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Tuning of PID Parameters by Integrated Taguchi Approach

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Abstract

Objectives: The effectiveness of Taguchi approach of tuning of PID controller by traditional hit and trail method is presented. **Methods/Statistical Analysis**: In multiple input parameter process, for obtaining the best output, one method is to conduct all possible experiments covering the entire range of parameters, a times, resulting in a huge number of experiments. To reduce the number of experimentation, a representative sample of experiments may be chosen and analyzed. Taguchi arrays helps selects the subset in such a way that ensures that all levels of all factors are represented equally. **Findings**: It has been shown that tuning of PID parameters by traditional hit and trial approach can be improved and made more effective by implementing the process with Taguchi approach. Using Taguchi's Method nearly best result can be obtained using lesser number of experimentations. Results thus obtained are authenticated by comparing them with those obtained by Exhaustive Search i.e. by conducting the entire set of experiments involving all possible combinations of the input parameters at different levels. **Application/Improvements:** Taguchi method helps achieve the target by conducting lesser number of experiments, thus saving on time, effort and cost, without compromising on the quality of result.

Keywords: Design Constraints, Orthogonal Array, PID Tuning, Taguchi Approach

1. Introduction

PID controller is the most widely used controller in industry. Therefore proper tuning of the three controller parameters i.e., the P (proportional), I (integral) and D (derivative) term is very significant for its proper impact as good close loop controller. In practice it is very difficult to get a good tuned PID controller. To tune a PID controller manually needs experience. The traditional trial-and-error method of tuning is not sufficient to meet the challenges of precision and accuracy required in most cases. Some common methods of PID tuning are, Ziegler–Nichols tuning method, developed by John G. Ziegler and Nathaniel B. Nichols. Though this method[1] provides best rejection of disturbance, but it is not suitable for minimizing overshoot. Tyreus Luyben method of tuning, Cohen–Coon method, Internal model control (IMC) based tuning approach etc., are some of the other popular methods[2,3]. Each method is associated with its own advantages and disadvantages.

2. PID Controller

A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems Figure 1. A PID controller[4] applies a correction based on proportional, integral, and derivative terms (sometimes denoted P, I, and D respectively) which give their name to the controller type.

The control signal u(t) is a weighted sum, K_p, K_i and K_d, are all non-negative and denote the coefficients for the proportional, integral and derivative terms, respectively (denoted *P*, *I*, and *D*).

In this model:

- P accounts for u(t) being proportional to error. Thus for large error the control output will also be large.
- I relates to past values of the error. For example, if there is a persisting error, the integral of the

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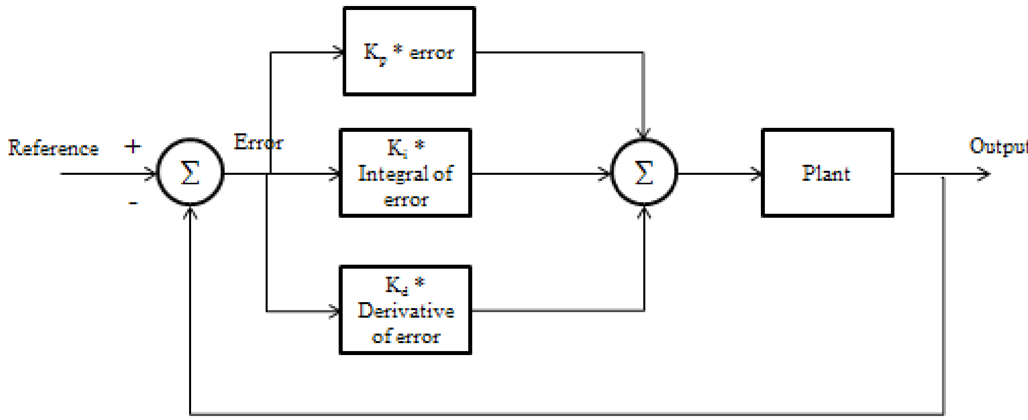

Figure 1. A block diagram of a PID controller in a feedback loop.

error will accumulate over time, and the controller applies a stronger action.

- D has anticipating nature, and generates control action based on rate of change of error.

Lot of research has been done to improve any optimization problem, by integrating the two or more methods to finally obtain better results[5,6]. In this paper the effectiveness of integrating Taguchi approach with the traditional hit and trail approach of PID parameter stuning is presented.

3. Taguchi Technique

In case of a multiple input parameter process to obtain the best output result, one of the ways is to conduct all possible experiments covering the entire range of parameters. For this a complete set of experiments is conducted to give desired results. As the number of experiments involved in many cases is extensively large it becomes a time consuming and costly affair to get a correct picture of the effects of various parameters on the observed data properly.

Sir R. A. Fisher was first to suggest the technique of laying out the conditions of experiments involving multiple factors. The method is popularly known as the factorial design of experiments. To overcome the problem of huge number of experiments to be conducted, Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted[7]. Taguchi method uses a special set of arrays called orthogonal arrays. These arrays allow you to consider a selected subset of combinations of multiple factors at multiple levels and ensure that all levels of all factors are considered equally.

Table 1. Levels of each parameter

Parameter	Level 1	Level 2	Level 3
K_p	1	11	21
K_i	100	300	500
K_d	0.1	0.3	0.5

The importance of these array designs lies in choosing the level combinations of the input design variables for each experiment. For this study, the data used is publicly available database for dc motor athttp://ctms.engin.umich.edu/CTMSas on 26 February 2017[8].

The performance requirements for any system are the worst case conditions, which the system will be expected to meet.

The design criteria requirements for position control in this example, decided areas follows.

- Settling time less than 0.040 seconds.
- Overshoot less than 16%.

The method has been tested using L_9 Taguchi array.

The number of factors to be tuned is three, i.e., K_p, K_i and K_d and as the array used is L9, the levels for each factor is kept three.

In this design,

- The proportional controller with gain ranges from 1 to 21.

- Integral gains *Ki* range is from 100 to 500.
- Derivative gains *Kd* range from 0.1 to 0.5.

To cover the entire range of each parameter and applying this method, three levels of each parameter (factor) considered is shown in Table 1.

Table 2. Full factorial design - the level combinations

S.No.	Factor combinations	K_p	K_i	K_d
1	111	1	100	0.1
2	112	1	100	0.3
3	113	1	100	0.5
4	121	1	300	0.1
5	122	1	300	0.3
6	123	1	300	0.5
7	131	1	500	0.1
8	132	1	500	0.3
9	133	1	500	0.5
10	211	11	100	0.1
11	212	11	100	0.3
12	213	11	100	0.5
13	221	11	300	0.1
14	222	11	300	0.3
15	223	11	300	0.5
16	231	11	500	0.1
17	232	11	500	0.3
18	233	11	500	0.5
19	311	21	100	0.1
20	312	21	100	0.3
21	313	21	100	0.5
22	321	21	300	0.1
23	322	21	300	0.3
24	323	21	300	0.5
25	331	21	500	0.1
26	332	21	500	0.3
27	333	21	500	0.5

For full factorial design the level combinations will be as shown in Table 2.

For full factorial design there are 27 number of experiments to be conducted and the one giving the best output is chosen as the values to be used as K_p, K_i and K_d values for the PID controller.

Table 3 gives the output results as obtained in Matlab platform.

Table 3. Output results for full factorial

S.No.	Factor combinations	Settling time(secs)	Overshoot(%)
1	111*	0.994	18.9333
2	112	1.0808	7.1234
3	113	1.1326	4.5001
4	121	NaN	NaN
5	122*	1.7571	8.7819
6	123	1.4441	5.2215
7	131	NaN	NaN
8	132	3.7690	9.8626
9	133*	2.0321	5.6616
10	211	0.0472	8.6704
11	**212***	**0.0129**	0.5559
12	**213**	**0.0194**	0
13	221	0.0523	13.1252
14	**222**	**0.0095**	0.4492
15	**223***	**0.0134**	0.0129
16	231*	0.0449	17.3519
17	232	0.0769	4.1435
18	**233**	0.0106	0.5330
19	311	0.0245	16.8698
20	**312**	0.0054	1.2074
21	**313***	0.0047	0
22	321*	0.0260	19.0152
23	**322**	0.0053	1.9351
24	**323**	0.0046	0
25	331	0.0267	21.1272
26	332*	0.0452	2.7960
27	**333**	0.0045	0

4. Result and Discussion

From the above table it can be seen that the following nine combinations meet our design requirement (shown bold in the Table 3):

212,213,222,223,233,312, 313, 322, 323,333

Out of these combinations, the last three combinations i.e., 313, 323 and 333 presents the output which is more desirable of all the 27 cases, as the overshoot percentage in all three of them is zero and settling time is minimum of all the combinations. These three combinations meet the design requirements and are also comparable.

Now applying the Taguchi criterion, the combinations to be considered is shown in Table 4.

Table 4. Layout of L9 orthogonal array

Experiment No.	Factor 1 (K_p)	Factor 2 (K_i)	Factor 3 (K_d)
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

Table 5. Normalized average deviation of multiple output

S.No.	Factor combinations	Settling time(secs) ST	Overshoot (%) OS	Normalized ST	Normalized OS	Average Deviation
1	111*	0.994	18.9333	0.489149156	0.99569292	0.742421038
2	122*	1.7571	8.7819	0.864672014	0.46183579	0.663253904
3	133*	2.0321	5.6616	1	0.29774075	0.648870377
4	212*	0.0129	0.5559	0.006348113	0.02923451	0.01779131
5	223*	0.0134	0.0129	0.006594164	0.0006784	0.003636284
6	231*	0.0449	17.3519	0.022095369	0.91252787	0.467311621
7	313*	0.0047	0	0.002312878	0	0.001156439
8	321*	0.026	19.0152	0.012794646	1	0.506397323
9	332*	0.0452	2.796	0.022243	0.14704026	0.084641631

Therefore on applying Taguchi criterion only **nine** out of the above **twenty-seven** experiments will have to be conducted. (*marked in the Table 3).

On inspecting the result it can be seen that only two experiments out of the nine conducted i.e., 212 and 313, qualify for the design constraints imposed and only these two combinations are to be considered to decide about the final value of the three parameters i.e., $K_{p,}$ K_i and $K_{d.}$ Comparing the output of these two experiments, factor combination 313 can be considered as the final choice.

On further analysis of the data, i.e. normalizing the deviations (from the desired) of the data for overshoot% and settling time on a scale of 0 to 1, the results, as obtained, are shown in Table 5.

Results obtained in the table, too support the selection made.

Thus it is evident that using Taguchi method for tuning, the effort required is three times lesser.

5. Conclusion

The experiment conducted reflects the following results:

- Using Taguchi's Method if not the best, but approximately best result can be obtained using lesser number of experimentations.
- Taguchi's method can be applied for analyzing any other optimization problem too (involving experimentation), thus saving on time, effort and cost.

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