Detection of Parkinson’s Disease Symptoms using Mobile Sensors

CS G513 STUDY IN ADVANCED TOPICS

Guided By
Prof. Vinayak Nayak

Submitted By

Kanika Gera
2018H1030041G
h20180041@goa.bits-pilani.ac.in

Problem Statement

Parkinson’s Disease is a nervous system disorder that leads to involuntary muscle movement.It is a common disease, especially in India , and has about 1 million cases every year.
Parkinson’s Disease is a degenerative disorder of the central nervous system[1].Symptoms starts with a barely noticeable tremor in finger of one hand, it gradually increases to tremor in complete palm and hand. In the early stages of Parkinson's disease, face may show little or no expression,arms may not swing while walking, speech may become soft or slurred. Parkinson's disease symptoms worsen over time[2].
The idea is to detect the symptoms in early stages by recording the data of day to day activities of the user, and ask the user to report to the doctor immediately if required.

Objective

Our goal is to build an application which can collect the data from the user that can be helpful in creating a prediction that a person may or may not have parkinson's.
Various Medical Literature and Existing Applications for Parkinson’s disease list various factors like touch, movement, voice, walk can be considered when predicting if candidate may have parkinsons or not.
Our milestone for this semester is to consider touch and movement related symptoms , and develop an end to end architecture for detection of parkinson’s disease.

Literature Survey

The literature survey involved understanding of parkinson's disease, symptoms shown by it, exploration of existing applications for collection of data using phone sensors .
In this report, I shall focus on **Tremor** as a symptom to detect parkinsons, and ways to detect Tremor using mobile app and analysis related to it.

Survey 1 - Tremor, Rodger J. Elble, Department of Neurology Southern Illinois University School of Medicine Springfield USA [3]

This is a chapter (chapter 20) in medical book named Neuro-Geriatrics, it defines tremor in medical perspective and states that tremor is a common neurological sign . It has significant diagnostic value only when characterized properly with a thorough history and physical examination.
Tremors can only be a physical abnormality i.e. isolated tremor or may be combined with neurologic signs.
Talking in respect to parkinson's resting tremor is most common symptom.The chapter explains other reasons for tremor but significantly states that resting tremor is associated with Parkinson's Disease in most of the cases.The differential diagnosis and treatment of these tremor syndromes are summarized in this chapter.
The tremor that occurs in Parkinson's disease is different than almost all other tremors because it is a "resting tremor," present primarily at rest. It goes away with movement, but often returns when the limb (usually a hand or the fingers) is held in one position, as in holding a spoon or fork to the mouth [6].
Chapter states that Rest tremor occurs in the limbs, lips, jaw and tongue of patients with Parkinson disease and rarely in patients with other parkinsonism diseases.
Rest tremor in the hand typically consists of a complex "pill rolling" movement of the fingers.
Rest tremor is suppressed, at least transiently, when a voluntary movement or posture is initiated, and re-emergent tremor is also common. Decrement in repetitive finger and hand movements is also a common and differentiating symptom.

Survey 2- MDS Clinical Diagnostic Criteria for Parkinson's Disease [4]

This document presents the Movement Disorder Society Clinical Diagnostic Criteria for Parkinson's disease. The benchmark for these criteria is expert clinical diagnosis; the aim was to systematize the diagnostic process, to make it reproducible across centers and applicable by clinicians with less expertise in PD diagnosis.

They conclude that motor abnormalities remain significant for detection of parkinson's disease, some non-motor abnormalities are also considered.
It is said that Rest tremor refers to a 4- to 6-Hz tremor in the fully resting limb, which is suppressed during movement initiation. Rest tremor can be assessed during the entire interview and examination. Kinetic and postural tremors alone (MDSUPDRS 3.15 and 3.16) do not qualify for parkinsonism criteria.

Note: In PD, a parkinsonian rest tremor in the hand also can be observed with prolonged posture (ie, "re emergent" tremor); however, to meet criteria, tremor also must be observed during rest. In patients with associated postural or kinetic tremor, care must be taken to ensure that the limb is fully relaxed during examination. The frequency of a true rest tremor usually will be slower than the associated action tremor Although postural instability is a feature of parkinsonism, it is not part of the MDS-PD criteria for parkinsonism caused by Parkinson's Disease. Postural instability often occurs in later stages of PD, but its presence early in disease suggests an alterative diagnosis.

Rest Tremor is included primarily for two reasons:
(1) rest tremor is less common in alternate conditions
(2) rest tremor may occasionally be less responsive to therapy; if so, criterion 1 may be harder to meet in tremor-predominant PD.

Survey 3-Variable expression of Parkinson’s disease: A base-line analysis of the DATATOP cohort [5]

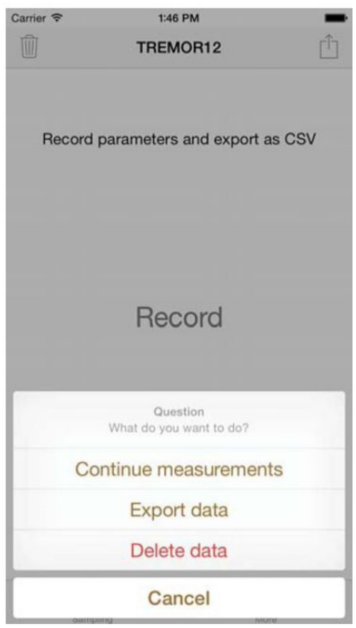
The Paper explores heterogeneity in Parkinson’s disease , and creates a baseline score to detect parkinsons using DATATOP database
which includes clinical information on 800 patients with early untreated Parkinson’s disease . The study provides support for the existence of at least 2 clinical subtypes of PD, the tremor-dominant and the PIGD forms. The data further indicates that patients with malignant PD have more PIGD and bradykinesia and less tremor at onset as compared with those with benign PD and that a deterioration in motor function is not necessarily accompanied by a cognitive decline.

	Tremor ($T/PIGD \geq 1.5$)		
Variable*	**Mean**	**SD**	**N**
Percent males	69.4		441
Age at onset	59.0	9.6	414
Age at entry	61.2	9.5	441
Duration of symptoms	2.2	1.3	419
H/Y stage at entry	1.6	0.5	441
S/E ADL score	92.5	6.4	441
Occup. disabil.	0.4	0.6	441
Intell. impair.	0.3	0.5	441
Lack of motivation	0.4	0.6	441
Speech diffic.	0.5	0.6	441
Swallow. diffic.	0.1	0.3	441
Falling	0.0	0.2	441
Freezing	0.0	0.1	441
Bradykinesia	0.8	0.7	441
At onset (%)			
Tremor	87.5		441
Bradykinesia	24.0		441
Rigidity	22.9		441
Post. instab.	5.0		441

Figure : Shows Trend in Speech Difficulty, Freezing etc for patients suffering with tremor efficient parkinson's disease.

Survey 4- Tremor12 [7]

TREMOR12 is an open-source mobile app that samples acceleration, rotation, rotation speed, and gravity, each in 3 axes and time-stamped in a frequency up to 100 Hz. The raw measurement data can be exported as a comma-separated value file for further analysis.
Quantitative features can be extracted from the motion sensors on the device and used to develop mathematical models for predicting rating scores from kinematic data
It implements the CMDeviceMotion class to extract 4 parameters, each in 3 axes (x, y, and z). These parameters are: acceleration (in g), rotation (in radians), rotation speed (in radians per second), and gravity (in g). The first three parameters offer tremor quantification parameters, the fourth can be used to calculate a standardized 3D space to facilitate between-measurements comparisons.
Sampling can be performed up to 100 Hz (tested on iPhone 6) and all samples are time stamped. Samples can be exported as a comma-separated value file for further analysis.



Record Button starts recording the mentioned sensors, and tapping it again stops it. Data can be exported as csv , and saved on local as well as icloud for further analysis.

Survey 5-The Identification of Parkinson’s Disease Subtypes Using Cluster Analysis: A Systematic Review [7]

This paper is to compare 7 studies that sub-classify Parkinson’s by using Cluster Analysis Technique, they have referred to in the paper and come to a conclusion about using Cluster Analysis to solve the stated problem.Six of the seven studies included motor symptoms assessed by the Unified Parkinson’s Disease Rating Scale (UPDRS), although different sum and subscores were used. Motor symptoms were combined with measures of cognition in five studies, out of which four also included depression and age-at-onset. Three of these latter four studies also included a measure of disease progression.

Basically features were selected from the given pool of - Motor symptoms, Onset symptoms, Cognitive impairment Depression, Apathy, Hallucinations, Motor Complications, Time to falls, Disease progression, Disease severity, Disease duration, Age at onset, Age, Medication, ADL -activities of daily living.
The values were standardized using Z-score in almost all the studies.
Information on the applied Cluster Analysis method was not reported in one study.All other studies used K-means .
8 clusters were identified with following cluster characteristics:

1. Old age at onset/rapid disease progression
2. Young age at onset/slow disease progression
3. Intermediate onset, anxiety, depression
4. Tremor dominant
5. Non-tremor dominant
6. More severe motor & cognitive impairment
7. Mild motor & mild cognitive
8. impairment Motor only

They basically found seven studies that performed Cluster Analysis on a combination of PD features with the aim to identify clinical subtypes in PD.
In a nutshell, they concluded that although Cluster Analysis has a great potential in identifying subtypes, since there are methodological differences between studies, there are differences in the cluster formation and hence a standard methodology must be followed , along with that some other considering drawbacks of K-Means some other clustering techniques should also be tried and tested.

Conclusion of Literature Survey

Survey 1 and Survey 2 defines the Tremor as a symptom to Parkinson's Disease. Survey 1 clears the fact that it is actually a resting tremor that differentiates Parkinson's patient from any other neurologically impacted patient. Survey1 clarifies medical definition of rest tremor , also states that rest tremor in the hand typically consists of a complex "pill rolling" movement of the fingers for Parkinson's Patient.It also states that rest tremor is suppressed when a voluntary movement or posture is initiated,
Keeping this in mind we can design activities in our application that collects actual useful information , rather than some random data.Survey 3 gives an idea to identify patient with parkinson's using some scoring system, which is often used by doctors to examine patients.Although Survey 3 is more about differentiating between tremor-dominant and the PIGD patients with some scoring strategy, we can use a similar technique to identify tremor-dominant and non tremor person i.e. a parkinson's patient and a healthy person.Survey 5 again gives us an idea of Cluster Analysis that can be useful for clustering healthy and a diseased person. Survey 4 is implementation details of collecting tremor using sensors of phone. It is an ios application for getting data of acceleration (in g), rotation (in radians), rotation speed (in radians per second), and gravity (in g) sensors present in the phone.

Methodology

The project is divided into four phases , Phase 1 and Phase 2 's discussion , outcomes and results of which are written below.Phase 3 and Phase 4 are explained in detail in the rest of the report.

Phase 1 : Identify Essential Activities to detect Parkinsons

In order to detect parkinsons, as seen from literature survey tremor is an essential factor. Various potential activities that we have identified to successfully record resting tremor are the following

1. Movement Related Activities
    a. Stand, raise the hand 90 degrees , palm facing upwards, and place the phone on palm.
    b. Hold Phone in hand and place a hand on your leg, while sitting on a chair
    c. Hold Phone in your palm and place elbow on the table , while the person is sitting on a chair.

Different positions of holding the phone will produce different tremors, because of different muscular tremors, different materialistic supports.

2. Touch Related Activities
    a. Touch and Hold the circle visible on screen for a few seconds, circles position should change after every few seconds.
    b. Pinch the circles , shown on screen and drag it to another location on screen (goal), measure the time to pinch properly.

As stated in [3] pinch is difficult for a person suffering with parkinson's , hence he/she might take more time or in worst case they might not even do that , as compared to a healthy person. Activity, if while holding the circle on the screen , too many taps are detected instead of one long press, the person's hand might be shaking/ experiencing resting tremor.

Phase 2 : Map Activities to Sensor Data

All the Movement Related Activities that we have designed above needs to identify tremor , using the idea of Survey 4 , we can use four sensors to identify tremor, these four sensors are acceleration (in g), rotation (in radians), rotation speed (in radians per second), and gravity (in g). Since the Tremor12 Application is in iOs , and we are interested in Android Applications , following sensors are available in android sdk as:

1. Most Android-powered devices have an accelerometer as hardware sensor.There are two sensors for this purpose with slight difference

a. TYPE_ACCELEROMETER
It measures Acceleration force along the x ,y, and z axis including gravity. Unit is m/s^2
TYPE_ACCELEROMETER_UNCALIBRATED
It measures Acceleration force along the x ,y, and z axis without any bias compensation. Unit is m/s^2

This measures the acceleration applied to the device (A). Conceptually, it does so by measuring forces applied to the sensor itself (F) using the relation:

$$A = - \sum F / mass$$

In particular, the force of gravity is always influencing the measured acceleration:

$$Ad = g - \sum F / mass$$

That is why, when the device is sitting on a still table, the accelerometer reads a magnitude of g = 9.81 m/s^2, Also when the device is in free-fall and therefore dangerously accelerating towards the ground at 9.81 m/s^2, its accelerometer reads a magnitude of 0 m/s^2. To measure the real acceleration of the device, the contribution of the force of gravity must be eliminated.

2. Gravity is software based sensor available as TYPE_GRAVITY , used for measuring the force of gravity along the x,y and z axis. Unit is m/s2
3. Rotation Sensor in Android is TYPE_ROTATION_VECTOR.
The rotation vector represents the orientation of the device as a combination of an angle and an axis, in which the device has rotated through an angle θ around an axis <x, y, z>.

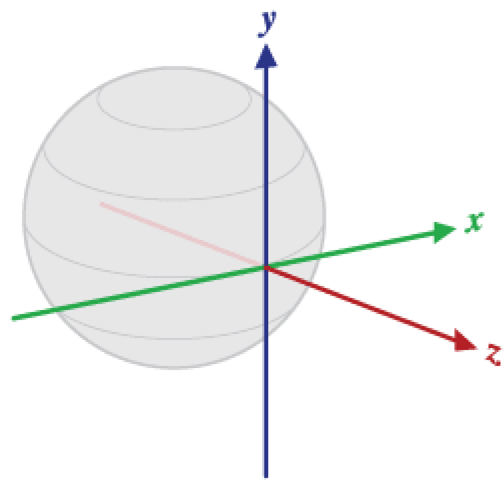
The three elements of the rotation vector are <x*sin(θ/2), y*sin(θ/2), z*sin(θ/2)>, such that the magnitude of the rotation vector is equal to sin(θ/2), and the direction of the rotation vector is equal to the direction of the axis of rotation.

Elements of the rotation vector are unitless. The x,y, and z axis are defined in the same way as the acceleration sensor.

The reference coordinate system is defined as a direct orthonormal basis, where:

a. X is defined as the vector product Y.Z (It is tangential to the ground at the device's current location and roughly points East).
b. Y is tangential to the ground at the device's current location and points towards magnetic north.

c. Z points towards the sky and is perpendicular to the ground.



- values[0]: x*sin(θ/2)
- values[1]: y*sin(θ/2)
- values[2]: z*sin(θ/2)
- values[3]: cos(θ/2)
- values[4]: estimated heading Accuracy (in radians) (-1 if unavailable)

values[3], originally optional, will always be present from SDK Level 18 onwards. values[4] is a new value available in SDK Level 18.

So basically two sensors in ios , one for Rotation Angle in Radians, and Other for Rotation Speed is replaced in Android with one Rotation Sensor where x denotes speed and the other term sin of rotation angle/2.

For all the touch related activities we to identify following gestures touch , long holds, taps at the same location , count for taps at particular location within given time period, and pinch.

1. Detecting Touch
   onTouchEvent() is a function defined in MotionEvent class to handle touch screen motion events returns true or false.Alternatively we can attach an OnTouchListener object to any on screen object using the setOnTouchListener() method.
2. Detecting Long Holds
   setIsLongpressEnabled() function in class GestureDetector is used to enable Longpressed. onLongClick() in MotionEvent is called when the View is long-pressed.
3. Count number of Taps in particular region on screen (identified as view) can be done by following fragment of code
   View rootView= getActivity().findViewById(android.R.id.content));

Set View.onTouchListener on this view by:

```
view.setOnTouchListener(new View.OnTouchListener()
 {
      @Override
       public void onClick(View v) {
            count_tap++;
        }
    });
```

4. A pinch gesture is detected by first identifying number of fingers on the screen and then tracking the distance between two fingers , if it is reduced to some threshold, we consider the gesture as pinch, as stated in reference [8].

Phase 3: Build End to End Model

This phase includes development of mobile application to collect the sensor data that gets stored on database hosted on cloud in real time, and hence can be used to identify trends in data for prediction on parkinsons. The application developed in this phase is used for collection of data for machine learning analysis.

Phase 4: Develop a Machine Learning Model

In this phase we focused on activity proposed by us in phase 1 i.e.

Stand, raise the hand 90 degrees , palm facing upwards, and place the phone on palm.

We performed the proposed activity as normal healthy adult , as well as by voluntarily producing the tremor , to produce the dataset. We engineered various features from the raw data of accelerometer sensor, and trained a machine learning model to predict tremors.

Solution Design

Infrastructure Design

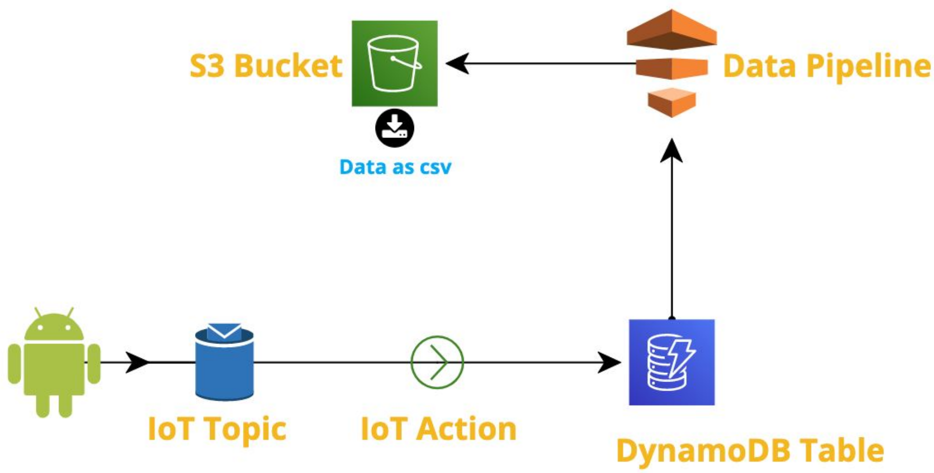


Figure 1

Figure 1 shows infrastructure used to send data from android phone to database hosted on AWS cloud. Data is then stored in S3 Bucket to be used as csv for Model Training Purposes.

Android Sends Data to AWS-Iot Topic, Iot Action defined for this topic splits the message according to headers in the message , and write each message as a tuple in DynamoDB with seven columns.DynamoDB has scheduled pipeline associated with it , which puts the data from table to Amazon S3 bucket.

This design has various advantages,

1. Use of AWSIoT core makes it possible to receive data from various android applications and write them to DynamoDB in real-time.
2. DataPipeline can be scheduled once in some time-period , to store data in csv .Infrasture used behind data pipeline is as shown in Figure 2.The use of EMR i.e. Hadoop cluster makes it possible to transfer huge data collected in DynamoDB over time , stored in S3, successfully.

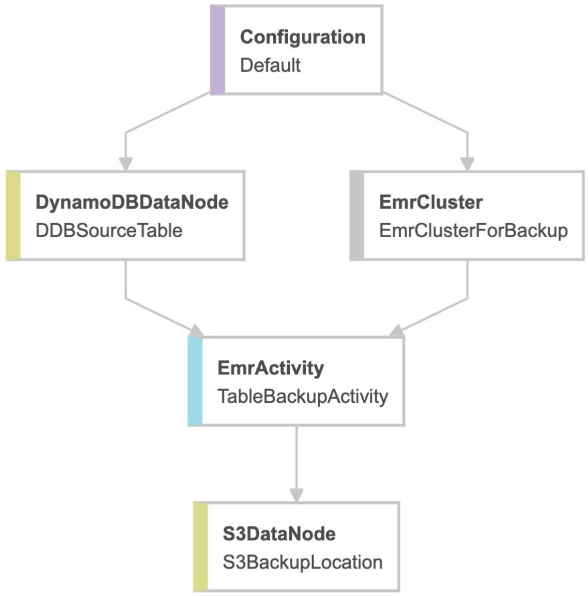


Figure 2

The DataPipeline associated with DynamoDB Table , Starts the EMR-Cluster i.e. Hadoop cluster hosted on the cloud , The Activity is to read data from the table and write into the S3-Bucket. Since it is Map-Reduced activity, the data combined is not in the same order as in DynamoDB. Hence we sort the data according to timeStamp , as we get it in S3-Bucket.

Android Application Design

Figure 3

Android application Developed uses amazon aws api to connect to the topic hosted on cloud.
It uses the MQTT Manager to connect to the IoTTopic hosted on cloud, and sends the data from sensors at the same sampling rate .
Stop Buttons stop sending data to the IoTTopic.

Data Collection

The proposed activity was performed as normal healthy adult ,and by voluntarily producing the tremor using the android application developed ,to collect the dataset. The application sends data to IoT-Topic associated with each sensor, the tuple is of format

DeviceID, TimeStamp, accX, accY, accZ, Activity, Tremor.

accX,accY,accZ were accelerometer values in X,Y and Z direction .
Activity was set to 1 specifying the ID to proposed activity.
Tremor was set 0 or 1 manually for each time we perform activity with and without tremor.

Activity: *Stand, raise the hand 90 degrees , palm facing upwards, and place the phone on palm.*
Activity Duration : 1.5 mins

We took 55 observations for Non Tremor, each of 1.5 min duration and 88 observations for Tremor each 1.5 min duration.There were total 3.575 hours of total data.

Data Preprocessing

The data we collected was raw data, first data was sorted according to timestamp, these sensor signals are preprocessed by sampled in fixed-width windows(sliding windows) of 15 seconds each. From Each window, a feature vector was obtained by calculating variables from the time and frequency domain.

Feature Engineering

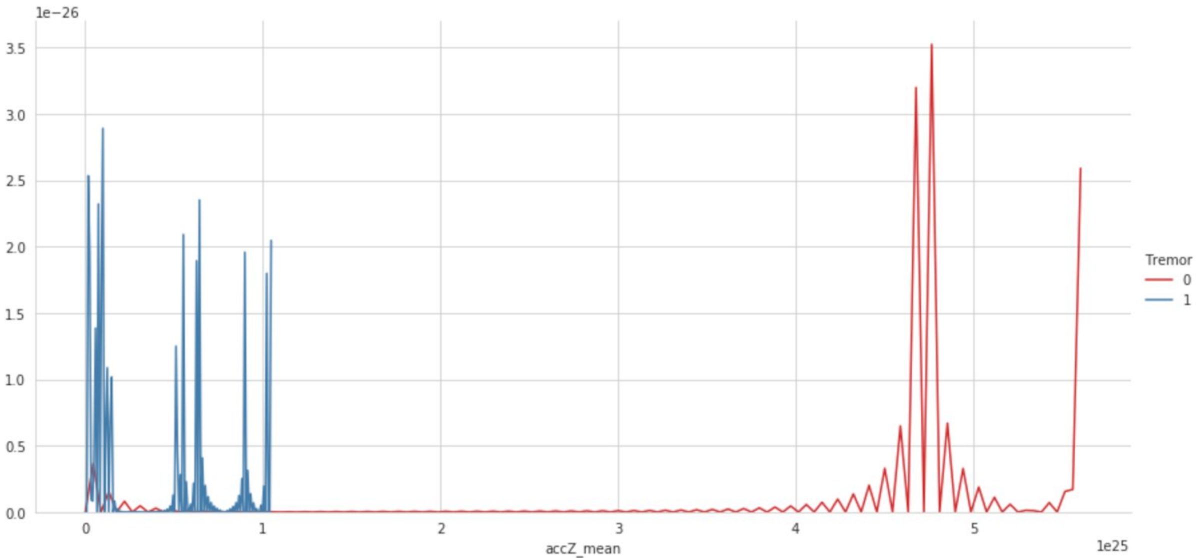
For each window obtained , following features for each axis.

- ***mean()***: Mean value -Frequency Domain
- ***std()***: Standard deviation-Frequency Domain
- ***mad()***: Median absolute deviation -Frequency Domain
- ***max()***: Largest magnitude -Frequency Domain
- ***min()***: Smallest magnitude -Frequency Domain
- ***iqr()***: Interquartile range -Frequency Domain
- ***sma()***: Signal magnitude area -Time Domain
- ***energy()***: Energy measure. Sum of the squares divided by the number of values. -Time Domain
- ***entropy()***: Signal entropy -Time Domain
- ***skewness()***: skewness of the frequency domain signal -Time Domain
- ***kurtosis()***: kurtosis of the frequency domain signal -Time Domain

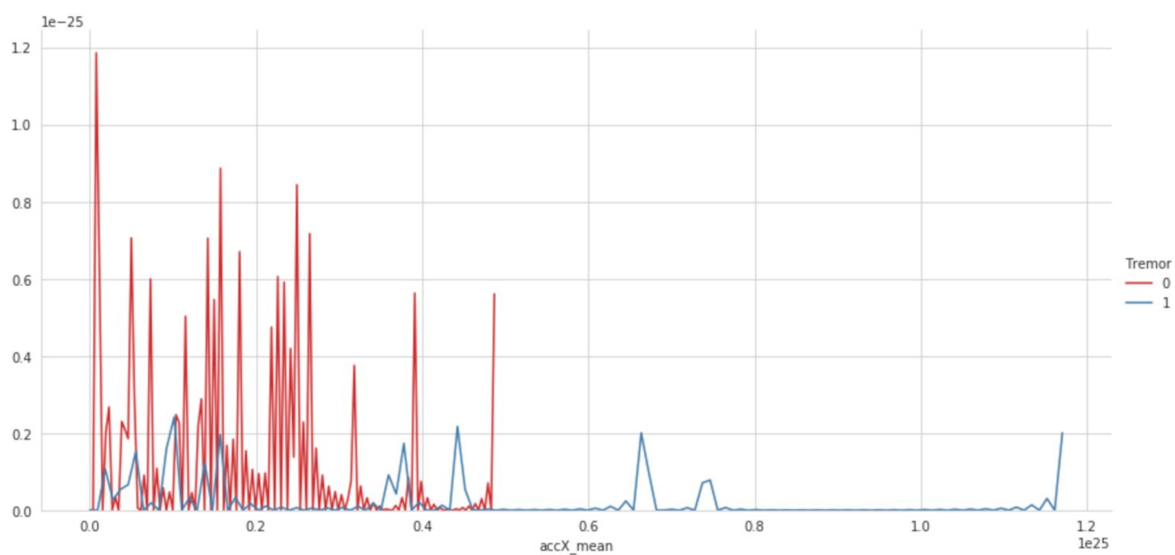
Hence now we had 33 features in total.

Exploratory Data Analysis

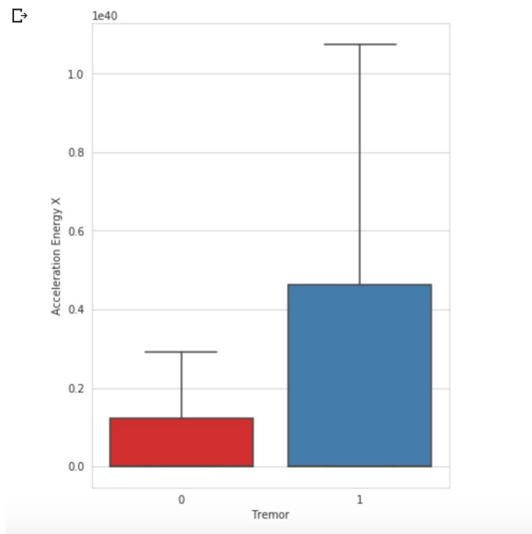
- Acceleration Mean in Z direction can be useful in perfect segregation of Tremor and Non- Tremor.



- All other features in X & Y direction have significantly different magnitudes but much more overlapping along x-axis.



- Magnitude of features like Acceleration Energy, Acceleration Mean can separate the classes well



- **Applying T-SNE (tsne)** an algorithm for dimensionality reduction to visualize the data. Normalizing the data and applying min-max scaler , to bring the data in range of 0-1 , with mean=0 and standard deviation =1 before applying T-SNE , to avoid data loss, due to conversion of float64 type of data to int32 .

The above concludes , data can seperated with plane separation modeling techniques.

Machine Learning Models

Taking Insights from EDA , we applied three models based on plane separation techniques Logistic Regression, Linear SVC and RBF SVM.Best results were achieved after scaling and normalizing data using min-max technique.

- Model Training without Normalization & Standardization gave following results.

	Accuracy	Error
Logistic Regression	: 77.26%	22.74%
Linear SVC	: 94.77%	5.231%
rbf SVM classifier	: 65.79%	34.21%

- Model Training with Normalization only gave the following results.

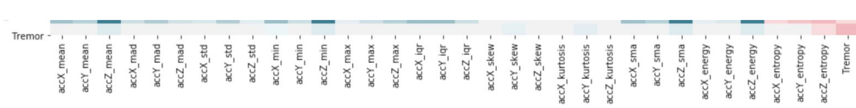
	Accuracy	Error
Logistic Regression	: 91.95%	8.048%
Linear SVC	: 95.57%	4.427%
rbf SVM classifier	: 94.37%	5.634%

- **Model Training with Normalization & Standardization gave following results.**

	Accuracy	Error
Logistic Regression	: 98.39%	1.61%
Linear SVC	: 98.79%	1.207%
rbf SVM classifier	: 99.8%	0.2012%

- Model was train after dropping non-correlated features according to correlation matrix obtained but feature dropping didn't give better results.

	Accuracy	Error
Logistic Regression	: 45.47%	54.53%
Linear SVC	: 46.28%	53.72%
rbf SVM classifier	: 62.98%	37.02%



Row corresponding to Tremor Shows Only accZ_mean , accY_skew , accY_kutrosis , accZ_sma, accz_entropy , accZ_energy as correlated. The catch here is correlation matrix shows correlation among features according to Pearson Coefficient , but as we saw in EDA , magnitude of features can be used as a good separator for distinguishing class . The result of dropping features is thus justified.

Results

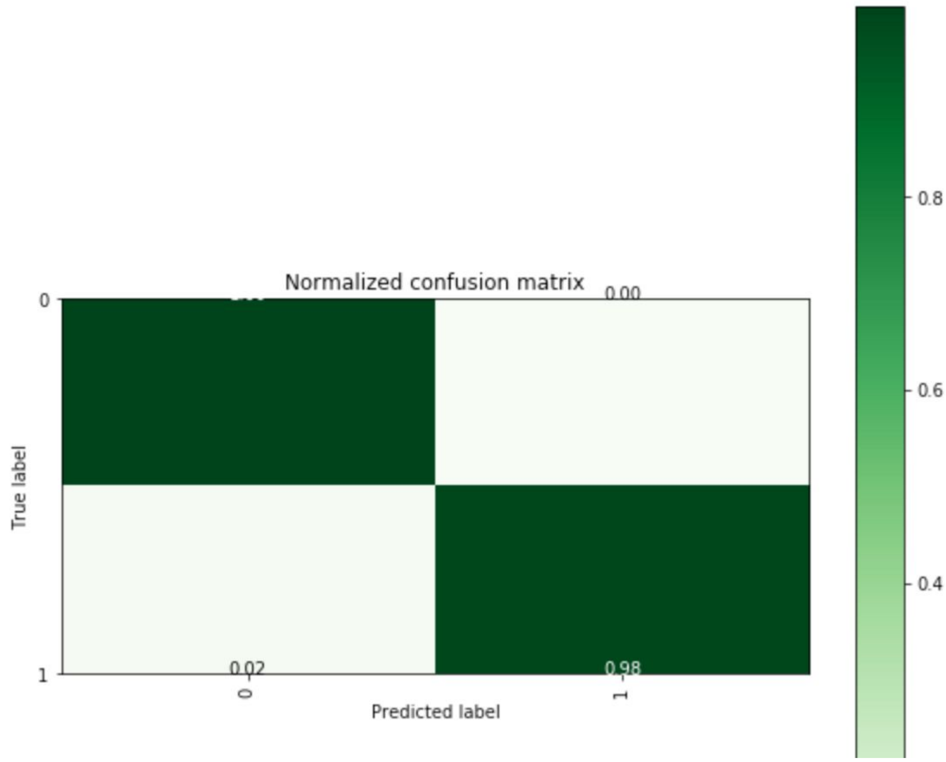
Best Model

All the models mentioned in previous section are after fine tuned by applying grid-search over various parameters.
Linear SVC is performing best in all the cases and gave the best result after normalization and standardization,hence we choose it as the best model,it also gave best f1 score among all, which is shown in figures below. The model after tuning was as follows

```
--------------------------
|      Best Estimator     |
--------------------------

        LinearSVC(C=0.5, class_weight=None, dual=True, fit_intercept=True,
          intercept_scaling=1, loss='squared_hinge', max_iter=1000,
          multi_class='ovr', penalty='l2', random_state=None, tol=5e-05,
          verbose=0)

--------------------------
|     Best parameters     |
--------------------------
        Parameters of best estimator :

        {'C': 0.5}

---------------------------------
|   No of CrossValidation sets   |
--------------------------------

        Total numbre of cross validation sets: 3

--------------------------
|        Best Score       |
--------------------------

        Average Cross Validate scores of best estimator :

        0.9900793650793651
```

Best Model's Confusion Matrix

```
--------------------
| Confusion Matrix |
--------------------

 [[229   1]
 [  5 262]]
```



Best Model's Evaluation Metrics

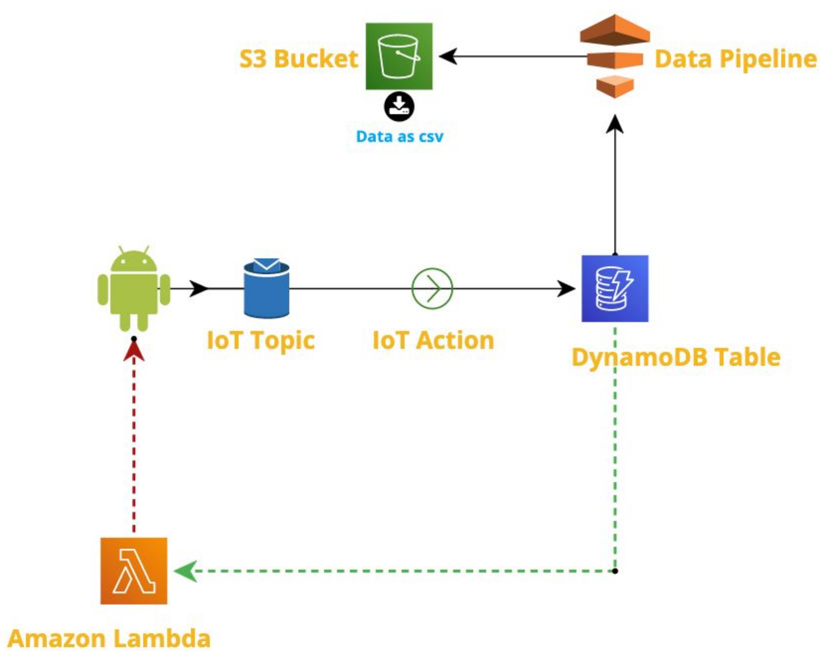
```
-------------------------
| Classifiction Report |
-------------------------
              precision    recall  f1-score   support

           0       0.98      1.00      0.99       230
           1       1.00      0.98      0.99       267

    accuracy                           0.99       497
   macro avg       0.99      0.99      0.99       497
weighted avg       0.99      0.99      0.99       497
```

Conclusion

Idea is to make use of mobile phones , and use touch and movement related symptoms , to develop an end to end architecture for detection of parkinson's disease.
The literature survey concludes that resting tremor is an effective symptom to detect the parkinson's efficiently.We have concluded with four types of activities to be implemented on android application that could effectively detect resting tremor .
We developed an application taking into account one of the proposed activities, i.e. holding the phone in hand by holding the hand at 90 degrees from leg , palm facing upwards, and place the phone on palm. We collected the data by voluntarily producing tremor . The Application sends data to database stored in the cloud , the data has been used to train a machine learning model,feature engineering is applied to generate features for machine learning , we finally achieved 98.79% accuracy.

Challenges

The android application is complete from one end , that is sending data from the mobile application to the cloud , and using it for training model. The other end to use the trained model and give back the prediction to android faced many difficulties. We extended our architecture as follows to complete the other end .



We successfully implemented line in green , where lambda function takes tuples from dynamodb for past 15 sec , on getting triggered through api-endpoint , hit when the stop button is pressed on android application. These tuples are then passed through various functions to create features that were used in training of model, and hence a datapoint is created.
This datapoint needs to pass through trained model, which is saved as finalized_model.sav in lambda environment. Since The model was trained using sklearn libraries , to use the model, same library is required, which could not be added as a Layer to the Lambda Environment.Thus prediction is not being made and hence not returned.

Future Work

The application can be scaled by including all data for all other activities proposed as well. More search can be done to add sklearn library to Lambda Environment, and hence return the result to android application.

Code Link

https://drive.google.com/drive/folders/17L12QMZLjbmyu9gIX3jhLnVE98CLL59I?usp=sharing

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