Prediction Project-Exercise data

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```
library(lattice)
library(ggplot2)
library(plyr)
library(randomForest)
```

```
## Warning: package 'randomForest' was built under R version 3.5.3
```

```
## randomForest 4.6-14
```

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

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

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

```
library(caret)
```

```
## Warning: package 'caret' was built under R version 3.5.3
```

```
library(rpart)
library(rpart.plot)
```

Executive Summary

Based on a dataset provide by HAR http://groupware.les.inf.puc-rio.br/har (http://groupware.les.inf.puc-rio.br/har) we will try to train a predictive model to predict what exercise was performed using the dataset

We'll take the following steps:

- Explore the data
- Process the data
- Model selection
- Model examination
- Predicting
- Conclusion

```
training_data <- read.csv("pml-training.csv", na.strings = c("NA", "#DIV/0!", ""))
test_data <- read.csv("pml-testing.csv", na.strings = c("NA", "#DIV/0!", ""))
```

Exploratory data analyses

Look at the dimensions & head of the dataset to get an idea

```
# Res 1
dim(training_data)
```

```
## [1] 19622   160
```

```
head(training_data)
```

```
##   X user_name raw_timestamp_part_1 raw_timestamp_part_2   cvtd_timestamp
## 1 1  carlitos           1323084231               788290 05/12/2011 11:23
## 2 2  carlitos           1323084231               808298 05/12/2011 11:23
## 3 3  carlitos           1323084231               820366 05/12/2011 11:23
## 4 4  carlitos           1323084232               120339 05/12/2011 11:23
## 5 5  carlitos           1323084232               196328 05/12/2011 11:23
## 6 6  carlitos           1323084232               304277 05/12/2011 11:23
##   new_window num_window roll_belt pitch_belt yaw_belt total_accel_belt
## 1         no         11      1.41       8.07    -94.4                3
## 2         no         11      1.41       8.07    -94.4                3
## 3         no         11      1.42       8.07    -94.4                3
## 4         no         12      1.48       8.05    -94.4                3
## 5         no         12      1.48       8.07    -94.4                3
## 6         no         12      1.45       8.06    -94.4                3
##   kurtosis_roll_belt kurtosis_picth_belt kurtosis_yaw_belt
## 1                 NA                  NA                NA
## 2                 NA                  NA                NA
## 3                 NA                  NA                NA
## 4                 NA                  NA                NA
## 5                 NA                  NA                NA
## 6                 NA                  NA                NA
##   skewness_roll_belt skewness_roll_belt.1 skewness_yaw_belt max_roll_belt
## 1                 NA                   NA                NA            NA
## 2                 NA                   NA                NA            NA
## 3                 NA                   NA                NA            NA
## 4                 NA                   NA                NA            NA
## 5                 NA                   NA                NA            NA
## 6                 NA                   NA                NA            NA
##   max_picth_belt max_yaw_belt min_roll_belt min_pitch_belt min_yaw_belt
## 1             NA           NA            NA             NA           NA
## 2             NA           NA            NA             NA           NA
## 3             NA           NA            NA             NA           NA
## 4             NA           NA            NA             NA           NA
## 5             NA           NA            NA             NA           NA
## 6             NA           NA            NA             NA           NA
##   amplitude_roll_belt amplitude_pitch_belt amplitude_yaw_belt
## 1                  NA                   NA                 NA
## 2                  NA                   NA                 NA
## 3                  NA                   NA                 NA
## 4                  NA                   NA                 NA
## 5                  NA                   NA                 NA
## 6                  NA                   NA                 NA
##   var_total_accel_belt avg_roll_belt stddev_roll_belt var_roll_belt
## 1                   NA            NA                NA            NA
## 2                   NA            NA                NA            NA
## 3                   NA            NA                NA            NA
## 4                   NA            NA                NA            NA
## 5                   NA            NA                NA            NA
## 6                   NA            NA                NA            NA
##   avg_pitch_belt stddev_pitch_belt var_pitch_belt avg_yaw_belt
## 1             NA                NA             NA           NA
## 2             NA                NA             NA           NA
## 3             NA                NA             NA           NA
## 4             NA                NA             NA           NA
## 5             NA                NA             NA           NA
## 6             NA                NA             NA           NA
##   stddev_yaw_belt var_yaw_belt gyros_belt_x gyros_belt_y gyros_belt_z
```

```
## 1              NA           NA         0.00         0.00        -0.02
## 2              NA           NA         0.02         0.00        -0.02
## 3              NA           NA         0.00         0.00        -0.02
## 4              NA           NA         0.02         0.00        -0.03
## 5              NA           NA         0.02         0.02        -0.02
## 6              NA           NA         0.02         0.00        -0.02
##   accel_belt_x accel_belt_y accel_belt_z magnet_belt_x magnet_belt_y
## 1          -21            4           22            -3           599
## 2          -22            4           22            -7           608
## 3          -20            5           23            -2           600
## 4          -22            3           21            -6           604
## 5          -21            2           24            -6           600
## 6          -21            4           21             0           603
##   magnet_belt_z roll_arm pitch_arm yaw_arm total_accel_arm var_accel_arm
## 1          -313     -128      22.5    -161              34            NA
## 2          -311     -128      22.5    -161              34            NA
## 3          -305     -128      22.5    -161              34            NA
## 4          -310     -128      22.1    -161              34            NA
## 5          -302     -128      22.1    -161              34            NA
## 6          -312     -128      22.0    -161              34            NA
##   avg_roll_arm stddev_roll_arm var_roll_arm avg_pitch_arm stddev_pitch_arm
## 1           NA              NA           NA            NA               NA
## 2           NA              NA           NA            NA               NA
## 3           NA              NA           NA            NA               NA
## 4           NA              NA           NA            NA               NA
## 5           NA              NA           NA            NA               NA
## 6           NA              NA           NA            NA               NA
##   var_pitch_arm avg_yaw_arm stddev_yaw_arm var_yaw_arm gyros_arm_x
## 1            NA          NA             NA          NA        0.00
## 2            NA          NA             NA          NA        0.02
## 3            NA          NA             NA          NA        0.02
## 4            NA          NA             NA          NA        0.02
## 5            NA          NA             NA          NA        0.00
## 6            NA          NA             NA          NA        0.02
##   gyros_arm_y gyros_arm_z accel_arm_x accel_arm_y accel_arm_z magnet_arm_x
## 1        0.00       -0.02        -288         109        -123         -368
## 2       -0.02       -0.02        -290         110        -125         -369
## 3       -0.02       -0.02        -289         110        -126         -368
## 4       -0.03        0.02        -289         111        -123         -372
## 5       -0.03        0.00        -289         111        -123         -374
## 6       -0.03        0.00        -289         111        -122         -369
##   magnet_arm_y magnet_arm_z kurtosis_roll_arm kurtosis_picth_arm
## 1          337          516                NA                 NA
## 2          337          513                NA                 NA
## 3          344          513                NA                 NA
## 4          344          512                NA                 NA
## 5          337          506                NA                 NA
## 6          342          513                NA                 NA
##   kurtosis_yaw_arm skewness_roll_arm skewness_pitch_arm skewness_yaw_arm
## 1               NA                NA                 NA               NA
## 2               NA                NA                 NA               NA
## 3               NA                NA                 NA               NA
## 4               NA                NA                 NA               NA
## 5               NA                NA                 NA               NA
## 6               NA                NA                 NA               NA
##   max_roll_arm max_picth_arm max_yaw_arm min_roll_arm min_pitch_arm
## 1           NA            NA          NA           NA            NA
## 2           NA            NA          NA           NA            NA
```

```
## 3           NA            NA          NA           NA            NA
## 4           NA            NA          NA           NA            NA
## 5           NA            NA          NA           NA            NA
## 6           NA            NA          NA           NA            NA
##   min_yaw_arm amplitude_roll_arm amplitude_pitch_arm amplitude_yaw_arm
## 1          NA                 NA                  NA                NA
## 2          NA                 NA                  NA                NA
## 3          NA                 NA                  NA                NA
## 4          NA                 NA                  NA                NA
## 5          NA                 NA                  NA                NA
## 6          NA                 NA                  NA                NA
##   roll_dumbbell pitch_dumbbell yaw_dumbbell kurtosis_roll_dumbbell
## 1      13.05217      -70.49400    -84.87394                     NA
## 2      13.13074      -70.63751    -84.71065                     NA
## 3      12.85075      -70.27812    -85.14078                     NA
## 4      13.43120      -70.39379    -84.87363                     NA
## 5      13.37872      -70.42856    -84.85306                     NA
## 6      13.38246      -70.81759    -84.46500                     NA
##   kurtosis_picth_dumbbell kurtosis_yaw_dumbbell skewness_roll_dumbbell
## 1                      NA                    NA                     NA
## 2                      NA                    NA                     NA
## 3                      NA                    NA                     NA
## 4                      NA                    NA                     NA
## 5                      NA                    NA                     NA
## 6                      NA                    NA                     NA
##   skewness_pitch_dumbbell skewness_yaw_dumbbell max_roll_dumbbell
## 1                      NA                    NA                NA
## 2                      NA                    NA                NA
## 3                      NA                    NA                NA
## 4                      NA                    NA                NA
## 5                      NA                    NA                NA
## 6                      NA                    NA                NA
##   max_picth_dumbbell max_yaw_dumbbell min_roll_dumbbell min_pitch_dumbbell
## 1                 NA               NA                NA                 NA
## 2                 NA               NA                NA                 NA
## 3                 NA               NA                NA                 NA
## 4                 NA               NA                NA                 NA
## 5                 NA               NA                NA                 NA
## 6                 NA               NA                NA                 NA
##   min_yaw_dumbbell amplitude_roll_dumbbell amplitude_pitch_dumbbell
## 1               NA                      NA                       NA
## 2               NA                      NA                       NA
## 3               NA                      NA                       NA
## 4               NA                      NA                       NA
## 5               NA                      NA                       NA
## 6               NA                      NA                       NA
##   amplitude_yaw_dumbbell total_accel_dumbbell var_accel_dumbbell
## 1                     NA                   37                NA
## 2                     NA                   37                NA
## 3                     NA                   37                NA
## 4                     NA                   37                NA
## 5                     NA                   37                NA
## 6                     NA                   37                NA
##   avg_roll_dumbbell stddev_roll_dumbbell var_roll_dumbbell
## 1                NA                   NA                NA
## 2                NA                   NA                NA
## 3                NA                   NA                NA
## 4                NA                   NA                NA
```

```
## 5                NA                    NA                NA
## 6                NA                    NA                NA
##   avg_pitch_dumbbell stddev_pitch_dumbbell var_pitch_dumbbell
## 1                 NA                    NA                NA
## 2                 NA                    NA                NA
## 3                 NA                    NA                NA
## 4                 NA                    NA                NA
## 5                 NA                    NA                NA
## 6                 NA                    NA                NA
##   avg_yaw_dumbbell stddev_yaw_dumbbell var_yaw_dumbbell gyros_dumbbell_x
## 1               NA                   NA               NA                0
## 2               NA                   NA               NA                0
## 3               NA                   NA               NA                0
## 4               NA                   NA               NA                0
## 5               NA                   NA               NA                0
## 6               NA                   NA               NA                0
##   gyros_dumbbell_y gyros_dumbbell_z accel_dumbbell_x accel_dumbbell_y
## 1            -0.02             0.00             -234               47
## 2            -0.02             0.00             -233               47
## 3            -0.02             0.00             -232               46
## 4            -0.02            -0.02             -232               48
## 5            -0.02             0.00             -233               48
## 6            -0.02             0.00             -234               48
##   accel_dumbbell_z magnet_dumbbell_x magnet_dumbbell_y magnet_dumbbell_z
## 1             -271              -559               293               -65
## 2             -269              -555               296               -64
## 3             -270              -561               298               -63
## 4             -269              -552               303               -60
## 5             -270              -554               292               -68
## 6             -269              -558               294               -66
##   roll_forearm pitch_forearm yaw_forearm kurtosis_roll_forearm
## 1         28.4         -63.9        -153                    NA
## 2         28.3         -63.9        -153                    NA
## 3         28.3         -63.9        -152                    NA
## 4         28.1         -63.9        -152                    NA
## 5         28.0         -63.9        -152                    NA
## 6         27.9         -63.9        -152                    NA
##   kurtosis_picth_forearm kurtosis_yaw_forearm skewness_roll_forearm
## 1                     NA                   NA                    NA
## 2                     NA                   NA                    NA
## 3                     NA                   NA                    NA
## 4                     NA                   NA                    NA
## 5                     NA                   NA                    NA
## 6                     NA                   NA                    NA
##   skewness_pitch_forearm skewness_yaw_forearm max_roll_forearm
## 1                     NA                   NA               NA
## 2                     NA                   NA               NA
## 3                     NA                   NA               NA
## 4                     NA                   NA               NA
## 5                     NA                   NA               NA
## 6                     NA                   NA               NA
##   max_picth_forearm max_yaw_forearm min_roll_forearm min_pitch_forearm
## 1                NA              NA               NA                NA
## 2                NA              NA               NA                NA
## 3                NA              NA               NA                NA
## 4                NA              NA               NA                NA
## 5                NA              NA               NA                NA
## 6                NA              NA               NA                NA
```

```
##   min_yaw_forearm amplitude_roll_forearm amplitude_pitch_forearm
## 1              NA                     NA                      NA
## 2              NA                     NA                      NA
## 3              NA                     NA                      NA
## 4              NA                     NA                      NA
## 5              NA                     NA                      NA
## 6              NA                     NA                      NA
##   amplitude_yaw_forearm total_accel_forearm var_accel_forearm
## 1                    NA                  36                NA
## 2                    NA                  36                NA
## 3                    NA                  36                NA
## 4                    NA                  36                NA
## 5                    NA                  36                NA
## 6                    NA                  36                NA
##   avg_roll_forearm stddev_roll_forearm var_roll_forearm avg_pitch_forearm
## 1               NA                  NA               NA                NA
## 2               NA                  NA               NA                NA
## 3               NA                  NA               NA                NA
## 4               NA                  NA               NA                NA
## 5               NA                  NA               NA                NA
## 6               NA                  NA               NA                NA
##   stddev_pitch_forearm var_pitch_forearm avg_yaw_forearm
## 1                   NA                NA              NA
## 2                   NA                NA              NA
## 3                   NA                NA              NA
## 4                   NA                NA              NA
## 5                   NA                NA              NA
## 6                   NA                NA              NA
##   stddev_yaw_forearm var_yaw_forearm gyros_forearm_x gyros_forearm_y
## 1                 NA              NA            0.03            0.00
## 2                 NA              NA            0.02            0.00
## 3                 NA              NA            0.03           -0.02
## 4                 NA              NA            0.02           -0.02
## 5                 NA              NA            0.02            0.00
## 6                 NA              NA            0.02           -0.02
##   gyros_forearm_z accel_forearm_x accel_forearm_y accel_forearm_z
## 1           -0.02             192             203            -215
## 2           -0.02             192             203            -216
## 3            0.00             196             204            -213
## 4            0.00             189             206            -214
## 5           -0.02             189             206            -214
## 6           -0.03             193             203            -215
##   magnet_forearm_x magnet_forearm_y magnet_forearm_z classe
## 1              -17              654              476      A
## 2              -18              661              473      A
## 3              -18              658              469      A
## 4              -16              658              469      A
## 5              -17              655              473      A
## 6               -9              660              478      A
```

```
str(training_data)
```

```
## 'data.frame':    19622 obs. of  160 variables:
##  $ X                       : int  1 2 3 4 5 6 7 8 9 10 ...
##  $ user_name               : Factor w/ 6 levels "adelmo","carlitos",..: 2 2 2 2 2 2 2 2 2
2 ...
##  $ raw_timestamp_part_1    : int  1323084231 1323084231 1323084231 1323084232 1323084232 1
323084232 1323084232 1323084232 1323084232 1323084232 ...
##  $ raw_timestamp_part_2    : int  788290 808298 820366 120339 196328 304277 368296 440390
484323 484434 ...
##  $ cvtd_timestamp          : Factor w/ 20 levels "02/12/2011 13:32",..: 9 9 9 9 9 9 9 9 9
9 ...
##  $ new_window              : Factor w/ 2 levels "no","yes": 1 1 1 1 1 1 1 1 1 1 ...
##  $ num_window              : int  11 11 11 12 12 12 12 12 12 12 ...
##  $ roll_belt               : num  1.41 1.41 1.42 1.48 1.48 1.45 1.42 1.42 1.43 1.45 ...
##  $ pitch_belt              : num  8.07 8.07 8.07 8.05 8.07 8.06 8.09 8.13 8.16 8.17 ...
##  $ yaw_belt                : num  -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -9
4.4 ...
##  $ total_accel_belt        : int  3 3 3 3 3 3 3 3 3 3 ...
##  $ kurtosis_roll_belt      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_picth_belt     : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_yaw_belt       : logi  NA NA NA NA NA NA ...
##  $ skewness_roll_belt      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_roll_belt.1    : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_yaw_belt       : logi  NA NA NA NA NA NA ...
##  $ max_roll_belt           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_picth_belt          : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_yaw_belt            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_roll_belt           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_pitch_belt          : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_yaw_belt            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_roll_belt     : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_pitch_belt    : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_yaw_belt      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_total_accel_belt    : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ avg_roll_belt           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_roll_belt        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_roll_belt           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ avg_pitch_belt          : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_pitch_belt       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_pitch_belt          : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ avg_yaw_belt            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_yaw_belt         : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_yaw_belt            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ gyros_belt_x            : num  0 0.02 0 0.02 0.02 0.02 0.02 0.02 0.02 0.03 ...
##  $ gyros_belt_y            : num  0 0 0 0 0.02 0 0 0 0 0 ...
##  $ gyros_belt_z            : num  -0.02 -0.02 -0.02 -0.03 -0.02 -0.02 -0.02 -0.02 -0.02 0
...
##  $ accel_belt_x            : int  -21 -22 -20 -22 -21 -21 -22 -22 -20 -21 ...
##  $ accel_belt_y            : int  4 4 5 3 2 4 3 4 2 4 ...
##  $ accel_belt_z            : int  22 22 23 21 24 21 21 21 24 22 ...
##  $ magnet_belt_x           : int  -3 -7 -2 -6 -6 0 -4 -2 1 -3 ...
##  $ magnet_belt_y           : int  599 608 600 604 600 603 599 603 602 609 ...
##  $ magnet_belt_z           : int  -313 -311 -305 -310 -302 -312 -311 -313 -312 -308 ...
##  $ roll_arm                : num  -128 -128 -128 -128 -128 -128 -128 -128 -128 -128 ...
##  $ pitch_arm               : num  22.5 22.5 22.5 22.1 22.1 22 21.9 21.8 21.7 21.6 ...
##  $ yaw_arm                 : num  -161 -161 -161 -161 -161 -161 -161 -161 -161 -161 ...
##  $ total_accel_arm         : int  34 34 34 34 34 34 34 34 34 34 ...
##  $ var_accel_arm           : num  NA NA NA NA NA NA NA NA NA NA ...
```

```
##  $ avg_roll_arm            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_roll_arm         : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_roll_arm            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ avg_pitch_arm           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_pitch_arm        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_pitch_arm           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ avg_yaw_arm             : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ stddev_yaw_arm          : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ var_yaw_arm             : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ gyros_arm_x             : num  0 0.02 0.02 0.02 0 0.02 0 0.02 0.02 0.02 ...
##  $ gyros_arm_y             : num  0 -0.02 -0.02 -0.03 -0.03 -0.03 -0.03 -0.02 -0.03 -0.03
...
##  $ gyros_arm_z             : num  -0.02 -0.02 -0.02 0.02 0 0 0 0 -0.02 -0.02 ...
##  $ accel_arm_x             : int  -288 -290 -289 -289 -289 -289 -289 -289 -288 -288 ...
##  $ accel_arm_y             : int  109 110 110 111 111 111 111 111 109 110 ...
##  $ accel_arm_z             : int  -123 -125 -126 -123 -123 -122 -125 -124 -122 -124 ...
##  $ magnet_arm_x            : int  -368 -369 -368 -372 -374 -369 -373 -372 -369 -376 ...
##  $ magnet_arm_y            : int  337 337 344 344 337 342 336 338 341 334 ...
##  $ magnet_arm_z            : int  516 513 513 512 506 513 509 510 518 516 ...
##  $ kurtosis_roll_arm       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_picth_arm      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_yaw_arm        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_roll_arm       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_pitch_arm      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_yaw_arm        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_roll_arm            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_picth_arm           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_yaw_arm             : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_roll_arm            : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_pitch_arm           : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_yaw_arm             : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_roll_arm      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_pitch_arm     : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_yaw_arm       : int  NA NA NA NA NA NA NA NA NA NA ...
##  $ roll_dumbbell           : num  13.1 13.1 12.9 13.4 13.4 ...
##  $ pitch_dumbbell          : num  -70.5 -70.6 -70.3 -70.4 -70.4 ...
##  $ yaw_dumbbell            : num  -84.9 -84.7 -85.1 -84.9 -84.9 ...
##  $ kurtosis_roll_dumbbell  : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_picth_dumbbell : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ kurtosis_yaw_dumbbell   : logi  NA NA NA NA NA NA ...
##  $ skewness_roll_dumbbell  : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_pitch_dumbbell : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ skewness_yaw_dumbbell   : logi  NA NA NA NA NA NA ...
##  $ max_roll_dumbbell       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_picth_dumbbell      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ max_yaw_dumbbell        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_roll_dumbbell       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_pitch_dumbbell      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ min_yaw_dumbbell        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ amplitude_roll_dumbbell : num  NA NA NA NA NA NA NA NA NA NA ...
##   [list output truncated]
```

```
summary(training_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    Min.   :-2.121
##  1st Qu.:  1.7600   1st Qu.: -88.30   1st Qu.: 3.00    1st Qu.:-1.329
##  Median :  5.2800   Median : -13.00   Median :17.00    Median :-0.899
##  Mean   :  0.3053   Mean   : -11.21   Mean   :11.31    Mean   :-0.220
##  3rd Qu.: 14.9000   3rd Qu.:  12.90   3rd Qu.:18.00    3rd Qu.:-0.219
##  Max.   : 60.3000   Max.   : 179.00   Max.   :29.00    Max.   :33.000
##                                                        NA's   :19226
##  kurtosis_picth_belt kurtosis_yaw_belt skewness_roll_belt
##  Min.   :-2.190      Mode:logical      Min.   :-5.745
##  1st Qu.:-1.107      NA's:19622        1st Qu.:-0.444
##  Median :-0.151                        Median : 0.000
##  Mean   : 4.334                        Mean   :-0.026
##  3rd Qu.: 3.178                        3rd Qu.: 0.417
##  Max.   :58.000                        Max.   : 3.595
##  NA's   :19248                         NA's   :19225
##  skewness_roll_belt.1 skewness_yaw_belt max_roll_belt     max_picth_belt
##  Min.   :-7.616       Mode:logical      Min.   :-94.300   Min.   : 3.00
##  1st Qu.:-1.114       NA's:19622        1st Qu.:-88.000   1st Qu.: 5.00
##  Median :-0.068                         Median : -5.100   Median :18.00
##  Mean   :-0.296                         Mean   : -6.667   Mean   :12.92
##  3rd Qu.: 0.661                         3rd Qu.: 18.500   3rd Qu.:19.00
##  Max.   : 7.348                         Max.   :180.000   Max.   :30.00
##  NA's   :19248                          NA's   :19216     NA's   :19216
##   max_yaw_belt   min_roll_belt     min_pitch_belt   min_yaw_belt
##  Min.   :-2.10   Min.   :-180.00   Min.   : 0.00   Min.   :-2.10
##  1st Qu.:-1.30   1st Qu.: -88.40   1st Qu.: 3.00   1st Qu.:-1.30
##  Median :-0.90   Median :  -7.85   Median :16.00   Median :-0.90
##  Mean   :-0.22   Mean   : -10.44   Mean   :10.76   Mean   :-0.22
##  3rd Qu.:-0.20   3rd Qu.:   9.05   3rd Qu.:17.00   3rd Qu.:-0.20
##  Max.   :33.00   Max.   : 173.00   Max.   :23.00   Max.   :33.00
##  NA's   :19226   NA's   :19216     NA's   :19216   NA's   :19226
##  amplitude_roll_belt amplitude_pitch_belt amplitude_yaw_belt
##  Min.   :  0.000     Min.   : 0.000       Min.   :0
##  1st Qu.:  0.300     1st Qu.: 1.000       1st Qu.:0
##  Median :  1.000     Median : 1.000       Median :0
##  Mean   :  3.769     Mean   : 2.167       Mean   :0
##  3rd Qu.:  2.083     3rd Qu.: 2.000       3rd Qu.:0
##  Max.   :360.000     Max.   :12.000       Max.   :0
##  NA's   :19216       NA's   :19216        NA's   :19226
##  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
##  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_picth_arm kurtosis_yaw_arm skewness_roll_arm
##  Min.   :-1.809    Min.   :-2.084     Min.   :-2.103   Min.   :-2.541
##  1st Qu.:-1.345    1st Qu.:-1.280     1st Qu.:-1.220   1st Qu.:-0.561
##  Median :-0.894    Median :-1.010     Median :-0.733   Median : 0.040
##  Mean   :-0.366    Mean   :-0.542     Mean   : 0.406   Mean   : 0.068
##  3rd Qu.:-0.038    3rd Qu.:-0.379     3rd Qu.: 0.115   3rd Qu.: 0.671
##  Max.   :21.456    Max.   :19.751     Max.   :56.000   Max.   : 4.394
##  NA's   :19294     NA's   :19296      NA's   :19227    NA's   :19293
##  skewness_pitch_arm skewness_yaw_arm  max_roll_arm     max_picth_arm
##  Min.   :-4.565     Min.   :-6.708   Min.   :-73.100   Min.   :-173.000
##  1st Qu.:-0.618     1st Qu.:-0.743   1st Qu.: -0.175   1st Qu.:  -1.975
##  Median :-0.035     Median :-0.133   Median :  4.950   Median :  23.250
##  Mean   :-0.065     Mean   :-0.229   Mean   : 11.236   Mean   :  35.751
##  3rd Qu.: 0.454     3rd Qu.: 0.344   3rd Qu.: 26.775   3rd Qu.:  95.975
##  Max.   : 3.043     Max.   : 7.483   Max.   : 85.500   Max.   : 180.000
##  NA's   :19296      NA's   :19227    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
```

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##  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
##  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_picth_dumbbell kurtosis_yaw_dumbbell
##  Min.   :-2.174         Min.   :-2.200          Mode:logical
##  1st Qu.:-0.682         1st Qu.:-0.721          NA's:19622
##  Median :-0.033         Median :-0.133
##  Mean   : 0.452         Mean   : 0.286
##  3rd Qu.: 0.940         3rd Qu.: 0.584
##  Max.   :54.998         Max.   :55.628
##  NA's   :19221          NA's   :19218
##  skewness_roll_dumbbell skewness_pitch_dumbbell skewness_yaw_dumbbell
##  Min.   :-7.384         Min.   :-7.447          Mode:logical
##  1st Qu.:-0.581         1st Qu.:-0.526          NA's:19622
##  Median :-0.076         Median :-0.091
##  Mean   :-0.115         Mean   :-0.035
##  3rd Qu.: 0.400         3rd Qu.: 0.505
##  Max.   : 1.958         Max.   : 3.769
##  NA's   :19220          NA's   :19217
##  max_roll_dumbbell max_picth_dumbbell max_yaw_dumbbell min_roll_dumbbell
##  Min.   :-70.10    Min.   :-112.90    Min.   :-2.20    Min.   :-149.60
##  1st Qu.:-27.15    1st Qu.: -66.70    1st Qu.:-0.70    1st Qu.: -59.67
##  Median : 14.85    Median :  40.05    Median : 0.00    Median : -43.55
##  Mean   : 13.76    Mean   :  32.75    Mean   : 0.45    Mean   : -41.24
##  3rd Qu.: 50.58    3rd Qu.: 133.22    3rd Qu.: 0.90    3rd Qu.: -25.20
##  Max.   :137.00    Max.   : 155.00    Max.   :55.00    Max.   :  73.20
##  NA's   :19216     NA's   :19216      NA's   :19221    NA's   :19216
##  min_pitch_dumbbell min_yaw_dumbbell amplitude_roll_dumbbell
##  Min.   :-147.00    Min.   :-2.20    Min.   :  0.00
##  1st Qu.: -91.80    1st Qu.:-0.70    1st Qu.: 14.97
##  Median : -66.15    Median : 0.00    Median : 35.05
##  Mean   : -33.18    Mean   : 0.45    Mean   : 55.00
##  3rd Qu.:  21.20    3rd Qu.: 0.90    3rd Qu.: 81.04
##  Max.   : 120.90    Max.   :55.00    Max.   :256.48
##  NA's   :19216      NA's   :19221    NA's   :19216
##  amplitude_pitch_dumbbell amplitude_yaw_dumbbell total_accel_dumbbell
##  Min.   :  0.00           Min.   :0              Min.   : 0.00
##  1st Qu.: 17.06           1st Qu.:0              1st Qu.: 4.00
##  Median : 41.73           Median :0              Median :10.00
##  Mean   : 65.93           Mean   :0              Mean   :13.72
##  3rd Qu.: 99.55           3rd Qu.:0              3rd Qu.:19.00
##  Max.   :273.59           Max.   :0              Max.   :58.00
##  NA's   :19216            NA's   :19221
##  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
```

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##  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   Min.   :-1.879
##  1st Qu.:  0.00   1st Qu.: -68.60   1st Qu.:-1.398
##  Median :  9.24   Median :   0.00   Median :-1.119
##  Mean   : 10.71   Mean   :  19.21   Mean   :-0.689
##  3rd Qu.: 28.40   3rd Qu.: 110.00   3rd Qu.:-0.618
##  Max.   : 89.80   Max.   : 180.00   Max.   :40.060
##                                     NA's   :19300
##  kurtosis_picth_forearm kurtosis_yaw_forearm skewness_roll_forearm
##  Min.   :-2.098         Mode:logical         Min.   :-2.297
##  1st Qu.:-1.376         NA's:19622           1st Qu.:-0.402
##  Median :-0.890                              Median : 0.003
##  Mean   : 0.419                              Mean   :-0.009
##  3rd Qu.: 0.054                              3rd Qu.: 0.370
##  Max.   :33.626                              Max.   : 5.856
##  NA's   :19301                               NA's   :19299
##  skewness_pitch_forearm skewness_yaw_forearm max_roll_forearm
```

```
##  Min.   :-5.241         Mode:logical         Min.   :-66.60
##  1st Qu.:-0.881         NA's:19622           1st Qu.:  0.00
##  Median :-0.156                              Median : 26.80
##  Mean   :-0.223                              Mean   : 24.49
##  3rd Qu.: 0.514                              3rd Qu.: 45.95
##  Max.   : 4.464                              Max.   : 89.80
##  NA's   :19301                               NA's   :19216
##  max_picth_forearm max_yaw_forearm  min_roll_forearm  min_pitch_forearm
##  Min.   :-151.00   Min.   :-1.900   Min.   :-72.500   Min.   :-180.00
##  1st Qu.:   0.00   1st Qu.:-1.400   1st Qu.: -6.075   1st Qu.:-175.00
##  Median : 113.00   Median :-1.100   Median :  0.000   Median : -61.00
##  Mean   :  81.49   Mean   :-0.689   Mean   : -0.167   Mean   : -57.57
##  3rd Qu.: 174.75   3rd Qu.:-0.600   3rd Qu.: 12.075   3rd Qu.:   0.00
##  Max.   : 180.00   Max.   :40.100   Max.   : 62.100   Max.   : 167.00
##  NA's   :19216     NA's   :19300    NA's   :19216     NA's   :19216
##  min_yaw_forearm  amplitude_roll_forearm amplitude_pitch_forearm
##  Min.   :-1.900   Min.   :  0.000        Min.   :  0.0
##  1st Qu.:-1.400   1st Qu.:  1.125        1st Qu.:  2.0
##  Median :-1.100   Median : 17.770        Median : 83.7
##  Mean   :-0.689   Mean   : 24.653        Mean   :139.1
##  3rd Qu.:-0.600   3rd Qu.: 39.875        3rd Qu.:350.0
##  Max.   :40.100   Max.   :126.000        Max.   :360.0
##  NA's   :19300    NA's   :19216          NA's   :19216
##  amplitude_yaw_forearm total_accel_forearm var_accel_forearm
##  Min.   :0             Min.   :  0.00      Min.   :  0.000
##  1st Qu.:0             1st Qu.: 29.00      1st Qu.:  6.759
##  Median :0             Median : 36.00      Median : 21.165
##  Mean   :0             Mean   : 34.72      Mean   : 33.502
##  3rd Qu.:0             3rd Qu.: 41.00      3rd Qu.: 51.240
##  Max.   :0             Max.   :108.00      Max.   :172.606
##  NA's   :19300                             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
##
##
```

What we see is a lot of data with NA / empty values.We first remove those data contains more than 95% of the observation to be NA. Let’s remove those

```
clnColumnIndex <- colSums(is.na(training_data))/nrow(training_data) < 0.95
clean_training_data <- training_data[,clnColumnIndex]
colSums(is.na(clean_training_data))/nrow(clean_training_data)
```

```
##                   X           user_name raw_timestamp_part_1
##                   0                   0                    0
## raw_timestamp_part_2      cvtd_timestamp          new_window
##                   0                   0                    0
##           num_window            roll_belt           pitch_belt
##                   0                   0                    0
##            yaw_belt    total_accel_belt         gyros_belt_x
##                   0                   0                    0
##         gyros_belt_y         gyros_belt_z         accel_belt_x
##                   0                   0                    0
##         accel_belt_y         accel_belt_z        magnet_belt_x
##                   0                   0                    0
##        magnet_belt_y        magnet_belt_z             roll_arm
##                   0                   0                    0
##           pitch_arm             yaw_arm     total_accel_arm
##                   0                   0                    0
##          gyros_arm_x          gyros_arm_y          gyros_arm_z
##                   0                   0                    0
##          accel_arm_x          accel_arm_y          accel_arm_z
##                   0                   0                    0
##         magnet_arm_x         magnet_arm_y         magnet_arm_z
##                   0                   0                    0
##        roll_dumbbell       pitch_dumbbell         yaw_dumbbell
##                   0                   0                    0
## total_accel_dumbbell     gyros_dumbbell_x     gyros_dumbbell_y
##                   0                   0                    0
##     gyros_dumbbell_z     accel_dumbbell_x     accel_dumbbell_y
##                   0                   0                    0
##     accel_dumbbell_z    magnet_dumbbell_x    magnet_dumbbell_y
##                   0                   0                    0
##    magnet_dumbbell_z         roll_forearm        pitch_forearm
##                   0                   0                    0
##          yaw_forearm  total_accel_forearm      gyros_forearm_x
##                   0                   0                    0
##      gyros_forearm_y      gyros_forearm_z      accel_forearm_x
##                   0                   0                    0
##      accel_forearm_y      accel_forearm_z     magnet_forearm_x
##                   0                   0                    0
##     magnet_forearm_y     magnet_forearm_z               classe
##                   0                   0                    0
```

```
colSums(is.na(clean_training_data))
```

```
##                   X           user_name raw_timestamp_part_1
##                   0                   0                    0
## raw_timestamp_part_2      cvtd_timestamp           new_window
##                   0                   0                    0
##           num_window            roll_belt           pitch_belt
##                   0                   0                    0
##             yaw_belt     total_accel_belt         gyros_belt_x
##                   0                   0                    0
##         gyros_belt_y         gyros_belt_z         accel_belt_x
##                   0                   0                    0
##         accel_belt_y         accel_belt_z        magnet_belt_x
##                   0                   0                    0
##        magnet_belt_y        magnet_belt_z             roll_arm
##                   0                   0                    0
##            pitch_arm              yaw_arm      total_accel_arm
##                   0                   0                    0
##          gyros_arm_x          gyros_arm_y          gyros_arm_z
##                   0                   0                    0
##          accel_arm_x          accel_arm_y          accel_arm_z
##                   0                   0                    0
##         magnet_arm_x         magnet_arm_y         magnet_arm_z
##                   0                   0                    0
##        roll_dumbbell       pitch_dumbbell         yaw_dumbbell
##                   0                   0                    0
## total_accel_dumbbell     gyros_dumbbell_x     gyros_dumbbell_y
##                   0                   0                    0
##     gyros_dumbbell_z     accel_dumbbell_x     accel_dumbbell_y
##                   0                   0                    0
##     accel_dumbbell_z    magnet_dumbbell_x    magnet_dumbbell_y
##                   0                   0                    0
##    magnet_dumbbell_z         roll_forearm        pitch_forearm
##                   0                   0                    0
##          yaw_forearm  total_accel_forearm      gyros_forearm_x
##                   0                   0                    0
##      gyros_forearm_y      gyros_forearm_z      accel_forearm_x
##                   0                   0                    0
##      accel_forearm_y      accel_forearm_z     magnet_forearm_x
##                   0                   0                    0
##     magnet_forearm_y     magnet_forearm_z               classe
##                   0                   0                    0
```

We also remove col1 to col7 because they are not related to the model

```
clean_training_data <- clean_training_data[,-c(1:7)]
clean_test_data <- test_data[,-c(1:7)]
```

We then partition the training data into training set and cross validation set

```
inTrainIndex <- createDataPartition(clean_training_data$classe, p=0.75)[[1]]
training_training_data <- clean_training_data[inTrainIndex,]
training_crossval_data <- clean_training_data[-inTrainIndex,]
```

change the test data set into the same

```
allNames <- names(clean_training_data)
clean_test_data <- test_data[,allNames[1:52]]
```

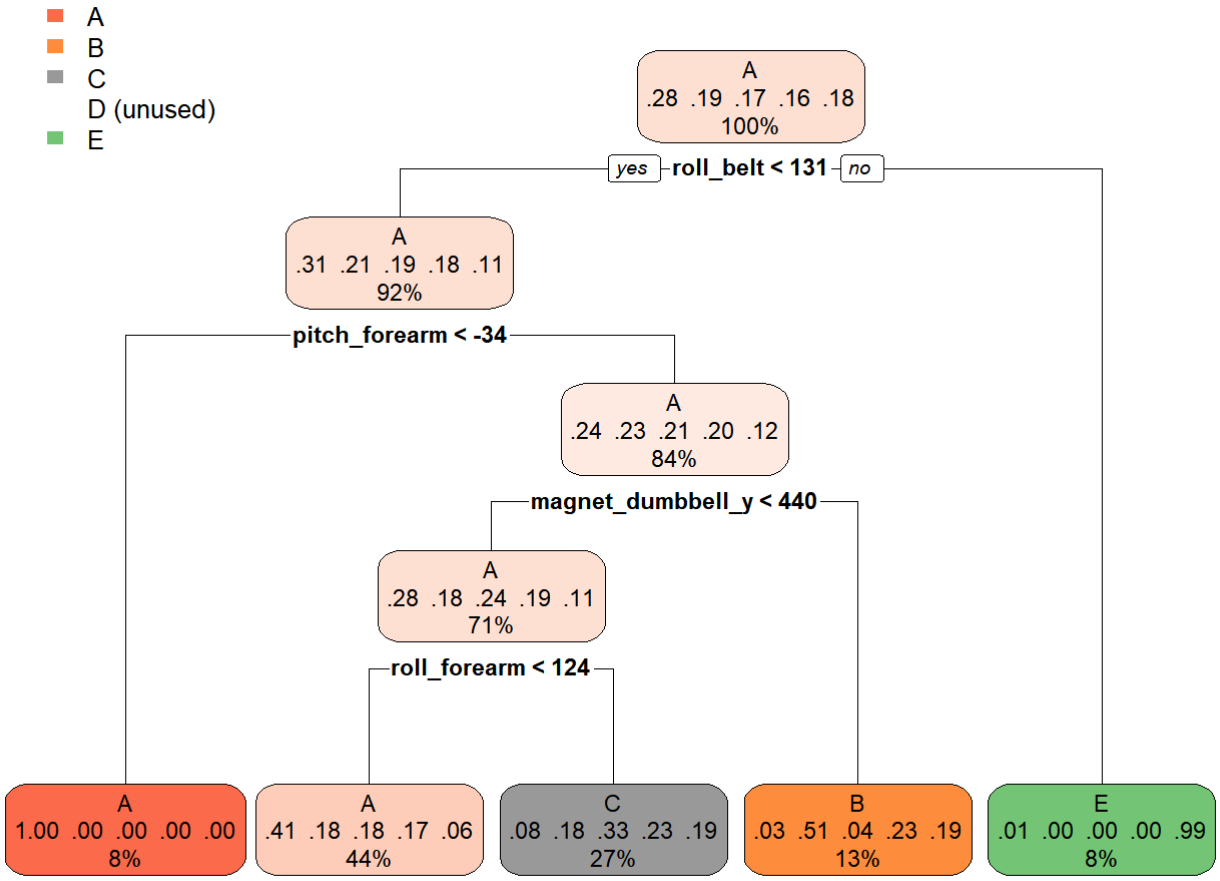
Decision Tree

```
decisionTreeMod <- train(classe ~., method='rpart', data=training_training_data)
decisionTreePrediction <- predict(decisionTreeMod, training_crossval_data)
confusionMatrix(training_crossval_data$classe, decisionTreePrediction)
```

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction    A    B    C    D    E
##          A 1266   17  110    0    2
##          B  396  317  236    0    0
##          C  406   26  423    0    0
##          D  382  134  288    0    0
##          E  143  124  234    0  400
##
## Overall Statistics
##
##                Accuracy : 0.4906
##                  95% CI : (0.4765, 0.5047)
##     No Information Rate : 0.5288
##     P-Value [Acc > NIR] : 1
##
##                   Kappa : 0.3335
##
##  Mcnemar's Test P-Value : NA
##
## Statistics by Class:
##
##                      Class: A Class: B Class: C Class: D Class: E
## Sensitivity            0.4882  0.51294  0.32765       NA  0.99502
## Specificity            0.9442  0.85254  0.88043   0.8361  0.88872
## Pos Pred Value         0.9075  0.33404  0.49474       NA  0.44395
## Neg Pred Value         0.6218  0.92389  0.78563       NA  0.99950
## Prevalence             0.5288  0.12602  0.26325   0.0000  0.08197
## Detection Rate         0.2582  0.06464  0.08626   0.0000  0.08157
## Detection Prevalence   0.2845  0.19352  0.17435   0.1639  0.18373
## Balanced Accuracy      0.7162  0.68274  0.60404       NA  0.94187
```

plotting the decision tree

```
rpart.plot(decisionTreeMod$finalModel)
```



#

Random Forest

```
rfMod <- train(classe ~., method='rf', data=training_training_data, ntree=128)
rfPrediction <- predict(rfMod, training_crossval_data)
confusionMatrix(training_crossval_data$classe, rfPrediction)
```

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction    A    B    C    D    E
##          A 1395    0    0    0    0
##          B    6  942    1    0    0
##          C    0   10  843    2    0
##          D    0    0   12  790    2
##          E    0    0    3    0  898
##
## Overall Statistics
##
##                Accuracy : 0.9927
##                  95% CI : (0.9899, 0.9949)
##     No Information Rate : 0.2857
##     P-Value [Acc > NIR] : < 2.2e-16
##
##                   Kappa : 0.9907
##
##  Mcnemar's Test P-Value : NA
##
## Statistics by Class:
##
##                      Class: A Class: B Class: C Class: D Class: E
## Sensitivity            0.9957   0.9895   0.9814   0.9975   0.9978
## Specificity            1.0000   0.9982   0.9970   0.9966   0.9993
## Pos Pred Value         1.0000   0.9926   0.9860   0.9826   0.9967
## Neg Pred Value         0.9983   0.9975   0.9960   0.9995   0.9995
## Prevalence             0.2857   0.1941   0.1752   0.1615   0.1835
## Detection Rate         0.2845   0.1921   0.1719   0.1611   0.1831
## Detection Prevalence   0.2845   0.1935   0.1743   0.1639   0.1837
## Balanced Accuracy      0.9979   0.9939   0.9892   0.9970   0.9985
```

Prediction

```
predict(rfMod, clean_test_data)
```

```
##  [1] B A B A A E D B A A B C B A E E A B B B
## Levels: A B C D E
```

Conclusion

The random forest algorithem far outperforms the decision tree in terms of accuracy. We are getting 99.25% in sample accuracy, while the decision tree gives us only nearly 50% in sample accuracy