QUALITY CONTROL OF STEEL TURNING MACHINING PROCESS

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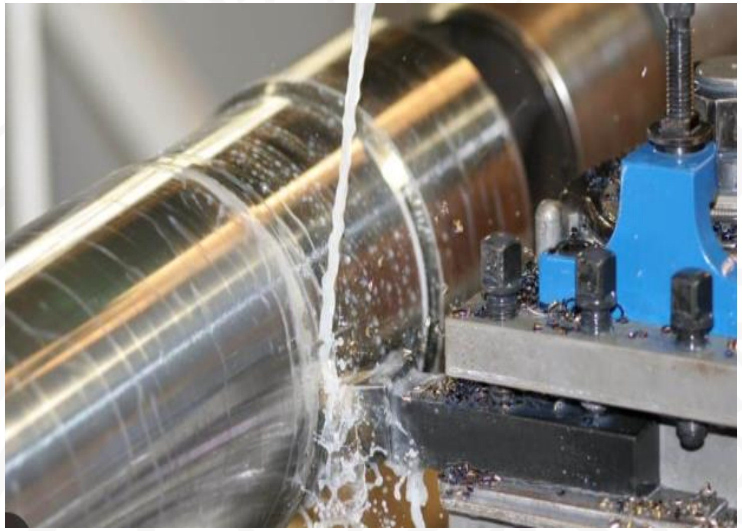
Introduction

Surface roughness is a critical quality factor that affects the performance of components, and its value is highly dependent on the manufacturing process parameters. In the turning process of steel, the surface roughness value varies with different depths of cut, feed rates, and cutting speeds. However, the current surface roughness value of a component does not meet the desired standard, leading to customer complaints and quality issues.

Problem statement: Due to the strong demand for steel, the production process may occasionally require greater output; as a result, the input parameters may be altered, sometimes causing the surface roughness value of the producing steel sheets to fall below the desired standard and leading to quality problems.

The objective of this project is to optimize the input parameters, including feed rate, minimum cutting speed of 50, maximum cutting speed of 250, and depth of cut varying from 0.5 to 2.5, to achieve the desired surface roughness value while maintaining process stability. The project scope includes the analysis of production data using advanced quality control techniques such as statistical process control (SPC), statistical analysis, EWMA, CUSUM, and change-point detection.



Data Structure

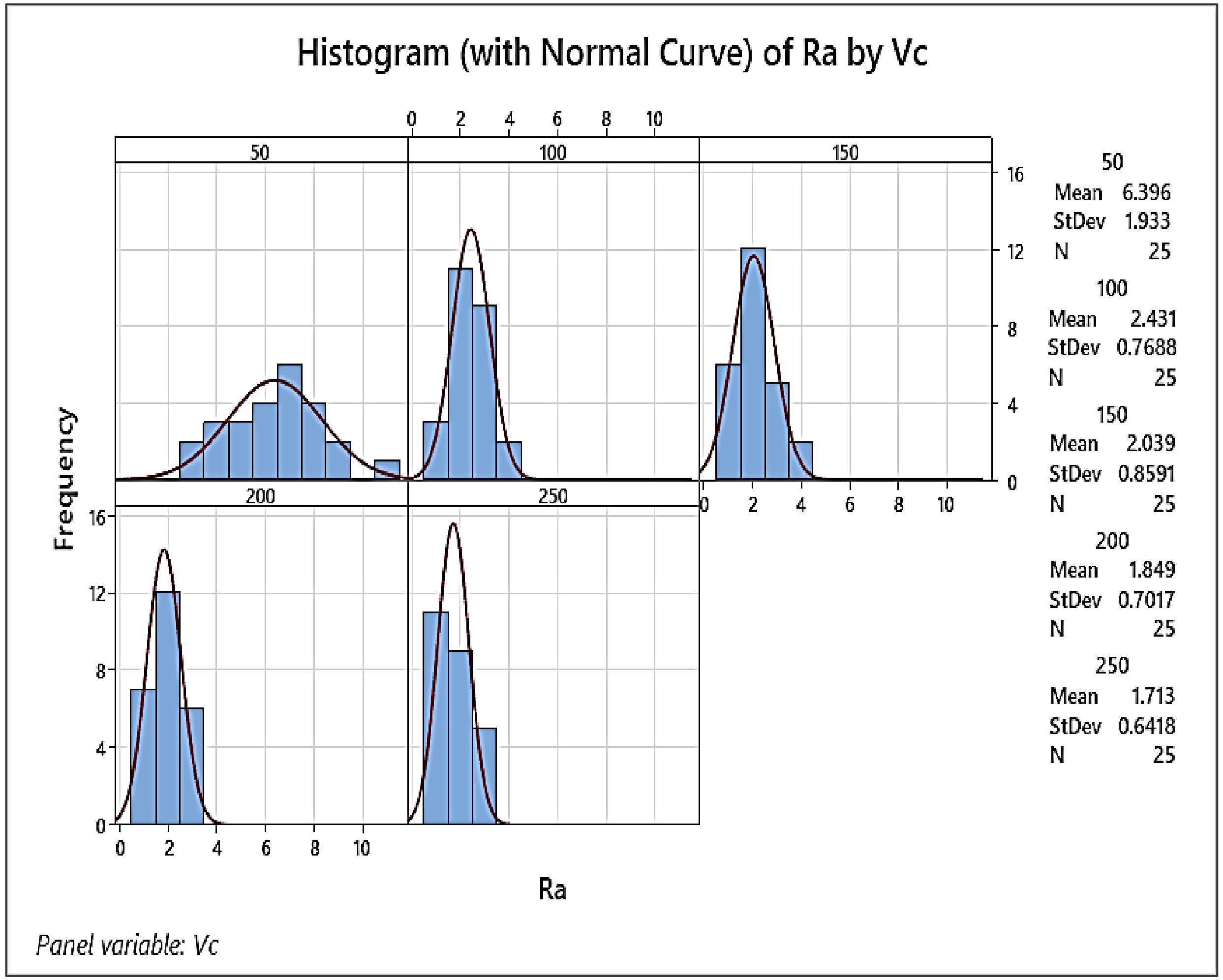
The data set here include the roughness of machining process with cutting parameters such feed rate depth of cut (ap), cutting speed (vc), feed rate (f), roughness(Ra).

Data Set :

Ap	f	Vc	Ra
0.5	0.05	50	3.36
0.5	0.05	100	2.48
0.5	0.0	150	1.52
0.5	0.05	200	1.72
0.5	0.05	250	1.13
0.5	0.1	50	5.03
0.5	0.1	100	2.54
0.5	0.1	150	2.03
0.5	0.1	200	1.93
0.5	0.1	250	1.81
0.5	0.15	50	5.86
0.5	0.15	100	2.58

Currently, dataset have feed rate ranging from 0.5 to 3 mm per sec, and cutting speed from 50 to 250.

Initial Analysis



Statistics

Variable	Vc	Mean	StDev	Minimum	Median	Maximum
Ra	50	6.396	1.933	3.360	6.660	10.580
	100	2.431	0.769	1.230	2.480	4.240
	150	2.039	0.859	0.620	2.030	4.290
	200	1.849	0.702	0.620	1.720	3.030
	250	1.713	0.642	0.670	1.700	2.730

ANALYSIS STEPS

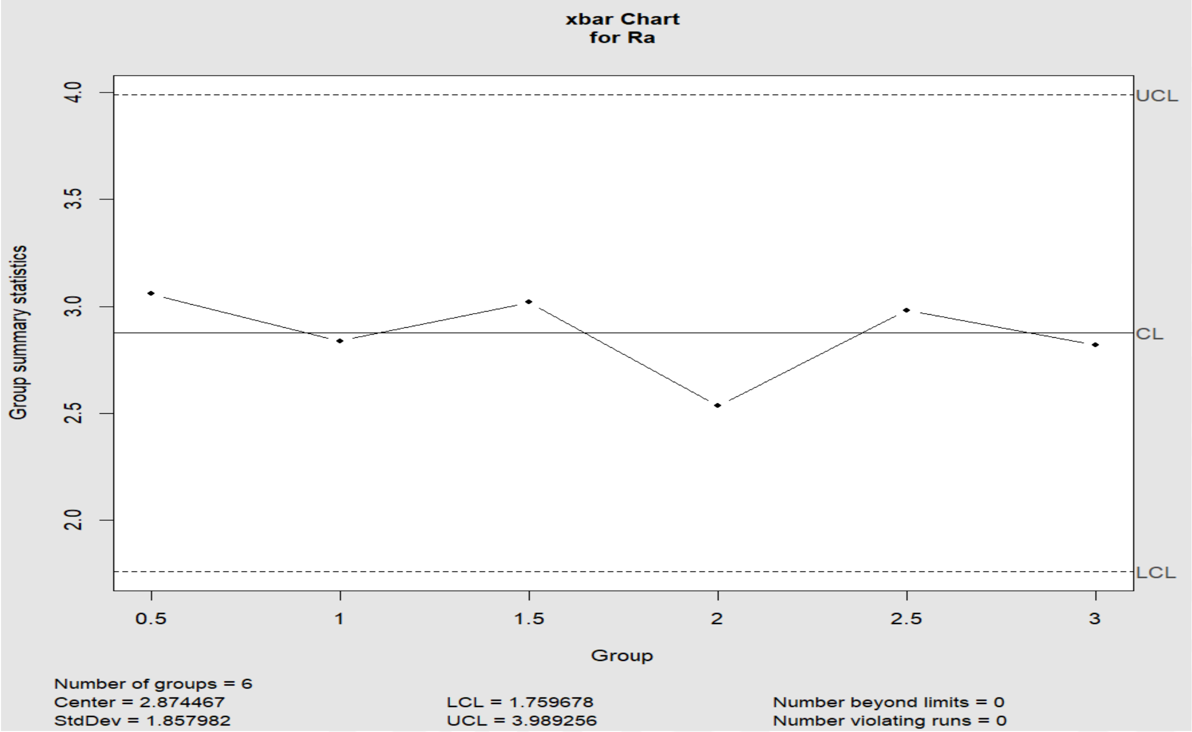
- DATA COLLECTION.
- DATA CLEANING.
- DESCRIPTIVE STATISTICS.
- SPC- X BAR , R AND S CHART.
- REGRESSION ANALYSIS.
- T^2 HOTELLING CHART
- CHANGE POINT DETECTION – CUSUM EWMA.
- SHEWHART CHART
- OPTIMIZATION- USING RESULTS.

XBAR Chart

Code

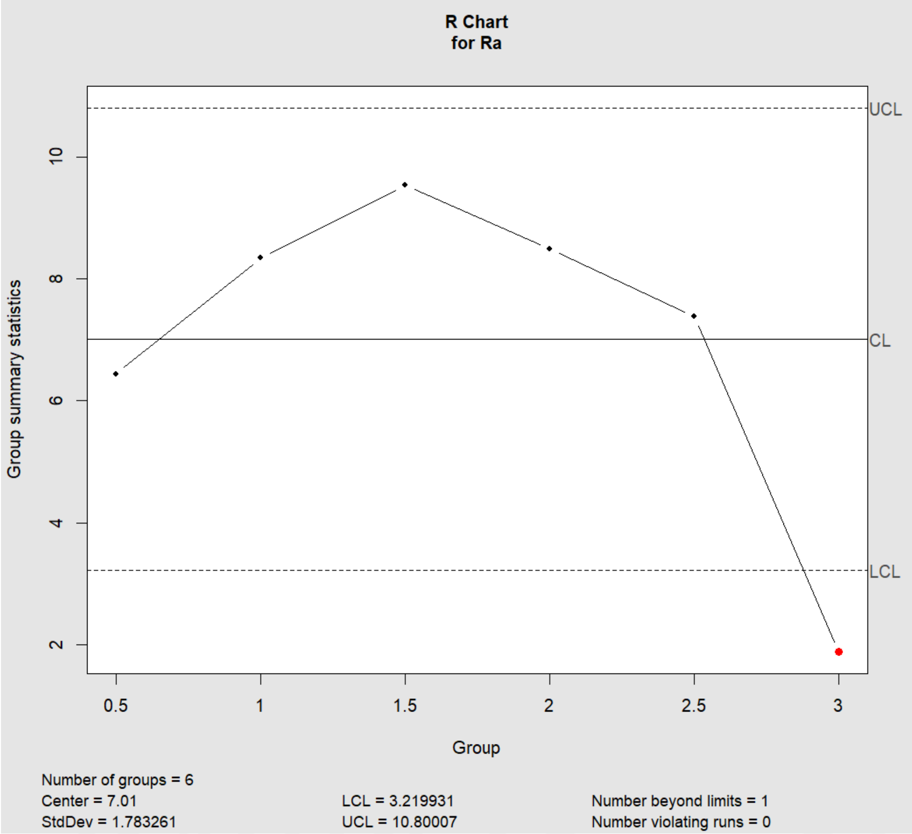
```r
library("qcc")
library(readr)
library(qicharts2)
input1CSV <- read_csv("G:/UB IE/aqc/Final project/input1CSV.csv")
View(input1CSV)
attach(input1CSV)
aggregate(Ra~Ap, data=input1CSV, mean)
Ra<-qcc.groups(Ra,Ap)
View(Ra)
qcc(Ra, type="xbar", std.dev="UWAVE-SD")
qcc(Ra, type="xbar", std.dev="UWAVE-R")
qcc(Ra, type="S")
qcc(Ra, type="R")
```

Output



R bar Chart

- The range for sample with depth of cut 0.5, 1, 1.5, 2,2.5 is greater enough.
- The difference between the maximum and minimum values of the sample data for each depth of cut is relatively large.
- This indicates that there is a high variability in the roughness measurements for each depth of cut.

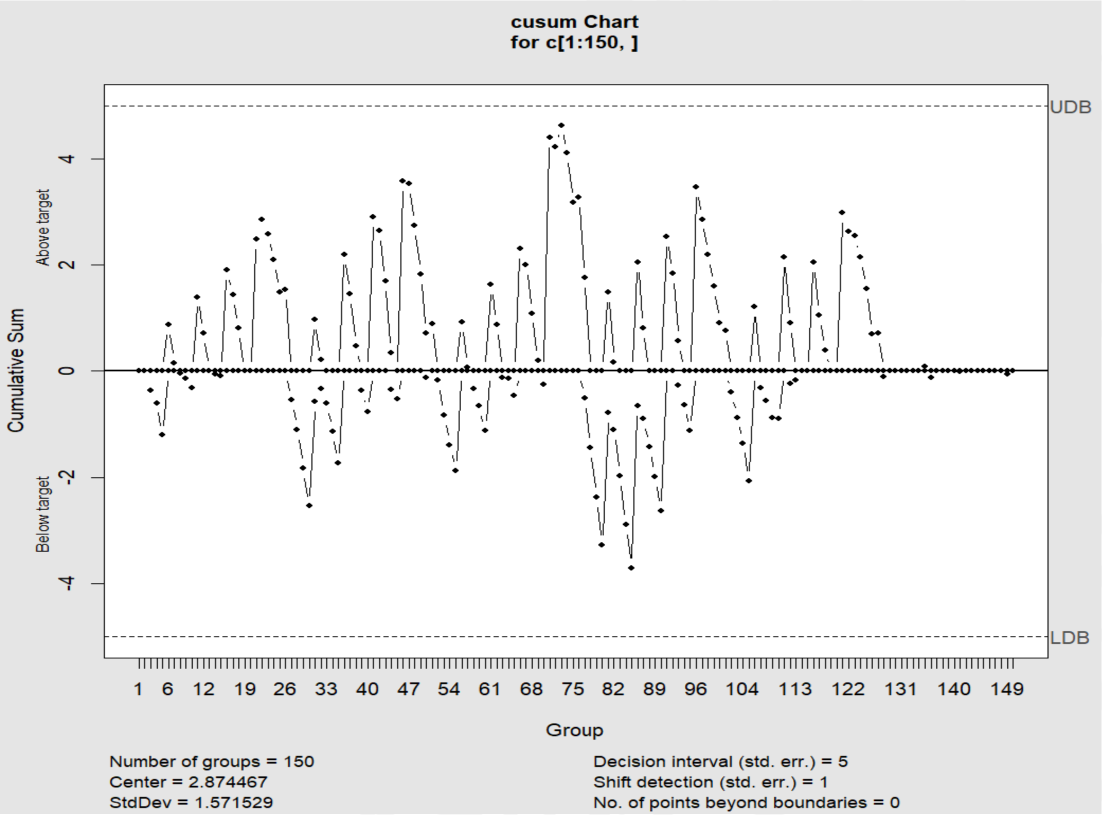


CUSUM Chart

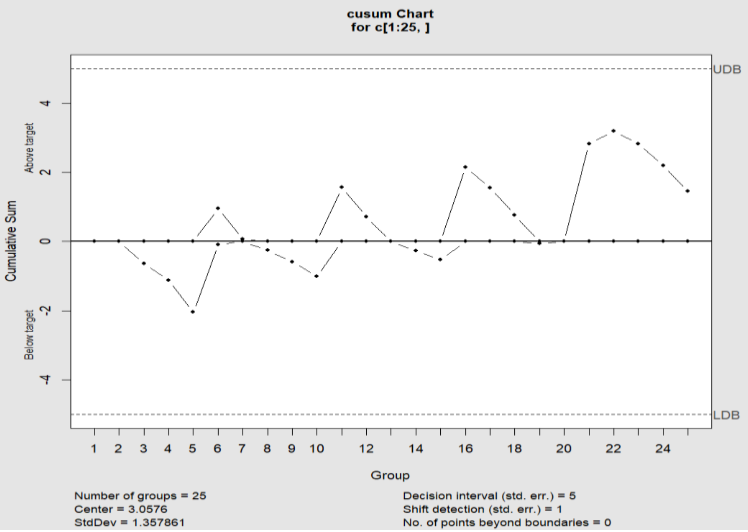
Code

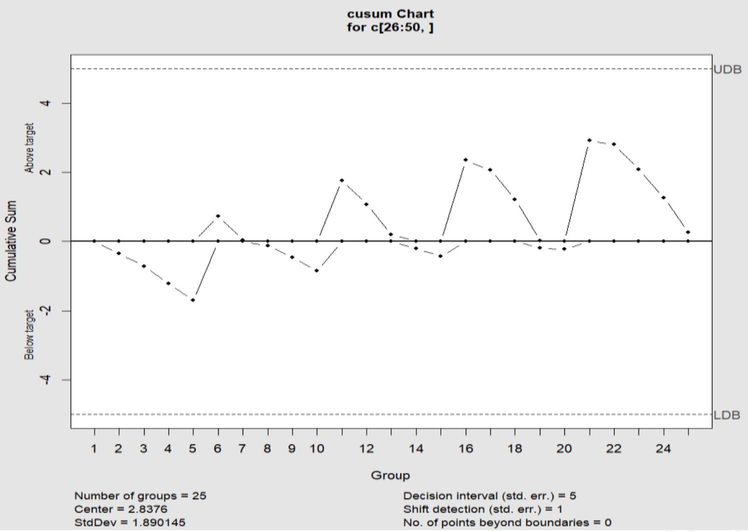
```
##############################  Cusum Chart

# Load the qcc package
library(qcc)
View(input1CSV$Ra)
c <- data.frame(input1CSV$Ra)
View(c)
# Create a sample data frame
q = cusum(c[1:150, ])
z=cusum(c[1:25, ])
a=cusum(c[26:50,])
b=cusum(c[51:75, ])
c=cusum(c[126:150, ])
q = cusum(Ra[1:6,])
q1 = qcc(Ra[1:6,], type="xbar")

set.seed(10)

x1 = c(input1CSV$Ra)
```

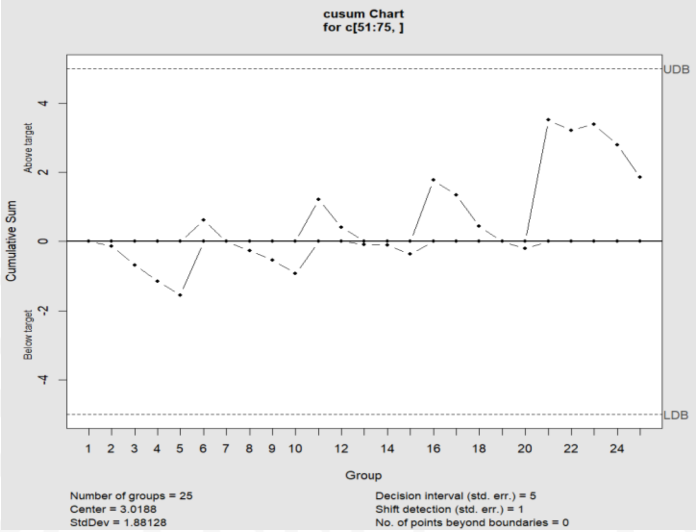
Output

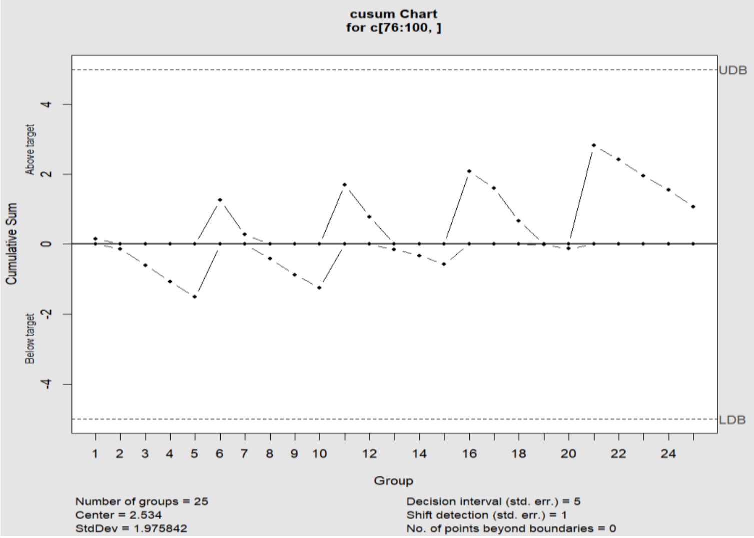


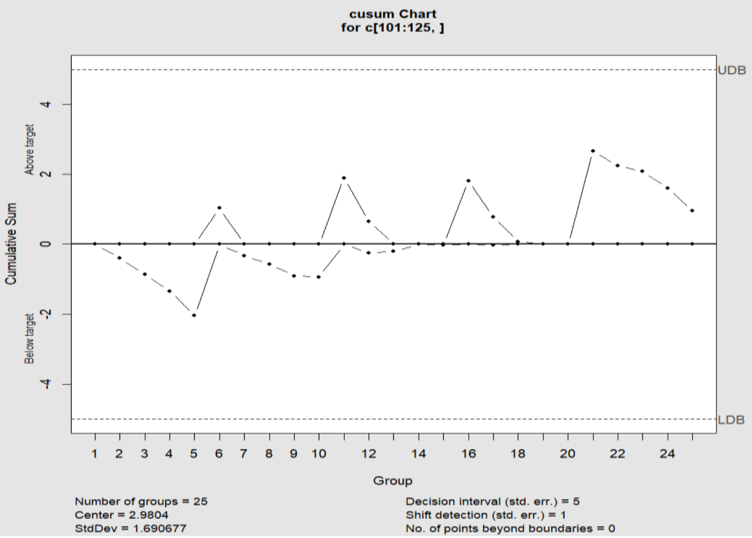
CUSUM For Individual Sample

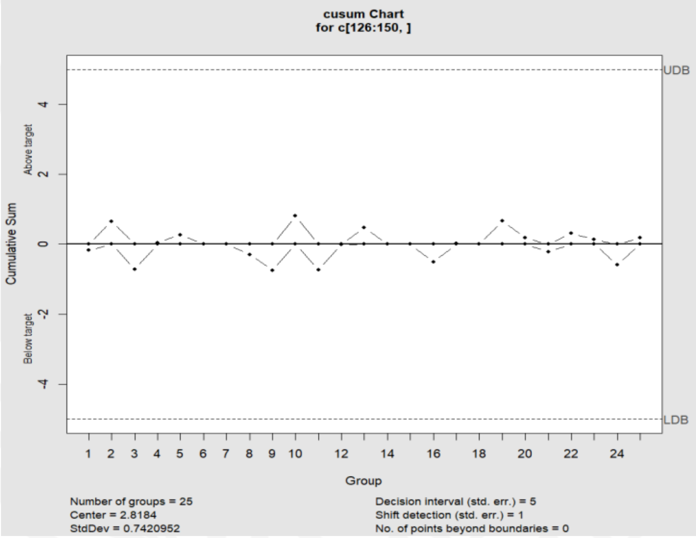










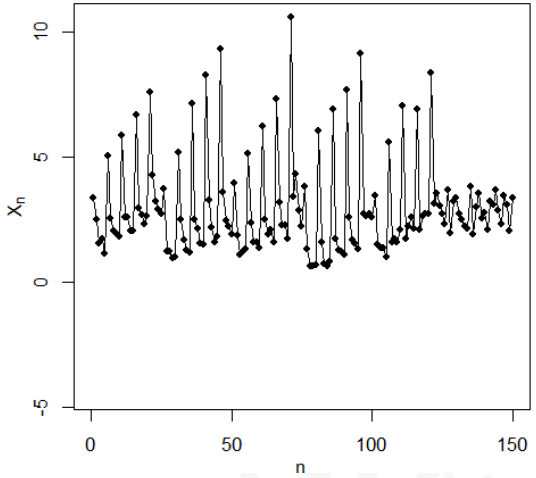


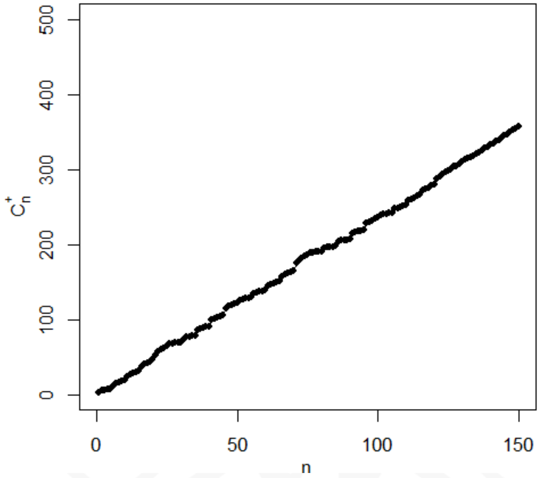
CUSUM(Multivariate)

Code

```
x1 = c(input1CSV$Ra)
View(x1)
N = length(x1)

k=0.5

cn1 = rep(0,N)
cn1[1] = max(0,x1[1]-k)

for(i in 2:N){
  cn1[i] = max(0,cn1[i-1]+x1[i]-k)

}


ii = seq(1,N)

par(mfrow=c(2,2), mar=c(4,4,2,2))

plot(ii,x1,type="o",lty=1,pch=16,xlab="n",
     ylab=expression(X[n]),mgp=c(2,1,0),xlim=c(0,N),
     ylim=c(-4.5,10.5), cex=0.8)
title(xlab="(a)",cex=0.9)
```

Output





T^2 Hotelling Chart

Code

```r
xfull =matrix(scan("G:/UB IE/aqc/Final project/Ratxt.txt",skip = 0),ncol=3,byrow=T)
View(xfull)
x = xfull[,1:3]
x
n = length(x[,1])
n

xbar = colMeans(x)
xbar
S2 = cov(x)
S2
solve(S2)

T12 = rep(0,n)

for(i in 1:n){
  T12[i] = t(x[i,]-xbar) %*% solve(S2) %*% (x[i,]-xbar)
}
T12

ii = seq(1,n)

plot(ii,T12,type="o",lty=1,pch=16,xlab="i",
     ylab=expression(T[list(1,i)]^{2}),mgp=c(2,1,0),xlim=c(0,150),
     ylim=c(0,30),cex=0.8)
```

Output

```
> S2 = cov(x)
> S2
            [,1]        [,2]        [,3]
[1,]  3.65472018 -0.04509999 -0.06378475
[2,] -0.04509999  2.31311977  0.31964321
[3,] -0.06378475  0.31964321  1.75768153
```

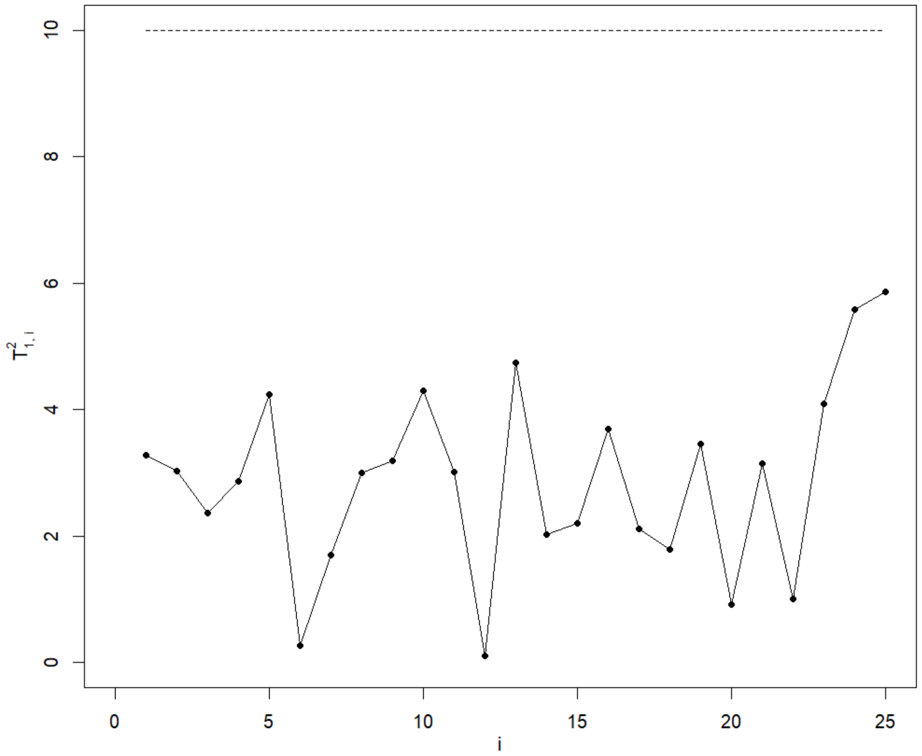
```
> T12
  [1]  0.34708830  1.29924730  1.61922152  1.59458957  0.99431503  2.51208692  0.32427580
  [8]  2.10511852  0.80476578  5.48005321  4.19462809  0.22261118  1.37879446  1.19994353
 [15]  1.44664891  5.04039909  2.48060926  1.53462464  1.36038681  2.19566201 13.84578312
 [22]  2.55636419  0.90322375  1.59536012  0.90028918  1.91823856  1.70183875  1.84507433
 [29]  2.08553478  1.97822846  3.56833751  0.09659136  0.63728563  2.88511018  1.98810687
 [36]  6.74165376  0.50244850  0.72544762  8.83662264  1.36405539  8.93989585  1.17989282
 [43]  3.15578073  0.77581216  0.95706138 13.07286817  8.96322589  1.76806395 10.02808474
 [50]  4.13663401  2.22777007  6.67626093  5.49531632  1.03553693  0.73189969  2.58775116
 [57]  0.31241196  1.73938198 27.33104360 10.15045917  4.22451173  1.66719558  1.83618045
 [64]  1.00804424  4.60628593  5.82906843  4.84010307  5.09888327  1.65597231  1.05227853
 [71] 19.31724540  0.53714227  1.65715597  1.41677230  2.32580829  3.16226960  3.24459852
 [78]  3.24275642  3.34136695  2.90824509  3.63404430  2.52926333  1.74624191 10.36654225
 [85]  1.75707253  7.85699485  2.10706684  1.50502921  1.48057189  2.33686269  9.31327127
 [92]  0.52067218  1.61965225  4.17500455  3.82418264 11.21297688  3.47673894 10.15079444
 [99]  2.94423165  0.59146625  1.14007572  1.70409262  1.19006509  1.04984131  2.40518308
[106]  3.04864940  0.80928473  4.21745338  1.57463180  1.99458572  4.97885355  1.46292310
[113]  2.42019019  5.78389614  2.20150169  4.55286603  2.31684357  0.78456302 13.40466182
[120]  2.90609021  9.70690247  2.33575771  0.18352562  0.71374999  0.74989253  0.85764793
[127]  0.45984349  0.46619166  0.18802615  0.87867750  0.12533042  0.08717724  0.16203734
[134]  0.32230734  0.38795230  0.60826382  0.18026861  0.95920814  0.19121236  0.63099762
[141]  0.41771951  0.25693075  0.60691788  0.20703424  0.34955332  0.64997434  0.28484117
[148]  0.10135472  1.03268461  0.75538570
```

T^2 Hotelling for 126 to 150 Sample Points

Code

```
# T^2 Hottling for 125 to 150
y = xfull[126:150,1:3]
y
n = length(y[,1])
n

ybar = colMeans(y)
ybar
S2 = cov(y)
S2
solve(S2)

T12 = rep(0,n)

for(i in 1:n){
  T12[i] = t(y[i,]-ybar) %*% solve(S2) %*% (y[i,]-ybar)
}
T12

ii = seq(1,n)

plot(ii,T12,type="o",lty=1,pch=16,xlab="i",
     ylab=expression(T[list(1,i)]^{2}),mgp=c(2,1,0),xlim=c(0,25),
     ylim=c(0,10),cex=0.8)
lines(ii,rep(10.0,n),lty=2,cex=0.8)
```

Output

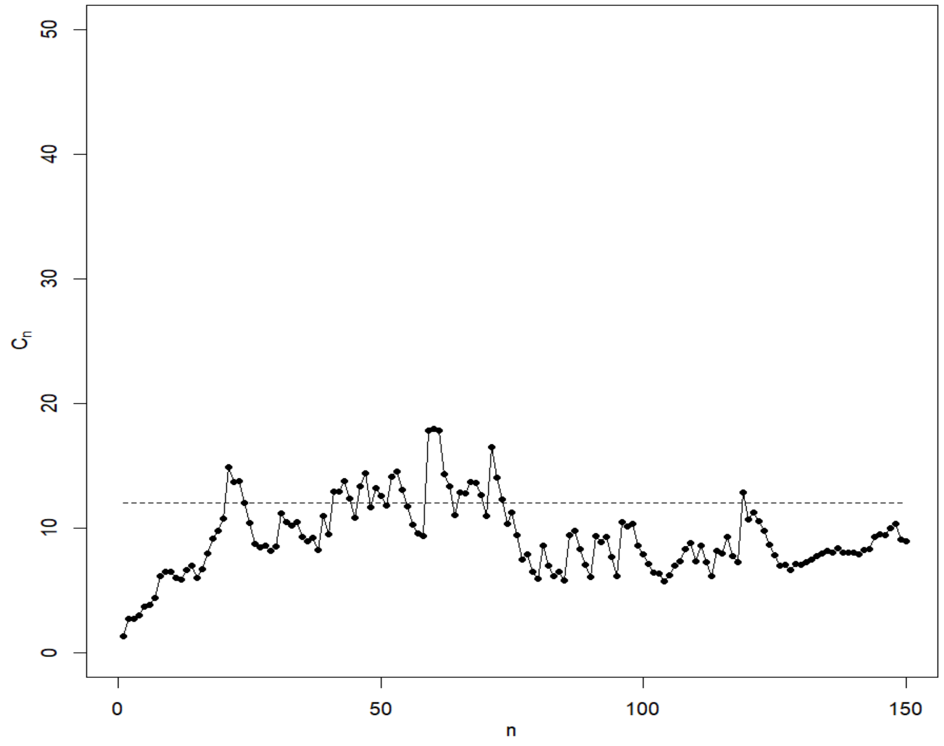


EWMA

Code

```
x= matrix(scan("G:/UB IE/aqc/Final project/Ratxt.txt",skip = 0),ncol=3,byrow=T)
m <- c(-0.1389 ,-0.0678, -0.1208)
cv <- matrix(c(3.65472018,-0.04509999, -0.06378475,
               -0.04509999,  2.31311977 , 0.31964321,
               -0.06378475, 0.31964321 , 1.75768153),3,3)
set.seed(100)
d1 <- mvrnorm(10,mu=m,Sigma=cv)
n = length(x[,1])
p = 3
lambda = 0.2               # Specify the weighting parameter
h = 12
U = chol(cv)           # Cholesky decomposition of Sigma1: Sigma1=U'U
L = solve(t(U))
L
y=matrix(0,n,p)
for(i in 1:n){
  y[i,] = L %*% (x[i,]-m)
}
y
En = array(0,c(n,3,3))

En[1,,]=lambda*(y[1,]%*%t(y[1,]))+(1-lambda)*diag(c(1,1,1))
for(i in 2:n){
  En[i,,]=lambda*(y[i,]%*%t(y[i,]))+(1-lambda)*En[i-1,,]
}

Cn=rep(0,n)                # Charting statistic of the MEWMA chart

for(i in 1:n){
  Cn[i] = sum(diag(En[i,,]))-log(det(En[i,,]))-p
}
```

Output

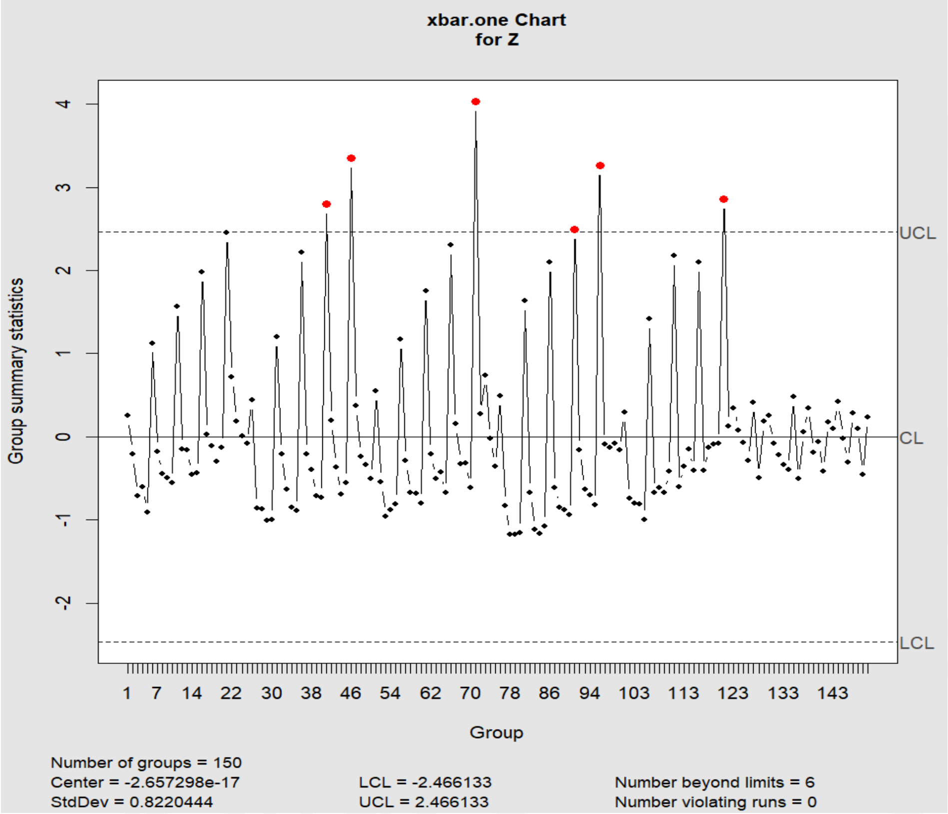


Shewhart Chart

Code

```
library(ggplot2)
library(qcc)
library(qicharts2)
data <- read_csv("G:/UB IE/aqc/Final project/input1CSV.csv")

Y= c(data$Ra)
View(Y)
mean_Y <- mean(Y)
sd_Y <- sd(Y)

Z <- (Y - mean_Y) / sd_Y
Z

Z_bar <- mean(Z)
Z_sigma <- sd(Z)

# Calculate control limits
UCL <- Z_bar + 3*Z_sigma
LCL <- Z_bar - 3*Z_sigma
qcc(Z, type="xbar.one", plot=TRUE)
```

Output

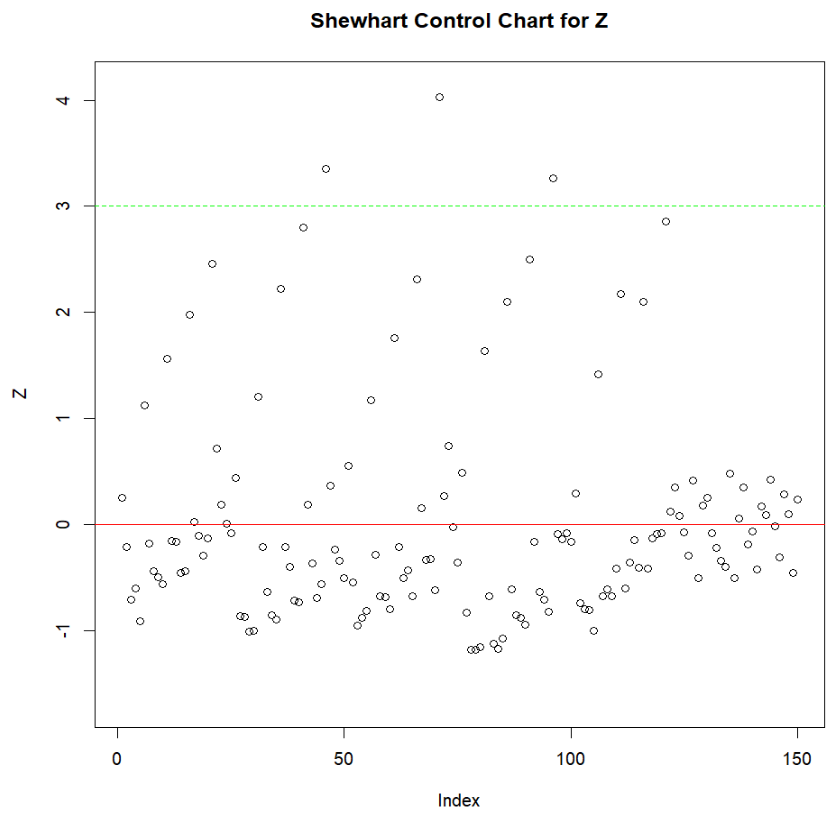


Shewhart Chart

Code

```
# Create Shewhart control chart
plot(Z, type="p", main="Shewhart Control Chart for Z", ylim=c(min(Z)-0.5, max(Z)+0.1))
abline(h=Z_bar, col="red")
abline(h=UCL, lty=2, col="green")
abline(h=LCL, lty=2, col="blue")
```

Output

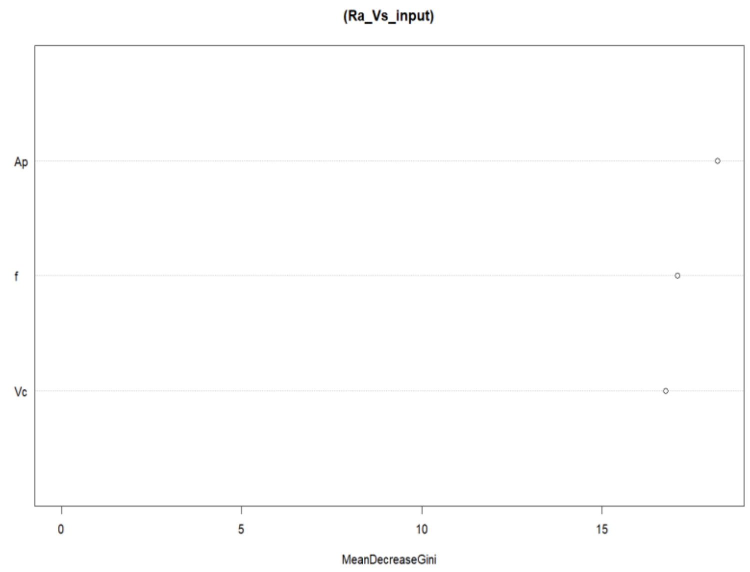


Feature Extraction Using Random Forest

Code

```r
library(readr)
input1CSV <- read_csv("G:/UB IE/aqc/Final project/input1CSV.csv")
library(dplyr)
library(randomForest)
Ra_attr <- (subset(input1CSV, select =c(Ra, Ap, f, Vc)))
Ra_attr
Ra_Vs_input <- randomForest(as.factor(Ra)~ Ap+f+Vc, data=Ra_attr, ntr
importance (Ra_Vs_input)
varImpPlot((Ra_Vs_input))
```

Output




```
500)
> importance (Ra_Vs_input)
   MeanDecreaseGini
Ap         18.20353
f          17.08887
Vc         16.76266
```

Conclusion:

- The surface roughness of the steel was observed to be in control for values 126 to 150.
- However, the roughness was out of control for values 1 to 125, with 7 points crossing the upper control limit.
- The roughness of the steel was found to be mostly dependent on the cutting parameters, such as depth of cut, feed rate, and cutting speed.
- To bring the process in control for the out-of-control values, further measurements and adjustments may be necessary.
- The use of statistical process control techniques can help monitor the process and identify when it is out of control, allowing for corrective actions to be taken.

References

- https://www.kaggle.com/datasets/adorigueto/cnc-turning-roughness-forces-and-tool-wear
- https://www.academia.edu/37002297/ANALYSIS_OF_SURFACE_ROUGHNESS_MILLED_OF_STEEL_AISI_1045_USING_X_BAR_AND_R_CONTROL_CHART
- https://journal.r-project.org/archive/2021/RJ-2021-034/RJ-2021-034.pdf

ANY QUESTIONS??