Applying Deep Learning for the Examination of Voice Disorders in the Identification of Parkinson's Disease

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***Abstract*—Parkinson's disease is a degenerative neurological condition marked by difficulties with coordination, tremors, and rigidity in the muscles. Positively, speech recordings show potential as a precocious biomarker for Parkinson's disease, able to identify minute alterations prior to the manifestation of other symptoms. The main objective of this research is to create a machine learning model that can analyse speech recordings and reliably determine whether Parkinson's disease is present. Key questions that the model aims to answer include how well it detects early signs of Parkinson's disease, how well it distinguishes between voice samples from healthy individuals and those from early stages of Parkinson's disease, and whether or not accuracy will vary depending on variables like the length or calibre of voice recordings. The primary goal is to use deep learning methods to analyse voice data to detect Parkinson's disease early on.**

***Index Terms*—Parkinson's disease, Deep Learning, Support vector machines, K-Nearest Neighbour, Standard Scalar, Extreme Gradient Boosting.**

I. Introduction

A degenerative neurological condition that impairs motor skills and presents with a variety of symptoms is Parkinson's disease. The symptoms include including tremors, bradykinesia (slowed movement), muscle rigidity, and postural instability. Named after Dr. James Parkinson, who documented its symptoms in 1817, computational techniques have emerged as pivotal tools for diagnosing and managing this complex disorder. Harnessing computer science, data analysis, and machine learning, these techniques contribute to early detection and continuous monitoring. Machine learning and deep learning methods, including Artificial Neural Networks, Support Vector Machines, Principal Component Analysis, Ensemble Methods, Transfer Learning, Autoencoders, Random Forest, Long-Short-Term Memory, Convolutional and Recurrent Neural Networks, XG Boost, have gained prominence in Parkinson's disease diagnosis.

Parkinson's disease is characterized by a progressive nature, and over 90% of patients experience speech disorders as the condition advances. Dysphonia, a symptom associated with vocal impairment, is prevalent in these patients. Clinicians utilize various indicators related to dysphonia as crucial and highly dependable tools for assessing voice-related issues and monitoring them at different stages of Parkinson's disease.

II. Related Works

The problem is to address the challenges of generalizability, robustness, and dataset variability in machine learning models for Parkinson's disease diagnosis through voice analysis, despite promising results, to enable their practical application in real-world clinical settings. Automated machine learning models using noninvasive voice biomarkers show promising results for disease diagnosis and prediction, demonstrating high accuracy with potential for expanded feature sets and modalities in future clinical applications. [1]

The challenge is to address the variability in vocal changes among Parkinson's disease patients, along with the influence of comorbid conditions and external factors, in order to enhance the reliability and accuracy of machine learning models utilizing voice analysis as a non-invasive biomarker for early parkinson's disease detection. In conclusion, utilizing voice analysis for Parkinson's disease detection holds significant clinical implications, offering a non-invasive and cost-effective approach for timely intervention, personalized treatment plans, and disease monitoring, although further research is needed to address challenges and enhance overall diagnostic accuracy. [2]

Additional research is essential to confirm the efficacy of deep learning models, particularly those involving long short-term memory (LSTM) networks, in voice-based Parkinson's disease detection on larger and more diverse datasets, despite their notable success in achieving higher accuracy and identifying early stages of the disease compared to traditional machine learning models.The study highlights the effectiveness of deep learning models, particularly stacked LSTM networks, in detecting Parkinson's disease through voice analysis, showcasing superior accuracy and early-stage identification potential, paving the way for promising applications in cost-effective and non-invasive diagnostic tools pending further validation on larger and diverse datasets. [3]

Ali suggests a novel two-dimensional data selection method that concurrently chooses both samples and features utilizing the chi-square statistical model. The effectiveness of this approach was assessed on a dataset comprising voice recordings from individuals with Parkinson's disease and healthy controls, achieving a remarkable accuracy of 94.2% on the held-out test set. This surpasses the performance of conventional machine learning models designed for the same task. In conclusion, Ali's paper highlights the potential of simultaneous sample and feature selection for voice-based PD detection, presenting accurate results on a tested dataset.Validation requires additional investigation with more extensive and diverse datasets, the study's findings suggest that this approach could contribute to more reliable and precise voice-based PD detection technologies in the future. [4]

In their publication, Wu Wang and colleagues introduce a deep learning model specifically crafted for the early identification of Parkinson's disease. The model undergoes training using a dataset that incorporates premotor characteristics, encompassing dopaminergic imaging markers, olfactory loss, cerebrospinal fluid data, and Rapid Eye Movement (REM) sleep behavior. Impressively, the model demonstrates an accuracy of 96.45% in distinguishing individuals in the early stages of Parkinson's disease from healthy counterparts. The authors highlight the necessity for further research to validate the model using more extensive and diverse datasets, aiming to refine models suitable for clinical application. This marks a promising step toward the advancement of deep learning-based tools for early PD detection. [5]

The challenge is the early detection of Parkinson's disease, given the subtle and nonspecific nature of initial symptoms, with speech abnormalities serving as potential early indicators; the study addresses this by proposing a novel bidirectional LSTM-based deep learning approach, highlighting promising results but emphasizing the need for further validation on larger datasets and comparative analyses with other state-of-the-art models.Ren's research introduces an innovative and encouraging method employing bidirectional LSTM models for the non-invasive and efficient early identification of Parkinson's disease through speech signals. The study attains a significant accuracy of 93.2%, emphasizing the need for additional research to validate and evaluate practical applicability. [6]

Dopamine transporter imaging (DAT imaging) is a form of nuclear imaging utilized to visualize the dopamine transporter system in the brain, responsible for reabsorbing the neurotransmitter dopamine crucial for movement control.Choi developed a deep learning-based system trained on a dataset of DAT images from PD patients and healthy controls. The system demonstrated an impressive 93.2% accuracy in PD diagnosis, surpassing radiologists relying on visual inspection alone. Notably, it successfully identified early-stage PD, a challenging aspect for traditional diagnostic methods. While promising, the study's limitations include a relatively small dataset, necessitating further validation on larger datasets, and the absence of comparison with other PD diagnostic methods. Despite these limitations, Choi's study suggests that deep learning holds the potential to create accurate and reliable systems for interpreting DAT images, thereby enhancing PD diagnosis, particularly in its early stages. [7]

In the methodology, researchers collected a dataset of handwritten samples from healthy individuals and Parkinson's disease (PD) patients using a smart pen to digitize the samples and capture features like pen pressure, acceleration, and velocity. The CNN was trained through supervised learning on the dataset comprising samples from both healthy subjects and those with PD. Evaluating the proposed method on a test set of handwritten samples from 100 healthy individuals and 100 PD patients yielded an impressive accuracy of 89.2%, outperforming traditional machine learning methods that relied on static handwritten features like letter size, shape, and spacing. However, limitations include a relatively small dataset and the method not being assessed on patients in the early stages of PD, prompting further exploration on larger datasets and the consideration of early-stage PD diagnosis. [8]

The paper suggests a system based on deep learning that employs vocal features for the classification of Parkinson's disease, employing a convolutional neural network (CNN), particularly suitable for audio classification tasks. Trained and evaluated on a dataset of vocal recordings from PD patients and healthy controls, the system achieved an impressive accuracy of 95% on the test set, surpassing previous systems reliant on handcrafted features. The study underscores the promise of deep learning in PD classification and suggests future efforts could concentrate on enhancing system accuracy and robustness to data noise. [9]

ML algorithms can be trained to identify subtle variations in voice signals associated with Parkinson's disease, potentially leading to the creation of affordable, non-invasive diagnostic tools. The authors developed a system using signal processing features and ML techniques to classify speech recordings from PD patients and healthy controls, achieving a 95% accuracy in distinguishing between the two groups and differentiating between various disease progression degrees. While the findings are encouraging, Validation requires additional research involving larger and more varied populations, along with evaluations in clinical settings to determine real-world practicality. If validated, the ML-based diagnostic tools could significantly impact PD diagnosis and management, offering non-invasive, cost-effective options for early detection and treatment in primary care settings, thereby improving patients' quality of life. The study by Frid et al. marks a promising step forward, emphasizing the need for continued research and validation in broader contexts. [10]

The paper addresses the limitations of traditional Parkinson's disease (PD) detection methods from speech signals, which heavily rely on hand-engineered features, demanding expert knowledge and being time-consuming.The authors suggest employing a comprehensive deep learning strategy for Parkinson's disease detection directly from unprocessed speech signals. This approach utilizes a time-distributed two-dimensional convolutional neural network (2D-CNN) to extract dynamic features and a one-dimensional CNN (1D-CNN) to capture relationships among these features. The performance of their model, assessed on a publicly available dataset of speech signals, attains an impressive accuracy of 91.4%, surpassing conventional methods. However, limitations include its evaluation on a single dataset, necessitating further testing for generalizability, and its complexity, demanding substantial training data. [11]

ML algorithms can analyze large datasets of medical information to identify patterns associated with PD, making it a valuable tool for early detection. In a study by Govindu and Palwe, audio recordings from thirty PD patients and thirty healthy volunteers were utilized alongside ML to identify PD. Extracting features such as jitter, shimmer, and dysphonia, the researchers trained four ML models—Support Vector Machine (SVM), Random Forest, K-NearestNeighbors, and Logistic Regression. The Random Forest model proved to be the most successful, attaining an accuracy of 91.83% and a sensitivity of 95%. Although the other models exhibited commendable performance, the study's constraints, such as a limited sample size and dependence exclusively on audio recordings for diagnosis, emphasize the necessity for additional research involving more extensive and diverse datasets. [12]

Convolutional Neural Networks (CNNs) were employed to train models for classifying patients and healthy subjects based on these feature vectors. The robustness of this approach was assessed across three languages—Spanish, German, and Czech—by training CNN models on speech signals in each language and evaluating their performance on signals from the other two languages. Impressively, the proposed multimodal approach achieved a 96.8% accuracy in classifying patients and healthy subjects, demonstrating resilience to linguistic variations with accuracies of 94.7%, 93.9%, and 92.2% for Spanish, German, and Czech, respectively. In conclusion, the proposed multimodal assessment utilizing deep learning presents a highly accurate and language-robust approach for diagnosing and monitoring Parkinson's disease, with potential applications across various clinical settings. [13]

Grover introduced a voice-based deep neural network (DNN) model for predicting Parkinson's disease severity. The DNN model demonstrated an impressive 99.15% accuracy in predicting PD severity, with precision and recall for severe PD at 98.93% and 99.23%, and an F1 score of 99.08%. The study suggests that deep learning (DL) can effectively predict PD severity using voice data, presenting a valuable tool for clinicians to identify at-risk patients and monitor disease progression. Limitations include the relatively small dataset and the focus solely on voice data, raising possibilities for performance improvement with larger datasets and extra data sources, including clinical and imaging data. [14]

The incorporation of multi-modal features, derived from diverse data sources such as wearable sensors, clinical records, and neuroimaging data, is crucial for enhancing the accuracy of PD detection. Results from experiments conducted on a dataset comprising 100 individuals with PD and 100 healthy controls exhibit notable accuracy. The feature-level framework attains a 95.5% accuracy rate, while the modal-level framework achieves a 94.5% accuracy rate, surpassing the performance of conventional machine learning approaches. The strengths of this approach include the use of a variety of multi-modal features, contributing to improved diagnostic accuracy, and the proposal of two deep learning frameworks that surpass traditional machine learning methods, as validated on a dataset of PD patients. [15]

III. Materials and Methods

A. System Architecture

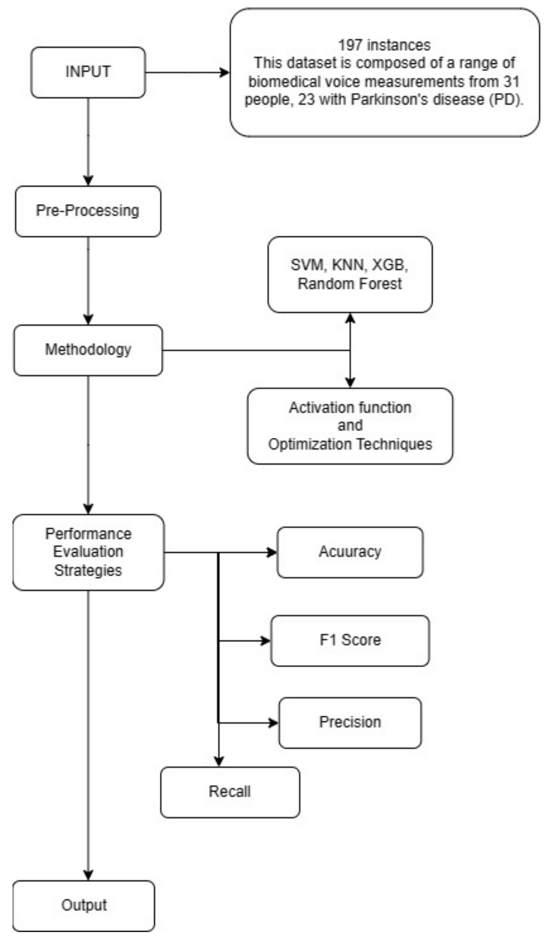

Fig. 1. Complete system architecture

B. Dataset Details

Parkinson Data and Voice Disorder: Parkinson's disease can be identified in an individual using the voice disorder dataset. While the analysis of complex voice disorders is limited by the limitations of current tools, research and technological advancements have made it possible to develop Advancements in research and technology have facilitated the creation of novel algorithms capable of identifying distinct acoustic markers linked to Parkinson's disease in voice recordings. As a result, studying voice abnormalities can yield important insights into the diagnosis and treatment of Parkinson's disease.

The dataset includes a variety of biological voice measurements that were gathered from 31 persons, 23 of whom have been diagnosed with Parkinson's disease (PD). The 195 voice recordings that these people (whose names are in the "name" column) recorded are represented by each row in the table, with each column denoting a distinct voice metric. Based on the "status" column, where 0 denotes a healthy state and 1 denotes Parkinson's disease, the main goal of the data is to distinguish between those who are healthy and those who have PD. [16]

Matrix column attributes:

- name - ASCII representation of subject name and recording number.
- MDVP:Fhi(Hz), Flo(Hz), Fo(Hz) - Peak, Lowest, and Mean vocal fundamental frequency
- The following are some of the important features from the dataset that are useful for the classification:
  - MDVP:Jitter
  - MDVP:RAP
  - MDVP:Shimmer
  - MDVP:APQ
  - NHR
  - HNR

C. Proposed Approach

Support Vector Machines (SVM) is an abbreviation for Support Vector Machines, a category of supervised machine learning algorithms. This method identifies a hyperplane or a set of hyperplanes in an n-dimensional space to effectively separate various classes within a dataset. The goal is to maximize the margin between the nearest points of different classes, commonly known as support vectors. SVM is particularly valuable for high-dimensional datasets, where other algorithms may struggle to define a clear class boundary.

XGB: XGBoost or Extreme Gradient Boosting, is a powerful and efficient algorithm designed for regression and classification tasks. It is an approach to ensemble learning that constructs a sequence of less powerful predictive models, often decision trees, and merges their outputs to form a more robust and precise model. XGBoost employs a gradient boosting framework, optimizing the overall model by sequentially adding trees that correct errors made by previous ones. Notable features include regularization techniques to prevent overfitting, parallel computing for faster training, and the ability to handle missing data. XGBoost has become widely popular in various real world applications and data science competitions due to its speed, scalability, and ability to deliver high predictive performance.

KNN: K-Nearest Neighbors is a straightforward and instinctive algorithm utilized for both classification and regression tasks. Its functioning involves identifying the k closest data points in the feature space concerning a given input, utilizing a specified distance metric. In classification, the predominant class among these neighboring points determines the label for the input, whereas in regression, the algorithm predicts a continuous value by calculating the average or weighted average of the target values from k neighboring points. KNN's key attributes include its adaptability and simplicity of implementation.

Random Forest: It is a flexible ensemble learning technique used in machine learning for both classification and regression. During the training phase, the method entails creating a large number of decision trees and then calculating the mean prediction (for regression) or mode (for classification) among these individual trees. Acknowledged for its adaptability and wide range of applications, Random Forest is appreciated for its high precision, robustness, and ability to handle many kinds of data and structures. It proves effective for various tasks, such as classification, regression, and feature selection.

IV. Result and Discussions

The model's performance will be evaluated using:

1. Accuracy - It assesses the model's correctness by measuring the ratio of correctly classified instances to the total instances.

2. F1-Score - Considering both false positives and false negatives, offers a balanced metric of precision and recall, particularly valuable in scenarios with imbalanced class distribution.

3. ROC Curve and AUC - It depict the trade-off between sensitivity and specificity, with AUC serving as a quantification of the model's capacity to distinguish between classes.

4. Confusion Matrix - It is a tabular representation detailing the model's performance, presenting true positives, true negatives, false positives, and false negatives to offer insights into classification errors.

A. Experimental Analysis

- In Fig. 2, the confusion matrix for the SVM displays a True Positive value of 27, signifying that 27 individuals in the dataset are correctly identified as having Parkinson's disease.

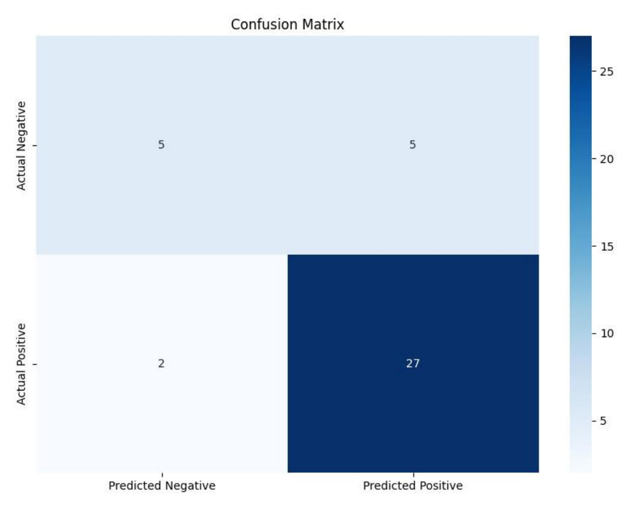

Fig. 2. SVM confusion matrix

- In Fig. 3, the confusion matrix for the KNN displays a True Positive value of 28, signifying that 28 individuals in the dataset are correctly identified as having Parkinson's disease.

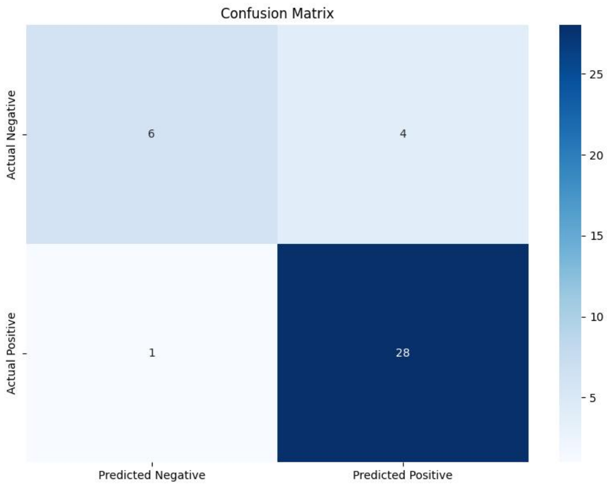

Fig. 3. KNN confusion matrix

- In Fig. 4, the confusion matrix for the Random Forest Classifier displays a True Positive value of 29, signifying that 29 individuals in the dataset are correctly identified as having Parkinson's disease.

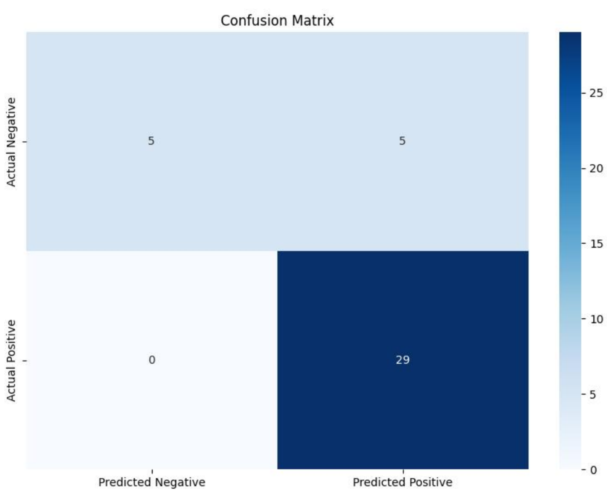

Fig. 4. Random Forest Classifier confusion matrix

- In Fig. 5, the confusion matrix for the XGB displays a True Positive value of 29, signifying that 29 individuals in the dataset are correctly identified as having Parkinson's disease.

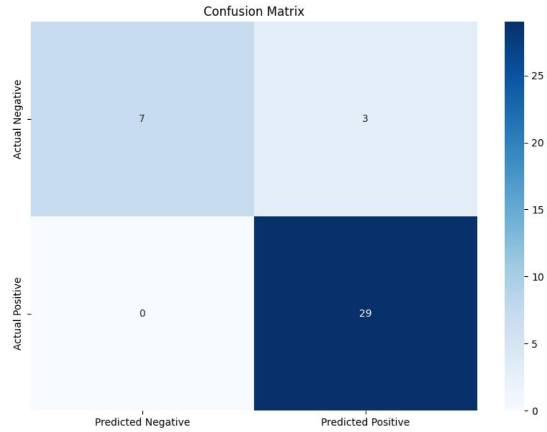

Fig. 5. XGB confusion matrix

- Fig. 6, It depicts a comparison of the accuracies of the classifiers employed (SVM, KNN, Random Forest, XGb), highlighting that XGB achieves the highest accuracy among them.

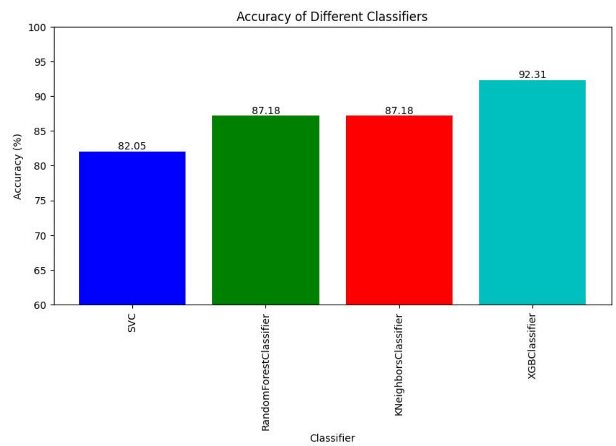

Fig. 6. Comparasion of accuracy between all classifiers used

B. Performance Evaluation

Table I Illustrates a comparison of various classifiers (SVM, KNN, Random Forest, XGB) utilized in the model, assessing them based on Accuracy, Precision, Recall, and F1 score.

TABLE I
COMPARISON OF VARIOUS CLASSIFIERS

Classifier	Accuracy	Precision	Recall	F1 Score
SVC	0.8205	0.8437	0.9310	0.88524
RandomForest	0.8717	0.8529	1.0	0.9206
KNNeighbors	0.8717	0.875	0.9655	0.9180
XGB	0.9230	0.9062	1.0	0.9508

Table II Displays a comparison between our research and a few other published papers.

TABLE II
OUR WORK IN CONTEXT OF RELATED STUDIES

Papers	Accuracy
Nishat et al. [17]	0.9163
Kumar et al. [18]	0.8983
Hoq et al. [19]	0.881
D. PAH et al. [20]	0.778
Our Paper	0.9230

C. Discussion

In this proposed approach, we employed various classifiers, such as K-NearestNeighbors (KNN), Random Forest, Support Vector Machine (SVM), and XGBoost, to obtain model predictions. Our observations revealed that SVM exhibited the lowest accuracy, while both KNN and Random Forest achieved similar accuracy rates. Interestingly, XGBoost outperformed the other models, attaining the highest accuracy of 92.30%. Nevertheless, it is crucial to acknowledge that this model is not without imperfections., as it falls short of 100% accuracy. Additionally, the limited availability of voice datasets obtained from the web posed a potential drawback, impacting the comprehensiveness of the model's training and testing data.

V. CONCLUSION

For medical practitioners, this deep learning model is a priceless non-invasive, fast, and reasonably priced tool for early Parkinson's disease (PD) detection. It makes it possible for prompt interventions, which may slow the disease's progression and enhance the life quality of patients.The development of dependable and precise diagnostic tools has been facilitated through the utilization of machine learning methods, including feature extraction techniques and deep learning models. These instruments leverage diverse vocal traits and features to distinguish individuals with Parkinson's disease from those without the condition. Notably, speech patterns and voice recordings are important data sources that provide economical and non-intrusive evaluation methods. The principal findings of this paper suggest that employing various classifiers yields differing accuracies based on the model training approach. We utilized XGBoost, Support Vector Machine, k-Nearest Neighbors and Random Forest. Our observations indicate that, in our case, XGBoost demonstrated the highest accuracy, although this outcome may vary for other cases.

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