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Frequency Analysis of Handwriting for Diagnosis of Parkinson’s Disease

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Abstract. Parkinson’s disease (PD) is one of the most common diseases which involves the central nervous system. In this disease, certain regions of the brain lose their ability to produce dopamine (one of the nerve carriers). The definite diagnosis of PD may occur several years after the early stages, so it is tried to find a way to diagnose PD in the early stages. Diagnosis of PD before it causes irreversible damage to the brain can significantly impact disease control. In this project, the different handwriting records of healthy people and those with PD under frequency behaviours were compared. The various analysis in different time frequencies and extracting different features to determine the accuracy of the diagnosis of PD in early stages were performed. It is tried to differentiate between various levels of PD. The amount of mean and standard deviation for accuracy is 75.78 and 3.29, for specificity is 74.91 and 3.91, and for sensitivity is 76.78 and 4.49. It shows that the system will report two classes of healthy people and people with PD with high accuracy.

Keywords. Time-Frequency Analysis, PD, Handwriting.

1. Introduction

PD is the disease PD is a disease that involves the central nervous system. For no apparent reason, certain regions of the brain lose their ability to produce a type of neurotransmitter called dopamine [1]. Lack of dopamine causes irregular body motions. Shaking hands and feet, muscle stiffness, slow motion and speech, disproportionate gait, and swallowing disorders are common symptoms of Parkinson's [2]. However, the symptoms of this disease are very different, to the extent that these symptoms can be considered personal [3]. The process of the disease and the speed of its progression also differ in different people [4, 5]. The definitive diagnosis of Parkinson's is made many years after the early stages [6]. The purpose of the research was to develop a method that can be used to diagnose Parkinson's in the early stages. Diagnosing PD, before it can cause irreversible damage to the brain, can have a significant impact on disease control [7].

Parkinson's is a chronic, progressive neurological disease that presents as tremors, dryness, and slow motion, mainly due to the loss of dopamine-producing cells in certain regions of the brain [8, 9]. When about 70% of brain cells' ability to produce dopamine is destroyed, these spots appear [10]. The early stages of PD can be identified by comparing the handwriting of healthy people and those with PD. Recognizing a change in handwriting can lead to early diagnosis of the disease in people. Studies in recent years show that there are unique differences between the handwriting of people with PD and other healthy people [11, 12, 13].

They analysed the handwriting with a new electronic pen and new signal features in 2016. In this research, different approaches have been evaluated, some of them are based on the characteristics of vibration, pressure position, and pen slope, and some are based on methods for measuring irregular signals. This article shows several features for diagnosing PD through handwriting measurements, which is an easy, low-cost, and non-invasive method [14].

According to a study (2013), patients were asked to write their name and address a paper attached to the digitizer. Mean pressure and mean velocity were measured while writing the name, address, and spatial and temporal characteristics of each motion. Impact length, width, and height mean pressure, meantime per impact, and mean speed was also measured for both name typing and address copying. The pure analysis was performed for two tasks, and one diagnostic feature was found for the group classification of all participants. Based on this performance, 97.5% of the participants were correctly classified [15].

In 2015, an article attempted to automatically scan images of people with PD by MATLAB software and to separate people with PD and healthy people by machine processing and machine learning methods. The MATLAB software for the diagnosis of PD consists of two parts, including feature extraction and classification. As a result, they were able to diagnose PD early by analysing the handwriting with MATLAB software [16].

In 2016, a handwriting database of people with PD was presented. The purpose of this study was to demonstrate the kinematic and pressure features during writing that can be used to diagnose people with PD. Experimental results showed that the analysis of cinematic features and pressure when writing can help evaluate the subtle features of writing and distinguish the people with PD from healthy people [17].

The researchers (2017) presented the handwriting identification of people with PD. Diagnosis of PD is very difficult, so researchers have worked on an algorithm-based diagnostic tool to separate Parkinson's patients from healthy people. Online handwriting analysis can be used to diagnose PD. The purpose of this study was to find a subset of handwritten features effective in the diagnosis of people with PD. The data used were collected from a database in Lebanon and included 16 people with PD and 16 healthy people. There are seven writing tasks: copying patterns, copying words in Arabic, and writing the full name. For each work, kinematic, pressure, energy, entropy, and intrinsic features were extracted. Feature selection was made in two steps.

The first step is to select a subset using statistical analysis, and the second step is to select the most appropriate features of this subset. Selected features are given to a support vector classifier machine with an RBF core that aims to diagnose people with PD. The accuracy of Parkinson's classification was 96.87%, with a sensitivity of 93.75%. The results and the selected features show that handwriting can be a valuable tool for diagnosing PD [18].

In 2017, an article was presented on handwriting analysis using EMG signals and computer methods. Handwriting analysis is a significant topic in various fields. An emerging field of research for the diagnosis of brain diseases is handwriting analysis. People with PD are diagnosed with abnormal handwriting because they have difficulty coordinating motions, and their cognitive ability is reduced. This article presents a new approach to the early diagnosis of PD. This approach is proposed using a handwriting analysis tool based on a limited number of features extracted by EMG signal processing techniques and processing using artificial neural network classification. The results of the research show that people with PD are separated from healthy people with high accuracy using a limited number of features. The obtained performance was analysed according to two specific groups. Although the number of subjects analysed is few, but the accuracy, sensitivity, and characteristics obtained were higher than 95% [19].

2. Materials and Methods

In this project, a system has been designed to diagnose this disease early from the handwriting of people with PD. The database of the Department of Neurology at Masaryk University and the Hospital of Sainte-Anne University in Brno, Czech Republic, was used. Each people performed eight different tasks, and each task was used as a signal. Violet conversion was taken from each signal and decomposed to one step. From this stage, approximate and detail coefficients were obtained. Then, from each of these coefficients, mean, standard deviation, Kurtosis, and Skewness were extracted. As a result, eight features were obtained for each task, and 64 features were obtained according to the eight tasks of the database.

2.1. Database Specifications

The database includes 37 people with PD (19 males and 19 females) and 38 healthy people of the same age (20 males and 18 females). People were placed in front of the table in comfortable conditions. Each subject was asked to complete a writing task in pre-written forms at a comfortable rate. People were allowed to repeat and correct the error if they made a mistake while writing. A tablet along with a blank sheet of paper (including printed lines and a square box to draw curves) and a special ink pen with a normal appearance and similar to other pens for fast and complete visual feedback was used. The signals were recorded using a digital tablet equipped with vacuum technology. The received signals are due to the motions when applying pressure on the writing surface and the motions above the writing surface. Vertical pressure was also measured on the surface of the tablet. Recording signals starts when the pen touches the tablet surface and ends when the task is done. Button position is a binary variable, zero position for motions above the writing surface and in the air, and position one for writing motions on the writing surface. For motion on the writing surface, the tablet's sampling rate is 100 samples per second, and the research team developed the software. Subsequent analyzes were performed by MATLAB and Python software [17].

2.2. Feature Selection

At this stage, a multi-stage discrete violet conversion signal is taken from each of the signals. For this purpose, multiple violet functions are used, and the results are compared. For each signal, the same and desired amount of data is used to convert the violet. So each of these coefficients will have a certain number of data

Using these coefficients, the calculator proceeds to the characteristic vector to create a characteristic vector for each signal. Since the neural network is used for classification, the vectors' values are normalized between zero and one before checking to enter the network, so that the network is not saturated.

2.3. Normalization of Data

In many practical situations, the features have occurred which their values are within different dynamic ranges. Therefore, features with large values may have a more significant effect on the cost function than features with small values, which this problem is solved by normalizing the features so that their values are within the same range. One of the normalization methods is that after calculating the mean and variance of each feature, the values of each are deducted from the mean value of the same feature and divided by the deviation of the corresponding criterion. In other words, normalizing the data causes the mean of the data to be zero and the variance to be equal to one.

2.4. Classifier

The central part of the proposed algorithm is its classifier. The SVM is one of the relatively new methods that has shown excellent performance in recent years compared to older methods for classification. The basis of the SVM classifier is the linear classification of the data, and in the linear division of the data, it is tried to select the line that has the most reliable margin. The SVM moves the data to a new space according to their predefined classes so that the data can be separated and classified linearly, and then by finding support lines tries to find the linear formula that creates the most significant distance between the two classes. In the figure below, the data are displayed in two classes, blue and red, and the dotted lines show the support vectors corresponding to each class, which are marked with two-line circles, and a continuous black line is the same as the SVM. The support vectors also each have a characteristic formula that describes the boundary line of each class.

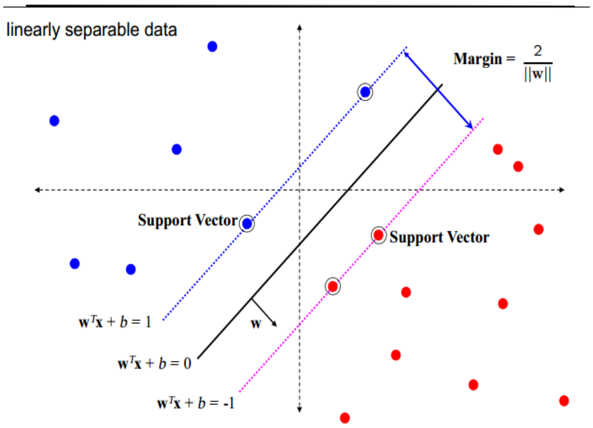

Fig. 1: Support vector machine (17)

3. Results

The data used in this research includes 72 samples and eight features. Data were evaluated, and 80% of the data were selected for training, and the remaining 20% for tests.

This means that the algorithm performs the learning operation from 80% of the data and tests itself from the remaining 20% and provides the result. In this way, it can be understood how accurate the algorithm is? Once the algorithm has performed the learning operation and built a model from this data, the data mining operation can be performed on the new data. In this project, the class with PD is considered positive, and the class of healthy people is considered negative, and they are named as follows.

$$C_1 = +1$$
$$C_2 = -1$$

The number of subjects that are appropriately classified within the related class is shown below.

$$TP = \ True\ Positive$$
$$TN = \ True\ Negative$$

These parameters represent the percentage of total samples that are correctly classified into healthy class and patient class. Thus, the number of samples that are incorrectly classified within another class is defined as follows.

$$FP = \ False\ Positive$$
$$FN = \ False\ Negative$$

Finally, the two quantities of specificity and sensitivity are obtained from the probability matrix using the following two formulas.

$$SP = TN/(TN + FP)$$
$$SN = \ TP/\ (FN + TP)$$

This indicates the degree of network specificity in diagnosing the disease class and the degree of network sensitivity in diagnosing the healthy class. The closer the value of these two parameters is to one, the better it is because the network can easily detect both classes with high accuracy.

Table 1. Event table

		Predicted Class	
		C_1	C_2
Actual Class	C_1	TP	FN
	C_2	FP	TN

After running the program several times in MATLAB, an example is given in the table below.

Table 2. An example of an event table

		Predicted Class	
		C_1	C_2
Actual Class	C_1	$TP = 22$	$FN = 8$
	C_2	$FP = 8$	$TN = 19$

Therefore, the degree of sensitivity and specificity can be calculated from this data according to the mentioned formula.

$$SP = TN/(TN + FP) = 19/(19 + 8) = 0.70$$

$$SN = TP/(FN + TP) = 22/(8 + 22) = 0.73$$

$$ACC = (TP + TN)/(TP + TN + FP + FN)$$

The sensitivity of 0.73 and specificity of 0.70 indicate that the network reports both healthy and patient classes with high accuracy.

The program has been run twenty times, and each time 80% of the data accidentally has been placed as training and the remaining 20% as a test. The values of sensitivity, specificity, and accuracy have been recorded each time. For each of the above parameters, the mean and standard deviation are calculated and recorded in the table below.

Table 3. The mean and standard deviation of sensitivity, specificity, and accuracy

	Mean	*std*
Sensitivity	76.78	4.49
Specificity	74.91	3.91
Accuracy	75.78	3.29

4. Conclusion

Comparison of the results obtained in this research with the mentioned researches shows:

1. So far, no similar projects have been done on the fusion of different works. In this project, all eight tasks are combined and analyzed from a frequency perspective.
2. In this project, a method for constructing a predictive model of PD from pressure and the kinematic feature is proposed. The use of kinematic and pressure features has been shown to increase classification accuracy by 75.78%. This approach is not provided to replace the physician but helps diagnose the disease more accurately and purposefully. Both pressure and kinematic features are very useful in distinguishing between healthy people and people with PD.
3. Among the many possible approaches, those who develop non-invasive methods for diagnosing and monitoring the disease are of increasing interest to physicians and medical engineers. This can be found by examining the frequency of people's handwriting.
4. The results presented in this study show that the use of handwriting-related features can help in the early diagnosis of PD. However, several limitations were encountered when interpreting the results. In the first stage, it is decided to focus only on the group of healthy people and people with the disease. Other diseases have been analyzed in other articles. Therefore, it is possible to differentiate between people with PD and healthy people with this method, and it is not possible to differentiate between Parkinson's and diseases such as Huntington's. Classification of different diseases is possible if there are various patterns among the variables. However, more in-depth handwriting analysis, which includes all methods, is needed because diagnostic features may be hidden in handwritten signals. The second limitation is that all people with PD took drugs and did so in writing while taking the drug. This suggests that the proposed method may be sufficiently sensitive to diagnose the disease even if it has reduced the symptoms of PD.
5. On the other hand, the drug's side effects on the patient's motions may affect the classification process. Before implementing this approach in clinical settings, a future study should be performed on patients who do not take drugs to examine how classification is performed according to these conditions. Third, it is shown that handwritings can be used as a biomarker to diagnose PD, but this should only be used as the first step in future studies. A longitudinal study should be performed on people at high risk for Parkinson's to report the result, whether it was successful. This could indicate whether the handwriting could be used as a biomarker to diagnose PD.

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