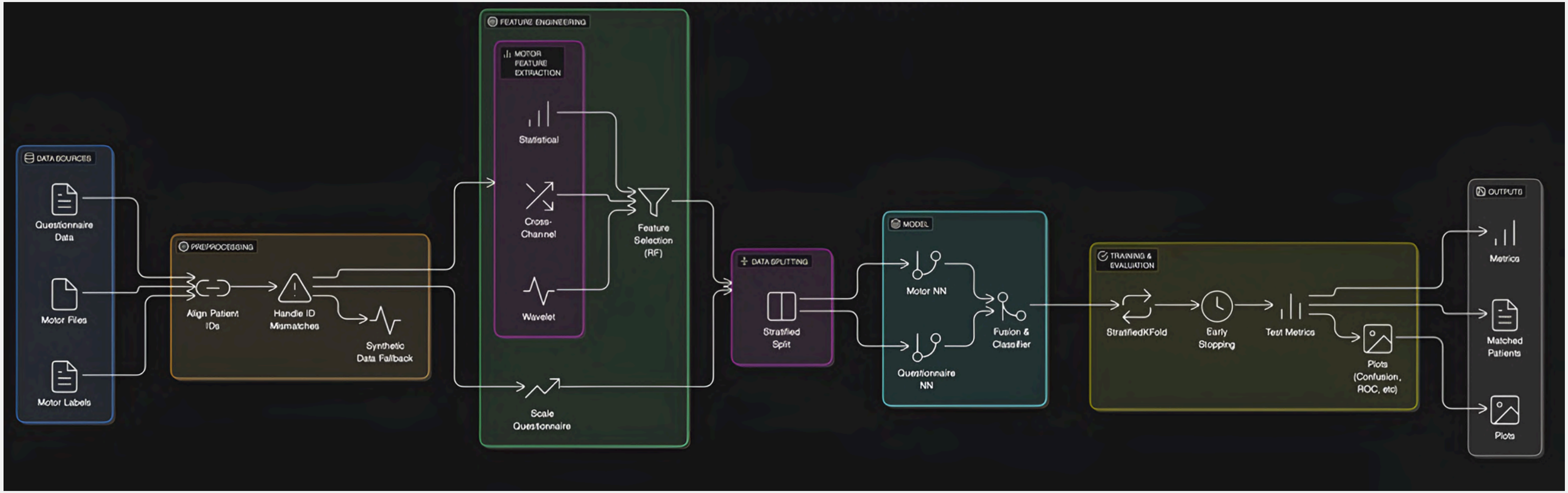
Input	Test folds	Balanced accuracy	F1	Precision	Recall
Smartwatch + Questionnaire	complete	72.42% (12.33%)	60.45% (16.7%)	54.92% (15.05%)	67.71% (19.45%)
	matched	69.56% (17.34%)	67.93% (19.84%)	70.36% (19.85%)	65.71% (19.93%)

PD vs DD

Smartwatch + Questionnaire	complete	91.16% (4.92%)	94.62% (2.21%)	96.98% (2.49%)	92.4% (2.64%)
	matched	89.25% (5.65%)	89.77% (5.24%)	89.79% (8.99%)	90.11% (3.13%)

PD vs HC

Pipeline


DATA SOURCES
Questionnaire Data
Motor Files
Motor Labels
PREPROCESSING
Align Patient IDs
Handle ID Mismatches
Synthetic Data Fallback
FEATURE ENGINEERING
MOTOR FEATURE EXTRACTION
Statistical
Cross-Channel
Wavelet
Feature Selection (RF)
Scale Questionnaire
DATA SPLITTING
Stratified Split
MODEL
Motor NN
Questionnaire NN
Fusion & Classifier
TRAINING & EVALUATION
StratifiedKFold
Early Stopping
Test Metrics
Plots (Confusion, ROC, etc)
OUTPUTS
Metrics
Matched Patients
Plots

PD vs. All Classification

- **Motor Branch (ParkinsonClassifier)**
  - Fully connected layers (256 → 128 → 64)
  - Inputs: Extracted features from motor data
  - Statistical
  - Wavelet
  - Cross-channel correlation
  - Feature selection via Random Forest

- **Questionnaire Branch (QuestionnaireNN)**
  - Two-layer feedforward network (128 → 64)
  - Inputs: Cleaned & scaled questionnaire data

- **Fusion Head (FusionModel)**
  - Concatenation of both branches
  - Final classifier: 64 → 1 with Sigmoid activation

```
Best model was from fold 5 with validation loss 11.1857
Best validation metrics: {'acc': 0.7866666666666666, 'prec': 0.7692307692307693, 'rec': 0.
9090909090909091, 'f1': 0.8333333333333333, 'auc': 0.8621700879765397}

Evaluating best model on test set...

Test Set Metrics:
Accuracy: 0.7872
Precision: 0.8182
Recall: 0.8182
F1: 0.8182
Auc: 0.8275
```

Outcomes

Added depth seperable convolution layers-

- Accuracy dropped by ~10%
- Validated our hypothesis that linearly separable models work better for our features.

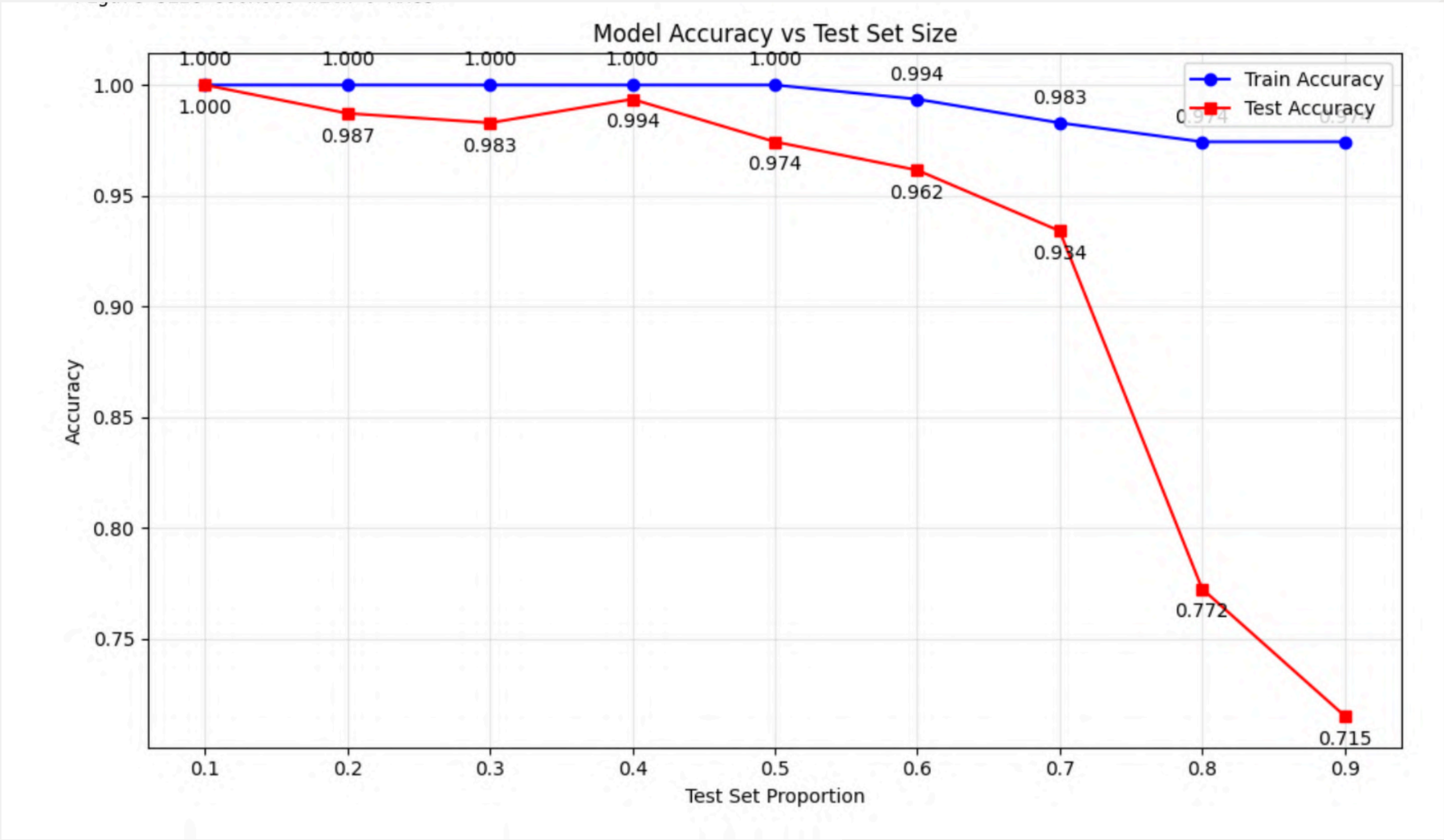
Extracted features + Neural Networks worked best
Smaller model (around 2 MB size)
Better suited for edge deployment (e.g., on wearables)

Challenges with Scaling Up

1. **Limited Labeled Data**
   - Small number of patients with both motor and questionnaire data.
   - Difficult to scale without significantly more labeled, multimodal samples.

2. **Class Imbalance**
   - Parkinson’s datasets are often imbalanced, especially with rare atypical subtypes.
   - Scaling up requires robust class-weighting or synthetic sample generation (e.g., SMOTE).

3. **Infrastructure & Compute**
   - Large-scale feature extraction + training demands high memory and GPU.
   - Scaling may need batch processing pipelines, cloud GPU infrastructure.


Model Accuracy vs Test Set Size
Train Accuracy
Test Accuracy
Accuracy
Test Set Proportion
1.00
0.95
0.90
0.85
0.80
0.75
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.000
1.000
1.000
1.000
1.000
0.994
0.983
1.000
0.987
0.983
0.994
0.974
0.962
0.934
0.772
0.715

Thank you