CLINICAL DECISION SUPPORT SYSTEM FOR PARKINSON'S DISEASE AND RELATED MOVEMENT DISORDERS

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ABSTRACT

The goal of this study is to accurately distinguish between finger tremors of Parkinson's disease and other movement disorders using a tri-axial gyroscope. Finger tremor is specifically studied here as compared to hand tremor since farther distance from radio-carpal joint results in better acquisition of tremor signal. This study is an effort towards providing physicians with a clinical decision support system to facilitate them in accurate diagnosis of Parkinson's disease (PD) and help them in discriminating between other movement disorders and PD. We designed the hardware to acquire angular displacement from tri-axial gyroscope and apply a series of techniques to extract different features in time and frequency domains. Both resting and postural tremor is studied for analysis. A total of 104 people participated in our study, using features from this data we were able to create a Clinical Decision Support System (CDSS) with overall accuracy of 82.43%. Additionally, CDSS was also used as a first hand diagnostic tool in a real hospital setting with an accuracy of 77.78%.

Index Terms— Parkinson's disease, Movement disorders, Tremor, Tri-axial Gyroscope, Clinical Decision Support Systems

1. INTRODUCTION

Parkinson's Disease (PD) [1] is the second most common neurodegenerative disorder after Alzheimer's disease and affects approximately seven million people globally and one million people in the United States [2]. Parkinson's disease at time is misdiagnosed as Vascular pseudo-parkinsonism [3], Alzheimer's disease [4], Dystonia [5] or Benign Essential Tremor [6]. This misdiagnosis occurs due to overlapping symptoms shared by these disorders, since like PD, people suffering from other movement disorders (OMD) also exhibit tremors, bradykinesia and impaired balance [7]. Hence, diagnosis and accurate discrimination is difficult for physicians due to non-availability of a standardized diagnostic test for Parkinson's disease [7]. Currently diagnosis is made through a combination of subjective neurological tests and examination of a patient's medical history [8]. To the best of our knowledge, an inexpensive yet effective method for diagnosis of PD is still non-existent. Hence, this poses a dire need for a test that reduces diagnosis time, is inexpensive and is significantly accurate as compared to contemporary diagnostic methods. With technological advancements in wearable devices and computational capabilities, various researchers have started to use wearable sensors to monitor motor symptoms of movement disorders [9], [10].

Tremor is the most common symptom of neurological disorders; where the behavior of tremor varies across different disorders. Therefore, different disorders can be distinguished on the basis of analyzing their characteristic tremor. Existing research in this area mainly uses wrist and other parts for signal acquisition and analysis [11]. However, in early cases of Parkinson's disease and in most cases of Benign Essential Tremor, wrist tremor and tremor in other parts of the body is not significant as compared to tremors in the fingers of the patient. Furthermore, the tremor in each finger exhibits different spectral behavior, which makes analysis of finger tremor the major focus for our investigation into Parkinson's disease diagnosis.

This work investigates the efficacy of computer aided diagnosis using wearable devices as compared to the initial diagnosis made by a physician in a hospital setting. To aid our research, we conducted a comprehensive subjective study involving 104 human subjects who were assessed by a neurologist prior to the clinical trial. Table 1 describes the distribution of participants of the study. In addition to these subjects used for training and testing the classifier, 9 additional subjects were chosen whose condition was initially unknown to the neurologist. For these later set of subjects, the proposed algorithm acted as the first hand diagnostic tool with the neurologist's assessment acting as a performance evaluator.

Table.1. Details of participants

Group	Participants	Mean Age (Years)
Parkinson's disease	37	66.84
Other movement disorders	16	47.5
Healthy	51	43.76
Total	104	52.54

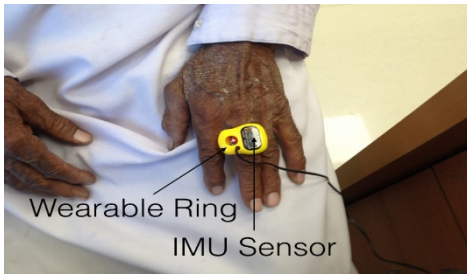


Figure 1: Participant wearing the MPU-6050 IMU for tremor signal acquisition on middle finger of left hand.

2. DESIGN METHODOLOGY

2.1. Experimental Setup

A 12-month study was conducted at the Department of Neurology and Rheumatology, Military Hospital Rawalpindi Pakistan. Military Hospital Rawalpindi is a 1200 bed hospital located in Rawalpindi, Pakistan. A military hospital was chosen for this study because of large military veteran customer base, who are more likely to suffer from Parkinson's disease as compared to people belonging to other professions who face less trauma [12]. Subjects participating in the study were divided into three groups:

1. Parkinson's disease ***PD*** (Class 1)
2. Other movement disorders ***OMD*** (Class 2)
3. Healthy Subjects (Class 3)

Participants suffering from movement disorders (including PD) were clinically diagnosed by a Neurologist prior to our experiment.

For acquisition of tremor signals, participants wore a small wearable ring on their fingers, which incorporated an InvenSense MPU-6050 Inertial Measurement Unit (IMU). MPU-6050 combines a 3-axis Gyroscope, a 3-axis Accelerometer and a Digital Motion Processor in one unit. For precision tracking of both fast and slow motions, MPU-6050 features a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2g, ±4g, ±8g, and ±16g. For the purpose of this study we acquired data using only the 3-axis gyroscope present in the MPU-6050 chip. A participant wearing the wearable sensor can be seen in Fig.1.

2.2. Signal Acquisition Procedure

In our study 12000 signal samples were acquired from each finger. During the acquisition process the participants were asked to stretch their arm without support. During acquisition process, the subject was asked to rest their arm for some time after acquisition was complete from each finger so that a tired arm does not change the tremor behavior. The tremor samples acquired from each finger were saved on a general purpose computer system along with other details of the patient such as name, age, identification number, years of disease, highest level of education and family history of related disease. Sometimes additional information was also stored if it was deemed useful for future reference and analysis such as asymmetric tremor behavior, previous traumatic experiences and the scale at which the participant was complying to instructions given to them related to the conduct of the experiment. Prior to the experiment a consent form was also signed by the participant and counter signed by the person conducting the experiment. Furthermore, on suggestion of the neurologist participants with prescription of levodopa were instructed to miss their morning levodopa dose for better tremor acquisition. Block Diagram for complete system is given as Figure 2. Data acquired from the IMU sensor is stored into a personal computer through a microcontroller unit. After storing data, signal conditioning techniques are applied to tremor signals which are explained in the next section.

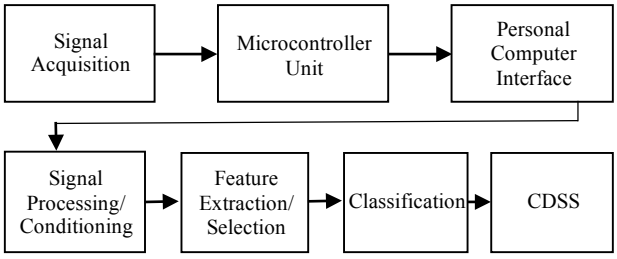


Figure 2: Block Diagram of complete system

2.3. Signal Preprocessing

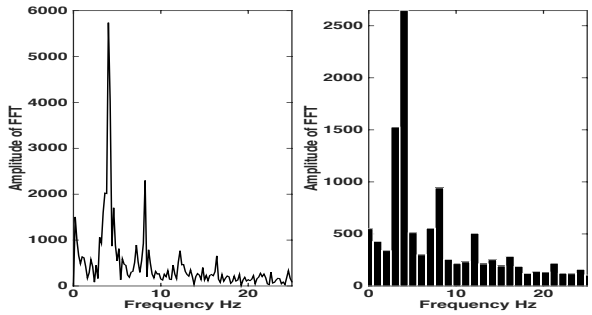
After successful acquisition of a participant's data the signals acquired from the gyroscope are preprocessed to remove random and impulse noise in order to enhance the performance of subsequent signal processing stages. Impulse noise creates undesirable artifacts in the frequency spectrum at higher frequencies. As most of our features are based on spectral analysis such artifacts reduce the accuracy and effectiveness of these features. An order 5 median filter is applied before feature extraction to condition the signal. Furthermore, to reduce sensor offsets and drifts due to various physical phenomenon, a high pass IIR filter with cut-off frequency $fc \approx 0.25\ Hz$ is applied to the signal [13].

2.4. Feature Extraction and Selection:

Tremor in PD is generally characterized by rhythmic movements at a frequency of approximately 4–6 Hz, which

predominantly occurs at rest but also can be present during action [14]. Tremor of other movement disorders (OMD) also exhibit a certain frequency range, the range of which partially overlaps the frequency ranges of PD tremor. For this purpose, in addition to spectral features, time-domain features were also extracted separately for each finger. As we were acquiring angular displacement $\theta_{r,p}$, the features extracted for velocity and acceleration were computed by taking 1st and 2nd derivative of $\theta_{r,p}$ respectively. As for using dominant frequency component F_{dom} of tremor signal as a single feature, we found out by analysis that dominant frequency component does not serve as a good feature in discriminating between PD and other movement disorders (OMD) . Hence, we bucketed the frequency spectrum of tremor signal and treated a single bucket as a single feature for the classifier as shown in Fig 3.

Figure 3. Frequency Spectrum of θ_r before and after bucketing.



Some of the features used for training have been inspired by time-frequency features used in [11], [15], [16]. Absolute velocity $\dot{\theta}_{rp}$ is calculated using the following relation:

$$\dot{\theta}_{rp} = \omega_{rp} = \sqrt{\omega^2_{\text{roll}} + \omega^2_{\text{pitch}}} \qquad (1)$$

After calculation of wide range of features, different combinations of features were tried for training and only those features were retained on which maximum accuracy was achieved. Table 2. gives the list of the features that resulted in maximum accuracy.

Mean, Standard Deviation and Kurtosis of $\dot{\theta}_{r,p}$ are effective statistical measures to quantify severity and behavior of tremor, which is different in case of Parkinson's disease and Benign Essential Tremor . Furthermore, using complete frequency spectrum as a feature adds an extra measure for diagnosis as compared contemporary diagnostic techniques.

Table.2. Summary of features extracted from tremor signals acquired through tri-axial gyroscope.

Feature	Definition
Behavior of Tremor	Behavior of limb tremor (symmetric/ asymmetric)
$\mathbf{r_{STD,Amax}}$	Correlation between Standard-deviation of angular velocity vs. peak spectral amplitude
$\mathbf{P_{av}}$	Power of Signal
$\boldsymbol{\eta}_{\mathbf{roll,pitch}}$	Cross-correlation between frequency spectrum of Roll and Pitch
$\boldsymbol{\mu}_{\mathbf{r}}$	Mean of Roll $\dot{\theta}_r$ velocity
$\boldsymbol{\mu}_{\mathbf{p}}$	Mean of Pitch $\dot{\theta}_p$ velocity
$\boldsymbol{\sigma}_{\mathbf{r}}$	Standard Deviation (STD) of Roll velocity $\dot{\theta}_r$
$\boldsymbol{\sigma}_{\mathbf{p}}$	Standard Deviation (STD) of Pitch velocity $\dot{\theta}_p$
$\mathbf{A_{roll}}$	Bucketed Frequency Spectrum of θ_r
$\mathbf{A_{pitch}}$	Bucketed Frequency Spectrum θ_p
$\mathbf{IQR}_{\mathbf{roll}}$	Interquartile Range of Roll velocity $\dot{\theta}_r$
$\mathbf{IQR}_{\mathbf{pitch}}$	Interquartile Range of Pitch velocity $\dot{\theta}_p$
$\boldsymbol{S}_{\boldsymbol{\theta}_r}$	Pearson's coefficient of skewness for Roll velocity $\dot{\theta}_r$
$\boldsymbol{S}_{\boldsymbol{\theta}_p}$	Pearson's coefficient of skewness for Pitch velocity $\dot{\theta}_p$
$\boldsymbol{\kappa}_{\mathbf{roll}}, \boldsymbol{\kappa}_{\mathbf{pitch}}$	Kurtosis of Roll $\dot{\theta}_r$ and Pitch $\dot{\theta}_p$ velocities
$\boldsymbol{\mu}_{\mathbf{avg}}$	Mean of absolute velocity $\mu_{av} = \sum_{i=1}^{n} \frac{av}{n} = \frac{\sum_{i=1}^{n} \sqrt{{\omega_i}^2_{roll} + {\omega_i}^2_{pitch}}}{n}$
$\boldsymbol{\sigma}_{\mathbf{av}}$	Standard deviation of absolute velocity

3. CLASSIFICATION AND CROSS-VALIDATION

For classification and prediction, we used Google's Prediction API. Prediction API is a machine learning black-box but a simple and stable way to train Machine Learning models. There are two model configurations to choose from: Classification and Regression.

We used 10-fold cross-validation (CV). 10-fold CV method divides data into 10 sets of size $\frac{n}{10}$. Model is trained on 9 datasets and tested on 1 data set. The process is repeated 10 times and mean accuracy is taken. Initially, we used Prediction API for classification of two classes, which results in three different cases:

1. Parkinson's disease vs. Other movement disorders
2. Parkinson's disease vs. Healthy
3. Other movement disorders vs. Healthy

Prediction results of the above three cases are reported in Table 3.

Table.3 Performance of classification for two classes 1. PD vs. Other movement disorders 2. PD vs. Healthy 3. OMD vs. Healthy. (All Results are reported in %)

	Sensitivity*	Specificity+	Overall Accuracy
PD vs. Other movement disorders	90.09	59.88	80.00
PD vs. Healthy	96.80	100.0	99.78
Other movement disorders vs. Healthy	95.28	72.95	95.28

*Sensitivity = TP/(TP+FN), where TP refers to true positives, while FN stands for false negatives.

+Specificity = TN/(TN+FP), where TN refers to true negatives, while FP stands for false positives.

Now new model on Prediction API was trained using all three classes which resulted in overall accuracy of 82.43%. Accuracies for individual classes are reported in Table 4.

Table.4 Accuracy with three classes

	Accuracy
Parkinson's disease	87.37
Other Movement disorders	60.00
Healthy	91.57

4. USE AS A DIAGNOSTIC TOOL

A software with GUI was developed for usability study of CDSS. In this separate study, the proposed system acted as a first hand diagnostic tool with the neurologist's assessment acting as a performance evaluator. Nine participants participated in this study which was conducted separately. The four-step process of usability study is explained below:

Steps of Usability Study:	
1	Signal Acquisition using hardware as described in Subheading 2.1.
2	Features computed and stored in database.
3	Feature vector sent to Prediction API and decision received prior to examination by a physician.
4	Decision from CDSS stored and compared with physician's hypothesis.

Of these nine participants, five were later diagnosed by a neurologist with Parkinson's disease and the rest were diagnosed with other movement disorders such as Benign Essential Tremor and Post-Stroke Parkinsonism [17]. Performance of usability study of CDSS is reported in Table 5.

Table.5 Performance of usability study of CDSS.

	Sensitivity	Specificity
PD vs. Other movement disorders	80.00	75.00

Among these 5 subjects who were diagnosed with PD, two of them were in early stages of PD which verifies that our Decision Support System is capable of correctly diagnosing PD in early stages where characteristic Parkinsonian tremor is still not evident. This supports the fact that performance of CDSS is satisfactory.

5. RELATION TO PRIOR WORK

Previous work [15] on classification of Parkinson's disease using wearable sensors classifies using only two classes: PD and Healthy. Though this technique gives very high accuracy but is not very pragmatic, the reason being that neurologists have prime difficulty in discriminating between tremor of PD and other movement disorders. Hence, taking this forward we analyzed not only finger tremor but also studied and classified tremor behavior of other movement disorders as compared to Parkinson's disease. Furthermore, a large and diverse set of data from subjects was acquired as compared to previous studies conducted in this area.

6. CONCLUSION

Using a tri-axial gyroscope we were able to discriminate among the three classes with significant accuracy. Thus, the performance of CDSS appears to be satisfactory in discriminating between PD and related movement disorders.

In the future, the CDSS can also incorporate additional data such as voice signals, gait analysis and finger tapping for greater accuracy and robustness of CDSS. Future studies can also incorporate prediction of UPDRS (Unified Parkinson's Disease Rating Scale) for PD and TETRAS (The Essential Tremor Rating Assessment Scale) for Essential Tremor, in order to give physician a better idea of progressive nature of such disorders. As effectiveness of levodopa in managing symptoms of PD gradually decreases with time. Hence, accurate prediction of UPDRS/TETRAS will not only result in greater diagnostic accuracy but also better drug prescription and monitoring management.

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