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Application of Satisfaction Function and Distance Measure Based Multi-Criteria Selection Method on Selection Optimal Cutting Parameters

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Abstract: In optimization of cutting parameter, multi criteria desicin making methods are used due to the results of multi-criteria for obtaining of optimal cutting parameters. In this study, the satisfaction function and distance mesaure based multi-criteria desicion making method was used for defining optimal cutting parameters. The method was used in machining of free-surfaces. In the experimental design, cutting tool diameter, rough machining stratejies, and finish machining stratejies were selected as input parameters. Form error, cutting force, and surface roughness were defining as output parameters. After the appliying of the method procedure, the optimal cutting parameters was optimized and the results were compared with grey relational analysis. As a results, the satisfaction function and distance measured based multi-criterai selection method could be successfully used in multi-criteria desicin making for optimization purpouse, in this way, the method can be used in research and development processes in terms of both cost and time.

Keywords: Satisfaction function, distance measure, cutting parameters, multi-criterie decision-making,

1. Introduction

In the machining operations, for example turning, milling, drilling operations, sorting of testing results and obtaining optimal experimental conditions have led to the using of different multi-criterai decision methods. For this purpose, Taguchi experimental design and optimization technique is widely used. But, the disadvanatge of the mothod is not suitable for multi-criteria desicion making. The hbyrid model that combined the Taguchi method and differen method was developed to overcome for this adverse situaiton. A study was done in 2012 by Kurt, et al and in the study, Taguchi based grey relational analysis method was used for optimization of experimental results[1]. In this study, L9 orthogonal array was used, and form error, cutting force and surface roughness were defined as output parameters of experiment. For every experimental conditions, the grey relational analysis degree were calculated and, the experimental results were sorting using the degree. Another study of this field was perfomed by D' Addona, et al in 2013 [2]. Genetic algarithm based optimization technique was used to optimize cutting parameters of turning operations. Also, Rajesh, et al done a study, and in this work, for minimization of surface roughness and cutting temperature, the regression models were prepared and this models were solved using genetic algorithm method [3]. In the litreture search, there are a lot of study, and the studies continues increasingly every year [4-6].

In this paper study, satisfaction function and distance measured based multi-criteria selection method, that used by A. Kar and A. Kentli in 2011 for selection of robots, was used for selection of optimal experimental results. The hybrid method was detailed in ref. 7 [7]. Applicaiton of the model has been done on literature data from our paper publised in 2012 [1]. The results of experimental studies were used, and initially, the satisfaction value of ech experimental conditions for every criteia were calculated. The distance measured values were calculated each experimental number, and the experimental results were sorting by using the distance value. The minimum value of distance shows that the experiment is the best experimental condition. Also, the results were compared with results of grey relational analysis method.

2. Satisfaction Function and Distance Based Multi-Criteria Selection Method

The satisfaction function and distance based multi-criteria selection method was used to optimize cutting parameters of free form surface machining process. The method was detailed in ref. 7. In this study, applicaiton of this method on optimization of cutting parameters was done, and performance of the method was search. For the application of the method, the experimental data was obtanied from literature. In the literatur study, the experimental table was perapered by using fractional experimental design method of Taguchi. L9 orthogonal array was used, and experiments were conducted. After the obtaining of experimental results, as first step, the satisfaction value of each output parameters of experiment (criteria) were calculated. In the calculation of the satisfaction value, 'smaller-the-better', 'larger-the-better' approaches were used according to expected value. This process was shown in Figure 1.

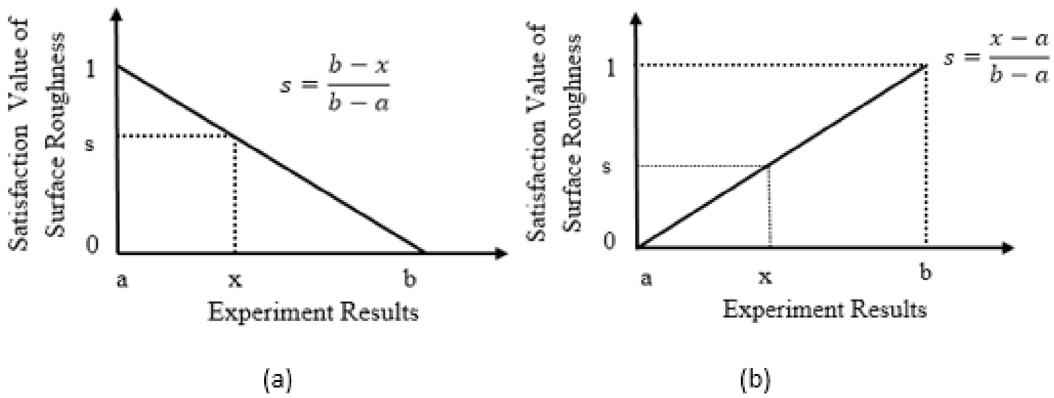

Figure 1: calculation of satisfaction value of each criterian according to a)'the smaller-the beter', b) 'the larger-the better' approaches

After the defining of satisfaction value of each criterian, the distance values were caculated by using equation 1.
Deney sonuçları en küçük uzaklık değerinden başlanarak sıralanır ve en küçük d değerine sahip deneysel şartlar optimal deneysel şartlardır.

$$d = [\sum_{i=1}^{n}(1-s_i)^2]^{\frac{1}{2}} \qquad (1)$$

Where, d is the distance value, n is experiment number, s: satisfaction value.

3. Case Study

The experimental data was obtained from literature [1]. In this study, he effects of cutting tool diameter, rough machining strategies, and finish machining strategies on form error, cutting force and surface roughness were examined, and optimized. Experiments was conducted at 3 axis CNC machine with ball-end mill to machine free form surface work piece. L9 orthogonal array was used as experimental table. AL7075-T6 material was used workpiece material. In the study, cutting forces measured during machining, and after, form error and surface roughness measured using manufactured workpiece.

In the present study, a three-factor cutting tool diameter, rough machining strategies, finish machining strategies are selected for input factors. Each factor has three levels. The input factors and their levels are listed Table 1. The experimental layout for cutting factors using L9 orthogonal array and experimental results are presented in Table 2.

Table 1: Process parameters and levels

	Factors	**Level 1**	**Level 2**	**Level 3**
1	(A) Cutting Tool Diameter	6 mm	8 mm	12 mm
2	(B) Rough Machining	zig-zag_lengthwise	Zigzag_transversal	Spiral
3	(C) Finish Machining	Sweep_up	sweep_down	sweep_lengthwise

Table 2: L9 Orthogonal array and experimental results

Exp. Num.	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2

5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

After the conduction of experiments using L9 orthogonal array experimental table, satisfaction value of each output parameters (criteria) was calculated. In the experimental study, there are 3 criteria: form error, cutting force and surface roughness. Satisfaction value of each criteria was calculated 'the lower- the best' approach. The next step, distance value from 1 was calculated using equation 1. The experiments were sorted by using the distance value. The minimal distance value of experiments shows the best experimental conditions.

4. Results and Discussion

The experimental table obtained from literature was shown in Table 3. The criteria of experiments were form error, cutting force, and surface roughness.

Table 3 Experimental results obtained from literature

Exp. Num.	A	B	C	Form Error	Cutting Force	Surface Roughness
1	1	1	1	0.0859	109	1,130
2	1	2	2	0.0991	91	1,100
3	1	3	3	0.0958	117	2,550
4	2	1	2	0.1203	131	1,150
5	2	2	3	0.1471	197	2,170
6	2	3	1	0.0890	133	1,360
7	3	1	3	0.0978	166	1,660
8	3	2	1	0.1721	213	0,850
9	3	3	2	0.1239	157	1,240

Satisfaction values of form error, cutting force, and surface roughness were calculated according to 'the lower – the best' approach. After that, the distance value of each criterian was calculated. The satisfaction and distance values of the experiments were listed in Table 4.

Table 4 Satisfaction values of each criterian and distance values.

	Satisfaction Value			Distance Value		
#	Form Error	Cutting Force	Surface Roughness	Form Error	Cutting Force	Surface Roughness
1	1.0000	0.8525	0.8353	0.0000	0.1475	0.1647
2	0.8469	1.0000	0.8529	0.1531	0.0000	0.1471
3	0.8852	0.7869	0.0000	0.1148	0.2131	1.0000
4	0.6009	0.6721	0.8235	0.3991	0.3279	0.1765
5	0.2900	0.1311	0.2235	0.7100	0.8689	0.7765
6	0.9640	0.6557	0.7000	0.0360	0.3443	0.3000
7	0.8619	0.3852	0.5235	0.1381	0.6148	0.4765
8	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000
9	0.5592	0.4590	0.7706	0.4408	0.5410	0.2294

Total distance value of each experiments were calculated, and the input parameters values and their total distance values were listed in Table 5.

Table 5 Input Parameters values and total distance value of each experiment

#	**Form Error**	**Cutting Force**	**Surface Roughness**	**Total Distance**	**Sorting**
1	0.0859	109.00	1.130	0.3122	2
2	***0.0991***	***91.00***	***1.100***	***0.3002***	***1***
3	0.0958	117.00	2.550	1.3280	7
4	0.1203	131.00	1.150	0.9034	4
5	0.1471	197.00	2.170	2.3553	9
6	0.0890	133.00	1.360	0.6802	3
7	0.0978	166.00	1.660	1.2293	6
8	0.1721	213.00	0.850	2.0000	8
9	0.1239	157.00	1.240	1.2112	5

As seen from the Table 5,experiment number of 2 has the minimum distance value, therefore, experiment 2 has optimal experimental conditions. In this conditions, form error, cutting force, and surface roughness are 0.091mm, 91N, and 1.100µm, respectively. The criteria weights were equally assumed in sorting of experiments.

In the literature, there are a lot of methods deal with sorting of experiments. Grey relational analysis is a method that is widely used in experimental studies.In the reference 1, the grey relational analysis method was detailed in reference 1. In the study, grey relational degree of each experiments were calculated and he experiments were sorted using this the degree value. The highest grey relational degree shows optimal experiment conditions. The results of grey relational analysis and satisfaction function – distance measured based multi-criteria selection methods were listed in Table 6.

Table 6 The grey relational degree and total distance of experiments, and sorting

#	**Form Error**	**Cutting Force**	**Surface Roughness**	**Total Distance**	**Sorting**	**GR Degree**	**Sorting**
1	0.086	109.000	1.130	0.312	2	***0.876***	***1***
2	0.099	91.000	1.100	***0.300***	***1***	0.770	3
3	0.096	117.000	2.550	1.328	7	0.572	8
4	0.120	131.000	1.150	0.903	4	0.649	5
5	***0.147***	***197.000***	***2.170***	***2.355***	***9***	***0.403***	***9***
6	0.089	133.000	1.360	0.680	3	0.780	2
7	0.098	166.000	1.660	1.229	6	0.647	6
8	0.172	213.000	0.850	2.000	8	0.667	4
9	0.124	157.000	1.240	1.211	5	0.608	7

When the table 6 was examined, the experiment 2 is the best experiment condition according to satisfaction function and distance measured based multi-criteria decision selection method, and the experiment 1 is the best experiment condition according to grey relational analysis method. The worst experiment condition is 5^{th} experiment according to each method. The commonality of both methods is to use same formulation for calculation normalization and satisfaction value. The formulation for calculation of grey relational degree and distance measure are different.Here, the equation of grey relational degree uses maximum and minimum value of normalization data of each criterian, and has a distinguishing constant ranging from 0 to 1. This constant takes generally value of 0.5. But, the equation of distance measure is similar to Euclidean norm. As a results of the study, the satisfaction function and distance measure based multi-criteria selection method is more accurate for selection optimal cutting parameters according to both results examination and expert opinion.

5. Conclusions

In this study, satisfaction function and distance measure based multi-criteria selection method was used to obtain optimal cutting parameters, and the method performance was studied. After the explanation of the model, the application of the method was done using data obtained from literature. The effect of cutting parameters of cutting tool diameters, rough machining strategies, and finish machining strategies on form error, cutting force, and surface roughness were examined. Firstly, satisfaction values were calculated for each criterian, and the distance value of each criterian was defining. The experiments were sorted by using this distance value. As the distance value decreases, optimal test conditions are achieved. The results of the method procedure compared with results of grey relational analysis method that is used widely in experimental studies.

As a results of this study,it is concluded that;

1. The satisfaction function and distance measured based multi-criteria selection method can be used successfully in experimental design,
2. The method can be used in different branches of science in terms of its algorithm and success in ranking of experiments
3. Because the method is more practical and accurate, in research and development process, the method can be used.
4. In the future works, the method can be integrated into other hybrid methods that used in experimental design and optimization.

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