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TELEDIAGNOSIS OF PARKINSON'S DISEASE SYMPTOM SEVERITY USING H&Y SCALE

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Abstract

Parkinson's disease is a long-term degenerative disorder of the central nervous system that mainly affects the motor function. As the disease progresses non-motor symptoms become increasingly common. The only way to detect the disease nowadays is by going to the hospitals which is both time consuming and tiresome. This paper investigates a novel method for the detection of Parkinson's Disease to avoid the physical and logistical difficulties and identify the progress and detection of the disease at the comfort of their homes. Tracking Parkinson's disease (PD) symptom progression often uses the Hoehn and Yahr Scale (H&Y), which classifies the patients into various stages based on symptom severity. Remote replication of H&Y assessment is demonstrated in this paper with clinically useful accuracy, using simple, and self-administered, speech tests. The findings are verified on a database which consists of 195 voice recordings of 23 PD Patients and 8 Healthy people. It is found that the detection of dysphonia, using this method, is useful as well as accurate for monitoring the progression of phonatory impairment for patients with PD, and helps assess the disease severity. This method can contribute to easy and early detection of the disease, which can be used to treat the patient at earlier stages of the disease

Keywords: Dysphonia, Hoehn and Yahr, Parkinson's disease, Severity, Speech, Symptoms.

1. Introduction

Parkinson's disease is a chronic and progressive movement disorder, meaning that symptoms continue and worsen over time. More than 10 million people worldwide are living with Parkinson's Disease. The cause is unknown, and although there is no cure presently, there are treatment options such as medication and surgery to manage its symptoms.

Parkinson's involves the malfunction and death of vital nerve cells in the brain, called neurons. Parkinson's primarily affects neurons in an area of the brain called the substantia nigra. Some of these dying neurons produce dopamine, a chemical that sends messages to the part of the brain that controls movement and coordination. As PD progresses, the amount of dopamine produced in the brain decreases, leaving a person unable to control movement normally [1].

Often, the diagnosis of Parkinson's is first made by an internist or family physician. Many people seek an additional opinion from a neurologist with experience and specific training in the assessment and treatment of Parkinson's disease - referred to as a movement disorder specialist.

The diagnosis of Parkinson's disease mainly depends upon one or more of the common symptoms known as the primary motor symptoms. In addition to this, there are secondary motor symptoms and non-motor symptoms that affect many people [2].

1.1. Primary motor symptoms

1.1.1. Resting tremor

The tremor that consists of a shaking or oscillating movement, and usually appears when a person's muscles are relaxed, or at rest, is termed as "resting tremor."

1.1.2. Bradykinesia

Bradykinesia means "slow movement." Bradykinesia causes difficulty with repetitive movements, such as finger tapping.

1.1.3. Rigidity

Rigidity causes stiffness and inflexibility of the limbs, neck and trunk. In Parkinson's rigidity, the muscle tone of an affected limb is always stiff and does not relax.

1.1.4. Postural instability

One of the most important signs of Parkinson's is postural instability, a tendency to be unstable when standing upright [2].

1.2. Secondary motor symptoms

1.2.1. Freezing

People who experience freezing will normally hesitate before stepping forward. They feel as if their feet are glued to the floor.

1.2.2. Micrographia

This term is the name for a shrinkage in handwriting that progresses the more a person with Parkinson's writes.

1.2.3. Mask- like expression

This expression, found in Parkinson's, meaning a person's face may appear less expressive than usual, can occur because of decreased unconscious facial movements.

1.2.4. Unwanted accelerations

Some people with Parkinson's experience movements that are too quick, not too slow.

1.3. Non-motor symptoms

The nonmotor symptoms for Parkinson's Disease are loss of smell, sleep disturbances, constipation, excessive production of saliva, weight loss or gain etc.

This paper will contain discussion about primary motor symptoms in Section 1.1, Secondary Motor Symptoms in Section 1.2 and Non motor Symptoms in Section 3. Discussions about Related work done on this topic can be found in Section 1.4, Hoehn and Yahr scale in section 1.5, a glimpse into dysphonia in Section 1.6, the material and methodology used in Section 2, results in Section 3 and conclusion in section 4, Limitations and Constraints in Section 5 and Future Scope and Motivation of work in Section 6.

1.4. Related work

Quantitative measures of speech impairment could help evaluate the seriousness levels of speech impairment in PD patients and concentrate the particular impeded speech parameters [3, 4]. The concurrent subjective and quantitative examinations can describe the overstated vocal tremor, feeble voice, unpleasantness, and other dysphonic manifestations in idiopathic PD analysis [5]. As of late, telemedicine frameworks with cutting edge system access have been successfully utilized for remote observing of patients with vocal impairment [6]. The telemedicine innovation gives moderately minimal effort clinical observing arrangements that help diminish visit physical visits for patients [7]. As suggested by Little et al. (2010) such telemedicine systems call for more reliable clinical tools and speech measurements for accurate detection and monitoring of vocal symptoms in PD.

Several novel speech measurement methods have been developed to assess dysphonic symptoms in the last decade [7-12]. The purpose of such speech measurements is to characterize the features of the acoustic signals associated with phonation disorders. Impairment of vocal folds often causes the unpredictable development in one or the two sides of the glottis that prompts obsessive vibration designs, for example, pitch recurrence variances, changes of wind stream volume, and amplitude alteration [13]. Along these lines, dysphonia is regularly seen in the generation of vowel sounds. This program used in this paper is used for identifying the severity of the disease from these variations that are mentioned below. This paper comes up with a simple and easier method to detect the disease without the hassle of going to a doctor to get the disease diagnosed and tested by simply using a small voice sample of one to two seconds. In this way this paper is unique from the other works. The other papers use programs that is done in programming languages such as Python which is quite difficult to understand. Whereas, the program used in this paper is done using MATLAB a simple and easy language that can be understood easily by even the laymen.

The fundamental frequency (F0) in vowels, mean of F0, variation of F0 (jitter), the variation of speech amplitude (shimmer), intensity from one vocal cycle to another are the most frequently used electroglottographic measures in standard speech tests [12,14-16]. Zwirner and Barnes [12] announced that the standard deviation of F0 in delayed vowels is a lot bigger for PD patients contrasted with normal people. The study of Hertrich and Ackermann [14], indicated increased jitter and higher mean of F0 in prolonged vowels for PD patients. Cnockaert et al. [17] used the wavelet analysis technique, to extract the phonatory frequency trace and low-frequency vocal modulation in sustained vowels. Their investigation recommended that the normal phonatory recurrence is altogether higher for male subjects with PD, and the modulation amplitude is essentially bigger for female PD patients [17]. It is hypothesized that the most informative features with regard to fundamental frequency, amplitude variability, and dynamics in vocal fluctuations could be properly selected and used in the nonlinear analysis methods for the accurate classification of PD patterns.

1.5. Hoehn and Yahr Scale

Parkinson's rating scales are a means of assessing the symptoms of the condition. They provide information on the course of the condition and/or assess quality of life. They may also help to evaluate treatment and management strategies, which can be useful to researchers, medical practitioners as well as to people with Parkinson's.

The Hoehn and Yahr Scale is used to measure how Parkinson's symptoms progress and the level of disability. Originally published in 1967 in the journal Neurology by Melvin Yahr and Margaret Hoehn, it included stages 1 to 5. Since then, stage 0 has been added and stages 1.5 and 2.5 have been proposed and are widely used.

- Stage 0 - No signs of disease
- Stage 1 - Symptoms on one side only (unilateral)
- Stage 1.5 - Symptoms unilateral and also involving the neck and spine
- Stage 2 - Symptoms on both sides but no impairment of balance
- Stage 2.5 - Mild symptoms on both sides, with recovery when the 'pull' test is given (the doctor stands behind the person and asks them to maintain their balance when pulled backwards)
- Stage 3 - Balance impairment, mild to moderate disease, physically independent
- Stage 4 - Severe disability, but still able to walk or stand unassisted
- Stage 5 - Needing a wheelchair or bedridden unless assisted [18].

1.6. Dysphonia

Dysphonia is a type of phonation disorder with an impairment in the ability to produce normal voice sounds [4]. Manifestation of dysphonic voice is characterized by hoarseness or weakness in phonation [13]. As the functional causes of dysphonia, neurological disorders sometimes make neurogenic interruptions in the laryngeal nerve paths that could interfere in normal vibration of vocal folds during exhalation [19]. Dysphonia is negative to personal satisfaction, because the speech impaired patient often encounters difficulty in personal communication that leads to depression and further social handicap [20]. According to the survey of Hartelius and Svensson [21], over 70% of the PD patients experienced speech deficit and voice impairment after the onset of their disease, and only 3% of the patients had received speech therapy

2. Materials and Methods

Telediagnosis refers to the diagnosis, or prognosis, that is made by the electronic transmission of data between distant medical facilities [18, 22]. This technique is utilized for the underneath referenced program wherein informational indexes with sound accounts which was obtained from the repository was utilized to group the individuals who could conceivably experience the ill effects of PD into the separate stages according to the Hoehn and Yahr (H&Y) scale. Utilizing this technique, monitoring and checking of patients can be performed effectively at their homes. Since this technique is easy to understand and cost effective, it very well may be utilized by both clinical and non-clinical experts without requiring any preparation. By gaining the voice recording through phones or some other strategy, these sound accounts are broken down by the program which groups these sound chronicles into the various phases of H&Y scale

The informational collection utilized in this investigation was made by Max Little of the University of Oxford, in a joint effort with the National Center for Voice and Speech, Denver, Colorado, who recorded the discourse signals. The first examination which was directed in the year 2008, distributed the component extraction techniques for general voice issue. It is additionally online accessible by means of University of California at Irvine (UCI) AI store [23]. This database was taken since we could download the voice samples and the table with ease, and the database contained the necessary values that were needed to compare with the experimental value obtained using the program. The referenced table (Table 1) gives an example of the dataset that is being utilised in the program.

Table 1. Sample version of dataset used for the program.

Name	MDVP:Fo(Hz)	MDVP:Jitter(%)	MVDP: Shimmer
phon_R01_S01_1	119.992	0.00784	0.04374
phon_R01_S01_2	122.4	0.00968	0.06134
phon_R01_S01_3	116.682	0.0105	0.05233
phon_R01_S01_4	116.676	0.00997	0.05492
phon_R01_S01_5	116.014	0.01284	0.06425
phon_R01_S01_6	120.552	0.00968	0.04701
phon_R01_S02_1	120.267	0.00333	0.01608
phon_R01_S02_2	107.332	0.0029	0.01567

The phonation data contain 195 sustained vowel records uttered by total 31 subjects. There were 8 healthy control subjects (3 males and 5 females), with the average age of 60.2 years (standard deviation: 8.6 years), participating in the speech tests. The PD patients included 16 males and 7 females (mean and standard deviation of age: 67.8±9.7 years). The disease stage of each PD patient was assessed with the Hoehn and Yahr (H&Y) scale [18], a widely used PD progression rating method in clinical practice.) Each column in the table is a particular voice measure, namely, Average fundamental frequency, various values of Jitter and shimmer etc. and each row corresponds one of 195 voice recording from these individuals ("name" column).

This program aims to overcome logistical and financial difficulty associated with the detection of severity of the disease. This method aims to be simple, authentic reliable and hassle free so that both the patient's and clinician's quality of life can be improved.

Little et al. [11] implemented the Kay Pentax multidimensional voice program (MDVP) to measure the perturbations in the sustained vowel records. Such perturbation measures include the period (jitter) and amplitude (shimmer) perturbations and harmonics-to-noise (and noise-to-harmonics) ratios.

The data is in American Standard Code for Information Interchange (ASCII), Comma Separated Value (CSV) format. The rows of the CSV file contain an instance corresponding to one voice recording. There are around six recordings per patient, the name of the patient is identified in the first column.

Since the data of healthy people is only used for distinguishing a record, as healthy or to be a patient, the control group being just 8, for the same, does not create a lot of discrepancy. The values of the parameters for the healthy people belong to a similar range and hence do not affect the authenticity of the method.

The program was developed using MATLAB 2017 programming language using the signal processing toolbox.

MATLAB is the abbreviation for Matrix laboratory. It is a multi-paradigm numerical computing environment used for different purposes. For example, mathematical calculations, development of graphical user interfaces etc. can be done. Signal Processing toolbox available in MATLAB provides various application and functions to analyse, generate, measure, visualize and transform the different signals. In this method, voice recordings were analysed by the above-mentioned toolbox.

The algorithm reads an input audio signal. The length of the audio signal is divided into 6 different parts in order to obtain 6 samples per person, to correlate easily with the database.

The voice signal that can be used in this algorithm needs to be of a sustained vowel phonation of the vowel /a/. The voice recording need not be a large one. A mere 1 or 2 second voice recording of the person is sufficient.

2.1. Fundamental frequency

The average fundamental frequency is calculated for the input audio signal using complex cepstrum. Complex cepstrum is often used as a feature vector to represent human voice signals. It is used to extract the fundamental frequency of the voice signal.

Once the fundamental frequency is obtained, it is used to determine if the voice signal belongs to a male or female by specifying ranges for male and female and classifying based on the frequency calculated for the input voice signal.

2.2. Jitter

Jitter is defined as the average absolute difference between consecutive periods divided by the average period. It is expressed in terms of percentage.

$$Jitter\ (Relative) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}|T_i - T_{i+1}|}{\frac{1}{N}\sum_{i=1}^{N-1}T_i} * 100\% \quad (1)$$

To calculate jitter from Eq. (1), the difference between two consecutive pitch periods are calculated and divided by the average value of the period.

2.3. Shimmer

Shimmer is expressed as the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude, expressed as a percentage.

$$Shimmer\ (Relative) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}|A_i - A_{i+1}|}{\frac{1}{N}\sum_{i=1}^{N}A_i} * 100\% \quad (2)$$

For shimmer as per Eq. (2), the difference between two consecutive amplitude values are calculated and divided by the average value of amplitude.

2.4. Usage of parameters

These 3 parameters, fundamental frequency, jitter and shimmer are very important for the analysis of PD.

Once the above mentioned three parameters are calculated for the input voice signal, they are compared with the values in the source database. The values for the input signal are compared with all the corresponding values in the database for healthy people and a matrix is obtained. The matrix gives a value 0 whenever it is in the range of the healthy subjects and a value 1 if it is not present in the range.

This matrix obtained is compared with a zero matrix to check if they match. If all the values in the matrix are the same as the zero matrix, it implies that the person has the fundamental frequency, jitter and shimmer in the range of a normal person and hence is healthy.

An output stating that the person is healthy is obtained. In the case that both the matrices aren't exactly equal, it implies that the person has values in the range beyond that of healthy subjects. Hence, the patient has PD. An output stating that the person has PD is obtained. Further if the person has PD, they are classified into the various stages of the Hoehn and Yahr Scale based on their value of fundamental frequency, jitter and shimmer which fall in the corresponding ranges of the different parameters, which is then used to classify the person into the different stages in the H&Y scale. Ranges are specified for jitter and shimmer for each stage. The calculated values of jitter and shimmer are compared with those in the range and further classified into the appropriate stage of the Hoehn and Yahr Scale. The above-mentioned content is summarized in the form of a flowchart as shown in Fig. 1.

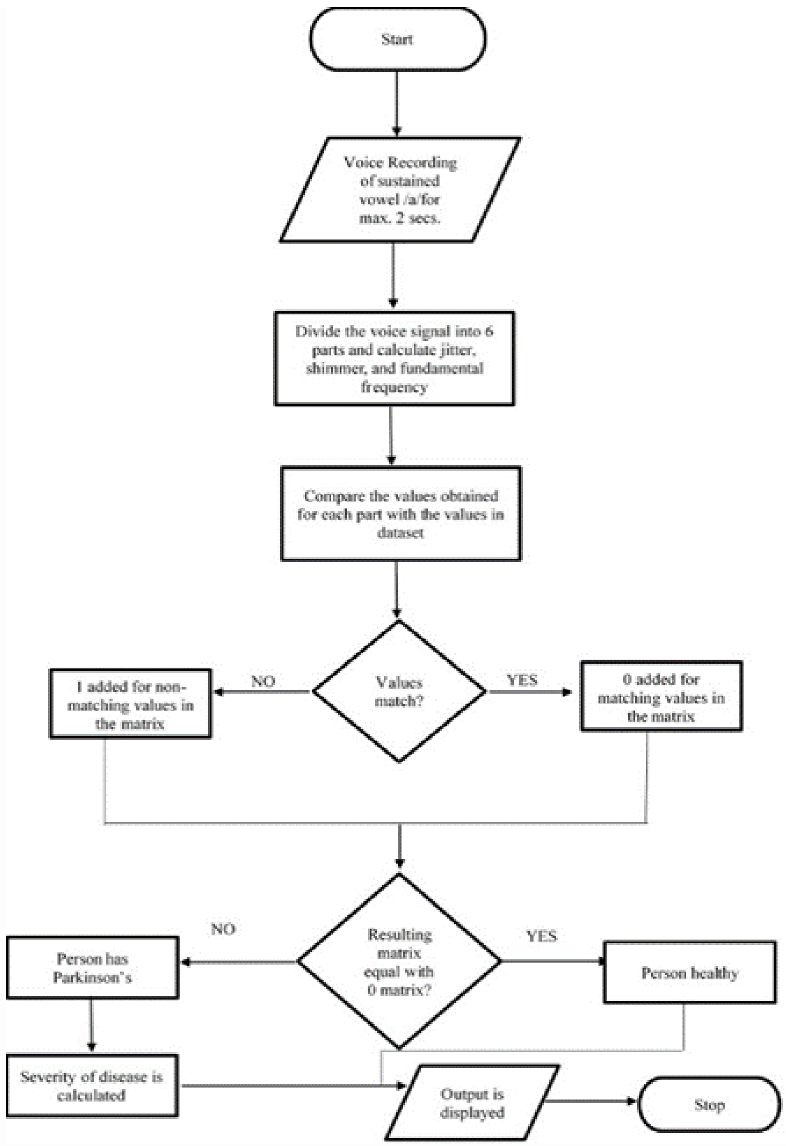

Fig. 1. Algorithm of the program developed.

3. Results

Sample mock results were obtained with an input voice signal of a patient with PD, which was obtained from UCI Machine Learning Repository. The mock results are for a person with PD illustrated below.

When the input voice signal was read, at first, the fundamental frequency of the signal was obtained using Complex Cepstrum. Cepstral analysis is a signal processing technique which is non-linear in nature that is most commonly applied for speech processing and for homomorphic filtering. Complex cepstrum is defined as the inverse Fourier Transform of the logarithm of the Fourier transform of the signal from the complex cepstrum obtained above, the fundamental frequency was obtained.

Figure 2 shows the complex cepstrum of patient. Further, various other characteristics of the sample input voice signal were obtained, the signal in time domain (Fig. 3), spectrogram of the signal (Fig. 4), amplitude of the signal (Fig. 5) and probability distribution of the signal (Fig. 6) was obtained.

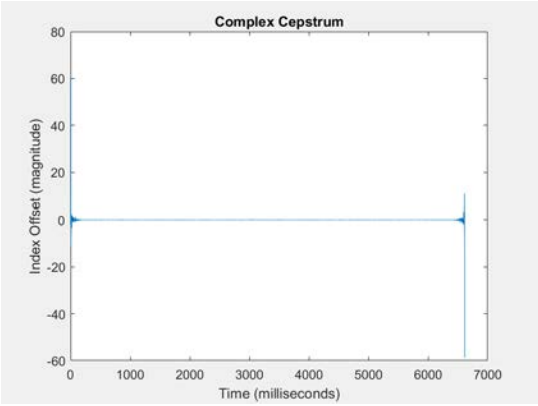

Fig. 2. Complex cepstrum of patient.

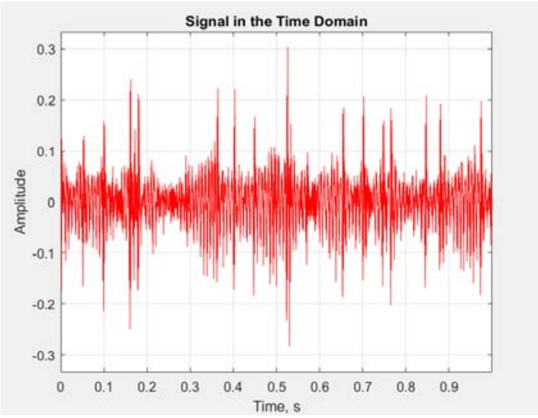

Fig. 3. Signal in time domain for patient.

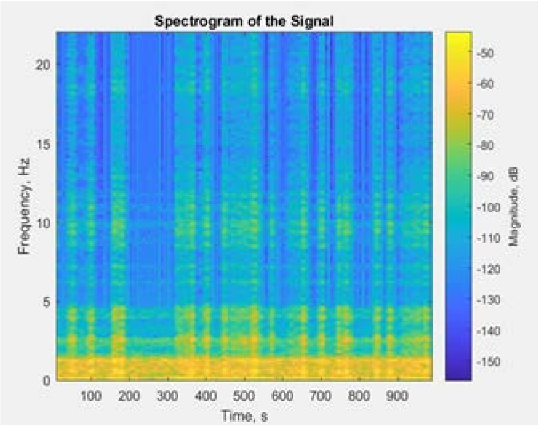

Fig. 4. Spectrogram of the patient.

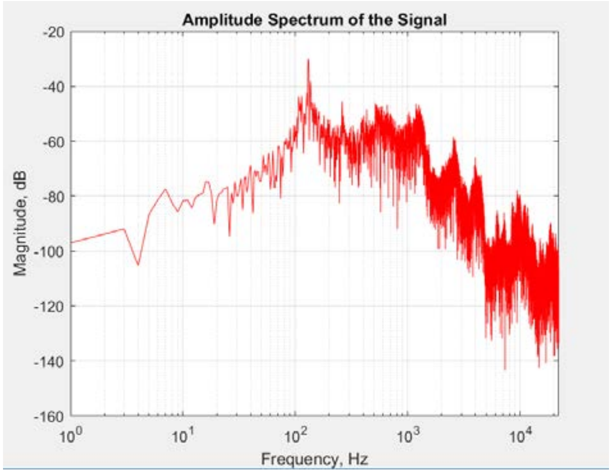

Fig. 5. Amplitude spectrum of the patient.

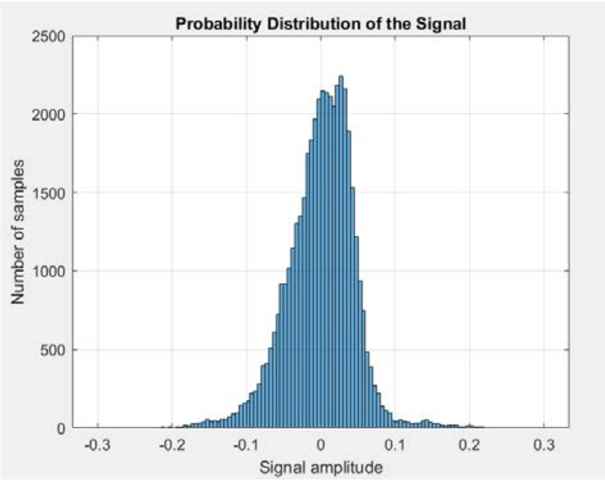

Fig. 6. Probability distribution of the patient.

The fundamental frequency, jitter and shimmer values were then compared with the corresponding values for each healthy person sample and a matrix of 0's and 1's is obtained for a match and non-match respectively. The matrix obtained for the sample voice signal consisted of a combination of 0's and 1's for all the 3 parameters. It was not an absolute match with the zero matrix. Hence, it was clear that the person is not healthy. The person has PD. Once the output was obtained that the person has PD, the jitter and shimmer ranges were compared to understand the stage of the disease in the patient. On analysis, it is found that the person belongs to Stage 1.5 - Symptoms unilateral and also involving the neck and spine.

The same procedure was repeated and the following results were obtained for a healthy person. Figure 7 shows the complex cepstrum of a healthy person. Further, various other characteristics of the sample input voice signal were obtained, the signal in time domain (Fig. 8), spectrogram of the signal (Fig. 9), amplitude of the signal (Fig. 10) and probability distribution of the signal (Fig. 11) was obtained.

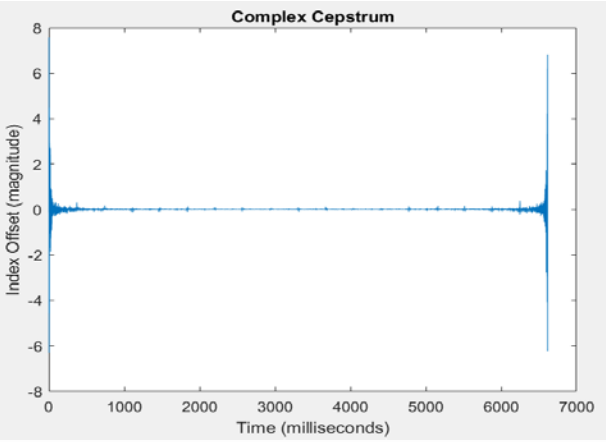

Fig. 7. Complex cepstrum of the healthy person.

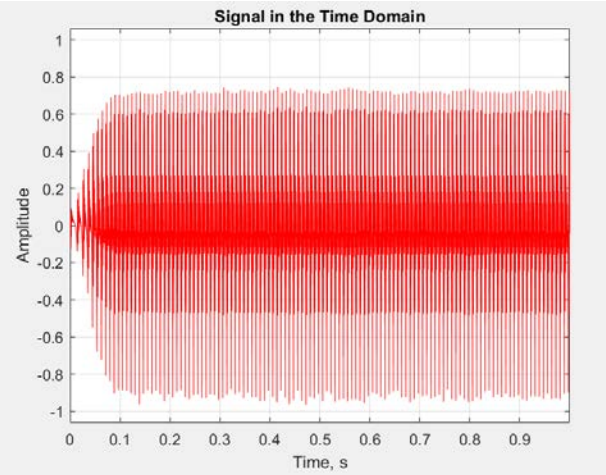

Fig. 8. Signal in time domain for healthy person.

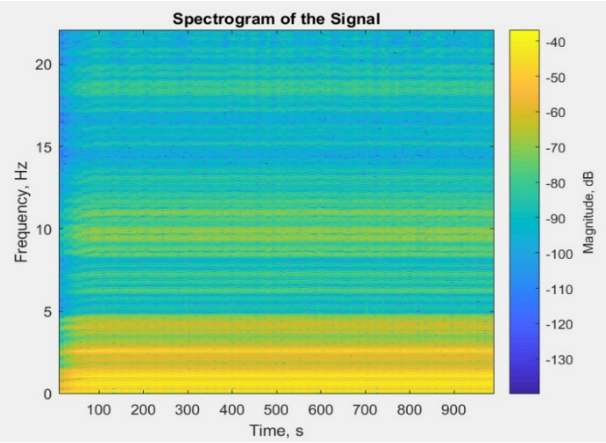

Fig. 9. Spectrogram of healthy person.

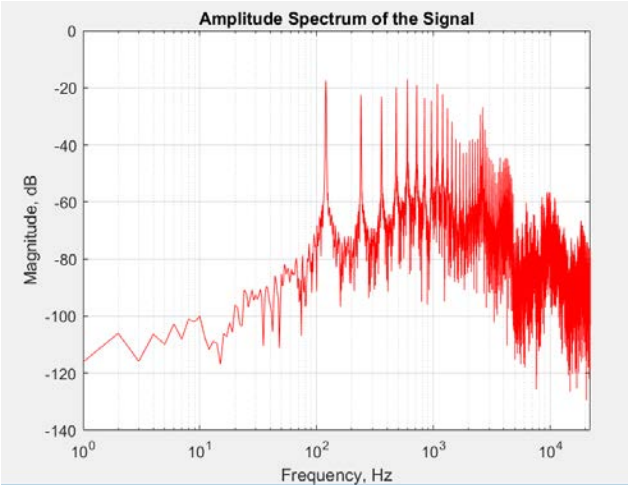

Fig. 10. Amplitude spectrum of the healthy person.

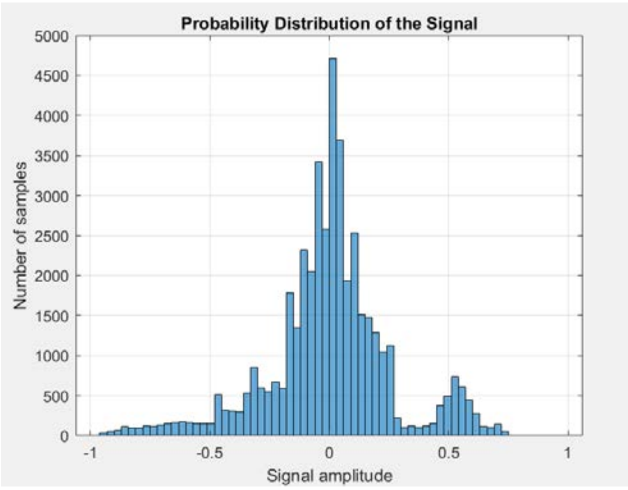

Fig. 11. Probability distribution for the healthy person.

There is a clear distinction between a patient and a healthy person as depicted in the figures shown in Table 2.

Table 2. Comparison of Jitter & Shimmer for healthy person & Patient with PD.

Category	Gender	Fundamental frequency	Jitter	Shimmer
Healthy	Male	119.19 Hz	5.57916 e-02%	1.2641 e-03%
Patient	Male	162.7306 Hz	0.0796%	

4. Discussion

From the above results, it can be observed that the parameter values for the patients is very high when compared with the healthy person. Using this result, we can easily identify the person with PD after finding the values for the different parameters.

This program aims to make the process of detecting this disease comfortable and hassle-free, allowing for the doctors at a remote location to confirm the severity of the disease as shown in the program.

5. Conclusion

Effective dysphonia detection can help provide better treatments towards speech improvement in Parkinson's Disease patients. This method helps to detect the symptom severity in the patient by voice recordings of sustained voice phonations of a vowel like /a/. This simple method helps to overcome any logistical and financial difficulty that is associated with detecting the severity of symptoms in the patient. Barring that, the algorithm seemed to show commendable accuracy in classifying the patients based on jitter and/or shimmer into the various stages.

The proposed method is based on a well-established and trusted database. It will be an assistive tool for the symptom detection of the disease and is expected to be willingly accepted on the part of the medical practitioners. This method, due to its simplicity, authenticity and reliability has a positive implication on the quality of life of the patients and clinicians alike. It serves as a hassle-free method for disease detection.

The financial implications for using this method are very little. This method is highly economical as it only requires the Matrix laboratory (MATLAB) software and a microphone to record the voice signals to input the same into the software. Therefore, the costs incurred is very less. The clinicians and staff require basic knowledge the of MATLAB software to implement this method.

This method is very simple as opposed to the other methods available. It uses the H&Y scale which is again a simple and yet a powerful scale to use for monitoring the symptom severity. The other methods have used the Unified Parkinson Disease Rating Scale (UPDRS) which is still a complicated scale to use. UPDRS is a scale is used to follow the longitudinal course of this disease manually. Hence, the detection based on H&Y scale serves its purpose to ensure simplicity of this method.

6. Limitations and Constraints

The dataset used in this program has voice signals of 28 people with 23 of them suffering from Parkinson's Disease. This is a small control group when compared with databases for other diseases. Increasing the control group can help increase the reliability and efficiency of the developed program.

The disadvantage associated with this method is that the patients with minimal functional disability have a probability of being incorrectly identified.

7. Further Scope and Motivation for the Work

For further research, this algorithm can be used to create an App which actively records the voice of the patient through the microphone in the mobile phone and classify patients to the appropriate stages.

The motivation for doing this work is to create awareness about a disease that has not been given much attention lately.

Nomenclatures

A_i	Extracted peak-to-peak amplitude data for the ith instance
A_{i+1}	Extracted peak-to-peak amplitude data for the i+1 th instance
N	Total Number of extracted fundamental periods
T_i	Extracted fundamental frequency period length
T_{i+1}	Extracted fundamental frequency period length for the immediately next instance

Abbreviations

ASCII	American Standard Code for Information Interchange
CSV	Comma-separated values
H&Y	Hoehn and Yahr
MATLAB	Matrix Laboratory
PD	Parkinson's disease
UCI	University of California Irwin
UPDRS	Unified Parkinson Disease Rating Scale

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