AUTOTUNING OF PID CONTROLLER FOR ROBOT ARM AND MAGNET LEVITATION PLANT

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Abstract

One of the most essential work of the control engineer is tuning of controller. Majority of the controller used in industry are of the PID type. An auto tuning is one of the method of controller tuning in which tuning of the parameters of controller is done automatically and possibly, without any user interaction expect from initiating the operation. Present study emphasis on the relay based auto tuning of PID controller. An auto-tuning method is implemented based on a relay experiment to determine the ultimate gain and the ultimate period, with which the PID parameters are obtained using the Ziegler-Nichols tuning rules. An auto tuning of robot arm model and magnet levitation model are carried out. Performance of relay based auto tuning on the basis of integral square error is better than artificial neural network.

Keywords: *Relay auto tuning, PID, FOPDT, SOPDT, Integral square error.*

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1. INTRODUCTION

Auto tuning of PID controller is studied in this paper. A large industrial process may have hundreds of these controllers. They have to be tuned individually to match the process dynamics in order to provide good and robust control performance in process industry, Most of the times it is difficult to tune the PID controller. Tuning of control loop is the adjustment of its control parameters (proportional gain, integral gain, derivative gain) to the optimum values. For the desired control response stability is a basic requirement. There are different methods of tuning. All are manually tuned; it is very similar to trial and error method. All this methods are very tedious and time consuming; the resultant system performance mainly depends on the experience and the process knowledge of the engineer. To overcome all the drawbacks of the manual tuning methods, auto tuning of PID controllers is preferred. “Auto tuning is an appropriate alternative to the continuous cycling method”. For relay auto tuning of PID controller relay feedback is used. Astrom[1]. have use of an ideal (on–off) relay to generate a sustained oscillation of the controlled variable and to get the ultimate gain (k_u) and the ultimate method a simple experimental test is used to determine k_u and p_u . For this test, the PID controller is temporarily replaced by a relay which exhibits a sustained oscillation that is the characteristic of on-off control. Ideal relay is used to generate sustained oscillation of control Variable and to get the ultimate gain (k_u) and ultimate period (p_u) directly from relay experiment frequency (w_u) directly from the relay experiment. Relay based auto tuning is the one of simplest and robust auto tuning technique for process controllers. In relay auto tuning

$$k_u = \frac{4h}{\pi a} \qquad (1)$$

$$w_u = \frac{2\pi}{p_u} \qquad (2)$$

1.1 Improved Relay Tuning Method

Relay consists of many sinusoidal waves of odd multiple of fundamental frequency and amplitude. This method incorporating the higher order harmonics explains the error in ultimate gain calculation [2].

$$k_u = 1.29(N)^{0.1}\left(\frac{h}{a}\right) \qquad (3)$$

Here, N =number of harmonics, k_u =ultimate gain, h =relay height, a =relay amplitude. At the time of performing experiment we can assumed various number of harmonics.

1.2 Taguchi’s Method

Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of this method is to produce high quality product at low cost to the manufacture. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. Taguchi method treats the optimization problem. The main aim of this method is to minimize variations in output even though noise is present in the process. The process then said to have become robust.

$$SNR = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (4)$$

Basic information as well as training procedure of artificial neural network is explained [3]. Relay parameters are considered as design variables. The error in ultimate gain (k_u) has been considered as performance functions to represent the performance of the design. The mean and the variance are combined into a single performance measure known as the Signal-to-Noise (S/N) ratio. The process design phase involves deciding the best value of the control factor. The optimum values obtained for relay parameters are used for calculation of ultimate gain (k_u) and consequently the optimum PID parameters. Taguchi method is used for robust analysis of the system. [4]. the procedure of relay auto tuning implementation is explained in MATLAB Simulink.

2. MODEL IDENTIFICATION

2.1 Artificial Neural Network

Artificial neural network have emerged from the studies of how brain performs. The human brain is made up of many millions of individual processing elements, called neurons that are highly interconnected. Information from the outputs of the other neurons, in the form of electrical impulses, is received by the cell at connections called synapses. The synapses connect to the cell inputs or space dendrites, and the single output of the neuron appears at the axons. An electrical pulse is sent down the axon when the total input stimuli from all of the dendrites exceed a certain threshold. Artificial neural networks are made up of simplified individual models of the biological neuron that are connected together to form a network. Information is stored in the network often in the form of different connection strengths, or weights, associated with the synapses in the artificial neuron models. Some of the various properties of neural networks are:

- Capability of learning information by example. The learning mechanism is often achieved by appropriate adjustment of the weights in the synapses of the artificial neuron models.
- Robustness to noisy data that occurs in real world application.
- Ability to generalize the new inputs.
- Fault tolerance.

A neural network is system with inputs and outputs and is composed of many simple and similar processing models. Processing elements have a number of internal parameters called weights. Changing the weights of an element will alter the behavior of the whole network. The goal here is to choose the weights of the network to achieve a desired input/output relationship. This process is known as training the network. [3]

2.2 Identification of Robot Arm and Magnet Levitation Model

By using identification tool and open loop response of the plant, we can get transfer function for the plant. Base fit for the robot arm plant is 99.03.The transfer function of the robot arm plant is as shown in Eq (5).

$$G_1(s) = \frac{0.006707}{s^2 + 0.5266s + 0.6672} e^{-0.03} \quad (5)$$

Base fit for magnet levitation plant is 96.88. Tranfer function of magnet levitation plant is as showm in Eq (6)

$$G_2(s) = \frac{0.02397}{s + 0.04456} e^{-1} \quad (6)$$

3. AUTO TUNING OF PID CONTROLLER

Example1:

Here we can consider robot arm plant with transfer function as obtained in Eq (5).The simulation diagram for relay tuning of the plant is as shown in fig.1.

Relay auto tuning experiment was carried out for different relay heights. The fig (2) shows the relay response for the relay height h=10. From the experimental results ultimate gain was calculated. In improved relay tuning method use relay height h=18 & N=9 put this value in Eq (3).In toguchi method expriment is carried out for different values of harmonics. SNR caluculated at each value of harmonics and orthogonal array as shown in table(1). sum of SNR at each height and harmonics caluclated. In this method used relay height h=10 & N=7 shown in table(2). Taguchi gives the optimum value of each parameter with the help of this optimum values we have calculated the ultimate gain and error in calculation of ultimate gain as shown in table(3). Percentage error in calculation of ultimate gain is 17.28% , 1.082% , 0.2506% for conventional , improved relay tuning , taguchi method respectively. The PID tuning paratmeter was calculated using Zigler Nicholus formula as shown in table(4).

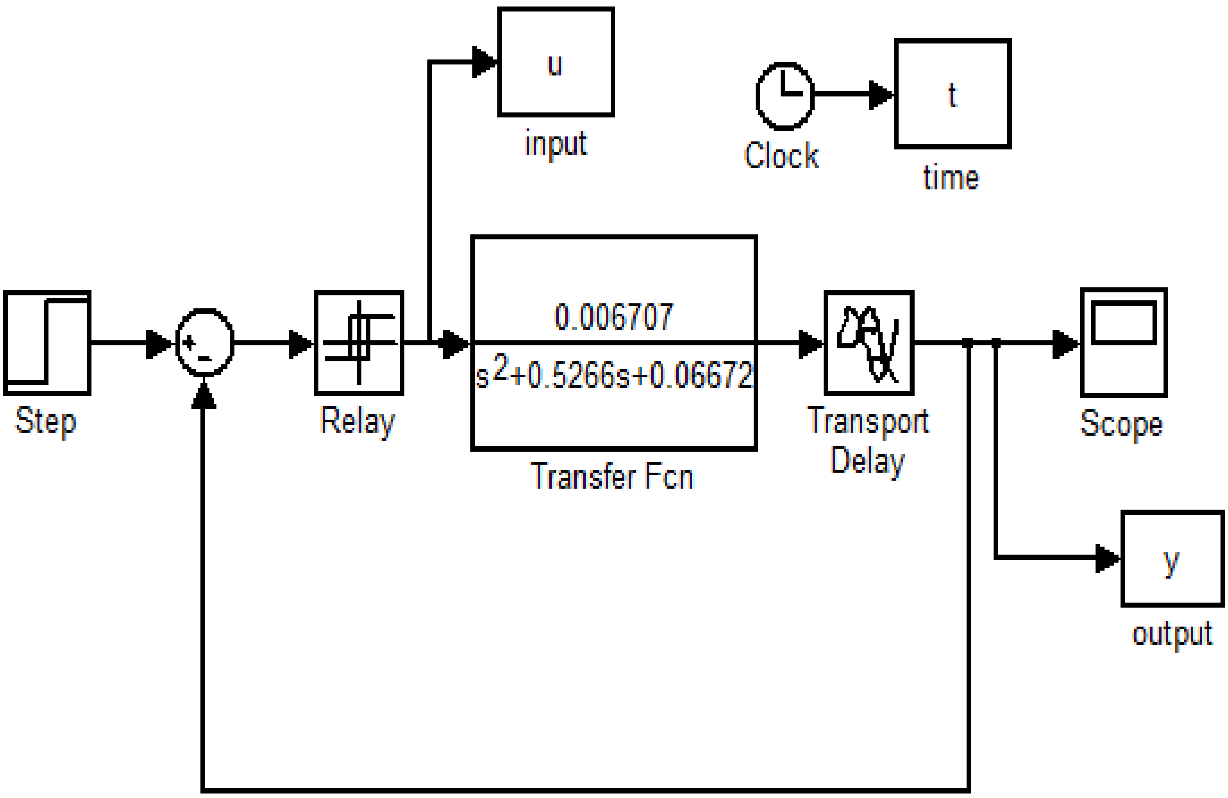

Fig.1: Simulink diagram for robot arm plant

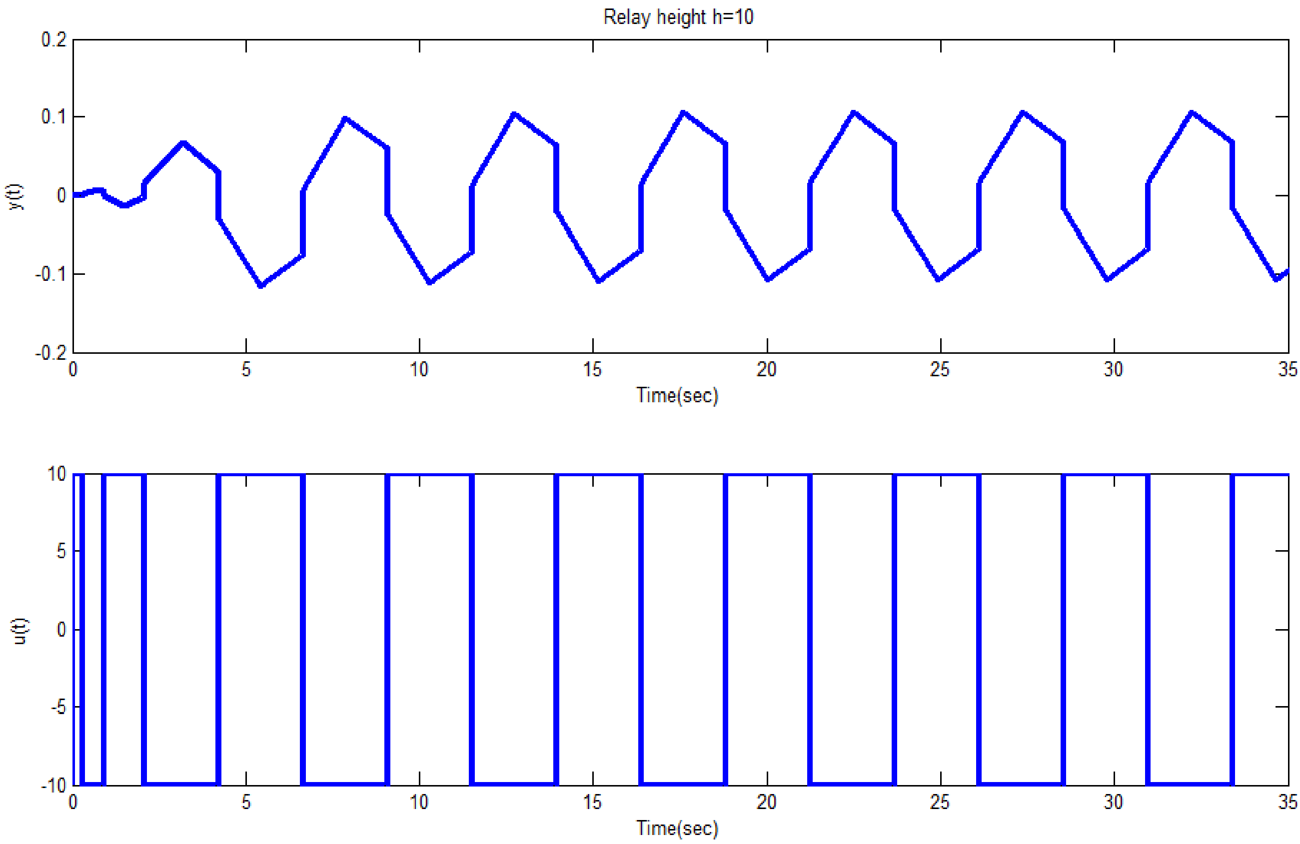

Fig .2: Process and Relay response for Robot Arm Plant.

Table-1: Taguchi OA for robot arm plant.

Sr.No	h	N	Ku(Cal.)	Ku(actual)	%error	SNR
1	10	1	121.34	146.9	17.46	15.911
2	10	3	135.31	146.9	7.8	22.158
3	10	5	142.41	146.9	3.0	30.411
4	10	7	147.28	146.9	0.25	51.744
5	10	9	151.033	146.9	2.813	31.015
6	12	1	119.35	146.9	18.75	14.539
7	12	3	133.21	146.9	9.31	20.621
8	12	5	140.21	146.9	4.96	26.820
9	12	7	144.99	146.9	1.30	37.721
10	12	9	148.68	146.9	-1.211	38.332
11	14	1	119.84	146.9	18.42	14.694
12	14	3	133.75	146.9	8.95	20.963
13	14	5	140.76	146.9	4.17	27.597
14	14	7	145.58	146.9	-0.89	40.928
15	14	9	149.28	146.9	-1.626	35.776
16	16	1	116.44	146.9	18.69	14.567
17	16	3	133.31	146.9	9.25	20.677
18	16	5	140.30	146.9	4.49	26.955
19	16	7	145.10	146.9	1.22	38.272
20	16	9	149.28	146.9	-1.62	37.788
21	18	1	119.19	146.9	18.86	14.481
22	18	3	133.04	146.9	9.43	20.509
23	18	5	140.01	146.9	4.69	26.509
24	18	7	144.80	146.9	1.42	36.954
25	18	9	148.49	146.9	-1.082	39.312

Table 2: Sum of SNR at different levels for relay tuning

Parameters	L1	L2	L3	L4	L5	Total
Relay height(h)	**151.2**	138.0	139.9	138.2	137	708
No. of harmonics (N)	74.20	104.9	138.4	**205.6**	182	708

Table-3: Comparison of % error in Ku calculation

Sr. No	Method	Ku (act)	Ku (Cal)	│%error│
1	Conventional Method	146.9	119.66	17.48
2	Improved Relay tuning Method	146.9	148.49	1.082
3	Taguchi Method	146.9	147.28	0.2586

Table-4: PID parameters using Ziegler-Nichols settings

Sr. No	Method	P	I	D
1	Conventional Method	70.3911	2.405	0.6125
2	Improved Relay tuning Method	87.3470	2.405	0.6125
3	Taguchi Method	86.635	2.405	0.6125

Example2:

Here we can consider magnet levitation plant with transfer function as obtained in Eq (6).The simulation diagram for relay tuning of the plant is as shown in fig 3.

In the present work same procedure like example 1 is carried out. In improved relay tuning method ,use relay height h=25 & N=7 put this value in Eq(3).In taguchi method used relay height h=10 & N=9. Percentage error in calculation of ultimate gain is 23.714% ,5.97 %, 3.5733% for conventional , improved relay tuning , taguchi method respectively shown in table(7). The PID tuning paratmeters was calculated using Zigler Nichols formule as shown in table(8).

Table-5: Taguchi OA for robot arm plant.

Sr. No	h	N	Ku(Cal)	Ku(actual)	%error	SNR
1	5	1	60.964	78.722	22.607	12.915
2	5	3	68.043	78.722	13.628	17.311
3	5	5	71.609	78.722	9.0926	20.826
4	5	7	74.060	78.722	5.922	24.550
5	5	9	75.944	78.722	3.5890	28.900
6	10	1	60.935	78.722	22.5943	12.920
7	10	3	68.011	78.722	13.605	17.355
8	10	5	71.575	78.722	9.077	20.8411
9	10	7	74.025	78.722	5.966	24.486
10	10	9	75.908	78.722	3.5733	29.037
11	15	1	60.944	78.722	22.58	12.925
12	15	3	68.021	78.722	13.592	17.334
13	15	5	71.587	78.722	9.063	20.854
14	15	7	74.036	78.722	5.951	24.508
15	15	9	75.920	78.722	3.558	28.975
16	20	1	60.935	78.722	22.594	12.920
17	20	3	68.011	78.722	13.605	17.326
18	20	5	71.575	78.722	9.0778	20.840
19	20	7	74.025	78.722	5.9665	24.485
20	20	9	75.908	78.722	3.573	28.939
21	25	1	60.941	78.722	22.587	12.922
22	25	3	68.017	78.722	13.597	17.3311
23	25	5	71.582	78.722	9.069	20.848
24	25	7	74.032	78.722	5.957	24.419
25	25	9	75.916	78.722	3.5643	28.960

Table-6: Sum of SNR at different levels for relay tuning

Parameters	L1	L2	L3	L4	L5	Total
Relay height(h)	104.5	**104.6**	104.5	104	104.2	522.4
No of harmonics (N)	64.60	86.62	103.8	122	**144.8**	522.4

Table-7: Comparison of % error in Ku calculation

Sr. NO	Method	Ku (act)	Ku (Cal)	│%error│
1	Conventional method	78.722	60.172	23.714
2	Improved Relay Method	78.722	74.032	5.957
3	Taguchi Method	78.722	75.908	3.5733

Table-8: PID parameters using Ziegler-Nichols settings

Sr. No	Method	P	I	D
1	Conventional Method	35.3952	1.6465	0.41162
2	Improved Relay tuning	43.548	1.6465	0.41162
3	Taguchi Method	45.545	1.6465	0.41162

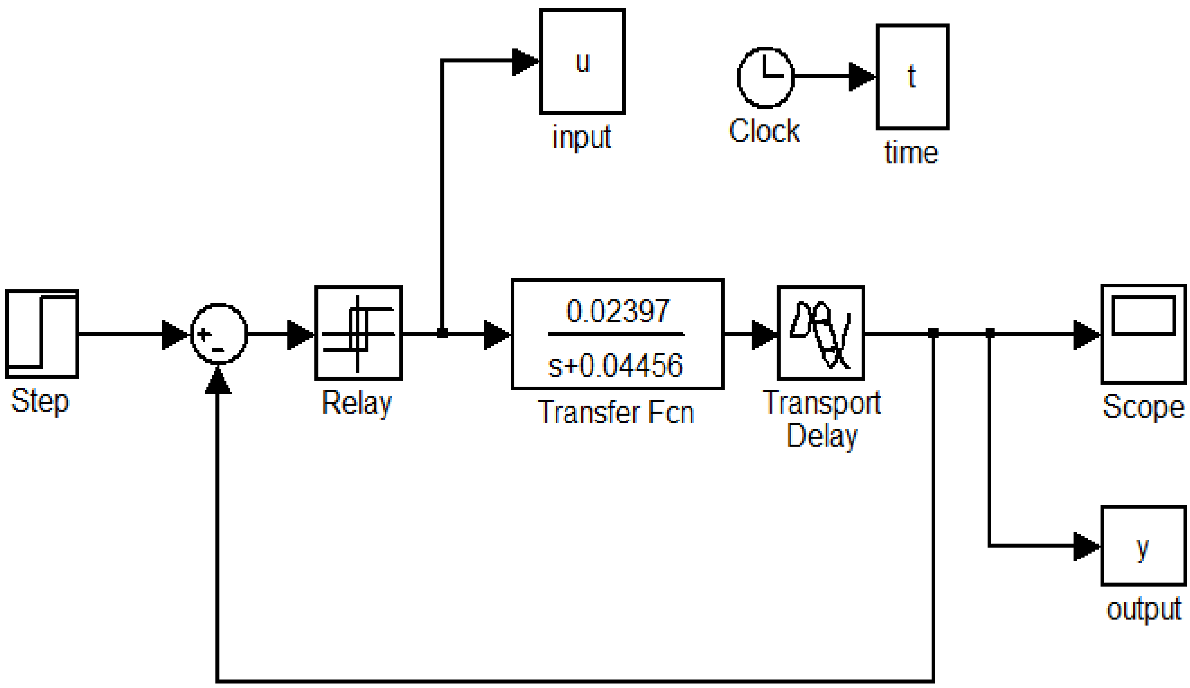

Fig 3: Simulink diagram for magnet levitation plant

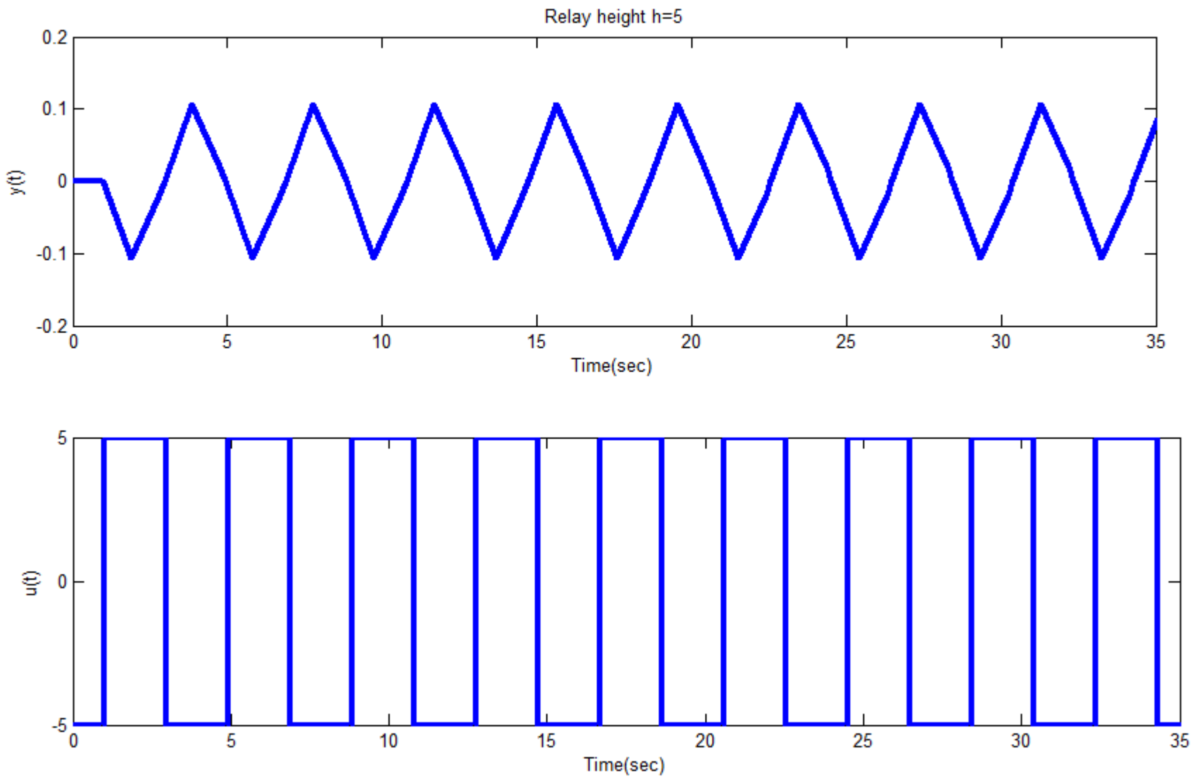

Fig 4: Process and Relay Response for Magnet

3.1 Artificial Neural Controller Training:

After the auto tuning of the plants we go through the artificial neural training. At first we train that controller. In this the PID controller replace by artificial neural network controller as shown in fig (5). Once training of that controller is over run that model and get the result. From result we can calculate the integral square error

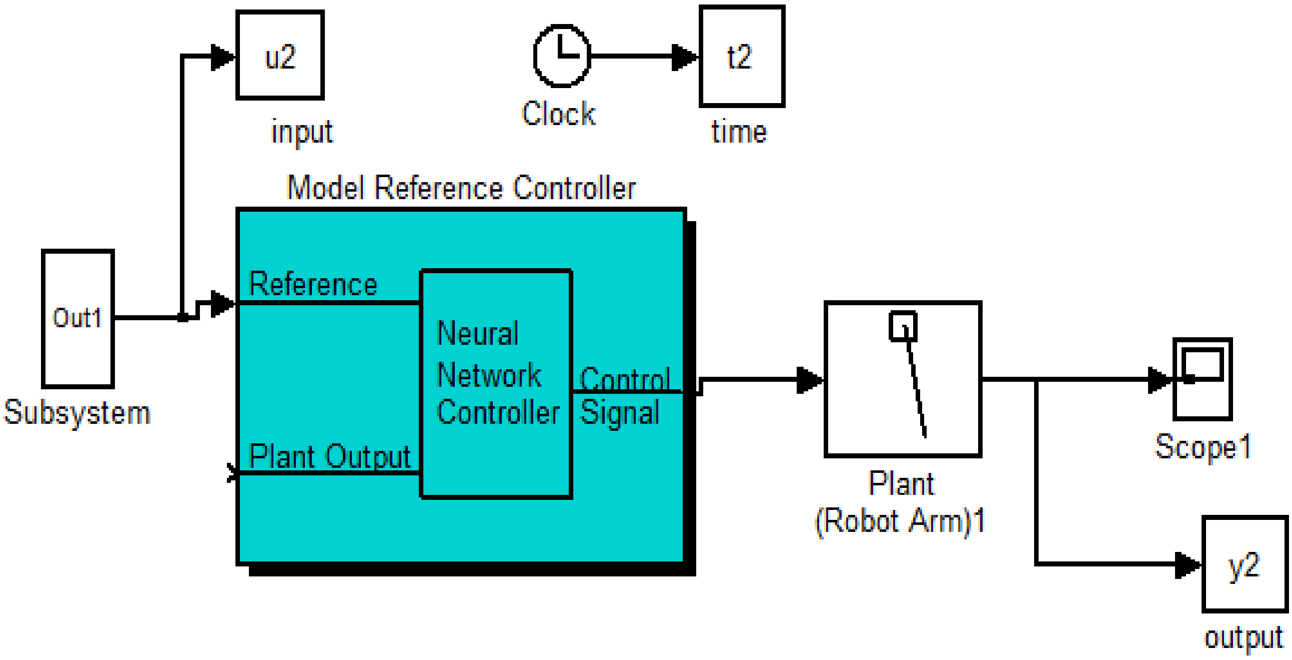

Fig 5: Artificial neural network model for robot arm plant

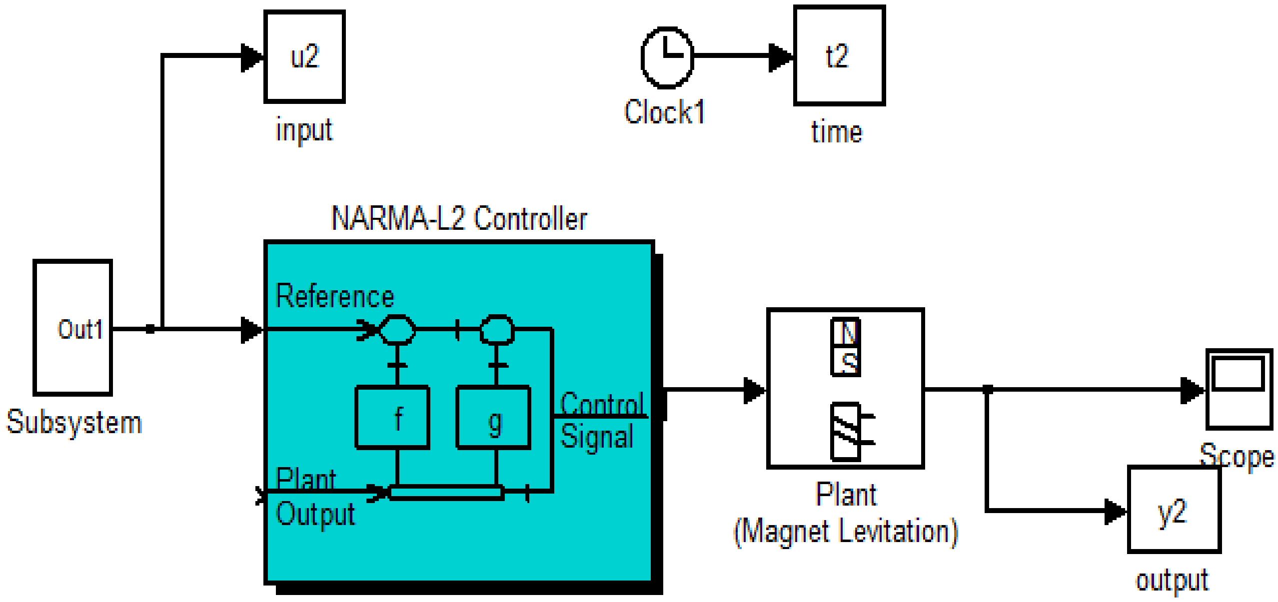

Fig 6: Artificial neural network model for magnet levitation plant

4. SIMULATION RESULTS

We obtained the results of artificial neural network and auto tuning in MATLAB Simulink for Robot arm plant and Magnet levitation plant. Step response of Auto tuning and artificial neural network for Robot arm plant on basis of results is shown in fig.(7)

The Integral Square Error (ISE) performance criteria were tested for both Auto tuning and ANN. The ISE values is 0.0024, 0.1607 for Auto tuning and ANN respectively.

Step response of Auto tuning and artificial neural network for magnet levitation plant on basis of results is shown in fig.(8) .The ISE values is 0.9004, 1.1371 for Auto tuning and ANN respectively.

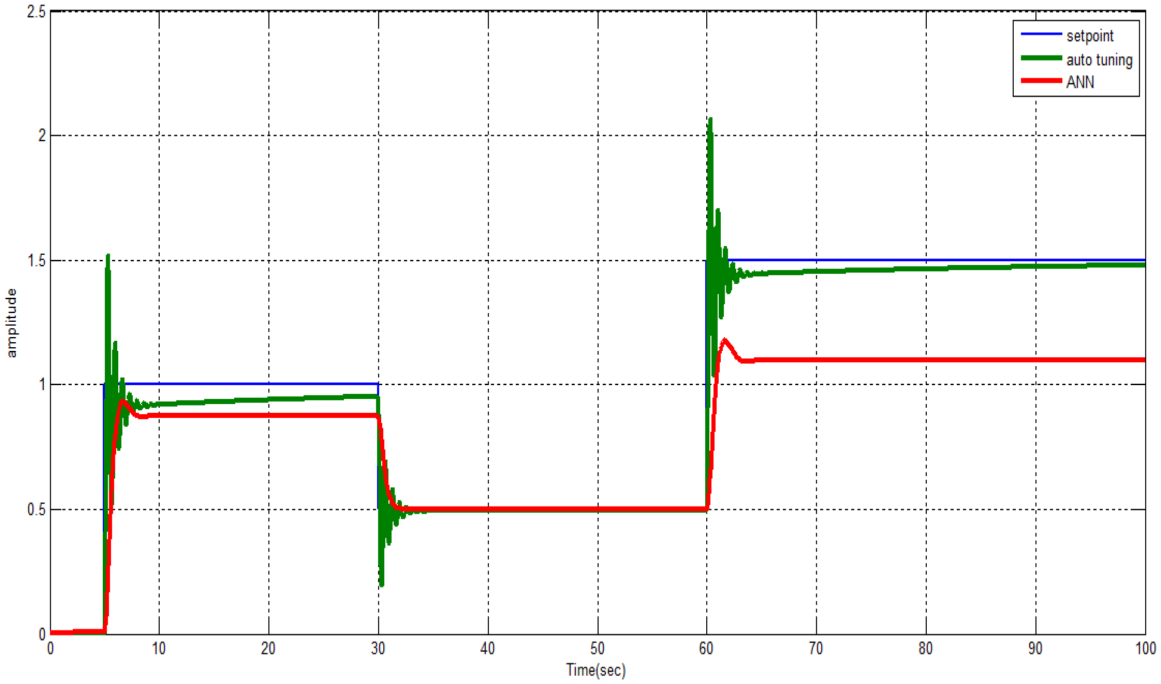

Fig 7: Step response of ANN and auto tuning for Robot arm plant

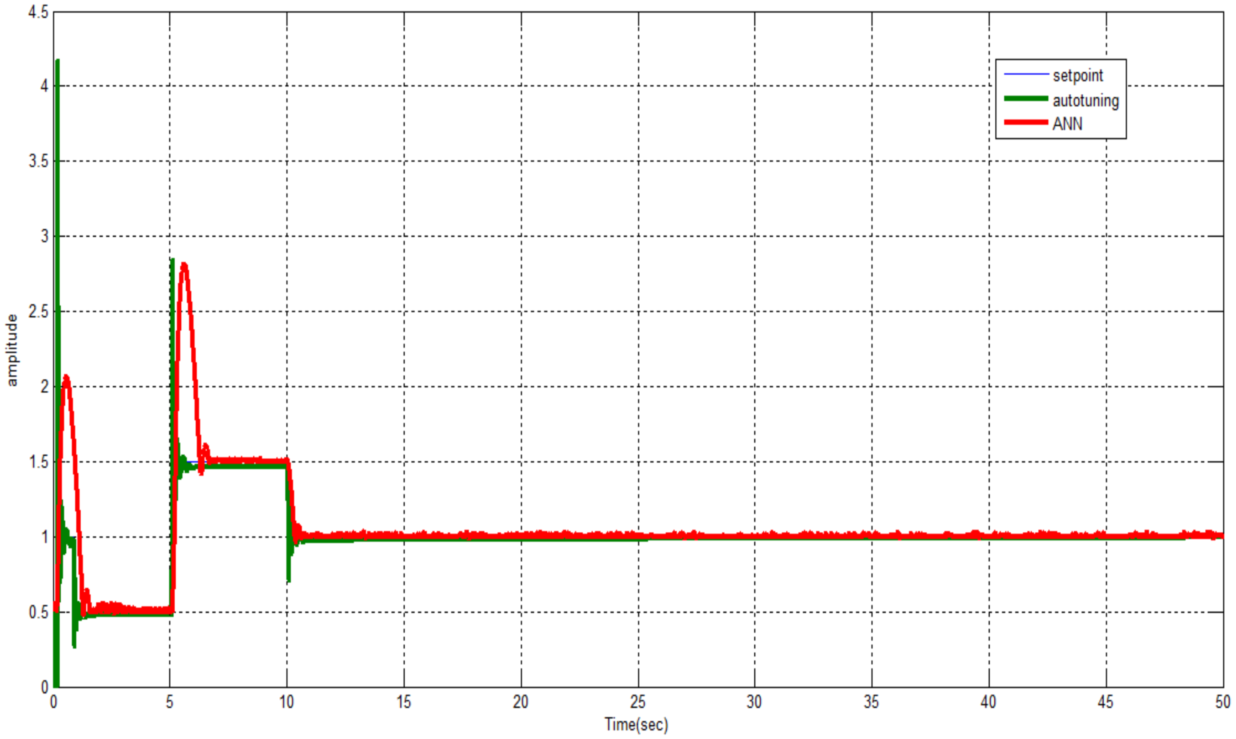

Fig 8: Step response for ANN and auto tuning for Magnet levitation plant

5. CONCLUSION

The manual PID tuning method is tedious and time consuming; the resultant system performance mainly depends on the experience and the process knowledge of the engineer. So, goal of present work is to carry out the auto tuning of PID controller using MATLAB Simulink. We obtained ultimate gain and ultimate period by performing relay experiment. Further controller parameters were determined by using Ziegler Nicholas method. The performance of auto tuned PID controller is better than that of artificial neural network. Hence Auto tuning of PID controller plays vital role, especially in the case where large number of controllers is required to be tuned simultaneously.

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