Design of Experiment for Tactile Imaging Sensor Pixel Response

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Description of The Experiment

Tactile Imaging System (TIS) is a type of sensor that can quantify the mechanical properties of an embedded object using optical method. As the LED illuminated, flexible sensing probe of the system compresses an object of interest in a relatively softer material, the sensing probe deforms. As a consequence, the light scatters. This forms a greyscale tactile image captured by a CCD camera. At the same time, a force gauge in the system records the applied force corresponding to an image. The feature of a tactile image is the number of pixels with nonzero values. This feature varies with the variation of applied forces. Forces of different values create different shape of deformation in the sensing probe which changes the amount of light scattered. The depth of the object from the surface of the softer material to the top of the object is another factor that affects the number of pixels. Also the potentiometer that controls the current to LED, is the controller of brightness. Therefore, change of potentiometer settings cause the change in the number of pixels.

We shall conduct an experiment to measure the number of pixels with nonzero values in tactile image formed from the compression of a 12 mm diameter spherical object. There are three factors: Forces from 1 to 10 N with 1 N interval, depth 2 mm and 4 mm, and the potentiometer settings 35 and 45. The response is the number of pixels with nonzero values. The number of observations will be $10 \times 2 \times 2 = 40$ observations.

To reduce the randomness in the operating the system, we shall attach it to a loading machine. The system will be moved upward and downward using a handle. TIS shall compress the object vertically. The experiment must be done in a dark room. Any external light is a noise for the feature of the tactile image. TIS will compress the object continuously from 0 to 10 N. However, only the tactile images corresponding to 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 N will be saved. In each run, for a particular depth and potentiometer settings, ten tactile images will be collected for ten levels of forces.

	Force	Depth	Pot	Pixel
1	1	2.33	35	213260
2	2	2.33	35	222507
3	3	2.33	35	231279
4	4	2.33	35	235623
5	5	2.33	35	241504
6	6	2.33	35	249615
7	7	2.33	35	255041
8	8	2.33	35	262613
9	9	2.33	35	266397
10	10	2.33	35	272416
11	1	2.33	25	205615
12	2	2.33	25	217965
13	3	2.33	25	220488
14	4	2.33	25	203001
15	5	2.33	25	230865
16	6	2.33	25	214568
17	7	2.33	25	236821
18	8	2.33	25	246326
19	9	2.33	25	253585
20	10	2.33	25	254040
21	1	5.04	35	306139
22	2	5.04	35	312969
23	3	5.04	35	316141
24	4	5.04	35	313699
25	5	5.04	35	314301
26	6	5.04	35	328158
27	7	5.04	35	331014
28	8	5.04	35	333491
29	9	5.04	35	337842
30	10	5.04	35	342122
31	1	5.04	25	271371
32	2	5.04	25	279558
33	3	5.04	25	285061
34	4	5.04	25	287166
35	5	5.04	25	283462
36	6	5.04	25	302775
37	7	5.04	25	304986
38	8	5.04	25	306515
39	9	5.04	25	288021
40	10	5.04	25	322867

Table 1: Data table from the experiment

Analysis of the design

The first ANOVA will be based on this model:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijk} \tag{1}$$

where
y_{ijk} = the observed response, the number of non-zero pixels,
μ = overall mean effect,
α_i= effect of i-th level of factor Force,
β_j= effect of j-th level of factor Depth,
γ_k= effect of k-th level of factor Potentiometer settings,
$(\alpha\beta)_{ij}$ = effect of interaction between i-th level of factor Force and j-th level of factor Depth,
$(\alpha\gamma)_{ik}$ = effect of interaction between i-th level of factor Force and k-th level of factor Potentiometer settings,
$(\beta\gamma)_{jk}$ = effect of interaction between i-th level of factor Depth and j-th level of factor Potentiometer settings,
$(\alpha\beta\gamma)_{ijk}$ = effect of interaction between i-the level of force, j-the level of depth, and k-the level of potentiometer settings,
ϵ_{ijk} = random error component.
All the factors are assumed to be fixed. There is only one replicate in this experiment, which means there is only one observation per cell.

We are interested in testing hypotheses about the equality of the main effects and interaction effect.

Fig. 1 shows the main effect and interaction effect plot. "Pot" refers to Potentiometer settings. The significant interaction will be indicated by the lack of parallelism of the lines. We observe that there is no significant interaction effect on the experiment.

The ANOVA table is shown in Table 2:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Force	9	8668526102.52	963169566.95		
Depth	1	51418149716.02	51418149716.02		
Pot	1	5547791390.63	5547791390.63		
Force:Depth	9	787966552.72	87551839.19		
Force:Pot	9	210347197.12	23371910.79		
Depth:Pot	1	469999369.22	469999369.22		
Force:Depth:Pot	9	546222364.52	60691373.84		
Residuals	0	0.00			

Table 2: ANOVA table for 3 way interactions

The program returns this message: ANOVA F-tests on an essentially perfect fit are unreliable.

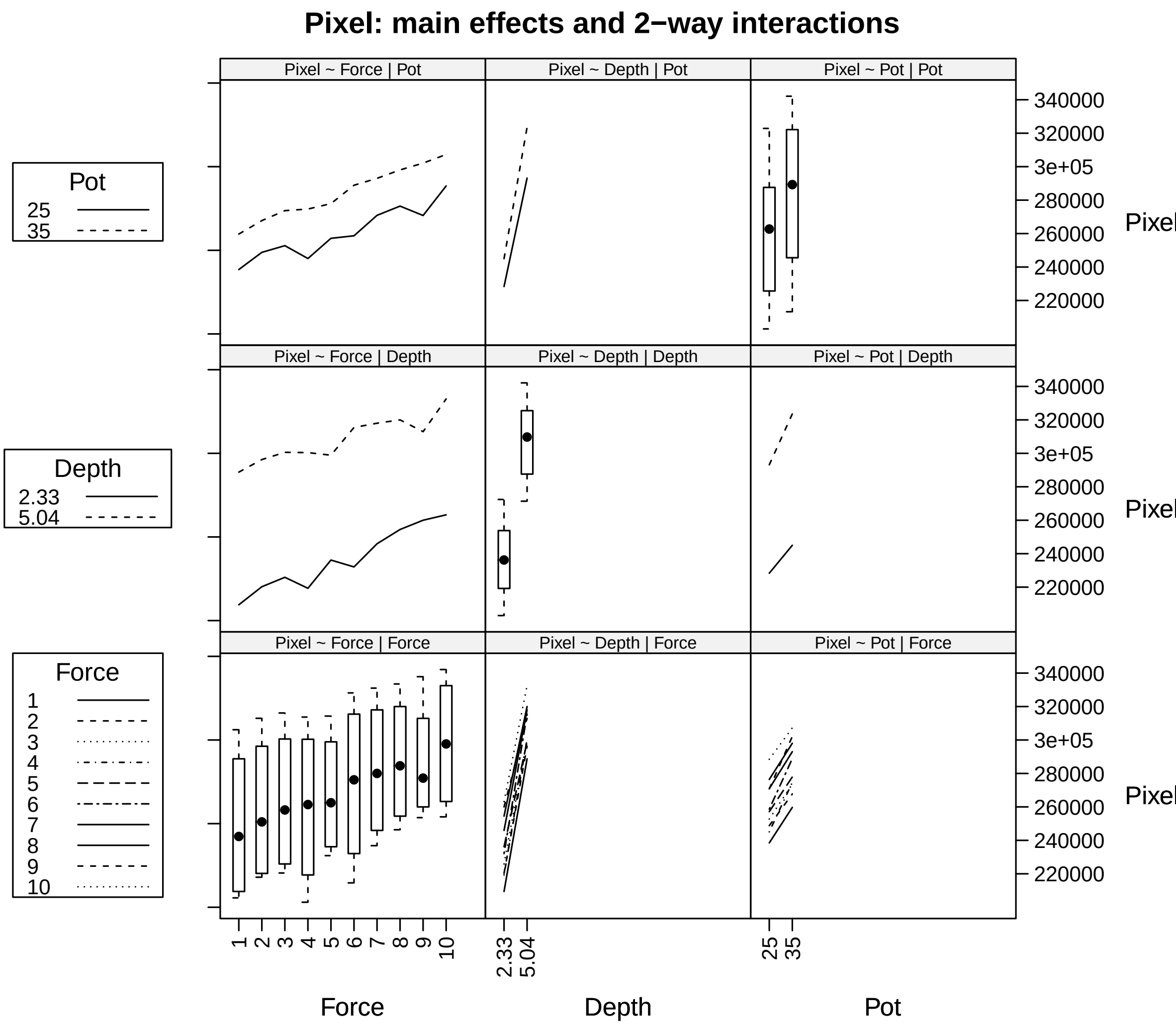

Figure 1: Main effect and two way interactions

Suppressing the 3 way interactions we get the ANOVA table as:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Force	9	8668526102.52	963169566.95	15.87	0.0002
Depth	1	51418149716.02	51418149716.02	847.21	0.0000
Pot	1	5547791390.63	5547791390.63	91.41	0.0000
Force:Depth	9	787966552.72	87551839.19	1.44	0.2970
Force:Pot	9	210347197.12	23371910.79	0.39	0.9143
Depth:Pot	1	469999369.22	469999369.22	7.74	0.0213
Residuals	9	546222364.52	60691373.84		

We observe that the main effects and depth and pot interaction is significant for 0.05 significance level. From this observation we keep Force, Depth, Pot, and Depth and Pot interactions in the model and get:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\beta\gamma)_{jk} + \epsilon_{ijk}. \tag{2}$$

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Force	9	8668526102.52	963169566.95	16.84	6.557×10^{-9}
Depth	1	51418149716.02	51418149716.02	898.84	$< 2.2 \times 10^{-16}$
Pot	1	5547791390.63	5547791390.63	96.98	1.971×10^{-10}
Depth:Pot	1	469999369.22	469999369.22	8.22	0.0080
Residuals	27	1544536114.37	57205041.27		

For a 0.05 significance level, from p-values in ANOVA table the main effects Force, Depth, Potentiometer settings, and Depth and Pot interaction effect are significant.

The next step in this project is to include size factor into consideration and do ANOVA.

With increase of depth, the number of pixel does not increase linearly since there is a depth-pot interaction effect. The number of pixels directly influence the size estimation of objects. However, in clinical setting, we do not have control over depth. We have control over potentiometer settings. A lower potentiometer setting mean a lower resistance and higher current to LED which essentially produce brighter light and the larger number of pixels in tactile image. In short, a lower potentiometer setting make the device very sensitive. In that case, even a smaller object with lower depth will produce larger number of pixels compared to a bigger object with larger depth. This may result into giving same value for size estimation even though they are different. Then the estimation accuracy will be function of the object's depth if the potentiometer setting is kept constant. To remove the potentiometer effect, we can first put a upper limit on depth value for which the device will be capable of detecting objects for specific force range. Then for that depth we can find which potentiometer setting produce the better and clear tactile image for the size range we are interested. Then we can fix the potentiometer setting at one level only.

Since depth and potentiometer interaction effect is significant, it would be interesting to consider the integrated pixel intensity as response variable. Pixel intensity is proportional to the amount of light energy incidents on CCD sensor. Integrated pixel intensity is the summation of all the pixel values in an image.

A The source file: DOETIS.R

```
library(xtable)
library(HH)
lattice.options(default.theme = standard.theme(color = FALSE))

setwd("E:/TEMPLE-STUDY/COURSE/Spring 2013/STAT8107/designofexpt/firdousstat")

tispixel10 <- read.csv("tispixel10.csv",header=TRUE, stringsAsFactors=FALSE)


#Anova with three way interaction

tispixel10$Force <- as.factor(tispixel10$Force)
tispixel10$Depth <- as.factor(tispixel10$Depth)
tispixel10$Pot <- as.factor(tispixel10$Pot)

interaction2wt(Pixel ~ Force + Depth + Pot, data=tispixel10, rot=c(90,0),
               par.strip.text=list(cex=.70))


tispixel10.3aov <- aov(Pixel ~ Force * Depth * Pot, data=tispixel10)
anova(tispixel10.3aov)

#suppress just the 3-way and show all of the 2-way interactions
tispixel10.3aov <- aov(Pixel ~ (Force + Depth + Pot)^2, data=tispixel10)

anova(tispixel10.3aov)
xtable(anova(tispixel10.3aov))


tispixel10.aov2 <- aov(Pixel ~ Force + Depth + Pot + Depth*Pot , data=tispixel10)
anova(tispixel10.aov2)
xtable(anova(tispixel10.aov2))
```