Telemonitering of Parkinson's Disease Progression through Non Invasive Speech Test

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Abstract – The project focuses on telemonitoring of Parkinson's disease, which is a neurodegenerative disorder. This disease destroys the ability to move and claim lives at an epidemic rate worldwide. What is interesting though is that voice is affected as much by Parkinson's as limb movements. Tracking Parkinson's disease (PD) symptom uses the Unified Parkinson's Disease Rating Scale (UPDRS). The project characterizes speech with signal processing algorithms, extracting clinically useful features of average PD progression to remotely replicate UPDRS assessment with accuracy. Tracking Parkinson's disease usually requires the patient's presence in clinic, and time-consuming physical examinations are done by trained medical staff. Symptom monitoring is costly and inconvenient for patient and clinical staff alike, also hampering recruitment for future large-scale clinical trials. So, Tele monitoring of PD would be the better option as it uses only simple self-administered and non-invasive speech tests. The features are extracted from the voice input using Pratt software. They cover a range of classical and novel clinical dysphonia analysis algorithms and the selected subset of features are passed to UPDRS using linear and nonlinear regression techniques, which includes classical least squares and non-parametric classification and regression trees(CART). These techniques are performed using R language in Rstudio.

Index Terms – Parkinson Disease, UPDRS, CART, Rstudio.

1. INTRODUCTION

Neurological disorders affect people profoundly and claim lives at an high rate worldwide, with Parkinson's disease being the second most common neurodegenerative disorder after Alzheimer's. incidence rates and prevalence rates of PD in different studies vary, with a large recent study reporting incident rates of 20/100,000 . It is believed that there are more than one million PWP in North America alone, while an analysis study in Europe reported prevalence rates approximately 108-257/100,000 and incidence rates 11-19/100,00. Furthermore, it is reported that an estimated 20% of PWP go untreated. Most sources claim the PD prevalence of men is higher than women and the current global average life expectancy, is estimated to be 4.4% for men and 3.7% for women.Our nervous system consists of a neurons that coordinates the actions and also transmits the signals to all parts of our body. It is very complicated, and intensive research has revealed that only a fraction of its functionality. The abundance of uncharted areas and speculative theories for certain regions of the brain and its various functional interconnections, suggest that we are still a long way from understanding how the central nervous system of our body works. The nervous system is responsible for processing sensory input, coordinating movements towards the desired goal, and also performs all other cognitive functions. Speech related organs which are involved are pulmonary organs, vocal folds, vocal tract.

Speech and Parkinson's disease:

Neurons orchestrate all muscle movement, managing the delicate co-ordination needed to successfully complete a given task, e.g. walking or lifting something. Similarly, there are neurons controlling the speech-related organs which have to co-operate in the production of speech. Loss of neurons associated with the task of controlling some of the speech-related organs, leads invariably to speech disorder. The relationship between speech and PD has been studied systematically at least as far back in the 1970's by Darley. More recent studies validate and extend these results comparing healthy controls and pwp with the majority of patients exhibiting laryngeal tremor during normal or loud phonation. A 40% reduction in vocal loudness was reported in Fox and Ramig, further endorsed later. however, the vocal sound pressure level (SPL) during sustained vowel phonation is no different from that of the healthy controls. PWP show signs of increased vibrational aperiodicity (the vocal folds' oscillating pattern departs from periodicity) and increased breathiness. hypophonia and dysphonia precede the rest of the disorders , and 98% of hypokinetic dysarthritic speech pathologies are related to PD . PD affects both genders differently with respect to their vocal performance level. . For example, a report suggests that the average increases in male PWP and decreases in female PWP compared to matched healthy controls. Recent studies have not taken into account this male-female distinction. Interestingly, a pilot study in 2004 revealed that speech impairment could be detectable as early as five years prior to diagnosis of PD.The speech recordings of two people (one of whom was eventually diagnosed with PD) of similar demographic characteristics (age, gender, and profession) had been examined for 11 years (including 7 years prior to diagnosis). Although that study consisted in comparing the voices of only two people and the authors caution regarding the interpretation of their findings, it is reasonable to assume that some early symptoms of the disease could be traceable before the patient is diagnosed.As soon as some dopaminergic

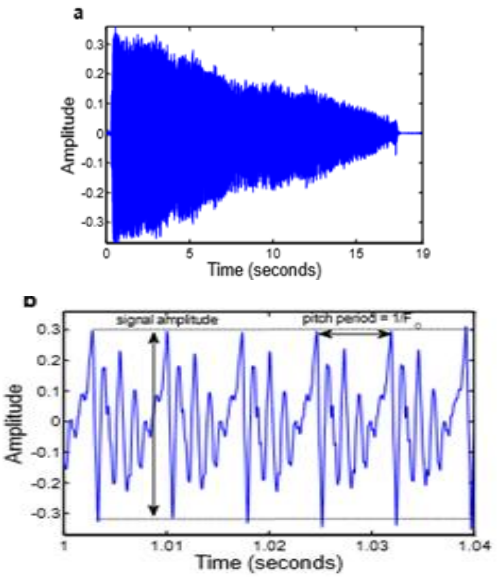
cells die, a subtle difference in muscle control might be detected with sensitive equipment and appropriate tests. Monitoring speech signals from patients who have been recently diagnosed with PD could facilitate understanding about the progression of the disease and give rise to improved diagnostic and treatment methods.

2. PORPOSED MODELLING

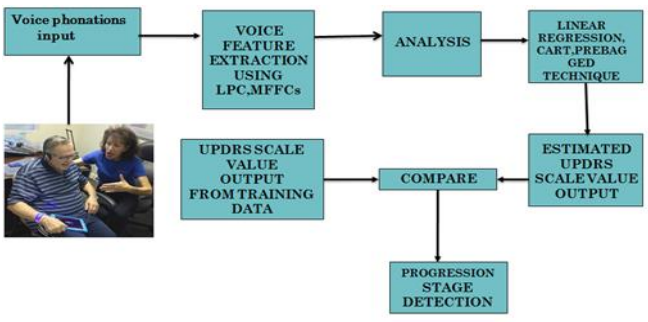
Remote replication of UPDRS assessment with clinically useful accuracy using only simple, self-administered, and non-invasive speech tests.Several robust feature selection algorithm, and statistically map the selected subset of features to UPDRS using linear and nonlinear regression techniques, which include classical least squares and non-parametric classification and regression trees (CART) are applied.

SUSTAINED VOWELS

The use of sustained vowel phonations to assess the extent of vocal symptoms, where the subject is requested to hold the frequency of phonation steady for as long as possible, is common in general speech clinical practice and has shown promising results in separating healthy controls from PWP, and PD monitor.The duration of maximum phonation has useful information, and a healthy person must be capable of sustaining his voice for about 20 seconds on average, although this depends on factors such as age, gender, body stature and general health condition .Sustaining vowels builds on the idea that a healthy subject can elicit a stationary phonation, whereas a subject with some form of vocal impairment cannot .Informally, a stationary process does not undergo change when it is shifted in time or place, and implies periodicity. In addition, using sustained vowels circumvents some of the confounding articulatory effects and linguistic components of running speech, i.e. the recording of standard phrases. The typical convention is adopted by us in the speech science literature to represent the sustained vowels and using them between slashes, e.g. for the sustained vowel _ahh…' we write /a/. The sustained vowels /a/, /i/ and /u/9 are used in some clinical applications to assess vocal performance; however, most studies focus solely on the sustained vowel /a/ because this is the simplest sound to produce, and empirically has been found to convey the most clinically useful information . Physiologically, /a/ involves the delicate combination of a variety of muscles in the vocal folds and the vocal tract, so it increases the probability that a neurological problem can be identified. Also, in /a/ the mouth is opened to the maximum extent compared to other vowels, which reduces the reflected air pulse going back to the vocal folds; therefore the recorded SPL at the lips is maximized .Vowel sounds in speech have particular formant patterns, and are typically characterized by the two lowest frequency formants labeled and , which can be plotted on an chart. In particular for the vowel /a/, ranges between 600-1,300 Hz and between 900-1,600 Hz, but this is somewhat subject-dependent. As an illustration of the concepts introduced above, shows a typical sustained vowel /a/ phonation. Qualitatively, we note that the overall speech signal amplitude is decaying towards zero .During the fianl seconds of the phonation process, the amplitude shrinks, which is a result of the lung collapse. Zooming in on the signal , we can extract the pitch period and the by observing the peaks between cycles (repetitions of the same pattern in the signal). This makes the tacit assumption that we can define T as the cycleto-cycle interval, which corresponds to the exact periodicity of the signal. But periodicity is a formal mathematical concept, and if we represent the speech signal, where is time, T should satisfy for all . In fact, periodicity does not actually apply to any real speech signal since successive cycles are never exactly the same, but this terminology pervades the speech science literature and will be used throughout this thesis. Slight disturbances in the pitch period are attributed to physiologic tremor in the laryngeal muscles, and are known as (smooth) vocal vibrato, suggesting that even speech signals from healthy people are not exactly periodic.We use the common terms nearly periodic, to describe the signals that get deviated a bit from periodicity, and aperiodic, to describe signals which do not exhibit any obvious oscillating pattern.



3. BLOCK DIAGRAM



Voice Phonations input

Parkinson's disease affected patients speak into microphone at 5cm distance. The portable home testing device records the speech signals. The recordings are transferred to the USB Pen drive. Data is transferred to the patients personal computer via USB pen drive and is sent to the clinic via Internet.

Praat Software for voice features extraction

Jitter (local): It is defined as the average value of absolute difference between the consecutive periods, divided by the average value of period. .

Jitter (local, absolute): It is defined as the average value of absolute difference between consecutive periods, in seconds.

Jitter (rap): This is the Relative Average Perturbation, the average absolute difference between a period and the average value of it and its 2 neighbors, divided by the average value of its period.

Jitter (ppq5): This is the five-point Period Perturbation Quotient, the average absolute difference between a period and the average of it and its four closest neighbours, divided by the average period.

Jitter (ddp): This is the average value of absolute difference between the consecutive differences between the consecutive periods, divided by the average value of period.

Shimmer (local): It is defined as the average value absolute difference between the amplitudes of consecutive periods, divided by the average amplitude. This parameter is called *Shim byMVDP*, and it gives 3.810% as a threshold value for pathology.

Shimmer (local, dB): It is defined as the average value of absolute base-10 logarithm of the difference between the amplitudes of consecutive periods, multiplied by 20. This parameter is called *ShdB by MVDP*, and it gives 0.350 dB as a threshold value for pathology.

Shimmer (apq3): The shimmer (apq3) is a 3-point Amplitude Perturbation Quotient, the average value of absolute difference between the amplitude of a period and the average value of the amplitudes of its neighbours, divided by the average value of the amplitude.

Shimmer (apq5): The shimmer (apq5) is a 5-point Amplitude Perturbation Quotient, the average value of the absolute difference between the amplitude of a period and the average value of the amplitudes of it and its four most close neighbours, divided by the average value of the amplitude.

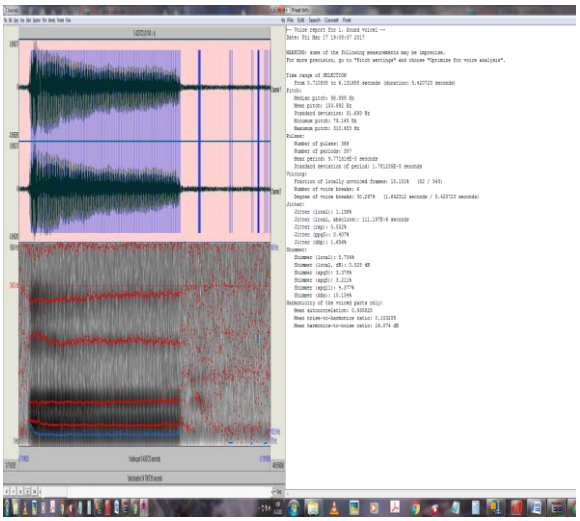
R SOFTWARE: R language is used for statistical computing and graphics related work. It is a GNU project which is similar to the S language and environment which was developed at Bell Laboratories (formerly AT&T, now Lucent Technologies) by John Chambers and colleagues. R language is a different type of implementing S. There are many differences, but most of the code written for S runs unchanged in R.R provides a wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, clustering, …) and graphics related implementation. It is also extensible to some extent

4. RESULTS AND DISCUSSIONS

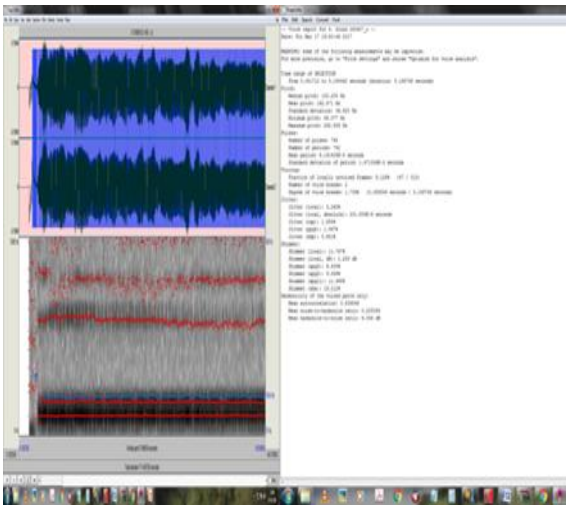
VOICE RESULT OF MALE

The voice report gives five kinds of jitter measurements, Jitter (local), Jitter(local, absolute), Jitter(rap), Jitter(ppq5), Jitter(ddp). The voice report gives six kinds of shimmer measurements, Shimmer(local), Shimmer(local,DB), Shimmer(apq3), Shimmer(apq5), Shimmer(apq11), Shimmer(ddP).

A SOUND

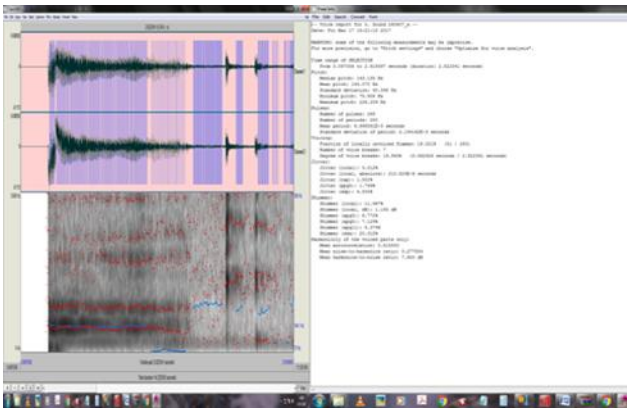


O SOUND

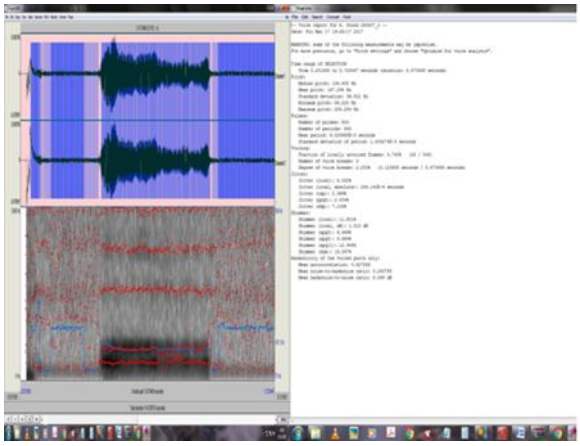


VOICE RESULT OF FEMALE

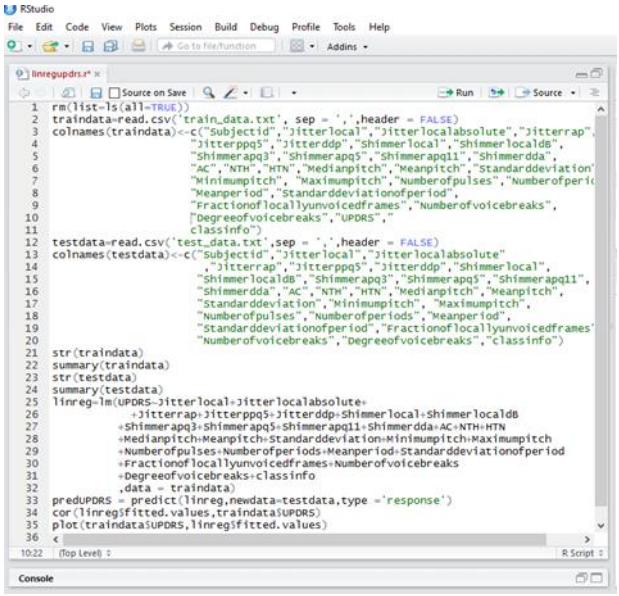
A SOUND



O SOUND



RMODULE



```
rm(list=ls(all=TRUE))
traindata=read.csv('train_data.txt', sep = ',',header = FALSE)
colnames(traindata)<-c("Subjectid","Jitterlocal","Jitterlocalabsolute","Jitterrap",
                       "Jitterppq5","Jitterddp","Shimmerlocal","ShimmerlocaldB",
                       "Shimmerapq3","Shimmerapq5","Shimmerapq11","Shimmerdda",
                       "AC","NTH","HTN","Medianpitch","Meanpitch","Standarddeviation"
                       "Minimumpitch", "Maximumpitch","Numberofpulses","Numberofperi
                       "Meanperiod","Standarddeviationofperiod",
                       "Fractionoflocallyunvoicedframes","Numberofvoicebreaks",
                       "Degreeofvoicebreaks","UPDRS","
                        classinfo")
testdata=read.csv('test_data.txt',sep = ',',header = FALSE)
colnames(testdata)<-c("Subjectid","Jitterlocal","Jitterlocalabsolute"
                      ,"Jitterrap","Jitterppq5","Jitterddp","Shimmerlocal",
                      "ShimmerlocaldB","Shimmerapq3","Shimmerapq5","Shimmerapq11",
                      "Shimmerdda","AC","NTH","HTN","Medianpitch","Meanpitch",
                      "Standarddeviation","Minimumpitch","Maximumpitch",
                      "Numberofpulses","Numberofperiods","Meanperiod",
                      "Standarddeviationofperiod","Fractionoflocallyunvoicedframes"
                      "Numberofvoicebreaks","Degreeofvoicebreaks","classinfo")
str(traindata)
summary(traindata)
str(testdata)
summary(testdata)
linreg=lm(UPDRS~Jitterlocal+Jitterlocalabsolute+
            +Jitterrap+Jitterppq5+Jitterddp+Shimmerlocal+ShimmerlocaldB
          +Shimmerapq3+Shimmerapq5+Shimmerapq11+Shimmerdda+AC+NTH+HTN
          +Medianpitch+Meanpitch+Standarddeviation+Minimumpitch+Maximumpitch
          +Numberofpulses+Numberofperiods+Meanperiod+Standarddeviationofperiod
          +Fractionoflocallyunvoicedframes+Numberofvoicebreaks
          +Degreeofvoicebreaks+classinfo
          ,data = traindata)
predUPDRS = predict(linreg,newdata=testdata,type ='response')
cor(linreg$fitted.values,traindata$UPDRS)
plot(traindata$UPDRS,linreg$fitted.values)
```

Prediction Training data UPDRS

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 [1] 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23  8  8  8  8  8  8  8  8
[35]  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8 40 40 40 40 40 40 40 40 40 40 40 40 40 40
[69] 40 40 40 40 40 40 40 40 40 40  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
[103]  5  5 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 46 46 46 46 46 46
[137] 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40
[171] 40 40 40 40 40 40 40 40 40 40 40 40 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
[205] 20 20 20 20 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 12 12 12
[239] 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24
[273] 24 24 24 24 24 24 24 24 24 24 24 24 24 24 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32
[307] 32 32 32 32 32 32 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23 23  5  5
[341]  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
[375] 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55
[409] 55 55 55 55 55 55 55 55  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
[443] 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 26 26 26 26 26 26 26 26 26 26 26 26
[477] 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46 46
```

Prediction linear regression UPDRS

```
       1        2        3        4        5        6        7        8
22.666709203 23.567746801 27.681458583 25.301956392 25.268095353 26.897276124 20.961546728 25.954843190
       9       10       11       12       13       14       15       16
21.409094982 22.906004194 23.874075096 22.453859766 20.127905729 24.351986188 25.130533874 27.689617569
      17       18       19       20       21       22       23       24
27.715159392 21.967539079 24.078161584 26.376289741 22.798866081 26.576394153 26.382508778 25.445756959
      25       26       27       28       29       30       31       32
23.925664172 23.133629638 23.616979476 25.135230538 26.870582013 21.036610993 24.880375434 21.542555113
      33       34       35       36       37       38       39       40
21.542000987 19.981962859 22.246357614 21.618036970 26.415744407 23.314691624 21.150965421 23.949602668
      41       42       43       44       45       46       47       48
23.018050505 22.624699040 24.594404193 22.875137768 24.358499547 24.948737272 23.773672072 20.466956798
      49       50       51       52       53       54       55       56
23.985166430 25.018014043 23.205894340 25.623997616 23.207790563 23.111323195 23.867641092 22.518679186
      57       58       59       60       61       62       63       64
25.407360516 31.832314290 27.593466850 29.853850378 26.854238615 27.523532113 30.906934165 31.046794902
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Prediction CART UPDRS

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      1       2       3       4       5       6       7       8       9      10      11      12
23.61333 23.61333 23.61333 27.90780 27.90780 23.61333 23.61333 23.61333 16.80328 23.61333 23.61333 23.61333
     13      14      15      16      17      18      19      20      21      22      23      24
23.61333 27.90780 27.90780 28.31579 27.90780 27.90780 23.61333 23.61333 23.61333 27.90780 27.90780 27.90780
     25      26      27      28      29      30      31      32      33      34      35      36
27.90780 23.61333 23.61333 23.61333 27.90780 16.80328 27.90780 16.80328 23.61333 16.80328 11.20000 16.80328
     37      38      39      40      41      42      43      44      45      46      47      48
27.90780 27.90780 23.61333 16.80328 27.90780 27.90780 16.80328 23.61333 23.61333 23.61333 23.61333 23.61333
     49      50      51      52      53      54      55      56      57      58      59      60
27.90780 23.61333 23.61333 27.90780 23.61333 23.61333 23.61333 16.80328 16.80328 38.82051 27.90780 38.82051
     61      62      63      64      65      66      67      68      69      70      71      72
27.90780 27.90780 38.82051 38.82051 38.82051 38.82051 38.82051 38.82051 38.82051 38.82051 27.90780 38.82051
     73      74      75      76      77      78      79      80      81      82      83      84
38.82051 28.31579 38.82051 27.90780 23.61333 27.90780  5.00000  5.00000  5.00000 23.61333 11.20000 23.61333
     85      86      87      88      89      90      91      92      93      94      95      96
23.61333 23.61333 11.20000 23.61333 11.20000 11.20000 23.61333 38.82051  5.00000  5.00000  5.00000  5.00000
```

Prediction Bagged UPDRS

```
 [1] 23.833894 24.461267 23.236897 28.052915 24.384134 25.135478 23.897604 28.707295 20.440042 24.149435
[11] 24.149435 24.149435 24.757110 29.493213 24.015339 32.698990 24.212334 31.207996 23.359885 24.741435
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[31] 21.704633 16.122117 16.606412 17.407645 18.303621 16.706129 25.014163 25.243844 20.059665 20.550570
[41] 19.390432 22.414157 19.976016 24.634718 20.263111 22.679978 21.067751 19.299272 27.633493 21.203122
[51] 20.820302 23.573676 20.079989 27.954758 27.954758 26.062603 26.208689 36.902173 34.065912 35.052255
[61] 33.150277 30.663564 36.877766 36.339436 35.299665 36.839325 33.326975 35.363441 36.493715 35.158476
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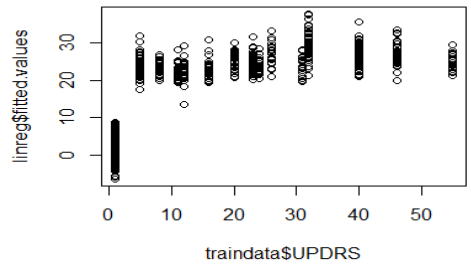
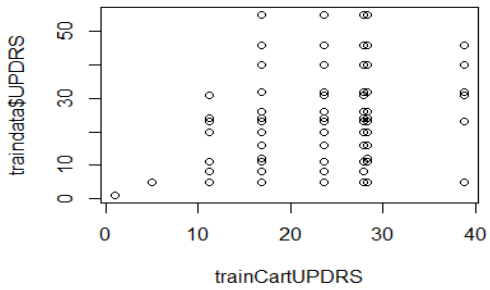
[91] 18.794681 27.212365 10.692532 15.028355 16.843280  9.468184  7.549596  8.182495  7.131834  7.708556
[101] 17.062328  7.549596  8.987919 21.984266 23.612529 24.357380 19.631249 23.643829 22.279722 26.433000
[111] 21.279899 23.577700 22.134704 18.390509 28.317998 18.260874 18.854247 20.046922 14.559768 30.354702
[121] 27.386778 32.223621 17.092604 19.743211 17.420285 22.170665 25.624978 22.493683 21.068672 17.775261
[131] 33.925063 30.176877 31.239094 29.374623 29.821285 32.034833 26.464897 24.459791 27.552930 29.264418
[141] 29.232653 28.652551 34.134650 30.283292 23.211304 33.016798 31.751113 30.352024 27.623227 27.410883
[151] 26.383307 29.434107 29.319036 26.688525 30.714693 28.411689 25.535028 25.207484 24.833039 22.319218
```

LINEAR REGRESSION VERSUS TRAINING DATA CORRELATION AND CART VERSUS TRAINING DATA UPDRS

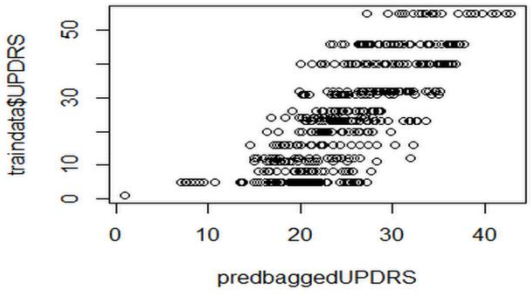
```
> cor(linreg$fitted.values,traindata$UPDRS)
[1] 0.778189
> cor(trainCartUPDRS,traindata$UPDRS)
[1] 0.8123901
```





PREBAGGED UPDRS VERSUS TRAINING DATA UPDRS

```
> cor(predbaggedUPDRS,traindata$UPDRS)
[1] 0.8830357
> plot(predbaggedUPDRS,traindata$UPDRS)
```



5. CONCLUSION

We have investigated the potential for using speech signals to estimate average PD progression with the standard reference clinical score, UPDRS. We stress that this study focused on PD*telemonitoring* and not PD *diagnosis*, which is a more difficult and subtle problem (to qualify as a diagnostic tool the methodology of the study must be applied in the form of sets of data which also include health controls along with subjects with various disorders that present PD-like symptoms). A wide range of known and novel speech signal processing algorithms (collectively known as dysphonia measures) have been implemented in order to uncover potentially concealed patterns in the PWP's voice and perform a mapping of these obtained patterns to UPDRS. We have performed the experiment with feature selection algorithms and we aim to select a model with good accuracy.

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