Parkinson's Disease Detection from Spiral and Wave Drawings using Convolutional Neural Networks: A Multistage Classifier Approach

Sabyasachi Chakraborty*, Satyabrata Aich*, Jong-Seong-Sim*, Eunyoung Han**, Jinse Park**,

Hee-Cheol Kim*

* Department of Computer Engineering/Institute of Digital Anti-Aging Healthcare/u-HARC, Inje University, South Korea

** Department of Neurology, Haeundae Paik Hospital, Inje University, South Korea

c.sabyasachi99@gmail.com, satyabrataaich@gmail.com, jssin93@naver.com, heyewha@gmail.com, jinsepark@gmail.com, heeki@inje.ac.kr

Corresponding Author: heeki@inje.ac.kr

Abstract— **Identification of the correct biomarkers with respect to particular health issues and detection of the same is of paramount importance for the development of clinical decision support systems. For the patients suffering from Parkinson's Disease (PD), it has been duly observed that impairment in the handwriting is directly proportional to the severity of the disease. Also, the speed and pressure applied to the pen while sketching or writing something are also much lower in patients suffering from Parkinson's disease. Therefore, correctly identifying such biomarkers accurately and precisely at the onset of the disease will lead to a better clinical diagnosis. Therefore, in this paper, a system design is proposed for analyzing Spiral drawing patterns and wave drawing patterns in patients suffering from Parkinson's disease and healthy subjects. The system developed in the study leverages two different convolutional neural networks (CNN), for analyzing the drawing patters of both spiral and wave sketches respectively. Further, the prediction probabilities are trained on a metal classifier based on ensemble voting to provide a weighted prediction from both the spiral and wave sketch. The complete model was trained on the data of 55 patients and has achieved an overall accuracy of 93.3%, average recall of 94%, average precision of 93.5% and average f1 score of 93.94%**

Keywords— **Parkinson, CNN, deep learning, machine learning, classification**

I. INTRODUCTION

Parkinson's disease (PD) is known to be one of the most common neurodegenerative diseases among older people aged more than 65. Since this disease is progressive in nature, negligence in the diagnosis of this disease in the early stage and monitoring at different stages would create a severe negative impact on the patients in terms of healthcare costs as well as the severe health-related disorders. Some of the movement disorders symptoms such as rigidity, instability in posture, tremor, and bradykinesia are usually observed on the PD patients at different stages [1]. To prevent the major negative impact on PD patient's it is necessary to detect the PD at the early stage. One of the most common effects that are easily noticeable among the PD patients and used most commonly in the early stage of diagnosis is finding the difference in handwriting and sketching abilities [2, 3]. The non-invasive measures such as sketching of a shape such as spiral, waves, and other handwritten texts could be easily distinguished from one person to another person as well as a person with PD and a person without PD [4]. Previous researchers and clinicians already found some kind of association between the sketching of the spirals and handwriting in the early stages of the PD [5, 6]. However, the major drawback of these kinds of diagnoses needs proper interpretation of sketching and handwriting. Traditionally the sketching or handwritings were performed in the papers and interpreted manually by the interpreters specialized in those fields. With the availability of digital devices, it is easier to perform those tasks digitally as well as the assessments were done by the machine in a more precise and accurate manner compared to the traditional ways. Some of the common features present inside the sketches could be considered as the potential indicators to differentiate different group of subjects that includes healthy subjects and PD subjects and those tasks can be used to perform the reliability analysis in the real-time [7, 8]. In recent days the wisest decision for detecting something in real-time is to make the system automatic so that we can perform the same operation with less time as well as in a more precise way. In this respect machine learning techniques are more effective and shown enough potential to be used in real-life situations [9].

So, in this paper, an attempt has been made to develop an automated system that trained with the features extracted from the different sketches performed by the healthy group of patients as well as PD patients to assess the severity of the PD disease among different stages as well as between the healthy groups of patients. The investigation performed in this study to differentiate the healthy subjects from PD subjects based on the spiral sketches by extracting features from the images sketched by the healthy subjects and PD subjects. The structure of the paper is organized in the following way. Section 2 presents the past works. Section 3 presents the materials and methods in this paper. Section 4 presents the architecture of the model. Section 5 presents the results and discussion of the study. Section 6 presents the conclusion of this study.

II. RELATED WORKS

Some of the studies related to the implementation of the machine learning techniques for the development of an automated system using different datasets related to Parkinson's disease has been discussed here to support our studies. Zham et al. proposed a study that used two criteria such as speed, and pen-pressure while performing the sketches to distinguish PD subjects at different stages. They have extracted features from the sketches and proposed a method that can provide a correlation factor between the features and severity level of the PD. Finally, they performed the Mann-Whitney test to validate the study that these methods can be used to distinguish different stages of the PD. They observed that there was a significant difference in the correlation factor at different stages of PD [10]. Kotsavasiloglou et al., presented an investigation based on the trajectory of the tip of the pen on the surface of the pad while drawing simple horizontal lines by the healthy subjects and PD subjects. They extracted features from the simple drawings and trained the machine learning algorithms using those features to distinguish the PD subjects from the healthy subjects. They have used different classifiers such as Naïve Bayes, AdaBoost, Logistic Regression, J48, Support Vector Machine (SVM), and Random Forest classifiers to train the features for developing an automated system. The performance metrics used in that study were accuracy, Area under the curve (AUC), True positives (TP), and True negatives (TN). They achieved an accuracy of 91%, and TP of 0.88 and TN of 0.95[11].

Memedi et al. proposed a study based on the spiral data collected using telemetry touch screen devices in the home environments to distinguish off episodes and peak dose dyskinesia using machine learning algorithms. Several features were extracted from the data and used as input to the machine learning classifiers. They have used Support Vector Machine, Logistic Regression, Random Forest, and Multi-Layer Perceptron (MLP) to train the features for the development of automated systems and found MLP performed well among all the classifiers with an accuracy of 84% [12]. Aich et al. proposed a study that used a voice dataset to distinguish PD patients from others. They have used different feature selection techniques to find the best features that can be used to train different classifiers. The feature selection techniques used for that study is principal component analysis. Finally, a performance comparison study was performed using two groups of datasets such as original feature sets and PCA based feature sets using nonlinear decision tree-based classifiers. It was found that the random forest classifier (RFC) was the best classifier among them and PCA based feature set performance is better than the original feature sets. The best accuracy of 96.83% was found with RF classifier and PCA based feature sets [13].

III. METHODOLOGY

A. Data Collection and Specification

The data for the study has been collected from Kaggle's data repository which was posted by [7]. The data acquisition process was performed at the RMIT, University, Melbourne, Australia. For the data acquisition procedure, 55 subjects were recruited were 28 subjects belonged to the Control Group and 27 subjects from the Parkinson Group. All the subjects were asked to take two tests namely the Spiral drawing test and the Wave drawing test. The drawing of the spiral was captured using an A3 size commercially used a tablet, where an A3 paper was placed over the tablet and an ink pen was used to sketch the spiral and the wave. Figure 1 shows a sample of images that were obtained from the data acquisition process.

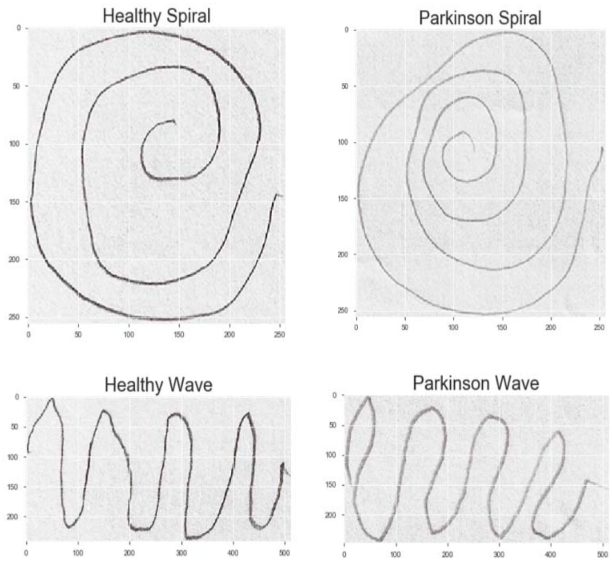


Figure 1. Sample Images for both the sketches and of both the classes.

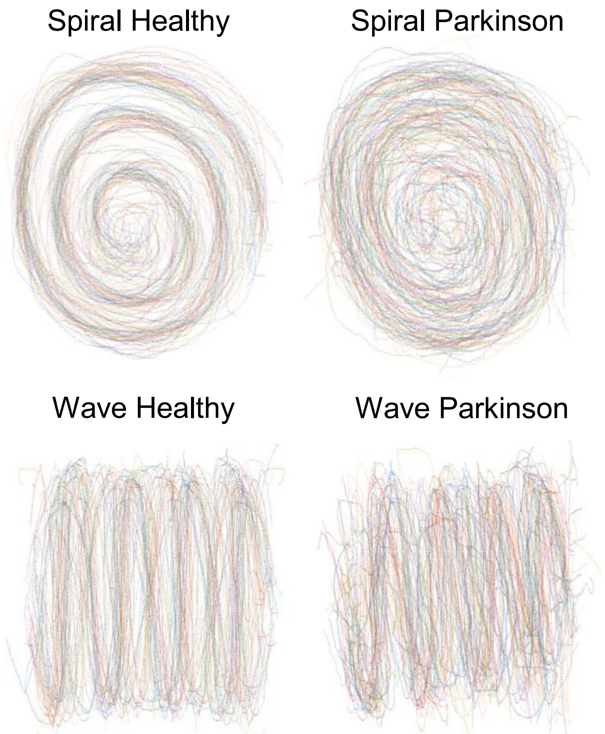


Figure 2. Overlapped Sketches of the Drawings made by Parkinson Patients and Healthy Subjects

Also, Figure 2 plotted above shows the overlapped sketches of all the patients divided into two classes namely, healthy subjects and Parkinson's subjects. In the figure, the irregularity in the sketching patterns of the patients suffering from Parkinson's disease can be duly observed in both the Spiral and Wave respectively.

B. Data Preprocessing and Augmentation

The images used in the study were subjected to resizing and histogram equalization. The images from the spiral sketches were resized to 256 px width and 256 px height, whereas the wave sketches were resized to the width of 256 px and height of 512 px. In the images that have been collected for the study, it can be observed that the images lack contrast and brightness and overall clarity. Therefore, contrast enhancement and adjustment were performed over all the images using Histogram equalization.

For the preparation of images for training, all the images were subjected to a static policy-based augmentation. As the number of images is quite less in the dataset, therefore, the application of Deep Learning algorithms such as CNN's becomes quite difficult. Therefore to ingest some synthetic samples in the training dataset and also to increase the diversity in the dataset image augmentations were performed. Table 1 and Table 2 below show the different image augmentation parameters which were applied to the training data for wave and spiral sketched respectively. Moreover, Figure 3 shows the histogram equalized and augmented images of the training data set from both wave and spiral sketches.

TABLE 1. DATA AUGMENTATION PARAMETERS FOR SPIRAL DRAWINGS

Augmentation Parameters	Settings
Horizontal Flip	True
Vertical Flip	True
Width Shift Range	0.1
Height Shift Range	0.1
Brightness Range	(0.5, 1.5)
Shear Range	0.2
Zoom Range	0.2
Max Crop Percentage	0.2
Crop Probability	0.3
Rotation Range	360

TABLE 2. DATA AUGMENTATION PARAMETERS FOR WAVE DRAWINGS

Augmentation Parameters	Settings
Horizontal Flip	True
Vertical Flip	True
Width Shift Range	0.1
Height Shift Range	0.1
Brightness Range	(0.3, 1.8)
Shear Range	0.2
Zoom Range	0.2
Max Crop Percentage	0.3
Crop Probability	0.1
Rotation Range	5

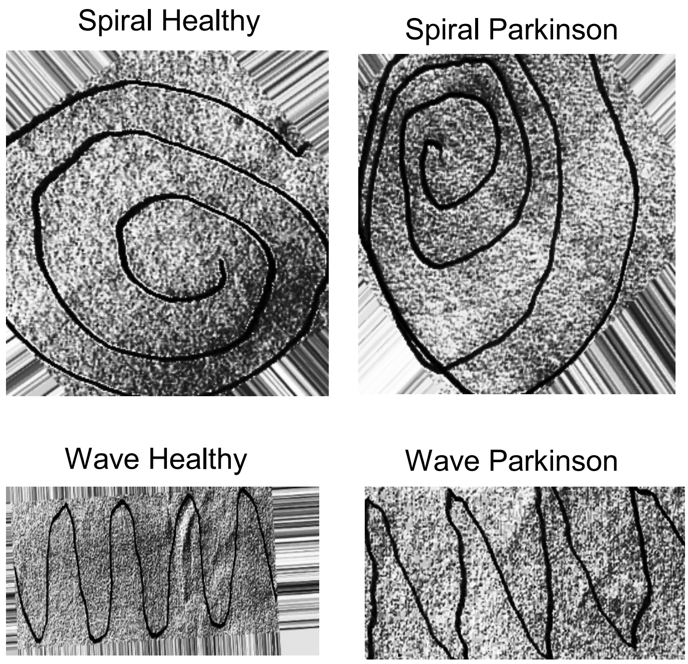


Figure 3. Histogram Equalized and Augmented Training Samples of both Spiral and Wave sketches from Parkinson's patients and Health patients.

C. Model Development

With the recent development in the field of machine intelligence after the advent of deep learning has plotted a paradigm shift in all the sectors. More specifically, in the healthcare sector, the emergence of deep learning and sophisticated computer-aided detection systems has levied to more precise and accurate diagnosis efficiently. In terms of Parkinson's disease, there are multiple biomarkers that need to be analyzed for determining the clinical condition of a particular patient. One of the widely observed impairments that are caused by Parkinson's disease is hand tremors and diffused motor flexibility in hands which leads to a decrease in the ability to sketch and write. Therefore, determining the ability measure of writing and sketching can be considered as a very important biomarker for determining the clinical progression and detection of Parkinson's disease.

In this study, a system is developed to analyze the sketching pattern of spirals and waves in patients suffering from Parkinson's disease and also the detection of Parkinson's disease. For the development of the system two-dimensional convolutional neural networks and voting-ensemble classifiers were used as shown in Figure 4 to analyze the sketching pattern and detection of Parkinson's disease. In the study, a total of 102 spiral sketched and 102 wave sketches were used to train and validate the system.

Figure 4 which describes the architecture of the complete system is basically divided into three different sections. The first section is the generator section that serves wave sketch and spiral sketch images for a particular patient. Section 2 describes

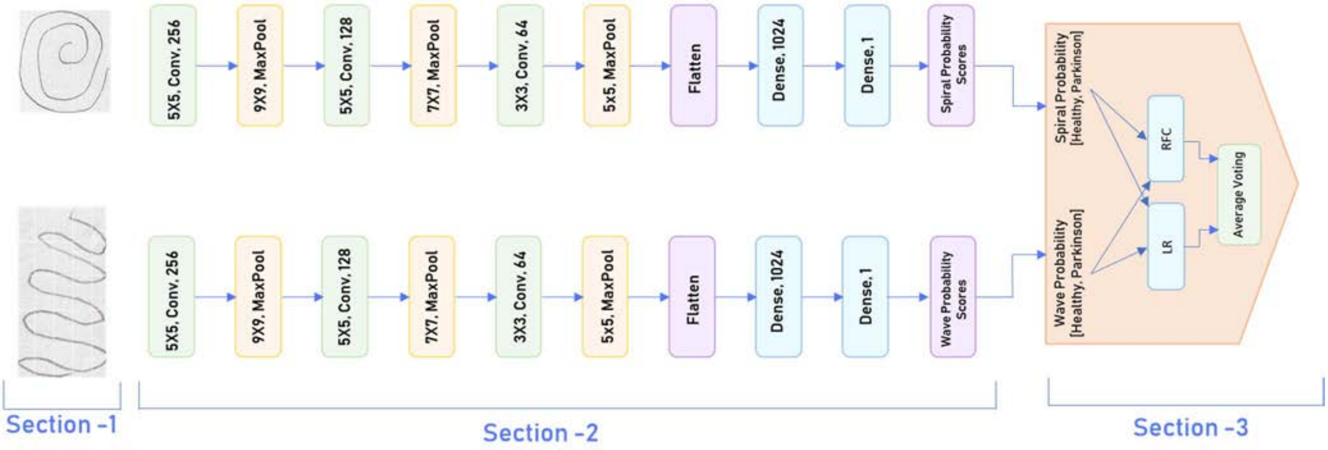


Figure 4 .Multistage Classifier Architecture

the convolutional neural network architecture that is responsible for generating the feature representations of the images and pass it through a fully connected dense layer for fetching the prediction probabilities of a particular type of image. Section 3 on the other defines the meat classifiers which will analyze the prediction probabilities of both the Convolutional Neural Network architectures and make a final prediction. For the development of meta classifier two different algorithms were used namely, Logistic Regression (LR) and Random Forest Classifier (RFC). Both classifiers take the Prediction Probabilities of wave and spiral convolutional neural network and predict the outcome that is health or Parkinson's disease. In the end, the predictions from both the classifiers are taken for average voting and the final outcome is presented.

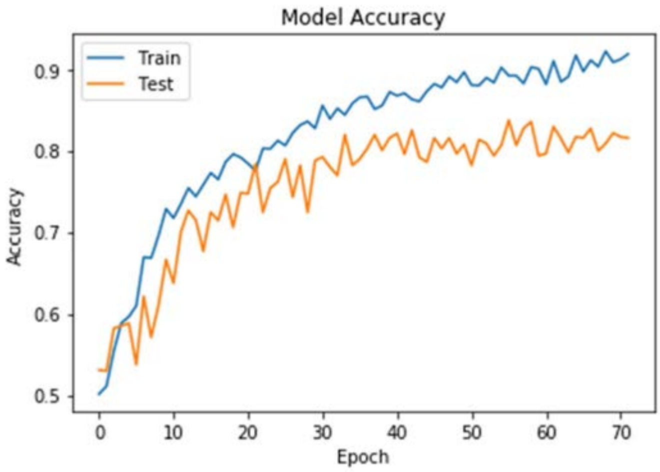
Both the convolutional neural networks model for wave and spiral sketches performed decently with respect to the number of true positives. But the initial null hypothesis that was crafted suggested that Healthy patients can be predicted as Parkinson's patients with minute misclassifications but there must not be single misclassification for Parkinson's patients. And this particular hypothesis was not accorded by the CNN models due to the presence of 2 and 3 misclassification in spiral and wave respectively for Parkinson's patients. Therefore, a combinatory analysis was ought to be performed and hence we leveraged the prediction probabilities of both the wave and spiral CNN model to train two distinct classifiers to get an Ensemble decision.

IV. Results

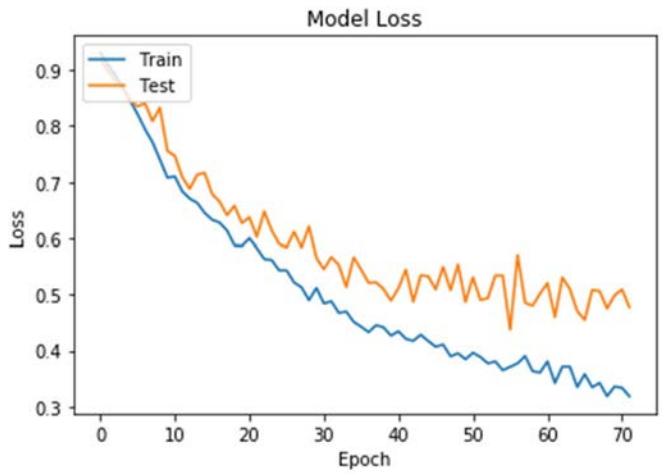
The multistage classifier that was developed in work by leveraging convolutional neural networks and machine learning algorithms provided us with some sound results in the detection of Parkinson's disease from Spiral and Wave Sketches. The model developed in the work prompted an accuracy of 93.3%, average recall of 94%, average precision of 93.5% and average f1 score of 93.94% respectively. Moreover, a 5 Fold cross-validation was also performed on the complete dataset to check the generalizability of the model and it was found that the model generalized pretty decently over the two classes and also showed a constant tendency towards the precision and recall over random data folds of training, validation, and testing. The testing dataset contained 30 images of wave sketch and 30 images of spiral sketch respectively. Figure 5 below shows the Confusion Matrix of the complete system which was derived after the process of average voting. It can be observed in the figure that the performance of the model is in full accordance with the hypothesis that was initially devised. Also, from the confusion matrix, we can observe that there are two misclassifications in the Healthy class which was predicted as Parkinson's disease. Now after closely analyzing the probabilities of those two misclassified samples it was found that the sketched made by those particular subjects were quite distorted which is partially similar to the drawing of the Parkinson's patients. Therefore, it can be a possibility that the person who is healthy and predicted as Parkinson may be a subject of progression as all the healthy subjects were chosen by matching the same age group.

Figure 5. Confusion Matrix

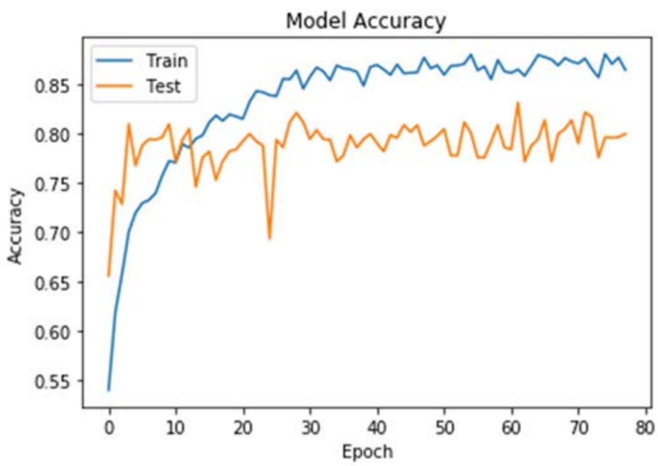
Moreover, Figure 6(a - d) has been plotted for reference to show the performance graph of the CNN models. Figure 6(a) and (b) represents the model performance of Spiral sketch-based CNN and Figure 6(c) and (d) show the model performance of the Wave sketch-based model. The performance graph shows that the model ran for 70 and 80 epochs for spiral and wave CNN respectively, whereas while fitting the model a maximum limit of the epoch was kept to be 600 while plotting an early stop protocol. The early stop protocol was developed in such a way that, if the validation loss does not decrease for consecutive 18 epochs by reducing the learning rate twice by the fraction of 0.8, then the model needs to be stopped.



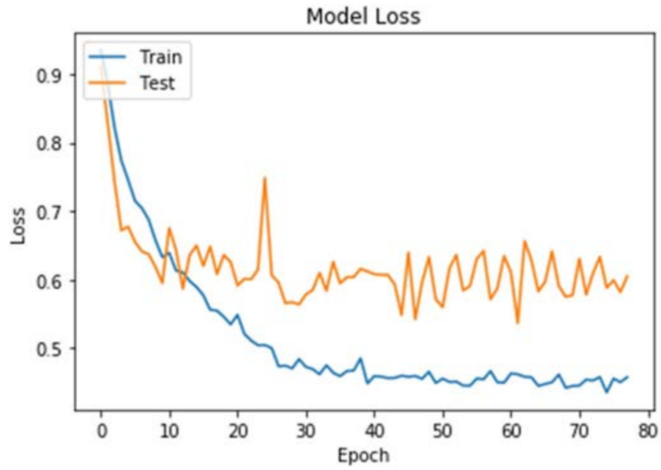
(a)



(b)



(c)



(d)

Figure 6. **(a)** Spiral Sketch CNN Model Accuracy **(b)** Spiral Sketch CNN Model loss **(c)** Wave Sketch CNN Model accuracy **(d)** Wave Sketch CNN Model loss.

V. Discussion

In this study, the authors focus on the development of a system based on the Multistage Classification approach for the analysis and the detection of Parkinson's disease from Wave and Spiral sketches. The ability to sketch, draw and write reduces tremendously with the increase in severity of Parkinson's disease. Therefore, understanding the patterns in sketching is considered to be an important biomarker when it comes to the detection of Parkinson's disease. The system developed for the purpose of prediction and detection performed pretty decently in terms of the initial devised hypothesis. For the development of the system, two convolutional neural networks were used to perform an initial analysis of the individual type of sketch. But it was observed that certain samples performed better for a wave-based model and certain samples in the spiral based model. Therefore, to enforce a combinatory decision based on both the image types, an ensemble voting was performed using a meta classifier. The meta classifier used two machine learning algorithms namely, Logistic Regression and Random Forest Classifier. Both the Algorithms were fitted individually with the prediction probabilities that were obtained from the CNN Models. Further the prediction probabilities of the individual meta classifiers were used to perform average voting and determine the state of a subject. And at the end it was found out that the prediction made by the average voting of meta classifiers completely adhered to the initial hypothesis that was devised.

VI. Conclusion

In this paper, a system based on multistage classification is developed by leveraging Convolutional Neural Networks and Ensemble Voting classifiers for the detection of Parkinson's disease from spiral and wave sketches. The work predominantly leveraged spiral and wave sketch data performed by Parkinson's patients and healthy subjects for classification purposes. The approach that has been proposed in the work lays out to be very decent in closely differentiating the sketches made by Parkinson's patients and healthy subjects. The model plotted an accuracy of 93.3%, average recall of 94%, average precision of 93.5% and average f1 score of 93.94% for both the classes respectively.

Now as the classifier results seem to be pretty decent but the methodology discussed in the paper and the performance of the classifier can be further improved. The improvements that can be made in the current methodology is that the number of data samples can be increased significantly, different types of drawing must be employed apart from spiral and wave and also multiple iterations can be made for choosing some state-of-the-art architecture for the second section. But the present system enabled us with much confidence that this kind of system can be employed in real-life scenarios and stable production environments.

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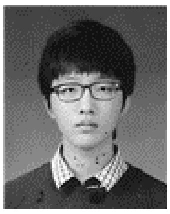
Sabyasachi Chakraborty is pursuing his Master's in computer engineering from Inje University. He has previously worked on multiple real-life projects related to computer vision, data sciences, biosignal analysis, and text mining. His research interest aligns with Computer Vision, Artificial Intelligence, BioSignal Processing, Algorithms, and Blockchain.

Satyabrata Aich is working as a research professor in the field of computer engineering. He has published many research papers in journals and conferences in the realms of Machine learning, Text mining, and Supply Chain Management. His research interests are natural language processing, Machine learning, supply chain management, Artificial Intelligence, Blockchain.



Sim Jong Seong is a graduate student of the Institute of Digital Anti-aging and Healthcare. He has completed his BS degree in the department of computer engineering, Inje University. His research interests are system design and development, framework development, cloud computing, Blockchain architecture development.

Eunyoung Han is a clinical researcher focused on Parkinson's disease patients in department of neurology at Inje University Paik Hospital. She is a Korean Certified Music Therapist (KCMT). Currently she is pursuing Ph.D. on music therapy at Ehwa Womans University. She is a visiting professor in Seoul Cyber University, Korea and has created the convergence contents in terms of 'healthcare' and 'music-wellness' as an owner of Peace & Piece, R&D in Korea.

Jinse Park is associate professor who work in Haeundae Paik Hospital, Inje University, Busan, Korea. He is expert of movement disorder including Parkinson's disease. He graduated from college of medicine in Hanyang University in 2003. He got doctor degree from Hanyang University in 2016. His research field is gait analysis in Parkinson's disease. He wrote many reports including SCI and SCOPUS journal and patent about gait analysis in Parkinson's disease.

Hee-Cheol Kim received his BSc at the Department of Mathematics, MSc at the Department of Computer Science in SoGang University in Korea, and Ph.D. at Numerical Analysis and Computing Science, Stockholm University in Sweden in 2001. He is a Professor at the Department of Computer Engineering and Head of the Institute. Digital Anti-aging Healthcare, Inje University in Korea. His research interests include Machine learning, Text mining, Bio Informatics.