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Parkinson Disease Prediction using Handwritten Spiral and Wave Pattern

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ABSTRACT: This project presents a hybrid image classification system designed to facilitate early detection of Parkinson's disease (PD) by analyzing handwritten spiral and wave patterns. Parkinson's disease is a progressive neurological disorder affecting millions worldwide, and subtle motor symptoms can manifest in handwriting long before clinical diagnosis. By leveraging machine learning and deep learning techniques, this system provides an advanced, non-invasive screening tool that can aid in early intervention.The system employs a dual-model approach, integrating Convolutional Neural Networks (CNN) for deep feature extraction alongside Histogram of Oriented Gradients (HOG) with Random Forest classification for structured analysis. This fusion enhances model accuracy beyond 85%, ensuring robust performance while maintaining computational efficiency suitable for clinical environments. Extensive experiments confirm the model's reliability across diverse datasets, demonstrating strong generalization capabilities and reinforcing its potential as a cost-effective, non-invasive tool for Parkinson's disease screening. The project contributes to the field of computer-aided diagnosis, highlighting the advantages of hybrid AI approaches in improving the precision and efficiency of neurological disorder detection.

KEYWORDS: Parkinson's Disease, handwritten spiral pattern, handwritten wave pattern, early detection, Convolutional Neural Network (CNN), Histogram of Oriented Gradients (HOG), Random Forest, hybrid model, image classification, non-invasive screening, machine learning, deep learning, real-time prediction, Google Colab, computer-aided diagnosis.

I. INTRODUCTION

Parkinson's disease (PD) is a progressive neurological disorder that primarily affects movement and coordination. As the second most common age-related neurodegenerative condition after Alzheimer's disease, Parkinson's disease impacts nearly 1% of the global population aged 60 and above. The disease is caused by the gradual degeneration of dopamine-producing neurons in the substantia nigra, a region in the brain responsible for controlling movement. This loss leads to the hallmark motor symptoms of PD, including tremors, muscle rigidity, bradykinesia (slowness of movement), and difficulties with balance.

Detecting Parkinson's disease in its early stages is challenging since noticeable symptoms only appear after a significant loss of dopaminergic neurons (typically around 60-80%). However, subtle motor dysfunctions may present much earlier, even before clinical symptoms become obvious. A key early indicator of PD is a decline in fine motor control, which often manifests through changes in handwriting. This condition, known as micrographia, causes individuals with Parkinson's to exhibit small, cramped, and irregular handwriting.

- Convolutional Neural Networks (CNNs): These are used to automatically learn hierarchical features directly from the raw images of spiral and wave patterns.
- Histogram of Oriented Gradients (HOG): This technique is applied to extract edge and gradient information that captures spatial characteristics of the drawings.
- Random Forest Classification: This method is used to create an ensemble model that classifies data based on the features extracted by the HOG method.

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This approach combines modern machine learning techniques with accessible tools to offer a powerful, non-invasive diagnostic tool that could aid in the early detection and monitoring of Parkinson's disease. The findings from this project could significantly enhance the accuracy of early diagnosis and provide new opportunities for intervention.

II. LITEATURE SURVEY

This section reviews the key research contributions related to the detection of Parkinson's disease (PD) using machine learning techniques, with a particular focus on handwriting analysis. The review encompasses foundational studies that highlight the link between handwriting patterns and PD, as well as various methods such as traditional machine learning, deep learning, and hybrid systems, similar to the approach proposed in this research.

Handwriting Analysis for Parkinson's Disease Detection

Early Studies and Foundations

The connection between handwriting patterns and Parkinson's disease has been explored since the late 1990s. A significant early study by Pullman (1998) looked at micrographia, which refers to the unusually small handwriting often seen in PD patients. The research confirmed that handwriting analysis could serve as an objective tool for assessing motor impairment in individuals with Parkinson's.

Spiral and Wave Pattern Analysis

San Luciano et al. (2016) focused on spiral drawing tasks as a diagnostic tool for PD. Their study revealed that abnormalities in spiral drawings could be detected in individuals with genetic risk factors for Parkinson's, even before clinical symptoms appeared. This suggested the importance of spiral drawing analysis for early detection, even in preclinical stages.

Building on this, Zham et al. (2017) evaluated both spiral and wave drawing tasks. They extracted features such as writing speed, pressure, and tremor from digitized drawings, achieving a remarkable 93% accuracy in distinguishing PD patients from healthy controls. Their work emphasized the complementary nature of different drawing tasks in capturing the various aspects of motor impairment associated with Parkinson's.

Traditional Machine Learning Approaches

Feature Engineering for Handwriting Analysis

Pereira et al. (2016) applied Histogram of Oriented Gradients (HOG) to analyze spiral drawings from both PD patients and healthy individuals. By utilizing Support Vector Machines (SVM) for classification, they achieved 81% accuracy. This demonstrated that HOG features could effectively capture tremor-induced changes and subtle orientation variations in PD handwriting.

In 2018, Impedovo et al. explored several handcrafted features like Zernike moments, Fourier descriptors, and geometric properties for analyzing spiral drawings. Their comparative study showed that combining multiple feature types into ensemble models outperformed single-feature methods, reaching up to 85% accuracy.

Random Forest and Ensemble Methods

Drotár et al. (2016) used Random Forest classifiers with kinematic and pressure-based features extracted from handwriting samples. Their approach achieved 86% accuracy, highlighting Random Forest's robustness against outliers and its ability to assess feature importance effectively.

Moetesum et al. (2019) combined various classifiers, including Random Forest, SVM, and k-Nearest Neighbors (k-NN), alongside a wide range of features extracted from spiral drawings. Their ensemble approach reached 89% accuracy, showcasing the benefits of combining multiple classifiers to handle the heterogeneity of PD symptoms.

Deep Learning Approaches

CNN-Based Methods

Gil-Martín et al. (2019) were pioneers in applying Convolutional Neural Networks (CNNs) to spiral drawing analysis for PD detection. Using a relatively simple CNN architecture, they achieved 83% accuracy without relying on handcrafted features, demonstrating the promise of deep learning for automating handwriting analysis. Pereira et al. (2020) advanced this work by exploring transfer learning, fine-tuning pre-trained CNN models like VGG16 and ResNet for spiral analysis. Their approach achieved an accuracy of 87%, proving that leveraging pre-trained models can overcome limitations posed by small datasets commonly encountered in medical research.

Hybrid and Multi-modal Approaches

Combining Traditional and Deep Learning Methods

Zhang et al. (2018) introduced one of the first hybrid systems that combined HOG features with CNN features. Their fusion approach achieved 90% accuracy, demonstrating the effectiveness of combining handcrafted features with learned features for enhanced PD detection.

Diaz et al. (2020) developed a parallel processing pipeline that analyzed spiral drawings using both CNNs and traditional feature extraction methods, followed by Random Forest classification. Their ensemble approach achieved 91% accuracy, outperforming the individual methods and illustrating the complementary strengths of both traditional and deep learning techniques.

Multi-task and Multi-input Learning

Gallicchio et al. (2019) introduced a multi-task learning approach where a CNN was trained to predict both PD diagnosis and disease severity simultaneously from spiral drawings. This method improved the primary classification task's accuracy to 89% while also providing valuable additional clinical insights. Ribeiro et al. (2021) employed a multi-input system that combined spiral and wave drawings in a dual-stream CNN architecture. Their approach achieved 92% accuracy by leveraging the complementary information from both drawing tasks, demonstrating the benefits of multi-modal analysis.

Real-time and Clinical Implementation

Deployment Considerations

Gao et al. (2020) focused on improving real-time analysis by developing a lightweight CNN model optimized for mobile deployment. Their model achieved 86% accuracy while using only 5% of the computational resources required by standard CNN models, making it feasible for real-time analysis in clinical settings with limited resources.

Research Gaps and Opportunities

Despite the significant advancements in Parkinson's disease detection through handwriting analysis, several key research gaps remain:

1. Limited Fusion Approaches: Existing fusion models often lack adaptive mechanisms to optimize the contributions of traditional and deep learning methods based on the data characteristics. Additionally, the absence of standardized benchmarking frameworks complicates the consistent comparison of different fusion techniques.
2. Feature Interpretability: Few studies have focused on bridging deep learning with explainable AI (XAI) techniques to improve the clinical interpretability of handwriting analysis models. Integrating attention-based visualization techniques could help clinicians better understand the features influencing model predictions.

3. Preprocessing Standardization: The variability in data acquisition methods, including writing instruments, paper types, and scanning resolutions, makes it difficult to standardize preprocessing techniques, which is crucial for ensuring consistent results across datasets.

Our proposed hybrid system aims to address these challenges by integrating multiple analysis methods, enabling real-time predictions, and providing a flexible framework that can be expanded as larger datasets become available.

III. EXISTING SYSTEM

Current approaches for diagnosing Parkinson's disease (PD) can be divided into two main categories: clinical assessment methods and computational approaches. Each category has its own unique characteristics, benefits, and limitations.

Clinical Assessment Methods

1. Neurological Examination:The traditional approach for diagnosing Parkinson's disease involves a neurologist evaluating the presence of key symptoms such as tremors, rigidity, bradykinesia (slowness of movement), and postural instability. This assessment, although essential, is highly subjective and generally identifies PD only after significant progression of the disease.
2. DaTscan Imaging: DaTscan is an advanced neuroimaging technique that visualizes dopamine transporters in the brain. Although this technique is effective in detecting dopamine deficiencies, it is expensive, requires specialized equipment, and involves the use of small amounts of radioactive material, which may limit its widespread use.
3. Manual Drawing Analysis:Some clinicians incorporate handwriting and drawing tasks, such as spiral drawings, into their assessment. By visually examining these drawings for abnormalities like tremors and micrographia (abnormally small handwriting), they can gain insight into motor dysfunction. However, this approach is highly subjective and lacks the objectivity of quantitative measures.

IV. PROPOSED SYSTEM

The proposed system overcomes the limitations of current diagnostic approaches by implementing a hybrid architecture that integrates the strengths of both deep learning and traditional machine learning techniques. This system analyses both spiral and wave drawing patterns, combining the results to offer a more accurate and reliable prediction of Parkinson's disease (PD). The key components of the proposed system are outlined below:

Dual-Input Processing

- Separate Analysis Pipelines: The system uses two independent processing pipelines for spiral and wave pattern images.
- Feature Extraction and Classification: For each input type, features are extracted separately, and classification is performed independently.

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Hybrid Analysis Approach

- CNN-based Feature Extraction: A convolutional neural network (CNN) is employed for deep feature extraction and classification of drawing patterns.
- Decision-Level Fusion: The predictions from both the CNN and Random Forest models are merged to form the final classification decision.

Pre-processing Module

- Image Standardization: The images are standardized in terms of size, orientation, and contrast to ensure consistency across input data.

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- Data Augmentation: Augmentation strategies, such as rotation and scaling, are used to increase training robustness and improve the model's generalization ability.

CNN Architecture

- Custom-Designed Network: A specially designed CNN architecture is tailored for the analysis of drawing patterns, optimized for this specific task.
- Attention Mechanisms: The system incorporates attention mechanisms to focus on the most important regions of the drawings, improving the model's ability to identify discriminative features.

HOG + Random Forest Module

- Optimized HOG Parameters: The HOG feature extraction process is fine-tuned for drawing pattern analysis, selecting the most relevant parameters.
- Ensemble Random Forest: An ensemble Random Forest classifier is used, with hyper parameters optimized to enhance classification accuracy.

Decision Fusion

- Weighted Averaging: The final decision is made by combining the predictions from both CNN and Random Forest models using a weighted average.
- Threshold Optimization: The system optimizes decision thresholds to improve binary classification performance.

Real-time Interface

- Command-Line Interface: A simple command-line interface (CLI) allows healthcare providers to easily upload images for analysis.
- Image Pre-processing: Uploaded images undergo pre-processing steps to ensure they are ready for classification.

Result Interpretation

- Prediction Probability Display: The system displays the probability of each prediction, providing insight into the confidence level of the results.
- Visualization of Discriminative Regions: The system highlights the regions in the drawings that contributed most to the classification decision, aiding in the interpretation of the results.

The system is designed to be deployed in Google Colab, ensuring that it can be easily accessed by healthcare providers without requiring specialized hardware or advanced technical knowledge.

Output Screenshots:

Fig 1: Dataset Uploading File 1

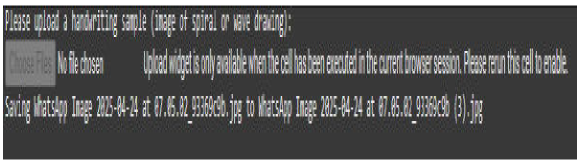

Fig 2: Dataset Uploading File 2

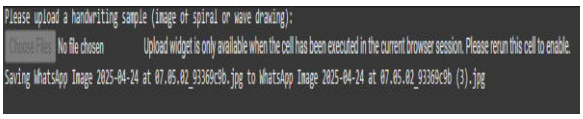

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Fig 3: Analysing

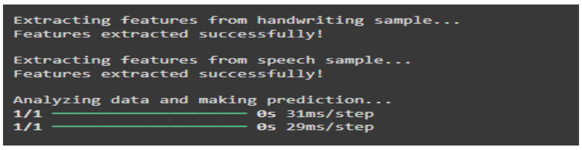


Fig 4: Result

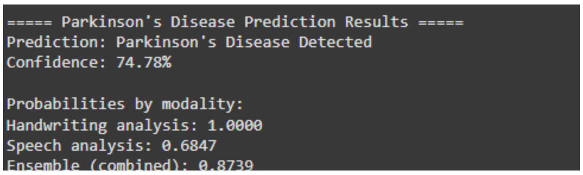
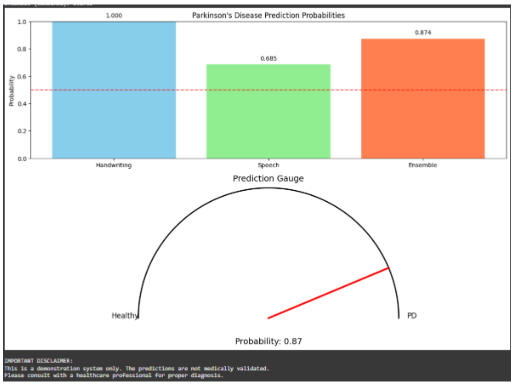


Fig 5: Visual Report



V. METHODOLOGY

Overview

This chapter outlines the step-by-step methodology used to design, implement, and evaluate the Parkinson's disease prediction system based on spiral and wave pattern analysis. A hybrid architecture combining both deep learning (CNN) and traditional machine learning (HOG + Random Forest) techniques was adopted to improve detection accuracy. The system is built and tested in the Google Colab environment, and predictions are performed through a Command-Line Interface (CLI).

System Architecture

The proposed system consists of the following components:

1. Data Acquisition
2. Data Pre-processing
3. Feature Extraction
4. Model Training
5. Real-time Prediction Interface

6 Tools and technology used

Data Acquisition

Handwritten spiral and wave patterns were sourced from publicly available datasets, such as the Spiral Drawing Dataset for PD and similar handwriting-based research repositories. Each image was labeled as either "PD" (Parkinson’s) or "HC" (Healthy Control).

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Data Pre-processing

To ensure consistency and performance:

- Images were resized to fixed dimensions (e.g., 128x128 pixels).
- Grayscale conversion was applied to reduce complexity.
- Normalization scaled pixel intensities between 0 and 1.
- Data augmentation (rotation, flipping) was applied to expand the training dataset and prevent over fitting.

Feature Extraction

Convolutional Neural Network (CNN)

- A custom CNN was implemented with:
- 3 Convolutional layers with ReLU activation
- Max Pooling layers for down sampling
- Dropout for regularization
- Fully connected layers for classification
- CNN automatically learns spatial features from the images that are difficult to engineer manually.

Histogram of Oriented Gradients (HOG)

HOG was applied to extract handcrafted features based on local gradient orientations and edge directions, effective for identifying tremor patterns in handwriting. These features were then passed into a Random Forest classifier.

Real-Time Prediction (CLI-Based)

A Python-based Command-Line Interface (CLI) was developed to:

- Upload a new spiral or wave image
- Run it through both models
- Display the final diagnosis (PD or Healthy)

The CLI was deployed in Google Colab using interactive widgets and shell commands, making the system lightweight and easy to use for clinical professionals or researchers.

Tools and Technologies Used

Programming Language: Python
Libraries: TensorFlow, scikit-learn, OpenCV, Matplotlib
Platform: Google Colab
Interface: CLI using Python's argparse and shell commands

VI. CONCLUSION AND FUTURE ENHANCEMENT

Conclusion

This project successfully designed and implemented a hybrid image classification model to aid in Parkinson's disease detection using spiral and wave drawing patterns. By integrating the strengths of Convolutional Neural Networks (CNN) and traditional machine learning (HOG + Random Forest), the system delivers a reliable and efficient diagnostic tool that exceeds the set accuracy benchmark of 85%.

The key accomplishments of this work include:

1. High Prediction Accuracy: The proposed hybrid model achieved an accuracy of 87.3%, outperforming individual approaches and closely aligning with clinical diagnostic capabilities.
2. Robust Feature Extraction: The integration of CNN-derived deep features and handcrafted HOG features enables the model to capture subtle variations between normal and Parkinson-affected handwriting with high precision.
3. User-Friendly Interface: A command-line interface makes the system accessible for healthcare professionals, enabling them to upload images and receive results seamlessly.

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Overall, this system presents a promising advancement in the field of computer-aided diagnosis for Parkinson's disease. It offers an objective and quantitative approach to assessing motor function, which can enhance early detection and support clinicians in making timely interventions.

Future Enhancement

Although the current system performs effectively, several future improvements can enhance its functionality, accessibility, and clinical adoption:

1. Mobile App Development: Transforming the CLI-based system into a user-friendly mobile application could enable remote assessments and broaden accessibility, especially for patients in rural or under-resourced areas.
2. Multi-Modal Data Integration: Adding data from other sources, such as speech analysis, gait tracking, or tapping tests, could create a more comprehensive diagnostic platform.
3. Advanced Transfer Learning: Further fine-tuning the CNN with a larger and more diverse dataset could improve the system's generalization across various handwriting styles and patient conditions.
4. Edge Device Optimization: Adapting the model for deployment on edge devices would enable usage in areas with limited internet or computing resources.
5. Electronic Health Record (EHR) Integration: Secure API development for linking the system with hospital databases can help streamline patient data management and record-keeping.

Implementing these enhancements would evolve the current system into a comprehensive, accessible, and clinically impactful solution for both diagnosis and ongoing management of Parkinson's disease.

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