http://doi.org/10.35784/iapgos.7008 *received: 28.12.2024 | revised: 16.09.2025 | accepted: 30.11.2025 | available online: 20.12.2025*

HYBRID MODELS FOR HANDWRITING-BASED DIAGNOSIS OF PARKINSON'S DISEASE

Asma Ouabd, Achraf Benba, Abdelilah Jilbab, Ahmed Hammouch
Mohammed V University in Rabat, National School of Arts and Crafts, Electronic Systems Sensors and Nanobiotechnologies, Rabat, Morocco

Abstract. *Parkinson's disease (PD) is a progressive neurodegenerative disorder that primarily impairs motor functions, leading to symptoms such as tremors and micrographia. Even though early identification of PD is crucial for effective intervention, existing methods of diagnosis are highly invasive and not very sensitive to the early stages of the diseases. The goal of this research is to determine if handwriting could be a non-invasive way to diagnose PD at an early stage. We employed a dataset of 3,264 hand-drawn waves and spirals to evaluate the performance of hybrid machine learning and deep learning models which included Support Vector Machine (SVM), Random Forest (RF), Visual Geometry Group-16 (VGG-16) and MobileNetV2. Combing SVM with VGG-16 for the task reached a stunning 99.00% accuracy for identifying PD, performing the best out of all tested models, demonstrating superior performance in the early identification of PD. The proposed approach not only outperforms existing diagnostic methods but also underscores the transformative potential of handwriting analysis tools in PD diagnosis, aiding in automatic PD detection and enhancing patient outcomes.*

Keywords: Parkinson's disease, handwriting analysis, deep learning, machine learning, early diagnosis

HYBRYDOWE MODELE DO DIAGNOZY CHOROBY PARKINSONA NA PODSTAWIE PISMA RĘCZNEGO

Streszczenie. *Choroba Parkinsona (PD) jest postępującym zaburzeniem neurodegeneracyjnym, które w głównej mierze upośledza funkcje motoryczne, prowadząc do objawów takich jak drżenie i mikrogracja. Wczesna identyfikacja PD jest kluczowa dla skutecznej interwencji, jednak istniejące metody diagnostyczne są wysoce inwazyjne i mało czułe na wczesne stadia choroby. Celem niniejszych badań było ustalenie, czy analiza pisma ręcznego może stanowić nieinwazyjny sposób diagnozowania PD na wczesnym etapie. Wykorzystaliśmy zbiór danych obejmujący 3 264 odręcznie rysowanych fal i spiral do oceny wydajności hybrydowych modeli uczenia maszynowego i głębokiego, w tym Maszyny Wektorów Nośnych (SVM), Lasu Losowego (RF), Visual Geometry Group-16 (VGG-16) oraz MobileNetV2. Połączenie SVM z VGG-16 osiągnęło imponującą dokładność na poziomie 99,00% w identyfikacji PD, przewyższając wszystkie testowane modele i wykazując doskonałą skuteczność we wczesnym rozpoznawaniu PD. Zaproponowane podejście nie tylko przewyższa istniejące metody diagnostyczne, lecz także podkreśla transformacyjny potencjał narzędzi do analizy pisma ręcznego w diagnozie PD, wspierając automatyczne wykrywanie choroby i poprawiając wyniki leczenia pacjentów.*

Słowa kluczowe: choroba Parkinsona, analiza pisma ręcznego, głębokie uczenie, uczenie maszynowe, wczesna diagnoza

Introduction

Parkinson's disease (PD) is the second most common neurological syndrome in the world after Alzheimer's disease [2]. Its progressive nature results in a spectrum of symptoms that profoundly affect motor functions essential for daily tasks such as movement coordination and execution [19]. The wide range of symptoms associated with PD creates an urgent need for improved diagnostic methods beyond traditional clinical assessments. The aging population, coupled with increased life expectancy, has led to an increase in the prevalence of PD worldwide. As a result, there's an urgent need for advances in early detection and real-time monitoring to optimize patient care and improve motor function regulation [5]. Recent advances in diagnostic methods offer promising avenues for improving PD diagnosis. From using machine learning algorithms to telemonitor tremor and voice analysis to exploring handwriting as an objective tool for early detection, researchers have taken innovative approaches to unraveling the complexities of PD diagnosis [15]. These efforts not only underscore the multifaceted nature of PD, but also highlight the transformative potential of technology to augment traditional diagnostic paradigms [16].

In this context, the goal of this research is to try and contribute towards the growing field of PD detection using hybrid machine/deep learning techniques with the addition of hand drawings. Further, building upon previous work in the field, we aim to utilize the complex kinematics of handwriting to aid in the earlier and more accurate identification of patterns relating to PD.

This document consists of five parts: The first part is the introduction, the second is the literature review, the third is the proposal of the study, the fourth is the results and discussions, and the final part is the conclusion.

1. Related works

Studies suggest that handwriting analysis can be useful for the early diagnosis and screening of Parkinson's Disease (PD). In [15], basic handwriting features were analyzed in order to identify patients with PD and healthy controls and achieved classification accuracy of 97.5 percent. Likewise, [5] air movement during handwriting and made accurate classifications for the diagnosis of PD. Additionally, [15] showed results of automated PD diagnosis within a group of dozens of patients using computer vision techniques and a deep learning set. Other studies include the attempt to identify PD with the use of handwritting movements, like in [16], where a CNN as a deep learning method for detecting PD was proposed. Also, in [6], the PaHaW database was introduced alongside results employing kinematic and pressure parameters of handwriting for the differential diagnostic of PD. In [17], the use of computer vision systems for the diagnosis of PD offered a technique based on the use of spirals and meanders in handwriting.

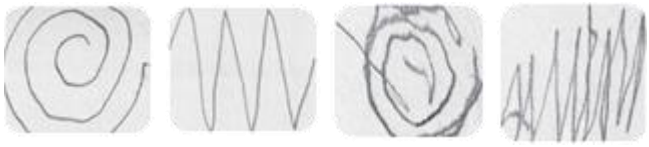
[21] studied handwriting anomalies, including micrographia, shedding light on the analysis of various kinematic features for PD diagnosis. In [9], dynamic handwriting analysis supported earlier PD diagnosis and exhibited promising specificity performance. Additionally, [18] utilized CNNs to extract features from handwriting images, achieving high accuracy in PD identification. [3] introduced biometric handwriting analysis, demonstrating high relevance in PD detection and evaluation. Moreover, [4] explored dynamically enhanced static handwriting representations for PD detection, surpassing traditional methods. In [14], visual attributes in handwriting were evaluated for PD prediction, yielding an overall accuracy of 83%. [7] proposed a machine learning approach using Histogram of Oriented Gradients for PD identification from handwritten images. Furthermore, [10] showcased the effectiveness of deep learning-based algorithms for early PD diagnosis using patient handwriting samples. [1] employed hybrid models for PD diagnosis, combining convolutional neural networks with figure-copying tasks, achieving high accuracy rates. In [13], a CC-Net (Continuous Convolution Network) was implemented to diagnose PD from Spiral Handwriting, achieving a classification accuracy of approximately 89.3%. In [1], a convolutional neural network focusing on figure-copying completed the task with an accuracy of 93.5% by differentiating between the PD patients and healthy controls. Finally, [12] introduced use of transfer learning through MobileNetV2 for PD

detection with hand drawings and achieved a remarkable accuracy of 97.70%. All these studies support each other and emphasize the promise of handwriting analysis as a crucial aid in improving early detection and diagnosis of Parkinson's disease.

2. Proposed work

2.1. Dataset

The dataset utilized in this research, obtained from Kaggle, is tailored for the prediction of Parkinson's disease using hand-drawn images, particularly focusing on spiral and wave patterns. Figure 1 shows examples of these patterns: (a,b) from healthy controls and (c,d) from Parkinson's disease patients. Initially limited in size, the dataset was expanded to 3264 images, divided into two distinct classes, through the implementation of data augmentation techniques detailed by B. Anil Kumar [12]. To build the classification model, the dataset was divided into 2611 images (80% of the total) for training and 653 images (20% of the total) for testing. Utilizing spiral analysis techniques, which examine spatial, dynamic, and kinematic aspects alongside motor function indicators, enables the evaluation of handwriting impairment. The study cohort, comprising 55 individuals, was collected from both healthy controls and Parkinson's disease patients. Among them, there were 28 healthy individuals and 27 Parkinson's disease patients, with mean ages of 71.32 years (Standard Deviation (SD): 7.21) and 71.41 years (SD: 9.37), respectively. Parkinson's disease patients exhibited a mean disease duration of 6.7 years, with a standard deviation of 4.44 years [22].



a b c d

Fig. 1. Spiral and wave samples from: (a,b) healthy control and (c,d) PD patient

2.2. Proposed methodology

The proposed methodology for this study employs a hybrid approach that combines deep learning (DL) and machine learning (ML) techniques to enhance the accuracy and robustness of Parkinson's disease diagnosis. Figure 2 illustrates the structure of the proposed methodology. In DL, neural networks are structured with multiple layers to directly learn complex patterns and features from raw data. DL models such as VGG16, VGG19, ResNet50, AlexNet, and MobileNetV2 excel at feature extraction from images, capturing intricate relationships and nuances within the data.

VGG16: developed by Karen Simonyan and Andrew Zisserman, consists of 13 convolutional layers, four max-pooling layers, and three fully connected layers, operating on input images of size 224x224 pixels with RGB channels [22].

VGG19: developed by the Visual Geometry Group at Oxford University, features 16 convolutional layers, 5 pooling layers, and 3 fully connected layers, operating on input images of the same size [22].

ResNet50: addresses the issue of vanishing or exploding gradients using a residual network architecture, comprising 48 convolutional layers, a MaxPool layer, and an Average Pool layer, iteratively applying the CNN architecture [8].

AlexNet: serves as the CNN architecture with various layers including input, convolution, pooling, dropout, and fully connected layers [8].

MobileNetV2: is a lightweight DL architecture tailored for mobile image classification tasks, offering improved performance with minimal computational requirements, ideal for transfer learning applications [12].

On the other hand, ML algorithms focus on learning patterns from labeled data for making predictions or decisions. The ML models employed in this study encompass decision tree, naive Bayes, K-nearest neighbors (KNN), support vector machine (SVM), and random forest.

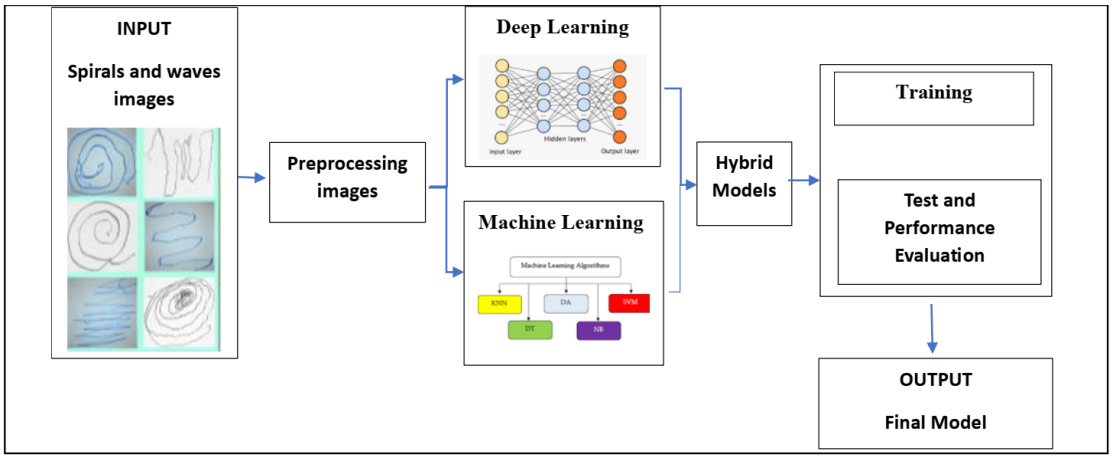


Fig. 2. Structure of the proposed methodology

Each ML algorithm offers unique strengths: decision tree's interpretability, naive Bayes' simplicity and efficiency, KNN's proximity-based classification, SVM's effectiveness in high-dimensional spaces, and random forest's ensemble learning for enhanced accuracy.

Decision Tree: A tree-based algorithm commonly used in data mining that categorizes input data into predefined classes for classification purposes [7].

Naive Bayes: is a probabilistic classifier that operates under the assumption of feature independence. It computes class probabilities by analyzing input features and assigns the label associated with the highest probability.

KNN: A popular machine learning method for image classification that relies on the distance between feature vectors to accurately classify images based on labeled data [7].

SVM: Transforms nonlinear data into a higher-dimensional space to achieve linear separability, with the goal of maximizing the distance between classes [20].

Random Forest: is a classifier consisting of multiple individual decision trees operating as an ensemble, with the final estimate determined by the class with the highest number of votes [7].

By integrating DL and ML approaches, we leverage the complementary advantages of both paradigms to enhance the overall performance of the PD diagnostic system. The utilization of multiple DL and ML frameworks facilitates the exploration of diverse architectural designs and learning mechanisms, thereby enhancing the adaptability and generalization capabilities of the diagnostic model.

3. Results and discussion

3.1. Performance metrics

Evaluation metrics for performance are indispensable tools used to gauge the effectiveness and accuracy of various models. These metrics, encompassing accuracy, precision, recall, and F1 score, are pivotal in making predictions based on provided data. When analyzing these metrics, four key components are considered:

- True Negatives (TN): Accurately identifying negative cases.
- True Positives (TP): Correctly identifying positive cases.
- False Positives (FP): Incorrectly predicting positive results for cases that are actually negative.
- False Negatives (FN): Erroneously predicting negative outcomes for cases that are truly positive.

The formulas for calculating these metrics are as follows:

$$\text{Accuracy} = (TP+TN)/(TP+TN+FP+FN) \quad (1)$$

$$\text{Precision} = TP/(TP+FP) \quad (2)$$

$$\text{Recall} = TP/(TP+FN) \quad (3)$$

$$\text{F1\_Score} = (2*\text{Precision}*\text{Recall})/(\text{Precision}+\text{Recall}) \quad (4)$$

$$\text{Speceficity} = TP/(TP+FN) \quad (5)$$

3.2. Model selection

In analyzing the effectiveness of the classification models outlined in Fig. 3, it's evident that MobileNetV2 stands out as the most proficient model among the deep learning architectures. With an accuracy of 93.00% and sensitivity of 93.00%, MobileNetV2 demonstrates exceptional overall performance in Parkinson's disease classification. These results are further bolstered by an F1 score of 93.00%, indicating a balanced ability to detect both true positives and true negatives. Additionally, its specificity of 94.00% underscores its capability to correctly identify negative cases. Thus, MobileNetV2 emerges as the optimal choice for Parkinson's disease diagnostic applications owing to its remarkable efficacy in image classification.

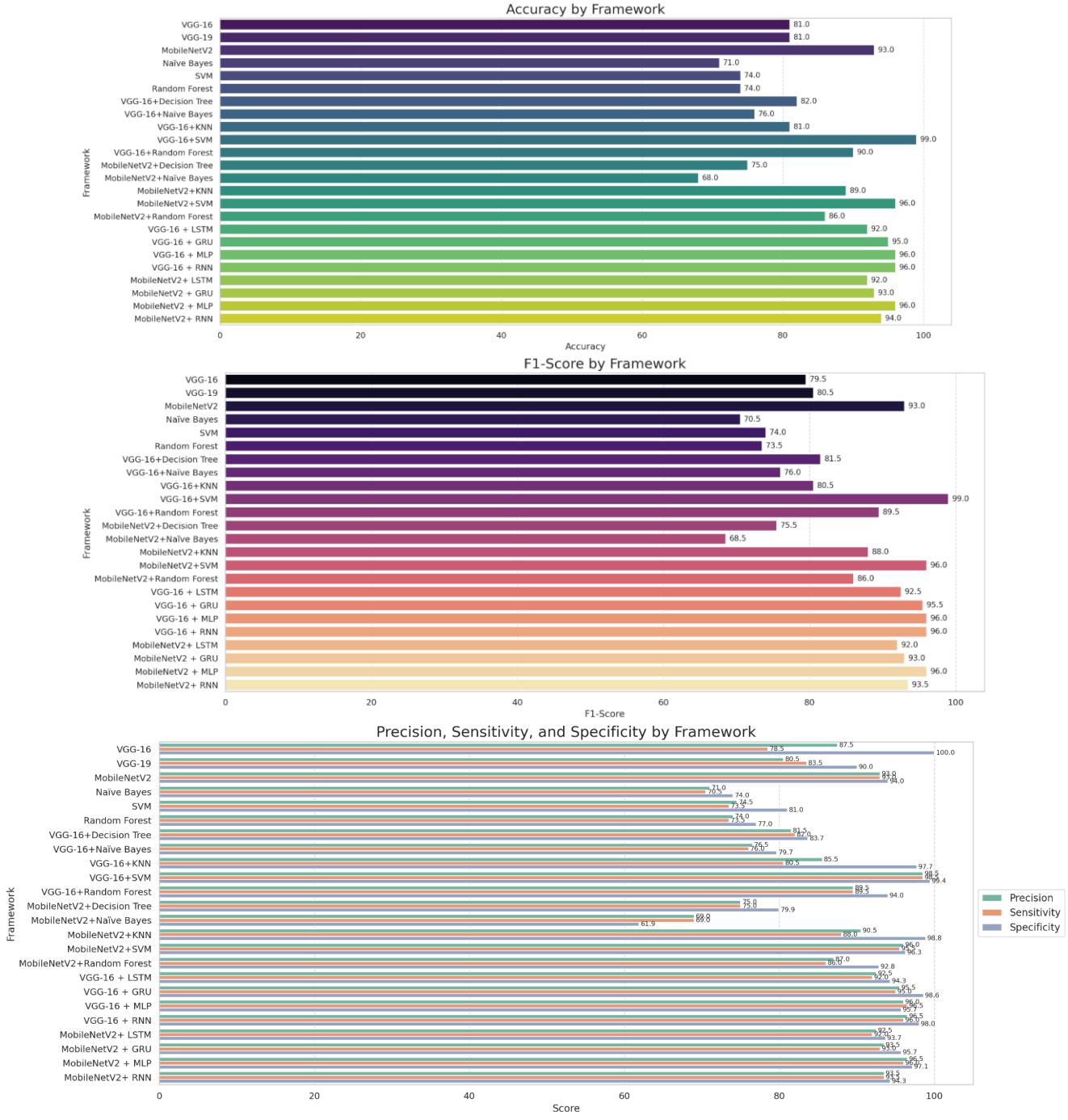


Fig. 3. Evaluation metrics for hybrid model performance

The combination of deep learning architectures such as VGG-16 and MobileNetV2 with various machine learning and deep learning frameworks has proven highly effective for classifying Parkinson's disease. Leveraging the feature extraction capabilities of VGG-16 and MobileNetV2, these hybrid models capture critical attributes from images that are then used for classification tasks.VGG-16 combined with SVM stands out with exceptional performance, achieving an accuracy of 99.00%, a sensitivity of 98.50%, and a specificity of 99.43%, making it one of the most effective models for this task. In contrast, the combination of VGG-16 with Naïve Bayes shows the lowest performance, with an accuracy of 76.00%, indicating that not all machine learning algorithms can optimally utilize the features extracted by VGG-16. MobileNetV2 shows similar trends, where the combination with SVM also performs remarkably well, achieving an accuracy of 96.00%. However, combinations such as MobileNetV2 with Naïve Bayes yield lower accuracy (68.00%), suggesting the superiority of SVM for this application. Hybrid deep learning models also show strong results, particularly with VGG-16 + MLP and VGG-16 + RNN, both achieving an accuracy of 96.00%, illustrating the efficiency of combining deep learning with other advanced neural network architectures for Parkinson's disease classification. Overall, SVM emerges as the top-performing algorithm when paired with both VGG-16 and MobileNetV2, highlighting its robustness in detecting Parkinson's disease when coupled with deep learning feature extractors.

The radar chart in Fig. 4 provides a comprehensive comparison of the leading hybrid models across multiple evaluation metrics. Among the tested approaches, the CNN–SVM hybrid demonstrates the most consistent and superior performance, maintaining high values in accuracy, precision, recall, F1-score, and specificity. Conversely, models combined with Naïve Bayes exhibit weaker outcomes, especially in recall and precision, which suggests limited generalization capacity. The Random Forest and Decision Tree hybrids achieve intermediate results, offering a balance between interpretability and reliability, but still underperform compared to the SVM-based framework. Overall, the visualization highlights that the integration of a convolutional feature extractor with SVM provides the most stable and effective classification performance within this experimental setup.

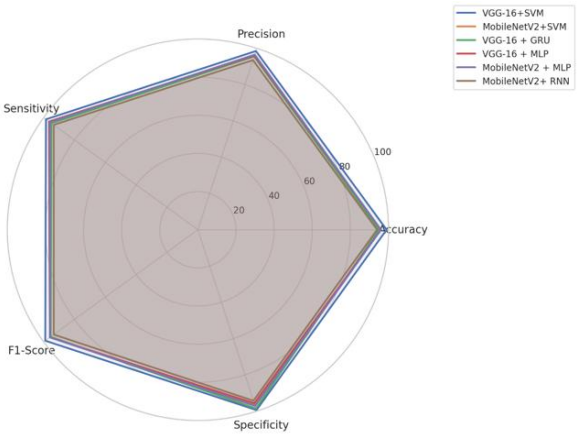


Fig. 4. Comparison of top-performing hybrid models

The results of our study demonstrate the efficacy of our hybrid VGG-16 + SVM model in the analysis of the confusion matrix in Figure 5. This model obtained an outstanding accuracy of around 99% when tested on spiral and wave drawing analyses individually. The combined integration of VGG-16 and SVM resulted in strong feature discrimination performance where PD patients and healthy controls were identified with high precision. This method achieves favorable accuracy in distinguishing PD patients from healthy controls and thus is suitable for early and preventive diagnosis of PD due to the accuracy achieved as seen in the confusion matrix in comparison to the data presented in the literature report [1]. Furthermore, we performed a comparative analysis of the articles in the "Related Works" section in terms of accuracy in Table 1. According to the results tabulated in Table 1, our work achieves the highest accuracy.

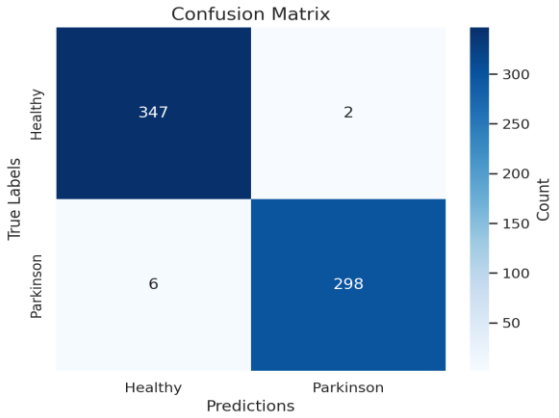


Fig. 5. VGG-16+SVM confusion matrix

Table 1. Performance comparison between our method and related works across multiple datasets.

DATASET	Subjects	Methodology	Accuracy (%)	Reference
HandPD	PD: 74 HC: 18	Naıve Bayes, Optimum-Path Forest SVM with RBF kernel	78.90 77.10 75.80	[15]
PaHaW	PD: 37 HC: 38	SVM AdaBoost K-NN	81.30 78.90 71.70	[6]
PaHaW	PD: 37 HC: 38	KNN SVM-RBF SVM-Linear NB LDA RF ADA	67.90 71.33 68.24 57.29 66.81 73.38 62.81	[9]
PaHaW	PD: 37 HC: 38	SVM	83.00	[14]
Kaggle	PD: 27 HC: 28	RESNET-50 + SVM	98.45	[22]
Their dataset (Custom)	PD: 43 HC: 43	CC-Net	89.30	[13]
Their dataset (Custom)	PD: 58 HC: 29	CNN (19 layers)	93.53	[1]
Kaggle	PD: 27 HC: 28	MMNV2	97.70	[12]
Kaggle	PD: 27 HC: 28	VGG-16 + SVM	99 .00	this work

4. Conclusion

The timely identification of Parkinson's disease is crucial for enhancing treatment outcomes. Our research concentrates on early detection utilizing hand-drawn images, particularly spirals and waves, which mirror the motor impairments linked with Parkinson's disease. We extensively explored various machine learning and deep learning models, such as SVM, RF, VGG-16, and MobileNetV2, within a hybrid framework. Notably, our hybrid model, amalgamating VGG-16 and SVM, demonstrated exceptional performance, achieving an accuracy rate of 99.00%, sensitivity of 98.50%, and specificity of 99.43%. These findings highlight the potential of our innovative approach in enhancing early detection strategies for Parkinson's disease.

In summary, our research contributes to ongoing efforts to improve Parkinson's disease diagnosis through novel computational methods. By applying deep and machine learning techniques to hand-drawn image datasets, we provide a valuable tool for clinicians and researchers to advance the early detection and management of Parkinson's disease, thereby improving patient care and quality of life.

Looking ahead, our future work will involve combining handwriting and speech simultaneously to effectively diagnose Parkinson's disease.

Acknowledgment

The authors would like to acknowledge the support of the National Center for Scientific and Technical Research (CNRST) of Morocco through the "PhD-ASsociate Scholarship – PASS" program.

Data availability statement

The dataset used in this study is publicly available and can be accessed at Kaggle [8].

Declarations

Conflict of interest: The authors declare no competing interests.

References

[1] Alissa M. et al.: Parkinson's Disease Diagnosis Using Convolutional Neural Networks and Figure-Copying Tasks. Neural Computing and Applications 34(2), 2022, 1433–1453 [https://doi.org/10.1007/s00521-021-06469-7].
[2] Benba A., Jilbab A., Hammouch A.: Using Human Factor Cepstral Coefficient on Multiple Types of Voice Recordings for Detecting Patients with Parkinson's Disease. IRBM 38(6), 2017, 346–351 [https://doi.org/10.1016/j.irbm.2017.10.002].
[3] Cascarano G. D. et al.: Biometric Handwriting Analysis to Support Parkinson's Disease Assessment and Grading. BMC Medical Informatics and Decision Making 19(9), 2019, 252 [https://doi.org/10.1186/s12911-019-0989-3].
[4] Diaz M. et al.: Dynamically Enhanced Static Handwriting Representation for Parkinson's Disease Detection. Pattern Recognition Letters 128, 2019, 204–210 [https://doi.org/10.1016/j.patrec.2019.08.018].
[5] Drotár P. et al.: Analysis of In-Air Movement in Handwriting: A Novel Marker for Parkinson's Disease. Computer Methods and Programs in Biomedicine 117(3), 2014, 405–411 [https://doi.org/10.1016/j.cmpb.2014.08.007].
[6] Drotár P. et al.: Evaluation of Handwriting Kinematics and Pressure for Differential Diagnosis of Parkinson's Disease. Artificial Intelligence in Medicine 67, 2016, 39–46 [https://doi.org/10.1016/j.artmed.2016.01.004].
[7] Ferdib-Al-Islam, Akter L.: Early identification of Parkinson's disease from hand-drawn images using histogram of oriented gradients and machine learning techniques. Emerging Technology in Computing, Communication and Electronics (ETCCE). Bangladesh, 2020, 1–6 [https://doi.org/10.1109/ETCCE51779.2020.9350870]
[8] https://www.kaggle.com/datasets/banilkumar20phd7071/handwritten-parkinsons-disease-augmented-data (available: 28.12.2024)
[9] Impedovo D., Pirlo G., Vessio G.: Dynamic Handwriting Analysis for Supporting Earlier Parkinson's Disease Diagnosis. Information (Switzerland) 9(10), 2018 [https://doi.org/10.3390/info9100247].
[10] Kamran I. et al.: Handwriting Dynamics Assessment Using Deep Neural Network for Early Identification of Parkinson's Disease. Future Generation Computer Systems 117, 2021, 234–244 [https://doi.org/10.1016/j.future.2020.11.020].
[11] Karapinar Senturk Z.: Early Diagnosis of Parkinson's Disease Using Machine Learning Algorithms. Medical Hypotheses 138, 2020 [https://doi.org/10.1016/j.mehy.2020.109603].
[12] Kumar B. A., Bansal M.: A Transfer Learning Approach with MobileNetV2 for Parkinson's Disease Detection Using Hand-Drawings. 14th International Conference on Computing Communication and Networking Technologies (ICCCNT), IEEE, 2023 [https://doi.org/10.1109/ICCCNT56998.2023.10307641].
[13] Li Z. et al.: Early Diagnosis of Parkinson's Disease Using Continuous Convolution Network: Handwriting Recognition Based on Off-Line Hand Drawing Without Template. Journal of Biomedical Informatics 130, 2022, 104085 [https://doi.org/10.1016/j.jbi.2022.104085].
[14] Moetesum M. et al.: Assessing Visual Attributes of Handwriting for Prediction of Neurological Disorders – A Case Study on Parkinson's Disease. Pattern Recognition Letters 121, 2019, 19–27 [https://doi.org/10.1016/j.patrec.2018.04.008].
[15] Pereira C. R. et al.: A Step Towards the Automated Diagnosis of Parkinson's Disease: Analyzing Handwriting Movements. Proceedings – IEEE Symposium on Computer-Based Medical Systems (CBMS), IEEE, 2015, 171–176 [https://doi.org/10.1109/CBMS.2015.34].
[16] Pereira C. R. et al.: Deep Learning-Aided Parkinson's Disease Diagnosis from Handwritten Dynamics. SIBGRAPI Conference on Graphics, Patterns and Images, IEEE, 2016, 340-346 [https://doi.org/10.1109/SIBGRAPI.2016.054].
[17] Pereira C. R. et al.: A New Computer Vision-Based Approach to Aid the Diagnosis of Parkinson's Disease. Computer Methods and Programs in Biomedicine 136, 2016, 79–88 [https://doi.org/10.1016/j.cmpb.2016.08.005].
[18] Pereira C. R. et al.: Handwritten Dynamics Assessment through Convolutional Neural Networks: An Application to Parkinson's Disease Identification. Artificial Intelligence in Medicine 87, 2018, 67–77 [https://doi.org/10.1016/j.artmed.2018.04.001].
[19] Rosenblum S. et al.: Handwriting as an Objective Tool for Parkinson's Disease Diagnosis. Journal of Neurology 260(9), 2013, 2357–2361 [https://doi.org/10.1007/s00415-013-6996-x].
[20] Sivaranjini S., Sujatha C. M.: Deep Learning-Based Diagnosis of Parkinson's Disease Using Convolutional Neural Network. Multimedia Tools and Applications 79(21–22), 2020, 15467–15479 [https://doi.org/10.1007/s11042-019-7469-8].
[21] Thomas M., Lenka A., Pumar Pal K.: Handwriting Analysis in Parkinson's Disease: Current Status and Future Directions. Movement Disorders Clinical Practice 4(6), 2017, 806–818 [https://doi.org/10.1002/mdc3.12552].
[22] Varalakshmi P. et al.: Diagnosis of Parkinson's Disease from Hand Drawing Utilizing Hybrid Models. Parkinsonism and Related Disorders 105, 2022, 24–31 [https://doi.org/10.1016/j.parkreldis.2022.10.020].

M.Sc. Asma Ouabd
e-mail: asma_ouabd@um5.ac.ma

She's a Ph.D. student in engineering sciences and technologies at the National School of Computer Science and Systems Analysis (ENSIAS). She received her master's degree in electrical engineering from the National School of Arts and Crafts (ENSAM) of Rabat, Mohammed V University, Rabat, Morocco, in 2023. Currently, she is also working as a student researcher in the Electronic Systems Sensors and Nanobio-technologies (E2SN) research team at ENSAM-RABAT. Her main research focus is on the use of intelligent systems for the diagnosis of Parkinson's disease.

https://orcid.org/0009-0009-8623-3350

Ph.D. Achraf Benba
e-mail: a.benba@um5r.ac.ma

He's a professor at ENSAM (National School of Arts and Crafts) in Rabat, Morocco. He holds a Ph.D. in electrical engineering from ENSIAS and a master's degree in electrical engineering from the Higher Normal School of Technical Education. His research focuses on the use of speech analysis to detect Parkinson's disease and other neurological disorders. He integrates his electrical engineering expertise with a passion for biomedical applications to drive innovation and make significant contributions to the field.

https://orcid.org/0000-0001-7939-0790

Ph.D. Abdelilah Jilbab
e-mail: abdelilah.jilbab@ensam.um5.ac.ma

He's a professor at ENSAM (National School of Arts and Crafts) in Rabat, Morocco. He earned his degree in electronic and industrial computer aggregation in 1995. Since 2003, he has been actively involved as a member of the LRIT laboratory, which is associated with the National Center for Scientific and Technical Research and the Faculty of Sciences in Rabat (FSR) at Mohammed V University. He completed his Ph.D. in computer and telecommunications from Mohammed V-Agdal University in Rabat in 2009. His research interests primarily focus on signal processing and embedded systems.

https://orcid.org/0000-0002-1577-9040

Ph.D. Ahmed Hammouch
e-mail: a.hammouch@um5r.ac.ma

He's a professor at ENSAM (National School of Arts and Crafts) in Rabat, Morocco. He holds a Ph.D. in computer science and telecommunications from Mohammed V University, Rabat, and in Electronics, Electrical Engineering, and Automation from the University of Haute Alsace, Mulhouse, France. With extensive academic experience, including roles as a professor at Mohammed V University and leadership positions in research and innovation, his research focuses on multimedia computing and telecommunications, with notable contributions to international publications.

https://orcid.org/0009-0005-8691-6662