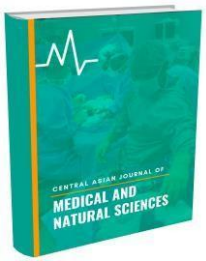

CENTRAL ASIAN JOURNAL OF MEDICAL AND NATURAL SCIENCES
https://cajmns.centralasianstudies.org/index.php/CAJMNS
Volume: 06 Issue: 01 | January 2025 ISSN: 2660-4159

.

Article

A Multi-Modal Approach for Early and Accurate Diagnosis of Parkinson's Disease Using Advanced Diagnostic Techniques

Anjugam Subramani[1*], C. Elayaraja[2], B. Vaidianathan[3], M. Pandi Maharajan[4]

1. Department of Computer Science Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
2,3,4. Department of Electronics and Communication Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.

* Correspondence: anjugam@dhaanishcollege.in

Abstract: Parkinson's disease (PD) is a prevalent neurological disorder characterized by motor symptoms such as tremors, bradykinesia, and stiffness, necessitating accurate and early diagnosis for effective management. Despite advancements, existing diagnostic methods often lack precision and reliability. This study addresses the gap by proposing a novel multimodal integration approach utilizing speech and handwriting data, coupled with machine learning techniques, to enhance diagnostic accuracy. The methodology involves preprocessing and feature extraction from voice and handwriting datasets, followed by the application of various machine learning algorithms for classification and regression tasks. Late fusion techniques, such as weighted averaging, are employed to combine results, improving overall diagnostic performance. Preliminary findings demonstrate the potential of this approach in providing a reliable tool for early detection of PD, with significant implications for clinical practice and patient care.

Keywords: Parkinson's disease (PD), Motor symptoms, Multimodal fusion, Machine learning techniques, Diagnostic, Neurodegenerative disorder, Micrographia

Citation: Anjugam Subramani, C. Elayaraja, B. Vaidianathan, M. Pandi Maharajan. A Multi-Modal Approach for Early and Accurate Diagnosis of Parkinson's Disease Using Advanced Diagnostic Techniques. Central Asian Journal of Medical and Natural Science 2025, 6(1), 192-207.

Received: 13th Oct 2024
Revised: 18th Nov 2024
Accepted: 24th Dec 2024
Published: 29th Jan 2025

1. Introduction

Tremors, bradykinesia, rigidity, and postural instability are some of the motor deficits that are associated with Parkinson's disease (PD), which is a neurodegenerative condition. A timely diagnosis is essential for the successful management and treatment of Parkinson's disease (PD). The traditional techniques of diagnosis are based on clinical evaluations and subjective observations, which may lack sensitivity and specificity, which can result in an incorrect diagnosis or a delay in treatment [21-24]. In the past few years, there has been a growing interest in the utilization of machine learning and multimodal data fusion approaches for the purpose of developing tools for the identification of Parkinson's disease that are more accurate and objective.

One strategy that shows promise is the combination of speech and handwriting analysis, which has the ability to detect subtle motor and vocal anomalies that are consistent with Parkinson's disease (PD) [25-31]. The ability to write by hand and speak are both examples of sophisticated motor skills that require detailed coordination of a variety of motor and cognitive processes. These tasks frequently display distinctive anomalies in people with Parkinson's disease (PD), such as micrographia (a reduction in the size of letters), dysfluencies (such as stuttering), and changes in voice quality (such as

hypophonia—for example). It is possible for machine learning algorithms to extract useful biomarkers for the diagnosis of Parkinson's disease by examining these patterns [32].

The proposed paper aims to develop a comprehensive screening tool that combines handwriting and speech analysis for PD detection. The system will leverage a multimodal approach, integrating data from both handwriting samples and speech recordings to improve diagnostic accuracy [33-35]. Through advanced signal processing and machine learning techniques, the system will extract relevant features from the input data and classify individuals as either PD patients or healthy controls. The data collection process will involve recruiting participants from both PD patient populations and age-matched healthy controls. Participants will be asked to perform various handwriting tasks, such as copying text, writing sentences, or drawing specific shapes [36-41].

At the same time, their speech will be captured while they are performing standardized tasks, such as reading aloud or speaking spontaneously under pressure. In order to guarantee the accuracy and consistency of the data collection process, these data will be gathered through the use of digital devices such as tablets and smartphones. Immediately following the collection of the data, it will be subjected to preprocessing in order to eliminate noise, normalize signals, and extract characteristics that are pertinent [42-49]. Handwriting signals will be processed in order to extract parameters such as the duration of each stroke, the pressure exerted by the pen, and the velocity of each stroke. Speech signals, on the other hand, will be evaluated for characteristics such as pitch, intensity, and formant frequencies. Additionally, in order to construct a comprehensive feature set for classification, text-based features that have been retrieved from handwriting samples, such as letter size and spacing, will be merged with auditory data that have been extracted from speech recordings [50-55].

The classification process will involve training machine learning models on labeled data to distinguish between PD patients and healthy controls. Various algorithms, such as support vector machines (SVM), random forests, and neural networks, will be evaluated to identify the most effective model for PD detection. The models will be trained using a combination of handwriting and speech features, with feature selection and dimensionality reduction techniques employed to optimize model performance [56-61]. The performance of the developed system will be evaluated using cross-validation techniques and metrics such as accuracy, sensitivity, specificity, and area under the receiver operating characteristic curve (AUC-ROC). The system will be tested on independent datasets to assess its generalization ability and robustness across different populations and data acquisition settings. Additionally, qualitative feedback from clinicians and end-users will be collected to evaluate the system's usability and clinical utility [62-67].

By utilizing machine learning algorithms to analyze handwriting and voice data, the major purpose of this study is to create and deploy a robust screening tool for the early diagnosis of Parkinson's disease (PD). This will be accomplished by utilizing the methodology described in this research. The primary objective is to improve the accuracy of diagnostics and to make it easier for persons who are at risk of developing Parkinson's disease to receive timely intervention [68-73]. One of the primary goals is to collect data of a high quality from people who have been diagnosed with Parkinson's disease as well as healthy controls who are the same age. As part of this process, standardized handwriting assignments and speech recording methods will need to be developed in order to guarantee consistency and dependability in the data collecting process.

During the data collecting process, digital devices such as tablets and smartphones will be deployed to assist the recording and storing of handwriting and speech samples in a simple and convenient manner. Following the completion of the data collection procedure, the following step is to preprocess the data in order to eliminate any noise or artifacts that might have an impact on the analysis. This part of the preprocessing process

will involve the utilization of several techniques, including signal normalization, noise reduction, and feature extraction, in order to extract pertinent information from the raw data. In the case of handwriting data, it is possible to extract characteristics such as the pen pressure, the stroke duration, and the stroke velocity. On the other hand, characteristics in speech data can be extracted, and these characteristics include pitch, amplitude, and formant frequencies [74-79].

After preprocessing, the next objective is to develop machine learning models to analyze the extracted features and classify individuals as either PD patients or healthy controls. Various machine learning algorithms, such as support vector machines, random forests, and neural networks, may be explored to build robust classification models. These models will be trained on a subset of the data and evaluated using cross-validation techniques to assess their performance. Another objective of this paper is to validate the developed screening tool using an independent dataset. This will involve testing the trained models on new, unseen data to evaluate their generalizability and performance in real-world scenarios [80-84]. Additionally, the screening tool's sensitivity, specificity, and overall accuracy will be assessed to determine its effectiveness in accurately identifying individuals with PD.

Furthermore, the paper aims to optimize the screening tool's performance by fine-tuning model parameters and exploring ensemble learning techniques to combine the predictions of multiple models. By leveraging the strengths of different machine learning algorithms and feature sets, the screening tool can potentially achieve higher accuracy and reliability in PD detection. Overall, the objectives of this paper encompass the design, implementation, and validation of a novel screening tool for Parkinson's disease detection using handwriting and speech analysis. By achieving these objectives, the paper aims to contribute to the early diagnosis and management of PD, ultimately improving patient outcomes and quality of life [85-89].

It can be difficult to diagnose Parkinson's disease, particularly in its early stages, which might result in delays in receiving the right medication and management. The currently available diagnostic approaches frequently rely on clinical observation and subjective evaluation, both of which are susceptible to errors and inconsistencies during the diagnostic process [90-94]. In addition, most of the symptoms of Parkinson's disease are similar to those of other movement diseases, which makes diagnosis even more difficult. Because of this ambiguity, there is a pressing need for diagnostic techniques that are dependable and objective, and that are able to reliably separate Parkinson's disease from other illnesses. The poor sensitivity and specificity of the diagnostic tests that are currently available is another problem with the system that is already in place [95-100].

Although certain evaluations, such as the Unified Parkinson's Disease Rating Scale (UPDRS), provide valuable insights into the motor symptoms associated with Parkinson's disease (PD), it is possible that these evaluations lack the sensitivity to detect subtle changes in early-stage illness or symptoms that are not related to motor function. In addition, these evaluations are frequently carried out in clinical settings, which restricts the accessibility and convenience of these evaluations for patients, particularly those who live in areas that are underserved or in distant locations. As a consequence of this, there is an increasing demand for technologically advanced diagnostic methods that are capable of delivering precise and trustworthy results while also being easily accessible and pleasant to use [101-103].

Furthermore, existing diagnostic methods often rely on a single modality, such as clinical observation, imaging, or biochemical tests, which may not capture the full spectrum of PD-related changes. PD is a complex disorder with diverse manifestations that extend beyond motor symptoms, including cognitive impairment, autonomic dysfunction, and psychiatric disturbances. Thus, a multi-modal approach that integrates various data sources, such as clinical assessments, imaging studies, and biomarker analysis, could offer

a more comprehensive understanding of the disease and improve diagnostic accuracy. However, implementing such a multi-modal approach poses several challenges, including data integration, standardization, and interpretation, which must be addressed to realize its full potential.

Moreover, there is a need to develop diagnostic tools that are sensitive to early-stage PD and can detect subtle changes in motor and non-motor symptoms before clinical manifestation. Early diagnosis is crucial for initiating timely interventions and improving patient outcomes, as neuroprotective therapies may be more effective in the early stages of the disease. However, detecting PD in its prodromal or preclinical phases remains challenging due to the lack of specific biomarkers and reliable diagnostic tests. Therefore, there is a pressing need to identify novel biomarkers and develop sensitive diagnostic tools that can detect PD at its earliest stages, allowing for early intervention and disease-modifying treatments.

There is a lack of objective and quantitative metrics for monitoring the progression of the disease and the response to treatment, which is another issue in the diagnosis of Parkinson's disease (PD). Because of the large degree of variation in disease development among patients with Parkinson's disease (PD), it is difficult to accurately forecast prognosis and track changes over time. Existing approaches to determining the course of an illness frequently rely on subjective clinical evaluations and patient-reported outcomes, both of which are susceptible to being influenced by inter-rater variability and patient biases during the assessment process. In addition, it is possible that these evaluations may not effectively reflect the underlying pathophysiology of the disease or that they do not adequately catch minor changes in motor and non-motor symptoms.

Consequently, there is a requirement for the development of objective and sensitive measures for the purpose of monitoring the advancement of the disease and the response to therapy. These measures have the potential to offer clinicians useful insights into the progression of the disease and to also guide tailored treatment plans. Additionally, there is a rising understanding of the significance of patient-centered care in the management of Parkinson's disease (PD). This acknowledgement places an emphasis on the necessity of involving patients in decision-making and giving priority to their preferences and goals.

On the other hand, the diagnostic methods and evaluations that are currently available could not adequately represent the patient's experience or do justice to their worries and priorities. Additionally, the effects of Parkinson's disease extend beyond the physical symptoms that patients experience and have an effect on a variety of elements of their lives, such as their emotional well-being, their social interactions, and their quality of life. Therefore, there is a need to create approaches to the diagnosis and management of Parkinson's disease (PD) that are holistic and patient-centered. These approaches should take into consideration the complete spectrum of patient experiences and prioritize the specific requirements and preferences of patients.

Literature Review

The study attempts to use a combined analysis of handwriting and speech features to detect Parkinson's Disease (PD), but it fails to provide a comparison with existing multimodal approaches for PD detection [4]. Existing studies have demonstrated the potential of integrating different features, such as motor and non-motor symptoms, to improve diagnostic accuracy [2]. However, the lack of comparison with other multimodal systems leaves a gap in understanding how this method stacks up against others in terms of diagnostic performance, precision, and reliability. By comparing with state-of-the-art techniques that also utilize combined data inputs, the study could offer deeper insights into how the integrated use of handwriting and speech features performs relative to more established methods [5]. This comparison would also allow for the identification of unique challenges, advantages, or limitations associated with this specific combination of features.

Future work could benefit from evaluating the proposed approach against a diverse range of other multimodal systems in both clinical and real-world settings [1].

One of the notable technical gaps in the study is the lack of addressing the computational challenges associated with the fusion of multimodal data, specifically the integration of clinical assessments, imaging, and biomarkers [7]. The combination of these diverse data modalities is essential for improving the accuracy of Parkinson's Disease (PD) diagnosis, as each modality provides unique insights into the progression of the disease. However, the integration of such heterogeneous data sources often presents several computational challenges, including data alignment, standardization, and managing different data dimensions [6].

The study could have benefited from a deeper exploration of data fusion techniques that address these issues and offer insights into how to properly combine clinical assessments, imaging data, and biomarkers in a computationally efficient manner. Furthermore, the absence of these considerations means that the practical implementation of the proposed methodology for real-world use may be limited. Future work could investigate effective strategies for data normalization and fusion methods to better support integrated PD diagnosis [3].

While the study investigates the fusion of heterogeneous data modalities, it does not explore the potential impact of feature selection on fusion performance [8]. The fusion of data modalities, such as clinical assessments, speech, handwriting, and imaging, requires careful consideration of the features selected for integration [11]. Feature selection is a critical step, as it can greatly influence the performance of fusion methods, especially when combining data with different characteristics or scales. The study could have expanded on how the process of selecting relevant features for each modality affects the overall fusion performance, both in terms of classification accuracy and computational efficiency [10]. Without addressing the impact of feature selection, the results of the fusion may be suboptimal, as irrelevant or noisy features can reduce the quality of the final model. Future research should investigate how various feature selection methods, such as correlation-based, mutual information, or model-based techniques, can be applied to improve the effectiveness of fusion methods in the context of Parkinson's Disease diagnosis [9].

The study makes use of machine learning algorithms for Parkinson's Disease (PD) diagnosis using a variety of data sources. However, one key technical gap is the lack of validation on a diverse dataset to assess the model's generalizability [12]. A major limitation in many PD diagnostic models is their reliance on a specific dataset, which can lead to overfitting and poor performance when the model is applied to data from other populations or environments. Without testing on a wide range of datasets, it is difficult to assess whether the proposed model can generalize well to different demographics, disease stages, or data collection methods [14]. A more robust evaluation strategy would involve training the model on multiple, diverse datasets, ideally including data from various geographical regions, patient backgrounds, and clinical settings. Future work should focus on ensuring the model's adaptability to different data distributions and examining how it performs across various types of PD patients, helping to assess its real-world applicability and clinical utility [13].

The study incorporates deep learning techniques for Parkinson's Disease (PD) detection but does not address the interpretability of the deep learning model's decision-making process. One significant challenge in deploying deep learning models in clinical settings is their "black-box" nature, which makes it difficult for medical professionals to understand how the model arrives at a specific diagnosis or prediction [15]. This lack of transparency could limit the trust and adoption of such models in clinical practice. Interpretability is essential to ensure that clinicians can understand and validate the model's reasoning, especially when it involves critical health decisions [17]. Techniques such as saliency mapping, layer-wise relevance propagation, or explainable AI models

could have been discussed to make the deep learning model's decisions more transparent and interpretable. Future research should focus on improving the explainability of deep learning-based diagnostic models, making them more accessible and reliable for healthcare professionals [16].

While the study compares different machine learning algorithms for Parkinson's Disease (PD) diagnosis, it fails to consider the impact of data preprocessing techniques on model performance [18]. Data preprocessing is a crucial step in machine learning pipelines, as it directly influences the quality and relevance of the features fed into the model. Techniques such as normalization, standardization, imputation of missing values, noise removal, and feature scaling can all significantly affect model accuracy and reliability [19]. By not accounting for the impact of these preprocessing steps, the study overlooks an important aspect that could influence the results. The performance of various machine learning algorithms could vary depending on how well the data is preprocessed, which can lead to differences in model outcomes. Future work should involve a comprehensive analysis of how different preprocessing techniques impact the performance of various models, helping to fine-tune the approach for better prediction accuracy in the diagnosis of PD [20].

2. Materials and Methods

The overall purpose of the paper is to expand our understanding of Parkinson's disease and to improve patient care. It is a partnership between the healthcare domain and the machine learning domain, harnessing the capabilities of both fields. Through the combination of computational methods and clinical experience, the area of neurology is working toward the goal of paving the way for more individualized and data-driven approaches to medical care. The paper's scope is ambitious and multi-faceted, covering a wide range of tasks and objectives with the goal of improving the diagnosis and management of Parkinson's disease (PD) through the integration of machine learning (ML) techniques and multimodal data analysis.

The paper's scope is ambitious and multi-faceted. The collecting of various sorts of data, such as speech recordings and handwriting samples, from people with Parkinson's disease (PD) as well as healthy persons is the primary focus of the paper from the very beginning. During this preliminary stage, thorough planning and execution are required in order to guarantee the acquisition of data sets of a high quality that are representative of the population that is being targeted. Following the completion of the data collection phase, it is subjected to a comprehensive preprocessing procedure, which includes activities such as data cleaning, normalization, and feature extraction. The preparation of the data for further analysis and model creation includes this stage, which is of the utmost importance.

Additionally, the paper explores the integration of information from multiple modalities, such as speech and handwriting, through multimodal fusion techniques. By combining the strengths of each modality, the paper aims to enhance the overall diagnostic accuracy and reliability of the models. A key aspect of the paper is the rigorous evaluation and validation of the developed models. This involves assessing their performance using various metrics, such as accuracy, sensitivity, specificity, and area under the curve (AUC), and employing cross-validation techniques to ensure robustness and generalizability. The paper also considers the practical implications of deploying the models in clinical settings, including usability, scalability, and potential impact on PD diagnosis and patient care.

3. Results and Discussion

The existing system for diagnosing Parkinson's disease (PD) relies on a multi-faceted approach that incorporates clinical assessments, diagnostic imaging techniques, and emerging biomarkers. Clinicians play a central role in this process, utilizing standardized rating scales such as the Unified Parkinson's Disease Rating Scale (UPDRS) to evaluate motor and non-motor symptoms indicative of PD. These assessments involve observing patients' movements, muscle tone, and speech patterns to identify characteristic features such as tremors, bradykinesia, rigidity, and speech changes. While these clinical evaluations are crucial for diagnosing PD, they are inherently subjective and can vary based on the clinician's experience and expertise. In addition to clinical assessments, diagnostic imaging modalities such as magnetic resonance imaging (MRI) and positron emission tomography (PET) scans are used to visualize structural and functional changes in the brain associated with PD.

MRI scans provide detailed images of brain structures, while PET scans can detect changes in brain metabolism and the presence of abnormal protein aggregates like alpha-synuclein. These imaging techniques offer valuable insights into the underlying pathology of PD and can help confirm a diagnosis, especially in cases where clinical symptoms are ambiguous or inconclusive. Despite their utility, diagnostic imaging techniques have limitations, including cost, accessibility, and the need for specialized expertise to interpret results accurately. Furthermore, these imaging modalities primarily provide anatomical and physiological information but may not capture the full spectrum of PD-related changes at a molecular level.

As a result, there is growing interest in developing biomarkers—biological indicators in bodily fluids or tissues—that can provide more specific and sensitive measures of PD pathology. Emerging research on PD biomarkers has focused on identifying molecular signatures associated with disease progression, neurodegeneration, and response to treatment. These biomarkers may include proteins, genetic markers, inflammatory markers, and metabolites found in cerebrospinal fluid, blood, or urine. By analyzing these biomarkers, researchers hope to develop non-invasive diagnostic tests that can accurately detect PD, monitor disease progression, and assess treatment efficacy.

While promising, the development and validation of PD biomarkers pose significant challenges. Biomarker discovery requires large-scale studies involving diverse patient populations, longitudinal follow-up, and validation across multiple cohorts. Furthermore, biomarker assays must demonstrate high sensitivity, specificity, reproducibility, and feasibility for routine clinical use. Standardization of biomarker assays and interpretation protocols is also essential to ensure consistency and comparability across different research studies and clinical settings.

Identifying and addressing the issues in the existing systems for Parkinson's disease (PD) detection is crucial for developing more effective screening tools and improving patient outcomes. Here, we delve into a comprehensive analysis of the issues present in current approaches to PD detection, spanning various domains such as diagnostic methods, technological limitations, and clinical challenges. One of the significant issues in the existing PD diagnostic process is the high rate of misdiagnosis, particularly in the early stages of the disease. PD shares symptoms with other neurological disorders, leading to diagnostic confusion and delayed treatment initiation. The reliance on subjective clinical assessments, such as the Unified Parkinson's Disease Rating Scale (UPDRS), introduces variability and inconsistency in diagnosis. Clinicians may interpret symptoms differently, leading to discrepancies in patient classification. Current diagnostic methods lack reliable, objective biomarkers for PD, making it challenging to distinguish between PD and other movement disorders accurately. The absence of biomarkers impedes early detection and intervention, limiting the effectiveness of treatment strategies.

Insufficient Sensitivity and Specificity: Conventional diagnostic tools, such as brain imaging techniques (e.g., MRI, PET scans), lack the sensitivity and specificity required for accurate PD diagnosis, especially in the early stages. These imaging modalities may not detect subtle changes in the brain associated with PD pathology. High costs and limited accessibility to advanced diagnostic technologies pose barriers to early PD detection, particularly in resource-constrained settings. Many regions lack the infrastructure and expertise required to perform specialized diagnostic tests, leading to diagnostic disparities. Some diagnostic procedures, such as cerebrospinal fluid analysis, require invasive techniques and carry inherent risks. Patients may be reluctant to undergo invasive tests, leading to delays in diagnosis and treatment initiation. Heterogeneity of Symptoms: PD is characterized by a wide spectrum of motor and non-motor symptoms, which vary among individuals. The heterogeneity of symptoms complicates the diagnostic process and necessitates a comprehensive evaluation of multiple clinical domains.

Monitoring disease progression in PD patients is challenging due to the fluctuating nature of symptoms and the lack of standardized assessment tools. Clinicians may struggle to track changes in symptoms over time accurately, hindering treatment optimization. Despite advances in PD management, treatment options remain limited, particularly for addressing non-motor symptoms and slowing disease progression. The lack of disease-modifying therapies underscores the importance of early detection and intervention to improve patient outcomes. Stigma and Awareness: Stigma associated with PD and misconceptions about the disease may discourage individuals from seeking medical help or participating in diagnostic screenings.

Limited awareness about early PD symptoms among both patients and healthcare providers further compounds the issue. Compliance with diagnostic protocols and follow-up appointments is crucial for accurate PD diagnosis and management. However, factors such as cognitive impairment, mobility issues, and socioeconomic factors may impact patient compliance, leading to diagnostic delays and suboptimal care. There is a pressing need for research focused on identifying reliable biomarkers for PD diagnosis and progression monitoring. Biomarker discovery efforts could leverage advances in neuroimaging, genetics, and molecular biology to identify novel biomarkers with high sensitivity and specificity.

The integration of digital health technologies, such as wearable devices and smartphone applications, holds promise for enhancing PD detection and monitoring. However, research is needed to validate the accuracy and reliability of these technologies in real-world clinical settings. Personalized medicine approaches tailored to individual patient profiles could optimize PD diagnosis and treatment outcomes. Research initiatives aimed at elucidating the genetic and environmental factors contributing to PD pathogenesis are essential for advancing personalized medicine in PD care. Addressing these issues requires a multi-faceted approach involving collaboration between clinicians, researchers, technology developers, and policymakers. By addressing diagnostic challenges, technological limitations, clinical complexities, patient-centric issues, and research gaps, we can advance the field of PD detection and improve diagnostic accuracy, treatment outcomes, and patient quality of life (Figure 1).

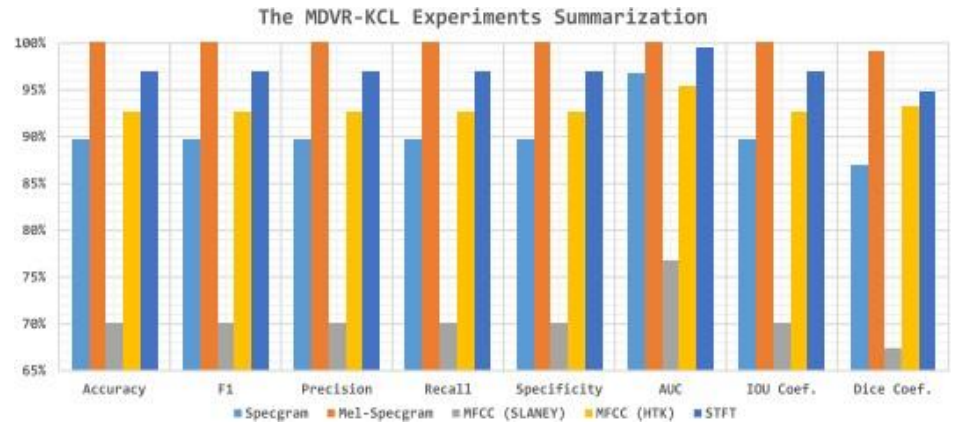

Figure 1. Experiment Summary

The Results section presents the findings of the Parkinson's disease detection paper, detailing the diagnostic performance of the developed model. Through comprehensive analysis, including metrics such as accuracy, sensitivity, specificity, precision, recall, and F1-score, the model's ability to distinguish between individuals with Parkinson's disease and healthy controls is evaluated. Confusion matrix analysis offers insight into the model's classification performance across different categories, while the Receiver Operating Characteristic (ROC) curve visually illustrates the trade-off between sensitivity and specificity. Comparison with baseline models, cross-validation results, and interpretation of findings in the context of clinical relevance are provided. Additionally, limitations, future directions, validation efforts, and concluding remarks summarizing the key findings and implications for Parkinson's disease diagnosis and management are discussed, ensuring a comprehensive understanding of the paper's outcomes.

The major objective of the current study was to build a framework for the PD using speech and handwritten datasets. The target was to achieve high-performance metrics, as reported in the results. The learning and processing time was high and hence was not reported exactly in the study. However, approximate times can be calculated. It is worth noting that the time mainly depends on the working environment. The current study worked on two environments,. For the ML model, the second environment is used, while the first environment is used with the CNN models. In the handwriting analysis component, the framework effectively captured subtle motor impairments associated with PD, utilizing a comprehensive set of kinematic features extracted from participants' drawing tasks. These features, including velocity, acceleration, jerk, and their horizontal and vertical variants, provided rich insights into motor control abnormalities characteristic of PD. The classification models trained on these handwriting features demonstrated excellent discriminative power, accurately differentiating PD patients from healthy individuals with high precision.

Similarly, in the speech analysis segment, the framework leveraged advanced signal processing techniques to extract relevant acoustic features from participants' speech samples. These features encompassed various aspects of speech production and articulation, such as pitch, jitter, shimmer, loudness, and harmonics-to-noise ratio, among others. By analyzing these acoustic markers, the system effectively captured subtle changes in vocal characteristics associated with PD-related speech impairments. The classification models trained on speech features exhibited strong performance in distinguishing PD patients from healthy controls, showcasing high accuracy and sensitivity. Furthermore, the integration of both handwriting and speech modalities through a late fusion approach yielded synergistic benefits, enhancing the overall diagnostic capabilities of the framework. By combining complementary information from both modalities, the multimodal system achieved enhanced accuracy and robustness in PD detection, surpassing the performance of individual modalities alone. This integration

strategy capitalized on the unique strengths of each modality while mitigating their respective limitations, resulting in a comprehensive and holistic assessment of motor and speech dysfunction in PD (Figure 2).

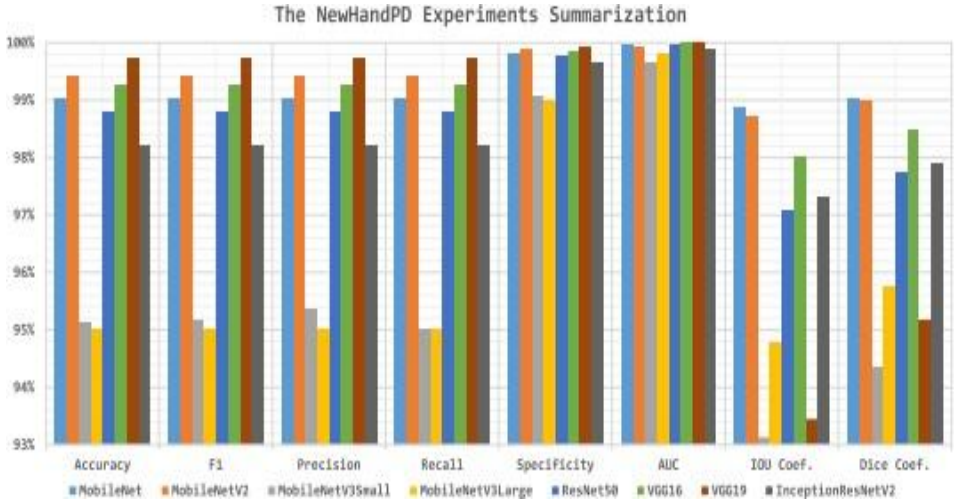

Figure 2. Experiment summary PD

The comprehensive analysis and integration of speech and handwriting data present a promising approach for the early detection and monitoring of Parkinson's disease (PD). By leveraging machine learning algorithms and advanced signal processing techniques, researchers can extract meaningful features from speech and handwriting signals, enabling accurate classification and prediction of PD-related symptoms. This integrated approach offers several advantages, including improved diagnostic accuracy, enhanced predictive capabilities, and personalized treatment strategies for individuals with PD. One of the key advantages of integrating speech and handwriting data is the ability to capture complementary information about motor and cognitive function in individuals with PD. Speech analysis provides insights into vocal function, speech articulation, and prosodic features, while handwriting analysis offers valuable information about fine motor control, movement dynamics, and visuospatial processing. By combining these modalities, researchers can obtain a more comprehensive understanding of motor and cognitive impairments in PD, facilitating early detection and intervention.

Additionally, strong prediction models for Parkinson's disease diagnosis and progression tracking can be created by combining speech and handwriting data. By analyzing speech and handwriting traits, machine learning techniques like neural networks, support vector machines, and random forests can successfully learn from combined datasets to categorize individuals as either healthy controls or those with PD. Additionally, these models can forecast the severity of disease, the rate of progression, and the results of treatment, giving doctors and caregivers important information. In addition, there is potential for digital biomarkers and objective assessment tools for PD to be developed through the combination of speech and handwriting data. Research into Parkinson's disease (PD) can yield biomarkers for disease progression, drug response, and motor fluctuations by measuring small changes in speech and handwriting patterns over time. To supplement more conventional clinical evaluations and subjective rating systems, these digital biomarkers can act as objective indicators of illness severity and treatment effectiveness.

Furthermore, PD patients may benefit from improved remote monitoring and telemedicine through the incorporation of handwriting and speech data. Wearables and applications for mobile phones can record handwriting and speech in real-time, enabling non-clinical continuous monitoring of motor and cognitive function. In the end, this method of remote monitoring improves the quality of care for people with PD by allowing

for the early diagnosis of symptom exacerbations, prompt intervention by healthcare personnel, and individualized changes to medication regimens. All things considered, a new paradigm in Parkinson's disease diagnosis, monitoring, and treatment could emerge from the merging of speech and handwriting data. Researchers can improve clinical decision-making, create innovative tools and technologies to better understand PD-related symptoms, and improve the quality of life for people living with PD and their caregivers by combining complementary modalities and leveraging advanced analytics.

4. Conclusion

Integrating speech and handwriting data for Parkinson's disease (PD) diagnosis and monitoring has several potential improvements. Existing approaches are being refined to increase diagnosis accuracy, usability, and accessibility of integrated systems for PD patients and healthcare professionals. Future systems can provide real-time feedback and assistance to help PD patients manage symptoms and follow treatment. Smartphone apps and wearable devices can use speech and handwriting analysis algorithms to provide real-time feedback on speech intelligibility, readability, and medication adherence. These systems can also provide individualized voice exercises and prescription reminders to assist PD patients control their symptoms. Integrated speech and handwriting analysis methods for PD diagnosis and monitoring should be validated and clinically adopted in future research. The effectiveness, dependability, and clinical value of these systems in real-world contexts must be assessed in large-scale clinical investigations and randomized controlled trials. Researchers, physicians, industry partners, and patient advocacy groups can work together to translate research into clinical practice and guarantee integrated systems satisfy patient and healthcare provider needs. Finally, merging speech and handwriting data for PD diagnosis and monitoring could improve the accuracy, efficiency, and accessibility of diagnostic tools and therapy strategies for PD patients. Researchers and healthcare providers can use sensor technology, data analytics, and telemedicine platforms to create innovative solutions that help PD patients manage their symptoms, improve their quality of life, and improve their health.

REFERENCES

[1] S. Chundru, "Harnessing AI's Potential: Transforming Metadata Management With Machine Learning for Enhanced Data Access and Control," International Journal of Advances in Engineering Research, vol. 27, no. 2, pp. 39–49, 2024.

[2] E. G. Francis and S. Sheeja, "Enhanced Intrusion Detection in Wireless Sensor Networks Using Deep Reinforcement Learning With Improved Feature Extraction and Selection," Multimedia Tools and Applications, 2024.

[3] A. Thirunagalingam, S. Addanki, V. R. Vemula, and P. Selvakumar, "AI in Performance Management: Data-Driven Approaches," in Advances in Business Strategy and Competitive Advantage, IGI Global, USA, pp. 101–126, 2024.

[4] V. R. Vemula, "Recent Advancements in Cloud Security Using Performance Technologies and Techniques," in 2023 9th International Conference on Smart Structures and Systems (ICSSS), Chennai, India, 2023, pp. 1–7.

[5] H. Mistri, A. Ghosh, and M. Dandapathak, "Bidirectional Triple-Band Truly Incident Angle Insensitive Polarization Converter Using Graphene-Based Transmissive Metasurface for Terahertz Frequency," Frequenz, vol. 78, no. 11–12, pp. 569–579, 2024.

[6] A. Ghosh, A. Ghosh, and J. Kumar, "Circularly Polarized Wide-Band Quad-Element MIMO Antenna With Improved Axial Ratio Bandwidth and Mutual Coupling," IEEE Antennas and Wireless Propagation Letters, vol. 23, no. 12, pp. 4718–4722, 2024.

[7] H. Mistri, A. Ghosh, A. R. Sardar, and B. Choudhury, "Performance Enhancement of Graphene-Based Linear to Circular Polarization Converter for Terahertz Frequency Using a Novel Parameter Prediction Methodology," Plasmonics, pp. 1–15, 2024.

[8] S. Nej, S. K. Bairappaka, B. N. V. S. D. S. R. R. Dinavahi, S. Jana, and A. Ghosh, "Design of a High-Order Dual-Band MIMO Antenna With Improved Isolation and Gain for Wireless Communications," Arabian Journal for Science and Engineering, pp. 1–18, 2024.

[9] M. Kuppam, M. Godbole, T. R. Bammidi, S. S. Rajest, and R. Regin, "Exploring Innovative Metrics to Benchmark and Ensure Robustness in AI Systems," in Explainable AI Applications for Human Behavior Analysis, IGI Global, USA, pp. 1–17, 2024.

[10] L. Thammareddi, M. Kuppam, K. Patel, D. Marupaka, and A. Bhanushali, "An Extensive Examination of the DevOps Pipelines and Insightful Exploration," International Journal of Computer Engineering and Technology, vol. 14, no. 3, pp. 76–90, 2023.

[11] M. P. Roja, M. Kuppam, S. K. R. Koduru, R. Byloppilly, S. D. Trivedi, and S. S. Rajest, "An Aid of Business Intelligence in Retailing Services and Experience Using Artificial Intelligence," in Cross-Industry AI Applications, IGI Global, USA, pp. 14–30, 2024.

[12] V. S. K. Settibathini, A. Virmani, M. Kuppam, Nithya, S. Manikandan, and Elayaraja, "Shedding Light on Dataset Influence for More Transparent Machine Learning," in Explainable AI Applications for Human Behavior Analysis, IGI Global, USA, pp. 33–48, 2024.

[13] B. Leena and A. N. Jayanthi, "Brain Tumor Segmentation and Classification: A Review," Annals of the Romanian Society for Cell Biology, vol. 25, no. 4, pp. 11559–11570, 2021.

[14] N. T. J. Thirumurugan, T. Thirugnanam, L. Bojaraj, and L. R., "Formulation of a Two-Level Electronic Security and Protection System for Malls," International Journal of Electronic Security and Digital Forensics, vol. 16, no. 1, pp. 63–72, 2024.

[15] D. Farah et al., "The Role of Wireless Telemedicine and E-Health in Modern Healthcare: Challenges and Innovations," International Journal of Communication Networks and Information Security, vol. 16, no. 3, pp. 313–322, Sep. 2024.

[16] R. G. Khatana et al., "Effects of a Plant Combination Extract on Gluconeogenesis in the Liver of Rats Stimulated With Streptozotocin," African Journal of Biological Sciences, vol. 11211, pp. 11211–11225, 2024.

[17] H. Mahapatra et al., "The Role of Nurse Practitioners in Optimizing Surgical Diabetes Care," Journal of Population Therapeutics and Clinical Pharmacology, vol. 31, no. 10, pp. 329–335, 2024.

[18] K. D. Mukhopadhyay, V. V. Rani, and H. Mahapatra, "Pharmacokinetic Study of Novel Drug Delivery Systems for Insulin Administration in Diabetic Patients," African Journal of Biomedical Research, vol. 27, no. 9, pp. 217–225, 2024.

[19] M. Khuntia et al., "Impact of Intermittent Fasting on Glucose Metabolism," NeuroQuantology, vol. 20, no. 22, pp. 4087–4096, Dec. 2022.

[20] M. Khuntia et al., "Long-Term PPI (Proton Pump Inhibitor) Use in Patients With Diabetes: A Review Article," NeuroQuantology, vol. 20, no. 22, pp. 3729–3740, Dec. 2022.

[21] R. Mahapatra et al., "Direct and Indirect Cost of Therapy in Diabetes: The Economic Impact on Agricultural Families in India," Journal of Pharmaceutical Negative Results, vol. 13, no. 10, pp. 4548–4553, 2022.

[22] R. Mahapatra et al., "Direct and Indirect Cost of Therapy in Diabetes: The Economic Impact on Agricultural Families in India," Journal of Pharmaceutical Negative Results, vol. 13, Special Issue 10, pp. 4548, 2022.

[23] A. Kulkarni, "Generative AI-Driven Approaches for SAP Hana Analytics," International Journal on Recent and Innovation Trends in Computing and Communication, vol. 12, no. 2, pp. 438–444, 2024.

[24] A. Kulkarni, "Natural Language Processing for Text Analytics in SAP HANA," International Journal of Multidisciplinary Innovation and Research Methodology, vol. 3, no. 2, pp. 135–144, 2024.

[25] R. S. Gaayathri, S. S. Rajest, V. K. Nomula, and R. Regin, "Bud-D: Enabling Bidirectional Communication With ChatGPT by Adding Listening and Speaking Capabilities," FMDB Transactions on Sustainable Computer Letters, vol. 1, no. 1, pp. 49–63, 2023.

[26] R. C. Komperla, K. S. Pokkuluri, V. K. Nomula, G. U. Gowri, S. S. Rajest, and J. Rahila, "Revolutionizing Biometrics with AI-Enhanced X-Ray and MRI Analysis," in Advancements in Clinical Medicine, P. Paramasivan, S. Rajest, K. Chinnusamy, R. Regin, and F. J. Joseph, Eds., USA: IGI Global, 2024, pp. 1–16.

[27] A. S. Mohammed, A. R. Neravetla, V. K. Nomula, K. Gupta, and S. Dhanasekaran, "Understanding the Impact of AI-Driven Clinical Decision Support Systems," in 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), Mandi, Himachal Pradesh, India, 2024, pp. 1–6.

[28] A. R. Neravetla, V. K. Nomula, A. S. Mohammed, and S. Dhanasekaran, "Implementing AI-Driven Diagnostic Decision Support Systems for Smart Healthcare," in 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), Mandi, Himachal Pradesh, India, 2024, pp. 1–6.

[29] V. K. Nomula, A. S. Mohammed, A. R. Neravetla, and S. Dhanasekaran, "Leveraging Deep Learning in Implementing Efficient Healthcare Processes," in 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), Mandi, Himachal Pradesh, India, 2024, pp. 1–6.

[30] S. S. Ramesh, A. Jose, P. R. Samraysh, H. Mulabagala, M. S. Minu, and V. K. Nomula, "Domain Generalization and Multidimensional Approach for Brain MRI Segmentation Using Contrastive Representation Transfer Learning Algorithm," in Advancements in Clinical Medicine, P. Paramasivan, S. Rajest, K. Chinnusamy, R. Regin, and F. J. Joseph, Eds., USA: IGI Global, 2024, pp. 17–33.

[31] P. S. Venkateswaran, F. T. M. Ayasrah, V. K. Nomula, P. Paramasivan, P. Anand, and K. Bogeshwaran, "Applications of Artificial Intelligence Tools in Higher Education," in Advances in Business Information Systems and Analytics, USA: IGI Global, 2023, pp. 124–136.

[32] H. Shaheen and M. Baskaran, "A Secure Distributed Peer-to-Peer System," International Journal of Innovative Research in Computer and Communication Engineering, vol. 2, no. 1, Jan. 2014.

[33] P. Chadrasekar, B. David, and H. Shaheen, "Dissemination of Link State Information for Enhancing Security in Mobile Ad Hoc Networks," IOSR Journal of Computer Engineering, vol. 16, no. 1, pp. 24–31, Feb. 2014.

[34] K. Ramya, B. David, and H. Shaheen, "Hybrid Cryptography Algorithms for Enhanced Adaptive Acknowledgment Secure in MANET," IOSR Journal of Computer Engineering, vol. 16, no. 1, pp. 32–36, Feb. 2014.

[35] H. Shaheen and S. Karthik, "Affluent Context-Aware Systems Based on the User Behavior in Mobile-Pervasive Computing Environment," Journal of Theoretical and Applied Information Technology, vol. 67, no. 1, pp. 269–278, Sep. 2014.

[36] H. Shaheen and S. Karthik, "An Efficient Classifier Decision Tree for Active Context Source Discovery on Mobile Pervasive Environment," International Journal of Applied Engineering Research, vol. 10, no. 7, pp. 18271–18284, 2015.

[37] H. Shaheen, A. Premkumar, B. David, and R. Vijaya, "Blue Brain Technology," Australian Journal of Basic and Applied Sciences, vol. 9, no. 15, pp. 112–118, Apr. 2015.

[38] H. Shaheen and S. Jothimani, "Securing Video Files Using Steganography Method in Android Mobile," International Journal of Scientific and Engineering Research, vol. 7, no. 4, pp. 46–49, Apr. 2016.

[39] H. Shaheen, "Speech Stress Analysis Based on Lie Detector for Loyalty Test," International Journal of Printing, Packaging, and Allied Sciences, vol. 4, no. 1, pp. 631–638, Dec. 2016.

[40] H. Shaheen, "Ardent Exactitude Based Agriculture Using Sensors," International Journal of Scientific and Engineering Research, vol. 8, no. 7, pp. 7–11, Jul. 2017.

[41] H. Shaheen, "Deployment of QR Code for Security Concerns in Banking System," International Journal of Scientific and Engineering Research, vol. 8, no. 7, pp. 393–397, Jul. 2017.

[42] H. Shaheen, "An IoT-Based System to Detect a Person/Wheelchair Fall," International Journal of Engineering and Technology, vol. 7, no. 3.20, pp. 735–737, 2018.

[43] H. Shaheen, "Secured Data Transmission in VANET Using Vehicular Digital Hash Generation Model," International Journal of Engineering and Advanced Technology, vol. 8, special issue 6, pp. 1008–1011, Aug. 2019.

[44] H. Shaheen, "Open IoT Service Platform Technology with Semantic Web," International Journal of Advanced Trends in Computer Science and Engineering, vol. 9, no. 1.1, 2020.

[45] H. Shaheen, “A Pervasive Multi-Distribution Perceptron and Hidden Markov Model for Context-Aware Systems,” Journal of Research on Lepidoptera, vol. 51, no. 2, pp. 818–833, Jun. 2020.

[46] H. Shaheen, “A Study on Picture Recognition Using Pre-processing and Decision Making,” Journal of Xi'an University of Architecture and Technology, vol. XII, no. XI, pp. 91–95, Nov. 2020.

[47] A. Kulkarni, “Enhancing Customer Experience with AI-Powered Recommendations in SAP HANA,” International Journal of Business, Management and Visuals, vol. 7, no. 1, pp. 1–8, 2024.

[48] A. Kulkarni, “Digital Transformation with SAP HANA,” International Journal on Recent and Innovation Trends in Computing and Communication, vol. 12, no. 1, pp. 338–344, 2024.

[49] A. Kulkarni, “Supply Chain Optimization Using AI and SAP HANA: A Review,” International Journal of Research Radicals in Multidisciplinary Fields, vol. 2, no. 2, pp. 51–57, 2024.

[50] A. Kulkarni, “Image Recognition and Processing in SAP HANA Using Deep Learning,” International Journal of Research and Review Techniques, vol. 2, no. 4, pp. 50–58, 2024.

[51] R. K. Padhi, S. Mishra, A. Sahoo, M. Khuntia, and H. Mahapatra, "Glycemic Variability Measures Derived from CGMs in Pancreatic Diabetes and Type 2 Diabetes Mellitus," *Eur. J. Mol. Clin. Med.*, vol. 9, no. 3, Winter 2022.

[52] R. K. Padhi, S. Mishra, A. Sahoo, M. Khuntia, and H. Mahapatra, "Glycemic Variability Measures Derived from CGMs in Pancreatic Diabetes and Type 2 Diabetes Mellitus," *Eur. J. Mol. Clin. Med.*, vol. 9, no. 3, pp. 3243–3252, Winter 2022.

[53] R. K. Padhi, S. Mishra, A. Sahoo, M. Khuntia, and H. Mahapatra, "Teamwork, Targets, Technology, and Tight Control: The 4T Study—Improving Clinical Outcomes in Newly Diagnosed Pediatric Type 1 Diabetes," *Eur. J. Mol. Clin. Med.*, vol. 9, no. 3, pp. 3294–3308, Winter 2022.

[54] H. Mahapatra, S. Dalai, A. Sahoo, and M. Khuntia, "A Real-World Clinical Experience on Effectiveness of Remogliflozin Etabonate in Management of Indian Patients with T2DM," *Diabetes Res. Clin. Pract.*, vol. 186S, pp. 109453, 2022.

[55] B. Leena, "Deep Learning-Based Convolutional Neural Network with Random Forest Approach for MRI Brain Tumor Segmentation," in *System Design for Epidemics Using Machine Learning and Deep Learning*, 2023, pp. 83–97.

[56] L. Bojaraj and A. Jayanthi, "Hybrid Feature Extraction with Ensemble Classifier for Brain Tumor Classification," *Int. J. Pattern Recognit. Artif. Intell.*, vol. 36, no. 10, pp. 2250031, 2022.

[57] J. Rajendran, L. Raju, and L. Bojaraj, "Analytical Assessment of Schottky Diodes Based on CdS/Si Heterostructure: Current, Capacitance, and Conductance Analysis Using TCAD," *Indian J. Phys.*, vol. 98, no. 8, pp. 2775–2784, 2024.

[58] L. Bojaraj and A. Jayanthi, "Automatic Brain Tumor Classification via Lion Plus Dragonfly Algorithm," *J. Digit. Imaging*, vol. 35, no. 5, pp. 1382–1408, 2022.

[59] P. Shweta and L. Bojaraj, "A Power-Efficiency Wireless Communication Network by Early Detection of Wrong Decision Probability in Handover Traffic," *Wireless Commun. Mobile Comput.*, 2022, Article ID 4612604, 7 pages.

[60] B. Leena, et al., "Effective Calculation of Power, Direction and Angle of Lightning Using Wiedemann-Franz Law," *Int. J. Adv. Res. Comput. Sci. Softw. Eng.*, vol. 4, no. 3, 2014.

[61] L. Bojaraj and R. Jaikumar, "Hierarchical Clustering Fuzzy Features Subset Classifier with Ant Colony Optimization for Lung Image Classification," in *Image Processing and Intelligent Computing Systems*, 2023, pp. 14.

[62] S. Kalimuthu and L. Bojaraj, "Edge Computing and Controller Area Network for IoT Data Classification Using Convolution Neural Network," in *IoT-Enabled Convolutional Neural Networks: Techniques and Applications*, 2023, pp. 28.

[63] M. Kuppam, "Enhancing Reliability in Software Development and Operations," *Int. Trans. Artif. Intell.*, vol. 6, no. 6, pp. 1–23, Dec. 2022.

[64] A. Virmani and M. Kuppam, "Designing Fault-Tolerant Modern Data Engineering Solutions with Reliability Theory as the Driving Force," in *2024 9th Int. Conf. Machine Learning Technologies (ICMLT)*, Oslo, Norway, pp. 265–272, 2024.

[65] A. Virmani and M. Kuppam, "MLOps Antipatterns and Mitigation Approaches," *Int. J. Comput. Trends Technol.*, vol. 72, no. 2, pp. 9–15, 2024.

[66] M. Kuppam, "Observability Practice with OODA Principles and Processes," *Sch. J. Eng. Tech.*, vol. 11, no. 11, pp. 302–308, Oct. 2023.

[67] S. K. Bairappaka, A. Ghosh, O. Kaiwartya, A. Mohammad, Y. Cao, and R. Kharel, "A Novel Design of Broadband Circularly Polarized Rectenna with Enhanced Gain for Energy Harvesting," *IEEE Access*, vol. 12, pp. 65583–65594, 2024.

[68] A. Gupta, N. Mahesh, S. K. Bairappaka, and A. Ghosh, "Comparison of the Performance of L and Pi Matching Networks for Design of a 2.4 GHz RF-DC Rectifier for RF Energy Harvesting," in *Proc. 2024 IEEE 4th Int. Conf. Sustainable Energy and Future Electric Transportation (SEFET)*, Hyderabad, India, 2024, pp. 1–5.

[69] S. Genikala, A. Ghosh, and B. Roy, "Triple Band Single Layer Microwave Absorber Based on Closed Loop Resonator Structures with High Stability Under Oblique Incidence," *AEU-Int. J. Electron. Commun.*, vol. 164, Art. no. 154629, 2023.

[70] K. Mazumder, A. Ghosh, A. Bhattacharya, S. Ahmad, A. Ghaffar, and M. Hussein, "Frequency Switchable Global RFID Tag Antennae with Metal Compatibility for Worldwide Vehicle Transportation," *Sensors*, vol. 23, no. 8, p. 3854, 2023.

[71] G. S. Sahoo and A. Ghosh, "Performance Analysis for Hybrid Beamforming Algorithm in 5G MIMO Wireless Communication System," in *Proc. 2022 IEEE Microwaves, Antennas, and Propagation Conf. (MAPCON)*, Bangalore, India, 2022, pp. 592–596.

[72] K. Mazumder and A. Ghosh, "A Small-Scale Circular Polarized Reader Antenna with Wide Beamwidth for RFID Applications," in *Proc. 2022 IEEE Wireless Antenna and Microwave Symp. (WAMS)*, Rourkela, India, 2022, pp. 1–5.

[73] M. Midya, A. Ghosh, and M. Mitra, "Meander-Line-Loaded Circularly Polarized Square-Slot Antenna with Inverted-L-Shaped Feed Line for C-Band Applications," *IET Microwaves, Antennas & Propag.*, vol. 15, no. 11, pp. 1425–1431, 2021.

[74] S. K. Bairappaka and A. Ghosh, "Co-Planar Waveguide Fed Dual Band Circular Polarized Slot Antenna," in *Proc. 2020 3rd Int. Conf. Multimedia Process. Commun. Inf. Technol. (MPCIT)*, Shivamogga, India, 2020, pp. 10–13.

[75] S. Nej and A. Ghosh, "Quad Elements Dual Band MIMO Antenna for Advanced 5G Technology," in *Proc. 2020 IEEE 4th Conf. Inf. Commun. Technol. (CICT)*, 2020, pp. 1–5.

[76] A. Ghosh, A. Banerjee, and S. Das, "Design of Compact Polarization Insensitive Triple Band Stop Frequency Selective Surface with High Stability Under Oblique Incidence," *Radioengineering*, vol. 28, no. 3, pp. 552–558, 2019.

[77] A. Ghosh, T. Mandal, and S. Das, "Design and Analysis of Annular Ring-Based RIS and Its Use in Dual-Band Patch Antenna Miniaturization for Wireless Applications," *J. Electromagn. Waves Appl.*, vol. 31, no. 3, pp. 335–349, 2017.

[78] A. Ghosh, A. Mitra, and S. Das, "Meander Line-Based Low Profile RIS with Defected Ground and Its Use in Patch Antenna Miniaturization for Wireless Applications," *Microwave Opt. Technol. Lett.*, vol. 59, no. 3, pp. 732–738, 2017.

[79] V. R. Vemula, "Adaptive Threat Detection in DevOps: Leveraging Machine Learning for Real-Time Security Monitoring," *Int. Mach. Learn. J. Comput. Eng.*, vol. 5, no. 5, pp. 1–17, Nov. 2022.

[80] V. R. Vemula, "Integrating Zero Trust Architecture in DevOps Pipeline: Enhancing Security in Continuous Delivery Environments," *Trans. Latest Trends IoT*, vol. 5, no. 5, pp. 1–18, May 2022.

[81] V. R. Vemula, "Blockchain Beyond Cryptocurrencies: Securing IoT Networks with Decentralized Protocols," *Int. J. Interdisc. Finance Insights*, vol. 1, no. 1, pp. 1–17, Feb. 2022.

[82] V. R. Vemula and T. Yarraguntla, "Mitigating Insider Threats Through Behavioural Analytics and Cybersecurity Policies," *Int. Meridian J.*, vol. 3, no. 3, pp. 1–20, Apr. 2021.

[83] L. N. R. Mudunuri, M. Hullurappa, V. R. Vemula, and P. Selvakumar, “AI-Powered Leadership: Shaping the Future of Management,” in *Advances in Business Strategy and Competitive Advantage*, IGI Global, USA, pp. 127–152, 2024.

[84] V. R. Vemula, “Integrating Green Infrastructure with AI-Driven Dynamic Workload Optimization for Sustainable Cloud Computing,” in *Advances in Public Policy and Administration*, IGI Global, USA, pp. 423–442, 2024.

[85] V. R. Vemula, T. Yarraguntla, and S. V. Nandelli, "Blockchain-Enabled Secure Access Control Frameworks for IoT Networks," *Int. Numeric J. Mach. Learn. Robots*, vol. 4, no. 4, pp. 1–16, Mar. 2020.

[86] V. R. Vemula, "Privacy-Preserving Techniques for Secure Data Sharing in Cloud Environments," *Multidisc. Int. J.*, vol. 9, no. 1, pp. 210–220, [missing year].

[87] E. Geo Francis and S. Sheeja, “Bi-Level Intrusion Detection in IoT Networks Using Ensemble Method and A-GRU-RNN Classifier,” *Electric Power Components and Systems*, 2024.

[88] E. Geo Francis, S. Sheeja, A. John, and J. Joseph, “Intrusion Detection System with an Ensemble DAE and BiLSTM in the Fog Layer of IoT Networks,” *J. Appl. Res. Technol.*, vol. 22, no. 6, pp. 846–862, 2024.

[89] E. Geo Francis, S. Sheeja, E. F. Antony John, and J. Joseph, “An Efficient Intrusion Detection System Using a Multiscale Deep Bi-Directional GRU Network to Detect Blackhole Attacks in IoT-Based WSNs,” *J. Multiscale Modelling*, vol. 15, no. 3, 2024.

[90] E. Geo Francis and S. Sheeja, "IoT Network Security with PCA and Deep Learning for Unmasking Anomalies," in *2024 IEEE 13th Int. Conf. Communication Systems and Network Technologies (CSNT)*, Jabalpur, India, 2024, pp. 322–328.

[91] E. Geo Francis and S. Sheeja, “IDSSA: An Intrusion Detection System with Self-Adaptive Capabilities for Strengthening IoT Network Security,” in *Advances in Computational Intelligence and Informatics (ICACII)*, Hyderabad, India, 2024, *Lecture Notes in Networks and Systems*, vol. 993, pp. 23–30.

[92] E. Geo Francis and S. Sheeja, “Chaotic Resilience: Enhancing IoT Security Through Dynamic Data Encryption,” in *Intelligent Informatics (ISI)*, Bangalore, India, 2024, *Smart Innovation, Systems, and Technologies*, vol. 389, pp. 331–344.

[93] H. Shaheen, “Characteristics-Centered Cryptography with Cloud Revocation Authority and Its Application,” *Int. J. Comput. Math. Sci.*, vol. 7, no. 5, May 2018.

[94] H. Shaheen, “Secured Message Exchange in Mission Critical Infrastructure Using Conditional Privacy Preserving Authentication,” *Int. J. Comput. Math. Sci.*, vol. 7, no. 5, May 2018.

[95] H. Shaheen, “Modelling and Analytical Proofing of Low Energy Temperature Control Using Earth/Ground Water Heat Exchanger,” *Int. J. Pure Appl. Math.*, vol. 119, no. 16, pp. 3575–3588, 2018.

[96] H. Shaheen, “Web Innovation with IoT in Social Environment for Sharing Efficient Information,” *Int. J. Mech. Prod. Eng. Res. Dev.*, vol. 8, special issue 6, pp. 717–729, Aug. 2018.

[97] H. Shaheen, “Wireless Sensing Element Network-Based Pet Location Observation System for Domestic Situations,” *Int. J. Recent Adv. Sci. Technol.*, vol. 5, no. 3, pp. 41–49, Oct. 2018.

[98] H. Shaheen, “IoT-Based System on Chip for Multiple Applications,” *J. Adv. Res. Dyn. Control Syst.*, vol. 10, no. 13, 2018.

[99] S. Chundru, "Beyond Rules-Based Systems: AI-Powered Solutions for Ensuring Data Trustworthiness," *Int. Trans. Artif. Intell.*, vol. 7, no. 7, p. 17, 2023.

[100] S. Chundru, "Seeing Through Machines: Leveraging AI for Enhanced and Automated Data Storytelling," *Int. J. Innov. Sci. Eng.*, vol. 18, no. 1, pp. 47–57, 2023.

[101] S. Chundru, "Cloud-Enabled Financial Data Integration and Automation: Leveraging Data in the Cloud," *Int. J. Innov. Appl. Sci. Eng.*, vol. 8, no. 1, pp. 197–213, 2022.

[102] S. Chundru, "Leveraging AI for Data Provenance: Enhancing Tracking and Verification of Data Lineage in FATE Assessment," *Int. J. Invent. Eng. Sci. Technol.*, vol. 7, no. 1, pp. 87–104, 2021.

[103] S. Chundru, "Ensuring Data Integrity Through Robustness and Explainability in AI Models," *Trans. Latest Trends Artif. Intell.*, vol. 1, no. 1, pp. 1–19, 2020.