RESEARCH PAPER

A Two-Stage Machine Learning Framework for Voice-Based Detection and Severity Classification of Parkinson's Disease

Mayura Tapkire[1], Likitha M P[2], Pooja M V[3], Mahe Mubeen Akhtar.D[4], Manjunath Naganna[5], Lavanya M S[6*]

[1,4]Department of Computer Science and Engineering, The National Institute of Engineering, Mysuru, Karnataka, India

[2,6]Department of Information Science Engineering, JSS Science and Technology University, Mysuru, Karnataka, India

[3]Department of Computer Applications, JSS Science and Technology University, Mysuru, Karnataka, India

[4]Department of Computer Science and Engineering, Vidya Vikas Institute of Engineering & Technology,Mysuru, Karnataka, India

***Corresponding author:** Lavanya M S*

Abstract: People with Parkinson's disease experience difficulties in maintaining steady vocal control and producing speech sounds, which results in voice biomarkers functioning as a successful nondestructive testing method to identify the disease and track its advancement through speech signal analysis. The research presents a two part complete voice based system which detects Parkinson's disease and measures its severity through three steps that begin with acoustic feature extraction and end with machine learning classification and result display. The first stage employs a Random Forest binary classifier to separate healthy individuals from Parkinson's disease patients based on their recorded voice biomarkers. The training and evaluation of severity classification models including Random Forest and XGBoost use sixteen clinically important biomarkers which include jitter and shimmer and harmonics-to-noise ratio and RPDE and DFA and PPE to create a model that predicts Mild and Moderate and Severe conditions, selecting the best model based on its performance. The Streamlit interface provides users with a simple platform to receive real time predictions and probability assessments while viewing speech data. Random Forest shows strong performance for disease detection according to experimental results, while XGBoost delivers better results for Parkinson's disease severity assessment.

Keywords: Parkinson’s Disease, Voice Biomarkers, Acoustic Feature Extraction, Severity Grading, XGBoost, Speech Signal Analysis, Machine learning

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Introduction The voice changes that occur in Parkinson's disease show the progression of this disorder which affects both movement abilities and speech capacity and vocal track stability. The combination of shaky pitch and irregular tone and unstable frequency and amplitude shifts and background noise creates symptoms that reveal both the presence of the disease and its development. The early assessment of these symptoms helps establish treatment plans while ongoing monitoring of symptom development leads to better results [1,2]. The assessment process experiences two major problems because it depends on clinician expertise as the sole method of evaluation which results in delayed results and varied assessment outcomes. The development of data analysis tools provides a valuable solution because these tools deliver ongoing assistance for diagnosis procedures. The application of machine learning which represents a branch of artificial intelligence provides researchers with a method to use voice signals for Parkinson diagnosis. The three models Random Forest Support Vector Machine and XGBoost demonstrate strong performance when they predict disease presence. Most studies either focus on comparing Parkinson's patients with healthy individuals or they assess disease severity through separate evaluations [3]. The research employs a two-step process to complete its work because Random Forest handles the first stage which separates healthy people from Parkinson's patients while XGBoost handles the second stage which assigns severity levels to identified cases [4]. The research The research presents a machine learning system that uses 16 voice measurements to track Parkinson's disease progression through their assessment of frequency changes and amplitude variations and noise patterns and speech signal disturbances. The XGBoost model uses motor_UPDRS cutoff values to categorize cases into three degrees of disease severity which includes Mild and Moderate and Severe [5]. The system predicts outcomes while it shows hidden voice characteristics through visual displays that present sound waves and pitch [6].

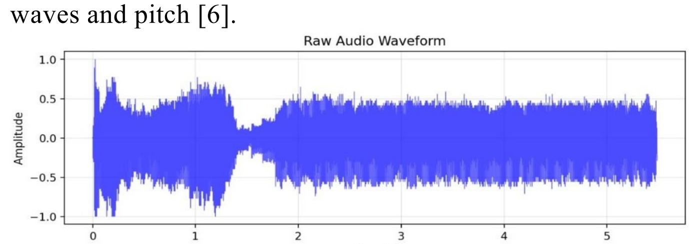


Figure 1: Representative raw audio waveform of a speech recording used for extracting acoustic biomarkers such as jitter, shimmer, and harmonic-to-noise ratio for Parkinson’s severity classification.

1. Literature Survey

Recently The latest research studies have investigated different techniques which utilize artificial intelligence and machine learning methods to identify Parkinson's disease [7]. The field typically employs Support Vector Machines, Random Forest, XGBoost, and hybrid deep learning systems as its standard machine learning models [8]. The methods evaluate speech through their analysis of non-linear characteristics while using motor UPDRS and total UPDRS scores as clinical assessment tools. Voice assessment becomes the most studied method because it costs less than traditional clinical tests and does not require physical contact with patients and can scale to more patients than existing methods [9].

The current advancements still possess fundamental restrictions which need to be addressed. The majority of existing research studies dedicate their efforts to establishing tests which determine whether someone has Parkinson's disease or not [10]. The current study investigates vocal biomarker based severity grading which remains a less common research area [11,12].

The existing research treats detection and severity estimation as distinct diagnostic processes which need to be addressed through an integrated diagnostic approach [13,14]. The majority of models function as black-box systems which provide limited system transparency, leading to decreased trustworthiness for medical applications. The present research depends on one dataset which does not provide enough external validation to build strong and broadly applicable results.

The research area lacks sufficient studies which create a hierarchical two-stage framework that initiates with disease detection and only applies severity assessment to confirmed Parkinson's diagnoses [15].

The project addresses existing research deficiencies through the creation of a two stage voice based framework which uses Random Forest classifier technology to detect Parkinson's disease and then uses XGBoost to evaluate severity based on acoustic biomarkers. The framework creates an integrated system through its combination of three methods [16].

The table presents a comparison of machine learning, ensemble learning, and deep learning techniques used for predicting Parkinson’s disease severity based on vocal biomarkers. The prediction performance of these techniques is evaluated using the Unified Parkinson’s Disease Rating Scale (UPDRS), which is widely used to assess the severity and progression of Parkinson’s disease [17].

The table includes various approaches such as Machine Learning (ML), Deep Learning (DL), Extreme Gradient Boosting (XGBoost), Optimized Learning Vector Quantization (OLVQ1), and Adaptive Neuro-Fuzzy Inference System (ANFIS), highlighting their applications and effectiveness in predicting Parkinson’s disease severity [18].**Table 1:** Comparison of AI Techniques for Parkinson’s Severity

S.No	Author & Year	MethodTechnique Used	Description	Limitations
1	Tsanas et al., 2009	Nonlinear Speech Features With Regression	From the start, voice patterns helped estimate symptom severity in Parkinson’s patients using the UCI telemonitoring collection. Instead of clinical visits, sound features served as proxies for motor function ratings.	Small data volume weakens reliability; fails to apply current machine learning verification standards.
2	Motamedi et al., 2025	Hybrid Ensemble Learning	Starting with voice recordings collected remotely, the approach combined multiple tuned models to estimate motor scores. Instead of relying on a single algorithm, predictions emerged from weighted outputs across several learners. For total UPDRS, performance improved by blending model strengths through iterative refinement. Voice features captured changes over time, feeding into adjusted predictions. Rather than simplifying complexity, the system preserved variability found in real-world samples.	Still needs testing in actual medical settings.
3	Pechprasarn, 2023	Machine Learning Regression	Applied regression models on UCI vocal biomarkers for Parkinson’s severity estimation.	Most findings apply only to narrow cases. Validation happens on a small scale, limiting broader relevance.
4	ML Analysis of Telemonitoring Dataset, 2025	Advanced ML Models	Proposed improved ML approach for direct PD severity prediction from voice features.	Comparison remains necessary when examining deep learning techniques.
5	Mishra et al., 2024	Hybrid Deep Learning	Developed PD-DETECTOR model for severity estimation using voice biomarkers.	Testing across several centers is needed to confirm reliability.
6	Zogaan et al., 2024	OLVQ1 + ANFIS	Combined hybrid intelligent models for Motor and Total UPDRS prediction.	Even standard approaches today struggle with certain constraints in how well they perform.
7	Tong et al., 2025	Mixed Effects with Neural Networks	Using UCI and Oxford telemonitoring datasets, performance of complex neural networks was measured. Hybrid model behavior emerged clearly during testing phases. Advanced systems showed distinct patterns across varied conditions.	Further confirmation required across broader patient groups.
8	Mahmood et al., 2025	Deep Learning Ensemble	Proposed multimodal ensemble model for motor severity prediction from vocal biomarkers.	Requires testing on unseen external cohorts.

3 Proposed Methodology

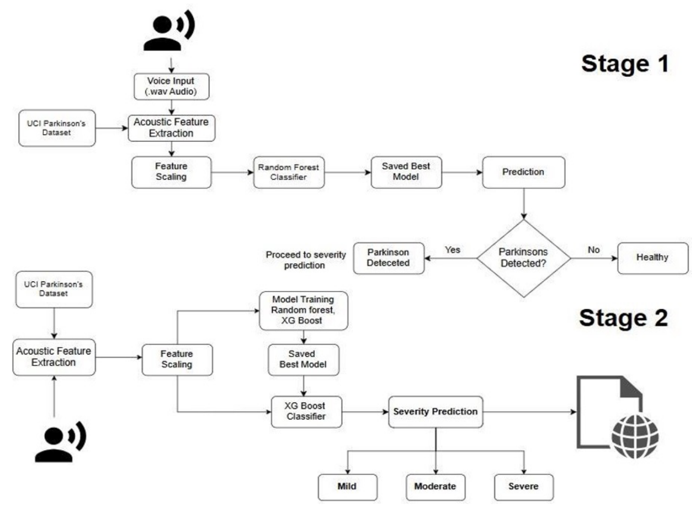


Figure 2: Proposed Parkinson’s Disease Prediction Model Architecture

The proposed system is a two stage voice analysis framework for Parkinson's disease detection and severity grading. The framework combines acoustic feature extraction and machine learning classification together with visualization and an interactive user interface which enables users to make predictions in real time. The system uses a hierarchical two-stage approach to enhance both screening procedures and assessments of disease progression [19].

The first stage begins with voice recordings which generate acoustic biomarkers that undergo processing before the Random Forest model performs binary classification to separate healthy controls from Parkinson's patients through feature scaling [20]. The system proceeds to Stage two after it detects Parkinson's disease [21]. The second stage uses sixteen important voice biomarkers which include jitter and shimmer as well as HNR and NHR and RPDE and DFA and PPE to create an XGBoost classifier which grades disease severity into Mild and Moderate and Severe categories [22]. The proposed framework adopts a layered structure which consists of two main components, Presentation Layer [23] . The Streamlit based frontend allows users to upload voice recordings or enter manual features while it displays predictions together with probabilities and visual content. Processing and Machine Learning Layer The system conducts acoustic feature extraction together with preprocessing and binary detection and severity classification through Random Forest and XGBoost models.

The system contains trained model artifacts together with feature datasets and stored classification components which handle inference operations. The structure of the system enables the organization of data processing together with user interactions and decision support for detecting Parkinson's disease and assessing its severity.

Dataset and Preprocessing

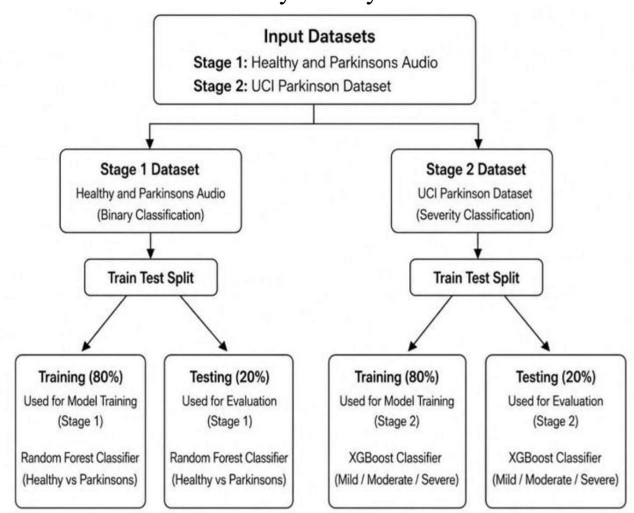
The researchers selected publicly accessible voice-based Parkinson's disease datasets which contain recordings of speech from healthy control subjects as well as Parkinson's disease patients to conduct their research together with the University of California Irvine (UCI) Parkinson's Telemonitoring dataset which provides information for determining disease severity. The dataset includes vocal recordings which contain voice metrics and medical data for each sample that contains vocal biomarkers which researchers extracted from sustained phonation samples. The evaluation required sixteen essential acoustic features which included jitter and shimmer together with harmonics-to-noise ratio (HNR) and noise-to-harmonics ratio (NHR) and recurrence period density entropy (RPDE) and detrended fluctuation analysis (DFA) and pitch period entropy (PPE) to measure severity. The researchers used motor_UPDRS thresholds to create disease severity labels which divided samples into Mild and Moderate and Severe categories to create a multi-class classification challenge.

The data scientists conducted preprocessing operations to establish data quality and consistency before beginning the model training process by applying various operations which included missing value treatment and duplicate record elimination and Standard Scaler feature scaling and numerical conversion of voice features into machine learning algorithm compatible data. The researchers developed a binary classifier which used the dataset from Stage one to identify healthy control subjects and Parkinson's patients. The severity grading dataset underwent partitioning in Stage two to create training and testing subsets which used an 80 to 20 split for model evaluation and generalization testing. The structured preparation process establishes a framework which enables both effective training and objective evaluation of predictive system performance.

Figure 3.1: Distribution of input datasets and train–test split used for model training and evaluation

3.2 Machine Learning Model

The study uses the Random Forest algorithm as its main method to classify Stage one Parkinson's disease patients. The method uses ensemble learning to create multiple decision trees which it combines through majority voting for its final outcome. The system enhances classification performance by decreasing overfitting problems and making the system more reliable toward different situations [24]. The proposed framework uses Random Forest to classify healthy individuals and Parkinson's



patients through analysis of their jitter and shimmer and harmonics-to-noise ratio and noise-to-harmonics ratio and nonlinear speech indicators. The model works effectively as a binary disease detection tool because it can identify vocal feature patterns and handle noisy data and maintain consistent results with biomedical data that has an organized structure [25]. The system uses feature-driven methods to find which vocal biomarkers help diagnose Parkinson's disease.

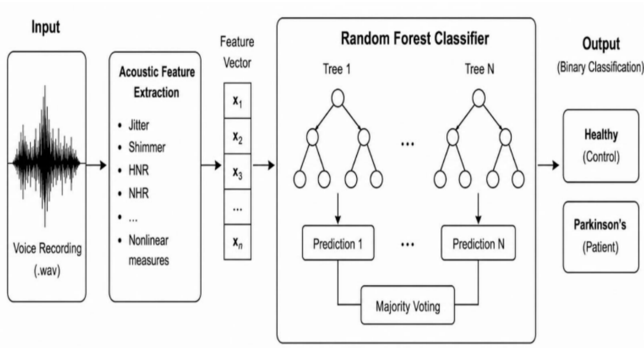
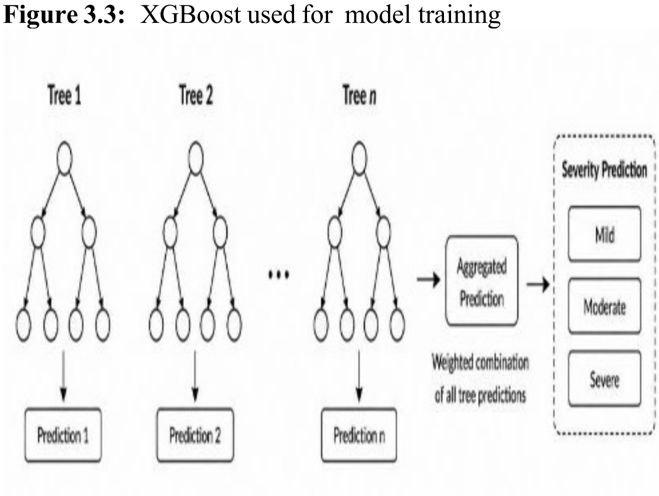


Figure 3.2: Random Forest Classifier used for model training

The XGBoost algorithm serves as the main classification system which classifies Stage wo Parkinson's disease severity levels. The XGBoost system operates as a gradient boosting ensemble system which constructs decision trees in a sequential manner. The proposed system utilizes XGBoost to train sixteen important acoustic biomarkers together with motor_UPDRS based severity labels which enable the model to distinguish between three Parkinson's disease stages: Mild, Moderate, and Severe. The algorithm was chosen because it effectively handles nonlinear feature interactions while supporting multiclass classification and using regularization techniques to prevent overfitting and achieving high accuracy in tabular biomedical datasets. XGBoost outperformed all other tested models in severity prediction which led to its selection as the primary model for Stage two classification.

Figure 3.3: XGBoost used for model training



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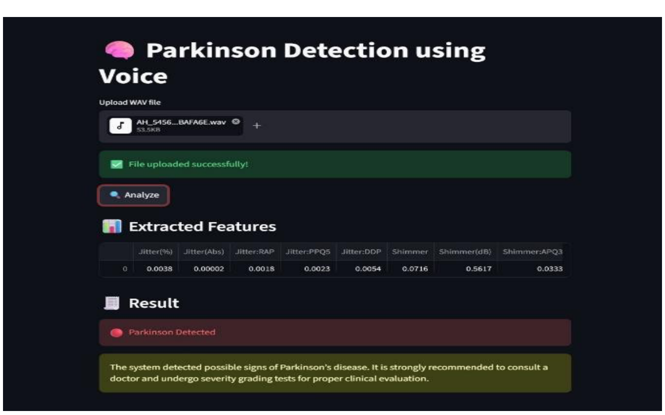

4 Results and Discussion

The proposed two stage voice based Parkinson's disease framework used acoustic biomarkers which it extracted from voice recordings to evaluate both disease detection and severity grading testing. The experimental results show that the system successfully identifies healthy controls and Parkinson's patients during Stage one while it then proceeds to classify Parkinson's disease severity into Mild and Moderate and Severe categories during Stage two. The system gives users two types of outputs which include probability-based predictions and visualization outputs that users can access through the Streamlit interface.

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4.1 User Interface used for Voice Upload

The system develops an interactive system that allows users to upload voice recordings which are in WAV format and to input their extracted acoustic biomarkers through manual entry. The interface allows users to operate the Parkinson's prediction system while using it as their main system to input information needed for both detecting the disease and assessing its severity.

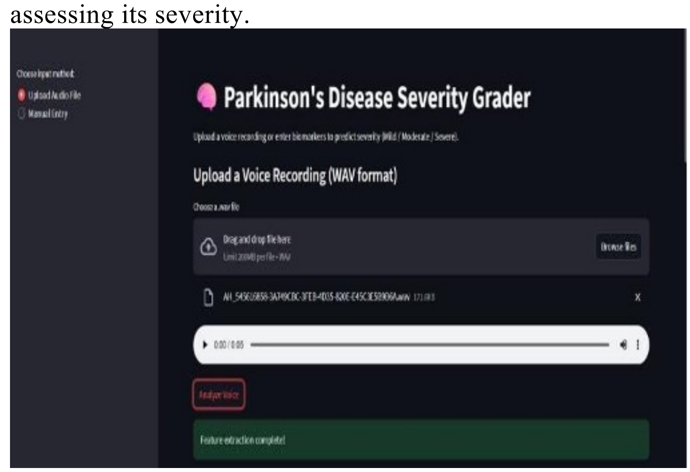


Figure 4.1: User Interface to upload Voice

4.2 Healthy Person Pediction

The Random Forest classifier predicts whether a person belongs to the Healthy or Parkinson class by analyzing voice biomarkers after feature extraction. The model prediction output shows confidence probabilities which indicate the certainty level of the prediction.

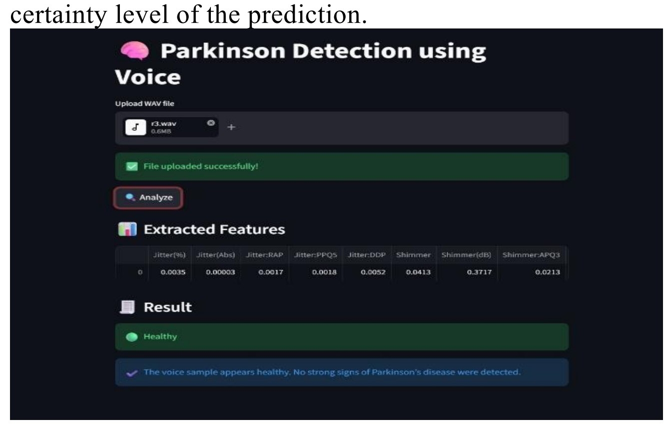


Figure 4.2: Healthy Person Predicted

4.3 Pediction of Affected Person

The XGBoost classifier predicts disease severity for Parkinson-positive cases using three categories which are Mild, Moderate and Severe. The results show class probabilities which enable users to interpret the outcomes based on their confidence level.

Figure 4.3: Severity of Person Affected

4.4 Acoustic Feature Extraction and Visualization

The system enables users to see all extracted biomarkers which include waveform and spectrogram and pitch contour and jitter and shimmer representations. The visual outputs show vocal instability patterns which people with Parkinson's disease display through their speech patterns.

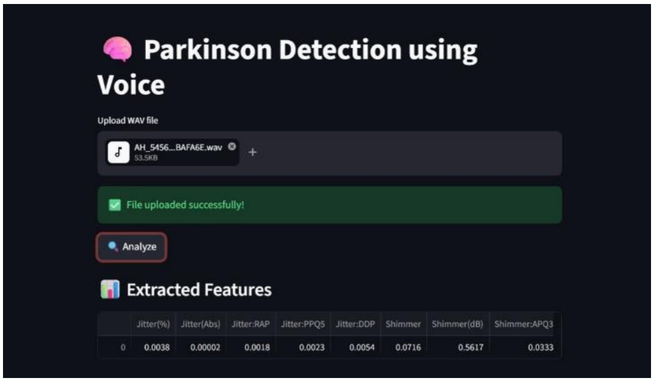


Figure 4.4: Acoustic Features Extracted

4.5 Severity Prediction Results

The XGBoost classifier divided Parkinson's severity into three distinct classes which included Mild and Moderate and Severe. The sample received Moderate classification according to Fig. 4.5 because the system showed high confidence in its display. The model translation becomes more understandable through probability estimates which show the chances of different severity levels appearing.

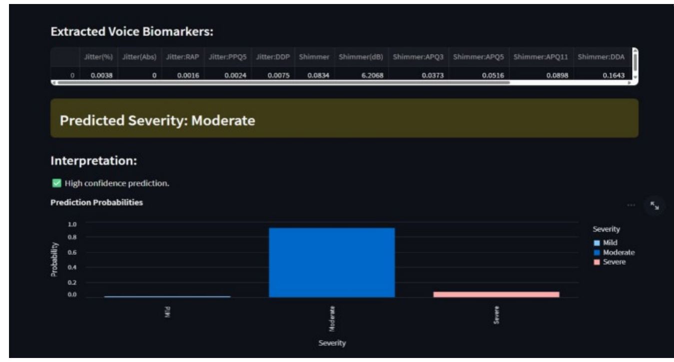
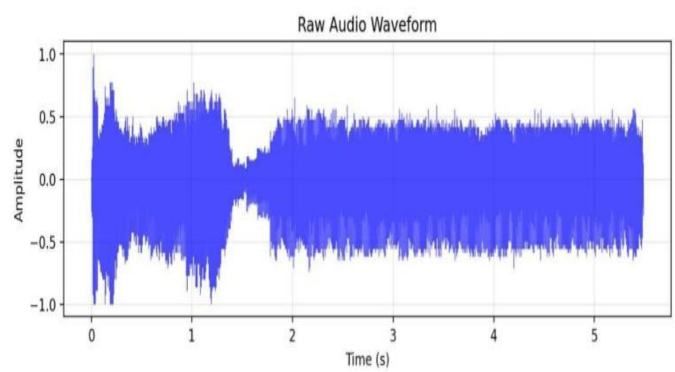


Figure 4.5: XGBoost Severity Classification Output

4.6 Waveform Analysis

Waveform analysis shows how speech signals change their amplitude through different points in time. Parkinson's disease causes people to show unstable vocal patterns which produce irregular amplitude patterns. The visual patterns confirm the biomarker measurements which scientists used to classify the samples.

Figure 4.6: Raw Audio Waveform Visualization



4.7 Spectrogram Analysis

The spectrogram shows how the recorded speech sample produces time-based sounds throughout different frequency ranges. Parkinson-related speech disorders produce specific speech abnormalities which can be detected through changes in frequency distribution and spectral energy patterns.

Figure 4.7: Spectrogram Representation of Voice

4.8 Pitch Contour Analysis

Pitch contour analysis evaluates changes in the fundamental frequency (F0) over time. People with vocal control issues show reduced pitch variation according to their instability in producing sound. The extracted.

Figure 4.8: Fundamental Frequency (Pitch) Analysis

4.9 Jitter Analysis

Jitter indicates the frequency changes which occur during each voice cycle. The system calculates jitter values which show the degree of vocal fold irregularity in Fig. 4.9. The feature provides essential assistance for identifying diseases and determining their level of progression.

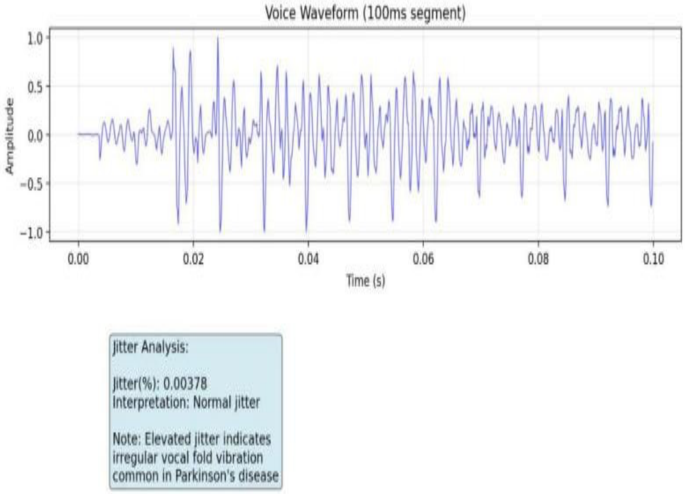


Figure 4.9 Jitter Visualization and Interpretation

4.10 Shimmer Analysis

Shimmer measures the changes which occur in a voice signal's amplitude from one cycle to the next. Parkinson's disease patients often show heightened shimmer because they lose control over their ability to modulate sound intensity. The visualization created by the system helps clinicians make their evaluations.

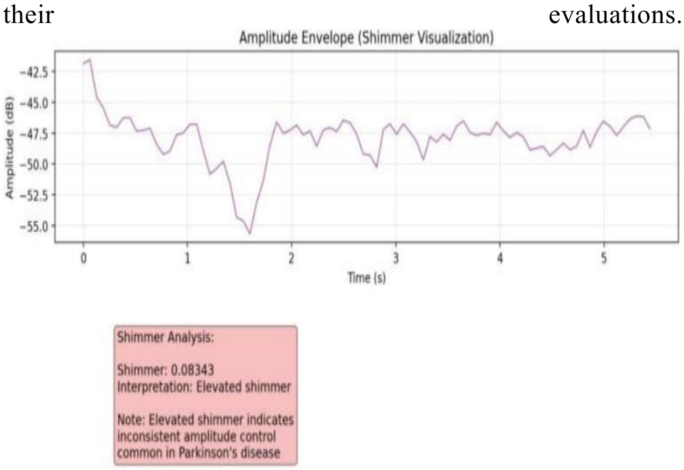


Figure 4.10 Shimmer Visualization and Interpretation

4.11 Performance Evaluation

Figure 4.11 Model Evaluation

Our team used classification accuracy as their main measurement method to test the effectiveness of the system. XGBoost achieved 78% accuracy for severity classification.

CONCLUSION

The research delivered a vocal assessment system dedicated to predicting Parkinson's disease which employs machine learning methods and acoustic biometrics to enable doctors to identify patients in the early stages of the condition and track its development. The proposed framework uses a two-stage prediction architecture. The first stage uses a Random Forest classifier to separate healthy people from Parkinson's patients by employing voice features that researchers collected from their speech patterns. The second stage employs an XGBoost classifier which assigns disease severity levels as Mild Moderate and Severe using clinically relevant acoustic biomarkers to achieve accurate multiple class prediction results. The findings indicate that the proposed method enables non-invasive Parkinson's evaluation through voice analysis which serves as a diagnostic tool. The main achievement of this research integrates voice analysis through visual representation of waveform spectrogram pitch contour jitter and shimmer attributes which enables users to comprehend prediction processes with better transparency. The Streamlit-based interface enables users to detect diseases and assess their severity through its capability to process real-time voice input display extracted features and calculate severity probabilities while producing analysis reports which enhances user experience and makes the system more accessible. The proposed system combines predictive accuracy with interpretability to function as an effective decision-making support system for Parkinson's disease detection and monitoring disease advancement. The system enables future development through its modular framework which allows for system expansion and integration into various clinical decision-making support systems.

FUTURE WORK

The developed Parkinson's disease prediction system achieves accurate classification results which also provide severity assessment and system understanding through its use of Random Forest and XGBoost combined models. The system has several strong points yet there remain multiple areas which need development. The researchers need to construct a larger and more diverse voice sample collection which will enhance their ability to create a model that works well with various population groups and different recording environments. The research team will test advanced deep learning methods which include CNNs LSTMs and transformer-based speech models to achieve better prediction results. The system will expand its ability to explain features through SHAP which provides additional explanation methods. The system's real-world value will increase through its development of continuous disease tracking capabilities which include mobile usage and wearable device connections and clinical testing. The upcoming study will examine multimodal analysis through the combination of voice and gait and handwriting and sensor data which enables complete Parkinson's assessment. The suggested framework establishes a secure base which delivers dependable healthcare decision-support systems that maintain clinical validity throughout their entire system operation.

Data availability

The dataset used in this study is publicly available at: https://www.kaggle.com/datasets/rishidamarla/parkinsons-telemonitoring-data

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