ISTF-PID Based Single Joint Robotic Arm Control

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ABSTRACT

The objective of this research work is to compare the different classical tuning methods for the PID gains against an intelligent tuning technique that uses fuzzy logic controller for tuning the PID gains. The classical tuning techniques that have been used in this work are Cohen Coon as well as Ziegler Nichols. The Intelligent Tuning methodology used is Improved Self Tuning Fuzzy-PID. The tuning is performed using a PID controller on a single joint robotic arm. The robotic arm is moved using a servo motor. The comparison between the different tuning techniques is made based on the settling time of the object that is being balanced on the robotic arm.

Keywords- Cohen Coon, Improved Self Tuning Fuzzy-PID, PID, Single Joint Robotic Arm, Ziegler Nichols

1. INTRODUCTION

In today's massively industrialized world, where time is of the essence and value for money is the foremost parameter in determining the performance of enterprises, automation is the need of the hour. It has revolutionised the face of industry in recent times, with human beings being replaced by intelligent machines and devices to perform mundane and repetitive tasks.

A Robotic Arm is a programmable, mechanical arm that performs functions similar to a human arm. It may be a complete automation system by itself, or a part of a larger machine. It can be controlled to perform desired tasks such as welding, gripping, spinning, balancing, painting, performing surgeries like LASIK etc. Robotic Arm is also used in other application including space retrieval systems, as well as intricate CNC systems like 3D printing machines. Applications employing Robotic Arm like in industries, surgeries, and defence need to be very precise and quick in their action. As an example, LASIK surgery which works on human body as a subject, needs precise control, otherwise, there can be dire consequences.

To overcome the shortcoming as mentioned above, various classical and intelligent PID tuning techniques have been applied [1]. The combination of proportional, integral and derivative control is called the PID controller. PID controllers are mostly used to regulate the time-domain behaviour of various types of dynamic plants [2]. The popularity of the PID controllers resides in the fact that, the PID controllers can usually provide good closed-loop response characteristics [3]. The PID gains have been controlled using the classic control tuning techniques of Ziegler-Nichols and Cohen Coon which are then compared to an Intelligent tuning technique that uses fuzzy logic to control the robotic arm [4]. Ziegler-Nichols tuning method heuristically tunes the PID gains. However, it can only work satisfactorily on processes where dead time is less than half the length of the time constant [5]. Therefore, we introduce the Cohen-Coon method where this drawback is taken care of [6]. Further,

in the Improved Self Tuning Fuzzy (ISTF)-PID control method the values of the parameters of the PID controller such as Kp, Ki, Kd are obtained using the fuzzy controller [7]. The control action in a fuzzy logic controller can be expressed with simple 'IF THEN' rules. A fuzzy logic controller can cover a wider range of operating conditions and can operate under noise and other disturbances [8].

D.C. servo motors provides excellent control of speed for acceleration and deceleration of Robotic Arm. D.C. servo motors are usually less expensive, more robust and have speed torque characteristics superior to A.C. motors [9]. D.C. servo motors have a long-history of being used as adjustable speed control machines and various methods have been evolved for this purpose. NI myRIO is an embedded hardware device based on technology used in industry for controls and robotics. It is a real-time embedded evaluation board used to develop applications that utilize its on board FPGA and microprocessor. It has all the I/O and processing power needed to control the robots. It requires LabVIEW (Laboratory Virtual Instrument Engineering Workbench).

In this work, the various key components of the project are highlighted along with the mechanical, electrical and software elements. Various control techniques have been compared to determine the optimal technique that can be used.
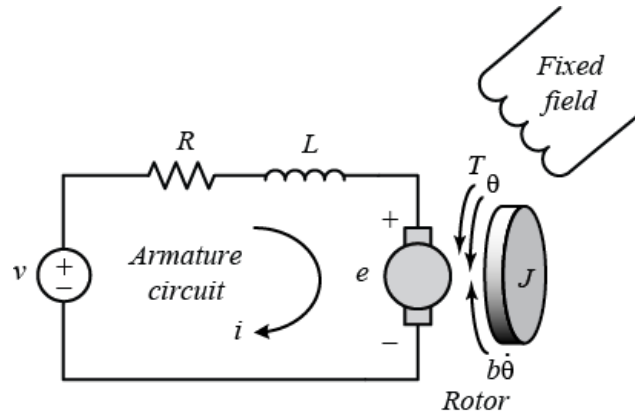
II. DESCRIPTION OF SINGLE JOINT ROBOTIC ARM

The robotic technology has quickly progressed and this has led to the application of robots in diverse fields such as industries, guarding and domestic. There are six degrees of freedom associated with a robotic arm. Each degree of freedom is a join on a robot arm [9]. This joint enables the arm to translate or rotate. A single joint Robot arm is a system with one degree of freedom [10]. Having both electrical and mechanical parameters, a single joint robot arm is an application example of a Mechatronics electromechanical system used in industrial automation.

Intentional speed variation carried out manually or automatically is referred to as speed control. D.C. servo motors are most used for wide range of speed control. A servomotor uses position feedback to control its motion and final position. The measured position and command position are compared and an error signal is generated. This causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. When the error signal reduces to zero, the motor stops.

To simplify the modeling process, linear approximations are used in such a way that the approximation does not lead to major deviations from reality [11-12]. Single joint robot arm system consists of three main parts; arm, connected to actuator through gear train with gear ratio, n.

The robotic arm has the following nominal values: arm length, L=0.4 m; arm mass, M=1kg; and viscous damping constant, b = 0.09 N.sec/m. The nominal values for the various parameters of electric motor used: Vin=12 Volts; Jm=0.02 kgmÇ, bm =0.03; Kt =0.023 N-m/A;   Kb =0.023 Vs/rad; R=1 Ohm; L=0.23 Henry; TL, gear ratio, n=1.

Figure 1: circuit diagram of a dc servomotor The transfer function of a single joint robotic arm without any load can be approximated to the following equations:

$$Gangle(s) = \frac{\theta(s)}{Vin(s)} = \frac{Kt}{\{[La\ Jm\ s^3 + (Ra\ Jm + bm\ La)\ s^2 + (Ra\ bm + Kt\ Kb)\ s]\}} \quad (1)$$

$$Gspeed(s) = \frac{\omega(s)}{Vin(s)} = \frac{Kt}{\{[La\ Jm\ s^2 + (Ra\ Jm + bm\ La)\ s + (Ra\ bm + Kt\ Kb)\ ]\}} \quad (2)$$

To compensate for the effect of loading, we must calculate and replace Jeq and beq. This is done by using the following equations and substituting the appropriate values:

$$beq = bm + bload\left(\frac{N1}{N2}\right)^2 \quad (3)$$

$$Jeq = Jm + Jload\left(\frac{N1}{N2}\right)^2 \quad (4)$$

$$Jload = \frac{ml^2}{12} = \frac{0.4^2}{12} = 0.013334\ kgm^2 \quad (5)$$
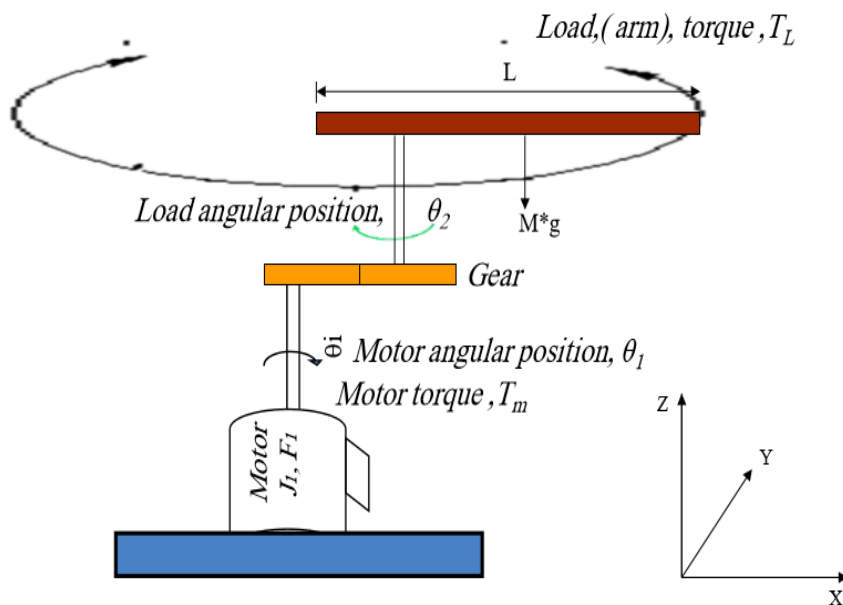

Figure 2:simplified schematic model of a single joint robotic arm [13] Substituting, we obtain, Jeq,

$$Jeq = Jm + Jload = 0.02 + 0.013 = 0.033\ kgm^2$$

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Obtaining the total damping, beq, gives:

$$beq = bm + bload = 0.03 + 0.09 = 0.12\ Nsec/m$$

Substituting the above values in equation 3.1 and using the nominal values of robotic arm and the motor, we obtain:

$$Gangle(s) = \frac{\theta(s)}{Vin(s)} = \frac{0.023}{(0.003\ s^3 + 0.0193\ s^2 + 0.0155\ s)} \tag{6}$$

The Equation 6 has been used as the transfer function of the robotic arm, and thus the plant, in all further mathematical models.

III. PID GAIN TUNING TECHNIQUES

The combination of proportional, integral and derivative control is called the PID controller. PID controllers are mostly used to regulate the time-domain behaviour of various types of dynamic plants. The popularity of the PID controllers resides in the fact that, the PID controllers can usually provide good closed-loop response characteristics.
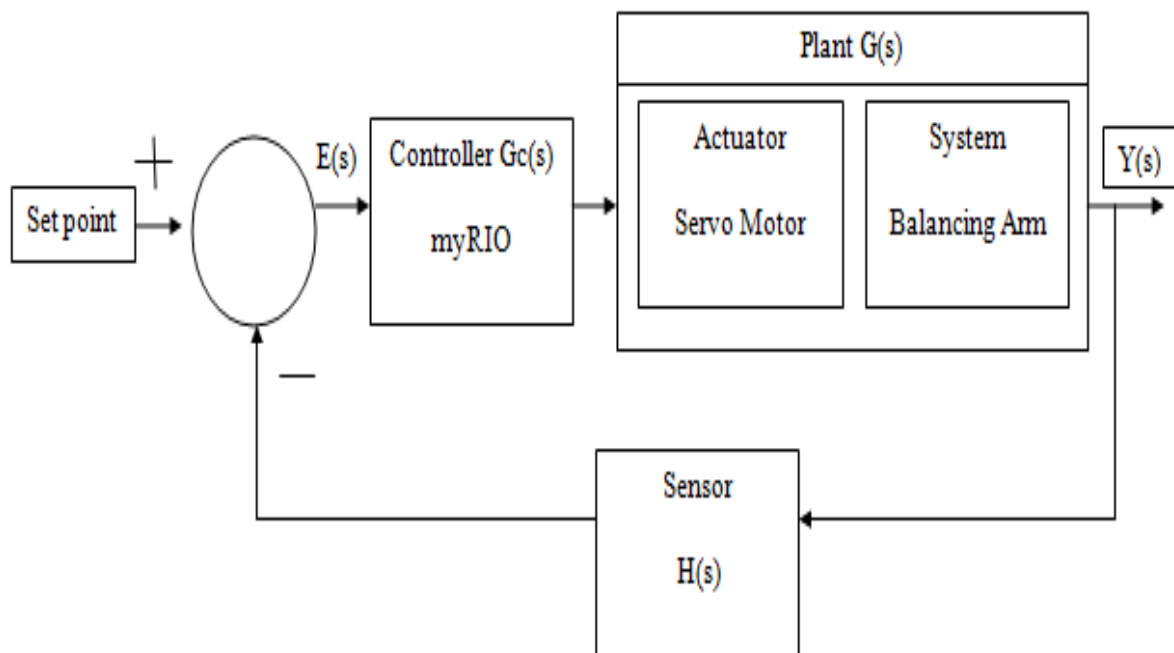
Figure 3: robotic arm balance control system

In this research work, classical tuning techniques like Ziegler Nichols and Cohen Coon are compared with the new and adaptive control technique, that is, Improved Self Tuning Fuzzy PID or ISTF-PID.

3.1 Ziegler Nichols

The Ziegler-Nichols tuning method is used for the tuning of PID controller using Heuristics. In this method, the nonlinear system of higher order is reduced to a linear first order system and the ultimate gain K_u and the time period T_u found from the equation are utilized to find the PID gains.

Table 1: Determination of Ziegler Nichols parameters

| Control Type	k_p	t_i	t_d
P	$0.5k_u$	-	-
PI	$0.45k_u$	$t_u/12$	-
PD	$0.8k_u$	-	$t_u/8$
PID	$0.6k_u$	$t_u/2$	$t_u/8$

3.2 Cohen-Coon

The response of most of the process under a step change in input yields a sigmoidal shape which can be adequately approximated by the response of a first order process with dead time. This approximated response has gain K, time constant τ and delay time td. The control parameters can then be determined by substituting the values in the given table.

Table 2: Determination of Cohen-Coon parameters

Control Type	k_c	τ_i	τ_d
P	$\dfrac{1}{K}\dfrac{\tau}{td}\left(1+\dfrac{td}{3\tau}\right)$	-	-
PI	$\dfrac{1}{K}\dfrac{\tau}{td}\left(0.9+\dfrac{td}{12\tau}\right)$	$td\,\dfrac{30+3\,td/\tau}{9+20\,td/\tau}$	-
PID	$\dfrac{1}{K}\dfrac{\tau}{td}\left(1.33+\dfrac{td}{4\tau}\right)$	$td\,\dfrac{32+6\,td/\tau}{13+8\,td/\tau}$	$td\,\dfrac{4}{11+2\,td/\tau}$

3.3 Improved Self Tuning Fuzzy PID

In the ISTF-PID tuning technique, A rule-base has been created for the system in accordance with the arm length and the arm range. This technique is an improvement to the previous tuning techniques since it uses the fuzzy logic controller to tune the parameters of PID at the run time [14]. The tuning of the parameters during runtime makes its an adaptive controller [15].
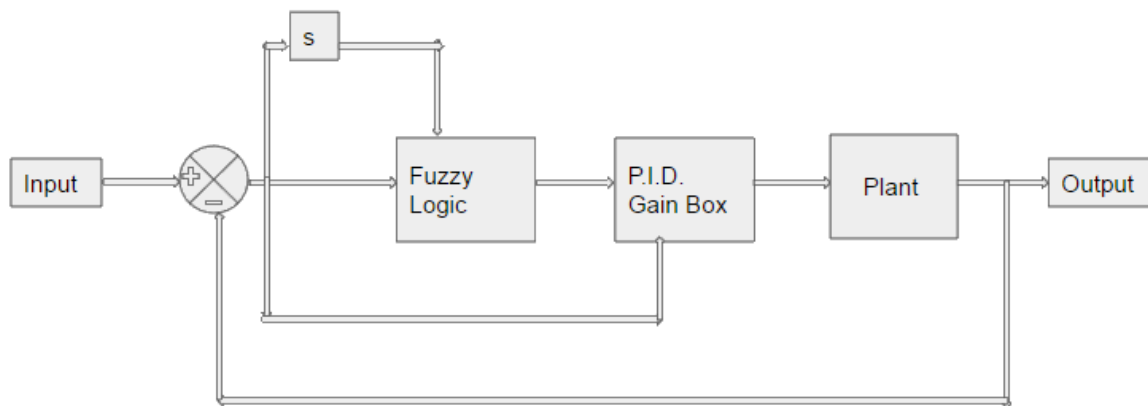
Figure 4: block diagram of an ISTF-PID

Like the previous techniques, the error signal is taken as the difference of set-point and feedback from the sensor. The error signal is fed into the fuzzy logic controller. But in this technique, along with the error signal, derivative of error signal is also fed into the fuzzy logic controller.

The output from the fuzzy logic controller is the PID parameters. The parameters along with the error signal are put as the input to the PID controller. The output from the PID controller is then fed to the plant consisting of PWM servo motor and the robotic arm. The feedback is taken using the infrared sensor. Centroid Defuzzification is used to get the crisp output.

Table 3: fuzzy rule-base matrix for ISTF-PID parameters

$de(t)/dt$ $e(t)$	LN	SN	Z	SP	LP
LN	LP, LP, LN	LP, LP, LN	SP, LP, SN	Z, LP, Z	SN, LP, SP
SN	SN, LP, Z	SN, LP, SP	SN, LP, SP	LN, SP, SP	LN, SP, LP
Z	Z, SP, SN	Z, SP, SN	Z, SP, SN	SN, Z, Z	SN, Z, Z
SP	SP, LN, Z	SP, LN, LN	SP, SN, SN	Z, SN, SN	Z, SN, SN
LP	LP, LN, LN	LP, LN, LN	LP, LN, LN	LP, LN, LN	SP, LN, LN

IV. WORKING AND RESULTS

This section briefly explains the working of the single joint robotic arm along with the results obtained with the use of different tuning techniques. The microcontroller used for the experiment is myRIO. The software environment used for the experiment is LabVIEW.

The error signal, e(s) is the difference between the set-point and the feedback from the infrared sensor. This signal is fed into the controller that is driven by myRIO. The plant consists of servo motor, that acts as an actuator along with the balance arm system.

Figure 5: complete setup of the single-joint robotic arm

In this experiment, three points were marked on the robotic arm, namely, 'A', 'B', and 'C'. Point A is farthest from the set-point and point 'C' being the closest to the given set-point. The set-point in this experiment is taken to be of '50% of arm length'. While performing the experiment the ball was placed on these points and the time taken by the ball to attain the given set-point against different controllers was noted.
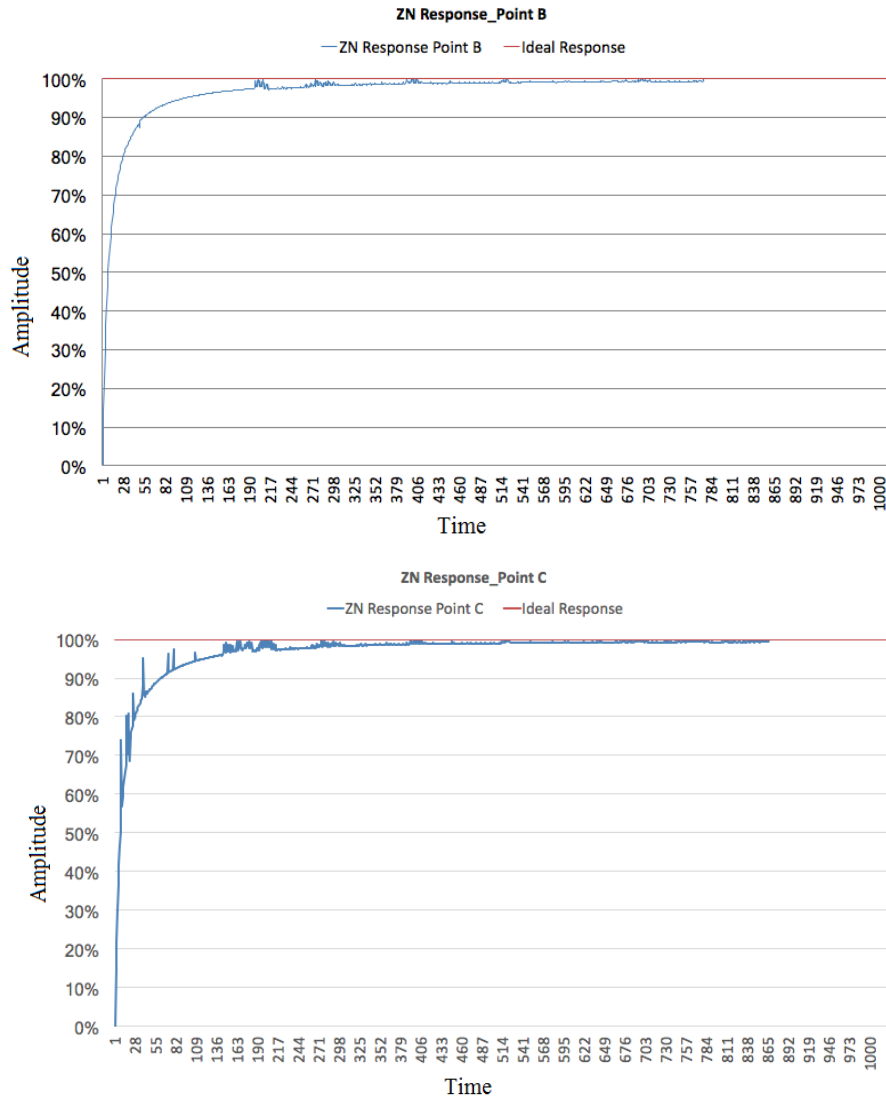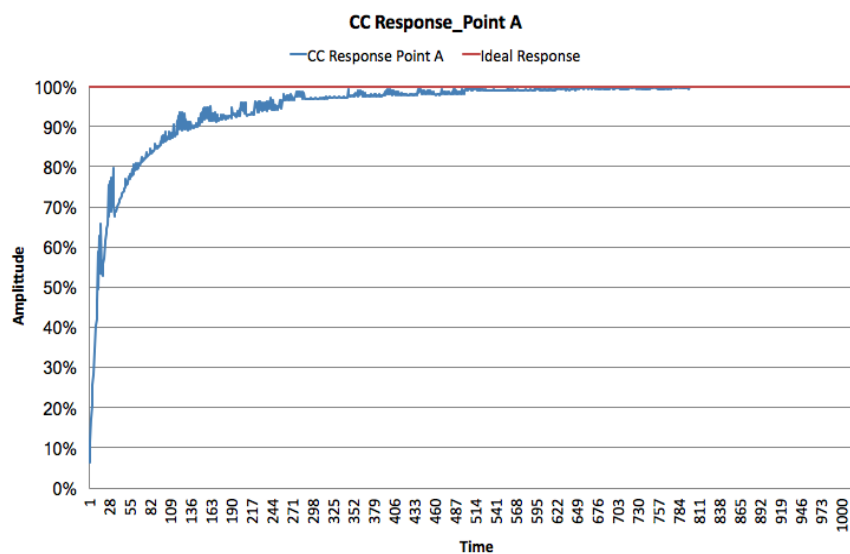
4.1 Ziegler Nichols
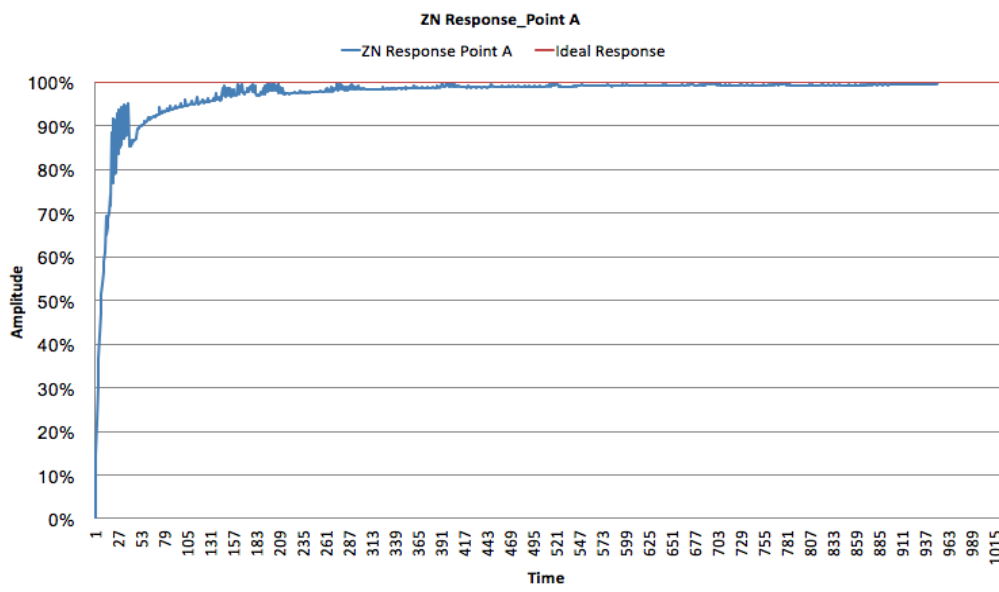
Figure 6: plot between zn response and ideal response for point (a) A (b) B and (c) C
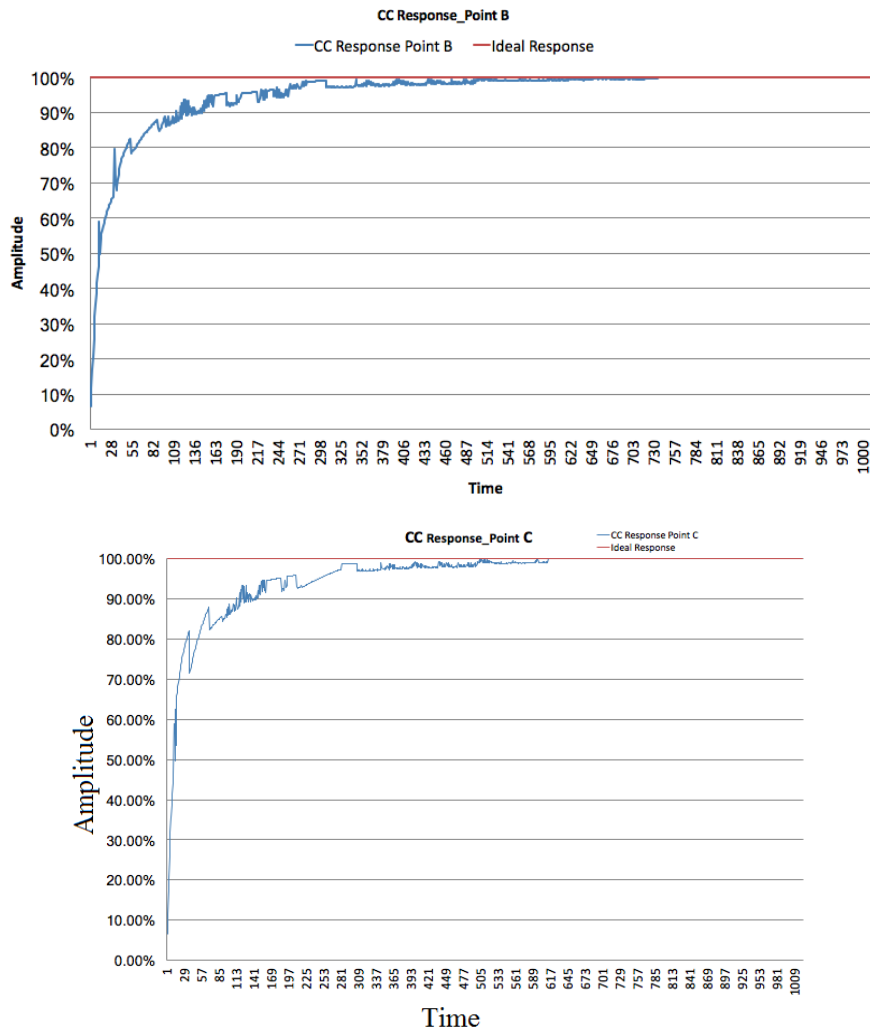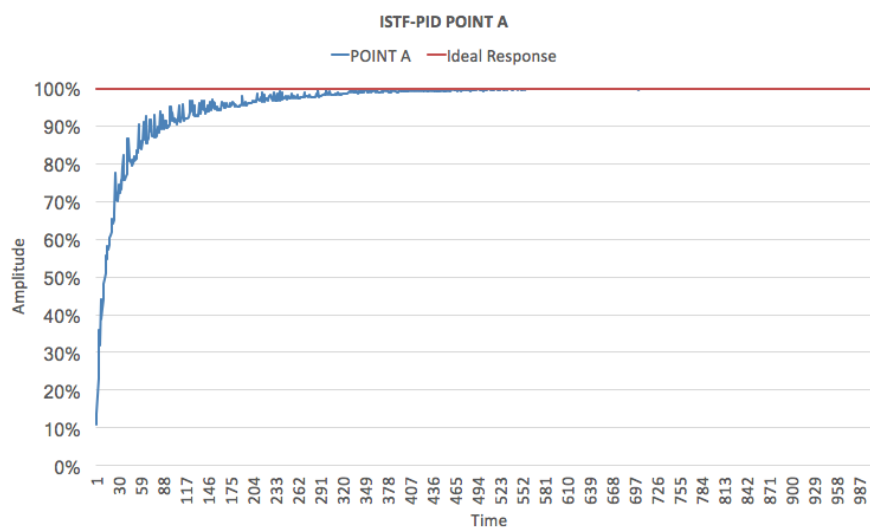
4.2 Cohen-Coon

Figure 7: plot between c-c response and ideal response for point (a) A (b) B and (c) C
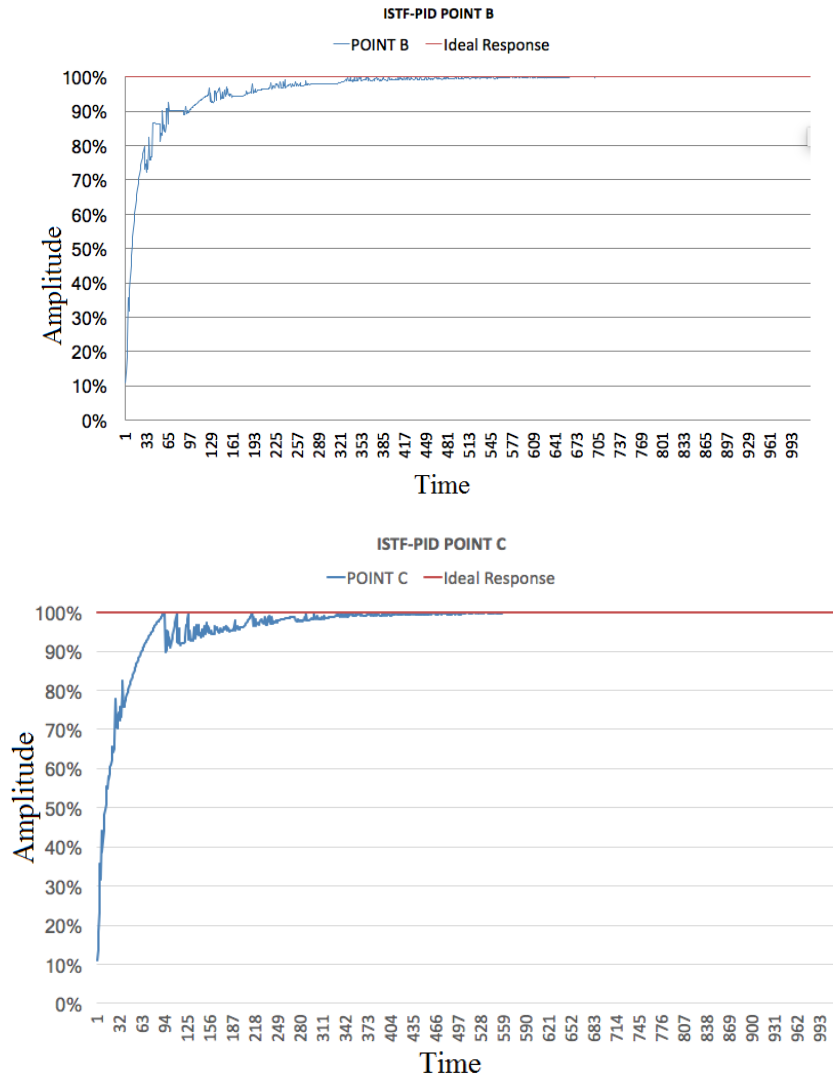
4.3 ISTF-PID

Figure 8: plot between ISTF-PID response and ideal response for point (a) A (b) B (c) C

The results are summarized in the table below.

Table 4: Results obtained

TUNING POINT	ZIEGLER NICHOLS	COHEN-COON	ISTF-PID
A	9.69	9.31	8.63
B	7.73	7.54	6.93
C	6.68	6.12	5.76

V. CONCLUSION

In this paper, we have compared different methodologies used for the tuning of PID controllers that is used for controlling a single joint robotic arm. Among various tuning techniques, three PID based tuning techniques were

utilised to control the balance arm based system. The tuning techniques used were Ziegler Nichols, Cohen Coon and Improved Self Tuning Fuzzy PID(ISTF-PID) tuning technique. The results obtained from the experiments were analysed and compared as mentioned in the table-4. On comparing the Ziegler Nichols and Cohen Coon based tuning techniques, it is observed that the settling time of Cohen Coon method is relatively lower than Zeigler Nichols method under all test cases, hence it can be concluded that Cohen Coon is a better tuning technique with respect to this model of single joint robotic arm. Similarly, when the Cohen Coon method is compared to the Improved Self Tuning Fuzzy PID(ISTF-PID) technique, it is observed that the settling time of Improved Self Tuning Fuzzy PID technique is relatively lower than Cohen Coon method, under all the test cases. Therefore, the Fuzzy based PID tuning technique is found to be superior to the Cohen Coon based method.

The PID based control tuning techniques and study analysis of their responses were the main area of concentration in this paper and the results obtained clearly determine that the Improved Self Tuning Fuzzy PID (ISTF-PID) tuning is by far the most superior as it guarantees, in general, very good performances in the set point and load disturbance step responses. Also, this tuning technique requires a modest implementation effort. Hence, its practical implementation in industrial environments appears to be very promising.

In the future research work, we would be tuning the PID controller for single joint robotic arm using Artificial Neural Networks and Genetic algorithm and comparing the results with the Improved Self Tuning Fuzzy PID (ISTF-PID) tuning technique.

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