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OPTIMUM LEVEL DETERMINATION OF DIFFERENTIATED SOFT PAD COMPLIANCE PARAMETERS FOR ROBOTIC LIMBS

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ABSTRACT :

The most studies of differentiated layer soft pad for robots' hand fingertips have focused on the relationship between the pad compliance and parameters like compressive load, material and shape of pad. In addition, pressure distribution of contact process should be considere . They did not remark directly the effective set combination of above parameters on the compliance, or studied the weight of each parameter on the process of contact. In this paper, Taguchi method has been used to investigate the optimum set of parameters (compressive load, shape and, material) that give the best flatting of pad. Also the analysis of variance technique (ANOVA) has been employed to compare parameters and predict the contribution of each parameters the compliance. The results explain the effective parameter is the material of soft pad not the shape. In addition, these two methods Taguchi and ANOVA represent good techniques to estimate the effective parameter in the design of robotic hand pad.

Key words: soft fingertips for robotic hands, Taguchi method, Analysis of variance Technique.

إيجاد أفضل مستوى لمتغيرات المطاوعة للوسائد المرنة المفاضلة لأطراف يد الرجل الالي

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الخلاصة :

ركزت معظم الدراسات للوسائد المرنة المفاضلة لأطراف يد الرجل الالي على العلاقة ما بين مطاوعة الوسادة والمتغيرات، مثل القوة الضاغطة، مادة وشكل الوسادة. كذلك اخذت بالاعتبار تصرف عملية التماس وتوزيع الضغط. ولكنهم لم يشيروا بصورة مباشرة الى تأثير تلك المتغيرات مجتمعةً على المطاوعة أو دراسة وزن كل من هذه المتغيرات على عملية التماس. في هذا البحث تم استخدام طريقة تاكوجي للتحقق من أفضل تركيبة للمتغيرات (الحمل الضاغط، الشكل والمادة) التي تعطي أفضل تسطح للوسادة، وكذلك تطبيق طريقة تحليل التباين لمقارنة المتغيرات واستنتاج مساهمة كل وحد منهم على المطاوعة. بينت النتائج ان العامل الأكثر تأثيرا هو مادة الوسادة وليس الشكل. بالإضافة الى ذلك، هتين الطريقتين تمثلان وسيلتان مفيدتان لتقدير العامل المؤثر عند تصميم أطراف يد الانسان الالي.

الكلمات الدالة : الأطراف المرنة لأصابع يد الروبوت، طريقة تا كوجي، طريقة تحليل التباين.

INTRODUCTION :

In recent years, trending of robot hand design has been directed towards parts inspired to biological models precisely to human hand. In order, mimic the human tissue, fingers of robotic hand should be covered with an elastic (soft) material. Mechanics of soft finger contact enhance the stability of grasping in addition; safe object prehension and handling during manipulation may be improved. Also, compliance of pad contact increases, which in turn means larger contact areas for a given load reduces contact pressure, reduced material stress and enhance the damping of vibration (M. R. Cutkosky 1987) (M. R. Cutkosky et al. 1987). Many types of materials and shapes for pad are used. The shape takes the forms:

- A traditional pad, which consist of thick compliant layers of viscos-elastic materials cover a rigid core (Yanmei Li and Imin Kao 2001) and (Elango N. and Marappan R. 2009).
- Differentiated layer pad (DLP), which represented by a core covered with layers of different materials, or adopting a single material with different structural design for each layer. The compliance of differentiated layer pad is more efficient than the traditional pad (Giovanni Berselli and Gabriele Vassura 2009).

So that, many previous works have considered with the compliant surface of differentiated layer pad. (Giovanni Berselli and Gabriele Vassura 2009) suggested the pad with differentiated layer and tested five different shape of pad with two materials under different loads and types of contact surfaces. As well as verification assumed power law model of flatting with experimental results. (Marco Piccinini, Giovanni, and Gaberiele 2009, July 2010) highlighted the reliability of using the nonlinear finite element to predict the differentiated soft pad (DSP) compliance, and for analyzing contact variables like (contact area and pressure). In addtion, they investigated the dynamic model for fluid filled soft pad. A ramp-hold test did to estimate the constants of system and pad response to displacement at different velocities. Also, showed that the Fung's model capable to modeling one dimensional viscoelastic behavior of the fluid-filled pads, even though it's not uniform pad. To mimic the human fingers, (Giovanni, Marco and Gabriele May 2010 and 2011) presented a soft viscoelastic pad that based on differentiated soft pad filled with viscous fluid. These two works, examined the time-dependent phenomena and the increasing of the damping effect. The nonlinear finite analysis used to optimize the internal layer morphology, as well as to estimate the hardness with friction influence on the pad compliance. (P. Subramaniam and R. Marappan 2014) designed and studied a semi cylindrical fluid-filled pad from silicon, in these two studies the amount of contact force that should be applied was tested and effect of wall thickness of pad on the carrying load capacity was investigated.

In the aforementioned literatures, there seems to be no trend to address the effects of a combination set of parameters (load , shape , material , pressure distribution, etc…) on the compliance, but they analyzed each parameter individually, which will be not give a good indication to the interference of parameters effects on the process of contact in the same time. In addition, they did not remark to the amount of contribution of parameters upon the performance of operation.

The aim of this work is, to demonstrate the influence of parameters (load, shapes, and materials) with the optimum level upon the contact performance of differentiated layer soft pad; this was done by using Taguchi method. In addition, the analysis of variance technique (ANOVA) was employed, to identify the contribution and weight of each parameters on the response of contact process.

EXPERIMENTAL DATA :

The patterns of pad and their experimental data have been taken from the reference (Giovanni and Gabriele 2009). In this reference, four patterns of fingertip-differentiated pad were designed. The basic structure of these differentiated pad patterns compose from an internal core, an external continuous layer covers, and an intermediate layer that presents the voids. As shown in Fig. 2.

Four patterns could be described as:

- Pattern with equally spaced hemispherical protrusions (pad I), Fig. 2-a.
- Pattern with equally spaced hemispherical voids (pad II), Fig. 2-b.
- Pattern with circumferential ribs connecting the core to the external layer (pad III). Each rib is inclined of 45^o with respect to the normal to the external surface. Thus transforming normal loads act on the contact with bending actions applied on each rib, as shown in Fig. 2-c.
- Pattern with a series of inclined micro-beams, fundamentally subjected to bending (pad IV), Fig. 2-d.

Four configurations made from two elastic materials, as shown in Fig. 3:

- Tango Gray™ with tensile strength of 4.36 MPa, elongation at break of 47%, hardness 75 Shore A.
- Tango Plus™ with tensile strength of 1.5 MPa, elongation at break of 218%, hardness 27 Shore A.

The tests were carried out by pressing the specimen (fingertip) on a contact rigid surface, in which performed for each material. Results of tests are shown in Figure 4 which are considered as the data for this work.

TAGUCHI METHOD AND (ANOVA) :

Taguchi method

Taguchi method has developed by a Genichi Taguchi. In which based on using orthogonal array (OA) with fewer experiments to get an optimum setting of parameters for process. This method uses a statistical measurment called signal- to- noise ratio (S/N) which is logarithmic function of desired output. Taguchi's signal-to-noise ratios take both the mean and the variability. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The standard S/N ratios generally used are; Nominal the best (NB), lower the better (LB) and higher the better (HB) (Hadi Kalani and Alireza Akbarzadeh 2012). In this work, the higher flattening is the best, therefore the equation for higher the best is used (Hadi Kalani and Alireza Akbarzadeh 2012).

$$S/N = -10\ \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right) \tag{1}$$

Where:

y : is the observed data.

n : is the number of observations.

Three parameters of contact are chosen; load, shape, and material, with three levels are used as explained in Table 1.

Table 1 shows three parameters, two of them have three levels and one has two levels only. Hence, the orthogonal arrays make list of (18) experiments in a particular order that cover all factors, Table 2 indicates this array with the matrix of parameters and response (flattening).

Selection of levels based on levels of load that is selected to cover the region of steepest change in data, as shown in Figure 5. While selection of three shapes instead of four was depended on two reasons; first, the behavior of shape, pad IV shows biggest variation in flattening unlike others (I, II, III). Secondly, experimental model of IV obey another formula differs from other shapes. So that, there is some kind of abnormality in the data of shape IV.

Analysis of variance technique (ANOVA) .

ANOVA is a statistically based, it's a good technique for determining the effect of any given input parameter from a series of experimental results by designing of experiments process (Bala, Biswanat and Sukamal 2009), it represent an objective decision-making tool for detecting any differences in the average performance of groups of tested items. ANOVA helps in formally testing the significance of all variables of parameters. The total sum of squared deviations SS_T is (Ram Rao S. and Padmanabhan G. 2012) :

$$SS_T = \sum_{i=1}^{n}(n_i - n_m)^2 \tag{2}$$

Where n is the number of experiments (observation) in the orthogonal array, n_i is the mean S/N ratio for the ith experiment, and n_m is the mean of all parameters (grand mean).
The percentage contribution P could be calculate as:

$$P = \frac{SS_d}{SS_T} \tag{3}$$

d.o.f of any parameter(factor) = k-1 (4)

Total d.o.f = n-1 (5)

$$\text{d.o.f of error} = \text{ total d.o.f} - \sum \text{d.o.f of papramelers} \tag{6}$$

$$V = \frac{SS_d}{\text{d.o.f}} \tag{7}$$

$$F = \frac{V}{V_E} \tag{8}$$

Where:
SS_d: sum of the squared deviations.
k: number of levels for each parameter.
V: variance of the parameter (factor)
V_E: variance of error
d.o.f: degree of freedom.
P: percentage contribution.
F: F- test, which indicate the significant effect on the quality characteristic of process.

RESULTS AND DISCUSSION:

The values of orthogonal array with signal- to- noise ratio (S/N) were explained in Table 3.

The analysis of mean results according to S/N ratio and according to flattening were demonstrated in (Table 4 with Fig. 6) and (Table 5 with Fig. 7), respectively. From these Tables and Figures, the optimum set of levels is (A3 B3 C2). The optimal level gives the best characteristic of contact process. The delta values calculated from the difference between the highest and lowest level value indicate that the load has more effect than the shape and material, the material takes the second place while the shape takes the third place, so that they ranked as 1, 3 and 2.

Table 6 represents the ANOVA calculations. From table, the parameter of higher contribution in enhancement of compliance is the material (P= 42.59 %) while, the shape is less one (P=15.21 %). In which means, the change in shape of pad will be not conditionally effective than change in material.

CONCLUSIONS:

This paper has been outlined using of Taguchi method to determine the optimum operating conditions of contact that give the best compliance. Using of ANOVA to examine the contribution of parameters on flattening was efficient. It illustrated that material has weight more than shape to enhance the compliance of soft pad. From this study, the two methods (Taguchi and ANOVA) could be provide a powerful tool to suggest the significant parameters that are taken in consideration to design the soft pad of robot's hand fingertips.

Table 1 Contact parameters and levels

Symbols	Parameters	Levels		
		Level-1	Level-2	Level-3
A	Load (N)	1	3	5
B	Shape	I	II	III
C	Materials	Mat-1	Mat-2	-

Table 2 Orthogonal Array

No. of experiment	A- Load N	B- shape	C- Materials	Flattening mm
1	1	Shap-1	Mat-1	0.213
2	3	Shap-1	Mat-1	0.428
3	5	Shap-1	Mat-1	0.593
4	1	Shap-2	Mat-1	0.135
5	3	Shap-2	Mat-1	0.336
6	5	Shap-2	Mat-1	0.464
7	1	Shap-3	Mat-1	0.4
8	3	Shap-3	Mat-1	0.904
9	5	Shap-3	Mat-1	1.197
10	1	Shap-1	Mat-2	0.657
11	3	Shap-1	Mat-2	1.101
12	5	Shap-1	Mat-2	1.367
13	1	Shap-2	Mat-2	0.625
14	3	Shap-2	Mat-2	1.028
15	5	Shap-2	Mat-2	1.294
16	1	Shap-3	Mat-2	0.68
17	3	Shap-3	Mat-2	1.491
18	5	Shap-3	Mat-2	1.793

Table 3 Orthogonal array with S/N values

No. of experiment	A- Load	B- shape	C- Materials	Flattening mm	S/N
1	1	Shap-1	Mat-1	0.213	-13.432
2	3	Shap-1	Mat-1	0.428	-7.371
3	5	Shap-1	Mat-1	0.593	-4.539
4	1	Shap-2	Mat-1	0.135	-17.393
5	3	Shap-2	Mat-1	0.336	-9.473
6	5	Shap-2	Mat-1	0.464	-6.67
7	1	Shap-3	Mat-1	0.4	-7.959
8	3	Shap-3	Mat-1	0.904	-0.877
9	5	Shap-3	Mat-1	1.197	1.562
10	1	Shap-1	Mat-2	0.657	-3.649
11	3	Shap-1	Mat-2	1.101	0.836
12	5	Shap-1	Mat-2	1.367	2.715
13	1	Shap-2	Mat-2	0.625	-4.082
14	3	Shap-2	Mat-2	1.028	0.24
15	5	Shap-2	Mat-2	1.294	2.239
16	1	Shap-3	Mat-2	0.68	-3.35
17	3	Shap-3	Mat-2	1.491	3.47
18	5	Shap-3	Mat-2	1.793	5.072

Table 4
Analysis of mean results according to S/n

Symbols	Parameters	Level-1	Level-2	Level-3	Delta	Rank
A	Load	-8.311	-2.196	0.063	8.248	1
B	Shape	-4.24	-5.857	-0.347	5.51	3
C	Materials	-7.35	0.388		6.962	2

Table-5 Analysis of mean results according to flattening

Symbols	Parameters	Level-1	Level-2	Level-3	Delta	Rank
A	Load	0.452	0.881	1.118	0.666	1
B	Shape	0.727	0.647	1.078	0.431	3
C	Materials	0.519	1.115		0.596	2

Table 6 ANOVA results

Source	Sum sq.	d.o.f	Mean sq.	F	P%
A	222.5	2	112.62	32.42	35.17
B	96.246	2	48.123	13.85	15.21
C	269.453	1	269.453	77.57	42.59
Error	41.685	12	3.474		6.59
Total	632.624	17			

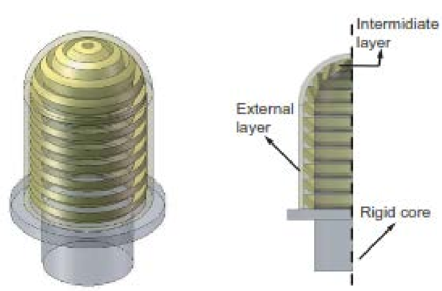

Figure 1 The structure of differentiated pad (Giovanni and Gabriele 2009)

Figure 2 Differentiated pad patterns (Giovanni and Gabriele 2009)

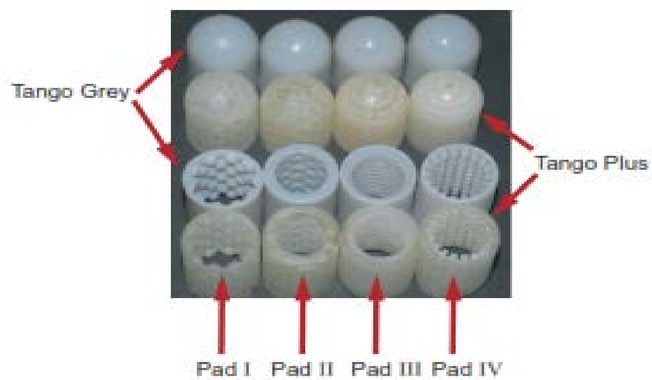

Figure 3 Test specimens (Giovanni and Gabriele 2009)

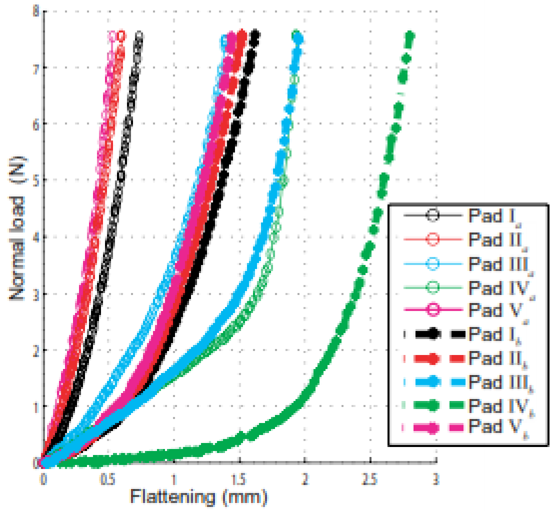

Figure 4 Experimental results (Giovanni and Gabriele 2009)

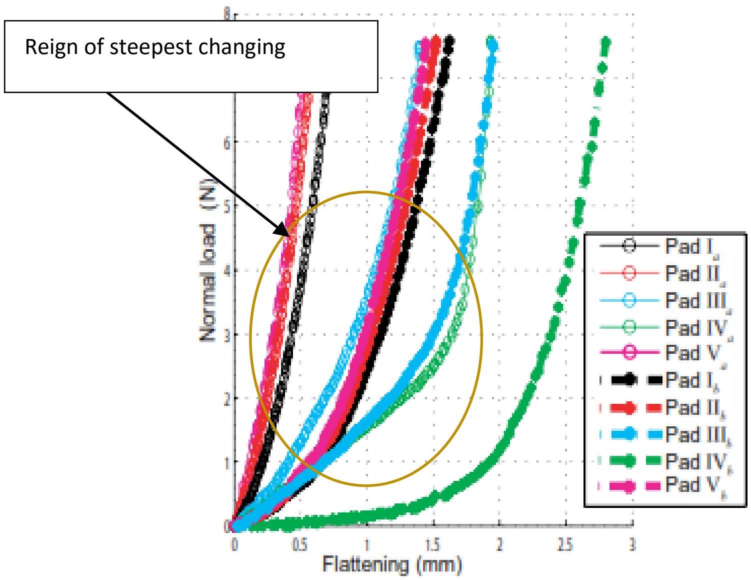

Figure 5 the region of steepest changing in the results

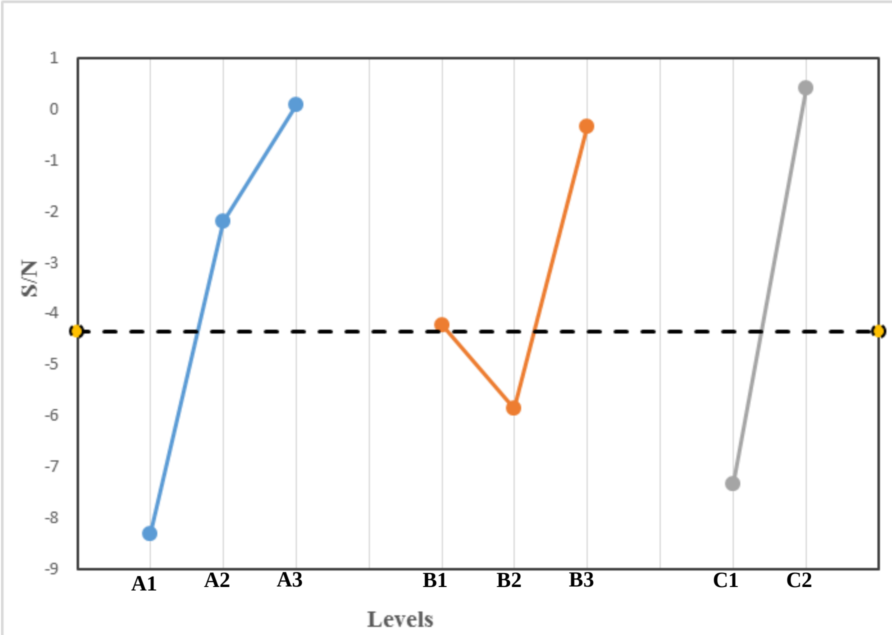

Figure 6 The levels- S/N curves

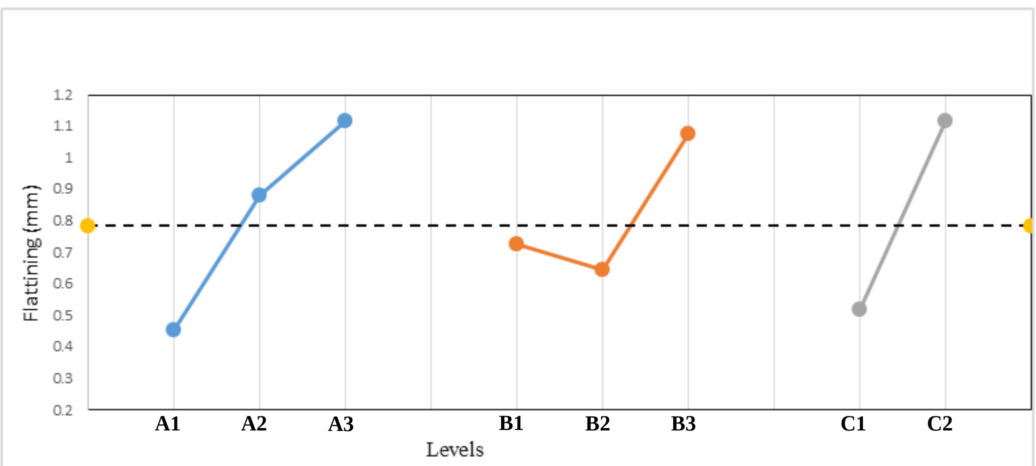

Figure 7 The levels – flattening curves

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