

# Machine Learning Project

## Introduction

Using devices such as Jawbone Up, Nike FuelBand, and Fitbit it is now possible to collect a large amount of data about personal activity relatively inexpensively. These type of devices are part of the quantified self movement – a group of enthusiasts who take measurements about themselves regularly to improve their health, to find patterns in their behavior, or because they are tech geeks. One thing that people regularly do is quantify how much of a particular activity they do, but they rarely quantify how well they do it. In this project, your goal will be to use data from accelerometers on the belt, forearm, arm, and dumbbell of 6 participants. They were asked to perform barbell lifts correctly and incorrectly in 5 different ways. More information is available from the website here:

<http://groupware.les.inf.puc-rio.br/har> (see the section on the Weight Lifting Exercise Dataset).

## Analysis

### Approach

- Load the data set and briefly learn the characteristics of the data
- Use cross-validation method to built a valid model; 70% of the original data is used for model building (training data) while the rest of 30% of the data is used for testing (testing data)
- Since the number of variables in the training data is too large, clean the data by 1) excluding variables which apparently cannot be explanatory variables, and 2) reducing variables with little information.
- Apply PCA to reduce the number of variables
- Apply random forest method to build a model
- Check the model with the testing data set
- Apply the model to estimate classes of 20 observations

### Loading data

```
data <- read.csv("pml-training.csv")
colnames(data)
```

```
## [1] "X" "user_name"
## [3] "raw_timestamp_part_1" "raw_timestamp_part_2"
## [5] "cvtd_timestamp" "new_window"
## [7] "num_window" "roll_belt"
## [9] "pitch_belt" "yaw_belt"
## [11] "total_accel_belt" "kurtosis_roll_belt"
## [13] "kurtosis_pitch_belt" "kurtosis_yaw_belt"
## [15] "skewness_roll_belt" "skewness_roll_belt.1"
## [17] "skewness_yaw_belt" "max_roll_belt"
```

## [19]	"max_picth_belt"	"max_yaw_belt"
## [21]	"min_roll_belt"	"min_pitch_belt"
## [23]	"min_yaw_belt"	"amplitude_roll_belt"
## [25]	"amplitude_pitch_belt"	"amplitude_yaw_belt"
## [27]	"var_total_accel_belt"	"avg_roll_belt"
## [29]	"stddev_roll_belt"	"var_roll_belt"
## [31]	"avg_pitch_belt"	"stddev_pitch_belt"
## [33]	"var_pitch_belt"	"avg_yaw_belt"
## [35]	"stddev_yaw_belt"	"var_yaw_belt"
## [37]	"gyros_belt_x"	"gyros_belt_y"
## [39]	"gyros_belt_z"	"accel_belt_x"
## [41]	"accel_belt_y"	"accel_belt_z"
## [43]	"magnet_belt_x"	"magnet_belt_y"
## [45]	"magnet_belt_z"	"roll_arm"
## [47]	"pitch_arm"	"yaw_arm"
## [49]	"total_accel_arm"	"var_accel_arm"
## [51]	"avg_roll_arm"	"stddev_roll_arm"
## [53]	"var_roll_arm"	"avg_pitch_arm"
## [55]	"stddev_pitch_arm"	"var_pitch_arm"
## [57]	"avg_yaw_arm"	"stddev_yaw_arm"
## [59]	"var_yaw_arm"	"gyros_arm_x"
## [61]	"gyros_arm_y"	"gyros_arm_z"
## [63]	"accel_arm_x"	"accel_arm_y"
## [65]	"accel_arm_z"	"magnet_arm_x"
## [67]	"magnet_arm_y"	"magnet_arm_z"
## [69]	"kurtosis_roll_arm"	"kurtosis_picth_arm"
## [71]	"kurtosis_yaw_arm"	"skewness_roll_arm"
## [73]	"skewness_pitch_arm"	"skewness_yaw_arm"
## [75]	"max_roll_arm"	"max_picth_arm"
## [77]	"max_yaw_arm"	"min_roll_arm"
## [79]	"min_pitch_arm"	"min_yaw_arm"
## [81]	"amplitude_roll_arm"	"amplitude_pitch_arm"
## [83]	"amplitude_yaw_arm"	"roll_dumbbell"
## [85]	"pitch_dumbbell"	"yaw_dumbbell"
## [87]	"kurtosis_roll_dumbbell"	"kurtosis_picth_dumbbell"
## [89]	"kurtosis_yaw_dumbbell"	"skewness_roll_dumbbell"
## [91]	"skewness_pitch_dumbbell"	"skewness_yaw_dumbbell"
## [93]	"max_roll_dumbbell"	"max_picth_dumbbell"
## [95]	"max_yaw_dumbbell"	"min_roll_dumbbell"
## [97]	"min_pitch_dumbbell"	"min_yaw_dumbbell"
## [99]	"amplitude_roll_dumbbell"	"amplitude_pitch_dumbbell"
## [101]	"amplitude_yaw_dumbbell"	"total_accel_dumbbell"
## [103]	"var_accel_dumbbell"	"avg_roll_dumbbell"
## [105]	"stddev_roll_dumbbell"	"var_roll_dumbbell"
## [107]	"avg_pitch_dumbbell"	"stddev_pitch_dumbbell"
## [109]	"var_pitch_dumbbell"	"avg_yaw_dumbbell"
## [111]	"stddev_yaw_dumbbell"	"var_yaw_dumbbell"
## [113]	"gyros_dumbbell_x"	"gyros_dumbbell_y"
## [115]	"gyros_dumbbell_z"	"accel_dumbbell_x"
## [117]	"accel_dumbbell_y"	"accel_dumbbell_z"

```
## [119] "magnet_dumbbell_x"      "magnet_dumbbell_y"
## [121] "magnet_dumbbell_z"      "roll_forearm"
## [123] "pitch_forearm"          "yaw_forearm"
## [125] "kurtosis_roll_forearm"  "kurtosis_pitch_forearm"
## [127] "kurtosis_yaw_forearm"   "skewness_roll_forearm"
## [129] "skewness_pitch_forearm" "skewness_yaw_forearm"
## [131] "max_roll_forearm"        "max_pitch_forearm"
## [133] "max_yaw_forearm"         "min_roll_forearm"
## [135] "min_pitch_forearm"       "min_yaw_forearm"
## [137] "amplitude_roll_forearm"  "amplitude_pitch_forearm"
## [139] "amplitude_yaw_forearm"   "total_accel_forearm"
## [141] "var_accel_forearm"       "avg_roll_forearm"
## [143] "stddev_roll_forearm"     "var_roll_forearm"
## [145] "avg_pitch_forearm"       "stddev_pitch_forearm"
## [147] "var_pitch_forearm"       "avg_yaw_forearm"
## [149] "stddev_yaw_forearm"      "var_yaw_forearm"
## [151] "gyros_forearm_x"         "gyros_forearm_y"
## [153] "gyros_forearm_z"         "accel_forearm_x"
## [155] "accel_forearm_y"         "accel_forearm_z"
## [157] "magnet_forearm_x"        "magnet_forearm_y"
## [159] "magnet_forearm_z"        "classe"
```

`summary(data)`

```
##           X           user_name raw_timestamp_part_1 raw_timestamp_part_2
## Min.      :    1      adelmo :3892      Min.      :1.322e+09      Min.      :   294
## 1st Qu.: 4906      carlitos:3112      1st Qu.:1.323e+09      1st Qu.:252912
## Median : 9812      charles :3536      Median :1.323e+09      Median :496380
## Mean    : 9812      eurico  :3070      Mean    :1.323e+09      Mean    :500656
## 3rd Qu.:14717      jeremy  :3402      3rd Qu.:1.323e+09      3rd Qu.:751891
## Max.    :19622      pedro  :2610      Max.    :1.323e+09      Max.    :998801
##
##           cvtd_timestamp new_window num_window roll_belt
## 28/11/2011 14:14: 1498 no :19216      Min.      : 1.0      Min.      :-28.90
## 05/12/2011 11:24: 1497 yes:  406      1st Qu.:222.0      1st Qu.:  1.10
## 30/11/2011 17:11: 1440                      Median :424.0      Median :113.00
## 05/12/2011 11:25: 1425                      Mean    :430.6      Mean    :  64.41
## 02/12/2011 14:57: 1380                      3rd Qu.:644.0      3rd Qu.:123.00
## 02/12/2011 13:34: 1375                      Max.    :864.0      Max.    :162.00
## (Other)                :11007
##           pitch_belt           yaw_belt total_accel_belt kurtosis_roll_belt
## Min.      :-55.8000      Min.      :-180.00      Min.      : 0.00              :19216
## 1st Qu.:  1.7600      1st Qu.: -88.30      1st Qu.:  3.00      #DIV/0! :   10
## Median :  5.2800      Median : -13.00      Median :17.00      -1.908453:    2
## Mean    :  0.3053      Mean    : -11.21      Mean    :11.31      -0.016850:    1
## 3rd Qu.: 14.9000      3rd Qu.:  12.90      3rd Qu.:18.00      -0.021024:    1
## Max.    : 60.3000      Max.    : 179.00      Max.    :29.00      -0.025513:    1
##                                     (Other) :   391
## kurtosis_pitch_belt kurtosis_yaw_belt skewness_roll_belt
##           :19216           :19216           :19216
```

```

## #DIV/0! : 32      #DIV/0!: 406      #DIV/0! : 9
## 47.000000: 4      0.000000 : 4
## -0.150950: 3      0.422463 : 2
## -0.684748: 3      -0.003095: 1
## -1.750749: 3      -0.010002: 1
## (Other) : 361      (Other) : 389
## skewness_roll_belt.1 skewness_yaw_belt max_roll_belt max_pitch_belt
## :19216 :19216 Min. : -94.300 Min. : 3.00
## #DIV/0! : 32      #DIV/0!: 406 1st Qu.: -88.000 1st Qu.: 5.00
## 0.000000 : 4      Median : -5.100 Median :18.00
## -2.156553: 3      Mean : -6.667 Mean :12.92
## -3.072669: 3      3rd Qu.: 18.500 3rd Qu.:19.00
## -6.324555: 3      Max. :180.000 Max. :30.00
## (Other) : 361      NA's :19216 NA's :19216
## max_yaw_belt min_roll_belt min_pitch_belt min_yaw_belt
## :19216 Min. : -180.00 Min. : 0.00 :19216
## -1.1 : 30 1st Qu.: -88.40 1st Qu.: 3.00 -1.1 : 30
## -1.4 : 29 Median : -7.85 Median :16.00 -1.4 : 29
## -1.2 : 26 Mean : -10.44 Mean :10.76 -1.2 : 26
## -0.9 : 24 3rd Qu.: 9.05 3rd Qu.:17.00 -0.9 : 24
## -1.3 : 22 Max. : 173.00 Max. :23.00 -1.3 : 22
## (Other): 275 NA's :19216 NA's :19216 (Other): 275
## amplitude_roll_belt amplitude_pitch_belt amplitude_yaw_belt
## Min. : 0.000 Min. : 0.000 :19216
## 1st Qu.: 0.300 1st Qu.: 1.000 #DIV/0!: 10
## Median : 1.000 Median : 1.000 0.00 : 12
## Mean : 3.769 Mean : 2.167 0.0000 : 384
## 3rd Qu.: 2.083 3rd Qu.: 2.000
## Max. :360.000 Max. :12.000
## NA's :19216 NA's :19216
## var_total_accel_belt avg_roll_belt stddev_roll_belt var_roll_belt
## Min. : 0.000 Min. : -27.40 Min. : 0.000 Min. : 0.000
## 1st Qu.: 0.100 1st Qu.: 1.10 1st Qu.: 0.200 1st Qu.: 0.000
## Median : 0.200 Median :116.35 Median : 0.400 Median : 0.100
## Mean : 0.926 Mean : 68.06 Mean : 1.337 Mean : 7.699
## 3rd Qu.: 0.300 3rd Qu.:123.38 3rd Qu.: 0.700 3rd Qu.: 0.500
## Max. :16.500 Max. :157.40 Max. :14.200 Max. :200.700
## NA's :19216 NA's :19216 NA's :19216 NA's :19216
## avg_pitch_belt stddev_pitch_belt var_pitch_belt avg_yaw_belt
## Min. : -51.400 Min. :0.000 Min. : 0.000 Min. : -138.300
## 1st Qu.: 2.025 1st Qu.:0.200 1st Qu.: 0.000 1st Qu.: -88.175
## Median : 5.200 Median :0.400 Median : 0.100 Median : -6.550
## Mean : 0.520 Mean :0.603 Mean : 0.766 Mean : -8.831
## 3rd Qu.:15.775 3rd Qu.:0.700 3rd Qu.: 0.500 3rd Qu.: 14.125
## Max. : 59.700 Max. :4.000 Max. :16.200 Max. : 173.500
## NA's :19216 NA's :19216 NA's :19216 NA's :19216
## stddev_yaw_belt var_yaw_belt gyros_belt_x
## Min. : 0.000 Min. : 0.000 Min. : -1.040000
## 1st Qu.: 0.100 1st Qu.: 0.010 1st Qu.: -0.030000
## Median : 0.300 Median : 0.090 Median : 0.030000

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## Mean      : 1.341      Mean      : 107.487      Mean      : -0.005592
## 3rd Qu.: 0.700      3rd Qu.: 0.475      3rd Qu.: 0.110000
## Max.      :176.600     Max.      :31183.240     Max.      : 2.220000
## NA's      :19216      NA's      :19216
## gyros_belt_y      gyros_belt_z      accel_belt_x      accel_belt_y
## Min.      : -0.64000      Min.      : -1.4600      Min.      : -120.000      Min.      : -69.00
## 1st Qu.: 0.00000      1st Qu.: -0.2000      1st Qu.: -21.000      1st Qu.: 3.00
## Median : 0.02000      Median : -0.1000      Median : -15.000      Median : 35.00
## Mean      : 0.03959      Mean      : -0.1305      Mean      : -5.595      Mean      : 30.15
## 3rd Qu.: 0.11000      3rd Qu.: -0.0200      3rd Qu.: -5.000      3rd Qu.: 61.00
## Max.      : 0.64000      Max.      : 1.6200      Max.      : 85.000      Max.      :164.00
##
## accel_belt_z      magnet_belt_x      magnet_belt_y      magnet_belt_z
## Min.      : -275.00      Min.      : -52.0      Min.      : 354.0      Min.      : -623.0
## 1st Qu.: -162.00      1st Qu.: 9.0      1st Qu.: 581.0      1st Qu.: -375.0
## Median : -152.00      Median : 35.0      Median : 601.0      Median : -320.0
## Mean      : -72.59      Mean      : 55.6      Mean      : 593.7      Mean      : -345.5
## 3rd Qu.: 27.00      3rd Qu.: 59.0      3rd Qu.: 610.0      3rd Qu.: -306.0
## Max.      : 105.00      Max.      : 485.0      Max.      : 673.0      Max.      : 293.0
##
## roll_arm      pitch_arm      yaw_arm      total_accel_arm
## Min.      : -180.00      Min.      : -88.800      Min.      : -180.0000      Min.      : 1.00
## 1st Qu.: -31.77      1st Qu.: -25.900      1st Qu.: -43.1000      1st Qu.: 17.00
## Median : 0.00      Median : 0.000      Median : 0.0000      Median : 27.00
## Mean      : 17.83      Mean      : -4.612      Mean      : -0.6188      Mean      : 25.51
## 3rd Qu.: 77.30      3rd Qu.: 11.200      3rd Qu.: 45.8750      3rd Qu.: 33.00
## Max.      : 180.00      Max.      : 88.500      Max.      : 180.0000      Max.      : 66.00
##
## var_accel_arm      avg_roll_arm      stddev_roll_arm      var_roll_arm
## Min.      : 0.00      Min.      : -166.67      Min.      : 0.000      Min.      : 0.000
## 1st Qu.: 9.03      1st Qu.: -38.37      1st Qu.: 1.376      1st Qu.: 1.898
## Median : 40.61      Median : 0.00      Median : 5.702      Median : 32.517
## Mean      : 53.23      Mean      : 12.68      Mean      : 11.201      Mean      : 417.264
## 3rd Qu.: 75.62      3rd Qu.: 76.33      3rd Qu.: 14.921      3rd Qu.: 222.647
## Max.      : 331.70      Max.      : 163.33      Max.      : 161.964      Max.      : 26232.208
## NA's      :19216      NA's      :19216      NA's      :19216      NA's      :19216
## avg_pitch_arm      stddev_pitch_arm      var_pitch_arm      avg_yaw_arm
## Min.      : -81.773      Min.      : 0.000      Min.      : 0.000      Min.      : -173.440
## 1st Qu.: -22.770      1st Qu.: 1.642      1st Qu.: 2.697      1st Qu.: -29.198
## Median : 0.000      Median : 8.133      Median : 66.146      Median : 0.000
## Mean      : -4.901      Mean      : 10.383      Mean      : 195.864      Mean      : 2.359
## 3rd Qu.: 8.277      3rd Qu.: 16.327      3rd Qu.: 266.576      3rd Qu.: 38.185
## Max.      : 75.659      Max.      : 43.412      Max.      : 1884.565      Max.      : 152.000
## NA's      :19216      NA's      :19216      NA's      :19216      NA's      :19216
## stddev_yaw_arm      var_yaw_arm      gyros_arm_x
## Min.      : 0.000      Min.      : 0.000      Min.      : -6.37000
## 1st Qu.: 2.577      1st Qu.: 6.642      1st Qu.: -1.33000
## Median : 16.682      Median : 278.309      Median : 0.08000
## Mean      : 22.270      Mean      : 1055.933      Mean      : 0.04277
## 3rd Qu.: 35.984      3rd Qu.: 1294.850      3rd Qu.: 1.57000

```

```

## Max. :177.044 Max. :31344.568 Max. : 4.87000
## NA's :19216 NA's :19216
## gyros_arm_y gyros_arm_z accel_arm_x accel_arm_y
## Min. :-3.4400 Min. :-2.3300 Min. :-404.00 Min. :-318.0
## 1st Qu.:-0.8000 1st Qu.:-0.0700 1st Qu.:-242.00 1st Qu.: -54.0
## Median :-0.2400 Median : 0.2300 Median : -44.00 Median : 14.0
## Mean :-0.2571 Mean : 0.2695 Mean : -60.24 Mean : 32.6
## 3rd Qu.: 0.1400 3rd Qu.: 0.7200 3rd Qu.: 84.00 3rd Qu.: 139.0
## Max. : 2.8400 Max. : 3.0200 Max. : 437.00 Max. : 308.0
##
## accel_arm_z magnet_arm_x magnet_arm_y magnet_arm_z
## Min. :-636.00 Min. :-584.0 Min. :-392.0 Min. :-597.0
## 1st Qu.:-143.00 1st Qu.:-300.0 1st Qu.: -9.0 1st Qu.: 131.2
## Median : -47.00 Median : 289.0 Median : 202.0 Median : 444.0
## Mean : -71.25 Mean : 191.7 Mean : 156.6 Mean : 306.5
## 3rd Qu.: 23.00 3rd Qu.: 637.0 3rd Qu.: 323.0 3rd Qu.: 545.0
## Max. : 292.00 Max. : 782.0 Max. : 583.0 Max. : 694.0
##
## kurtosis_roll_arm kurtosis_pitch_arm kurtosis_yaw_arm skewness_roll_arm
## :19216 :19216 :19216 :19216
## #DIV/0! : 78 #DIV/0! : 80 #DIV/0! : 11 #DIV/0! : 77
## -0.02438: 1 -0.00484: 1 0.55844 : 2 -0.00051: 1
## -0.04190: 1 -0.01311: 1 0.65132 : 2 -0.00696: 1
## -0.05051: 1 -0.02967: 1 -0.01548: 1 -0.01884: 1
## -0.05695: 1 -0.07394: 1 -0.01749: 1 -0.03359: 1
## (Other) : 324 (Other) : 322 (Other) : 389 (Other) : 325
## skewness_pitch_arm skewness_yaw_arm max_roll_arm max_pitch_arm
## :19216 :19216 Min. :-73.100 Min. :-173.000
## #DIV/0! : 80 #DIV/0! : 11 1st Qu.: -0.175 1st Qu.: -1.975
## -0.00184: 1 -1.62032: 2 Median : 4.950 Median : 23.250
## -0.01185: 1 0.55053 : 2 Mean : 11.236 Mean : 35.751
## -0.01247: 1 -0.00311: 1 3rd Qu.: 26.775 3rd Qu.: 95.975
## -0.02063: 1 -0.00562: 1 Max. : 85.500 Max. : 180.000
## (Other) : 322 (Other) : 389 NA's :19216 NA's :19216
## max_yaw_arm min_roll_arm min_pitch_arm min_yaw_arm
## Min. : 4.00 Min. :-89.10 Min. :-180.00 Min. : 1.00
## 1st Qu.:29.00 1st Qu.: -41.98 1st Qu.: -72.62 1st Qu.: 8.00
## Median :34.00 Median :-22.45 Median : -33.85 Median :13.00
## Mean :35.46 Mean :-21.22 Mean : -33.92 Mean :14.66
## 3rd Qu.:41.00 3rd Qu.: 0.00 3rd Qu.: 0.00 3rd Qu.:19.00
## Max. :65.00 Max. : 66.40 Max. : 152.00 Max. :38.00
## NA's :19216 NA's :19216 NA's :19216 NA's :19216
## amplitude_roll_arm amplitude_pitch_arm amplitude_yaw_arm
## Min. : 0.000 Min. : 0.000 Min. : 0.00
## 1st Qu.: 5.425 1st Qu.: 9.925 1st Qu.:13.00
## Median : 28.450 Median : 54.900 Median :22.00
## Mean : 32.452 Mean : 69.677 Mean :20.79
## 3rd Qu.: 50.960 3rd Qu.:115.175 3rd Qu.:28.75
## Max. :119.500 Max. :360.000 Max. :52.00
## NA's :19216 NA's :19216 NA's :19216

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## roll_dumbbell      pitch_dumbbell      yaw_dumbbell
## Min.      :-153.71  Min.      :-149.59  Min.      :-150.871
## 1st Qu.: -18.49    1st Qu.: -40.89    1st Qu.: -77.644
## Median :  48.17    Median : -20.96    Median :  -3.324
## Mean   :  23.84    Mean   : -10.78    Mean   :   1.674
## 3rd Qu.:  67.61    3rd Qu.:  17.50    3rd Qu.:  79.643
## Max.    : 153.55    Max.    : 149.40    Max.    : 154.952
##
## kurtosis_roll_dumbbell kurtosis_pitch_dumbbell kurtosis_yaw_dumbbell
##           :19216           :19216           :19216
## #DIV/0!:    5           -0.5464:    2           #DIV/0!:  406
## -0.2583:    2           -0.9334:    2
## -0.3705:    2           -2.0833:    2
## -0.5855:    2           -2.0851:    2
## -2.0851:    2           -2.0889:    2
## (Other):   393           (Other):   396
## skewness_roll_dumbbell skewness_pitch_dumbbell skewness_yaw_dumbbell
##           :19216           :19216           :19216
## #DIV/0!:    4           -0.2328:    2           #DIV/0!:  406
## -0.9324:    2           -0.3521:    2
## 0.1110 :    2           -0.7036:    2
## 1.0312 :    2           0.1090 :    2
## -0.0082:    1           1.0326 :    2
## (Other):   395           (Other):   396
## max_roll_dumbbell max_pitch_dumbbell max_yaw_dumbbell min_roll_dumbbell
## Min.      :-70.10  Min.      :-112.90           :19216  Min.      :-149.60
## 1st Qu.: -27.15    1st Qu.: -66.70    -0.6      :    20    1st Qu.: -59.67
## Median : 14.85     Median :  40.05    0.2      :    19    Median : -43.55
## Mean   : 13.76     Mean   :  32.75   -0.8      :    18    Mean   : -41.24
## 3rd Qu.: 50.58     3rd Qu.: 133.22  -0.3      :    16    3rd Qu.: -25.20
## Max.    :137.00     Max.    : 155.00  -0.2      :    15    Max.    :  73.20
## NA's     :19216     NA's     :19216    (Other):   318    NA's     :19216
## min_pitch_dumbbell min_yaw_dumbbell amplitude_roll_dumbbell
## Min.      :-147.00           :19216  Min.      :  0.00
## 1st Qu.: -91.80    -0.6      :    20    1st Qu.: 14.97
## Median : -66.15    0.2      :    19    Median : 35.05
## Mean   : -33.18   -0.8      :    18    Mean   : 55.00
## 3rd Qu.:  21.20   -0.3      :    16    3rd Qu.: 81.04
## Max.    : 120.90  -0.2      :    15    Max.    :256.48
## NA's     :19216    (Other):   318    NA's     :19216
## amplitude_pitch_dumbbell amplitude_yaw_dumbbell total_accel_dumbbell
## Min.      :  0.00           :19216  Min.      :  0.00
## 1st Qu.: 17.06           #DIV/0!:    5    1st Qu.:  4.00
## Median : 41.73           0.00      :   401    Median :10.00
## Mean   : 65.93           Mean   :13.72
## 3rd Qu.: 99.55           3rd Qu.:19.00
## Max.    :273.59           Max.    :58.00
## NA's     :19216
## var_accel_dumbbell avg_roll_dumbbell stddev_roll_dumbbell
## Min.      :  0.000  Min.      :-128.96  Min.      :  0.000

```

```

## 1st Qu.: 0.378      1st Qu.: -12.33    1st Qu.: 4.639
## Median : 1.000      Median : 48.23     Median : 12.204
## Mean   : 4.388      Mean   : 23.86     Mean   : 20.761
## 3rd Qu.: 3.434      3rd Qu.: 64.37     3rd Qu.: 26.356
## Max.   :230.428     Max.   : 125.99    Max.   :123.778
## NA's   :19216      NA's   :19216     NA's   :19216
## var_roll_dumbbell  avg_pitch_dumbbell  stddev_pitch_dumbbell
## Min.    : 0.00      Min.    :-70.73    Min.    : 0.000
## 1st Qu.: 21.52      1st Qu.: -42.00    1st Qu.: 3.482
## Median : 148.95     Median : -19.91    Median : 8.089
## Mean   : 1020.27    Mean   : -12.33    Mean   :13.147
## 3rd Qu.: 694.65     3rd Qu.: 13.21     3rd Qu.:19.238
## Max.   :15321.01    Max.   : 94.28     Max.   :82.680
## NA's   :19216      NA's   :19216     NA's   :19216
## var_pitch_dumbbell avg_yaw_dumbbell    stddev_yaw_dumbbell
## Min.    : 0.00      Min.    :-117.950   Min.    : 0.000
## 1st Qu.: 12.12      1st Qu.: -76.696    1st Qu.: 3.885
## Median : 65.44      Median : -4.505     Median : 10.264
## Mean   : 350.31     Mean   : 0.202       Mean   : 16.647
## 3rd Qu.: 370.11     3rd Qu.: 71.234     3rd Qu.: 24.674
## Max.   :6836.02     Max.   : 134.905     Max.   :107.088
## NA's   :19216      NA's   :19216     NA's   :19216
## var_yaw_dumbbell   gyros_dumbbell_x    gyros_dumbbell_y
## Min.    : 0.00      Min.    :-204.0000   Min.    :-2.10000
## 1st Qu.: 15.09      1st Qu.: -0.0300     1st Qu.: -0.14000
## Median : 105.35     Median : 0.1300      Median : 0.03000
## Mean   : 589.84     Mean   : 0.1611      Mean   : 0.04606
## 3rd Qu.: 608.79     3rd Qu.: 0.3500      3rd Qu.: 0.21000
## Max.   :11467.91    Max.   : 2.2200      Max.   :52.00000
## NA's   :19216
## gyros_dumbbell_z   accel_dumbbell_x    accel_dumbbell_y    accel_dumbbell_z
## Min.    : -2.380    Min.    :-419.00     Min.    :-189.00     Min.    :-334.00
## 1st Qu.: -0.310     1st Qu.: -50.00     1st Qu.: -8.00      1st Qu.: -142.00
## Median : -0.130     Median : -8.00      Median : 41.50       Median : -1.00
## Mean   : -0.129     Mean   : -28.62     Mean   : 52.63        Mean   : -38.32
## 3rd Qu.: 0.030      3rd Qu.: 11.00     3rd Qu.: 111.00     3rd Qu.: 38.00
## Max.   :317.000     Max.   : 235.00     Max.   : 315.00     Max.   : 318.00
##
## magnet_dumbbell_x  magnet_dumbbell_y    magnet_dumbbell_z    roll_forearm
## Min.    : -643.0    Min.    : -3600      Min.    : -262.00     Min.    : -180.0000
## 1st Qu.: -535.0     1st Qu.: 231         1st Qu.: -45.00      1st Qu.: -0.7375
## Median : -479.0     Median : 311         Median : 13.00       Median : 21.7000
## Mean   : -328.5     Mean   : 221         Mean   : 46.05        Mean   : 33.8265
## 3rd Qu.: -304.0     3rd Qu.: 390         3rd Qu.: 95.00       3rd Qu.: 140.0000
## Max.   : 592.0      Max.   : 633         Max.   : 452.00      Max.   : 180.0000
##
## pitch_forearm      yaw_forearm          kurtosis_roll_forearm
## Min.    : -72.50    Min.    : -180.00     :19216
## 1st Qu.: 0.00      1st Qu.: -68.60     #DIV/0!: 84
## Median : 9.24      Median : 0.00       -0.8079: 2

```



```

## Mean : 10.71 Mean : 19.21 -0.9169: 2
## 3rd Qu.: 28.40 3rd Qu.: 110.00 -0.0227: 1
## Max. : 89.80 Max. : 180.00 -0.0359: 1
## (Other): 316
## kurtosis_picth_forearm kurtosis_yaw_forearm skewness_roll_forearm
## :19216 :19216 :19216
## #DIV/0!: 85 #DIV/0!: 406 #DIV/0!: 83
## -0.0073: 1 -0.1912: 2
## -0.0442: 1 -0.4126: 2
## -0.0489: 1 -0.0004: 1
## -0.0523: 1 -0.0013: 1
## (Other): 317 (Other): 317
## skewness_pitch_forearm skewness_yaw_forearm max_roll_forearm
## :19216 :19216 Min. : -66.60
## #DIV/0!: 85 #DIV/0!: 406 1st Qu.: 0.00
## 0.0000 : 4 Median : 26.80
## -0.6992: 2 Mean : 24.49
## -0.0113: 1 3rd Qu.: 45.95
## -0.0131: 1 Max. : 89.80
## (Other): 313 NA's :19216
## max_picth_forearm max_yaw_forearm min_roll_forearm min_pitch_forearm
## Min. : -151.00 :19216 Min. : -72.500 Min. : -180.00
## 1st Qu.: 0.00 #DIV/0!: 84 1st Qu.: -6.075 1st Qu.: -175.00
## Median : 113.00 -1.2 : 32 Median : 0.000 Median : -61.00
## Mean : 81.49 -1.3 : 31 Mean : -0.167 Mean : -57.57
## 3rd Qu.: 174.75 -1.4 : 24 3rd Qu.: 12.075 3rd Qu.: 0.00
## Max. : 180.00 -1.5 : 24 Max. : 62.100 Max. : 167.00
## NA's :19216 (Other): 211 NA's :19216 NA's :19216
## min_yaw_forearm amplitude_roll_forearm amplitude_pitch_forearm
## :19216 Min. : 0.000 Min. : 0.0
## #DIV/0!: 84 1st Qu.: 1.125 1st Qu.: 2.0
## -1.2 : 32 Median : 17.770 Median : 83.7
## -1.3 : 31 Mean : 24.653 Mean : 139.1
## -1.4 : 24 3rd Qu.: 39.875 3rd Qu.: 350.0
## -1.5 : 24 Max. : 126.000 Max. : 360.0
## (Other): 211 NA's :19216 NA's :19216
## amplitude_yaw_forearm total_accel_forearm var_accel_forearm
## :19216 Min. : 0.00 Min. : 0.000
## #DIV/0!: 84 1st Qu.: 29.00 1st Qu.: 6.759
## 0.00 : 322 Median : 36.00 Median : 21.165
## Mean : 34.72 Mean : 33.502
## 3rd Qu.: 41.00 3rd Qu.: 51.240
## Max. : 108.00 Max. : 172.606
## NA's :19216
## avg_roll_forearm stddev_roll_forearm var_roll_forearm
## Min. : -177.234 Min. : 0.000 Min. : 0.00
## 1st Qu.: -0.909 1st Qu.: 0.428 1st Qu.: 0.18
## Median : 11.172 Median : 8.030 Median : 64.48
## Mean : 33.165 Mean : 41.986 Mean : 5274.10
## 3rd Qu.: 107.132 3rd Qu.: 85.373 3rd Qu.: 7289.08

```

```

## Max. : 177.256 Max. :179.171 Max. :32102.24
## NA's :19216 NA's :19216 NA's :19216
## avg_pitch_forearm stddev_pitch_forearm var_pitch_forearm
## Min. :-68.17 Min. : 0.000 Min. : 0.000
## 1st Qu.: 0.00 1st Qu.: 0.336 1st Qu.: 0.113
## Median : 12.02 Median : 5.516 Median : 30.425
## Mean : 11.79 Mean : 7.977 Mean : 139.593
## 3rd Qu.: 28.48 3rd Qu.:12.866 3rd Qu.: 165.532
## Max. : 72.09 Max. :47.745 Max. :2279.617
## NA's :19216 NA's :19216 NA's :19216
## avg_yaw_forearm stddev_yaw_forearm var_yaw_forearm gyros_forearm_x
## Min. :-155.06 Min. : 0.000 Min. : 0.00 Min. :-22.000
## 1st Qu.: -26.26 1st Qu.: 0.524 1st Qu.: 0.27 1st Qu.: -0.220
## Median : 0.00 Median : 24.743 Median : 612.21 Median : 0.050
## Mean : 18.00 Mean : 44.854 Mean : 4639.85 Mean : 0.158
## 3rd Qu.: 85.79 3rd Qu.: 85.817 3rd Qu.: 7368.41 3rd Qu.: 0.560
## Max. : 169.24 Max. :197.508 Max. :39009.33 Max. : 3.970
## NA's :19216 NA's :19216 NA's :19216
## gyros_forearm_y gyros_forearm_z accel_forearm_x accel_forearm_y
## Min. : -7.02000 Min. : -8.0900 Min. : -498.00 Min. : -632.0
## 1st Qu.: -1.46000 1st Qu.: -0.1800 1st Qu.: -178.00 1st Qu.: 57.0
## Median : 0.03000 Median : 0.0800 Median : -57.00 Median : 201.0
## Mean : 0.07517 Mean : 0.1512 Mean : -61.65 Mean : 163.7
## 3rd Qu.: 1.62000 3rd Qu.: 0.4900 3rd Qu.: 76.00 3rd Qu.: 312.0
## Max. :311.00000 Max. :231.0000 Max. : 477.00 Max. : 923.0
##
## accel_forearm_z magnet_forearm_x magnet_forearm_y magnet_forearm_z
## Min. : -446.00 Min. : -1280.0 Min. : -896.0 Min. : -973.0
## 1st Qu.: -182.00 1st Qu.: -616.0 1st Qu.: 2.0 1st Qu.: 191.0
## Median : -39.00 Median : -378.0 Median : 591.0 Median : 511.0
## Mean : -55.29 Mean : -312.6 Mean : 380.1 Mean : 393.6
## 3rd Qu.: 26.00 3rd Qu.: -73.0 3rd Qu.: 737.0 3rd Qu.: 653.0
## Max. : 291.00 Max. : 672.0 Max. :1480.0 Max. :1090.0
##
## classe
## A:5580
## B:3797
## C:3422
## D:3216
## E:3607
##
##

```

## Cross validation

Use 70% of training set data to built a model, and use the rest to test the model

```
library(caret)
```

```
## Warning: package 'caret' was built under R version 3.3.1
```

```
## Loading required package: lattice

## Warning: package 'lattice' was built under R version 3.3.1

## Loading required package: ggplot2

set.seed(1111)
train <- createDataPartition(y=data$classe,p=.70,list=F)
training <- data[train,]
testing <- data[-train,]
```

## Cleaning the training data

Exclude identifier, timestamp, and window data

```
Cl <- grep("name|timestamp|window|X", colnames(training), value=F)
trainingCl <- training[, -Cl]
```

Select variables with high (over 95%) missing data, exclude them from the analysis

```
trainingCl[trainingCl==""] <- NA
NARate <- apply(trainingCl, 2, function(x) sum(is.na(x))/nrow(trainingCl))
trainingCl <- trainingCl[!(NARate>0.95)]
summary(trainingCl)
```

```
##      roll_belt      pitch_belt      yaw_belt      total_accel_belt
## Min.      :-28.80   Min.      :-55.8000   Min.      :-180.00   Min.      : 0.00
## 1st Qu.:  1.09    1st Qu.:  1.7900    1st Qu.: -88.30    1st Qu.:  3.00
## Median :114.00    Median :  5.2900    Median : -12.20    Median :17.00
## Mean   : 64.62    Mean   :  0.3364    Mean   : -11.01    Mean   :11.34
## 3rd Qu.:123.00    3rd Qu.: 15.0000    3rd Qu.:  12.90    3rd Qu.:18.00
## Max.    :162.00    Max.    : 60.2000    Max.    : 179.00    Max.    :29.00
##      gyros_belt_x      gyros_belt_y      gyros_belt_z
## Min.      :-1.040000   Min.      :-0.64000   Min.      :-1.4600
## 1st Qu.: -0.030000    1st Qu.:  0.00000    1st Qu.: -0.2000
## Median :  0.030000    Median :  0.02000    Median : -0.1000
## Mean     :-0.004932    Mean     :  0.03979    Mean     : -0.1311
## 3rd Qu.:  0.110000    3rd Qu.:  0.11000    3rd Qu.: -0.0200
## Max.     :  2.220000    Max.     :  0.63000    Max.     :  1.6100
##      accel_belt_x      accel_belt_y      accel_belt_z      magnet_belt_x
## Min.      :-120.000   Min.      :-69.00    Min.      :-275.00   Min.      :-52.00
## 1st Qu.: -21.000     1st Qu.:  3.00      1st Qu.: -162.00    1st Qu.:  9.00
## Median : -15.000     Median : 36.00      Median : -152.00    Median : 35.00
## Mean     : -5.605     Mean     : 30.27     Mean     : -72.97    Mean     : 55.57
## 3rd Qu.: -5.000      3rd Qu.: 61.00      3rd Qu.:  27.00     3rd Qu.: 59.00
## Max.     :  85.000     Max.     :164.00     Max.     : 105.00    Max.     :485.00
##      magnet_belt_y      magnet_belt_z      roll_arm      pitch_arm
## Min.     :354.0     Min.     : -623.0    Min.     : -180.00   Min.     : -88.200
## 1st Qu.:581.0     1st Qu.: -375.0    1st Qu.: -32.90     1st Qu.: -25.900
## Median :601.0     Median : -320.0     Median :  0.00      Median :  0.000
## Mean     :593.7     Mean     : -345.5    Mean      : 17.42     Mean     : -4.679
## 3rd Qu.:610.0     3rd Qu.: -306.0    3rd Qu.:  77.20     3rd Qu.: 11.200
```

```

## Max. :673.0 Max. : 286.0 Max. : 180.00 Max. : 88.500
## yaw_arm total_accel_arm gyros_arm_x gyros_arm_y
## Min. :-180.0000 Min. : 1.00 Min. :-6.37000 Min. :-3.3700
## 1st Qu.: -43.1000 1st Qu.:17.00 1st Qu.: -1.32000 1st Qu.: -0.8000
## Median : 0.0000 Median :27.00 Median : 0.08000 Median :-0.2600
## Mean : -0.5596 Mean :25.52 Mean : 0.05193 Mean :-0.2621
## 3rd Qu.: 46.7000 3rd Qu.:33.00 3rd Qu.: 1.59000 3rd Qu.: 0.1400
## Max. : 180.0000 Max. :66.00 Max. : 4.87000 Max. : 2.8400
## gyros_arm_z accel_arm_x accel_arm_y accel_arm_z
## Min. :-2.330 Min. :-377.00 Min. :-302.00 Min. :-636.00
## 1st Qu.: -0.070 1st Qu.: -242.00 1st Qu.: -54.00 1st Qu.: -142.00
## Median : 0.250 Median : -44.00 Median : 13.00 Median : -47.00
## Mean : 0.272 Mean : -60.59 Mean : 32.27 Mean : -71.02
## 3rd Qu.: 0.720 3rd Qu.: 84.00 3rd Qu.: 139.00 3rd Qu.: 23.00
## Max. : 3.020 Max. : 437.00 Max. : 297.00 Max. : 292.00
## magnet_arm_x magnet_arm_y magnet_arm_z roll_dumbbell
## Min. :-580.0 Min. :-386.0 Min. :-597.0 Min. :-152.83
## 1st Qu.: -299.0 1st Qu.: -11.0 1st Qu.: 129.0 1st Qu.: -18.48
## Median : 286.0 Median : 203.0 Median : 446.0 Median : 48.07
## Mean : 191.2 Mean : 156.8 Mean : 306.8 Mean : 23.77
## 3rd Qu.: 638.0 3rd Qu.: 323.0 3rd Qu.: 545.0 3rd Qu.: 67.47
## Max. : 782.0 Max. : 583.0 Max. : 694.0 Max. : 153.38
## pitch_dumbbell yaw_dumbbell total_accel_dumbbell
## Min. :-149.59 Min. :-150.871 Min. : 0.0
## 1st Qu.: -40.71 1st Qu.: -77.592 1st Qu.: 4.0
## Median : -20.99 Median : -2.172 Median :10.0
## Mean : -10.58 Mean : 1.917 Mean :13.7
## 3rd Qu.: 17.80 3rd Qu.: 79.645 3rd Qu.:19.0
## Max. : 149.40 Max. : 154.516 Max. :58.0
## gyros_dumbbell_x gyros_dumbbell_y gyros_dumbbell_z
## Min. :-204.0000 Min. :-2.10000 Min. : -2.3800
## 1st Qu.: -0.0300 1st Qu.: -0.14000 1st Qu.: -0.3100
## Median : 0.1300 Median : 0.05000 Median : -0.1300
## Mean : 0.1513 Mean : 0.04736 Mean : -0.1199
## 3rd Qu.: 0.3500 3rd Qu.: 0.21000 3rd Qu.: 0.0300
## Max. : 2.2200 Max. :52.00000 Max. :317.0000
## accel_dumbbell_x accel_dumbbell_y accel_dumbbell_z magnet_dumbbell_x
## Min. :-419.00 Min. :-189.00 Min. :-334.00 Min. :-643.0
## 1st Qu.: -50.00 1st Qu.: -8.00 1st Qu.: -142.00 1st Qu.: -535.0
## Median : -8.00 Median : 42.00 Median : -1.00 Median :-478.0
## Mean : -28.55 Mean : 52.28 Mean : -38.08 Mean :-328.8
## 3rd Qu.: 11.00 3rd Qu.: 110.00 3rd Qu.: 38.00 3rd Qu.: -307.0
## Max. : 235.00 Max. : 315.00 Max. : 318.00 Max. : 592.0
## magnet_dumbbell_y magnet_dumbbell_z roll_forearm pitch_forearm
## Min. :-744.0 Min. :-262.00 Min. :-180.00 Min. :-72.50
## 1st Qu.: 233.0 1st Qu.: -45.00 1st Qu.: -0.90 1st Qu.: 0.00
## Median : 311.0 Median : 13.00 Median : 20.90 Median : 9.11
## Mean : 222.4 Mean : 45.93 Mean : 33.57 Mean : 10.62
## 3rd Qu.: 391.0 3rd Qu.: 95.00 3rd Qu.: 140.00 3rd Qu.: 28.20
## Max. : 633.0 Max. : 452.00 Max. : 180.00 Max. : 89.80

```

```
## yaw_forearm      total_accel_forearm gyros_forearm_x
## Min.      :-180.0   Min.      : 0.00      Min.      :-22.0000
## 1st Qu.: -68.0    1st Qu.: 29.00      1st Qu.: -0.2100
## Median :  0.0     Median : 36.00      Median :  0.0500
## Mean   :  19.6    Mean   : 34.77      Mean   :  0.1614
## 3rd Qu.: 110.0    3rd Qu.: 41.00      3rd Qu.:  0.5600
## Max.    : 180.0    Max.    :108.00      Max.    :  3.9700
## gyros_forearm_y   gyros_forearm_z   accel_forearm_x   accel_forearm_y
## Min.      : -7.02000   Min.      : -8.0900   Min.      : -496.00   Min.      : -595.0
## 1st Qu.: -1.48000   1st Qu.: -0.1800   1st Qu.: -178.00   1st Qu.:  57.0
## Median :  0.02000   Median :  0.0800   Median : -58.00   Median : 201.0
## Mean   :  0.05502   Mean   :  0.1482   Mean   : -62.63   Mean   : 163.3
## 3rd Qu.:  1.59000   3rd Qu.:  0.4900   3rd Qu.:  76.00   3rd Qu.: 312.0
## Max.    :311.00000   Max.    :231.0000   Max.    : 477.00   Max.    : 923.0
## accel_forearm_z   magnet_forearm_x   magnet_forearm_y   magnet_forearm_z
## Min.      : -446.00   Min.      : -1280.0   Min.      : -896.0   Min.      : -973.0
## 1st Qu.: -182.00   1st Qu.: -615.0    1st Qu.:  -6.0    1st Qu.: 185.0
## Median : -38.00   Median : -379.0    Median : 591.0    Median : 510.0
## Mean   : -54.99   Mean   : -313.6    Mean   : 380.4    Mean   : 391.5
## 3rd Qu.:  26.00   3rd Qu.:  -77.0    3rd Qu.: 737.0    3rd Qu.: 652.0
## Max.    : 291.00   Max.    :  666.0    Max.    :1480.0    Max.    :1090.0
## classe
## A:3906
## B:2658
## C:2396
## D:2252
## E:2525
##
```

## PCA

Since the number of variables are still over 50, PCA is applied

```
preProc <- preProcess(trainingCl[,1:52],method="pca",thresh=.8) #12
components are required
preProc <- preProcess(trainingCl[,1:52],method="pca",thresh=.9) #18
components are required
preProc <- preProcess(trainingCl[,1:52],method="pca",thresh=.95) #25
components are required

preProc <- preProcess(trainingCl[,1:52],method="pca",pcaComp=25)
preProc$rotation
```

	PC1	PC2	PC3	PC4
## roll_belt	-0.3082767768	0.128610003	-0.0731469063	0.033656102
## pitch_belt	-0.0231907485	-0.291809047	-0.0685143222	0.036789712
## yaw_belt	-0.2020418745	0.252252671	-0.0223999149	0.004849847
## total_accel_belt	-0.3048865206	0.109010066	-0.0940550354	0.037797189
## gyros_belt_x	0.0930431442	0.193772398	0.1913523255	-0.051167307
## gyros_belt_y	-0.1039761092	0.207940341	0.0780087752	-0.032094220

## gyros_belt_z	0.1802068094	0.047539646	0.1030242772	-0.046001874
## accel_belt_x	0.0082973720	0.293652940	0.0852526681	-0.039490318
## accel_belt_y	-0.3167929547	0.037067434	-0.1001880424	0.045318638
## accel_belt_z	0.3169880425	-0.104142069	0.0690944981	-0.034313225
## magnet_belt_x	-0.0172305435	0.288796823	0.0414705025	-0.022122026
## magnet_belt_y	0.1155879322	0.088959091	-0.0727079114	0.006780614
## magnet_belt_z	0.0589673167	0.121574619	-0.0601428642	0.006066862
## roll_arm	0.0645602437	-0.179195476	0.0589558146	-0.033020677
## pitch_arm	0.0390114489	0.068422801	-0.2239692178	0.089056999
## yaw_arm	0.0495334247	-0.119805624	0.0040081137	-0.011056533
## total_accel_arm	0.1128413853	-0.035635001	0.0577559793	-0.005218965
## gyros_arm_x	-0.0130996385	0.050230851	0.0048143395	-0.002635787
## gyros_arm_y	0.0775359274	-0.078390151	-0.0099710116	0.002692608
## gyros_arm_z	-0.1573785200	0.186022854	0.0678677794	-0.013762326
## accel_arm_x	-0.1607250105	-0.106372825	0.1698639422	-0.074439031
## accel_arm_y	0.2687590996	-0.125784850	-0.1305988274	0.032916301
## accel_arm_z	-0.1266612366	-0.007507594	-0.2724679722	0.088713024
## magnet_arm_x	-0.0913233441	-0.008611590	0.2608209864	-0.104704814
## magnet_arm_y	0.0652802627	0.023287920	-0.3627876000	0.124607498
## magnet_arm_z	0.0321127993	0.023670953	-0.3032856319	0.109793768
## roll_dumbbell	0.0884699209	0.127847271	0.0588787503	-0.033608866
## pitch_dumbbell	-0.1063618257	-0.151357802	0.0966318458	-0.042468146
## yaw_dumbbell	-0.1216867207	-0.269170349	0.0096751674	0.011710183
## total_accel_dumbbell	0.1687847134	0.147969142	-0.1169197540	0.043241257
## gyros_dumbbell_x	-0.0075019165	-0.008664765	-0.1580583992	-0.433044225
## gyros_dumbbell_y	0.0031857495	0.038623016	0.1127331920	0.357144893
## gyros_dumbbell_z	0.0040930889	0.004790453	0.1420156344	0.435547553
## accel_dumbbell_x	-0.1685414077	-0.141110938	0.1302396690	-0.058039773
## accel_dumbbell_y	0.1826162565	0.181307212	-0.0009602129	-0.007885764
## accel_dumbbell_z	-0.1517232513	-0.249541202	0.0714961163	0.006720825
## magnet_dumbbell_x	-0.1662279630	-0.196838517	-0.1385267404	0.045034468
## magnet_dumbbell_y	0.1448327680	0.171476316	0.2027256728	-0.059681516
## magnet_dumbbell_z	0.1710265982	-0.023319489	0.1817178168	-0.072513355
## roll_forearm	0.0675406437	-0.043823121	-0.1444799770	0.030448055
## pitch_forearm	-0.1437374432	-0.102716782	0.0958301074	-0.030985274
## yaw_forearm	0.1160381818	-0.037040115	-0.1205637617	0.032401971
## total_accel_forearm	0.0005320603	0.095001883	0.0067212482	0.021924994
## gyros_forearm_x	-0.0710849512	0.189157086	-0.1189312269	-0.171335168
## gyros_forearm_y	0.0003600379	0.021621067	0.1335158605	0.402626097
## gyros_forearm_z	0.0067616027	0.022834616	0.1455126819	0.436186095
## accel_forearm_x	0.1921783678	-0.089563502	-0.1227372377	0.018494604
## accel_forearm_y	0.0406845167	0.090105316	-0.1111624930	0.043640909
## accel_forearm_z	-0.0321709104	0.037513668	0.2064141663	-0.065669743
## magnet_forearm_x	0.1015507951	-0.010367286	0.0066803328	-0.006549479
## magnet_forearm_y	0.0294886302	0.049947513	-0.1327894947	0.054721120
## magnet_forearm_z	-0.0368058362	0.111396687	-0.1891982109	0.061146141
##	PC5	PC6	PC7	PC8
## roll_belt	0.010707701	-0.018820703	0.0399211091	-0.081250640
## pitch_belt	-0.108513768	0.174169602	-0.1175090822	-0.038935356
## yaw_belt	0.057638146	-0.118567372	0.0932858126	-0.034276199

## total_accel_belt	-0.012150654	-0.018842659	0.0413140679	-0.091419779
## gyros_belt_x	0.103253666	0.176478456	-0.0782868140	0.043720553
## gyros_belt_y	0.060882618	0.152226314	-0.0689666973	-0.037765451
## gyros_belt_z	0.048061222	0.119328241	-0.1437217535	0.015693795
## accel_belt_x	0.131164476	-0.160631161	0.0969846970	0.020420317
## accel_belt_y	-0.024178388	0.031836376	0.0080999738	-0.084413098
## accel_belt_z	-0.027658465	0.021085103	-0.0349583871	0.087154184
## magnet_belt_x	0.125022830	-0.185328957	0.1056487510	-0.017013904
## magnet_belt_y	-0.273167115	0.152473719	-0.0189744343	0.149856140
## magnet_belt_z	-0.245435463	0.176083515	-0.0571996740	0.198216982
## roll_arm	0.093025655	-0.214336627	0.0167769379	0.099949078
## pitch_arm	0.198751342	0.045407726	0.0428015366	0.032758564
## yaw_arm	0.109632991	-0.138687160	0.0086761644	0.047995914
## total_accel_arm	-0.067889388	-0.020789606	-0.0509718342	-0.334376860
## gyros_arm_x	0.004653927	-0.042126242	-0.5244116484	0.052387135
## gyros_arm_y	0.013947434	0.055097985	0.4977706491	-0.038605284
## gyros_arm_z	0.018310957	0.080566404	-0.2293888997	-0.040157154
## accel_arm_x	-0.262697901	-0.218522279	0.0623668555	0.017405702
## accel_arm_y	0.116238493	-0.002809301	0.0237721471	0.133264670
## accel_arm_z	0.166693225	0.052685195	0.0989045927	0.268068247
## magnet_arm_x	-0.239583067	-0.106602178	0.0677615971	0.138747881
## magnet_arm_y	0.191479002	0.107464541	-0.0089469604	0.040772651
## magnet_arm_z	0.266926579	0.156116169	-0.0004665002	0.200236041
## roll_dumbbell	-0.074498500	-0.064785799	0.1312104304	0.304183892
## pitch_dumbbell	0.082768695	-0.077818237	0.0445417263	0.273460973
## yaw_dumbbell	0.018904615	0.021309410	-0.0728024595	0.057429114
## total_accel_dumbbell	-0.154368152	-0.126338607	0.1418031195	-0.014078085
## gyros_dumbbell_x	-0.012590858	0.007516018	0.0026173716	-0.028302891
## gyros_dumbbell_y	-0.031656557	0.015781972	0.0073398019	-0.045226707
## gyros_dumbbell_z	0.002302218	-0.018862824	0.0153944415	0.026679872
## accel_dumbbell_x	0.167420532	-0.044748613	-0.0122704815	0.181242788
## accel_dumbbell_y	-0.134670288	-0.093586158	0.1401009034	0.182760938
## accel_dumbbell_z	0.144076679	-0.014125599	-0.0810722905	0.048868587
## magnet_dumbbell_x	-0.057672085	-0.207868755	0.1074862387	0.043672283
## magnet_dumbbell_y	0.049116035	0.217090809	-0.0710359205	0.116032326
## magnet_dumbbell_z	0.252893640	-0.216865460	0.0469876900	0.019833622
## roll_forearm	-0.187480034	-0.153356693	-0.0552906315	-0.010788436
## pitch_forearm	-0.075567581	0.093782051	0.0732947463	0.272502398
## yaw_forearm	-0.046915818	-0.277437302	-0.1432599317	0.065490310
## total_accel_forearm	0.031506776	-0.193876590	-0.0168906255	0.252111788
## gyros_forearm_x	0.037102409	-0.137121013	0.0741432756	0.034298795
## gyros_forearm_y	-0.021888801	-0.025262239	0.0262763278	0.002169069
## gyros_forearm_z	0.004136515	-0.063151659	0.0256531170	0.020329920
## accel_forearm_x	-0.016655695	-0.179330046	0.0274445351	-0.279819038
## accel_forearm_y	0.014311132	-0.401432431	-0.1861296049	0.036113422
## accel_forearm_z	0.339395044	-0.065896787	-0.0749922579	-0.057221172
## magnet_forearm_x	0.098112226	0.016525808	0.1651604030	-0.365819098
## magnet_forearm_y	-0.013645077	-0.223174084	-0.3503387676	-0.005597523
## magnet_forearm_z	-0.334934250	-0.000283164	-0.0296192845	0.017960851
##	PC9	PC10	PC11	PC12

## roll_belt	0.016321259	-0.0126723095	0.001201272	-0.029547835
## pitch_belt	-0.026425095	-0.0464538881	0.025913266	-0.160081291
## yaw_belt	0.026773074	0.0175522184	-0.016254397	0.127653773
## total_accel_belt	0.020242733	-0.0041637058	0.006254269	-0.063401449
## gyros_belt_x	-0.064000754	-0.1197262175	-0.069853464	-0.054767409
## gyros_belt_y	-0.072133097	-0.0602612980	-0.192185866	0.018912202
## gyros_belt_z	-0.144858127	0.0451633176	-0.185148681	0.016856329
## accel_belt_x	0.007712434	0.0374475789	-0.029282895	0.101891045
## accel_belt_y	0.023252002	-0.0223839784	0.011995016	-0.039995301
## accel_belt_z	-0.006239466	0.0203417741	0.001090421	0.056328983
## magnet_belt_x	0.018590755	0.0678225466	0.034631493	0.054284797
## magnet_belt_y	0.096934177	-0.0183289052	-0.054485942	0.363476744
## magnet_belt_z	0.085065237	-0.1110619652	-0.051353647	0.449817830
## roll_arm	-0.016270068	0.1643833248	0.007533207	0.309769075
## pitch_arm	0.050247858	-0.0008024292	0.267956229	0.064062385
## yaw_arm	-0.046530122	0.2366642575	-0.087679404	0.106971807
## total_accel_arm	0.138946389	-0.2585869302	0.431596843	0.104753439
## gyros_arm_x	0.298812973	0.2989264200	0.067291537	-0.021160615
## gyros_arm_y	-0.305258231	-0.2882276584	-0.039861295	0.023160898
## gyros_arm_z	0.125811173	0.0190550566	0.035785763	-0.026818096
## accel_arm_x	-0.020457032	0.1781581288	-0.037639349	-0.005549989
## accel_arm_y	0.004257977	0.1356282020	-0.021022128	-0.068528829
## accel_arm_z	-0.051704486	0.1737751412	-0.214764365	-0.044244428
## magnet_arm_x	-0.092253317	0.2169172411	-0.208069112	-0.057004441
## magnet_arm_y	0.106371658	0.0092145478	0.058569438	-0.022965312
## magnet_arm_z	-0.021475244	0.0583858733	-0.134755614	-0.033849030
## roll_dumbbell	0.335129838	-0.1936232203	0.013910515	-0.249708256
## pitch_dumbbell	0.339019383	-0.2991538342	-0.071003847	-0.032616672
## yaw_dumbbell	0.076524050	-0.1522982776	-0.050424946	0.046269006
## total_accel_dumbbell	0.103186679	0.1571904928	0.162865577	-0.233622788
## gyros_dumbbell_x	-0.008202767	-0.0109408736	0.038602657	-0.048167501
## gyros_dumbbell_y	-0.007166149	-0.0295168647	0.005649570	-0.132789878
## gyros_dumbbell_z	0.011534809	0.0273156167	-0.038725433	0.063952044
## accel_dumbbell_x	0.208881893	-0.2510066042	-0.124068548	0.120742646
## accel_dumbbell_y	0.223092585	-0.0312006749	0.058150898	-0.253885678
## accel_dumbbell_z	0.048125716	-0.1344013973	-0.045336626	0.071492067
## magnet_dumbbell_x	0.192334585	-0.0026110448	0.103152304	-0.089337321
## magnet_dumbbell_y	0.026365752	-0.1624550167	-0.093845084	-0.164526017
## magnet_dumbbell_z	0.034927484	0.0735120835	0.040022205	-0.083446135
## roll_forearm	-0.021715799	-0.0190684049	-0.198667688	-0.146260822
## pitch_forearm	-0.132122387	0.1488755437	0.097090289	-0.130334959
## yaw_forearm	-0.136976422	-0.0631991600	0.069734085	0.069946512
## total_accel_forearm	-0.100721111	-0.1157976214	0.266724619	0.219560792
## gyros_forearm_x	0.018757473	-0.0021193059	-0.054373207	0.165473403
## gyros_forearm_y	0.016117113	0.0052357364	-0.003723191	0.033343654
## gyros_forearm_z	0.013715449	0.0260894875	-0.019916588	0.059833178
## accel_forearm_x	0.198911776	-0.0529913015	-0.317100538	0.023004015
## accel_forearm_y	-0.170344458	-0.2315913503	-0.178045938	0.013916469
## accel_forearm_z	-0.059029156	-0.0236341886	-0.030075718	-0.146084739
## magnet_forearm_x	0.372055616	0.0551159064	-0.365044937	0.123247276



## magnet_forearm_y	-0.259391688	-0.3200576039	-0.107675610	-0.153575930
## magnet_forearm_z	0.003466336	-0.1029606831	-0.208704320	-0.080437089
##	PC13	PC14	PC15	PC16
## roll_belt	2.594959e-02	-0.0358351932	0.070660579	-0.052326476
## pitch_belt	-5.424648e-02	-0.0008249014	0.096161506	-0.124520723
## yaw_belt	5.407271e-02	0.0018658986	0.028472564	0.032384850
## total_accel_belt	3.025251e-02	-0.0277542962	0.093655554	-0.072290920
## gyros_belt_x	9.547052e-02	0.1862057785	0.014354458	0.054557462
## gyros_belt_y	6.931105e-05	-0.4670787935	0.101013594	-0.217249507
## gyros_belt_z	-7.846758e-02	-0.5891345505	-0.049405120	-0.147453253
## accel_belt_x	6.925540e-02	-0.0131846702	-0.100731460	0.093690430
## accel_belt_y	1.379719e-02	-0.0223904573	0.129906592	-0.076057923
## accel_belt_z	-2.633796e-02	0.0399884021	-0.019231484	0.052607436
## magnet_belt_x	9.652310e-02	0.0517390855	0.026429948	0.036913601
## magnet_belt_y	2.524733e-02	0.0751573421	0.369431705	0.009383207
## magnet_belt_z	7.480812e-02	0.1718634858	0.227787563	0.007044863
## roll_arm	2.340673e-01	-0.0657172750	-0.098866366	0.085109718
## pitch_arm	5.300024e-02	-0.1455625728	0.120975723	0.327510220
## yaw_arm	4.621093e-01	0.0783283745	0.080331937	-0.612787579
## total_accel_arm	2.151829e-01	-0.1274018678	-0.064834358	-0.053228321
## gyros_arm_x	-3.812695e-02	-0.0141156367	-0.104954347	0.038091921
## gyros_arm_y	3.804813e-02	-0.0124534830	0.070369093	-0.056142820
## gyros_arm_z	7.155353e-02	0.0589653903	0.105816803	-0.026774031
## accel_arm_x	-1.343108e-01	0.0046400806	0.090336267	-0.001325136
## accel_arm_y	-4.124044e-02	0.0262803955	-0.038403028	-0.022037079
## accel_arm_z	-1.245141e-01	0.0401863514	0.042177888	0.025115010
## magnet_arm_x	-1.731997e-01	0.0598967560	0.068665104	0.044734140
## magnet_arm_y	6.789053e-02	-0.0157325281	-0.009486145	-0.110618851
## magnet_arm_z	-4.687020e-02	0.0409203134	0.006910433	0.034976509
## roll_dumbbell	-2.775925e-02	0.0044948501	-0.049518380	-0.157236016
## pitch_dumbbell	4.987647e-02	-0.0937472563	-0.065214333	-0.009136927
## yaw_dumbbell	-5.025532e-02	0.0330467433	0.104406382	-0.034207304
## total_accel_dumbbell	-3.894472e-02	-0.0350153757	0.211265466	-0.108966533
## gyros_dumbbell_x	7.140881e-03	-0.0103689390	0.067819357	0.050946328
## gyros_dumbbell_y	1.735908e-02	0.1117850544	-0.170436109	-0.072720129
## gyros_dumbbell_z	-2.893288e-03	-0.0223679847	-0.051261086	-0.047245725
## accel_dumbbell_x	1.272390e-01	-0.0922393183	-0.088194315	0.076064866
## accel_dumbbell_y	6.866653e-02	-0.0382997669	0.082533709	-0.132181206
## accel_dumbbell_z	-4.860486e-02	0.0127546239	0.136812650	-0.018045710
## magnet_dumbbell_x	-4.202951e-02	-0.1097974346	0.131219520	-0.054516788
## magnet_dumbbell_y	6.436647e-02	0.0279674353	0.028831508	-0.017138517
## magnet_dumbbell_z	-2.057940e-02	0.0297896105	0.273331808	0.120582939
## roll_forearm	2.846066e-01	-0.3106913488	0.163948784	0.404331716
## pitch_forearm	3.874533e-01	-0.0742364867	-0.177720057	0.192139102
## yaw_forearm	3.418385e-02	-0.1894015746	0.232512434	-0.128272963
## total_accel_forearm	-4.939866e-01	-0.1875646646	-0.083911804	-0.089676221
## gyros_forearm_x	1.638015e-02	0.0348841467	-0.273597148	-0.127142961
## gyros_forearm_y	2.728049e-02	-0.0340829391	0.139360024	0.107342183
## gyros_forearm_z	1.227378e-02	-0.0535543484	0.015453745	0.011082506
## accel_forearm_x	-8.352215e-02	0.0573065190	-0.086985374	0.009688686

## accel_forearm_y	4.367216e-02	0.0967450474	-0.106499606	0.087205056
## accel_forearm_z	2.503221e-02	0.0671173434	0.432888877	0.066856136
## magnet_forearm_x	-1.151905e-01	-0.0344630564	0.029140839	0.031383231
## magnet_forearm_y	-1.357390e-04	0.2200631638	0.056926279	-0.095462168
## magnet_forearm_z	1.449558e-01	-0.0717671156	-0.138981485	0.075215964
##	PC17	PC18	PC19	PC20
## roll_belt	0.018925699	-0.0196027405	0.033530376	0.0016282967
## pitch_belt	0.027404417	0.0984645140	0.014293755	0.0514597460
## yaw_belt	-0.024346563	-0.0663727157	0.025519925	-0.0338679159
## total_accel_belt	0.016539357	-0.0001961996	0.044068966	0.0017506306
## gyros_belt_x	0.215679484	0.0485230110	0.058315400	0.0691644792
## gyros_belt_y	-0.219193807	0.0843176362	-0.025946901	0.0376597767
## gyros_belt_z	-0.242844246	-0.0029906481	0.041108753	-0.0192017368
## accel_belt_x	-0.014083656	-0.1146855235	-0.021558360	-0.0744392403
## accel_belt_y	-0.007075921	0.0259140285	0.029930551	0.0174094910
## accel_belt_z	-0.031126748	0.0251747910	-0.037049523	-0.0214755029
## magnet_belt_x	-0.027846886	-0.0225345382	0.052483639	-0.1025499258
## magnet_belt_y	-0.168235038	0.0596514182	-0.062838534	-0.1027170286
## magnet_belt_z	-0.077557903	0.0454211466	0.018772115	-0.0340193876
## roll_arm	-0.084088145	0.1065859439	0.207161663	0.2540551806
## pitch_arm	-0.173611934	0.1652941316	0.100934739	0.6076695135
## yaw_arm	0.170082515	-0.1803477772	-0.202514962	0.2959079786
## total_accel_arm	-0.134791266	-0.0224334350	-0.091379765	-0.1096425543
## gyros_arm_x	-0.028068308	-0.0117560451	-0.027375608	-0.0457923565
## gyros_arm_y	0.002913081	0.0323307572	0.004564699	0.0252189636
## gyros_arm_z	0.143465612	0.0734856466	0.057652629	0.1515814417
## accel_arm_x	-0.100281150	0.0400660584	0.019675271	0.0654131502
## accel_arm_y	-0.037845704	-0.0133028107	-0.056654602	-0.1309433720
## accel_arm_z	-0.041598510	-0.0063999619	0.041793727	-0.0376301925
## magnet_arm_x	-0.035914762	0.0334565822	0.062118755	0.1222371755
## magnet_arm_y	0.010368155	-0.0632550394	-0.040964423	-0.1733859266
## magnet_arm_z	0.003494754	-0.0128719626	0.024218087	-0.0394248552
## roll_dumbbell	-0.066926268	0.0419686364	0.069450981	0.1786838210
## pitch_dumbbell	0.007706322	-0.0598123968	0.047500159	-0.0842654039
## yaw_dumbbell	-0.063367606	0.1751190450	-0.144621546	0.0419776682
## total_accel_dumbbell	-0.107161576	0.0581236561	-0.092646363	0.0189422653
## gyros_dumbbell_x	-0.003148070	-0.1745924388	0.095550324	0.0644009403
## gyros_dumbbell_y	0.047370146	0.3737962073	0.210493408	0.1408872716
## gyros_dumbbell_z	-0.010937322	0.1502031645	-0.131290287	-0.0810042263
## accel_dumbbell_x	0.067428305	-0.1233866532	0.058327508	-0.1122470625
## accel_dumbbell_y	-0.053608794	0.0249803314	0.034888734	-0.0023715932
## accel_dumbbell_z	-0.017584549	0.1252887624	-0.118768255	0.1294414785
## magnet_dumbbell_x	-0.117883295	0.0069895597	-0.017994211	-0.0814975436
## magnet_dumbbell_y	0.148714129	0.0114989529	0.017078002	0.1313873886
## magnet_dumbbell_z	-0.082437889	0.0781057319	-0.124054423	-0.1192319845
## roll_forearm	0.435460492	0.1451788226	-0.363205645	0.0034820980
## pitch_forearm	-0.222942720	0.0188169002	0.131651374	-0.1165657549
## yaw_forearm	0.355970059	0.1610093136	0.636821447	-0.2354361409
## total_accel_forearm	0.316909103	-0.1498713241	-0.211564171	0.2034450329
## gyros_forearm_x	0.016200857	0.5664745419	-0.216861917	-0.1667007564

## gyros_forearm_y	-0.006665406	-0.4135055892	0.086045764	0.0006464183
## gyros_forearm_z	-0.032692619	-0.0078456176	-0.093657765	-0.0788592993
## accel_forearm_x	-0.127274074	-0.0298795344	0.094824371	0.0893125376
## accel_forearm_y	-0.230644061	-0.0646926572	-0.072903520	0.0637769860
## accel_forearm_z	-0.082597025	0.0775613392	-0.109599146	-0.0917984529
## magnet_forearm_x	0.106527364	0.0121985358	0.151986810	0.0991367049
## magnet_forearm_y	-0.241905345	-0.0286692127	0.039855894	0.0666784983
## magnet_forearm_z	0.031249827	-0.1620178356	-0.082168905	0.1193189956
##	PC21	PC22	PC23	PC24
## roll_belt	0.031791303	0.006361663	-0.058085488	-0.067885470
## pitch_belt	0.042527383	-0.037967852	0.087389899	-0.098022783
## yaw_belt	-0.010752409	0.026926177	-0.087695194	0.024212781
## total_accel_belt	0.035750768	0.013387396	-0.046558747	-0.071694853
## gyros_belt_x	-0.010741656	0.022357844	-0.282358156	-0.008935338
## gyros_belt_y	0.092858919	-0.039673114	0.035648482	-0.166691986
## gyros_belt_z	-0.050907452	0.086862896	-0.131194518	0.280157354
## accel_belt_x	-0.037003714	0.073279320	-0.081982224	0.082607782
## accel_belt_y	0.039681617	-0.011350043	-0.032731955	-0.114802027
## accel_belt_z	-0.024237241	-0.029436290	0.047745485	0.057681555
## magnet_belt_x	-0.054363854	0.150415514	-0.160459184	0.202885638
## magnet_belt_y	0.097270938	-0.199299725	0.020124620	-0.173789444
## magnet_belt_z	-0.014222095	0.008214459	-0.112195683	0.173576401
## roll_arm	0.442989171	0.424973985	0.090882588	-0.313663523
## pitch_arm	-0.349104289	-0.198795250	0.003742229	0.016365433
## yaw_arm	-0.148521884	-0.196019102	-0.061745070	0.060579164
## total_accel_arm	0.041943283	-0.140532692	-0.110337832	0.143786149
## gyros_arm_x	-0.074276494	-0.034421955	-0.140816874	-0.140366385
## gyros_arm_y	0.034377095	0.007766984	0.097007712	0.066611411
## gyros_arm_z	0.292211435	0.041001939	0.582914176	0.555654440
## accel_arm_x	-0.132745419	-0.094618140	-0.031619687	0.081759845
## accel_arm_y	0.064961449	-0.042261962	-0.013601695	0.095723727
## accel_arm_z	0.059080087	-0.057453830	-0.073108158	0.132389073
## magnet_arm_x	-0.085825282	-0.133815881	-0.041546284	0.115351124
## magnet_arm_y	0.082685819	-0.011570531	-0.032070156	-0.006311844
## magnet_arm_z	0.036323694	0.007644350	0.018597497	0.077765941
## roll_dumbbell	-0.256271877	0.217373029	0.120322180	-0.096185209
## pitch_dumbbell	-0.059123714	-0.108022435	0.054545842	0.010273718
## yaw_dumbbell	0.007256978	0.321792445	-0.258326776	0.248879355
## total_accel_dumbbell	0.226573360	0.131232467	-0.075460445	0.028639545
## gyros_dumbbell_x	0.066625966	0.014481001	-0.126934059	0.051900856
## gyros_dumbbell_y	0.300561338	-0.231122949	-0.434378786	0.139565757
## gyros_dumbbell_z	-0.107421623	0.007633279	0.182331485	-0.064000804
## accel_dumbbell_x	0.057415866	-0.174861060	-0.055377327	0.026641832
## accel_dumbbell_y	0.122568457	0.051660466	-0.017972022	-0.004744940
## accel_dumbbell_z	0.005991762	0.216508963	-0.167396715	0.087410112
## magnet_dumbbell_x	0.101279787	-0.088405222	-0.051007949	0.063630742
## magnet_dumbbell_y	0.108209772	-0.053902273	-0.007237879	-0.158324383
## magnet_dumbbell_z	0.142455335	-0.124222251	-0.028918248	0.063326636
## roll_forearm	-0.037215978	0.031267610	-0.030285875	0.052757322
## pitch_forearm	0.147407420	-0.328302195	0.087284701	0.036571850

## yaw_forearm	-0.169166223	-0.019871205	0.019037295	-0.015157959
## total_accel_forearm	0.286301660	-0.239853899	-0.016194785	-0.050037885
## gyros_forearm_x	-0.120987285	-0.036596386	0.097020702	-0.075130824
## gyros_forearm_y	-0.042243616	0.127236211	-0.052366060	0.028066881
## gyros_forearm_z	-0.102222500	0.048674916	0.145100159	-0.055111896
## accel_forearm_x	0.067135635	-0.136407840	0.060681331	0.062238905
## accel_forearm_y	0.035479777	-0.099244144	0.033436807	0.058756137
## accel_forearm_z	0.076241126	-0.120730826	0.028520531	-0.243058175
## magnet_forearm_x	0.066904754	-0.188652830	0.036333483	-0.053777215
## magnet_forearm_y	-0.008724677	-0.024911774	0.076365568	-0.048426781
## magnet_forearm_z	0.171001751	0.019489604	-0.105979791	-0.111227130
##	PC25			
## roll_belt	0.033403842			
## pitch_belt	0.191505819			
## yaw_belt	-0.082364194			
## total_accel_belt	0.082652824			
## gyros_belt_x	0.512162050			
## gyros_belt_y	-0.169563154			
## gyros_belt_z	0.174783342			
## accel_belt_x	-0.147252709			
## accel_belt_y	0.091168333			
## accel_belt_z	-0.037327233			
## magnet_belt_x	0.086655920			
## magnet_belt_y	-0.179055490			
## magnet_belt_z	0.117999681			
## roll_arm	0.059415357			
## pitch_arm	0.107912911			
## yaw_arm	-0.019718107			
## total_accel_arm	-0.067718027			
## gyros_arm_x	-0.002393028			
## gyros_arm_y	0.001282794			
## gyros_arm_z	-0.036775995			
## accel_arm_x	0.023563418			
## accel_arm_y	-0.042043978			
## accel_arm_z	-0.032251025			
## magnet_arm_x	0.013127137			
## magnet_arm_y	-0.021816388			
## magnet_arm_z	-0.042916013			
## roll_dumbbell	-0.324167383			
## pitch_dumbbell	0.145320938			
## yaw_dumbbell	-0.050319005			
## total_accel_dumbbell	0.300743162			
## gyros_dumbbell_x	-0.065688606			
## gyros_dumbbell_y	-0.337067083			
## gyros_dumbbell_z	0.106500985			
## accel_dumbbell_x	0.069386264			
## accel_dumbbell_y	0.093811479			
## accel_dumbbell_z	-0.055051048			
## magnet_dumbbell_x	0.184614162			
## magnet_dumbbell_y	0.052298471			

```
## magnet_dumbbell_z      -0.028489456
## roll_forearm           -0.104316208
## pitch_forearm          0.095223319
## yaw_forearm            -0.033772094
## total_accel_forearm    0.056316162
## gyros_forearm_x        0.193518397
## gyros_forearm_y        0.050728155
## gyros_forearm_z        0.110191959
## accel_forearm_x        0.098778154
## accel_forearm_y        -0.015679041
## accel_forearm_z        -0.100215958
## magnet_forearm_x       0.077033497
## magnet_forearm_y       0.097713775
## magnet_forearm_z       -0.007475300
```

```
trainingPC <- predict(preProc,trainingCl[,1:52])
```

## Random forest

Apply random forest method (non-bionominal outcome & large sample size)

```
library(randomForest)
```

```
## Warning: package 'randomForest' was built under R version 3.3.1
```

```
## randomForest 4.6-12
```

```
## Type rfNews() to see new features/changes/bug fixes.
```

```
##
```

```
## Attaching package: 'randomForest'
```

```
## The following object is masked from 'package:ggplot2':
```

```
##
```

```
##      margin
```

```
modFitRF <- randomForest(trainingCl$classe ~ ., data=trainingPC,
do.trace=F)
```

```
print(modFitRF)
```

```
##
```

```
## Call:
```

```
## randomForest(formula = trainingCl$classe ~ ., data = trainingPC,
do.trace = F)
```

```
##              Type of random forest: classification
```

```
##              Number of trees: 500
```

```
## No. of variables tried at each split: 5
```

```
##
```

```
##              OOB estimate of  error rate: 2.59%
```

```
## Confusion matrix:
```

```
##      A      B      C      D      E class.error
```

```
## A 3876      9     13      5      3 0.007680492
```

```
## B    44 2571    34    2    7 0.032731377
## C     5  38 2326    24    3 0.029215359
## D     7   6  104 2130    5 0.054174067
## E     1   8   21   17 2478 0.018613861
```

Importance of each predictor.

```
importance(modFitRF)
```

```
##           MeanDecreaseGini
## PC1             572.3609
## PC2             458.8458
## PC3             501.5873
## PC4             365.8816
## PC5             556.7810
## PC6             430.9262
## PC7             402.8629
## PC8             705.3515
## PC9             505.6043
## PC10            396.0036
## PC11            339.7100
## PC12            582.3393
## PC13            346.2943
## PC14            653.4349
## PC15            468.9175
## PC16            441.0693
## PC17            444.8101
## PC18            284.7219
## PC19            347.1358
## PC20            359.8680
## PC21            410.1221
## PC22            420.2179
## PC23            249.5559
## PC24            230.5189
## PC25            385.3894
```

### Check with test set

```
testingCl <- testing[, -Cl]
testingCl[testingCl==""] <- NA
NArate <- apply(testingCl, 2, function(x) sum(is.na(x)))/nrow(testingCl)
testingCl <- testingCl[!(NArate>0.95)]
testingPC <- predict(preProc, testingCl[, 1:52])
confusionMatrix(testingCl$classe, predict(modFitRF, testingPC))
```

```
## Confusion Matrix and Statistics
```

```
##
##           Reference
## Prediction    A    B    C    D    E
##           A 1660    2   10    2    0
##           B   13 1098   18    2    8
##           C    0   12 1000   12    2
```

```
##           D      3      0      48      910      3
##           E      0      1      11       7      1063
##
## Overall Statistics
##
##           Accuracy : 0.9738
##           95% CI : (0.9694, 0.9778)
##           No Information Rate : 0.2848
##           P-Value [Acc > NIR] : < 2.2e-16
##
##           Kappa : 0.9669
##           McNemar's Test P-Value : NA
##
## Statistics by Class:
##
##           Class: A Class: B Class: C Class: D Class: E
## Sensitivity      0.9905   0.9865   0.9200   0.9753   0.9879
## Specificity      0.9967   0.9914   0.9946   0.9891   0.9960
## Pos Pred Value   0.9916   0.9640   0.9747   0.9440   0.9824
## Neg Pred Value   0.9962   0.9968   0.9821   0.9953   0.9973
## Prevalence       0.2848   0.1891   0.1847   0.1585   0.1828
## Detection Rate   0.2821   0.1866   0.1699   0.1546   0.1806
## Detection Prevalence 0.2845   0.1935   0.1743   0.1638   0.1839
## Balanced Accuracy 0.9936   0.9890   0.9573   0.9822   0.9920
```

### Predict classes of 20 test data

```
testdata <- read.csv("pml-testing.csv")
testdataCl <- testdata[, -Cl]
testdataCl[testdataCl==""] <- NA
NARate <- apply(testdataCl, 2, function(x) sum(is.na(x))/nrow(testdataCl))
testdataCl <- testdataCl[!(NARate>0.95)]
testdataPC <- predict(preProc, testdataCl[, 1:52])
testdataCl$classe <- predict(modFitRF, testdataPC)
```

## Conclusion

In this analyses, 19622 observations from weight lifting exercise were used to analyze and predict correct body movement from others during the exercise. 70% of the total observations (13737 observations) were used to build a model by random forest method, and the rest of 30% of the observations (5885 observations) were used for model validation (cross-validation). The model statistics showed that the built model had the overall accuracy of 97% for the testing set, which is not overlapping with observations used to built the model. The sensitivity was in between 92%-99% and the specificity was over 99% for all classes (class A-E, total 5 classes. class A is the data from correct exercise while the other classes were data from exercises done in a wrong way). Overall, the model is well developed to predict the exercise classes during weight lifting. As for the limitation in this study, the observation data used in the analyses was collected from 6 young health participants in an experiment using Microsoft Kinect. Therefore, under those condition, the model is expected to perform over 95% accuracy; however, with different conditions, such

as experiments with elderly people and/or using different device, the model might not perform well as shown in the analysis.