

Detection of Parkinson's disease Using Machine Learning Algorithms

Shams Ul Arifeen (Corresponding author)

Department of Computer Science, Abdul Wali Khan University, Mardan

Email: shamsjan99090@gmail.com

Naseer Ahmad

Engineering, Computing and Mathematical Sciences (ECaMS) Department, Lewis University, Romeoville Illinois

Abdullah Sadiq

Department of Computer Science, Bacha Khan University Charsadda

Atif Amin Ullah

Department of Computer Science, Abdul Wali Khan University, Mardan

Mian Farhan Shah

Department of Computer Science, Bacha Khan University Charsadda

Email: mianfarhanshah5@gmail.com

ABSTRACT

A Comparative Study of Support Vector Machine, Random Forest, and Gradient Boosting Classifier Parkinson disease (PD) is a neurodegenerative disorder that is disabling and non-motor, in which millions of people around the globe are affected. This paper constructs and analyzes the performance of the Machine Learning (ML) algorithms in PD detection using clinical data. On a dataset of 756 PD 564 patients and 192 healthy participants, we obtained a set of seven features on dataset, trained and tested Support Vector Machine (SVM) algorithm, Random Forest (RF) algorithm, and Gradient Boosting Classifier (GBC) algorithm. Findings indicate that GBC had maximum accuracy. The SVM also had a relatively poorer performance compared to GBC yet relatively good, Random Forest (RF) is also a good performer but scored a little low. Analysis of feature importance showed use of such as Pitch Period Entropy (PPE), Detrended Fluctuation Analysis (DFA), Recurrence Period Density Entropy (RPDE), Number of Pulses (numPulses), Number of Periods of Pulses (numPeriodsPulses), Local Shimmer (locShimmer) and Amplitude Perturbation Quotient 3 (apq3Shimmer) which contribute to a better detection of the Parkinson disease. The paper shows that ML algorithms are effective to identify PD and help the clinician to diagnose and plan treatment earlier, which will lead to the improvement of patient outcomes.

Keywords: Parkinson's Disease Detection, Machine Learning, Clinical Decision Support Systems, Early Diagnosis, Predictive Modeling.

Introduction

Parkinson disease (PD) is a neurodegenerative disorder of progressive origin that is linked mainly with the motor system, even though a number of non-motor symptoms can also be associated with it, such as cognitive impairment, depression, and autonomic dysfunction. It is among the most prevalent neurodegenerative disorders, where more than 10 million individuals have been infected all around the world and with the world growing old, the disease is likely to increase. The disease is commonly diagnosed in people aged above 60 and the common features of the disease include tremors, rigidity, bradykinesia (slowness of movement) and postural instability which gradually increase as time moves. Deterioration of dopamine producing neurons in the substantia nigra, which is part of the brain that regulates movement is the hallmark pathology of the Parkinson disease. This is caused by the loss of dopamine and this causes motor symptoms of the disease.

The disease can also result in cognitive impairment in the individuals such as loss of memory, attention difficulties, and executive dysfunction, which can have further impacts on the quality of life as the disease advances. Early diagnosis and treatment are implicit in the treatment of the disease, reducing the speed of its development, and enhancing the quality of life of the patient. Nevertheless, at an early age the diagnosis can still be a serious problem because the symptoms of Parkinson could be insidious and similar to other diseases including essential tremor, and some of the clinical manifestations can take quite a long time to be realized. Also, the existing diagnostic techniques are based on the subjective assessment of such items as their history, clinical examination, and medical imaging, which might be time-consuming, expensive, and subject to errors. The need to have more reliable, efficient and non-invasive early detection methods is increasing.

In that regard, voice analysis has proven to be a potential tool of identifying Parkinson disease at an earlier stage. Voice recording is able to record fine motor changes that occur at the early stages of PD including changes in the pitch of the speech, volume, and frequency. These alterations can be attributed to the damage of the laryngeal muscles that are affected by the impacts of the disease on the motor control. The voice methods are non-invasive, user-friendly, and affordable and hence suitable in large-scale screening.

This paper presents the possibility of applying machine learning algorithms to voice recordings to identify Parkinson diseases. Using machine learning, which is quite effective in identifying trends in multifaceted data, this study will be able to build a solid predictive tool that can effectively diagnose Parkinson disease at an initial phase. The paper specifically addresses three machine learning algorithms, namely, Support Vector Machine (SVM), Random Forest (RF), and Gradient Boosting Classifier (GBC), which have demonstrated potential in a host of medical applications, specifically in classification problems. The models have been selected because they can take high-dimensional data, are capable of differentiating between complex patterns and can give interpretable results, which are valuable in helping the clinical decision.

The final objective of the study is to establish an effective, scalable, and easy-to-use diagnostic tool that can be deployed to enable medical personnel to diagnose and manage Parkinson disease in its early stages, which will in turn help the patient by

providing quality care as they will be given a treatment plan that will suit him or her. This research will capture the voice analysis and machine learning together to break new grounds in the field of diagnostics that may revolutionize the approach of detection and management of Parkinson disease.

Literature Review

Voice feature analysis is a fast emerging field in medical diagnostics especially in scenarios like neurodegenerative diseases like Parkinson disease. The development of the parkinson disease may be seen in having minor voice alterations which may occur earlier than the development of the symptoms of the motor aspect. The recent improvements on machine learning have made it far more effective at identifying these subtle voice changes. Voice signal feature extraction methods, including jitter (varying frequency), shimmer (varying amplitude), and harmonic-to-noise ratio have been critical in assessing the output of the various machine learning methods. These non-invasive, objective, and vocal biomarkers are a promising alternative to conventional clinical evaluations which are usually based on subjective data and visual examination.

Machine learning (ML) models such as support vector machine (SVM), random forests (RF), and deep learning models have shown promise in enhancing the accuracy of diagnosing the Parkinson's disease using voice recordings. Not only has the recent spurt in voice-based diagnostic systems enabled the possibility of early diagnosis, but it has also led to development of systems capable of determining the severity of an illness over an extended period of time. Through paying attention to vocal characteristics, the present study will contribute to the improvement of diagnostic accuracy and once-prompted interventions.

Voice analysis is a cost effective, non-invasive and easily deployable technique of early detection of Parkinson. With the discipline still under development, there is still a high possibility of voice-assisted systems contributing to the accessibility of healthcare in the world, especially in underserved regions.

The voice feature analysis and machine learning have been integrated and turned out to be a core field of research in the diagnostics of the Parkinson disease. The application of voice biomarkers to identify Parkinson disease has been studied in many papers using both conventional and innovative machine learning techniques.

Some of the well-known studies are:

The analysis of acoustic voice can effectively diagnose Parkinson disease and this was highlighted in this study. It emphasizes a range of acoustic features, including changes in pitch which can be used to identify the patterns of speech which are unique to Parkinsonism and not to other disorders. The study highlights the fact that voice analysis may be a non-invasive diagnostic method with early predictive value that may provide clinicians with useful disease monitoring and progress. The paper goes further to explore the importance of voice alterations that are subtle at the onset of Parkinson that is not easily detected using conventional means of doing so [1].

Whale Optimization Algorithms (WOA) were proposed, a new two-step process of optimization of feature selection and classification parameters. The experiment showed that the WOA used on voice information can enhance the diagnostic quality of the Parkinsonian disease significantly. Such an approach emphasizes the

significance of high-level optimization algorithms in the optimization of diagnostic models [2].

This ground-breaking research came up with a series of nonlinear speech analysis algorithms with the sole aim of analyzing Parkinson disease. The researchers were able to measure speech characteristics like jitter, shimmer, and signal regularity and therefore they obtained a valid measure of the severity of the Parkinson disease. It was proved that these speech-based metrics were associated with severity of the diseases and can be used as a means of continuous monitoring of the conditions of the patients [3].

The review paper presents a discussion of some of the developments in voice analysis methods utilized in diagnosis of Parkinson disease. It pays attention to the old acoustic characteristics as well as the newer voice characteristics, including spectral entropy and formant frequency shifts, and their possible role in clinical practice. Anticipation of strong machine learning models by the authors to enhance the accuracy of diagnosis implies that the combination of acoustic features and data-based models can enhance sensitivity and specificity of the Parkinson disease detection. [4]. This study justifies the fact that voice analysis can be an effective diagnostic tool in the treatment of Parkinson's disease. It is also concerned with the implications of these discoveries to the use of voice analysis as a part of clinical practice to track disease progression in real-time [5].

The author employed a mixture of SHapley Additive explanations (SHAP) and a Hard Voting Ensemble method to classify voice-based Parkinson disease. The model demonstrated a very high accuracy of 83.5 and this demonstrates the strength of the ensemble learning methods to enhance the performance of the diagnostic. According to the authors, feature selection techniques can make machine learning models deal with the challenges associated with voice data, which yields more precise predictions [6].

Use deep learning methods, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), on voice recording-based detection of Parkinson's disease. Their model was found to be accurate in 81.9% which proves the possibility of the neural networks in detecting early-stage Parkinson disease. The work demonstrates that the results of deep-learning methods can enhance diagnostic performance by extracting nonlinear and more intricate relationships in voice samples [7].

To compare the conventional machine learning algorithms, which are Support Vector Machine (SVM) and Decision Trees, in the classification of the Parkinson disease. Although more complex models, such as those based on deep learning, are not able to achieve the same results as those of deep learning models, this paper demonstrated that more complex models used with well-engineered features can still exhibit good performance particularly in smaller-sized datasets. The highest accuracy of the model was 84.2; this means that the less-complex algorithms can be considered useful in clinical diagnostics [8].

The authors investigated the application of audio characteristics over the long term as predictors of the Parkinson disease. They revealed that a long-term average spectrum (LTAS) and formant frequencies may prove helpful in determining the differences between the voice patterns of Parkinson and healthy people. The paper shows the

significance of temporal and spectral elements in speech-based analysis and recommends the use of both elements as potential diagnostic modeling improvements [9].

Alevizos, V., et al. created a multi-modal method that incorporated the analysis of voice and video recordings of patients concerning motor tasks. The combination of both of them enhanced the general diagnostic performance in giving a more detailed analysis of the symptoms of the Parkinson disease. The paper highlights the possibilities of integrating various types of data, e.g., voice and motor function data, to attain the greater accuracy in diagnoses [10].

Research Methodology

There are various process steps in the methodology, including data collection, feature extraction, preprocessing, model training, and evaluation. The framework uses voice recordings of patients of the Parkinson disease and healthy individuals, derives a group of acoustic features and uses machine learning classifiers to detect Parkinson disease.

The initial stage is gathering a sample that contains voice recordings of the patients of Parkinson disease and healthy people. These recordings also contain different samples of these speech including sustained vowel phonation, which is considered to expose the minor vocal defects resulting in the Parkinson disease. The data is split into two datasets, including training and testing data. The model learning is based on the training data with the testing data being left to assess the performance of the classifiers.

The second step is to extract important features of the voice recordings. These characteristics, such as jitter, shimmer, harmonic-noise ratio (HNR), etc., are needed to document the tremors, anomalies of the voice that are specific to the Parkinson disease. Each voice sample is extracted to provide the following features:

Jitter

Jitter is the difference in the frequency between cycles. Cases of greater jitter are common in the people having Parkinson disease as the vibrations of vocal folds are shaky and unstable.

Shimmer

Shimmer is the measurement of the amplitude difference between consecutive voice cycles. It shows the instability of the oscillation of the vocal folds, more apparent in the patients of Parkinson.

RPDE (Recurrence Period Density Entropy)

RPDE is a statistic of irregularity of a time series. When applied to voice recordings, the differences in voice pattern due to the disease are represented, which is a useful characteristic in the process of detecting Parkinson.

PPE (Pitch Period Entropy)

PPE is an indicator of the change in period of pitch. Abnormal rhythm and pitch of speech can be caused by Parkinson disease, so this aspect can be used to classify the disease.

Apq3Shimmer

This type of shimmer is a measure of the changes in amplitude across various parts of the speech signal, which may be susceptible to the Parkinson disease-induced voice

changes.

Once these features are extracted, they are organized in a numeric format to be inputted in the machine learning models to be classified.

The features that are extracted are preprocessed to enhance the work of the machine learning models. This step involves scaling and normalization of the features to make the features fall within a similar range. Preprocessing is important as it aids in eliminating the bias that would be presented by features with varying numerical values. Standard Scaling applies and scales the features around the mean of the features to Standard Deviation of one.

After preprocessing the features, we then train three machine learning classifiers, which include: Support Vector machine (SVM), Random Forest (RF) and Gradient Boosting Classifier (GBC). All these classifiers are trained on the identical set of features, though with a varying learning strategy, to classify the samples of Parkinson diseases. Each of these classifiers is described in the following sections and the role of each of them in the proposed methodology.

Training Classifiers

After the preprocessing of the features, they are inputted in three machine learning classifiers to be trained. The classifiers are:

Support Vector Machine (SVM): The SVM classifier is the supervised learning model which operates on the basis of trying to find the optimal hyperplane separating the various classes (Parkinson and healthy). The non-linear kernel (Radial Basis Function or RBF) that is employed in SVM is capable of dealing with the non-linear nature of the voice data. The main task is to achieve the maximum between the classes with the minimal classification errors.

Random Forest (RF): Random Forest refers to an ensemble learning algorithm, which is used to create a number of decision trees and combine their opinions. Random Forest averages the results of many decision trees and thereby, minimizes overfitting and enhances the overall accuracy. It works well especially dealing with data that is highly varied like voice recordings.

Gradient Boosting Classifier (GBC): Gradient Boosting is an ensemble approach which produces decision trees one after the other. The tree always rectifies the mistakes of the previous tree thereby enhancing the accuracy of the model. GBC can be applied in a situation where the model must learn by the residual error in the predictions. It has proved to be much effective in the aspect of classification accuracy particularly in complex tasks like voice classification in the case of Parkinson disease.

Results and Comparative Analysis

The data employed in this research has 756 rows and 755 columns. A column of the table is a feature or a label, and a row of the table is a voice sample. The samples are both healthy people and those diagnosed with Parkinson disease hence a balanced dataset will be used in analysis.

The features applied in the present study were chosen according to their defined

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

applicability in the detection of Parkinson disease. These include:

PPE (Pitch Period Entropy): The voice signal period abnormalities are reflected and in most Parkinson patients, it is elevated because of tremors.

DFA (Detrended Fluctuation Analysis): Examines long-term associations, which gives attention to the slight alterations in voice patterns.

RPDE (Recurrence Period Density Entropy): This is a measure of predictability of voice signal paths, which is frequently impaired in patients of Parkinsonism.

NumPulses: Report abnormalities in voice pulses NumPeriodsPulses: Report abnormality in periodicity.

LocShimmer & Apq3Shimmer: The changes in voice amplitude are measured, which is vital in determining vocal instability.

The Support Vector Machine (SVM) Classifier

Support Vector Machine (SVM) classifier is a powerful algorithm that is extensively applied in binary classification problems. It works by identifying an optimal hyperplane that separates the two categories (healthy and Parkinson) in the data.

The main characteristics of SVM in this research are:

Kernel Function: There was the use of a Kernel (kernel=poly). The non-linear associations that exist among the features and the target variable can be modelled by this kernel.

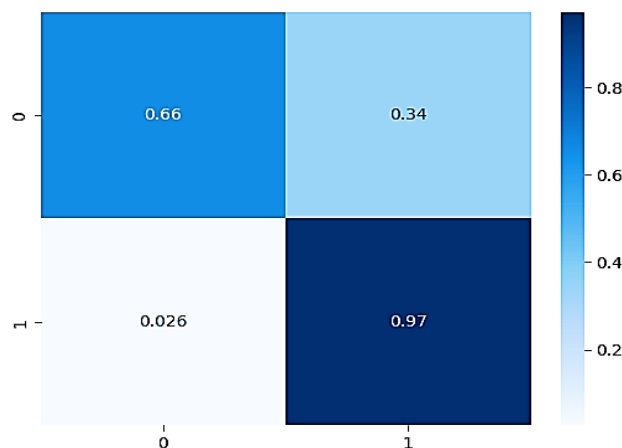
Gamma Parameter: the gamma was set at 1.0 which determines the effect of each training sample. When the gamma is greater, it means that the line dividing the decision is affected by the nearer points.

The strengths of SVM: Useful in High-Dimensional Spaces: As the dataset has many features, SVM is highly appropriate to work with them.

Resistant to Overfitting: This is particularly relevant in situations where the dimension size is higher than the sample size.

Outcome: The SVM classifier attained a precision of 89.47percent. F1 score of SVM is excellent and that is 0.93.

Confusion Matrix for SVM



Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Random Forest (RF) Classifier

Random Forest (RF) algorithm is an ensemble learning algorithm that is used to combine multiple decision trees to enhance classification. The trees in the forest are each trained on a random subset of the data thus making them robust and minimizing overfitting.

The following are the main characteristics of RF in this study.

N of Trees (nestimators): The model operates on 100 trees, which is a good compromise between the computation speed and performance.

Splitting Criterion (criterion): Gini impurity was selected and it is used to measure purity of split in tree building

Max Depth (max depth): This is set to 15 to avoid overfitting but not miss any meaningful patterns.

Feature Selection (max_features): The square root of the total features had been employed in the best splits.

Advantages of RF

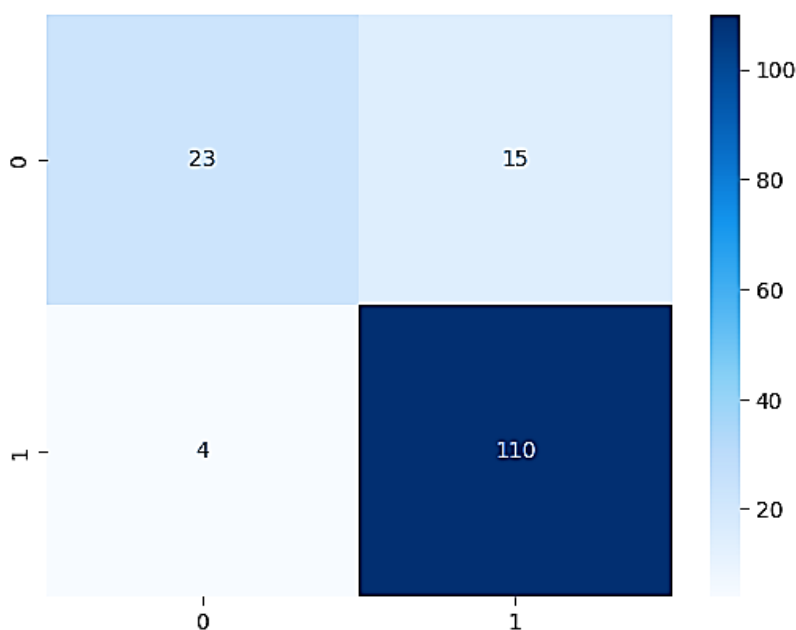
Deals with Non-Linear Data: RF is able to capture complicated data and interactions among the features.

Resistant to Noise: RF averages the prediction of several trees and this minimizes the effect of the noisy points.

Result for RF

The accuracy of the Random Forest classifier under the testing data was 87.5% therefore, successfully classifying the samples and showing that it is a robust tool to use in the complexity of voice feature data. The f1 score of RF is 0.9

Confusion matrix for RF



Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Gradient Boosting Classifier (GBC)

Gradient Boosting Classifier (GBC) is one of the powerful ensemble techniques, which constructs models one after another, with each model trying to correct the mistakes of the other model.

The important characteristics of GBC in this study include:

Number of Stages (nestimators): This will be fixed at 100, which will be adequate in reducing errors by boosting.

Loss Function (criterion): As an error measure, squared error was taken to determine the difference between the predicted and actual values.

Tree Depth (max depth): This was set at 3 to concentrate on simple yet effective splits.

Feature Selection (max_features): Logarithmic scaling was used in order to maximize the use of features between splits.

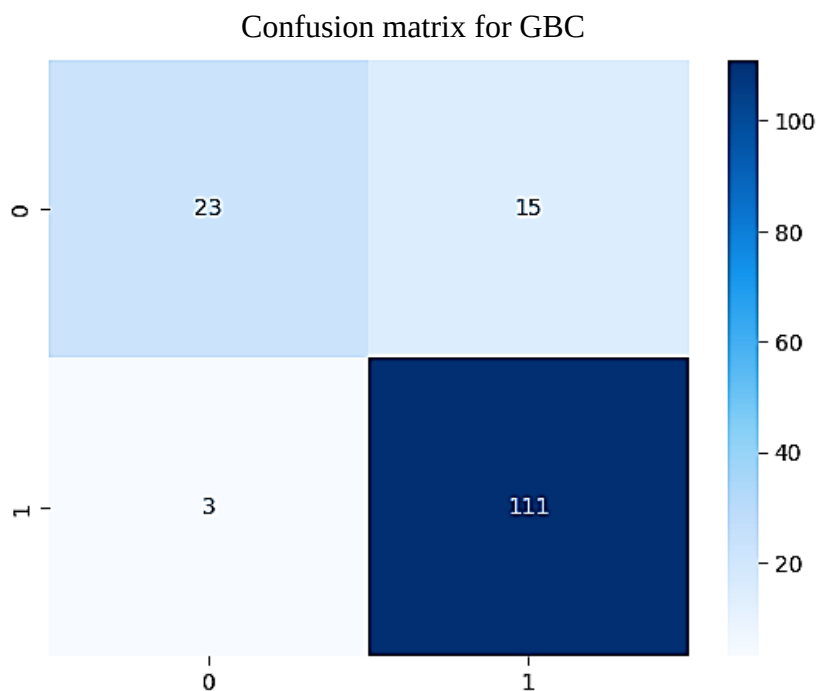
Advantages of GBC

Very Adaptive: GBC models non-linear relationships which are complex through the process of iterative model refinement.

Effective with Small Data: Performance is good, even with small data such as ours, and benefits boosting.

Result for GBC

Gradient Boosting Classifier was the most accurate with the correct classification of 91 percent of the testing data. The capability of this classifier to embrace complicated relationships in the data reflects its capability in the detection of Parkinson diseases. The f1 score of GBC is 0.91.



Comparative Analysis

The comparative analysis of the models is summarized in the following tables for different test sizes (20%, 25%, 30%, 35%, and 40%):

Test Size = 20%

Model	Test Size	Accuracy	F1 Score	Confusion Matrix
SVM	0.2	0.89	0.82	0.57
RF	0.2	0.88	0.77	0.23
GBC	0.2	0.91	0.81	0.22

Test Size = 25%

Model	Test Size	Accuracy	F1 Score	Confusion Matrix
SVM	0.25	0.83	0.92	0.52
RF	0.25	0.84	0.89	0.25
GBC	0.25	0.88	0.91	0.31

Test Size = 30%

Model	Test Size	Accuracy	F1 Score	Confusion Matrix
SVM	0.3	0.83	0.73	0.48
RF	0.3	0.85	0.91	0.34
GBC	0.3	0.86	0.91	0.34

Test Size = 35%

Model	Test Size	Accuracy	F1 Score	Confusion Matrix
SVM	0.35	0.85	0.72	0.53
RF	0.35	0.84	0.92	0.31
GBC	0.35	0.87	0.91	0.38

Test Size = 40%

Model	Test Size	Accuracy	F1 Score	Confusion Matrix
SVM	0.4	0.83	0.71	0.46
RF	0.4	0.86	0.84	0.34
GBC	0.4	0.85	0.89	0.39

Performance Comparison

Gradient Boosting Classifier (GBC): Gradient Boosting Classifier provided the best accuracy of 0.91% since it is a series of small, focused models that are built one on top of the other, each of which rectifies the errors of the other. The approach continuously enhances the accuracy by focusing on the areas in which the model

performs poorly. Because GBC is a combination of most of these small models, it is capable of detecting finer patterns in complicated data, which makes it quite efficient in your Parkinson's disease detection problem.

Support Vector Machine (SVM): Support Vector Machine was also doing relatively low compared to GBC but quite well. The principle of SVM is to locate an optimal boundary between various classes (healthy and Parkinson) in the data. Since it aims at maximizing this boundary (or margin) it works well with datasets where classes are clearly defined and can be separated such as voice features in Parkinson detection.

Random Forest (RF): The Random Forest is also a powerful performer although it got slightly low scores. It involves the use of several decision trees that are constructed by a random sample of the data to make predictions. It is able to make good decisions by combining many trees, but in some cases it simplifies patterns in the data too much in comparison to GBC hence why it did not work as well here.

The comparative analysis reveals that the Gradient Boosting Classifier had the best accuracy with different test sizes which means that it is effective in the detection of Parkinson disease using voice features. The SVM model was also highly performing especially on F1 score. Random Forest model demonstrated a little less accuracy but it yet remains competitive.

In general, the experiment findings suggest that machine learning models can be successfully used to differentiate between normal and patients with Parkinson disease, which is a part of the continuous research on the topic of early detection and treatment of this neurodegenerative disease.

Conclusion

The thesis was devoted to investigating the possibilities involving machine learning methods in the detection of Parkinson disease with a particular focus on voice features analysis as a non-invasive method of diagnosis. The experiment utilized three popular machine learning methods, Support Vector Machine (SVM), Random Forest (RF), and Gradient Boosting Classifier (GBC) to detect voice data as either healthy or having the Parkinson Disease. The performance of each algorithm was evaluated according to how it can handle certain voice characteristics and how well it can recognize Parkinson disease.

The results had demonstrated the usefulness of machine learning in revealing the trends in voice information that would not have been readily identifiable using the conventional diagnostic tools. One of the tested models, Gradient Boosting Classifier, was the most accurate it scored 91 per cent accuracy. This model was shown to have remarkable functions of handling complicated data, effectively working out non-linear associations, as well as determining complex patterns in voice features.

The Support Vector Machine was also not inferior with its accuracy standing at 89.47. It is a powerful tool that can be used in binary classification because it builds strong decision boundaries. With an accuracy of 87.5, random forest has demonstrated its benefit in identifying feature importance which has important insights to determine which voice parameters play the most significant role in identifying the presence of the Parkinson disease.

These findings enable confirming that machine learning provides an efficient system to detect Parkinson at an early stage since it provides an affordable and non-invasive alternative to conventional methods of diagnosis. This approach is based on the voice features; it makes the process of diagnosis more simplified and reaches wider accessibility as well as real-time analysis especially when combined with telemedicine platforms.

Contribution to the Field

The thesis has very important contributions on the disjunction of artificial intelligence and healthcare. It shows how voice-based diagnostics will be used as a feasible, scalable option in early neurodegenerative disease detection (such as Parkinson). The most essential works were:

Verification of Voice Features: The research verifies the use of the voice features by concentrating on the attributes of the voice including Pitch Period Entropy (PPE), Detrended Fluctuation Analysis (DFA), and Amplitude Perturbation Quotient (APQ3).

Comparison of Algorithms: Comparative analysis of SVM, RF, and GBC gives insights into the strengths and weaknesses of each algorithm which provides a roadmap in terms of which models to use in a similar application.

Practical Implementation: It will be developed to have an intuitive user interface that will enable the machine learning models to be readily adopted by clinicians and non-technical users. This is a big leap towards the real-world adoption.

Future Work

To extend the existing results, the research of the future may be extended in the following key directions:

Greater and More Varied Data: The voice samples gathered should represent a greater number of people and a wider demographic (different ages, genders, and disease progression).

Deep Learning Techniques: The further research into the use of cutting-edge technology, including Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), might help the model to better classify complex patterns of voice. These architectures are especially effective at time series data such as voice signals.

Hybrid and Ensemble Models: This can be achieved by taking several algorithms or a mixture of traditional machine learning and deep learning to complement each other and improve the accuracy of the predictions.

Integration with Wearable Devices: It could be possible to incorporate voice analysis into wearable devices or mobile applications and use it to monitor people at risk and intervene early.

Clinical Trials: It would be worth to implement the system in a clinical setting to see its effectiveness and suggest improvements.

Comparative Studies: To make the voice-based diagnostics more expanded and useful to more scenarios, it would be interesting to extend the analysis to other neurodegenerative diseases, including Alzheimer or ALS.

References

- [1]. Kowalska-Taczanowska, R., Friedman, A., & Kozirowski, D. (2020). Parkinson's disease or atypical parkinsonism? The importance of acoustic voice analysis in differential diagnosis of speech disorders. *Brain and behavior*, 10(8), e01700.
- [2]. Abdulkareem, K. H., Mohammed, M. A., Alyasseri, Z. A. A., Khutar, D. Z., & Alomari, O. A. (2025). WOA-COVID-19: Whale Optimization Algorithm for Selection of Multi-Examination Features based on COVID-19 Infections. *Mesopotamian Journal of Computer Science*, 2025, 172-185.
- [3]. Tsanas, A., Little, M. A., McSharry, P. E., & Ramig, L. O., "Accurate telemonitoring of Parkinson's disease progression by non-invasive speech tests," *IEEE Transactions on Biomedical Engineering*, vol. 57, no. 4, pp. 884-893, Apr. 2010.
- [4]. Quamar, D., Ambeth Kumar, V. D., Rizwan, M., Bagdasar, O., & Kadar, M. (2025). Voice-Based Early Diagnosis of Parkinson's Disease Using Spectrogram Features and AI Models. *Bioengineering*, 12(10), 1052.
- [5]. Chenausky, K., MacAuslan, J., & Goldhor, R. (2011). Acoustic analysis of PD speech. *Parkinson's Disease*, 2011(1), 435232.
- [6]. Ghaheri, P., Nasiri, H., Shateri, A., & Homafar, A. (2024). Diagnosis of Parkinson's disease based on voice signals using SHAP and hard voting ensemble method. *Computer methods in biomechanics and biomedical engineering*, 27(13), 1858-1874.
- [7]. Wodzinski, M., Skalski, A., Hemmerling, D., Orozco-Aroyave, J. R., & Nöth, E. (2019, July). Deep learning approach to Parkinson's disease detection using voice recordings and convolutional neural network dedicated to image classification. In *2019 41st annual international conference of the IEEE engineering in medicine and biology society (EMBC)* (pp. 717-720). IEEE.
- [8]. Islam, M. A., Majumder, M. Z. H., Hussein, M. A., Hossain, K. M., & Miah, M. S. (2024). A review of machine learning and deep learning algorithms for Parkinson's disease detection using handwriting and voice datasets. *Heliyon*, 10(3).
- [9]. Rashidi, M., Arima, S., Stetco, A. C., Coppola, C., Musarò, D., Greco, M., ... & Maffia, M. (2025). Prediction of Parkinson Disease Using Long-Term, Short-Term Acoustic Features Based on Machine Learning. *Brain Sciences*, 15(7), 739.
- [10]. Alevizos, V., & Papakostas, G. A. (2025). Ai-enabled multimodal analysis enhances detection of motor neuron disease pathways. *Iran Journal of Computer Science*, 1-21.